Application of current environmental research to golf course design, construction, and management practices

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Application of current environmental research to golf course
design, construction, and management practices

by

Mark Gregory Kuiper

A thesis submitted to the graduate faculty
in partial fulfillment of the requirements for the degree of
MASTER OF LANDSCAPE ARCHITECTURE

Major: Landscape Architecture
Major Professor: Mark J. Chidister

Iowa State University
Ames, Iowa
1997

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This is to certify that the Master's thesis of

Mark Gregory Kuiper

has met the thesis requirements of Iowa State University

Signatures have been redacted for privacy
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CHAPTER I: INTRODUCTION

Statement of the Problem

The recent proliferation of environmental research on golf courses has greatly expanded the understanding of the environmental impacts and costs of various golf course design, construction, and management strategies. This new body of research, however, has not yet been consolidated into a set of principles for sustainable golf course development and management. The purpose of this research will be to draw from current research to develop such a set of principles and, in particular, to examine the economic and environmental benefits of using native vegetation on golf courses.

Objectives

The objectives of this research were to:

• review and synthesize the large body of recent research to develop golf course design, construction, and management principles that have the greatest potential for maintaining playability, aesthetic value, and keeping costs down while minimizing environmental impacts (i.e. reduction of fertilizer and pesticide usage and runoff, reduced water consumption, and improved water quality);

• document the environmental impacts and potential maintenance savings possible through the construction and management of large areas of native vegetation in out-of-play areas such as buffer areas around lakes, streams, and ponds by examining selected, existing golf courses.

Delimitations

The principles articulated in this study were developed by synthesizing the large body of current research on the environmental impacts of various golf course design, construction, and management practices. This particular study focused more on issues of water quality, soil protection, and the use of native vegetation but less directly on wildlife ecology.
Definition of Terms

**Aerate or Aerify**: The process of coring the turf—removal of a core from the turfgrass with a soil probe or hollow metal tines—to allow more air into the soil and to relieve its compact nature. One of the reasons that spiked golf shoes are good for greens is that the spikes help to reduce compaction by aerating the green's surface (“Golf impact report,” 1996).

**Adsorption**: Retention of a chemical onto the surface of a soil particle (Kenna, 1995). The Coefficient of Adsorption ($K_{OC}$) quantifies this value; if this value is less than 100, the pesticide may be mobile (and more likely to leach through the soil); if it is between 100 and 1000, then the chemical may be moderately mobile; if it is greater than 1000, then the chemical is considered immobile (Branham et al., 1995).

**Buffer Strips**: Stands of native vegetation, usually perennial grasses, planted between developed areas and surface waters which help to retard flood flows, slow channel erosion, shade and cool the stream, and filter sediments and chemicals out of surface runoff.

**Contour Mowing**: To shape the border of the rough and fairway to add interest, direction or strategy to the golf hole. Contour mowing is also practiced on greens and green collars to enhance aesthetics (“Golf impact report,” 1996). It results in multiple fairway landing areas, offering progressively smaller target areas and requiring greater accuracy further from the tee (Silva, 1982).

**Dislodgeable Foliar Residues**: Pesticide residues able to be removed from leaf surfaces (Cooper et al., 1995).

**Drought Avoidance**: The ability of the turfgrass plant to avoid tissue damage in a drought period by postponement of dehydration. This can be done by limiting evapotranspiration (smaller leaf area, high canopy resistance) and through functions in water uptake (deeper rooting, root viability, resistance to edaphic stress like soil
oxygen, adverse temperatures, soil strength, salinity, adverse pH, and phytotox

elements) (Kenna and Horst, 1993).

**Drought Tolerance:** The ability of the turfgrass plant to tolerate drought through escape (lives through drought as dormant state or as seed) and hardiness to low tissue water amounts (Kenna and Horst, 1993).

**Effluent Water:** Waste water that is released after it has been used, processed, and treated.

**Evapotranspiration:** Water released into the atmosphere through transpiration and evaporation. Infiltration amounts are affected by this since infiltration equals the amount of precipitation minus evapotranspiration minus foliar interception minus runoff (Petrovic and Borromeo, 1994).

**Fertilizers:** Substances applied to plants in order to aid in their growth and development. For example, nitrogen (N) stimulates root growth, phosphorus (P) enhances stem and root strength, potassium (K) encourages seed ripening and stress tolerance, and phosphorus and potassium also improve the insect and disease resistance of the turfgrass plant (Barth, 1995b).

**Groundwater:** Water that saturates cracks, caverns, sand, gravel, and other porous subsurface rock formations. “Aquifers” are the zones in which readily extractable water saturates the pores of the formation (Kenna, 1995).

**Half-life (DT50):** The time (in days or weeks) that it takes for the pesticide to break down and reach half of the original concentration (a measure of persistence). The longer the persistence of a chemical, the more likely it will be a concern for leaching or runoff problems. If DT50 < 30 days, the chemical is considered non-persistent (even if DT50 is less than 100 is unlikely to move downward). For 30 < DT50 < 120 days is
moderate persistence, while DT$_{50}$ > 120 days is considered persistent (Branham et al., 1995).

**Hydroseeding**: A high-pressure spray technique for applying seed, mulch and fertilizer in a water slurry over a seedbed (“Golf impact report,” 1996).

**Integrated Pest Management**: “The coordinated use of pesticides and environmental information with available pesticide control methods to prevent unacceptable pesticide damage by the most economical means and with the least possible hazard to people, property, and the environment” (Muirhead and Rando, 1994).

**Leaching**: The downward movement by water of dissolved or suspended minerals, fertilizers, chemicals (pesticides), and other substances through the soil (Kenna, 1995).

**Lysimeter**: A bucket-like device installed in a test plot that collects soil water and makes it possible to monitor agrochemical movements (Branham et al., 1995).

**Macropores**: Large pore spaces in a soil profile that facilitate the downward percolation of water (and occasionally chemicals) below the turf.

**Maintenance**: The caretaking of the golf course and its elements, usually performed by golf course superintendents and their staff.

**Management**: A holistic approach to handling golf course operations where impact planning, continuing education, and experimentation are used to analyze and solve problems.

**Maximum Contaminant Level (MCL)**: An enforceable, regulatory standard for maximum permissible concentrations as an annual average of contaminants in water (Kenna, 1995). Levels of pesticide concentrations allowed in potable water are currently
being developed and defined by the EPA. Only a few of the pesticides used on turf have been given levels of regulation (for example, the MCL for 2,4-D is 70 ppb) (Smith, 1995).

**Native Grasses:** Grasses that are indigenous, occurring naturally in a particular region (“Golf impact report,” 1996).

**Nematodes:** Small, round worms, usually microscopic and colorless, that live in moist soil, water, or decaying or living organic matter. Parasitic forms puncture plant tissues and live by sucking the juice of the plant (“Golf impact report,” 1996). They are mainly a problem for warm-season turfgrass areas.

**Nonpoint Pollution:** Water contaminants coming from non-specific sources such as agricultural or urban runoff (Kenna, 1995).

**Overseed:** To sow seed over an area that is sparsely vegetated, or to plant cool-season grasses (such as Ryegrass) into dormant warm-season turfgrass for a temporary, green winter cover (“Golf impact report,” 1996).

**Perennial Grasses:** Grasses lasting or continuing from year to year in areas where adapted (“Golf impact report,” 1996).

**Pesticide:** A general term for chemicals applied for the control of undesirable insects and plants.

**Recycled Water:** The reuse of water for the purposes of conservation and efficient use. On golf courses, this refers to the collection of irrigation water (and stormwater runoff) into ponds to be reused for irrigation.
**Spoon Feeding:** A method of managing turfgrasses where the nutrient requirements of the turf are supplied at the most efficient rate with which the plants are capable of using them. This is only practical for higher maintenance uses such as on golf courses because of the expense and time required.

**Stimpmeter:** An instrument used to measure the relative speed of golf ball roll on putting greens. A number less than 5 is considered slow. Average speeds are 6 through 8, and a number of 10 or above is considered fast ("Golf impact report," 1996). Putting greens for most PGA golf tournaments measure 11 or more.

**Sustainable:** A type of system that requires few non-naturally occurring inputs and has only positive environmental impacts. There is a minimal loss of resources from this system and it therefore requires few inputs (Hull et al., 1994).

**Target Golf Course:** A type of golf course design that was developed in response to a limitation on the amount of acres allowed to be irrigated on desert courses. Tees, fairways, and greens (with maintained turfgrass) are often separated by areas that are not maintained, which gives the golfer the feeling of hitting from one target area to another. This offers opportunities for the use of native vegetation in these areas and reductions in the amounts of water and chemicals used on the course.

**Thatch:** A tightly intermingled layer of dead and living parts (roots, shoots, stems, leaf tissue, etc.) that develops between the green vegetation and soil surface ("Golf impact report," 1996). It forms a second canopy layer in the turfgrass through which pesticides must travel in order to enter the soil (Petrovic and Borromeo, 1994).

**Threshold Level:** Point at which pest populations or environmental conditions indicate that some action must be taken (Muirhead and Rando, 1994). Level at which the damage caused by pests is no longer acceptable and treatment is required (Greenspan, 1991).
**Topdressing**: A prepared mixture, usually containing silt, clay, sand and organic matter to a desired specification, that is used for leveling and smoothing the playing surface. It acts as an aid in controlling thatch and in maintaining biological balance ("Golf impact report," 1996).

**Transition Zone**: Commonly referred to as the geographical zone that is too far north to easily grow warm-season grasses and too far south to easily grow cool-season grasses ("Golf impact report," 1996).

**Vertical Mowing**: Also called verticutting, it is the thinning of turfgrasses by blades or wire tines that cut perpendicular to the soil surface. Specifically designed to remove mat, thatch and grain from greens and to thin dense turf ("Golf impact report," 1996).

**Volatilization**: Process by which chemicals go from a solid or liquid state into a gaseous state (Kenna, 1995).

**Xeriscape™**: A trademark of the National Xeriscape Council developed as a response to the critical environmental issue of water conservation. It involves the use of low water demand and drought tolerant plants and providing conditions that support healthy plant growth (Muirhead and Rando, 1994).

**Zone irrigation**: Method of grouping plants together with similar water demands to increase watering efficiency (Steinegger, 1991).

**Assumptions**

It was assumed that the results of experiments found in the literature that were conducted on functioning golf course practices or in a laboratory can be applied to actual course design, construction, and maintenance. It was also assumed that most golf course architects and maintenance personnel are willing to implement design, construction, and management practices that reduce impacts upon the environment.
Importance of the Study

A great deal of research has been conducted in the past few years concerning the environmental impacts of golf course construction and maintenance. Though many of the findings of these reports have been published, very little has been concluded about the relationship of the research to golf course design, construction, and management.

The golf industry has been widely criticized for water usage and water pollution, especially from pesticides and fertilizers. Most golf courses are viewed as environmental hazards rather than healthy ecosystems, possibly because of the amount of maintenance required to preserve the green color of the turf areas. There is, however, an emerging body of research and set of construction and management strategies that demonstrates the potential of golf courses to improve water quality and wildlife habitat.

How does this research relate to the design of golf courses? What design and planning principles can be drawn from these scientific results? The purpose of this study is to summarize the results of current scientific research and to use these results to create a set of golf course design, construction, and management principles. As an example of a more sustainable golf course design and management strategy, the expanded use of native vegetation in out-of-play areas will be discussed for three existing golf courses in an effort to evaluate the environmental and economic benefits of turfgrass conversion in these areas.

The Golf Course Controversy

Overview

There are currently more than 15,000 golf courses in the United States (“U.S. golf,” 1997). Assuming an average size of 120 acres of fairway/rough and two acres of putting greens per course, these courses collectively comprise approximately 1.8 million acres of fairway/rough and 30,000 acres of greens in the U.S. These are indeed staggering amounts of land dedicated to a recreational amenity.

According to the National Golf Foundation, 468 new golf courses were opened in the U.S. during 1995 (more than one per day), the most ever opened in one year (Hookway, 1996). The next largest year was 1996, when 442 new courses opened. In addition, 850 courses were under construction and 808 were in the planning stage as of July, 1997 (“U.S. golf,” 1997). One-third of the golf course construction in the past five years has been
devoted to expanding existing courses (160 expansion projects in 1995 alone). One reason for this may be that financing is more available for expansion than for new development. More than 50% of the 468 golf courses opened in 1995 were 9 hole layouts and 86% of the new courses were public. This is quite a contrast from 1920 statistics, when only 30% of the 4000 existing courses were public (Hookway, 1996).

Growth trends in course development are even greater worldwide. Geoffrey Cornish, a well-known golf course architect with many projects in other countries, estimates that 600 courses opened in countries outside the U.S. during 1995, and that an additional $4 billion of construction is currently in progress worldwide (Hookway, 1996).

Why the need for such high rates of development? Quite simply, there are more golfers than the current supply of golf courses can serve. The National Golf Foundation estimates that there are currently 24.5 million golfers in the U.S., and predicts that these numbers could exceed 30 million by the year 2000 (Smith, 1995). Assuming that the average golfer plays an average of twenty rounds of golf per year, this means that 490 million rounds of golf are currently played each year and approximately 600 million rounds would be played annually by the year 2000.

Obviously, careful consideration must be made in the conversion of such prodigious amounts of land to golf courses. What land uses are being replaced by this development? What are the current and anticipated environmental impacts of this development? Are common perceptions that golf courses are damaging to the environment accurate? Can golf courses be designed, constructed, and managed in such a way that they actually contribute to environmental quality? These and other questions will be explored in this study.

Benefits of Golf Courses

The literature chronicles many benefits attributed to golf course development. These benefits include:

- Reduced stormwater runoff from golf course turfgrass and native vegetation compared to agricultural fields and urban development (Kenna, 1995; Osmun, 1992).
- High rates of adsorption on leaves, thatch, and soil organic matter in addition to the high levels of microbial and chemical degradation rates in turfgrass systems allow golf
courses to act as filters for polluted waters. This not only makes them efficient users of applied chemicals, it also makes it possible for golf courses to be treated with wastewater as a source of irrigation (Kenna, 1995; Osmun, 1992).

- Absorption of gaseous pollutants (SO$_2$ and CO$_2$) and the supply of oxygen to the environment. Studies have shown that 625 sq. ft. of turf provides enough oxygen for one person for one day (Parascenzo, 1991) and 150 acres of turfgrass can provide 10,350 people with enough oxygen for one day (Muirhead and Rando, 1994).

- Golf course developments can improve the quality of degraded sites such as landfills, industrial waste dumps, abandoned sand and gravel mines, rock quarries, and coal mines (Dodson, 1996b; Brown, 1994). Funds generated by golf make it economically feasible to convert these abandoned lands when nothing else will work (Osmun, 1992).

- Groundwater recharge; 150 acres of golf course collects approximately 90 million gallons of rainwater per year (Osmun, 1992).

- Cooling effect, noise abatement, and fire breaks (Osmun, 1992).

- Increased real estate value for surrounding lands, provide a tax base and diverse array of jobs, generate revenue for the community (Brown, 1994).

- Most people enjoy the aesthetic beauty and greenspace preservation that golf courses provide (especially as a larger system of parks with bike and walking trails). Evidence for this can be seen in the high value of real estate that adjoins golf courses (Brown, 1994).

- 25 million Americans play golf (more all the time), gaining emotional benefits as well as health benefits from the exercise (Brown, 1994).

- Once the course is established, it provides soil erosion control (especially compared to agricultural production) while acting as a $3 billion contribution to national economy (Beard, 1994).

In addition to these items, the Audubon Society of New York currently operates an Audubon Cooperative Sanctuary Program in the interests of minimizing golf course impacts upon the environment. This program creates an opportunity for golf courses to educate the public in environmental issues and encourages home owners to take part in creating wildlife habitat around their homes.
Though each of these benefits is well founded, close examination reveals that this body of literature emanates largely from supporters of the golf industry. Another body of literature exists which questions the impacts of golf courses upon the environment.

**Criticisms of Golf Course Development**

The golf industry has been widely criticized for its impact upon the environment. Three broad areas of this critique include excessive water usage, degradation of water quality (from fertilizer and pesticide usage), and adverse impacts upon wildlife and their habitat.

**Water Usage**

Water usage is often one of the first criticisms of golf course developments. Many view the irrigation levels of most golf courses as excessive (Salvesen, 1996; Leonetti, 1995; Selcraig, 1993). This is a particularly heated issue where water resources are scarce. The state of Arizona, for example, has limited the amount of turfgrass area that can be irrigated for golf to 90 acres per course (Hurdzan, 1996). This has spawned an interest in the “target style” desert courses so common in that region.

More than one half of the U.S. population relies on groundwater for all or part of its potable water. However, only 18% of the water taken from groundwater aquifers is for domestic use, while 66% is used for irrigation (Yates, 1995). The remaining 16% is used for industrial production and other purposes. These percentages indicate our heavy reliance on irrigation water for food production, turfgrass maintenance, and other uses.

One example of the scale of water use in arid climates is Palm Springs Country Club (California) which uses 430 million gallons of water per year, enough for 11,000 people (Selcraig, 1993). This raises a very important, but difficult question. How much water use, if any, is acceptable?

**Water Quality Degradation**

Golf courses are also seen as having a negative impact upon the environment through the large amounts of pesticides and fertilizers used to maintain turfgrass. Some of this concern has been raised due to the increasing amount of technology available for
measuring the components of a sample of water. Whereas a part-per-million was considered an adequate measure of testing water quality less than ten years ago, a part-per-billion is now the standard of measurement in water quality monitoring. One part-per-billion (ppb) equals one teaspoon of salt in 26 million gallons of water (Smith, 1995). One author viewed this to be a continuing trend, “We will achieve recognition of concentrations of a part-per-quadrillion in the next decade. One day, we may recognize that there is something of everything in everything else. Yesterday's zero is no longer zero, and today's zero will not be zero tomorrow” (Smith and Tillotson, 1993).

According to Richard Klein, there is an inverse relationship between the quality of a waterway and the percent of drainage area devoted to golf courses. If more than 50% of the drainage area is golf course, waters have been observed with moderate to severe levels of degradation (Klein, 1994). There is also concern that, although golf courses have licensed maintenance personnel, the application of pesticides may be delegated to those who do not understand proper application techniques or the dangers of misuse (Edmondson, 1987).

Highly sandy sites are most susceptible to nutrient and pesticide leaching due to high permeability, low organic carbon content, and low cation exchange capacity (CEC). Golf course greens and tees are usually constructed using a sand base because of the importance of drainage in these areas, and are therefore areas of concern. According to A.M. Petrovic (1995), the worst case scenario for leaching (downward movement through the soil) is a highly mobile pesticide applied to a new stand of turfgrass over a shallow water table on highly leachable soil (sand). It must be noted that this describes many golf courses, particularly in the southern and coastal regions.

Several of the articles identified in this study confirmed that large amounts of pesticides are used on golf courses. A 1982 EPA study showed that the average course applies about 9 pounds of herbicides, fungicides, and insecticides per acre per year, roughly three times that used on agricultural lands (Selcraig, 1993). Another study, a 1990 report by the Environmental Protection Bureau of the New York Attorney General, involved a survey of 52 Long Island golf courses. The results of this study found 21 different herbicides, 20 fungicides, and 8 insecticides applied for an average of 18 pounds of
pesticides per treated acre per year. This amount is about seven times more than the 2.7 pounds per treated acre per year used on agricultural fields (Grossman, 1993).

While there is a disparity between the amount of pesticides applied in the 1982 study versus the one in 1990, this data does not lead to a conclusion that there has been an increasing trend in pesticide use over that time period. However, these numbers do provide a comparison for the evaluation of chemical usage compared to agricultural use. Noted golf course architect Michael Hurdzan is critical of a 1991 report by the New York State Attorney General's office which stated that golf courses use four to seven times more pesticides than agricultural lands. He believes that, "...if golf course superintendents applied 4 to 7 times the amount of chemicals that farms use...fairways and greens would all be dead from phytotoxicity" (Hurdzan, 1996, p. 372).

Though the pesticide usage levels on golf courses discussed above may seem excessive, they fail to reflect the efficiency with which turfgrass is able to utilize these nutrients. Petrovic and Borromeo (1994) determined that leaching is less from turfgrasses than from agricultural fields due to the higher shoot density, thatch layer, and active root zone microbial layer in turfgrasses. Most of the studies (Shirk, 1996; Carville, 1991; Grossmann, 1993; Snow, 1996a; Cohen et al., 1990; Horst et al., 1995; Petrovic et al., 1993; Smith et al., 1993; Snyder et al., 1995; Yates, 1995) were unable to find significant levels of these pesticides or fertilizers in groundwater or leaching samples. Pesticide and fertilizer levels measured in these studies were almost always less than the Maximum Contaminant Levels.

Murphy (1992) determined that, "The concentrations of most herbicides and banned pesticides in urban runoff appears to be well below the threshold for acute toxicity for most aquatic and terrestrial organisms" (Schueler, 1995c, p. 251). However, he also stated that there is a concern for potential chronic or sublethal toxicity because it has not been well documented in past studies. Even though nitrate-nitrogen levels less than 10 mg/L (as most water quality tests have shown) are not much risk to potable drinking water, concentrations of nitrogen and phosphorus have been measured high enough to trigger eutrophication (over-enrichment) in nutrient-sensitive surface waters (Barth, 1995a).

While these studies show that turfgrasses are efficient users of fertilizers and pesticides applied, there is still an impact in consuming such large amounts of these
substances and in the manufacturing required to produce them. Further discussion of the research on the impacts of golf courses on water quality can be found in the management section of Chapter II.

Wildlife and Landscape Impacts

Another criticism of golf course development is the loss, damage, or fragmentation of sensitive wildlife habitat and the contamination of non-target organisms and wildlife from the use of chemical fertilizers and pesticides (Muirhead and Rando, 1994). Although trends in planning and development are changing quickly, many golf courses have been created without a comprehensive view of what needs to be considered such as the ecological context of the site, construction feasibility, and long-term turfgrass maintenance considerations (Fream, 1982).

Though golf courses serve as wildlife habitat for many species, there is concern that the changes in habitat that occur through golf course development also alter the species mix and populations of these animals. “Construction of a golf course means certain death for the existing ecosystem,” according to Jolee Edmondson (1987, p. 30). There is no question that a golf course is a diverse ecosystem, but it is not the same as the ecosystem that existed before development. Golf courses tend to provide habitat that support and encourage edge species like fox, deer, rabbits, etc. In the process of converting pristine lands, some species may die off or move due to the development unless appropriate precautions are followed.

A very strong case can be made for the conversion of damaged lands such as landfills, industrial waste dumps, abandoned sand and gravel mines, rock quarries, and coal mines to golf courses (Dodson, 1996; Brown, 1994). An excellent example of this is Widow’s Walk Golf Course in Scituate, Massachusetts, a design by Michael Hurdzan set to open in 1997. When speaking about the site, a former sand and gravel quarry and dump area, Hurdzan said, “Local officials wanted to improve the property, but insisted that the development or improvements be financially self- supporting, create value for the town, and provide public recreational value. Only a golf course can do all that” (Whitten, 1996, p. 89). Development of golf courses on these degraded sites can create new habitat that supports many species of wildlife.
Conclusions

The golf industry has been widely criticized for negative impacts on wildlife habitat, excessive water usage, and water pollution, especially from pesticides and fertilizers. Most golf courses are viewed as environmental hazards rather than healthy ecosystems, possibly because of the amount of maintenance required to preserve the green color of the turf areas. The research indicates that golf courses provide excellent habitat for select species such as fox, deer, raccoon, and other edge species dwellers. When planned in conjunction with development, the inclusion of a golf course will provide far more wildlife habitat than a development without a course. However, it is also clear that an undisturbed site with large contiguous areas of native vegetation is better for wildlife than the same site with a golf course.

The issue of water usage is a harder one to identify and critique. The research indicates that less water could be used if golfers were willing to tolerate less than perfect turfgrass on the playing areas and if more out-of-play areas were planted with native vegetation. Chapter III of this research will discuss the economic and environmental benefits of this type of approach to golf course development. Water pollution seems to be the issue most misunderstood by those critical of golf impacts on the environment. The research outlined above and in the management section of Chapter II indicates that turfgrasses are very efficient users of the fertilizers and pesticides applied. It seems clear that golf courses have very little, if any, impact upon surface and groundwater quality when proper maintenance practices are followed. These practices are also outlined in the management section of Chapter II, such as the avoidance of excessive irrigation or chemical application, especially near surface waters. Design and planning also have a great deal of impact upon water quality impacts, such as the development of courses on appropriate soils and with adequate buffers for surface water areas. These principles are also developed in further detail in Chapter II.

A closer examination of the environmental impact of golf courses can be segmented into three critical activities: design, construction, and management. Each of these activities presents potential risks and, alternatively, potential promise for environmental quality issues. Each of these topics will be discussed in further detail in Chapter II: Current Literature and Case Studies.
CHAPTER II: CURRENT LITERATURE AND CASE STUDIES

Introduction

This chapter will introduce principles for golf course design, construction, and management that can be used by golf course architects and superintendents for both new construction and for renovation of existing courses. It contains data from research experiments related to the environmental impacts of golf courses and discussions of case studies which provide real-world examples of the possibilities that exist for future golf course development.

The information presented in this chapter is based on an extensive literature search which utilized both primary and secondary sources. Much of the scientific data represents results from experiments conducted as part of the United States Golf Association’s Environmental Research Program. Both refereed and non-refereed sources were utilized, primarily because much of the literature related to golf course design and criticisms of golf course development could only be found in non-refereed journals.

Golf Course Design Principles

Introduction

The game of golf, which is thought to have originated in Scotland as early as 1400, has continued to evolve over a period of more than 500 years into the game that we recognize today. The earliest playing fields for the game were the linkslands of the Scottish coastal landscape, areas consisting of windswept dunes of sand and hollows where grass would grow if the soil was substantial (Cornish and Whitten, 1993). The routing of play on these early playing fields was dictated by the terrain, and there was no recognized system of tees, greens, and fairways as there are today. Terrain manipulation for golf courses started in the late 1700’s, but the first recognized golf course designer was Allan Robertson of St. Andrews, Scotland, the first of many golf course architects who would follow in his footsteps (Cornish and Whitten, 1993).

Golf course architecture involves not only the application of spatial and aesthetic principles common to golf courses (tees, fairways, greens, and hazards) but also the
considerations that help the golf course function properly such as surface and subsurface drainage, safety issues, soil preparation, selection of turfgrasses and other vegetation, and management strategies. Many of the decisions made by the golf course architect affect the playability of the course, the cost of maintenance (and therefore cost of play), and impact of the course upon the environment. Therefore, proper design is one of the most important factors that influences the development of the golf course.

Though there are many instructional books that concern golf as a sport and how to play it, there are very few in existence that deal with golf course architecture. Even fewer still have been written in the past 50 years. Most of the literature concerning the subject can be attributed to designers from the “Classical Era” of golf course design from 1900-1930. Such well-recognized names as Tillinghast, Mackenzie, Maxwell, Thomas, and others practiced their art during this era. Many of the world’s most famous courses were designed by these pioneers, and several of them published books on the subject, such as Golf Course Architecture in America (Thomas, 1926), Some Essays on Golf Course Architecture (Colt and Alison, 1920), The Links (Hunter, 1926), Golf Architecture (Mackenzie, 1920), and The Architectural Side of Golf (Wethered and Simpson, 1929).

Interest in golf course design has experienced an unprecedented increase over the past twenty years. Accordingly, a few published works have become available that deal with the subject such as The Spirit of St. Andrews (Mackenzie, 1996), Golf Course Architecture: Design, Construction, and Restoration (Hurdzan, 1996), Bury Me in a Pot Bunker (Dye and Shaw, 1995), Golf Course Development and Real Estate (Muirhead and Rando, 1994), Golf by Design (Jones, 1993), The Architects of Golf (Cornish and Whitten, 1993), The Anatomy of a Golf Course (Doak, 1992), and The Golf Course: Planning, Design, Construction, and Maintenance (Hawtree, 1983). These texts and selected other sources will form the basis for the information presented in this Chapter related to environmental principles for golf course design, construction, and management.

Planning: Site Selection and Analysis

One of the most important considerations in discussing golf courses and environmental issues is the planning of the golf course development. Within the planning process, the analysis of the site selected is the most important step in evaluating the
potential environmental impacts of the golf course development and anticipating ways of mitigating these impacts. “Golf courses are not isolated recreational amenities but should be integral parts of larger networks of open space within the regional ecosystem.” This is the thought behind “Golf Courses as Ecologic Sanctuaries,” a concept developed by Desmond Muirhead and Guy Rando (1994). This concept is based on the premise that golf courses, as major landscape elements, offer special opportunities and potential to combine a recreational amenity with a program to improve environmental quality.

Planning with environmental concerns requires a commitment by the developer to be sensitive to all related issues, patient with the process, willing to risk “up-front” money, and open to making concessions and compromises (Hurdzan, 1994). The purchase of the land, the permitting process, and delays in the construction schedule are all probable in most development, and even more likely in cases where there are extensive environmental concerns. Ideally, developers will involve a golf course architect in this process along with a multidisciplinary team including an owner, engineer, ecologist, botanist, archaeologist, golf course architect, land planner, golf course superintendent, lawyer, and planning team coordinator (Hurdzan, 1994). Inclusion of this project team will greatly contribute to the overall success of the project.

Important physical elements of any site analysis for golf course development are required land area, soils and topography, hydrology, wildlife, and ecological concerns. Analysis of these factors will help to determine if the site is feasible for the type of development desired, and whether development is even possible or wise. It will also determine the success of the finished product as part of a healthy and functioning landscape.

Land Area Requirements

Golf courses are typically built to accommodate nine or eighteen holes, with each set of nine holes having two par threes, two par fives, and five par fours. The average eighteen-hole golf course requires approximately 160-200 acres of land in order to function properly. Successful courses have been built on less land, but the increasing length of travel of the golf ball over the years has also increased the length required for the golf course, hence the increasing land area required. Overall, eighteen hole course lengths are
usually greater than 6500 yards, with most courses seeking to exceed 7000 yards to increase the difficulty levels for better players.

The overall layout of the golf course is an important determining factor for design and playing flexibility, construction and maintenance expenses, safety concerns, land required for development, and home frontage (Muirhead and Rando, 1994). There are three basic layouts for golf courses; single fairway, continuous double fairway, and the core golf course. Though there are some variations on these layouts, such as with or without returning nines (this refers to whether play returns to the clubhouse after nine holes), they can be compared in these three categories.

Single fairway courses have more available frontage for homes and are most flexible for dealing with topographic problems (such as very hilly terrain), but they require more land area, are weak statements as open space, and are most expensive to maintain. They are problematic for golfers because they have limited playing flexibility (holes can only be played in a designated sequence) and because golfers would rather not play between houses, cross roads, nor travel long distances between holes (Muirhead and Rando, 1994).

In comparison, continuous double fairway designs use less land and are less expensive to maintain than single fairway courses, but they have less frontage for housing than single fairway and tend to be less safe. Core golf courses, on the other hand, have the least frontage for homes, but the frontage is of better quality. Less land area is required for core golf courses, golfers enjoy the design better (since they don’t have to play between houses and the distance between holes is less), the course makes a solid statement as an open space, there are fewer safety problems, and they are more efficient and less expensive to maintain (Muirhead, 1996). Because of these reasons, the core golf course is the concept most often used in contemporary golf course development.

Where land is limited, more modest-sized courses (25-60 acres) can be designed that utilize par threes and a few par fours to provide a variety of shot selections for golfers. Courses can also be designed with multiple tees and multiple greens that share common fairways (Fream, 1982). This type of course may only be appropriate for lower volume use because of the safety concerns such a course would raise. Although these types of golf developments on limited lands would be less expensive to build and maintain than a longer
course, they may not be wise investments considering the current growth trends in golf course use.

Donald Knott, a golf course architect with Robert Trent Jones II International, suggests that current trends of 7000 yard course lengths for 18 holes may not be healthy. He questioned whether some environmental impacts could be lessened by not always smashing 18 holes into a piece of land, and whether fewer (but better quality) holes would result in natural areas of better quality (Knott, 1994). Another environmental question related to required land area is whether golf courses should be designed to take up even more land than they currently do in order to embrace and preserve large habitat areas, or whether they should be limited to the development of rejected landfills and urban fringe lands (Pearce, 1993). Continued research is needed concerning the impacts of golf courses on native flora and fauna in order to evaluate these concerns.

Soils and Topography

Soils are particularly important in golf course development because of how greatly they impact the growth of turfgrass. No other element more greatly affects the health of turfgrass than the growing medium. This will determine the nutrient and water availability for the turfgrass plant and will greatly affect the long term maintenance success of the golf course.

Extensive field research should be conducted prior to construction to determine possible complications from soil characteristics. This should include a visit to other courses in the area to talk with superintendents and identify what grasses are best suited for the soils and climate of that area based on their the past performance (Poellot, 1992). Test holes should be dug on several different areas of the site in order to determine the depth of soil to rock, the type of underlying rock, the depth of soil to groundwater, and the characteristics of the constituents of the soil horizon profile (Hurdzan, 1996). Test plots should be conducted with possible soil and grass choices made for the course before final choices are made. The management section of this research will discuss the interactions of soil and turfgrass quality in more detail.

In addition to acting as the growing medium for turfgrass, soil is a precious resource in and of itself. Because of this, there is a need for any land conversion to take into account
the impact of the development upon the soil. It is important to identify the locations of steep slopes and highly erodible soils to prevent erosion, especially during the construction of the golf course. Coarse textured or shallow soils should also be avoided in order to decrease the likelihood of pesticide and fertilizer leaching. The design of the course should be done so that intrusion upon any of these features is minimized (Klein, 1994).

The engineering characteristics of the soil are important for construction concerns, especially where the building of greens, tees, cartpaths, access roads, and structures like the clubhouse or storage areas are concerned. Areas with weak bearing capacity or extensive shrink and swell characteristics should be identified and avoided, or the soil should be properly amended (if possible) before any construction begins.

Topography is also important in assessing the suitability of a site for a golf course. Golf courses have been built on every conceivable terrain, from flat desert courses to climbing and tumbling mountain designs. In general, a slightly rolling topography is desirable from a surface drainage and visual interest standpoint. It is best to avoid steep slopes because of the erosion and maintenance concerns they cause, and also because these courses tend to produce safety concerns and are difficult to walk. On the other hand, completely flat sites are often difficult to drain and lack the visual interest that even a small hill can provide (Doak, 1992).

In general, the best soil and topography conditions for a site seem to be those with a gently rolling topography and a soil profile that is consistent throughout the site. These factors will decrease construction and maintenance costs because a minimal amount of soil will need to be moved during construction and the conditions for maintenance will be relatively consistent throughout the course. The best soil types seem to be well-drained soils, such as sandy loam, that will be resistant to compaction but will be able to retain enough moisture for plant growth. Greens and tees require separate construction methods and soil distributions because of the intense traffic and maintenance conditions required in these areas.

Hydrology

Water is the precious resource that ties together all of the elements of the golf course. Most of the criticisms that have been raised concerning golf course impacts upon
the environment have dealt with water quality degradation and excessive water use. Therefore, it is very important to identify any possible water quality impacts before construction begins. This involves an evaluation of surface water impacts as well as groundwater impacts.

Powell and Jollie, in a 1993 report for the Baltimore County EPA (Schueler, 1994), developed guidelines that require detailed evaluation of wetlands, including the approximate type and distribution of existing vegetation, evaluation of depths and sizes of standing water areas, and soil information for the area. Perennial and intermittent streams, floodplains, steep slopes, forest stands, and habitat features for a proposed course were also to be identified and evaluated prior to the design of the course. They recommended that the course should then be configured to avoid or minimize disturbance of such areas.

In order to evaluate groundwater contamination potential, Cohen et al. (1993) recommended that soil samples should be gathered to determine organic carbon content, pH, field capacity, sand and clay content, bulk density, porosity, and infiltration rate. All of these factors greatly influence the downward percolation of water through the soil profile. They also recommended that any presence or likelihood of groundwater discharges to sensitive surface water bodies be identified and protected prior to construction. In addition to these elements, the proximity of the water table to the surface is an important factor in determining potential groundwater impacts.

Water use is another issue that must be addressed in the site analysis. The ability to obtain the necessary water for irrigation will always be an important factor in golf course development because of the need to keep the turfgrass areas healthy. Hurdzan (1996) states that, in the Midwestern regions, fairways require about one inch of water per week, while tees and greens need about one and one half inches per week. These numbers seem harmless enough, but when the total amounts of irrigation water for an eighteen hole golf course are calculated (assuming thirty acres of fairways and five acres of greens and tees), it becomes apparent that the course would require 810,000 gallons of water per week for the fairways and 202,500 gallons per week for the greens and tees. Courses in arid regions may need up to three times this amount of irrigation. Obviously, the availability of water is one of the most important issues in evaluating the suitability of a site for golf course development.
Irrigation restrictions currently placed on desert golf courses may one day be applied elsewhere as well, a change that will impact course design in the future. Perhaps these design concepts related to water conservation should be implemented before water resources become a greater concern. One method would be the use of the “target” course design philosophy in the non-arid regions of the country. This concept would decrease the amount of turfgrass area on the course, thereby decreasing water consumption and maintenance expense (less chemical application, less mowing, etc.). It would also provide expanded areas that could be planted with native vegetation for wildlife habitat.

Another strategy that has been used for water conservation is the design of courses with internal collection of rainwater and irrigation runoff into holding ponds for reuse. This not only decreases the demand for potable water for irrigation of the course, it decreases the likelihood of off-site transport of nutrients and chemicals from turfgrasses. The use of effluent water is another concept that has been implemented successfully on several courses in the U.S. (Frye, 1994; Salvesen, 1996; Poellot, 1992) and may provide promise for future golf course irrigation and water treatment needs in this country. Fresh water sources will always need to be available for irrigation during times of drought when pond levels drop and also as a supplement to the use of effluent water.

Surface and groundwater resources must be carefully identified and evaluated prior to construction of the course. Any use of these resources should be planned and monitored in order to avoid water quality degradation and excessive water use. One guideline for water usage identified in the literature was that sufficient water must be available to meet the irrigation needs of the golf course without either causing a decrease of more than five percent of the seven day, ten year low-flow level of any waterway in the vicinity or substantially reducing the yield of existing wells in the area (Klein, 1994). Following this guideline will provide the irrigation water necessary for turfgrass maintenance without negatively impacting the water resources of the surrounding ecosystem.

**Wildlife and Vegetation**

While analyzing a site for potential development, it is important to assess the quality of habitat that exists on the site and identify the impact that the development will have on the wildlife and vegetation already present. A “Habitat Suitability Index” such as that
commonly used by the U.S. Fish and Wildlife Service can be used to numerically rank habitat and evaluate site suitability. A biological inventory should be taken that includes habitat diversity, species diversity, species of special concern, endangered or threatened species, water resources, habitat integrity, and connections between habitat areas (Smart et al., 1993). Existing vegetation should also be evaluated for its type, health, age, distribution, and impact on wildlife (Hurdzan, 1994).

Following the assessment of the wildlife and vegetation on the site, there may be additional procedures needed to avoid certain areas and to mitigate any damage that may be caused by development. Potential planning requirements and restraints may include wetlands or other sensitive surface waters that require buffers for protection and potential and existing habitats (nesting and breeding areas), particularly those used by endangered species identified on the site (Hurdzan, 1994). Once these areas have been identified, the site analysis should also assess the possibility of enhancing existing habitat and creating a more sound ecological plan for the development. For instance, the inclusion of large contiguous patches of native vegetation can be connected together to form a matrix of habitat and travel corridors for wildlife.

There is ample evidence that golf courses provide habitat for a wide variety of plants and animals (USGA report, 1996; Borland, 1988; Carrick, 1994; Danielson, 1993; Etchells and Rinehimer, 1994; Harker et al., 1993; Hawes, 1996), though concerns still exist that the types of habitats which they provide favor edge species rather than a broader range of wildlife types. Funds generated by golf course development also make it economically feasible to reuse degraded sites such as landfills, industrial waste dumps, abandoned sand and gravel mines, rock quarries, and coal mines. Examples of this include the TPC of Michigan (Hawes, 1995), Harborside International in Chicago (Thompson, 1996), Old Works Golf Course in Anaconda, Montana (Duthie, 1996), and Widows Walk in Scituate, Massachusetts (Hurdzan, 1996; Whitten, 1996). These types of development offer tremendous opportunities for the future problems associated with waste disposal from the excessive resource use of our society.

The impact of golf course development upon existing flora and fauna in previously undisturbed sites, however, has yet to be fully evaluated. More research needs to be conducted in this area in order to assess potential impacts and opportunities for improving
habitat. If a previously undisturbed site is going to be developed, the design and construction of the course should be carried out with minimal disturbance to the out-of-play areas and with very careful consideration of potential ecological impacts.

**Additional Concerns**

In addition to the above physical characteristics that need to be addressed in the site analysis, there are other factors that are important in assessing the potential impacts of golf course development. Social factors often play an important role, particularly in the permitting process. Many of these factors can be identified through visiting the site and speaking with area residents as well as through extensive research of historical records. If area residents highly value the proposed site in its current condition, they are more likely to resist development in that area. Another issue could be the presence of rights-of-way, easements, or zoning restrictions for that area that would limit the types of development that could take place. Previous land use, particularly as it relates to historical significance, is an important factor since some of these areas will need special consideration and may possibly need to be avoided during construction. Adjoining land uses and future plans for the development of the surrounding lands will impact how the golf course will function as a landscape element and will contribute to the playing and living atmosphere (for instance, sites in the flyway for a nearby airport will continually be disrupted by the noise levels from air traffic). Below-ground concerns such as buried utilities, mineral rights, and potential archaeological sites are also of concern in the planning stages of development (Hurdzan, 1994).

All of these issues, in addition to required land area, soils, topography, hydrology, and ecological concerns, are important items that must be identified and analyzed during the planning process. If all of these criteria are properly evaluated, the design and construction of the golf course and any accompanying development will have the most chance of success for making a positive contribution to the functioning landscape.

**Surface Water Concerns**

Since it is one of the most criticized aspects of golf course development, it is important to deal carefully with the subject of surface water pollution. Groundwater impacts
and surface runoff studies concerning pesticides and fertilizers from turfgrasses are detailed in the management section of this chapter. This section will deal with golf course design impacts on surface water quality.

Possible causes of waterway degradation include stream channelization (straightening of streams which causes accelerated channel erosion from increased stormwater velocity), destruction of wetlands, lack of vegetated buffer for filtration of runoff, elevated water temperature (from lack of shading vegetation, reduced groundwater flow, heated water from ponds, and heated water from runoff of impervious surfaces), reduced base flow (due to ground and surface water withdrawal), release of toxic and oxygen-deficient water from ponds, intermittent pollution (pesticides, fertilizers, and fuel), stormwater pollutants from impervious areas, elimination of scouring benefits of flooding by altering the frequency and magnitude of flooding, poor erosion and sediment control during construction, and inadequate treatment of sewage and wastewater (Klein, 1994). The following paragraphs will address these areas of concern and how golf courses can be designed for protection of these hydrologic systems.

Wetlands

Environmental considerations are becoming an increasingly important part of any development process due to new regulations. Obtaining construction permits now takes a tremendous amount of time and has resulted in developers using more thoughtful and environmentally conscious site selection and design practices. Developers must be much more careful in the types of land they choose for expansion and how they treat them. One of the largest issues to emerge has been the treatment of wetlands.

The presence of wetlands on a potential golf course development site has a tremendous impact upon the planning and construction phases of a project. Section 404 of the 1979 Clean Water Act defines wetlands as, "...those areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions." (Balough and Walker, 1992). The presence of water in wetlands creates conditions that support vegetation adapted to wet conditions (hydrophytes) and produce characteristic soils (hydric soils) that develop under anaerobic circumstances.
Wetlands are recognized as a valuable natural resource in that they provide habitat for breeding and nesting waterfowl, reptiles, amphibians, and other aquatic birds. Many mammals also occupy wetlands (either periodically or permanently) including mink, muskrat, raccoon, and beaver. Wetland vegetation provides habitat for aquatic invertebrates, which are an important link in natural food chains. Many types of wildlife utilize wetlands for only a portion of their life cycle, while others require wetlands for their entire life cycle (Thompson, 1992). In addition to wildlife habitat, wetlands provide flood control (acting as a sponge for storm runoff), improvements in water quality (acting as a "sink" for trapping sediments and nutrients such as phosphorus and nitrogen), groundwater recharge and discharge, aesthetic and recreation areas, and shoreline erosion control (Balough and Walker, 1992). The biotic mass of emergent plants in wetlands can also be periodically harvested, composted, and used to amend soil, effectively removing nutrients from the water for reuse on turfgrass areas (Muirhead and Rando, 1994).

Pete Dye, in his book “Bury me in a Pot Bunker” (1995), said that, “Based on current environmental rules, it would be impossible to build the Stadium Course TPC (Sawgrass, Florida) today. Reclaiming usable land from swamps and marshes by draining the water into lagoons was allowable then but would not be permitted today.” While describing another of his projects, Harbor Town Golf Links on Hilton Head Island, South Carolina, he said, “Since the site was soggy, our crew began by dredging out narrow canals to drain off water....” These types of practices are generally no longer permitted without extensive mitigation. Many new golf courses use wetlands to their advantage by dedicating them to out-of-play areas or setting them aside as nature reserves that serve as a backdrop to the course and as a positive marketing feature.

Squaw Creek Resort in Olympic Valley, California is a good example of the integration of wetlands into an environmentally sensitive and successful golf course development. Because of the extensive amount of wetlands on the site and its location above a major source of drinking water, one of the limitations set on this course by the surrounding community was that two acres of wetlands would be preserved for every acre of tee and green built on the site. Contractors were able to do this by utilizing the existing wetland soils in the construction of new wetland areas. A tractor bucket was modified for use as a sod cutter to cut the wetland vegetation seed bank into rolls so it could be used
again elsewhere. The topsoil was removed at the new wetland location and soil was excavated below the water table to the appropriate depth for the vegetation that was to be sodded. The wetland seedbeds collected were then rolled out in the new location and the area was inundated to the desired depth. So far, these modified wetlands have performed wonderfully due to the use of the rolls of wetland seedbed in their establishment (Jewell, 1994).

Because of the positive benefits of wetlands related to water quality and wildlife habitat listed above, and because of the extensive restrictions on their use for development, sites with substantial amounts of existing wetlands should be handled carefully. If there is insufficient land available for development of the golf course (in addition to housing and other facilities) without damaging the wetlands, it would be wise to consider either a smaller scale of development (shorter course, less housing, etc.) or development of a different site altogether. Wetlands on site should be included in the plans as features and contiguous parts of the final landscape development.

**Constructed Ponds and Drainage Concerns**

The use of water as a hazard in golf course design has gained tremendous popularity in the United States, particularly following the invention of powered equipment that has made massive soil excavation possible. These ponds not only provide beauty to the golf course landscape and a hazard for the play of the game, they also help to control downstream flooding and make the storage of irrigation water for the course much more readily available. There are many important considerations in the location and design of constructed ponds and other drainage features of the course.

The use of constructed ponds within flowing streams should be avoided because of the thermal pollution and increased algae growth they cause (temperatures are raised in the captured waters) and because they act as barriers to fish migration (Klein, 1994). Instead, these ponds should be constructed away from other surface waters in their use as a source for irrigation. Ponds should be designed with some shallow areas to encourage growth of emergent plants (Ciekot, 1996). Not only does the emergent vegetation filter the water of nutrients from course runoff, these areas also provide habitat for birds that build nests that float or nests anchored to emergent vegetation. This shallow water vegetation area is the
most productive area of any water body, providing a majority of the habitat for aquatic
invertebrates, a valuable food source for many species of wildlife (Thompson, 1992).

Figure 2.1 shows a typical concept section for the hydrologic cycle of a golf course
where surface drainage is diverted to retention ponds. The contouring of fairways and
rough with a one foot slope away from adjacent surface waters will keep the systems from
interacting (Smart et al., 1993). The use of these vegetative berms and mounds will make it
possible to contain and redirect surface runoff away from sensitive environments. These
waters can then be filtered by the turfgrass or collected in stormwater management ponds
which will reduce suspended nutrients and sediment in drainage water (Muirhead and
Rando, 1994). Runoff from parking lots, buildings, and other impervious areas should also
be collected and filtered in retention ponds. The biologically filtered water can then be
pumped onto the golf course by the irrigation system.

The use of vegetative filtering systems contained in swales and infiltration trenches
throughout the course (see Figure 2.2) can be another very effective way of treating
irrigation runoff on site (Schueler, 1994b). This is particularly important for the treatment of
water collected from sand-based areas such as greens and tees which are designed to
have higher infiltration rates to increase drainage effectiveness.

Streams, Rivers, and Lakes

The design of the course should seek to minimize the occurrence of water crossings.
If the crossing of a waterway cannot be avoided, cart paths should be perpendicular to the
flow of the stream, less than eight feet wide, and elevated on pilings from the edges of the
floodplain. This would avoid the use of culverts, which tend to reduce the connectivity of
habitat within the waterway (Klein, 1994).

Figure 2.2 shows a concept plan (Schueler, 1994b) for a stream crossing that
minimizes impacts upon the stream. Note that all fairway crossings are perpendicular to the
stream and that no more than two stream crossings are recommended per 1000 feet of
stream length. Also notice that the surface runoff and leachate outflow from fairways, tees,
and greens is treated by a combination of vegetative filtration areas (swales and wetlands),
as mentioned in the previous section.
Figure 2.1: Illustration of the golf course hydrologic cycle and drainage solutions (adapted from Muirhead and Rando, 1994)

Figure 2.2: Concept plan for a stream crossing that minimizes impacts upon the stream and vegetative filtration of collected runoff (adapted from Schueler, 1994b)
Stream channelization (straightening of flow channels for maximization of runoff and drainage) should be avoided because increased stormflow velocities tend to cause erosion and sedimentation problems both on site and downstream. Lack of stormwater storage and higher levels of runoff associated with development and channelization also cause increased peak flows and create additional erosion and flooding problems downstream. Naturally meandering channels, on the other hand, make it possible to establish vegetation which provides soil protection and increased frictional surfaces for flood flows. Natural channels are longer than those that are channelized, and this provides additional storage capacity of surface runoff waters and valuable habitat for a variety of aquatic invertebrates that are intolerant of higher flow velocities.

Buffer Strips

One of the proposals that has been made for the protection of surface waters is the use of native vegetation, usually perennial grasses, in a buffer planting between developed areas and surface waters. According to Richard Klein (1994), the presence of buffer strips in these areas would help to retard flood flows, slow channel erosion, shade and cool the stream, filter sediments and chemicals from runoff, and would contribute organic matter to the system, thus improving the quality of the soil.

Though there seems to be a consensus in the research that buffer strips are important contributors to the health of surface waters, there are differing opinions as to the appropriate width of these areas. Klein (1994) recommends a buffer width of 75 to 150 feet along waterways. Doug Carrick (1994), on the other hand, described a golf course he designed in eastern Canada where a 30 meter (100 foot) buffer strip was used between turfgrass areas and a sensitive trout stream, and 15 meters (50 feet) in other areas (Carrick, 1994). Bruneau et al. (1996a) agree on the use of a 50 foot buffer around wetlands, and recommend that golfers, irrigation water runoff, parking lot runoff, and maintenance vehicle wash be designed to avoid interaction with these systems.

Based on these research results, it appears that a minimum of 50 feet of native vegetation should be planted as a buffer to surface water areas. Widths closer to 100 feet will provide even more opportunities for wildlife habitat and ecological health for the site.
widths less than this are required, steps should be taken to route storm water runoff away from the surface water bodies through the use of berms and swales.

**Wildlife Habitat: Creation and Conservation**

After assessing the quality of the habitat that exists on the site and identifying the impact (both positive and negative) that the development will have on the wildlife and vegetation already present on the site, it then becomes important to incorporate this information into the design of the course. This approach extends through the construction phase and ultimately into the management plan for the course and surrounding lands.

According to Bill Roberts, a past president of Golf Course Superintendents Association of America (GCSAA), "Early golf course architecture traditionally tried to work with the shape of the land. Then, beginning in the 1960's, builders and architects began moving a lot of dirt, trying to create some different looks. And that had an impact on habitat" (Frye, 1994). During the routing phase of the golf course design, the information gathered in the site analysis will be vital in minimizing environmental impacts and avoiding areas where it will be most difficult to mitigate damage. One of the keys of creating wildlife habitat and overall health in the ecosystem is the retention of contiguous connections and wildlife corridors. Preservation of these connections during the design and construction of the course will make it possible for wildlife to travel through the site and will encourage the health and growth of a wider range of animals, thereby promoting the biodiversity of the site. This work should be done in collaboration with ecologists and botanists in order to determine the configurations of contiguous habitats required to support and protect specific species types (Muirhead and Rando, 1994).

Qualified professionals should be on site during staking and clearing to identify (tag) endangered and sensitive flora. A very effective method for protecting these areas is by fencing off areas that will remain undisturbed and avoiding them during construction. If these areas cannot be avoided, any endangered species should be transplanted to other undisturbed areas on the site. Endangered or sensitive species and habitat that are identified should be noted in construction documents with photographs and drawings, and clear and detailed specifications should be provided for the transplanting of sensitive flora during construction. The specifications should also include locations and recommendations...
for the care and monitoring of endangered or sensitive species (or those relocated) for inclusion in golf course management and operating plans (Muirhead and Rando, 1994).

Throughout the development and management of the site, an effort should be made to use plant species that are native to the area. One effective method for determining plant quantities needed for planting is to take into account the survival rate of the species. For example, if 50% are expected to survive, then two should be planted to compensate (Klein, 1994). According to Powell and Jollie (1993), no more than 25% of the pre-existing forest cover should be removed in the watershed (Schueler, 1994). An effort should also be made to create and maintain snags (piles of brush and dead vegetation) of various sizes and ages in out-of-play areas, unless they are a safety hazard, since they provide valuable food and shelter for wildlife.

Additional information concerning the use of native vegetation on golf courses can be found in the management section of this chapter. Chapter III will extend the benefits of native vegetation to an economic comparison of its use to turfgrass. The management section also describes the Audubon Cooperative Sanctuary Program and the positive impacts that it has had upon golf course developments and their implementation of ecological principles.

Because of the size of this topic and the availability of quality sources of information, further discussion of design principles related to biodiversity, connectivity, wildlife habitat, and ecological restoration will be limited. For more information on these topics, the reader is referred to works such as *Landscape Ecology Principles in Landscape Architecture and Land-Use Planning* (Dramstad, Olson, and Forman, 1996), *Landscape Restoration Handbook* (Harker et. al, 1993), *Ecology of Greenways* (Smith and Hellmund, 1993), and *Prairies, Forests, and Wetlands* (Thompson, 1992).

**Soils and Topography**

No other factor influences the health of turfgrass and affects future maintenance concerns as much as proper soil preparation. In addition to the methods outlined for the site analysis of the proposed development such as avoiding steep slopes (greater than fifteen percent) and highly erodible soils, there are additional concerns that should be dealt with during the design of the golf course.
One of the first tasks is to identify and, if necessary, change soil that is inappropriate for turfgrass growth. Because of the perennial nature of turfgrass systems, it is wisest to amend the soil as needed prior to planting in order to avoid future problems. Cation exchange capacity (CEC) is an important indicator of soil fertility. If it is too low (as is the case with highly sandy soils), it may be beneficial to add organic matter to the soil, which would raise the CEC levels. Another important factor related to soil health is pH, which reveals whether the soil is acidic (pH less than seven) or alkaline (pH greater than seven). If soil tests reveal a pH level that is too high or too low (six to seven is optimal for nutrient availability for turfgrass plants) it may be necessary to add lime (CaCO₃) to the soil (to raise a low pH). If high levels of sodium are present in the soil, gypsum may be added in order to improve soil structure and infiltration capacity. Calcareous soils (containing high levels of lime) create problems for management that will need to be considered as well. These concerns are discussed in more detail in the management section of this paper.

Methods of analysis should be in place to ensure that the growing medium of the course has enough depth and porosity, and that the subsurface and surface drainage are sufficient (Poellot, 1992). An underdrain system should be installed for all fairways, greens, and tees located on coarse-textured soils (such as sand susceptible to leaching) or anywhere the depth to bedrock or the water table is less than four feet. Another alternative would be the use of clay soils (to eliminate infiltration) or low maintenance vegetation (to avoid chemical usage) in these areas (Klein, 1994).

John Roedall, head superintendent at Chesapeake Bay Golf Course in the village of Northeast, Maryland, has found that improving the soil is the most important step toward the elimination of most maintenance problems. He also states that minimizing contour changes during design and construction is wise because, “You never know what you'll find once you start digging, and microclimate changes can be created by changing the topography.” His course uses organic conditioners to improve poor native soils (a kelp-concentrate biostimulant and fish emulsion product), in addition to a 100% silicon wetting agent that helps irrigation water penetrate the soils. Both of these practices reduce the nitrogen requirement for turfgrass maintenance (Roedall, 1996).

For cases where an existing golf course is undergoing renovation, it is important to know the age of the course and the management practices that have been applied to it. If
the golf course existed prior to 1980, the greens, tees, and fairways should be analyzed for organochlorine and metallic pesticide residues. If residues are found, measures should be taken to minimize their movement into surface and groundwater. Some methods for doing this would be the collection and treatment of water percolating out of these root systems, or through an increase in the organic matter content of the soil (Klein, 1994).

Soils and topography will also affect the costs for construction and management of golf courses. In general, golf courses developed on sites with a slightly rolling topography and sandy loam soils will require less earthwork and soil modification during construction, and therefore will have lower construction costs. Future management of such sites will also be more efficient because there is more likely to be proper drainage for the turfgrass areas and there will tend to be less compaction and better nutrient availability for turfgrasses in these types of soils. Whenever possible, earthwork should be kept to a minimum in order to protect existing soils from potential erosion during construction and to keep construction costs down, thereby providing cost savings to golfers that will play the course in the future.

**Design and Construction of Greens**

The designs of golf course greens have undergone a great deal of change over the past 50 years. In the early 1900’s, the slopes of greens usually ranged from 5-8%, which is quite steep compared to the slopes of 1-4% used on today’s greens. This disparity can be attributed to changes in grass varieties used on greens, lower mowing heights with new mowers, and softer greens from higher amounts of irrigation required to grow grass at the low mowing heights. Another important factor is that modern golf clubs hit the ball higher and with more spin, so that the ball goes farther (eight to twelve yards longer than in 1960) and spins more than ever before (3). This makes it possible for players to land approach shots on the green and stop the quickly, even on the flatter putting surfaces.

One factor that has influenced this trend toward flatter and more closely mowed greens is the Stimpmeter. A golf ball is placed in a grooved hole on this device and one end is lifted until gravity causes the ball to roll down its length and across the green. The length of the ball roll is measured in feet, and this value can then be compared with other greens. A number less than five is considered slow. Average speeds are six through eight, and a number of ten or above is considered fast (“Golf impact report,” 1996). Putting greens for
most PGA golf tournaments measure eleven or more. Originally, this device was helpful to
golf course superintendents because it made it possible to check the greens on their course
for consistency. Now, however, it has become a problem because golfers continue to
desire higher Stimpmeter readings for their greens. Turfgrasses maintained at such low
mowing heights require more frequent and higher amounts of water and chemical
applications (they are less disease and drought resistant because they are less able to
tolerate additional stress).

The evolution of the golf green continues as more research is conducted on root
zone mixes and new varieties of turfgrasses are discovered and tested. Because sand has
a very low cation exchange capacity (CEC, or the ability of a soil to accommodate positively
charged ions), nutrients are less available for turfgrasses in this type of rooting medium.
However, sand is required for high traffic areas such as tees and greens because it has
excellent drainage characteristics and is able to withstand compaction where normal soils
(with higher CECs) perform poorly. It has been found that mixing peat moss with sand in
putting green construction reduces nitrogen leaching because of the higher CEC which
these organic materials possess (Snow, 1996). This presents problems, however, since
peat moss is a resource that is being used at a tremendous rate, and the peat bogs that are
being destroyed for this purpose are not being replaced. Because of this, alternatives for
peat moss need to be found for use as organic soil amendments.

The two most widely recognized methods of green construction using sand-based
media are the USGA Method and the California Method. The USGA Method uses a four
inch base layer of small gravel, overlain with two to four inches of course sand (optional),
followed by twelve inches of laboratory-tested sand blended with a small amount of organic
matter (USGA Green Section Staff, 1960). Water is conserved in the root zone by the
creation of a perched water table (water held in sand root zone because of the particle size
transition between layers), making it more available to the turfgrass. The California Method
also has twelve inches of carefully selected sand, but removes the gravel layer in the
interest of rapid drainage.

Prior to the use of sand-based media, greens were built with native soil which
became known as “push-up” green construction. This type of green is still very common
throughout the U.S., particularly where native soils have a higher sand content. Though this
method can still be effective and is much less expensive to implement than the other two types, these greens tend to develop problems with compaction and drainage under heavy traffic. Use of one of the other methods is usually better in the long run unless the soils on the site have a high sand content and can support the expected traffic.

Tim Hiers, head superintendent at Collier's Reserve in Naples, Florida, recommends the USGA Green construction method because he says it is better for controlling the leaching of chemicals. Although this method may have a higher up-front cost than other methods, it saves money in the long term by reducing water demand, the frequency of chemical application, avoiding soil compaction, and increasing the health of the turfgrass (Goldsby, 1991). The USGA specifications are continually being tested in the interest of promoting turfgrass health and course playability while decreasing water and chemical usage. They are currently enlisting golf courses from different areas throughout the country to implement experimental practice greens which will make it possible to test different green construction methods under normal golf course maintenance and traffic conditions.

Golf course superintendents are leaders in experimentation with golf course maintenance strategies. John Roedall and his crew at Chesapeake Bay Golf Course used the USGA construction method with calcified diatomaceous earth (DE) soil amendment at ten percent by volume in the top six inches of the root zone mix. This DE balances the air content in the soil, helping to control fungal development. It promotes the development of strong, deep roots, and it lowers the bulk density and helps prevent compaction (Roedall, 1996). At Squaw Creek Resort in Olympic Valley, California, head superintendent Carl Rygg has been operating a no-spray program since 1988. In other words, no pesticides, fertilizers, or fungicides are used on the course, and only limited nitrogen usage is allowed because of the location of the course over a major groundwater source. Part of that program has involved the use of charcoal filters in the greens to keep nitrogen out of water table (Jewell, 1994). These and other strategies will be discussed in more detail in the management section of this paper.

One environmental concern regarding the USGA method is that the water collected from the sand and gravel layers below turf is not given an outlet in the USGA specifications. These specifications show a four inch drain for collecting the percolate but they don't describe how this water should be treated beyond saying that, "...considerations should be
given to disposal of drainage waters away from play areas, and to the laws regulating drainage water disposal" (USGA, 1997). Treatment of drainage water is also a concern for other methods of green construction and for water collected from other areas of the course, whether they are fairway depressions or teeing areas. Tom Schueler recommends that the collected infiltration should drain to a depression area with an organic layer, sand layer, and stone layer that will filter it, as was shown in Figure 2. He also recommends that the green be constructed more than four feet above the water table or bedrock layers in order to avoid possible groundwater contamination (Schueler, 1994).

Much of the traffic damage and maintenance problems encountered on golf greens can be avoided by properly designing the green to accommodate the expected amount of traffic for the course. According to Muirhead and Rando (1994), greens should have an area of at least 6500 square feet on high traffic courses, with six or more pin placements that are at least fifteen feet from the edges of the green. Hurdzan (1996) recommends a minimum of fourteen pin placements on each green. An effort should also be made to avoid draining the green to the front, which would result in a soggy approach susceptible to damage from foot traffic. The use of alternate greens (one with cool season grasses, one with warm) can be an effective solution for limiting year around traffic on greens in southern climates (Muirhead and Rando, 1994).

In addition to these design strategies, efforts should be made to raise mowing heights and lower green speeds in the interest of increased turfgrass health and decreased water and chemical usage. This will mean the return of increased slopes to golf greens in order to maintain the same level of playability. Continued research may reveal better methods of green construction, better rootzone mixes, and better varieties of turfgrasses for use at low mowing heights. Based on a review of the literature, the USGA method of green construction seems to be the best available based on the research results related to water conservation and improved turfgrass health. For areas with higher amounts of precipitation, the California method may be a better solution because of its drainage characteristics, but the same principles of proper treatment of collected drainage water should be used no matter which construction method is chosen.
Considerations for the Golfer

It is important to pause here and consider for whom these principles are written. Minimizing the impacts of golf course design, construction, and management is important for the future health of our ecosystem. It is important for the preservation of precious resources such as air, water, soil, fossil fuels, and the biodiversity of developed land. And, ultimately, it is good for the game of golf. Ethical land use in golf course development will mean the preservation of vital open spaces for the enjoyment of golfers and non-golfers alike. As more and more people enjoy the game, it becomes increasingly important to understand how the development will impact the land and the natural systems on which it depends. It is also vital that changes made to golf course design, construction, and management take the needs of those who play the game into consideration. The following are some of the issues related to the golfer that must be dealt with in order to create the best balance of golfer needs and environmental considerations.

Scoring System

Some of the interest that has been generated about golf has been through its expanded television coverage over the years. Originally, golfers were much more concerned about playing one-on-one against an opponent. This type of play, known as match play, was much more conducive to conservation, since the use of natural areas meant difficult play for both competitors, and there was less pressure to score well for the round. Most professional tournaments, however, have scoring based on a comparison with par for the course. Par is the score that an expert player is expected to make on a given hole, and seventy-two strokes is usually par for eighteen holes. Because of this, stroke play is now the most common way golfers evaluate their performance on the course. Since golfers have become so concerned about their scores compared to par, this has caused courses to be maintained for speed of play and keeping balls in play rather than for conservation.

Point-to-Point Golf™ is another approach to producing a scoring system that will reward accuracy and finesse rather than distance (Muirhead and Rando, 1994). This type of target scoring system could make it possible for smaller land areas to be developed for
the game of golf and still provide the rewards for playing with higher levels of accuracy. This concept will be discussed further in the section on Innovations in Golf Course Design.

**Golfer Expectations**

One of the key points raised throughout the literature reviewed for this study has been the influence of the golfer upon the design and maintenance of the golf course. Perhaps no other single factor has more of an impact upon golf course development than the expectations of the golfer. Many golfers demand emerald green turf areas without signs of wear or disease throughout the course. They expect lightening quick and very smooth greens, fairways without a bad lie, and out-of-play areas where they can still find their ball and play it easily. They also desire longer golf ball flights and purchase clubs and balls that will optimize their distance for each shot.

These demands have had a profound effect upon golf course development over the past thirty years. Perhaps golfer expectations have been influenced by the popularity of golf on television. Many have come to expect superintendents at their courses to maintain the perfected conditions they have observed on the courses which professional players compete upon each week. They fail to realize that these perfected conditions can only be maintained through the use of increased amounts of irrigation water, pesticides, and fertilizer. This is particularly true for the lower mowing heights that are also being demanded, especially on greens. The shorter the mowing height, the more difficult it becomes for the turfgrass plant to live. Because they no longer have the leaf surface required to conduct normal photosynthesis, the plants must increase the shoot density below the mowing height and therefore uses up energy that would normally be used for root growth. The result is reduced drought and stress tolerance. More water and nutrients must be applied because there is inadequate root growth, and more chemical pesticides must be applied because the plants are no longer as resistant to diseases and pests.

The longer golf ball flights desired by golfers have produced an expanding length of contemporary golf courses that will be discussed in the following section on equipment regulation. By changing golfer expectations about equipment and maintenance standards, less water and chemicals would be required and the firmer conditions would produce more shotmaking skill in golfers because they would be required to think more about how to
approach each hole (Doak, 1992). Shorter courses with healthier turfgrasses could be
developed for the benefit of the environment and the game of golf.

Playability Concerns

The National Golf Foundation estimates that at least one course needs to be built
per day up to the year 2000 in order to keep up with golfer demand (Hannigan, 1989). If
this estimate is accurate, there is a need for more playable and less expensive courses as a
wider range in playing ability develops among golfers. However, choosing an acceptable
level of playability is not an easy task when considerations for the environment are added to
the equation.

As discussed previously, the expanded use of target course design would reduce
construction and maintenance costs, lower water consumption, and be a return to the
original concepts of golf courses. However, the inclusion of more native vegetation in the
areas adjacent to the course will mean that more golf balls will be out-of-play compared to
existing turfgrass uses. This may result in fewer golfers playing the game because of the
difficulty, and there may be fewer courses in the long run because of increased economic
pressure (increasing land and resource prices and decreased demand for golf).

Because of the increased difficulty, the extensive use of native vegetation may be
best suited to semi-private and private courses, which tend to have better golfers and less
traffic (Seaberg, 1992). A decrease in maintained turf may require the construction of
additional forward tees for playability. Also, by allowing golfers a free drop (a provisional
ball without penalty) when their ball enters these natural areas, slow play (from looking for
lost balls) can be avoided and the native vegetation can be protected from foot traffic.
Because golf courses need to be developed and maintained that use less water and
chemicals and provide more opportunities for wildlife habitat, serious considerations need to
be made with regard to playability impacts through the conversion of turfgrass areas to
native vegetation.

Should all golf courses be playable by all levels of golfers? This would be an
unrealistic goal, especially considering the mounting costs of maintaining the large areas of
turfgrass required for this level of playability. Perhaps there are some courses that could be
designed and maintained for the needs of the beginning golfer, such as short courses that
require less land area. Most courses, however, should be developed with the goal of integrating the game with the land through maximization of wildlife habitat and native vegetation. Golfers will then be required to demonstrate skill in playing the course with rougher out-of-play areas and narrower turf areas. They may need to spend more time developing their swings on practice tees, but this will be best in the long run both for the game of golf and for the environment.

Alternative grasses such as mixtures of fescues can also be effectively used to balance playability and environmental concerns. They form an excellent and lower maintenance turf when mowed short, but can also be allowed to grow out and form maintenance-free zones. Courses can then maintain flexible boundaries between the primary and secondary rough areas depending upon where golfers tend to hit the ball on any particular hole. An example of this is the Devil’s Paintbrush course in Caledon, Ontario, where fescues have been allowed to grow out or have been mowed short depending upon playability and maintenance considerations. As golfers have become more familiar with this course, superintendents have been able to allow more of these areas to grow out because golfers are no longer hitting into them (Wright, 1997).

Safety Concerns

Because of the size, composition, and speed of travel of the golf ball, it is capable of causing damage to property and injury to people while in flight. Courses therefore need to be designed with considerations for the safety of both people and property. This relates to environmental impacts in that longer golf ball travel translates into increasing amounts of land required for golf course developments. Fairways need to become wider and holes become longer through the continued improvements in golf ball and club technology, again demonstrating the need for limits in this area.

As in the previous discussion on land usage, core golf courses tend to have fewer safety concerns than single fairway development, since the holes are adjacent to each other and homes aren’t being built within range of most of the holes. An increasing amount of litigation has occurred over the past ten years related to golf ball damage to homes on golf courses. This has mainly been a problem in residential developments where homes are being placed directly adjacent to fairways, often on both sides of each hole. “If people are
willing to live on a golf course, they should know the dangers and design their homes accordingly," says golf course architect Desmond Muirhead (1996). This can be done through the use of things like hooded windows, blank walls facing drives and approach shots, and lakes and tree groupings to protect the properties.

By limiting the flight of the golf ball, safety concerns and hole lengths can be decreased, thereby making it possible for golf courses to be developed on less land. This applies particularly to the amount of turfgrass required on the course, and the land not required can be planted with native vegetation for all of the benefits of its use. Equipment and rules changes will be discussed in more detail in the following section.

**Innovations in Golf Course Design**

“Golf course architects must resist the myopic vision of current golf courses and expand the envelope of accepted standards," according to Donald Knott (1994, p. 500), a golf course architect with Robert Trent Jones II International. Knott believes that there are some unhealthy parameters that exist concerning contemporary golf course development, including fairways with perfect lies, trees on all sides of holes, fairways always well defined, greens puttable and fair at high Stimpmeter readings, greens always visible from the fairway, fairness value of courses measured by stroke-minded pros, and the limit of always having a 7000 yard course length and nine or eighteen holes (Knott, 1994). He also questioned whether some environmental impacts might be reduced by not always smashing eighteen holes into a piece of land, and whether fewer (but better quality) holes result in better quality natural areas.

It is quite possible that water scarcity, increased restrictions on chemical usage, and land use regulations may dictate a scruffier, lay-of-the-land style for course design in the near future (Whitten, 1993). These restrictions may also require renovation of existing courses in order to decrease water and chemical usage and maximize the use of the land for the benefit of the environment. For this reason, and because of the positive impacts that golf courses can have for both golfers and for the environment, it would be wise to consider some additional alternatives to traditional golf course design.
Changes to the Rules of Golf

The USGA recently amended the Rules of Golf to protect recognized environmental areas. Golf balls entering them cannot be retrieved; the golfer is allowed a free drop without penalty for hitting into these areas which are designated by an appropriate authority (Fuller, 1996). According to Trey Holland, USGA Rules of Golf Committee Chairman, "It was necessary to find a way for players to be able to continue to play the game when an environmentally sensitive area affected their play. We want the Rules of Golf to reflect that golf courses and nature reserves can be blended together. And they can" (Ryan, 1996).

This rule change makes it possible for sensitive areas on golf courses to be designated as out-of-play, no traffic zones for golfers while maintaining speed of play by not penalizing shots that enter these areas. Identification of these out-of-play areas might involve simply posting signs in rough areas which read, “Environmentally sensitive area: do not retrieve balls,” although it may be more beneficial to describe the reasons for this area to be set aside. For example, if there is a community of sensitive wetland plants present, this may represent an excellent opportunity to have interpretive signage that describes the plant communities and types of animals that utilize that area. It may be necessary to enforce a penalty for entering into these areas. One course enforced this rule by ejecting those that entered sensitive areas from the course (Osmun, 1992), but it may only be necessary to warn golfers as their appreciation for these natural areas begins to grow.

Artificial Playing Surfaces

While golfing purists are appalled with the thought of artificial surfaces for playing golf, there has been extensive progress made in this area of research. Artificial turf has been used extensively on practice ranges for more than fifteen years, but rarely are they used on golf courses. The use of mats on golf course tees would eliminate the extensive maintenance they require, especially on par three holes where more divots are taken by iron shots (Fream, 1978). Some golf courses in the deserts of Saudi Arabia take the use of mats to an extreme by having golfers carry them for the entire round and play each shot from them. Poles mark the boundaries for fairways and hazards, and the greens are made by sprinkling oil over the sand (Helphand, 1992). The arid conditions of the course dictate
this type of solution, and players accept it because it is their only opportunity to play golf in that area.

Another opportunity for the future may be the use of synthetic materials on golf course greens. Since these areas of the course require the highest amounts of maintenance in terms of mowing, fertilization, irrigation, and chemical treatment, this may indeed represent some beneficial alternatives. “Tour True” synthetic putting greens are currently being built for use at a par three course in New Hampshire. This is the first time that they have been used in a northern climate, but these types of greens have been implemented successfully at the Callaway Test Site in Carlsbad, California, and at the homes of several professional golfers (Labbance, 1996).

According to Pete and Mark Johnson, owners of “Tour True”, these greens have some great advantages as an alternative for normal greens. For example, the permitting process for courses is shorter and the environmental impact of greens is much less. Synthetic greens are faster to install and establish than natural turfgrass greens. Though they are more expensive to install, synthetic greens can provide a huge savings in chemicals and maintenance expense. They also make it possible to open the course six weeks earlier in the spring and close later in the fall, since synthetic greens are always playable and don’t require the same amount of protection from the elements.

Though synthetic greens may never gain acceptance for widespread use, they may be an excellent alternative where environmental impacts (particularly from chemical leaching and runoff) are a concern. Other problem areas include those where there is inadequate soil or insufficient sunlight, drainage, and air circulation. The traffic tolerance on these synthetic greens has been reasonable thus far. A 3000 square foot green was installed at the Mission Hill Golf Center (the busiest practice facility in the San Francisco Bay area) where it has seen 200-500 golfers per day for the past four years, and it has held up very well (Labbance, 1996).

Construction procedures for synthetic golf greens start with basic site preparation and grading similar to normal natural green construction. Surface drainage is a very important consideration in this process. Ground-up rubber from recycled tires is then applied as a subsurface layer (absorbs shock), followed by another shock-absorbing layer (non-compactable natural and artificial aggregates). Open tufted synthetic turf is spread out
over the surface and tied down in place. Maintenance of synthetic greens simply involves applying a sand topdressing in order to give the green its speed, and daily brooming keeps the putting surface uniform. As more research is conducted in this area, we may see further developments of synthetic turf that more closely resembles natural turfgrass, which would be ideal for use in high traffic areas such as tees and greens that are the most difficult to maintain.

Changes in Golf Equipment

According to the Rules of Golf published by the USGA (1997, p. 117), the Overall Distance Standard states that golf balls, "...when tested on apparatus approved by the USGA...shall not cover an average distance in carry and roll exceeding 280 yards (256 m) plus a tolerance of six percent." This standard, however, does not account for the advances that have been made in clubhead and shaft technology, and many professional golfers are now able to drive the ball longer than 300 yards with a great deal of frequency. According to Desmond Muirhead (1996), "Consistently longer drives and approaches obtained by new equipment demands increasingly longer courses. Clearly, the equipment requires regulation standards much more than golf courses."

There is a need to throttle back the liveliness of the golf ball in order to decrease the length of golf courses and the land area which they require. There may be a danger from lawsuits by ball manufacturers and touring pros, but if the ball isn't standardized, then tournament courses will continue to get longer, and existing classic designs will no longer be appropriate (3). Increasing amounts of land will be required by golf developments to account for the added length and safety concerns from longer golf ball flights. By limiting the length of the golf ball flight, golf courses will no longer need to add new tees and redesign fairways and hazard locations in order to accommodate the golf ball. Classic designs will again be viable alternatives for golf tournaments as they were intended to be and will again be the challenge for contemporary golfers that they were for past players.

Consider what would happen if new technologies were applied to baseballs and baseball bats. The ball would continue to fly farther and travel faster, creating safety problems for players and fans and requiring continual enlargements of baseball stadiums to
accommodate play. Just as equipment standardization makes sense for the game of baseball, it also makes sense for the game of golf.

Target Course Design

Target (also referred to as "natural") golf course design incorporates forced carries off the tee and between predetermined landing areas throughout the course in an effort to limit the amount of turfgrass area that will need to be maintained (see Figures 2.3 and 2.4). Although some of the most recognized designs of this type have been developed in arid regions because of irrigation restrictions (including many courses in the southwestern U.S.), this type of design is not a new concept. Many of the oldest golf courses in the world (particularly the links courses discussed previously) have forced carries and fairways bordered closely by native vegetation. This was how the game of golf developed, in a close relationship with its surroundings and with minimal disturbance of out-of-play areas.

According to golf course architect Ronald Fream (1982), the design of a golf course should concentrate on providing the finest possible teeing surfaces, green sites, and interconnecting fairways, but beyond that, should also make the best possible use of the natural environment. The use of target style golf course design would have many of the same benefits for non-arid regions as it has had on desert courses. Because of the smaller areas dedicated to maintained turf, the out-of-play areas on the course could be protected during the development of the site. This would be especially beneficial for those developments taking place on previously undisturbed sites. Existing natural areas could be preserved and the golf course would have less of an impact upon the land. Also, because of the enlarged areas devoted to native vegetation, more habitat and travel corridors would be provided for wildlife, enhancing the suitability of the site for more diverse species types. This has value for both previously undeveloped sites and for courses built on highly modified landscapes.

Target course design makes it possible to build shorter courses which will rely more on accuracy and finesse than on distance (Wyllie, 1983). This type of development would reduce construction and maintenance costs since courses would be shorter and only the greens, tees, and fairways would be need to be developed and maintained. Lower water consumption, because of the decreased amount of maintained turf, reduces water use and
Figure 2.3: Plan view of a typical golf hole

Out-of-play Areas (opportunities for the use of native vegetation)

Figure 2.4: Concept plan for the same hole with target course design principles
lowers water costs by requiring less water and smaller pumps and irrigation lines. Maintenance is thereby reduced up to 35% and water use by 30-50% (Borland, 1988). This will not only reduce irrigation costs, it will also decrease public concerns related to golf course water use and environmental impacts. Decreased amounts of fertilizers and pesticides will mean additional maintenance cost savings and reduced environment impacts. The native plantings will form natural buffers to nutrient and chemical movement away from the turf areas and will provide storage of excess rainfall, reducing flood flows on site and downstream. The benefits of this type of minimal golf course design are many, and the expansion of this concept would represent a return to the original concepts of golf courses and their relationships with the land (Graves, 1982).

Another issue related to this concept is actually a management practice currently used on many courses. Target area mowing, also called contour mowing, creates strategic landing areas on each golf hole and encourages better shot making from the player. It results in multiple fairway landing areas, offering progressively smaller target areas and requiring greater accuracy further from the tee (Silva, 1982). The use of contour mowing adds challenge to the game, increases the opportunities for the use of native vegetation in the roughs, and is more aesthetically appealing than straight fairway edges. The establishment of native vegetation on existing golf courses through the use of this target concept would be an excellent way for golf courses to provide habitat for wildlife and decrease maintenance costs.

A model for expected maintenance cost savings through the use of native vegetation versus turfgrass is outlined in Chapter III. Information related to the benefits of native vegetation and steps in establishment can be found in the management section of this chapter. Also, because of the severity of hazards and natural areas on target style golf courses, they can be frustrating and difficult for the average player to play (Hannigan, 1989). The issue of playability is addressed in more detail in the section related to considerations for the golfer.

**Point-to-Point Golf™**

This concept was created by Desmond Muirhead and Guy Rando (1994) in response to the problems caused by the drive for distance in golf course design: longer
courses mean more land area is converted during development, courses are more expensive to build and maintain, there is less safety because of the longer golf ball flights, and the old and classic designs are becoming outdated. The idea of Point-to-Point Golf™ is to land each consecutive shot within a point zone identified on the course, as close to a designated “hot point” as possible. The closer the ball is to that point, the more points that are awarded for the shot. Scoring is cumulative throughout the course, and the highest score wins.

This playing concept was designed to reward finesse and accuracy rather than distance. It can be played from existing tees and greens and therefore requires very little investment from golf courses. It produces challenging play on both short and long courses alike, is a challenge for all skill levels, and the course can be played with or without the system once it is in place. Because this playing system rewards accuracy rather than distance, it may be an excellent method for use with a target style golf course. It may also create a great deal more interest in shorter courses without par fives and decrease the amount of land required for golf developments.

**Wastewater Use for Irrigation**

Effluent water (treated wastewater) has been used for irrigation purposes for about thirty years in some areas of the country. It has been implemented successfully on many golf courses in the U.S. (Frye, 1994; Salvesen, 1996; Poellot, 1992) and may provide promise for future golf course irrigation and water treatment needs in this country. Effluent irrigation works especially well in arid regions such as the southwestern U.S., where more than twenty percent of the public golf courses use effluent as the primary source of irrigation water (Bishop, 1990). Because it is possible to grow turf throughout the year, waste continues to be utilized and there are no long periods of dormancy.

There are many advantages to the use of effluent for irrigation. Wastewater is available at a constant rate, and turfgrass plants require many of the nutrients already present in the effluent (nitrogen, phosphorus, potassium, and others), so additional fertilizer inputs can be reduced (Hayes et al., 1990). The cost of effluent water is significantly less than potable municipal water supplies (in some cases, the water itself may be free).
Turfgrass has the ability to use large quantities of organic waste that many other plants cannot withstand, and can therefore utilize effluent water that might otherwise be wasted.

One of the primary advantages to the use of effluent is that it creates another use for that land area devoted to golf course development. The course becomes not only a recreational area, it also preserves a community open space, provides habitat for wildlife, and acts as a wastewater treatment plant. For example, sewer pipes can collect waste from buildings into a lagoon near the course, where air is pumped up from the bottom in order to aerate the sewage. The resulting settling then creates sludge on the bottom which can be collected once every twenty years and composted for other uses. The water stays in the lagoon for about 36 days, then is pumped to another reservoir to go through sand filtration. After being treated with chlorine to kill bacteria, the treated water can then be used for irrigation of the golf course. The turfgrass and soil combine to act as a living filter for the reused wastewater, actually exceeding the benefits of traditional sewage treatment (Muirhead and Rando, 1994).

There are also disadvantages to the use of effluent that must be considered. For instance, there are usually restrictions on where and when wastewater can be applied, and requirements for monitoring of potable and wastewater for problems is costly. Effluent water often contains materials that can cause problems in turfgrass maintenance. Some of the water quality concerns related to turfgrass irrigation include suspended solids, pH levels, total soluble salts, leaching requirements, sodium absorption ratio, biological or chemical oxygen demand, toxic materials, and total or fecal coliforms. Because of the lack of purity of effluent water, there are also problems related to corrosion and plugging of the irrigation system, accumulation of suspended solids in storage ponds, chlorine toxicity to plants, and the interaction of many of these factors together (Peacock, 1994). Effluent irrigation may cause a reduction in the emergence of turfgrass seedlings during establishment. The turf may also experience heat stress due to excess nitrogen in the effluent or chloride toxicity, which is the most common problem encountered (Mancino, 1994).

A comparison of the costs and benefits of using effluent is an important step in determining the feasibility of its use for golf course irrigation. Some of the costs include the use of additional soil amendments to mitigate problematic salt and sodium levels, higher costs for the use of fresh water leaching systems for greens, higher water quality
management costs (as listed above), and poorer turf quality means the requirement of more fertilizer, herbicides, fungicides (Gill and Rainville, 1994). In spite of these costs, the use of effluent can be up to ten times less expensive than normal irrigation practices. One reason for this is that the cost of pumping effluent water is four to five times less (Peacock, 1994).

In some cases, golf courses have obtained additional funding from public or federal agencies for development with wastewater irrigation capabilities. For example, Meadow Lakes Golf Course in Prinville, Oregon received $5 million from the Environmental Protection Agency for the construction of their irrigation system, ten storage ponds, and a sewage treatment system. Because of this development, the annual city discharge of wastewater was reduced by 130 million gallons, a third of its normal output (Salvesen, 1996). This type of financial incentive may contribute to a growth in the use of wastewater effluent throughout the country.

A vital question concerning effluent water usage is whether those that generate the waste (industrial users, commercial users, and homeowners) or the recycled water users (in this case, the golf course) should pay for wastewater treatment (Rodie, 1994). Some courses have been given free access to irrigation water in exchange for acting as a wastewater treatment area for the municipality. An excellent example of this type of multiple use can be seen at Gainey Ranch in Scottsdale, Arizona. This golf course is designed around an effluent recycling system; the city pipes waste to the course for treatment at a tertiary treatment plant, where the effluent is stored in a pond and used for irrigation. The development saves $150,000–200,000 per year in water costs, and supplies the city with free wastewater treatment. Interconnected drainage systems recycle the water back to lakes for use in irrigation (Poellot, 1992). Ideally, people would see the benefit of the creation of this type of multiple use for that land area and be willing to subsidize the costs of this type of water treatment.

There are also maintenance concerns associated with effluent water usage. Superintendents will need to take into account the nutrients in the water so that they are not over-applied.Baseline levels for water monitoring are necessary for future testing of contamination and management effects to water quality (Smart et al., 1993). In particular, water high in salinates, sodium, boron, and chlorine should be avoided, or they should be mixed with higher quality water to dilute the effects of these impurities (Mancino, 1994).
Irrigation with effluent may also require higher rates of leaching to control salinity levels, more frequent applications of water amendments (gypsum and sulfur), more frequent soil aerification, adjustment of fertilizer application based on effluent levels, and higher seeding rates to make up for reduced seed emergence (Smart et al., 1993).

Hayes et al. (1990) tested the impacts of effluent irrigation upon Bermuda and Perennial Rye grasses for a 64 week test period. They found that effluent irrigation had lower seed emergence but improved seed establishment, and that it also showed signs of overfertilization, greater heat stress, and chlorosis (especially the Perennial Rye). They were able to produce a high quality turf, but higher soluble salt and nutrient contents require special consideration with wastewater use. It was recommended that, because of the lower emergence of Bermuda from the increased salinity and ammonium content in the water, potable water should be used during germination, or else higher seeding rates should be used if good sources of water are not available (Hayes et al., 1990).

From a turfgrass management perspective, the use of effluent water for irrigation is not desirable if there is an abundance of high quality surface or groundwater nearby (Peacock, 1994). However, because of the importance of maintaining water quality and creating opportunities for multiple uses for the land, it would be wise for communities to consider the use of wastewater irrigation for golf courses. This is particularly true in those regions that have very few times of freezing temperatures throughout the year, thereby making continual operation of the wastewater facility a possibility. Wastewater Reuse for Golf Course Irrigation (1994) is an excellent source of information related to this topic.

Development on Marginal Lands

As mentioned previously, golf course developments can improve the quality of degraded sites such as landfills, industrial waste dumps, abandoned sand and gravel mines, rock quarries, coal mines, and flood plains (Duthie, 1996). The funds generated by golf (from green fees on the course and from the increased value of the land after its conversion) make it economically feasible to convert these abandoned lands when nothing else will work (Osmun, 1992). This is probably one of the main arguments for the benefits of the use of golf courses as quality land uses.
Landfills offer one of the best opportunities for multiple use of abandoned lands. Golf courses can be built on these areas without significant problems because few structures are required that will need support. This makes it possible to provide storage for solid wastes (a growing problem in this country and in other areas throughout the world) and provide a community recreation open space rather than an eye sore. Another alternative to building on the landfill could be to use the golf course as a greenbelt around the landfill to buffer adjacent land uses (Muirhead and Rando, 1994).

One of the problems associated with the construction of golf courses on landfills is the development of gases (especially methane) which come up and are toxic to plants, smell bad, and create problems because they are combustible. Another area of concern is that uneven settling of the constituents of the landfill can cause surface drainage problems. Use of heavy equipment on the surface should be limited because of compaction and settling concerns, and special haul roads must be made to allow access of equipment to the site. The poor structural integrity also limits the locations on which golf course buildings can be built, usually requiring their location on areas exterior to the landfill.

Since the clay cap must be kept intact in order to eliminate downward migration of water, it then becomes necessary to use fill on top of this cap to shape golf course features. Enough room must be made that will allow for an appropriate gas barrier and space for irrigation and drainage lines. It is best to develop the design of the golf course and the landfill together, so that the fill locations and the shape of the clay cap can blend into the desired final contours of the course. The best landfill conditions for this type of development include those with low fill heights (20-35 feet) and those that have been closed less than 20 years (Muirhead and Rando, 1994).

There are many examples of the successful use of abandoned lands for golf course development. Harborside International Golf Course is a 425 acre landfill course in South Chicago, Illinois. In this design, Nugent Associates Design of Long Grove, Illinois utilized biosolids as a topsoil and growing medium over a cap of clay soil (although the greens and tees were planted with sand because of their special maintenance needs). The use of biosolids for topsoil may represent opportunities for golf courses to provide treatment of waste products, even those not constructed on landfills, and particularly for those that may have other types of soil problems. These biosolids, however, contain high levels of salts,
and poor drainage has been a problem at Harborside that will need to be addressed. Runoff from the course drains to seven inlets that retain water and feed it to a wastewater facility for treatment. Willow Hill, another Nugent design in Winnetka, Illinois, was also built over a landfill, and this course has a system for the collection of methane gas that makes it possible for it to be converted to electricity (Thompson, 1996). This again demonstrates the opportunities that exist for golf course developments with multiple uses of the land.

Widow’s Walk, a Michael Hurdzan design set to open in 1997 in Scituate, Massachusetts, was built on a sand and gravel quarry and dump site. Hurdzan said of the project, “Local officials wanted to improve property but insisted that the development be self supportive, create value for the town, and provide public recreational value...only a golf course can do that” (Whitten, 1996). The course will also use recycled asphalt cartpaths, pulverized coconut for organic material (instead of peat moss), and drought tolerant fescue grasses (the turf in the fairways and rough will be allowed to turn brown in drought conditions). The course anticipates a cut in water, fertilizer, pesticide, and fossil fuel use of 50%. Irrigation water will be pumped from non-potable wells for use on the course and recycled via a tiling system.

Widow’s Walk represents a different approach to golf course construction in that it has been developed with the goal of gathering scientific data related to the environmental impacts of golf courses. Experiments will be conducted with the greens at Widow’s Walk in order to determine which construction method and drainage system will work best. Six of the greens will be constructed according to USGA specifications, six will use the California (pure sand) method, and six will be built with existing soil. Three types of subsurface drainage will be used for each type of green construction. Computer sensors in these drainage systems will measure and record percolate data like soil temperature, moisture, and fertility, and the greens will be built with drainage chambers from which samples can be removed and tested (Duthie, 1996).

Golf courses are even being built on EPA Superfund sites. Community leaders, the EPA, ARCO (Atlantic Richfield Company), and course designer Jack Nicklaus have partnered to produce Old Works Golf Course in Anaconda, Montana. Industrial waste (high in copper and zinc) left over from years of copper smelting on the site were capped with two inches of limestone, a twelve to fifteen inch layer of clay, and four to six inches of mixed
topsoil. Underground pipes collect and recycle excess water to prevent leaching from the site and make this water available for the irrigation needs of the course (Duthie, 1996). The EPA supervision increased the cost of the course to an estimated $11 million and the cleanup to about $30 million. Still, ARCO saved millions. Company officials estimate removing the waste could have cost as much as $65 million (Hanley, 1997). The course was turned over to the community when it opened and are able to reap the benefits of a high-end public golf course, such as increased tourism, land that creates revenue and jobs, and increased property values throughout the area. This again demonstrates the value that golf courses can have in the reclamation of damaged lands.

Much of the land relegated to golf course development occurs after a developer has selected the optimum ground for housing. This means that many courses have been built in floodplain areas. Examples such as The Village Links of Glen Ellyn (Illinois) have demonstrated that properly designed golf courses are able to utilize floodplain lands with minimal effects from flooding, even from some of the most severe events ever recorded. This is accomplished through the use of interconnected irrigation and retention ponds, contours that conduct floodwaters through areas resistant to damage, and elevation of higher maintenance areas such as tees and greens far above flood stages (Dodson, 1996). This type of development shows promise as we reconsider how floodplains have been developed in the past and look for new solutions for avoiding flood damage.

Golf Course Construction Principles

Introduction

Information gathered during the site analysis phase can be used by the golf course architect to develop plans for the construction of the golf course and surrounding property. Plans prepared by the architect usually include a golf course master plan, staking and clearing plans, grading and drainage plans, green detail plans, irrigation plans, turfgrass planting plans, and a landscape planting plan (Beard, 1982). Additional visits to the site and meetings with community officials and the client will help the architect in this process by continuing to provide information relevant to the project. If residential development will accompany the golf course, it will usually be done in conjunction with different phases of the
construction process for the course and will influence many of the final layout decisions, utility connections, and other factors in the development.

As mentioned previously, it is vital to the success of any development project to include a multidisciplinary team during the design of the course. As construction of the course begins, the course architect, construction contractor, the owner, and the superintendent take on the most important roles. By taking part in the design and construction process, the superintendent will be able to understand how the course has been built and will know how to best care for the course once it is completed. When minor modifications need to be done to the course in the future, they can then be done in a manner that is efficient and in keeping with the original concept of the intended design.

Construction methods used for golf course development can have both short and long term effects upon the success of the golf course. These methods have a great impact upon whether the course will be built on time and on budget, which are important considerations for the economic success of the development as well as making play more affordable for golfers. They will also greatly influence the environmental impact of the development, as will be discussed in the following paragraphs. Each of the steps encountered in the construction process are described, and then the discussion is expanded as to the opportunities some of these practices will provide for protecting and enhancing the developed lands.

The Construction Process

The process of the construction of a golf course involves a great deal of expense and complexity. Though there are some variations on how and when some of these tasks are accomplished, there is a general progression that occurs in construction that is followed by contractors in order to operate in an efficient manner. The following is a brief outline of the construction process as outlined by some of the contemporaries in the golf course construction field (Hurdzan, 1996; Muirhead and Rando, 1994; Beard, 1982).

Pre-construction Meeting

Conducted on site, this meeting includes the golf course architect, construction contractor, subcontractors, the client, representatives of any utility with existing or planned
installations, course superintendents, and other personnel involved in the planning of the course such as engineers, other architects, and land planners. This meeting establishes lines of communication between parties, schedules and deadlines for work, construction sequences, site data that may have changed, and any other areas of concern that may exist prior to construction (Hurdzan, 1996). It is at this meeting that the importance of environmental stewardship can be established for all the parties involved, and the development can take place with the optimization of environmental benefits in mind.

**Erosion Control and Environmental Protection**

This is done throughout the construction process and involves the use of methods that will identify areas of concern on the site, such as erosion-prone soils and sensitive vegetation and will provide means of protection for these areas. This is discussed in greater detail below because of its importance in minimizing the environmental impact of golf course construction.

**Staking and Clearing**

The architect and contractor identify the locations of key golf course elements such as tees, greens, fairways, and water features by using stakes and flagging. Preliminary staking usually involves a stake for the back tee, for the center of the landing zone(s) or dogleg(s), and in the center of the green (Hurdzan, 1996). Once the centerlines of the golf holes are identified with stakes according to the plans, these centerlines are then cleared for twenty five feet on both sides so that final verification of the golf course routing can be completed. Care must be taken during this process that sensitive environmental elements are not damaged. Qualified professionals should be on site during staking and clearing to identify (tag) endangered and sensitive flora. By physically delineating (fencing off) these sensitive areas, contractors will be able to avoid compaction or destruction of elements that can be incorporated into the golf course landscape. It may also be possible to transplant sensitive or endangered species from these areas until construction of the course has been completed (Muirhead and Rando, 1994). Selective clearing can take place once the routing of the course is finalized and all sensitive areas have been identified. The most important
aspect of this process is the protection of sensitive vegetation and the disturbance of as little of the land as possible for construction of the course.

**Disposal of Cleared Debris**

An effort is usually made to salvage many of the stones and timber removed during clearing for use on the course or for sale to lumber companies. The remaining roots, stumps, vegetation, rubbish, and other debris are then pushed into burning piles or pits, hauled away (very expensive), buried in pre-selected out-of-play areas, or shoved up into large piles for wildlife habitat (Hurdzan, 1996). Care must be taken that the debris is not buried under structures or course elements where it may become a problem for stability, irrigation and utility lines, or other earthwork and long term maintenance operations. The topsoil is usually removed and stockpiled during the early stages of the project in order to protect it and make it available for re-application after rough grading is completed.

**Drainage**

After clearing and disposal have been completed, the major drainage structures that will be necessary on the course are installed. This will include catch basins, culverts, ditches, dry wells, and subsurface drain lines. An effort should be made to use as few of these structures as possible, and instead rely upon natural drainage systems for the handling of water on the developed site. The extent to which this can be accomplished depends greatly upon adjacent land uses, since high amounts of runoff occur from more heavily developed sites and will need to be accounted for in the design of the course. Ideally, stream reaches, springs, wetlands, and natural lakes can be avoided during construction in order to protect water resources and provide wildlife corridors and minimal disturbance to natural water systems. The utilization of drainage trenches with native vegetation rather than piping underground will produce much better results in terms of on-site storage and filtering of surface waters.

**Earthwork**

After the topsoil has been stockpiled for later use, some of the larger scale earthwork will take place. Some of the major elements that require the largest amount of
earthwork are water impoundments and structures, drainage ways, and large cuts and fills. The contractor uses the construction plans to establish the site and extent of cuts and fills, using grade stakes to identify existing and proposed elevations in these areas. Rough grading involves working the subgrade of the course to within approximately six to twelve inches of the final desired elevations, and is followed by feature shaping, which will begin to establish many of the design features for the course. Greens and tees will begin to take shape in this process, but they require different construction procedures than do the other areas on the course. Topsoil is then added once the subgrade is worked and graded to conform to the required grades on the project plans. Final shaping should produce a minimum depth of six inches of topsoil over fairways, mounds, and the slopes around tees and greens, and four inches over rough areas (although six inches is more desirable). Additional modifications to the topsoil may be needed such as pH adjustment, preplant fertilization, or the addition of other soil amendments that will prepare the soil for the establishment of turfgrass. Drainage is one of the most important considerations in the shaping of the course to the final elevations, since there needs to be a minimum of two to three percent of pitch to allow water to surface drain across turfgrass (Hurdzan, 1996). Since there are limitations to the amount of detail that can be achieved with construction plans, it is vital that the course be built in such a way that poor drainage and ongoing maintenance problems can be avoided.

Construction of Greens, Tees, and Bunkers

The construction of greens and some of the environmental implications of them were discussed in the design section of this paper. Tees also have special considerations in that they are high traffic areas that usually require the use of a sand or soil mixture that will accommodate compaction and higher maintenance needs. Tees are usually surface drained at a three-quarter to one percent slope. The turfgrass will be able to filter and use the chemicals that exist in the water in an efficient manner. Bunkers usually have little environmental impact related to drainage water collected from within them, since it is filtered by the sand and contains none of the chemicals applied to turfgrass areas. It is important that the final grades of these elements be established before the installation of irrigation begins so that major changes will not need to be made and the irrigation system can be
protected from damage. Sand is usually added to the bunkers during the landscaping phase of the process.

Irrigation Installation

Systems that will provide for the long-term water management needs on the course are added as the earthwork process is drawing to a close. This usually involves the installation of a pump house, pumps, pipes, and programming systems. Selection and implementation of these systems has a huge impact upon the maintenance and environmental impacts of the golf course. Irrigation efficiency and timing are key factors in the design, and often an irrigation specialist is employed by the golf course architect in order to lay out the design of the irrigation system. Water conservation practices such as the use of recycled irrigation water from retention ponds and irrigation with effluent water are valuable methods that were discussed in the design section of this paper. Soil moisture sensors, weather stations, computer application systems, and low-volume, low-pressure heads will also become more valuable as the costs of irrigation of courses continues to rise. These and other topics will be discussed in greater detail in the management section of this paper.

Seedbed Preparation and Planting

This is usually accomplished by plowing the area intended for turfgrass planting to allow growth without competition from weeds. Corrective applications of fertilizer, lime, and other soil amendments can then be applied as needed, based on soil test results from each area. These amendments are spread onto the finished grade of the soil and lightly tilled into the top two to three inches of topsoil to aid the establishment of turfgrass. The architect then performs an inspection of the site to ensure low spots have been filled, the soil is not overly compacted and has the proper moisture content, the irrigation system is in working order (it will be necessary during the establishment of the turfgrass), and proper erosion control procedures have been established. Green and tee complexes are usually established first, then fairways, then rough areas. The turfgrass can be seeded, sprigged, or sodded, with sod being the most expensive but also the most efficient method of establishment. The planted seedbed is lightly rolled to establish plant and soil contact, and
then mulch is added to moderate soil temperatures and retain moisture. The irrigation system is then used to assure proper moisture levels for the germinating plants (Hurdzan, 1996). From an environmental standpoint, the keys to this process are protection of soil from erosion, avoidance of areas not intended for development, and proper soil preparation that will maximize the efficiency of future turfgrass needs for water and chemical applications.

**General Construction and Final Inspection**

As the construction process draws to a close, many other tasks may need to be performed before the course is opened for play. Construction of cartpaths, bridges, shelters, rest rooms, and water fountains are often elements that will need to be included, depending upon the individual needs of each course. As the golf course superintendent manages the grow-in stage of the turfgrass, they will also take part in any final landscaping needs on the course such as trees and shrubs around the clubhouse or planting beds on the course. Final inspection will include all aspects of the development. It will pay particular attention to the course itself, establishing its readiness for golfer traffic based on the health of the turfgrass and proper functioning of other golf course elements. The course is then declared open for play, and ready to function as a source of enjoyment and recreation for golfers and as a healthy part of the surrounding landscape.

**Minimizing Site Disturbance**

The construction of the golf course lasts only a short time compared to the long-term maintenance of the facility once it is completed. However, much of what occurs during construction has ongoing impacts upon the wildlife, vegetation, water quality, and future maintenance concerns of the course.

**Water Quality Concerns**

Water quality is one of the most important factors to consider during the construction of the course. As stated previously, respect should be given to unique wetlands and other sensitive areas, avoiding their disturbance and incorporating them into the design of the course. This can be done by providing and maintaining a vegetative buffer zone of at least
50 feet next to all water courses, as discussed in the design section of this paper. Manipulation of streams and other water courses should be avoided, and operation of heavy construction equipment should be limited near these surface water areas. It is also important to monitor groundwater quality before, during, and after construction of the course, which will make it possible to compare these results and determine whether any changes occur in water quality.

**Construction Scheduling**

One of the primary considerations in scheduling for construction is efficiency. It is important that the various activities be coordinated and timed properly in order to avoid the possibility of one task damaging the finished work of another, which makes it possible for the project to proceed on time and on budget. In addition to these economic considerations, construction scheduling plays a key role in limiting the impacts of golf course construction upon the environment. For example, during the development of Belfair (Hilton Head, South Carolina), construction times were coordinated around site nesting seasons, and home site construction was designed to allow birds time to acclimate to new (post-construction) surroundings (Duthie, 1996). Doug Carrick, a golf course architect that has done extensive work with natural areas in Canada, recommends scheduling work adjacent to rivers after September and before June to protect spawning fish (Carrick, 1994). These are good examples of the type of thinking that will make a great difference in the amount of impact that the construction process will have upon wildlife.

Construction scheduling should also protect soils by minimizing the exposed area and the amount of time the ground is left without cover. This means planning for the completion of final grading to coincide with the best time for turfgrass establishment. It also means paying attention to the weather and avoiding the exposure of soils to potentially heavy rainfall events. A good rule of thumb is that disturbed areas should be made non-erosive and stable within thirty working days after completion of work in that area (Bruneau et al., 1996b). Additional soil concerns are addressed in the following section.
Erosion and Sediment Control

Soil erosion is one of the most important concerns related to the impacts of construction upon the environment. Once the golf course has been established and the turfgrasses and other vegetation have matured, very little if any soil erosion will take place from a golf course. It is during the construction phase, however, where extensive erosion control measures must be in place to prevent sediment from leaving the site through surface runoff.

There are many methods by which erosion and sediment control can be accomplished, but the best one is disturbance of as little of the site as possible. No other erosion control method will work as well or provide the same number of benefits for the developed site in terms of wildlife habitat and water quality preservation. This is particularly the case for golf courses developed on previously undisturbed sites. For highly disturbed sites, however, it may be beneficial to replant an area that is dominated by weedy volunteer vegetation. Either way, exposure of these soils should be limited to the minimum necessary amount of time.

Disturbance of steeply sloped terrain (especially those exceeding fifteen percent) should be avoided if possible due to the difficulty of machinery operation and erosion control in these areas. For any areas that will be disturbed during construction, dikes, diversions, and waterways should be established before clearing and grading takes place. This will divert runoff waters from disturbed areas and greatly decrease the threat of erosion (Bruneau et al., 1996b). Silt fencing should be erected in all work areas adjacent to river and stream corridors, especially in adjoining drainage swales (Carrick, 1994). Vegetative buffers should be preserved around sensitive areas, particularly surface water bodies on the site. Vegetation can be selected that will rapidly re-vegetate exposed soils and hold them in place (Muirhead and Rando, 1994).

Exposed soils can also be protected during construction through hydroseeding, sodding, or using mulch ("Environmentally responsible," 1993). Hydroseeding is a method of applying seed in a mixture with water for the establishment of turfgrass or other types of seed on a prepared soil. This can be an effective method for applying seed to slopes where equipment may cause erosion and accessibility is a problem. Whether for seeding from a drop spreader or from hydroseeding, the application of a straw mulch with asphalt or
similar-type binder is an effective way to prevent soil erosion and provide moisture for germinating turfgrass seed, particularly on sloping sites. According to Beard (1982), “Jute net and excelsior mat mulching or sodding are quite effective in waterway erosion control where high-velocity water flow is probable during rainstorms.” The use of sod rather than establishing areas with seed adds greatly to the expense of the construction, but the benefits that the quickly establish sod will have in terms of soil protection often outweigh these costs. This is particularly true in situations where construction is taking place on sloping lands or on highly erodible soils.

Rebuilding and Modifying Existing Courses

In addition to the high rates of golf course development discussed in Chapter I, there has been a substantial growth in the number of courses that have been rebuilt or modified over the past twenty years. According to the National Golf Foundation, there were 174 course expansions that opened in 1996, and an additional 272 were under construction. About 80 percent of these expansions were nine-hole additions to an existing course, a trend that has been consistent for the past five years (“U.S. golf,” 1997).

There are various reasons to rebuild or expand existing facilities, including the following identified by Beard (1982):

1. Lengthen the Course--this could be due to equipment modifications that allow longer ball flights, a desire to increase playing difficulty, or to add a second nine holes to an existing nine-hole course
2. Improve Strategy--usually through reshaping or rebuilding greens, bunkers, and tees or changing the hazards on the course
3. Improve Flexibility--by adding tees for different handicap levels and allowing more versatility of play for the course
4. Improve Speed of Play--this may involve removing blind shots and unnecessary hazards
5. Improve Safety--reduction of the number of blind shots, planting of screening vegetation, and providing proper spacing between holes
6. Correction of Design and Construction Flaws--includes surface and subsurface drainage and compaction problems and blind or unfair hazards
7. Minimize Traffic Effects--reducing compaction and wear by providing larger greens and tees and altering the placement of elements that create concentrated traffic patterns. In addition to these concerns, there are also environmental considerations that may cause renovation of existing golf courses such as:

8. Endangered Flora and Fauna--the course may have opportunities to provide habitat areas for sensitive species, or may need to be reconfigured in order to protect their habitat.

9. Water Quality--it may be necessary to provide more vegetative buffer plantings near surface water areas or to avoid maintenance practices on areas that are sensitive to groundwater impacts from pesticides and fertilizer applications such as in karst (fractured limestone) topography or on shallow water table areas where infiltration is a concern.

10. Water Conservation and Reduced Maintenance Expense--construction of larger tees and greens that can handle more traffic, installation of a more efficient irrigation system, promotion of functionality and accessibility of maintenance equipment, improving seedbed preparation, and conversion of unnecessary turfgrass areas to native vegetation.

Any of these alternatives may be necessary for existing courses as they continue to age, particularly those that were built more than twenty years ago. The methods used by the architect and builder have a tremendous influence on the durability and continued functionality of the course. Courses designed and built with features that cause traffic concentrations in tight areas, safety concerns, or improper construction methods that cause recurring maintenance problems will require attention that much more quickly than those that are properly designed and built. Maintenance costs for courses are heavily affected by construction practices such as seedbed preparation, size and layout of greens, tees, and hazards, and the amount of turfgrass area that needs to be maintained.

The same can be said for the environmental considerations of the developed course. Those that are designed and built with a vision for the needs of providing habitat for wildlife, function as multiple users of the land (landfills, wastewater irrigation, flood storage, etc.), and minimize water and chemical usage will be far more likely to have continued success as
the rising costs of water and chemical usage drive up the costs of building courses and playing the game.

**Golf Course Management Principles**

**Introduction**

Once the golf course has been designed and built, management becomes the key issue in the relationship of the golf course with the environment. Golf course superintendents are given the primary responsibility for the care of the course, which includes a very broad range of activities. In managing the turfgrasses on the course, the superintendent accounts for applications of irrigation water, fertilizer, and pesticides as well as cultural practices such as mowing, aerification, thatch removal, and assessment of turfgrass conditions. The superintendent is often involved in water quality monitoring and the care of other native vegetation and wildlife on site. Most of the smaller scale renovations that are frequently made to golf courses (tee and green reconstructions, bunker modifications, additional plantings of trees and shrubs, etc.) are supervised by superintendents. They also bear the responsibility for the day-to-day appearance of the course and therefore are often under pressure to maintain “tournament conditions” on their courses.

Because of the importance of their role in the operation and management of the golf course, superintendents need to be involved in the construction of new courses before they are completed. They need to know the intent of the design, the construction materials that were used, and the techniques necessary for best management of the course (Poellot, 1992). Superintendents also need to stay abreast of current research related to golf course management and understand their role in minimizing the environmental impacts of golf courses.

**Current Research on Turfgrass Establishment and Management**

A substantial body of recently published research on turfgrass has greatly expanded the understanding of the effects of establishment and management practices on turfgrass health and water quality. Collectively, they point to three major factors which must be well understood if risk of water contamination is to be avoided: specific site and soil conditions,
characteristics of turfgrass species planted, and chemical properties of fertilizers and pesticides used.

Kenna (1995) describes some of the considerations for assessing the amount of risk that may exist for groundwater and surface water contamination on any particular site. Chemical properties such as high water solubility, low soil adsorption, long half-life (indicating longer persistence), and low volatility create conditions in which fertilizers and pesticides are more likely to leach into the soil profile or be transported into adjacent surface waters. Therefore, pesticide selection is a very important indicator of potential contamination. Porous soils (particularly high in sand content) with low levels of organic matter are considered more susceptible to downward movements of chemicals, and sites with these characteristics should be carefully treated (particularly in coastal areas). Sites with a shallow water table on sloping land are also areas of concern, particularly those near surface water bodies and those that may have sink holes or abandoned wells present within the area which would allow more rapid movement of chemicals. Cultural practices of management also impact potential risk of contamination. Incomplete planning, misapplication (applying excessive amounts or using the wrong materials), poor timing (applying in high winds or prior to storm events), and over-irrigation following application of chemicals are practices that increase the potential for contamination. All of these conditions need to be avoided in order to control the influence of chemical treatments and to ensure that golf courses maintain their utility in providing recreation while functioning as part of a healthy ecosystem.

**Pesticide Selection**

As stated previously, chemical usage on golf courses is extensive, and therefore requires careful management to be effective and avoid exposure of humans and non-target organisms to foliar residues, runoff into surface waters, and potential contamination of groundwater. One of the keys to the success of any management program includes the effective selection of pesticides that will protect turfgrasses from damage due to pests. The three major pests that cause damage to turfgrasses include weeds, insects, and fungal diseases. The chemicals (or pesticides) used to control these pests are herbicides, insecticides, and fungicides, respectively.
Pesticides differ greatly in their chemical properties. This, in turn, affects how they are applied and how they will behave when they are used for weed, insect, and disease control. One key property is pesticide fate, or the way in which the chemical breaks down in the environment. Pesticide fate is determined primarily by the following factors (Kenna, 1995):

- *Water Solubility*—the extent to which a chemical dissolves in water and, hence, how susceptible it will be to movement with surface and groundwaters;
- *Sorption*—the extent to which chemicals attach to soil particles, dependent upon the chemical and physical characteristics of the pesticide and the soil composition of the site;
- *Microbial Degradation*—breakdown, through microbial activity, of chemicals not used by pests and disease-causing organisms. The rate of this breakdown is influenced by soil depth (more activity occurs near the surface), concentration of microbes, air and soil temperature, soil water content, soil pH and oxygen status, amount and type of prior pesticide use, and soil fertility;
- *Chemical Degradation*—breakdown of chemicals occurring as a result of hydrolysis, oxidation, reduction, and photochemical breakdown (from exposure to the sun);
- *V olatilization and Evaporation*—transformation of a substance from a solid or liquid state into a gas. Volatilization and evaporation of pesticides is affected by the timing of application, amount of wind present on the site, and whether irrigation water is applied following application of pesticides; and
- *Plant Uptake*—a plant’s effectiveness at absorbing water and chemicals. Plants with high transpiration rates have lower susceptibility to leaching because of their efficient use of water and chemicals.

Pesticide selection is one of the key factors affecting how well pest and disease control is accomplished and how much impact those treatments may have upon the environment. Some specific quantifiable properties of pesticides that indicate potential chemical mobility and thus a potential for groundwater and surface water contamination include the following (Balough and Walker, 1992):
• **Water Solubility**—the rate at which a pesticide dissolves in water. Those chemicals with values greater than 30 ppm are considered more mobile because of their ability to mix in solution with surface and groundwater movements;

• **Soil Partition Coefficient** ($K_d$)—a soil-specific unit of measure used to describe the sorption tendency of a pesticide to a soil (Kenna, 1995). An effort should be made to use pesticides with values less than five, although most pesticides usually have values less than one;

• **Adsorption Coefficient** ($K_{OC}$)—describes the sorption tendency of a pesticide to the organic content of the soil. If this value is less than 100, the pesticide may be mobile; if between 100-1000, then moderately mobile; if greater than 1000, it is considered immobile;

• **Hydrolysis Half-Life**—the time required for fifty percent of the applied pesticide to break down chemically in water. Values greater than 175 days indicate that the pesticide is highly persistent and may be a cause for concern; and

• **Photolysis Half-Life**—the time required for fifty percent of the applied pesticide to break down through exposure to the sun. Pesticides with values greater than seven days are considered highly persistent and should be avoided.

Though critics of chemical usage on golf courses observe that more pesticides and fertilizers are used in turfgrass management than in growing agricultural crops, most fail to understand the effectiveness with which turfgrasses utilize these chemicals and nutrients. One of the main avenues of pesticide and fertilizer decomposition in turfgrass systems is thatch, a layer of dead and living plant and root matter that exists just above the soil surface. Pesticide fate is highest in thatch because this layer contains the highest percentage of organic matter, which tightly adsorbs water-insoluble pesticides. The high microbial populations that exist in thatch also cause accelerated biological degradation of the pesticides (Petrovic and Borromeo, 1994). Since no thatch layer exists in agricultural systems, turfgrasses are far more effective in utilizing chemicals that are applied for pest and disease control.

There is, however, the issue of raw consumption of resources for the production, distribution, and application of pesticides. The off-site costs for the use of materials on golf courses are an area of concern in any discussion of future sustainability of these areas.
Because of the environmental concerns and economic implications of pesticide use (both on and off site), golf courses should seek to minimize chemical usage, particularly where opportunities may exist for the conversion of turfgrass to native vegetation.

Pesticide Leaching

Leaching, the downward movement of chemicals (transported by water) into the soil profile, is one of the primary concerns discussed in relation to chemical pesticides and their usage in turfgrass management. This section will describe some of the scientific research that has been conducted and how the results of that work can be utilized for the protection of groundwater resources.

One method developed by Bruneau et al. (1996b) for evaluating different pesticides is the Pesticide Leaching Potential (PLP) index. Characteristics of pesticides that affect PLP include their ability to bind to organic matter, persistence, and the application timing and amount. PLP rankings range from zero to one hundred with higher numbers indicating a higher potential for leaching. Any PLP value greater than seventy is considered a concern for leaching. Golf courses should use pesticides with the lowest PLP indices whenever possible, and avoid usage of those chemicals with PLP values greater than seventy.

Cohen et al. (1990) conducted a three year study of four courses in Cape Cod, Massachusetts selected as worst case scenarios for groundwater contamination (sandy soils of glacial origin, above normal pesticide and nutrient applications, and continuous operation for more than thirty years). In the three years of monitoring at nineteen test wells, ten out of seventeen pesticides applied to the course were detected. Most of the measurable values were less than 5 parts-per-billion (ppb) and were associated with tees and greens. The most frequently detected was the herbicide DCPA. Chlordane was also detected, though it has been illegal for use on golf courses since 1978. Nitrate levels averaged 1-6 mg/l, with only a few above the drinking water standard of 10 mg/l. Though these values are acceptable for human consumption, there may still be enough present to create eutrophication in surface waters. Some of the concern generated by this study has been that it dealt with only one set of pesticides in one hydrologic environment. The study recommends further research for other types of pesticides and hydrologic environments,
especially for courses in the southern climates that use nematicides, which are more mobile and persistent than other chemicals (Grossmann, 1993; Schueler, 1994a).

Horst et al. (1995) showed that, after sixteen weeks under golf course management conditions, detectable residues of isazofos, metalaxyl, chlorpyrifos, and pendimethalin pesticides found in the soil, thatch, and verdure were 1% or less of the total application amount. They concluded that pesticide fate was most affected by environmental variables (high air and soil temperatures, high water contents through rainfall and irrigation, low wind speeds, and few cloudy days create conditions that decrease pesticide fate), the range in sampling times, and site location (different soil types, weather, and thatch amounts). The average $DT_{90}$ (days to 90% degradation) of the four applied pesticides was two months in fairway-managed turfgrasses. Thatch played a significant role in pesticide adsorption and degradation. $DT_{50}$ values for the pesticides were sixteen days for metalaxyl, twelve days for pendimethalin, ten days for chlorpyrifos, and seven days for isozofos (Horst et al., 1995; Kenna, 1995).

Niemczyk and Krause (1994) evaluated the behavior and mobility of benfluralin, trifluralin, bensulide, oxadiazon, pendimethalin, and DCPA (with its two metabolites), all of which are pre-emergence herbicides. Their data indicated a need to consider carryover of oxadiazon and bensulide in relation to the need for and rate of application necessary for continuous pre-emergent weed control in turfgrass (Niemczyk and Krause, 1994). Of eight pesticides tested by Branham (1995) with Kentucky bluegrass in a sandy loam soil, six were never detected in the leachate samples (which were collected at a depth of four feet). The two that were detected with some frequency were triadimefon and dicamba at levels of 2 to 31 ppb. The study also showed that 2,4-D is potentially very mobile, but it did not show up in the leaching samples that were collected.

Petrovic (1995) studied pesticide and nutrient leaching from fairways as influenced by soil texture (sand, sandy loam, and silt loam), pesticide properties (persistence and mobility), rainfall differences (moderate versus heavy rainfall), turfgrass maturity (density and organic matter accumulation), and organic matter content (from the addition of peat to a sand putting green). It was observed that 50-62% of the mecoprop (MCPP) applied to newly established turf leached in these conditions.
Petrovic et al. (1993) studied trichlorfon (an insecticide with a soil sorption coefficient of 6, where less than 100 is considered highly mobile) on fine sandy loam, silt loam, and a sand (each seeded with Creeping Bentgrass or Agrostis palustris). They then measured leaching by using lysimeters, which are bucket-like devices installed in a test plot that collects soil water and makes it possible to monitor agrochemical movements (Branham et al., 1995). They simulated above and below average precipitation, and the trichlorfon moved downward quite rapidly, with traces still detectable in leachate twenty-three days after application. The percentage recovered in leachates were 1-4% for low and high rates of irrigation, respectively. Leachate was highest in fine sandy loam at high precipitation, and lowest in silt loam at low precipitation levels (Petrovic et al., 1993).

Smith et al. (1993) found that less than 0.5% of the applied 2,4-D, mecoprop, dithiopyr, and dicamba was found in leachate from the simulated USGA putting green over a ten week period. They also found that, for all four chemicals, concentrations were less than 4 ppb, which demonstrated that current computer prediction models overestimate potential leaching of pesticides through turfgrass systems (the GLEAMS model estimated 50 to 60 ppb). No chlorpyrifos (Dursban) and less than 0.2% of the total applied chlorthalonil (Daconil) was detected in the leachate from the simulated putting greens. The differences between the measured and predicted leaching of 2,4-D can be partially accounted for by the lack of qualitative understanding of herbicide fate on vegetative surface and in the turf thatch horizon (volatilization, sorption, and degradation) (Smith and Tillotson, 1993). Yates (1995) found that leaching of 2,4-D was very low in soils containing clay, but up to 6.5% leached from sandy putting green soil (again, unaffected by irrigation amount). Less than 0.1% of the carbaryl leached, regardless of soil type.

Starrett and Christians (1995) found that pesticide and fertilizers applied to Kentucky bluegrass have the potential to leach through 20 inch soil profile if irrigated improperly. Leaching can be greatly reduced during the four weeks following application by irrigating lightly and more frequently, rather than heavily and less frequently.

Though many of these studies were performed for specific pesticides on only one type of hydrologic environment, there are some general conclusions that can be made that are helpful in avoiding chemical leaching from turfgrasses. One consideration is that chemical leaching (and runoff) is less likely to occur on mature turf than on bare soil, newly
established turf, or on dormant turf. Mature turf has denser root systems and thatch layers; thatch plays a significant role in adsorbing and degrading pesticides. Therefore, chemical usage on newly established turf should take into account the increased likelihood of leaching and protect against improper amounts of chemical application or irrigation.

According to Petrovic (1995), highly sandy sites (especially greens and tees) are most susceptible to nutrient and pesticide leaching due to high permeability, low organic carbon content, and low cation exchange capacity (CEC). He stated that the worst case scenario for golf courses are highly mobile pesticides applied to a new stand of turfgrass over a shallow water table on highly leachable soil (sand) and a rainfall pattern likely to leach. These conditions should be considered in developing and managing the course, particularly on sites with sandy soils and high amounts of precipitation. Care should especially be taken on courses in the southern climates that use nematicides, which are more mobile and persistent than other chemicals and are more likely to leach through the soil profile. Difficulty may be encountered in the future on southern golf courses because the EPA may restrict the use of fenamiphos (a pesticide currently used to control nematodes) and alternatives have yet to be developed for their control (Goldsby, 1991).

Irrigation also plays an important role in pesticide leaching. In general, less leaching occurs with multiple and light irrigation amounts rather than single, heavy applications (Snow, 1996). However, fewer and heavier applications of water are usually preferred in terms of water conservation (since less evapotranspiration occurs) and turfgrass health (deeper and infrequent applications encourage the deep root growth that will help the plant survive stress periods and make it more resistant to drought and disease). Therefore, a balance must be struck in the application of irrigation water. Most of the time, less frequent and heavy irrigation is best so that the plants push down deep roots. However, at times of chemical application, irrigation should be lighter and more frequent to avoid leaching.

Some additional considerations for site selection and turfgrass management that influence whether leaching occurs include the following (Petrovic and Borromeo, 1994):

- **Soil Characteristics**—this includes physical and chemical properties such as moisture content, organic matter content, hydraulic conductivity, porosity, bulk density, structure, texture, clay content, and pH as well as biological properties such as vegetative cover type and microbial activity. Soils with high moisture
content, high porosity, low bulk density, high hydraulic conductivity, low adsorption, and low organic matter content are more likely to leach;

- **Climatic Properties**—these factors include precipitation, temperature, and rate of evapotranspiration. Areas with higher levels of precipitation and less loss of chemicals and water through evapotranspiration are more likely to experience leaching events;

- **Management Practices**—excessive amounts of irrigation, poor surface drainage, lack of adequate thatch development, chemical applications to bare soil areas or to bunkers, and the use of chemicals more susceptible to leaching are conditions that should be avoided;

- **Groundwater Depth**—distances between the turfgrass surface and groundwater levels should be more than four feet (Klein, 1994);

- **Presence of Macropores**—large pore spaces within the soil profile often permit higher amounts of water and chemical movement. Some mitigation from their affects can be achieved through the use of drip irrigation. Adding a layer of sand can also help slow this movement; and

- **Pesticide Properties**—some of the factors that influence leaching include pesticides with low volatility, high water solubility, long persistence, low adsorption potential, and applications at high rates during times of likely precipitation. Chemicals with longer persistence (higher \(DT_{50}\) values) and water solubility values less than 30 mg/l may be mobile in permeable soils (such as sand) with low adsorptivity. EPA guidelines suggest that pesticides with \(K_{OC} < 300\) and \(DT_{50} > 21\) days have more potential to leach.

### Pesticide Runoff

Growing public awareness of the presence of pesticides and other nutrients in surface waters through agricultural and urban non-point sources has also caused criticism of golf courses. Although research on the surface runoff of turfgrass pesticides is limited, there is no evidence yet to substantiate these claims. The studies that do exist indicate that intense rainfall is required in order to produce runoff from a stand of turfgrass (Schueler, 1995c). Some of the studies described below tested runoff from turfgrass with one to two
inches of simulated rainfall per hour, a rate which occurs rarely as an actual storm event. Even at these high levels of input, runoff from turfgrass plots was difficult to generate.

Pesticide runoff is also affected by climate, soil type, pesticide selection, and management practices. In general, finely compacted soils (especially clays), soils with high moisture content, sloping lands, more water soluble and persistent pesticides, liquid rather than granular forms of pesticides, excessive irrigation applications, and seeded rather than sodded establishment of turfgrasses tend to produce more runoff of chemical pesticides (Petrovic and Borromeo, 1994). Smith et al. (1993) found that data from fairway runoff plots with a five degree slope indicate that there is a potential for small quantities of 2,4-D, dicamba, and mecoprop (MCPP) to leave the plots in surface water during a two inch rainfall at an intensity of one inch per hour. The runoff was attributed to poor infiltration on a high-clay soil.

Smith (1995) conducted 25-day runoff studies on 2,4-D, mecoprop, and dicamba treatments on Bermuda grass with a five percent slope and seven events of simulated and natural precipitation. Overall, 42% of the average rainfall event left the plots as runoff, and they carried 8% of the total applied pesticides. Four-fifths of the herbicides that left did so during the first simulated event, which was a two inch per hour, high intensity storm. Management strategies determined in this study for controlling pesticide runoff include:

- Increase water infiltration through aerification, coring, and verticutting;
- Light irrigation following pesticide application to wash chemicals from foliage to soil profile; and
- Make application during period that has low chance for rainfall for twelve hours, and irrigate them no sooner than six hours after application.

Murphy (1992) said that, “The concentrations of most herbicides and banned pesticides in urban runoff appears to be well below the threshold for acute toxicity for most aquatic and terrestrial organisms” (Schueler, 1995c, p. 249). However, there is also a concern that potential chronic or sublethal toxicity may occur from pesticide runoff because it is not well documented historically. Clearly, there is a need for more research related to runoff of pesticides from turfgrasses. Because of the uncertainty of these runoff effects, surface water areas on golf courses should be buffered by stands of native vegetation at least 50 feet wide, as suggested in the design section of this paper.
Pesticide Dislodgment and Volatilization

In addition to the environmental concerns related to pesticide leaching and runoff, losses of chemicals through dislodgment (physical removal from leaf surfaces by humans or animals) and volatilization (passage from a solid or liquid state into a gas that can affect air quality) are also a concern. Both of these avenues of loss are dependent upon the following factors that influence foliar interception of pesticides (Petrovic and Borromeo, 1994):

- **Method of Application**—liquid applications vary depending upon the height of the spray nozzle, the type of nozzle design, the sprayer operating pressure, and the volume of liquid applied. Granular applications vary based on the size of the granules and whether there is moisture present on the foliage at the time of application. Granular forms usually have less foliar interception than liquid for the same amounts of chemical applied, but are less susceptible to evaporation losses than liquids;

- **Irrigation Practices**—foliar washoff is influenced by the amount of precipitation or irrigation, the chemical properties of the pesticides, and the formulation used. If pesticides are lightly irrigated following application, the occurrence of dislodgment or volatilization is greatly diminished; and

- **Climatic Factors**—Conditions of high wind, high temperature, and low humidity (high evaporation losses) during application are more likely to experience higher amounts of volatilization.

One of the vital concerns related to dislodgeable foliar residues is whether humans and animals can be affected by exposure to chemically treated turfgrass areas. Extensive experimentation has shown that humans encounter little or no exposure to chemical pesticides on golf courses, with the exception of those that are in direct contact with the substances as they are applied. The Institute of Wildlife and Environmental Toxicology (TIWET) at Clemson University has conducted extensive testing of the affects of golf course pesticides at the Ocean Course at Kiawah Island, South Carolina. Although the study showed that there is potential for birds to be exposed to pesticides, they were able to find no measurable levels of pesticides in birds studied or negative impacts due to their exposure ("Golf and wildlife," 1996).
Cooper et al. (1995) evaluated volatile losses of pesticides over a two-week observation period with irrigation. They found that less than 1% of total MCPP (herbicide) applied was lost to volatilization. Triadimefon (a commonly used fungicide) had about 8% loss, about 7.3% of which occurred in the first five days. Isozafos (insecticide) experienced a 13% loss within first seven days, but less than 1% after that. Trichlorfon (insecticide) had 9% loss with irrigation and 13% loss without. Throughout the study, volatile losses were highest when surface temperature and solar radiation were greatest, and it can then be concluded that application is best done early or late in the day when temperatures are lower. Total volatile loss was directly related to vapor pressure, and most of the losses took place during the first five days after application. Volatile losses were up to 1000 times below levels that should cause health concerns and irrigating plots after pesticide application greatly reduced volatile and dislodgable losses the first day following treatment. Yates (1995) found that less than 0.05% of carbaryl and less than 1% of 2,4-D volatilized from the plots that were tested. Based on these results, turf may require different volatility regulations than agricultural crops. It should also be noted that the use of windbreaks can be a very effective method for limiting losses due to volatilization.

Dislodgeable foliar residues (through physical contact) were also tested by Cooper et al. (1995). MCPP loss was less than 1%, Triadimefon had 2.4% loss (less than 1% after 3 hours), Isozafos had 1.8% loss, and Trichlorfon had similar losses to isozafos. There was four times more loss through dislodgment for the Trichlorfon when the plots were not irrigated after application. Throughout the study, pesticide residues were rapidly bound to the leaf surfaces, with less than 1% of all residues dislodging (by rubbing with cotton gauze) eight hours after application (30). Dislodgeable residues are highest immediately after application and are higher with emulsified application than with granular. However, as mentioned above, irrigation after application greatly reduces safe entry times and possible exposure to animals and humans (Petrovic and Borromeo, 1994).

Fertilizer Leaching

Because of the high amounts of traffic on golf courses and the desire for a high quality playing surface, fertilizers are used to supplement the nutrient needs of the turfgrass plant, especially during times of stress. The primary nutrients for turfgrasses are nitrogen,
phosphorus, and potassium. Additional nutrients utilized by turfgrasses to lesser degrees are iron, magnesium, sulfur, manganese, calcium, boron, and zinc. Of these nutrients, nitrogen and phosphorus are of primary concern related to environmental impacts of fertilizer usage. Phosphorus and potassium are not as mobile as nitrogen and are therefore less of a concern for potential leaching into the soil profile.

Approximately three to five pounds of nitrogen are applied per thousand square feet of turfgrass on golf courses in the Midwest, but this amount varies with climate, turfgrass selection, and other factors. Most golf courses use synthetic organic sources of nitrogen such as urea and sulfur-coated urea (formulates the urea in a way that makes it release nitrogen at a slower rate). Yates (1995) found through experimentation that turf uses most of the nitrogen which is applied, even in conditions of over-watering that cause leaching of pesticides. Under bi-weekly applications of urea and sulfur-coated urea, less than 1% of the amount applied leached, and manipulation of irrigation and fertilizer type didn't seem to affect these results. Care must be taken, however, in the use of these sources of nitrogen, since they are highly water soluble and therefore very mobile in surface and groundwater movement.

Sources of fertilizer (nitrogen and phosphorus) fate include plant uptake, volatilization into the atmosphere, runoff in surface water, adsorption to soil particles, degradation by biological and chemical processes, and leaching into the soil profile. These fates are affected by the following (Balough and Walker, 1992):

- **Soil Characteristics**--soils with high water content, low bulk density, extreme pH, high temperature, low organic matter content, open structure, and low cation exchange capacity are more susceptible to nitrogen movement through the profile;
- **Climate and Slope**--sites where there is less volatilization and less slope are more likely to experience leaching of nitrogen;
- **Fertilizer Characteristics**--those with higher water solubility and chemical concentrations are more likely to leach; and
- **Management Practices**--high application rates on immature turf, timing (too much during times which negatively affect the turf), formulation (high
concentrations), and excessive irrigation will increase the likelihood of nitrogen leaching.

Bowman et al. (1995) found that nitrate leaching from both Tall Fescue (*Festuca arundinacea*) and Bermuda (*Cynodon species*) turf was very low (1% or less of nitrogen applied leached). Higher levels of salinity in the root zone, drought, or a combination of these stresses caused high concentrations and amounts of nitrate to leach from both types of turf. This demonstrates that, under high stress conditions, management practices will need to be modified to eliminate the stress, or nitrate leaching may be a problem. Bowman et al. (1995) also measured the effect of salinity on nitrate leaching and concluded that, “When root zone salinity is maintained at moderate levels and in the absence of other stresses, nitrate leaching is unlikely to be of concern. However, if salts build up or stress (drought) limits turf growth, nitrates may be a problem” (p. 47).

Petrovic (1995) found that only 2 of 1385 leachate samples from experiments conducted had more than 10 mg/l concentrations of nitrate-nitrogen, and most measured were below 1 mg/l. Phosphorus leachate levels were usually less than 0.05 mg/l (which was the limit of detection) and none had concentrations greater than 0.3 mg/l, which is considered to be the phosphorus concentration of eutrophic surface waters.

Rieke and Ellis (1973) showed that nitrogen leaching could best be reduced through proper irrigation methods such as reduced application rates, lighter and more frequent application instead of a single heavy one, application to only healthy turf, and strict watering practices to prevent over-irrigation. Starrett and Christians (1995) also concluded that heavy irrigation increases nitrogen transport compared to light and frequent ones, and determined that macropores may play an important role in the transport of surface nitrogen through soil profile. They also showed that liquid urea volatilized less than 3% when followed with irrigation (less than 1% when applied in a single heavy amount) and that the irrigation rate does not affect phosphorus transport after seven days.

Petrovic (1995) demonstrated that more leaching occurred in newly planted turf than in mature, established turf, and that nitrate-nitrogen leaching samples did not exceed EPA drinking water standards (10 mg/l). Branham (1995) showed that less than 0.2% of the applied nitrogen was recovered at a depth of four feet below the surface, and any nitrogen levels detected were at least ten times below the drinking water standard of 10 mg/l. It was
estimated that up to 34% of the nitrogen volatilized following application of the fertilizer to the turfgrass. Phosphorus leaching potential was found to be very low except in some sandy soils with low adsorption ability. It is in these areas that phosphorus applications require closer management to avoid leaching.

Brauen and Stahnke (1995) found the following factors important in determining the probability of nitrate leaching:

- **Rooting Medium**—more leaching occurs through a pure sand rootzone than through one of sand modified with peat moss or other organic materials;
- **Age of Turf**—more leaching occurs during the first year of establishment because there are less roots, less thatch, and less organic matter present;
- **Frequency of Application**—in studies comparing applications of nitrogen every fourteen days versus every 28 days, it was found that smaller amounts applied more often leaches less;
- **Application Rates**—less than 8 pounds of nitrogen per 1000 square feet will cause little or no leaching; and
- **Slow Release**—leaching is usually less if more than 70% of chemical applied is from a slow release source of nitrogen.

Carl Rygg, head superintendent at Squaw Creek Golf Course in Olympic Valley, California, has employed a “no-spray” program at his golf course (i.e. the course operates without the use of pesticides). He uses an average of 2 pounds nitrogen, 6 pounds sulfate of potash, and 0.5 pounds of phosphorus per 1000 square feet on his course. There are some variations in the grass color and the grass grows slower without the higher nitrogen rates that are used on other courses, but this nutrient program has produced very effective water quality enhancement throughout the site. Potash has made it possible to have lower nitrogen usage throughout the course, has produced denser and deeper root systems, controls plant stomas for precise pore opening and closing and optimization of nutrient usage, has made micronutrients more available to the turfgrass plants, has reduced salt levels and the likelihood to burn turf, and it adds sulfur, which gives grass better tolerance against drought and cold. One problem encountered at the course due to the lack of pesticide use is the higher labor costs, since weeds are pulled or cut out of the turf by hand instead of through chemical treatment (Jewell, 1994).
Current research generally supports the notion that turf grown on finely textured soils with moderate inputs of nitrate fertilizer and irrigation doesn’t have the nitrate leaching potential of row crops, nor does it pose a significant risk to potable water supplies. The key exception to this is over-watered lawns on sandy soils, where leaching may be a concern and more care must be taken in management (Schueler, 1995a). Turfgrass root zone and thatch layers have a high level of biological activity which enables turf to work like a filter when pesticides and fertilizers are applied. “Nitrogen applied to a dense, well-maintained turf is rapidly utilized by the turf with little chance of downward nitrogen mobility” (Branham, 1995, p. 35).

Fertilizer applications should be based on plant tissue and soil tests to prevent over-fertilization of the turfgrass. The goal of the nutrient program should be to provide just enough nutrients for the plants so that they will be slightly stressed but will not become chlorotic (yellowing of the tissues that indicates nutrient deficiency). That way, the turf will develop more extensive root systems and will tolerate stress such as drought or disease more readily than will the succulent growth caused by over-fertilization. Compacted soils should be aerified (process of removing small plugs of soil) to allow water and air to mix with the soil and decrease the stress on the turfgrass plants. Use of fertilizer on slopes and near surface waters should be avoided to prevent nitrogen from traveling in surface water runoff. Iron should be used as a supplement to nitrogen for greening response because it is a necessary element for the process of photosynthesis in turfgrass plants. Lighter and more frequent applications of nitrogen are preferred to prevent damage to turf and possible runoff or leaching of excess amounts. Grass clippings can be collected and recycled as an added source of nitrogen, or they can be left where they are cut for the same purpose (Bruneau et al., 1996a).

Surprisingly, several of the experiments above demonstrated that the form of fertilizer applied (inorganic versus slow release) appeared to have little direct effect on the concentrations of leached nitrate in the absence of over-watering. It appears that the critical factor in terms of nitrogen leaching is the amount of irrigation and rainfall the site experiences, and care should be taken to avoid excessive amounts of water following application (Schueler, 1995). Light applications of slow release nitrogen sources on frequent intervals are better for leaching protection. According to seven university studies
on nitrogen leaching, very little occurred when these materials were applied as appropriate for the needs of the turf, the soil type of the site, and when irrigation levels were correct according to rainfall amounts (Snow, 1996).

The use of organic materials with sand in putting green construction has been a very effective method for reducing nitrogen leaching. Though peat moss has been widely used for this purpose, other materials should be developed for this purpose in order to avoid the degradation of peat bogs. Brauen (1995) found that the addition of organic matter (such as sphagnum peat) proved to be the most important factor in reducing nitrogen leaching from newly constructed greens, and that “spoon feeding” (lighter applications of fertilizer on shorter intervals) significantly reduced nitrogen leaching from young greens. The study also show that, as putting greens matured, nitrogen fertilization rate was the major factor affecting leaching. Rates of 8 pounds or less of nitrogen per 1000 square feet per year resulted in little or no nitrate leaching.

Fertilizer Runoff

Fewer studies have been conducted on fertilizer runoff than on fertilizer leaching. Most of the experiments on fertilizer runoff have shown that nitrogen runoff can be minimized by having a dense, mature turf cover, avoiding compacted soil conditions, avoiding high soil moisture levels, using buffer strips in drainage ways and along surface waters, and using slow-release products (sulfur-coated urea, for example) rather than water soluble products such as urea (Snow, 1996).

Linde et al. (1994) assessed the effects of turfgrass on runoff water quality using 9 to 14% sloped plots with creeping bent and perennial rye grasses under fairway management conditions. They showed that Creeping Bentgrass reduced the volume of runoff compared to Ryegrass because of its higher shoot density (more than 200 shoots/dm² versus 100 to 200 for perennial rye). This study was significant in that it studied runoff losses from seedling turf as well as from mature turf, whereas other studies have concentrated more on mature stands of turf (Petrovic, 1990; Harrison et al., 1993). Measurements of runoff revealed that nitrate-nitrogen concentrations were less than 10 mg/l for both species of turf, and the leaching and runoff concentrations measured were less than those measured in the irrigation water alone. Phosphate-P leachate and runoff
concentrations measured were also less than those present in the fertilizer and irrigation water.

Some additional studies have demonstrated similar results to pesticide runoff studies in that there was difficulty in generating adequate runoff amounts from turfgrass areas in order to observe any movement of nutrients. Morten et al. (1988) observed concentrations of 1 to 4 mg/l of nitrate, but only two runoff events were generated during the two year study (one from rain on top of snow and another from an intense storm). Gross et al. (1990) also observed minimal runoff amounts except in very large storms. It appears that well-maintained turfgrass seldom produces surface runoff, except from uncommonly large storm events. There is, however, concern for highly compacted soils or when there are short travel distances to impervious areas (Barth, 1995a). Where this is the case, measures should be taken to alleviate compaction and provide vegetative buffers along surface water areas.

**Integrated Pest Management**

Integrated Pest Management (IPM) is defined by the Environmental Protection Agency as, "...the coordinated use of pesticides and environmental information with available pesticide control methods to prevent unacceptable pesticide damage by the most economical means and with the least possible hazard to people, property, and the environment" (Muirhead and Rando, 1994, p. 99). The idea is to balance the costs, benefits, public health concerns, and environmental quality concerns while managing the golf course. IPM relies on ecological principles and uses both biological and chemical approaches. It aims at the development of healthy turf that can withstand pests and the judicious and efficient use of chemicals. This depends on strengthening natural organisms that benefit turfgrasses and on timing pesticide control measures to coincide with the pest's most vulnerable stage so that less pesticide is required (Smart et al., 1993).

According to McCarty and Elliot (1994), IPM involves the use of cultural, chemical, and biological methods for the control of pests. Cultural controls include host plant resistance (selection of cultivars resistant to pests), use of planting materials free of pests (seed, vegetative sprigs, or sod), proper site preparation (irrigation and drainage systems that provide precise water management, planting turf in soil which is free of pests, adequate
sunlight, proper ventilation, proper drainage on fairways, greens large enough to support anticipated traffic, and an adequate supply of good quality irrigation water), and agronomic practices (proper irrigation, fertilization, mowing, aerification, verticutting, and topdressing).

Developing an IPM program for turfgrasses is difficult because of the perennial nature of the plants, the shortage of reliable and cost-effective alternatives to pesticides, the limited sampling and decision-making guidelines available, and the limited tolerance golfers have for damage to the course (Brandenburg, 1994). Tim Hiers, now head superintendent at Colliers Reserve in Naples, Florida, says that, “Although IPM costs are initially higher than conventional programs, the long-term effects on course quality and maintenance will end up saving us a considerable amount.” Hiers has been able to reduce pesticide use at his golf course by fifteen percent, with additional savings still possible with some added stress to the turf (Goldsby, 1991).

The South Carolina Turf Information and Pests Scouting (TIPS) program was administered to seven golf courses in South Carolina, where scouting was performed and recommendations were made to superintendents on agronomic practices and the judicious use of pesticides. This program produced a 30% reduction of fungicide use by monitoring weathering parameters and not applying chemicals until conditions are favorable for disease development. It also produced a 35% reduction in nitrogen use and significant cost savings for the courses (McCarty and Elliot, 1994). As part of their IPM program, Chesapeake Bay Golf Course has encouraged bat and bluebird nesting to keep mosquitoes in check and to feed on sod webworms and cutworms, which saves one spray of pesticides per year and about $2000-8000 of their maintenance budget (Roedall, 1996).

Another good example of IPM at work is Pine Ridge Golf Course in Towson, Maryland, which sees an average of 85,000 rounds of golf played per year (twice national average of 45,000 per year). Anne Leslie, a turf specialist with the EPA and editor of the Handbook of Integrated Pest Management for Turf and Ornamentals (1994), worked with this course to set threshold levels for pests and diseases and to help create treatment regimens. A “Pestcaster” computer program was used for monitoring, which included a 21-day log of relative humidity, wind speed, precipitation, leaf moisture, and other factors. It was able to generate data that would indicate when to start looking for specific diseases. Some of the alternatives to chemical treatment used at Pine Ridge included the application
of milky spore (a bacteria) to control white grubs, 1 oz. of Chlorox bleach per 1000 square feet for control of black algae, and ground up chicken feathers for control of summer patch (microorganisms promote balance in soil). The feathers were put down behind the mowers and watered into the turf. The mixture was applied once a month during the summer and cut pesticide use throughout the course in half. Overall, the IPM program produced excellent cost savings for the course through reductions in chemical application ($7,000 or one-third of the normal cost), use of bleach instead of other chemicals (saves $500 alone per spray), and less spraying means maintenance personnel have more time to devote to other tasks (Greenspan, 1991).

Squaw Creek Resort in Olympic Valley, California has had a “no-spray” program in effect since 1988 because the course is located over a major source of drinking water. No pesticides, fertilizers, or fungicides are used on the course, and nitrogen applications are limited. A “Technical Review Committee” of concerned citizens was created to oversee the no-spray program. They developed a Chemical Application Management Plan that allows weed control by mechanical methods only, which has required the course to hire five to ten new people to pull weeds by hand. The only caveat to this is that 2-4,D and Roundup can be used on maintained fairway and tee areas if mechanical methods fail to work. The only fungicide approved for use on greens is Fungicide II (OM Scott) with 6% chloroneb, which may be applied only once per year and only to greens. Throughout the course, there is a “no increase tolerance level”, which means that the current level of nitrates measured in groundwater cannot increase due to management practices. The extra maintenance (increased labor for pulling weeds), test well construction, and water monitoring have cost $20,000 more than conventional management budgets. In general, it is approximately three percent more expensive to maintain a “no-spray” course (Carville, 1991).

According to Squaw Creek course architect Robert Trent Jones II, “This (no spray) can only be done in mountains. You can't abandon herbicides and pesticides where you don’t have a very cold snap season that controls insects naturally” (Carville, 1991, p. 10). Soil test samples were collected from eighteen different sites throughout the course, and each site is maintained according to soil needs identified from the soil samples. The course also hired a full-time biologist to care for the environmental areas (native grasses, forests, and wetlands). The Army Corps of Engineers has placed thirty-three water quality testing
sites throughout the course, and they are also testing the quality of Squaw Creek as it
enters and leaves the course to determine the effects of the course on surface and
groundwater quality. Their testing has revealed that nitrogen levels in Squaw Creek are
actually reduced by flowing through the course (Jewell, 1994).

Since leaching and runoff appear to be more of a problem from seedlings than from
mature turf, IPM measures can be utilized effectively during establishment as well.
Applewood Golf Course in Golden, Colorado seeded their grasses at higher than normal
rates in order to avoid using herbicides during establishment. They also set stringent
requirements for chemicals that were acceptable for use on the course; water solubility less
than 30 ppm, adsorption partition coefficient (Kd) greater than five, normalized partition
coefficient (Koc) greater than 500, hydrolysis half-life less than 24 weeks, soil half-life less
than two weeks, and toxicity values less than 2000 mg/kg (Miller, 1989).

The following are some effective IPM strategies based on contemporary research
that can be used in optimizing the use of chemical controls in turfgrass management
(Muirhead and Rando, 1994; McCarty and Elliot, 1994):

1. Define the role and responsibility of all people involved
2. Determine management objectives for specific areas of the course and correct
   all practices which favor development of pests or that place stress on turf
3. Generate a map with the following features identified: turf species in each area,
   mowing height and frequency, irrigation amount and frequency, shade and air
   circulation concerns, soil damage, soil analysis, fertilization program, and traffic
   patterns
4. Utilize a weather monitoring system to provide detailed, localized data on rainfall,
   soil temperatures, humidity and sunlight indices, and evapotranspiration rates
5. Set action thresholds (points at which pest populations or environmental
   conditions indicate that some action must be taken) and begin the monitoring
   and recording of infestation levels
6. Monitor action threshold and program effectiveness by maintaining written
   records of actions and results (plus any potential habitat modification caused by
   pesticide use)
7. Modify the pest’s habitat to reduce carrying capacity and make the site inhospitable for their survival
8. Select grasses more resistant to pests that are suitable for the site, climate, and use
9. Filter, trap, and neutralize waterborne nutrients in stormwater impoundments
10. Utilize vegetated buffer strips along surface water bodies
11. Establish a list of pesticides prohibited on the site because of their potential toxicity or hazard to wildlife, and avoid the use of highly persistent pesticides
12. Use bacterial or biological control methods whenever possible (plant growth regulators, etc.)
13. Increase mowing heights and decrease watering frequency (reduces weed and fungal infestation)
14. Control accumulation of thatch and compaction of soils
15. Use fungicides with computer monitoring and diagnostic tests, rotate their use to reduce likelihood of resistance development
16. Monitor positive and negative changes in flora and fauna
17. Educate the public and maintenance staff (continuing education)

Chemical controls are still the preferred means for dealing with turfgrass pests and diseases on most golf courses, and it is therefore important that IPM practices be carefully followed in their use. Pests should identified and monitored with reliable techniques to establish aesthetic thresholds. Pesticides are best applied during a particular stage in the life-cycle of weeds and insects (usually the early stage of development) or during certain weather conditions, and every effort should be made to coordinate the application times with these conditions of increase susceptibility. Efforts should also be made to select chemicals that will be the most effective treatment but the least toxic to non-target organisms (and least persistent). It is also a better practice to spot-treat on problem areas rather than use chemicals as a blanket application (McCarty and Elliot, 1994).

If biological controls are selected for use in IPM, it is important that they will not be harmful to desirable plants or other non-target organisms. They should also have the ability to reproduce quickly enough to prevent pests from building to major infestation levels and have the ability to survive and maintain a population equilibrium between themselves and
the pests. These organisms should be adapted to the environment of the host and should be free of their own predators or pathogens. It is important to accept that a minimum level of target pests will always be present (golfers especially need to understand this) and that complete elimination of pests is not feasible. Biological agents are complex, not totally effective, and not always predictable, and should therefore be considered carefully before they are implemented (McCarty and Elliot, 1994).

Subsurface pesticide application is another recently-developed method that has several advantages over traditional surface application methods. Its primary advantage is that it is more effective against soil-borne pests, which are traditionally the toughest to control in turfgrasses. For example, a subsurface application of chlorpyrifos is effective against mole crickets at half the rate needed for surface treatment. There is reduced surface residue, reduced odor, improved efficacy, reduced pesticide rates, reduced drift, and reduced need for post-treatment irrigation with this method. Disadvantages to subsurface application are that it takes longer to apply chemicals this way than for surface application (especially for liquid forms) and that there is a high front-end cost for equipment that can perform this function (Brandenburg, 1994). This method of application shows promise, however, for future pesticide application techniques.

Timing of application is one of the key factors in a successful IPM program. Tim Massuco, superintendent at Stratton (in Vermont) says that, “If you cut your finger, you don’t bandage your whole body.” He says that superintendents should treat problem areas in turf at proper times to avoid undesirable consequences (Parascenzo, 1991). In other words, problem areas should only be treated when pest populations reach threshold levels, which will maximize the effectiveness of the pesticides and fungicides applied (Edmondson, 1987). Criteria for pesticide selection in IPM include high effectiveness against pests, low toxicity to non-target species, low water solubility, and short residual (Smart et al., 1993).

To summarize, important steps in IPM include accurate pest identification, monitoring, and evaluation of risk (action thresholds). It is also important to learn which diseases occur during which seasons, to select disease and pest resistant turfgrasses, and to use correct management levels for irrigation, fertility, mowing, and aerification (Barth, 1995). Watering less often and more deeply (to encourage deeper root growth) and early in the morning (to minimize evaporation losses) is part of this approach. Label directions
should always be followed and applications should always be performed by licensed personnel. Chemicals should not be applied during conditions of high winds or when rain is in the forecast. Low-volume sprayers should be used in order to reduce drift. Careful records need to be kept that contain a specific history of pest emergence and control throughout the golf course. Maintenance workers should be extensively trained in the proper use, storage, and handling of pesticides (Smart et al., 1993). Whenever possible, chemical treatments should be curative rather than preventive. Applications should be made after problems have exceeded damage thresholds set for the turf or when conditions are likely for this to occur.

Much of the recent research related to pesticides and fungicides has dealt with the development of biological controls, such as predatory or parasitic organisms that can function in symbiotic relationships with turfgrass plants and protect them from harmful insects or disease-causing organisms. Compared to chemical pesticides, biological controls tend to be slower acting, more expensive, more difficult to implement, and less readily available. Predatory insects such as ladybugs, lacewings, parasitic wasps, and praying mantis can be used to help control undesirable insect levels. Courses can also provide food and habitat for Eastern bluebirds, tree swallows, and bats as another method of biological control of insects (Hiscock, 1997). As research continues in this area, more combinations of materials and predators are being used in an effort to eliminate the need for chemical usage on golf courses.

Effective use of IPM, along with the use of methods of water conservation through water recycling, efficient irrigation, appropriate turfgrass selection, and effective maintenance strategies (mowing, fertilization, etc.), can work together to provide savings to golf course management budgets and can preserve water resources and environmental quality for the rest of society as well.

**Turfgrass Selection and Management**

A sustainable turf is one which has a minimal loss of resources and therefore requires few material inputs and has only positive environmental impacts (Hull et al., 1994). Most turfgrasses are introduced species, are often subjected to intensive use, and do not constitute a climax vegetation where they are grown. These factors contribute greatly to
their genetic instability. Lawns are rarely sustainable without significant inputs because achieving self-sufficiency has not been an important goal of those in the fields of turfgrass research and management in the past. Serious turfgrass breeding has only been underway for about 50 years, and that has been mostly aesthetic (color, leaf size, and texture as a playing surface). These trends are changing as new strains of turfgrasses are developed that are more resistant to insect and disease damage and are more drought tolerant.

Annual nutrient losses contribute to a decline in turf quality and require inputs of fertilizers (for nutrient availability) and pesticides (for protection from disease). It is hoped that continued research will produce turfgrass species that will require less water and chemical application and will approach a sustainable plant community. The following are some of the criteria used in assessing the sustainability of turfgrasses (Hull et al., 1994):

- **Nutrient Use Efficiency**—minimize nutrient loss from the soil;
- **Water Use Efficiency**—maintain evapotranspiration rate sufficient to provide leaf cooling and the transport of nutrients from the roots, but no more; should be capable of entering into stress-induced dormancy;
- **Resisting Pests**—grasses which contain the genetic ability or are healthy enough to resist attack from diseases or harmful organisms; and
- **Healing Wounds**—grasses which grow through rhizomes and stolons are better than bunch types for filling areas that have been disturbed within the turf.

In order to address turfgrass sustainability issues, it is important to understand the flows of energy (inputs, storage factors, and outputs) of these systems. The primary energy inputs are sunlight, water, and fertilizers. Sunlight is a sustainable input of energy that makes it possible for the plants to conduct photosynthesis and produce the energy they need to function. Most of the nutrient inputs come from fertilizer applications which contain nitrogen, phosphorus, potassium, iron, and other nutrients. Nutrients are also contributed through irrigation water and surface runoff from adjacent impervious areas (Barth, 1995a).

Fixation of atmospheric nitrogen by turfgrass plants and the decomposition of turfgrass clippings left in place are another source of nutrients for turfgrass systems. Studies in the Washington, D.C. metro area have recorded nutrient inputs of 0.7 pounds of phosphorus and 1.7 pounds of nitrogen per acre per year through atmospheric deposition from power plant and vehicle emissions (Barth, 1995a). Petrovic et al. (1990) evaluated the
amount nitrogen recovered from grass clippings with the amount applied in fertilizers. They found that the percent recovery varies with grass species, fertilizer rate, and nitrogen availability rate (25-60%). Meyer (1995) found that one acre of clippings yields approximately 235 pounds of nitrogen, 210 pounds of phosphorus, and 77 pounds of potassium (Barth, 1995a). All of these sources of energy need to be considered in evaluating the nutrient needs of the turfgrass and ensure that over-fertilization is not taking place.

The two main energy storage components within turfgrasses systems are soil storage and thatch storage. Prior soil testing and fertilization history are important factors for determining the fertilization rates needed for management and make it possible to reduce nitrogen leaching potential caused by over-fertilization (Barth, 1995a). Thatch storage can account for approximately 14 to 21% of the nutrient recovery in the system according to a study by Petrovic (1990). Energy outputs from turfgrasses include volatilization (highest rates with the application of urea fertilizers without irrigation on turf with high levels of thatch), denitrification (soil bacteria conversion of nitrates to gaseous nitrogen, which goes to the atmosphere), surface runoff (outputs usually very low unless soils are highly compacted or travel distances to impervious surfaces are short), subsurface leaching (usually not a concern unless turf is over-fertilized and over-watered on pervious soils), and mower clippings (if they are collected and not returned to the soil) (Barth, 1995a).

In order to approach sustainable management of turfgrasses, efforts need to be made to decrease the amount of nutrient inputs that are required. Barth (1995a) identified the following as steps toward low input turfgrass management:

- **Lawn Conversion**—convert areas to native vegetation where turf is hard to grow such as frost pockets, exposed areas, dense shade, steep slopes, and wet areas;
- **Soil Building**—test for pH, fertility, compaction, texture, moisture content, and other factors to optimize growing conditions and nutrient availability;
- **Grass Selection**—specify species should be appropriate for the region and particular site characteristics such as shade, typical pests, and disease tolerance. Slow growers, dwarf cultivars, those that require less fertilizer and water, and endophyte-enriched (to battle disease) species are preferred when applicable;
• **Mowing and Thatch Management**—mow at the right heights at the right time (higher mowing heights means less weed competition and more root development and photosynthesis; should cut no more than 1/3 off at a time), don’t remove the clippings, and monitor thatch levels (more than 1/2" thatch is unhealthy);

• **Minimal Fertilization**—recycle clippings, use half of the recommended commercial fertilizer levels, avoid application when rain is imminent, fertilize only as needed with slow-release products, and use organic fertilizer or compost if possible to increase desirable microorganisms;

• **Weed Control and Tolerance**—use the least toxic methods available and seek to broaden the definition of lawn to include weeds that perform desirable functions; and

• **Implement IPM**—discussed in detail in the previous section.

In developing a design and management plan for Applewood Golf Course in Golden, Colorado, course architect Garritt Gill subdivided the turf into five areas with different grass cultivars and irrigation levels to reduce water usage and increase disease and pest tolerance (Miller, 1989):

1. Greens and Teeing Grounds (Penncross/Penneagle Bentgrass at varying mowing heights)
2. Landing Areas and Approaches (Ryegrass/Bluegrass mixture at 5/8")
3. Other Fairway Areas (Bluegrass/Chewings Fescue/Hard Fescue blend at 5/8")
4. Rough Areas (Buffalograss/Hard Fescue/Tall Fescue blend at 3")
5. Out-of-Play Areas (native vegetation, no maintenance required).

Christians and Engelke (1994) developed methods for choosing the right grasses to fit the environment. “Species and cultivars used outside their primary area of adaptation may require specific cultural inputs including the increased use of pesticides to overcome inherent biological limitations.” This article also includes an Adaptation Zone Map from which some general conclusions for turfgrass selection can be made. Kentucky Bluegrass, Bentgrasses, and fine Fescues should be used in the northern U.S. and Canada; Tall Fescue and Perennial Ryegrasses should be used in the transition zone (in addition to some Zoysia and Buffalograss areas); Zoysia should be used the south and east, Bermuda in the southwest, and St. Augustinegrass in parts of Florida. The article includes a good
description of each of the major genus and species of turfgrasses and some of their maintenance concerns.

Kenna and Horst (1993) evaluated different species of warm- and cool-season grasses for use in stress-related situations. Grasses that performed at the lowest water use rate included warm-season grasses (especially Bermuda, Zoysia, Buffalograss, Centipedegrass) and cool-season grasses (fine Fescues) with high densities and low growing heights. In terms of drought resistance, Bermuda (warm-season) and Fairway Wheatgrass (cool-season) performed the best in their respective growing environments. Seashore Paspalum (warm-season) and Weeping Alkaligrass (cool-season) should be selected for use where salt resistance is a desired characteristic, such as in coastal regions or for courses with high levels of sodium in the soils.

Extensive turfgrass breeding studies have begun across the country in an effort to develop new cultivars of turfgrasses for use on golf courses and in other turf uses as well. Buffalograss (described in the following paragraph), Alkaligrass, Blue Grama, and Fairway Wheatgrass are some of the native grasses currently being evaluated. Preliminary results have indicated that there is a need for continued research to understand the interactions between turfgrasses and atmospheric, edaphic, and biotic environmental stresses (both natural and man-made) that are imposed upon them (Kenna and Horst, 1993). Several other new turfgrass cultivars are also being tested for use on golf courses such as Alpine Bluegrass, Idaho Bentgrass, Supine Bluegrass, Seashore Zoysiagrass, and Velvet Bentgrass. So far, these cultivars have not been widely used, but it is hoped that continued research and cultivation will produce superior blends that will require less water and be more resistant to diseases and pests. Extensive testing still needs to be performed on some of the newly developed cultivars to observe how they perform under actual management and traffic conditions.

Buffalograss has been found to be adequate for golf course roughs, but not yet good enough for fairway use (Kenna and Horst, 1993). It will tolerate low mowing heights and low maintenance conditions and uses approximately 75% less water than cool-season grasses. It typically has an open and spreading growth habit, but better cultivars are being developed for turf uses because of the desire for a denser cover at lower mowing heights. The development of seeded improvements for Buffalograss takes more time than vegetative
cultivars because of the breeding methods involved. This species has two separate sexes whereas most turfgrasses have both sexes on the same plant (Riordan, 1991).

Management of Buffalograss is much less intensive and costly than that of other types of turfgrasses. Buffalograss is usually fertilized with 1 to 2 pounds of nitrogen per growing season, which is applied in two treatments (around July 1 and August 15). Irrigation water should be applied deeply and infrequently and only when necessary to maintain color and active root growth. This usually means irrigation once a month in the north and slightly more often in the southern U.S. Mowing should take place weekly for fairway turf and every four to six weeks for rough. Pesticide use is rare on Buffalograss, except when a preemergence control will be necessary for control of a specific problem (Riordan, 1991).

One of the primary advantages to drought tolerant species such as Buffalograss is that they will produce tremendous savings in water usage for golf courses and other lawn uses. Drought tolerance is the ability of the turfgrass plant to avoid tissue damage in a drought period by postponement of dehydration. This can be done by limiting evapotranspiration (decreased leaf area and high canopy resistance) and functions in water uptake (deeper rooting and resistance to stresses such as decreased soil oxygen levels, adverse temperatures, high salinity, adverse pH, and phytotoxic conditions). Drought tolerance is also accomplished through escape (living through drought periods in a dormant state or as seed) and hardiness to low tissue water deficits (Kenna and Horst, 1993).

Turfgrass cultivar recommendations and blends for specific locations are best obtained from local resource people such as county extension agents. These professionals are able to advise which cultivar(s) will perform best under specific growing conditions and management levels. There is also a National Turfgrass Evaluation Program which provides information on the performance of commercially available turfgrass cultivars under regional conditions such as climate, soil, management practices, and other factors (Christians and Engelke, 1994).

As previously discussed, management practices have a profound effect upon the health of the turfgrass and, therefore, upon how much water and chemicals will need to be applied. Mowing heights directly affect the depth and extensiveness of root systems (lower means less roots), and these heights should therefore be higher during stress periods (heat
and drought). Less than optimum water levels, low mowing heights, and over-fertilization results in decreasing stress tolerance in the plant. Turfgrasses should be managed to experience some levels of stress, but prolonged dormancy periods should be avoided during the growing season so that the turf density can be maintained at the levels needed to preclude weed invasion (Watson, 1983).

Clearly, there is a need to develop turfgrasses with lower water requirements, deeper root systems, better ability to remain green color during drought, tolerance to brackish (contaminated) waters, and tolerance to adverse soil conditions (Watson, 1994). The goal of turfgrass research in the future will be to produce species that will require less inputs and will be more tolerant of these conditions. This is achieved through improved germplasm of current turfgrasses and the identification and improvement of grasses not currently used (Carrow, 1994). Community benefits of a low input turf include reduced summer water demand, preservation of landfill capacity, and reduced cost for management of public lands. As research continues, turfgrass species may be produced that will require less water and chemical application and will approach a more sustainable plant community.

Management of Greens

Another issue related to turfgrass selection that has developed in recent years is the use of Creeping Bentgrass for golf course greens. Creeping Bentgrass produces a very fine-textured and uniform putting surface at low mowing heights, and is the preferred turfgrass for use on greens. However, because it is a cool-season grass, it usually requires extensive irrigation and chemical usage in order to survive in climates with high heat and humidity. Because of this, new strains of warm-season grasses with finer textures such as TW-72 Bermuda are continually being developed. Continued research related to the development of better turf for use on golf course greens will most likely reveal additional alternatives to Creeping Bentgrass for regions where it is difficult to maintain.

Annual Bluegrass (*Poa annua*) is usually considered a weed on golf course greens because it will become dormant during the warmer summer months and will affect the appearance and play of the putting surface. However, because of its genetic variability and ability to produce many seedheads at low mowing heights, Annual Bluegrass is very difficult to eliminate, as demonstrated by a long history of attempts at its control (Christians, 1997).
Some researchers, including Dr. Donald White at the University of Minnesota, are working on developing Annual Bluegrasses for use on putting greens in cooler regions with the idea that keeping them alive may be easier than trying to control them (Kenna and Horst, 1993).

Maintenance of golf greens has changed a great deal in the past twenty years. Golfers are demanding faster greens which also means a decrease in mowing heights. According to golf course architect Pete Dye (1995, p. 149), “All this talk about green speed on the (PGA) Tour has, in turn, convinced golf clubs and municipal courses to speed up their putting surfaces as well. In a day and age when course superintendents are attempting to find ways to cut back maintenance costs, increased green speeds are adding to them. The need to cut the greens short in order to make them lightening fast requires more course maintenance, since the surface must be mowed and watered so often.....has made (greens) more receptive to spin shots than the old firm greens.”

Robert Sommers (Zoller, 1983, p. 23) states that, “The production of fast-growing and soft greens and fairways should be avoided. They result in unnecessary maintenance problems...The truly proficient golfer relies on backspin to stop his shot, not a hose. Wet greens are easily damaged by spikes, ball marks, and mowing equipment. Shallow grass roots develop, annual bluegrass invades, and, before long, all damaging consequences of poor water management catch up....” Both of these sources reveal the need for slightly raised mowing heights on golf course greens in order to decrease the amount of maintenance they require. Decreased applications of water, pesticides, fungicides, and fertilizers will be a benefit economically as well as environmentally. Allowing the greens to become firmer through less watering will also encourage better shotmaking from players, as was discussed in the design section of this document.

Developing Environmental Plans

Environmental management plans help to define goals, assess what works and what needs fine-tuning, and plan new directions for continued management (Dodson, 1995). These plans seek to adapt an integrated approach that relates the history of the site to present surveys of species, communities, and habitats. The simplest form consists of a species list that provides information about species presence or absence and historical data (Brennan, 1994).
Two contemporary techniques for recording presence/absence data include DAFOR and Percent Coverage Domin Scale. The DAFOR method is commonly used in Britain. It evaluates species data by giving it a value of dominant (D), abundant (A), frequent (F), occasional (O), and rare (R). Each habitat is allocated a code and is color coded onto a base map (1:10000 scale) where A=woodland, B=grassland, C=tall herb/fern, D=heathland, E=bog, F=swamp, G=open water, H=coastland, I=rock, and J=miscellaneous. The Percent Coverage method evaluates presence/absence on a particular site by giving it a score between one and ten. A score of ten would mean 100% coverage, while a score of one would mean less than 5% cover (Brennan, 1994).

Either of these methods are effective for evaluating the existing conditions on the developed site. Once the important and vulnerable aspects of the site are identified, they can be used to construct a map of sensitive areas that require different approaches to management. GIS computer software can be used to construct layers of information related to historical data, wildlife habitat and vegetation inventories, soil types, depth to groundwater, proximity to other sensitive areas, and special management needs (Brennan, 1994). With the above information in hand, it will then be possible to prepare an environmental policy statement and action plan for the golf course that will guide future development and management on the site. It would also be wise to establish an environmental action committee for the course which can be involved in developing programs and fostering staff and member support through education and continued involvement ("Environmentally responsible," 1993).

Muirhead and Rando (1994) developed the following management zones as part of a concept for a golf course environmental plan:

- **Preservation/Conservation Zone**—highest level of protection to maintain existing levels of quality for habitat, retention of contiguous connections and wildlife corridors across a variety of habitats. Standing snags (dead trees used by cavity-dwelling animals) should be retained unless the become safety hazards. Brush piles should be provided approximately every 200 feet, eroded areas should be stabilized, and habitat should be reestablished and enhanced as applicable;
- **Secondary Rough**—drought-tolerant indigenous plants with high wildlife value should be used as shelter or food source;
• *Primary Rough*—a band of turf approximately 15-45 feet wide that is maintained with higher mowing heights and IPM thresholds and remains unirrigated; and

• *Maintained Turf Zone*—areas of play where soils are amended for turfgrass growth, appropriate IPM measures are in place, and where water and fertilizers are applied only on an as-needed basis.

The development of environmental management plans of this type will be beneficial for the course in many ways. It will provide direction of present and future management of the different habitat areas present on the course and will demonstrate to people in the community the benefits of the course and the steps it is taking in providing wildlife habitat, protecting surface and groundwaters, and decreasing water and chemical usage.

**Water Quality Monitoring Programs**

In addition to environmental plans, it is also important to be able to demonstrate that the course has a strategy in place to monitor water quality and deal with any problems that may arise (Dodson, 1995). Monitoring groundwater and surface water should begin one year prior to construction of any new course that is developed and should be continually monitored after that. This is particularly important for the first five years after construction. Monitoring data should be analyzed quarterly for ammonia, nitrate nitrogen, phosphorus, pesticides, and temperature changes (Klein, 1994). Any changes that are necessary to the management plan can then be based upon these results.

One excellent example of a water quality monitoring program at work is Queenstown Harbor in Queenstown, Maryland. This course, designed by Lindsey Ervin and William Love, is a 36 hole public course with 147 acres of wetlands within a mile of Chesapeake Bay. This area is known as the Chesapeake Bay Critical Area and is protected by very strict environmental regulations. Over seven years of permitting and 43 public hearings were required before the project could be completed. One of the goals of the design was to reduce the manicured portion of the course to the minimum required to play the game and to treat the rest as wildlife habitat, meadow, or forest. Buffer plantings of native species, 300 feet wide, were maintained between the course and surface water areas. Thirteen monitoring wells were installed prior to construction and were located based on subsurface water flows. These wells have been able to provide comparison data for nitrogen,
phosphorus, and other chemicals in the water supply and the effects of golf course upon these levels. Samples obtained prior to construction in 1990 showed that two of the wells had nitrogen readings of 14 and 19 mg/L. These levels, which exceeded the EPA drinking water standard of 10 mg/l, were attributed to runoff from agricultural fields upstream. Post-construction samples from 1994, however, demonstrate a marked improvement in water quality on the site. Tests samples showed undetectable levels of nutrients and other pesticides, and nitrate nitrogen levels dropped 35% from previous readings. Phosphorus levels also dropped throughout the test period (Shirk, 1996; Thompson, 1993). These numbers indicate that golf courses with proper management practices and buffer plantings are able to improve the water quality in a watershed that had demonstrated previous degradation.

Those courses that do not currently have water monitoring stations established will benefit greatly from the data that can be obtained from them. At little cost, lysimeters (bucket-like devices used to gather water samples for testing) can be used on the course to provide useful information on the quantity and quality of percolate occurring in response to various irrigation practices. Periodic evaluation of water quality for nutrients and pesticides (especially after application) would provide useful information on the success of management practices (Snyder and Cisar, 1995). It would also provide data that could be used to demonstrate to the public that the golf course is improving water quality in the watershed rather than having the detrimental effects that have been the subject of so much criticism.

**Water Conservation, Irrigation, and Runoff**

One of the primary considerations for the suitability of a site for golf course development is whether there are adequate sources of irrigation water available on the site. This is particularly true for developments in the desert, where the average 100 acre golf course requires approximately 650,000 gallons of water per day (Parascenzo, 1991). From an environmental standpoint, a good rule of thumb is that sufficient water must be available to meet the irrigation needs of the golf course without either causing a decrease of more than 5% of the low-flow (7 day, 10 year) of any waterway in the vicinity or substantially reducing the yield of existing wells in the area (Klein, 1994).
Many courses currently supplement water supplies for irrigation through development and enhancement of storage areas capable of capturing greater volumes of flood and storm water. A series of stormwater retention ponds can be used to store runoff and supply a constant level of available water for irrigation. This storage of runoff will also recharge groundwater supplies and will filter sediments and nutrients out of runoff before it reaches other surface water bodies (Muirhead and Rando, 1994). Many other courses, particularly those in arid regions, are being irrigated with wastewater, as was described in the design section of this chapter.

A top-of-the-line irrigation system can cost close to $1 million to install, but it uses less water (reduces demand by 15-30%), increases fuel efficiency, and wind resistance over a more modest system. It also decreases water application time, fertilizer leaching, disease susceptibility, weed and insect populations, soil compaction, and pump wear because it applies the water more efficiently and more evenly. All of these factors save money over the long run and make the initial investment worthwhile (Goldsby, 1991). A description of a high quality irrigation system design would include the ability to provide uniformity of application to minimize wet and dry areas (manipulate nozzle sizes, water pressures, and distribution patterns to develop the optimum combination for even coverage), fewer irrigation heads per zone and low volumes of water applied when appropriate, matching water application rates to soil infiltration rates, effective use of multiple water applications by pulse irrigation to allow infiltration, controller flexibility to develop the most effective irrigation program, and elimination of pipe leakage (Carrow, 1994).

Weather stations and computer software packages have been developed that make it possible to apply water only when it is necessary and at optimum levels for turfgrass needs. Moisture sensors can be incorporated in the soil to monitor water needs and control the irrigation system through the computer software. Not only does this system conserve water, it also keeps irrigation pumps running at their most efficient peaks, which saves power and reduces manpower to water the course (Hurdzan, 1996). It is best to use energy-efficient, variable-frequency pump stations driven by computer-controlled systems. The goal any of any irrigation system is a uniform application at rates which match the infiltration rates of the soil being irrigated (Fleming, 1990).
Drip irrigation can also be an effective method of water conservation for such site-specific applications as the watering of flowers, shrubs, and trees. Zone irrigation, which involves grouping plants together with similar water demands to increase watering efficiency, is also an effective method which requires little capital input (Steinegger, 1991). This is similar to the concept of Xeriscaping™ a trademark of the National Xeriscape Council developed as a response to the critical environmental issue of water conservation. It involves the use of low water demand and drought tolerant plants in addition to providing conditions that support healthy plant growth (Muirhead and Rando, 1994).

Because of the complexity of current irrigation systems, many courses have an irrigation technician who serves on the installation crew during the construction of the golf course who can then be hired for the maintenance team later as an expert on that system. This person then knows the important requirements for the system and how the different site data such as soil texture, salinity, monthly rainfall, relative humidity, grass species, and water quality will affect the functioning of the irrigation system (Hawes, 1996b).

There are several different general types of irrigation systems identified by Muirhead and Rando (1994). Single-row systems are routed down the center of the golf holes and irrigate to a width of 90 feet. They have the lowest installation cost of any of the systems, but they provide poor coverage and "scalloped" edges on the fairways. Double-row systems have a row of sprinkler heads on each side of fairway and irrigate to a width of 120 feet. They provide much more even coverage than single-row systems, but they do produce some overwatered areas. Triple-row systems irrigate to a width of 120-225 feet and are more efficient than single and double-row systems, since the flow of the outside rows can be restricted, but they are also more expensive. "Wall-to-wall" systems offer maximum coverage, but they also have the highest cost and highest water use rates of all the systems. Confinement systems utilize part-circle sprinklers on the perimeter of the irrigated areas and allow selective coverage depending upon turfgrass needs. These systems offer promise for the future in terms of less water use, although they also have a high front-end cost (Muirhead and Rando, 1994).

Olde Florida Club, Naples, Florida has an irrigation system that utilizes a Doppler radar and computer system called “Golf Link” that is able to predict weather to within fifteen minutes. This system is able to provide data for control of the irrigation system, which
applies water at less than 100% of the evapotranspiration rate. As an added measure of water quality preservation, compressed air is used to wash maintenance equipment instead of normal washing (Dodson, 1996). All of these considerations have combined to make this golf course a good example of the environmental benefits of a good irrigation system.

On golf courses, it is the responsibility of the superintendent to decide on proper irrigation amounts and irrigation intervals for turfgrasses. This is probably the most difficult task in managing water. They must consider the type of soil and the needs of the turf (including drought tolerance and evapotranspiration rate) for the best possible conservation method, and must use accurate timing methods to control the frequency and duration of water applied. With concerns related to water resource use on the rise, this will become even more crucial for future golf course management practices. Some important steps to water conservation that can be implemented by superintendents would include (Watson, 1994):

1. Highest priority to most intensively managed areas (greens first, then tees, then fairways, and least priority to rough areas);
2. Sound irrigation practices (conditions of reduced wind, lower temperatures, and higher humidity are preferred);
3. Reduce plant stress (maximize internal soil drainage, nutrient availability, and root growth through wise cultural practices such as raised mowing heights and soil tests to determine fertility); and
4. Expanded use of mulch and erection of wind barriers to slow evapotranspiration.

In addition to these practices, water should be applied at intervals that will balance the needs of the turf (water deep enough to encourage root growth and infrequent enough to increase tolerance to stress) and concerns for groundwater protection (avoid watering too deeply, where there may be concerns for leaching of chemicals and fertilizers through the soil profile). Special care should be taken for slopes, sandy soils, or compacted soils to avoid excess infiltration or runoff. Irrigation should take place in the morning or evening to minimize evapotranspiration losses (Bruneau et al., 1996b).

Superintendents can set an example for people that use the course by installing water conservation devices such as low-flow toilets and water restricter shower and sink heads in the clubhouse and maintenance facilities. It is important that superintendents keep
records for all of these efforts toward the conservation of water. One of the best ways to do this is to conduct an in-house water conservation audit in order find out how much water is being used and how much is paid for it. Once the conservation measures have been implemented, it is then possible to see how much water (and money) has been saved (Dodson, 1996). These types of numbers are beneficial for both the budget and for public acceptance of golf course water usage.

The following are turfgrass management aspects that influence water usage on golf courses, ranked by Carrow (1994) from the most important to least: selection of appropriate species/cultivars for the climate, turfgrass use and quality expectation, mowing height, nitrogen fertilization, soil cultivation, soil modification, irrigation timing, irrigation rate and frequency, alleviation of salt-affected soils, liming of acid soils (raising low pH level), mowing frequency, potassium fertilization, mowing blade sharpness, plant growth regulators, wetting agents, soil insect control, soil disease control, phosphorus nutrition, iron nutrition, antitranspirants, and use of other pesticides with plant growth regulation (PGR) activity.

There are many desirable benefits that result from efficient water usage. Maintenance budgets can be reduced by 25% through decreased watering and through less combating of weed and disease encroachment and compaction that is caused by overwatering. Annual bluegrass and weedy invaders disappear when fairways and greens are put under stress because they are less able to compete with desirable turf species under these conditions. Firmer greens are less susceptible to spike marks and heel prints from foot traffic. Best of all, golfers enjoy the game as much as ever because they continue to play on healthy turfgrass and are confronted with new shotmaking challenges (Zoller, 1995).

Rough and Natural Areas

One of the best water conservation strategies available to golf courses is the conversion of unnecessary turfgrass areas to native vegetation. When planned carefully, without greatly hindering playability, it may be possible to eliminate 20 to 30% of the irrigated turf at any particular golf course. The support areas around the green, behind greens, in the deep rough, and through the corridors from greens to the next tee are easy areas to transform into native, drought tolerant, low maintenance grounds. This
establishment of natural areas will be followed by an equal savings of 20 to 30% of the water budget, a reduction in pounds of pesticide and fertilizer to maintain these areas, and a reduction of staff and equipment time for maintenance of these areas once they have become established (Fleming, 1990).

Benefits of Prairies

Prairie communities are an important component of our nation's ecological history, and are an excellent example of native plant communities that require little or no maintenance. They provide important habitat for twenty different resident breeding and nesting birds. And, of the 102 mammalian species native to the prairie, eighteen use only grassland habitats, while the others utilize prairies in combination with other habitat types such as forests and wetlands. When prairies are located near other habitat types, an edge is created which increases the diversity of wildlife species present. Converting areas from turfgrass to prairie eliminates the need for continuous maintenance (mowing, fertilization, watering, and pesticide application) and, in the long run, reduces site management costs (Thompson, 1992).

Prairies are complex plant communities of grasses and forbs (forbs are perennial wildflowers). The percentage of plant species in a prairie is estimated to be about 60% grasses, 35% forbs, and 5% shrubs. Perennial wildflowers provide summer aesthetic value and provide an important nectar source for many butterfly and bee species. Many states in the Midwest, including Wisconsin, have placed some species of butterflies on the state threatened and endangered species lists. Iowa's native prairie flora is composed of about 400 species, although about 200 of these are much more common (Thompson, 1992). Establishment of prairies in out-of-play areas on golf courses should involve at least thirty species of grasses and forbs in order to create a dynamic system of plants that will be able to sustain itself. The greater the diversity of the plants used, the greater will be the long-term sustainability of the planting (Kurtz, 1997).

Case Studies

Eagle's Landing Golf Course in Eagle's Landing, Maryland is an excellent example of the benefits of natural areas. This course has meadows that wind through and around
tee areas, along fences, property borders, roadsides, and pond edges. They don’t require mowing, fertilization, irrigation, or chemical application, and they provide wildlife with habitat (cover and food from plants and seeds) along with safe travel routes. These areas also act as buffers and filters that prevent chemicals and silt from leaving the turfgrass areas (Ciekot, 1996). Native grasses are able to tolerate these low-maintenance conditions because they evolved to tolerate local soil conditions and temperature extremes, and they are less susceptible to damage from pests in that area (Voyt, 1996).

An example of a course that was designed and built with minimal earth moving and expansive areas of native grasses in out-of-play areas is Sand Hills Golf Club in Mullen, Nebraska, which opened in 1995. Course architects Bill Coore and Ben Crenshaw designed this links-type course to use a mixture of Chewings Fescue (*Festuca rubra commutata*) and Creeping Red Fescue (*Festuca rubra*) on the fairways, and Bentgrass on the tees and greens. The roughs contain a variety of native grasses including Gramagrasses, Switchgrass, Little Bluestem, and Sandhills Bluestem. According to head superintendent Corey Crandall, who assisted in the final stages of construction and the grow-in process, “It’s very low maintenance. Summer diseases and insect problems are nonexistent” (Hawes, 1996b).

The Village Links of Glen Ellyn, Illinois is another example of environmental stewardship in action. This course, designed by David Gill, was named the National Public Course winner of the GCSAA’s 1997 Environmental Steward Award for the third straight year. Timothy Kelly, head superintendent of the facility, has monitored a 32% reduction in water use over the 235 acre course, and fairways have been reduced from sixty-two to forty-two acres. Over forty acres of the site have been restored to native prairie, which no longer requires mowing, chemical treatment, or fertilization (Dodson, 1996). The course also includes a system of twenty-one interconnected lakes and ponds that double as water hazards and as the stormwater detention system for this heavily developed Chicago suburb. During heavy rainfall events, the course is designed to flood without covering tees and greens, and drains in a controlled manner that will not harm fairways or roughs. The lake water produces sixty percent of the irrigation water for the course (Hiscock, 1997). Eagle’s Landing is a good example of a course that provides multiple use of the land through recreation, flood control, urban open space, and wildlife habitat.
Selection of Native Vegetation

The design section of Chapter II discussed the importance of considering the impacts of the use of native vegetation upon the golfer in terms of aesthetic appeal and playability. Public reception of the use of native grasses on many courses, including those listed above, has been very positive (Ciekot, 1996; Duffy, 1981; Fream, 1978; Seaberg, 1992). In general, golfers appreciate the beauty of native areas bordering the maintained turf of the course, and also enjoy the wildlife that use these areas as habitat. Since playability becomes more difficult with more extensive use of native vegetation, care should be taken in where it is implemented. Alternative grasses such as mixtures of Fescues can be effectively used to address playability issues because they can be mowed short or allowed to grow out, thereby maintaining flexible boundaries between the primary and secondary rough areas depending upon where golfers tend to hit the ball on any particular hole (Hurdzan, 1996).

In addition to Fescues, there are a variety of plants that can be used for low-maintenance rough areas on golf courses. Selection of these plants will involve decisions on whether only native plants should be used, which plant materials can be obtained locally and at what cost, how the appearance of native plants will affect the goals of the golf course, and how the use of these areas will affect maintenance needs (Borland, 1988). If possible, it is best that plants be selected that are native to the desired site. Local County Conservation Boards can usually provide a list of distributors that supply native seed, plants, and trees. Wildflower nurseries, arboretums, and seed collectors are also becoming more common and can be excellent sources of native plants (Weston, 1990). Seeds can also be collected by hand from road ditches and railroad right-of-ways in the area.

Research has been conducted at the University of Illinois (Urbana) from 1988 to the present in order to evaluate prairie grasses under conditions where no fertilizer or pesticides are applied and only spring burns are necessary. Species that demonstrated strong ornamental appeal without becoming invasive included Big Bluestem, Sand Bluestem, Sideoats Grama, Blue Grama, Northern Sea Oats, Tufted Hairgrass, Bottlebrush Grass, Purple Lovegrass, Red Switchgrass, Little Bluestem, Indiangrass, Variegated Cordgrass, and Prairie Dropseed. Some of the grasses tested didn't survive under the testing conditions and aren't recommended for use, including Prairie Brome, Junegrass, and
Porcupine Grass. Several other species, including Cordgrass, Bluejoint, Vanillagrass, Canada Wildrye, and Switchgrass, were found to be overly invasive, and their use should be avoided in most situations (Voyt, 1996). Because of its aggressive growth habit and dense stem and root growth, Switchgrass may be beneficial for situations where erosion protection and chemical filtering of excess runoff are a concern.

Selection of forbs (broadleafed flowering plants) for use with native grasses is an important factor that is often overlooked in the establishment of low-maintenance areas. Adding prairie forbs to the seeding mix not only helps contribute species diversity for a more stable plant community, it also creates added aesthetic appeal through the beauty of the flowers. Flowering plants that perform these functions well include Black-eyed Susan (*Rudbeckia hirta*), Purple and Pale Purple Coneflowers (*Echinacea purpurea* and *pallida*), Butterfly Milkweed (*Asclepias tuberosa*), Culvers Root (*Veronicastrum virginicum*), Prairie Blazingstar (*Liatris pycnostachya*), Golden Alexander (*Zizia aurea*), Wild Indigo (*Baptisia species*), Gray-headed Coneflower (*Ratibida pinnata*), Sunflowers (*Helianthus species*), Goldenrods (*Solidago species*), Asters, and Gentians (Voyt, 1996). There are many other plants that will also perform these functions, and any plant selection will need to be based on site-specific factors such as local climate and soil types. Wildflower seeds can be continually added to the established plantings in order to add to the diversity of the site.

**Establishment and Management of Native Vegetation**

There are some basic criteria to keep in mind when considering the establishment of native vegetation. One factor is that it is important to research prairie plants and understand where they grow, how to plant them, and how to maintain them. It is also important to educate golfers on the importance of these areas through booklets and interpretive signs so that these plant communities can be appreciated and understood.

Prairies are stable communities of plants that include both grasses and forbs. These complex communities often take several years to become established, and, in the beginning stages, annual weeds will compete with the perennial plants. Management of prairie plantings takes patience by both superintendents and golfers. Prairie plantings are usually not showy during the first few years of establishment since they require longer periods of time to establish the root systems that make them tolerant of low-maintenance conditions.
(Weston, 1990). Therefore, weeds may dominate a new planting for the first couple of years, followed by a succession of more stable prairie plants that will out-compete these weeds. It is important that golfers and maintenance crew members understand this succession of plant communities and not expect too much during the first year or two after establishment. One way to mitigate this is to use annuals or two year old flowering plants to enhance aesthetic appearance during the first and second year of establishment.

Planting and maintaining native vegetation can be done in a variety of ways, but some methods have been developed that produce better results. The following steps in establishment are an adaptation of procedures developed by Carl Kurtz (1997), a respected prairie seed producer with nineteen years of experience, and by superintendents at Olympia Fields Country Club near Chicago, Illinois (Voyt, 1996):

- **Site Preparation**—Use non-selective herbicide glyphosate (Roundup) to kill existing vegetation (turfgrass or other) in the desired planting area. Allow the vegetation to die, then burn it or mow it short. Leaving the dead roots in place will help hold the soil during the establishment of new plantings. Light raking can help loosen the soil and aid establishment.

- **Seed Selection**—As discussed above, use plants native to the site, include a wide variety of grasses and forbs common to that area (at least thirty species), obtain seed from respected distributors to ensure quality.

- **Seeding**—Mix seeds for grasses and forbs and sow in a drop spreader (for seed with higher levels of harvested plant material) or drill the seed into the soil (for pure live seed applications). Seeding rates will vary from ten to twenty pounds per acre depending upon percentage of pure live seed. Annuallys can be added at low seeding rates during the first year planting to add color while perennials are being established (79). Hand rake to sow the seed into the soil, roll it lightly to create a firm seedbed and contact between the seeds and the soil, and irrigate to ensure establishment. Cover with a straw mulch to prevent wind and water effects.

In their first attempt at establishment, Olympia Fields tilled the soil after the herbicide application. However, after running into problems with soil erosion and weed infestation, they later found that it would be better to drill the seed into the seedbed instead of tilling the soil. Drills insert the seed into the soil and roll it with packing wheels. Because most prairie
seeds are light and fluffy, they tend to not distribute well in traditional broadcast seeding equipment. However, seeding by hand or with a dropspreader can also be effective.

Late-May to late-June is usually the best time to plant prairie vegetation. This avoids heavy early spring rains and allows the seeds to become established before summer drought sets in. However, due the variability of moisture levels and climatic conditions, seeding in the fall is also a viable option. This is particularly true for seeds that have been harvested by hand in that they are able to overwinter in the soil, germinate in the spring, and don't require special cold treatments to achieve good germination. Some forbs respond very well to fall planting (Kurtz, 1997).

Once the area has been seeded, management of native vegetation involves only a few simple steps. Mowing is usually required only during the first and second year of establishment. During the first year, the established beds should be mowed at a two to four inch height during the first half of the growing season, and this height can gradually be increased to eight inches toward the end of the year. This will reduce competition from weeds and give new seedlings a chance to become established. It should be noted that some prairie plants don’t emerge until the second or third year of establishment. The areas should be mowed again two to three times during the second year to a height of eight to ten inches. Beginning in the third year, mowing will not be required.

A healthy and diverse prairie planting will eventually out-compete weeds under low-maintenance conditions, so chemical applications are usually not necessary. Problem weeds can be spot-treated with herbicides or pulled by hand if necessary, but special care should be taken to avoid harm to native plants. An important step in the management of these natural areas is the education of maintenance staff in the identification of desirable and undesirable plant species. Prevention of thatch buildup and additional weed control is best accomplished through burning, if it is permitted on the golf course. Burning should take place in March or early April and should be done under the supervision of an experienced ecologist, forester, or resource manager. Burning is an essential part of prairie ecosystem management; many prairie plants require burning to complete their lifecycle. Where fire control is of particular concern, the area can be mowed to a height of four inches prior to burning, which will decrease the risk of rapid movement. Approximately one-third of
the prairie area should be burned on a rotational basis every year, thereby maintaining opportunities for wildlife habitat in adjacent areas (Kurtz, 1997).

Conclusions

The benefits of the use of native vegetation include lower cost of establishment per acre (versus turf), reduced maintenance costs (equipment and labor), fewer (if any) chemicals applied, and elimination of irrigation (Weston, 1990). Reduced water use through conversion of turfgrasses to native vegetation also decreases costs by requiring less water and enabling the use of smaller pumps and irrigation lines. Maintenance costs can be reduced up to 35% and water use by 30-50% (Borland, 1988). As discussed previously, these areas also provide tremendous opportunities for the creation of a more sustainable community of plants which support a greater diversity of plant and animal life. Further discussion of the economic benefits of turfgrass conversion to native vegetation is included in Chapter III.

Maintenance Facilities

Rising concerns related to the safety of chemical and fuel handling and storage on golf courses has produced improved technologies in these areas. Many golf courses have replaced older maintenance facilities with buildings that are designed to virtually eliminate the danger of chemical spills or fire. Fuel storage, pesticide storage, and rinsing areas for maintenance vehicles are three of the main concerns related to safety and protection of the environment.

Fuel Storage

Design concepts for the construction of fuel storage tanks are mainly concerned with fire safety and the potential for soil or groundwater contamination from leaking fuel. Underground storage tanks, which require professional design and construction in order to meet governmental regulations, are one option available to golf courses. These structures prevent leakage, simplify monitoring and leak cleanup, and have less visual impact than above-ground structures. They also are more expensive; the cost for two 500 gallon tanks
(gas and diesel), pumps, and necessary equipment is approximately $15,000 (Moore, 1996).

Above-ground containment structures are another option available for golf course use. These structures can be designed in-house, since they simply involve a concrete floor and walls, a roof, two 500 gallon tanks, and equipment. Though they have more visual impact than underground storage structures, they are easier to access for monitoring and cleanup and cost only about $5500, a great benefit for most maintenance budgets (Moore, 1996).

**Pesticide Storage**

Soil and water contamination are also concerns for pesticide and fungicide storage areas. In addition to leakage prevention, protection from potential theft, vandalism, and possible injury to employees are also important characteristics of their design. Pre-fabricated storage structures are available which are fire rated, secure, ventilated, lighted, and are very effective in containing leaks. Top-quality structures with all the necessary equipment cost between $9000 and $12,000. By comparison, an in-house construction of a similar storage unit costs approximately $4000, not including labor (Moore, 1996).

**Equipment Washing Area**

Equipment washing areas are often built in conjunction with the fuel and pesticide storage areas. They are designed to contain turfgrass clippings with nutrients and pesticide residues and rinsate from pesticide and fertilizer application equipment. Rinsate recycling equipment tends to be much more expensive because of the pumps and filters involved in screening the water. A pre-fabricated facility with all of the necessary equipment costs approximately $40,000 (Moore, 1996).

There are some other practices that are beneficial for equipment maintenance and environmental protection. Quick coupler valves installed throughout the course can be used as “pre-wash” sites for chemical application equipment and mowers before they reach the maintenance facility. Steam cleaners or air blowers are two additional options that can be used for washing equipment without the use of water. Application equipment should be carefully calibrated to minimize leftover fertilizer and pesticide levels after treatment. That
way, equipment can be repeatedly rinsed and the rinsate can be applied to the course rather than washed down a drain.

Conclusions

Proper construction of maintenance facilities is an important step towards decreasing the likelihood of soil and water contamination from fuel and chemical spills or rinsate. Spill kits should be available for any leaks of fuel or chemicals that may occur. Environmental consultants can be hired to perform a review of maintenance facilities for approximately $1500 in order to assess the needs or concerns that may exist there. Designs for these facilities, particularly those produced “in-house”, should be checked by licensed professionals before they are built to ensure quality construction and safety for maintenance workers and for the environment.

Audubon Cooperative Sanctuary Program

Sponsored by the USGA, this program is administered by the Audubon Society of New York State. The goals of the program are to protect and enhance wildlife habitat on existing and planned golf courses, educate the public about golf courses and their benefits as open space and environmental areas, and encourage golfers to learn about the environment and how to practice conservation (Muirhead and Rando, 1994).

In order to obtain full certification in the program, a course must demonstrate improvement of environmental quality in the following areas, each of which have been discussed in detail throughout this chapter (“Golf and wildlife,” 1996):

1. **Environmental Planning**—the course is designed and managed to maintain or improve the environmental integrity and wildlife value of the site;

2. **Public/Member Involvement**—the course actively involves both golfers and the community in its environmental activities through educational programs (discussed in the next section);

3. **Wildlife and Habitat Management**—the course conserves existing wildlife food sources wherever possible and supplements them where appropriate (includes planting trees, shrubs, native grasses, and wetland vegetation);
4. Integrated Pest Management--the course uses turfgrass management strategies that are timed to maximize pest damage and to have the least possible effect on people, property, and the environment;

5. Water Quality Management--the course utilizes management practices which maintain or enhance water quality in the area; and

6. Water Conservation--the course conserves water and reduces irrigation levels and other water uses whenever possible.

More than 1600 courses are currently enrolled in this program ("Golf and wildlife," 1996). There are two levels of certification in this program, Cooperative Sanctuaries and Signature Sanctuaries. In order to obtain Cooperative Sanctuary status, golf course owners must develop an environmental plan of action and appoint a committee to oversee implementation of the plan (Muirhead and Rando, 1994). The designation of courses as Signature Sanctuaries means that, from the inception of the planning through the construction of the course, the principles outlined above have been followed and evaluated by Audubon Society supervisors. Only seven courses have earned this designation, the first of which was Collier's Reserve in Naples, Florida. This course is described in more detail in Chapter III. The Village Links of Glen Ellyn, discussed above, was the first and only public course to date designated as a Signature Sanctuary (Hiscock, 1997).

Although golf course superintendents have been following these principles for many years, enrollment of golf courses in the Audubon Cooperative Sanctuary Program has had many benefits. It has created a set of published guidelines for practices in managing golf courses that can be followed by superintendents, increasing the dissemination of information related to environmental issues and golf courses. It also creates a system of checks so that golf courses are held accountable for design, construction, and management practices that are followed. Not only has it created a forum for the exchange of ideas, it has also produced opportunities for golf courses to be recognized by communities for the positive efforts they are making in protecting and enhancing the environment. These educational opportunities can have far-reaching effects in providing the community with living workshops for the study of the environment.
Education and Public Awareness

Golf courses can provide the surrounding community with excellent opportunities for education about the environment. By utilizing native vegetation and providing wildlife habitat on the site, they are able to function as living laboratories for the study of many different species of plants and animals. They can also function as demonstration projects for environmental experiments such as native vegetation restoration and management, water quality monitoring, habitat restoration, leaching and runoff studies, and wildlife studies.

The Village Links of Glen Ellyn has implemented a very successful environmental education program called the Glen Ellyn Backyard Wildlife Program for Schools, which has enabled local elementary schools to visit the course and learn principles for the use of native vegetation. They have also reached hundreds of area residents through the Backyard Program newsletter Backyard Briefings which discusses what is being done on the course and how backyards can be used for wildlife habitat through the use of native plantings. Their involvement in the community has been reported in local newspaper articles and television programs, and the publicity generated by these environmental programs has been good for the community as well as for the course itself (Hiscock, 1997).

Some courses have had nest box programs in conjunction with local farm and garden clubs, Boy and Girl Scout troops, or schools to encourage the nesting habitat for Wood Ducks, Bluebirds, and other beneficial wildlife. Workshops can be conducted for children and adults on the construction of bird boxes, wildlife observation, or the planting trees and other native vegetation (Edmondson, 1987). Educational information displays can be placed throughout the course so that golfers can learn about the various habitat types and animals that use them as they play their round of golf. Each hole can be given a name and have a sign and description for a native plant that is featured there (Weston, 1990). Educational displays inside the clubhouse can also provide useful information to visitors, and can include brochures about the management program at the course. Nature tours can be made available to golfers and non-golfers alike, depending upon the amount of area that is available for additional trails through native areas.

The Greenlinks Education Program is a concept developed by Harker et al. (1993) as a comprehensive program for naturalizing the landscape. It is divided into three basic
parts: a strong environmental education program, working with area landowners to link
greenspaces and natural areas together in a regional context, and developing a detailed
naturalization plan for the managed site. Any naturalization or ecological restoration project
benefits from a strong educational program. These projects, when implemented on a golf
course, can provide opportunities for education about a region's natural heritage, the value
of natural landscaping, and restoring natural communities (Harker et al., 1993).
CHAPTER III: ECONOMIC CONSIDERATIONS

Introduction

During the literature review process and creation of the principles for design, construction, and management outlined in Chapter II, it became evident that substantial opportunities exist for the use of native vegetation on golf courses. Much of the literature addressed the direct environmental benefits of their use, including creation of wildlife habitat and travel corridors, filtering of chemicals and sediment in stormwater runoff, and the aesthetic beauty of these areas that are appreciated by most golfers. There are also indirect environmental and resultant economic benefits created by the elimination of water, chemical, and fertilizer applications as well as the elimination of the need for cultural practices such as mowing, aerification, and seeding. This chapter will discuss these economic benefits in more detail as they relate to the environmental impacts addressed in Chapter II.

Water and Chemical Usage on Golf Courses

Only two gallons of fresh water are required to quench our thirst and cook the food we eat each day. However, per capita consumption of water in the U.S. exceeds one thousand gallons of water per day to grow the food, to keep us clean, to operate our home appliances, to flush away our waste, and to water our lawns (“Irrigation,” 1997). We are fortunate to live in a country that is water-rich. There seems to be adequate water available to meet our society’s needs, but there are few incentives for wise and conservative use of this resource or for effecting an efficient method of allocation among competing demands. Due to ever-increasing population, pollution, and a disregard for efficient water use, we are quickly running out of this precious commodity.

More than one half of the U.S. population relies on groundwater for all or part of its potable water. However, only 18% of the water taken from groundwater aquifers is for domestic use, while 66% is used for irrigation (Yates, 1995). The remaining 16% is used for industrial production and other purposes. These percentages indicate a heavy reliance upon irrigation water for food production, turfgrass maintenance, and other uses. Although
the primary use of irrigation water is for agricultural production, golf courses have also become large users of water resources over the past fifty years.

Golf courses use a tremendous amount of irrigation water for turfgrass maintenance. Michael Hurdzan (1996) states that fairways in the Midwest require about one inch of water per week, while tees and greens need about one and one half inches per week. These numbers seem harmless enough, but when the total amounts of irrigation water for an eighteen hole golf course are calculated (assuming thirty acres of fairways and five acres of greens and tees), it becomes apparent that the course would require 810,000 gallons of water per week for the fairways and 202,500 gallons per week for the greens and tees. Courses in arid regions may need up to three times this amount of irrigation.

The discussion on agricultural water usage in *The Economic Value of Water* (Gibbons, 1986) can be adapted to golf courses in order to illustrate the effects of irrigation water demand. Consider a golf course with a fixed acreage of turfgrass. The profit-maximizing superintendent tends to employ more of an input as long as its marginal value is greater than its cost. Because of the diminishing marginal productivity of most inputs (such as fertilizer or labor), the profit-maximizing level of input use will be less than the yield-maximizing level, unless the input is free. In the case of a golf course, "yield" is determined by the level of turfgrass health that can maintain traffic and resist disease and drought. The course's demand for irrigation water is thus derived from the value of its use in maintaining the health of the turfgrass.

With all other inputs held at constant levels, a course faced with water cost increases could only adapt by using less water. This can be accomplished on most golf courses by irrigating less, which results in a loss of appearance due to turfgrass plants entering periods of dormancy. Although it is important to consider plant stressing as an option, this strategy alone is ill-suited for long-term or continual adjustment to rising water costs. If non-water inputs are not held constant, however, the golf course can adapt to water cost increases by substituting improved capital or management practices. Some of these practices might include more efficient irrigation, use of recycled or effluent water, raised mowing heights (decreasing stress on plants), use of more drought resistant turfgrass species, and conversion of out-of-play turfgrass areas to native vegetation. Each of these management practices was discussed in Chapter II.
Golf course superintendents often use more water in turfgrass maintenance than may be necessary for healthy growth, and only reluctantly reduce irrigation amounts in the face of water cost increases. In order to avoid the risk of harming the turf and bearing the criticism from golfers expecting completely green turf areas, they also tend to be reluctant to use new technologies that are subject to uncertainty and that would cost them more money in the short run. At present, the demand for irrigation water appears to be price-inelastic in many areas, and it will remain so until water costs increase. Where water costs have been held artificially low, either through direct subsidization or with the aid of cheap energy, water usage rates have been high. As water costs rise, these usage rates are reduced, and golf courses have a greater incentive to conserve water or to consider alternative management practices (Gibbons, 1986).

This discussion on water usage can also be extended to fertilizer and pesticide usage on golf courses. Continually higher standards set for golf course maintenance conditions have caused many superintendents to use more chemicals in managing turfgrasses than may be necessary. Blanket treatments are used on many courses as a preventative measure against disease and pest damage rather than the use of IPM principles such as accurate application timing and observation of threshold limits. Industry trends, however, are towards more judicial use of chemicals out of concern for the environment and continued research into the needs of turfgrasses. Because of the high expense of chemical applications, there is also a significant economic incentive for wise chemical usage.

In addition to the economic issues discussed above, water and chemical usage on golf courses is heavily dependent on the type of design and management practices implemented on each course. The amounts used and the price of maintenance (and subsequently the price to play golf) is directly related to many individual site factors such as climate (precipitation, evapotranspiration rate, and length of season), soils, turfgrass species selection, amount of turfgrass versus native vegetation, irrigation practices, and golfer expectations. All of these factors must be taken into account in analyzing methods for decreasing water and chemical usage on golf courses and making the game more affordable for golfers.
Economic Analysis of the Use of Turfgrass Versus Native Vegetation

Prices for Golf and Maintenance

According to Ronald Fream (1982), “The ever-increasing energy costs, escalating land prices, looming water shortages, and inflationary clamorings for employee raises are all interconnected and interdependent pressures which combine to raise the cost of golf course construction and turfgrass maintenance, creating pressures which are demanding and dictating that something be done to moderate the cost of providing and playing golf.”

Letcher et al. (1996) found that the jump in green fees in Wisconsin over the past few years has been at double the rate of inflation. The jump is likely attributable to three factors:

1. *Increased Demand for Golf*—there has been a 3.2% increase in the number of golfers versus only a 1.9% increase in courses according to the National Golf Foundation;
2. *Course Maintenance*—the average cost of maintenance doubled from 1980 to 1990 due in part the demand for better conditions by golfers and the rising costs of water and chemicals; and
3. *Governmental Regulation*—environmental restrictions and permitting concerns have made the construction process more lengthy and expensive.

One of the primary ways that golf courses can reduce the prices for maintenance and the play of the game is through the conversion of non-essential turfgrass areas to native vegetation. David Seaberg (1992) developed the idea of Regenerative Golf Course Design as a proposal to, “...reduce manageable turf through natively acclimated vegetation.”

In assessing the maintenance savings through the conversion of turfgrass to native vegetation, he estimated that 18,000 square feet of turfgrass converted to native grasses produces an average savings of $180 per year (900 pounds) for fertilizer and $45 per year for chemicals. This would equal a total fertilizer and chemical savings of $544.50 per acre of turf converted for every year of operation, which does not include the cost of application.

Duffy (1981) found that up to 35% of a typical course maintenance budget can be saved annually by reducing the amount of turf considered as fairway, or about $500 per acre of fairway converted.

Paul Voykin (1981) calculated that most courses could reduce maintenance of rough areas, greens, tees by 50% and still have a presentable, slightly more difficult, and more
interesting course. Additional savings could also be realized through decreased machinery
operation, mechanical upkeep and gasoline savings, less fertilizer, less water, less
pesticides, less traffic damage, and more drought tolerance. The amount of savings
produced will depend upon the willingness of golfers to play under conditions of reduced
maintenance.

Chemical and water usage are of particular interest from an environmental
standpoint. As described in the management section of Chapter II, Integrated Pest
Management (IPM) plays an important role in decreasing chemical usage on the golf
course. Many courses have also discovered that management with respect for the
environment usually ends up reducing the maintenance budget as well. For example, the
Country Club of Oregon, located in Portland, saved $36,000 of the 1995 maintenance
budget by using chemicals only when necessary and avoiding blanket applications
(Thompson, 1996). Stratton Golf Club (Vermont) has also implemented a “spoon-feeding"
fertilizer program and a pesticide program that treats problem areas in the turf at proper
times to avoid over-application. Over a span of six years, the course’s fertilizer bill dropped
from $20,000 to $6,000 per year, and the pesticide bill dropped from $12,000 to $3,500 per
year (Parascenzo, 1991).

Another good example of IPM at work is Pine Ridge Golf Course in Towson,
Maryland, which has found excellent cost savings through reducing chemical application
using IPM and lower damage thresholds ($7,000 or one-third of the normal cost), use of
bleach instead of other chemicals to control black algae (saves $500 per spray), and fewer
applications means that maintenance personnel have more time to devote to other tasks,
which is also more cost-effective (Greenspan, 1991).

These case studies demonstrate that, in addition to the economic benefits of
reducing maintenance budgets on golf courses and making playing the game more
affordable, proper design and management practices have tremendous benefits for the
environment. Decreased chemical, fertilizer, and water usage and expanded areas of
native vegetation for wildlife habitat will be important characteristics of future golf courses as
maintenance costs and political pressures to be more environmentally responsible continue
to rise.
Current Costs of Turfgrass Management

This section compares the cost of long-term turfgrass maintenance with the cost of establishing and maintaining the same area with native vegetation. It will be assumed, for the purposes of this study, that conversion of turfgrass on golf courses to native vegetation will be most readily accepted in the rough areas. Rough can be defined as those areas on the course directly adjacent to the fairway which are usually mowed to heights of greater than one inch, compared to fairway (the preferred route to the hole from the tee) mowing heights of less than one inch. These areas are generally out-of-play and, though they receive the least amount of attention on the course in terms of maintenance, are still a source of ongoing expense.

This study involves three different golf courses. The first example is Veenker Memorial Golf Course in Ames, Iowa, a course that currently has large areas of maintained turfgrass. There are many opportunities for the conversion of turfgrass to native vegetation on this course because many of the acres currently maintained as rough are actually out-of-play, and therefore the use of native vegetation would do very little to disrupt the playability of the course. The second and third courses selected represent climates different from that of the Midwest. Collier’s Reserve in Naples, Florida and Devil’s Paintbrush in Caledon, Ontario, Canada have been selected as representatives of northern and southern climates and as good examples of courses built with areas of low-maintenance or native vegetation already in place.

Costs for management of turfgrass on each of these courses will be calculated based on data obtained from superintendents at each of the courses. These results will include costs for irrigation, chemical usage, mowing, aerification, and seeding of turfgrass, along with estimates of labor and machine usage expenditures. The final cost for the maintenance of the turfgrass will be calculated on a per acre, per year basis and will then be compared to the cost of establishment and management of prairie vegetation in the following section.

Veenker Memorial Golf Course: Ames, Iowa

Veenker Memorial is a public eighteen hole golf course operated in conjunction with Iowa State University. It was designed in 1934 by Perry Maxwell, a noted architect who is
also responsible for the design of Prairie Dunes in Hutchenson, Kansas and who did extensive remodeling to Augusta National in Augusta, Georgia as well (Cornish and Whitten, 1993). His original design of Veenker has been modified several times over the past fifty years, most notably some hole renumbering and a major renovation of the front nine of the course to address safety concerns for a highway that was built near the course.

The estimates generated in Table 3.1 are based on information obtained in a personal interview with John Newton, Head Superintendent of Veenker Memorial. This course has approximately 137 acres of roughs that are planted in Kentucky Bluegrass and Perennial Ryegrass. The grass in the roughs are maintained at approximately a two to three inch mowing height and are mowed one to two times per week. The table includes information on irrigation, chemical usage, mowing, aerification, and seeding of turfgrass, along with estimates of labor and machine usage expenditures. Machine usage figures include the cost of maintenance, fuel, and rental of the equipment. Note that labor includes different rates of payment depending upon the amount of expertise required for the maintenance practice.

**Table 3.1:** Estimated per-acre, per-year cost of maintaining golf course rough at Veenker Memorial Golf Course

<table>
<thead>
<tr>
<th>Maintenance Item</th>
<th>Description</th>
<th>Cost (per acre per year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irrigation</td>
<td>Not applied to rough areas</td>
<td>$ 0.00</td>
</tr>
<tr>
<td>Chemical and Fertilizer Use</td>
<td>Two applications of fertilizer and pre-emergent @ $56/acre</td>
<td>$112.00</td>
</tr>
<tr>
<td></td>
<td>Two applications of broadleaf weed control @ $48.10/acre</td>
<td>$96.20</td>
</tr>
<tr>
<td></td>
<td>Fall Fertilizer Application @ $37/acre</td>
<td>$37.00</td>
</tr>
<tr>
<td></td>
<td>Machine Usage: 1 hr/ac@ $8/hr (x5)</td>
<td>$40.00</td>
</tr>
<tr>
<td></td>
<td>Labor: 1 hr/ac @ $22/hr (x5)</td>
<td>$110.00</td>
</tr>
<tr>
<td>Mowing</td>
<td>Machine: ($7/ac)(1.5x/wk)(30 wk/yr)</td>
<td>$315.00</td>
</tr>
<tr>
<td></td>
<td>Labor: ($7/ac)(1.5x/wk)(30 wk/yr)</td>
<td>$315.00</td>
</tr>
<tr>
<td>Aerification (once per year)</td>
<td>Machine Usage: 1 hr/ac @ $5/hr</td>
<td>$5.00</td>
</tr>
<tr>
<td></td>
<td>Labor: 1 hr/ac @ $22/hr</td>
<td>$22.00</td>
</tr>
<tr>
<td>Seeding (once per year)</td>
<td>Seed: (1.5lb/1000ft2)($2.50/lb)(43560)</td>
<td>$163.35</td>
</tr>
<tr>
<td></td>
<td>Machine: 1 hr/ac@ $8/hr</td>
<td>$8.00</td>
</tr>
<tr>
<td></td>
<td>Labor: 1 hr/ac@ $22</td>
<td>$22.00</td>
</tr>
</tbody>
</table>

TOTAL COST = $1245.55/ac/yr
Collier's Reserve Country Club: Naples, Florida

This course is a private eighteen hole golf course operated in conjunction with a gated residential community. It was designed in 1993 by Arthur Hills and Associates, a firm also responsible for Ironhorse Country Club in Florida, another Audubon Cooperative Sanctuary course which was the subject of John Strawn's book Driving the Green (1991). Collier’s Reserve was the first course to be certified by the Audubon Society of New York as an Audubon Signature Sanctuary, and is one of only seven courses in the country to earn that designation. The course includes extensive areas of wetlands, forests, and native grasses in out-of-play areas, most of which were left undisturbed during construction. Collier's Reserve utilizes effluent water for irrigation of thirteen of its holes and pond water for the other six, and therefore has little or no cost associated with irrigation water usage. Water, pesticides, and fertilizers are applied in all areas on an “as needed” basis as suggested by the Audubon Cooperative Sanctuary Program.

Table 3.2: Estimated per-acre, per-year cost of maintaining golf course rough at Collier’s Reserve Country Club

<table>
<thead>
<tr>
<th>Maintenance Item</th>
<th>Description</th>
<th>Cost (per acre per year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irrigation</td>
<td>Wastewater and pond sources (minimal)</td>
<td>$ 0.00</td>
</tr>
<tr>
<td>Chemical and Fertilizer Use</td>
<td>One application of fertilizer $36.93/acre</td>
<td>$36.93</td>
</tr>
<tr>
<td></td>
<td>Pesticide Usage (minimal in rough areas)</td>
<td>$0.00</td>
</tr>
<tr>
<td></td>
<td>Machine Usage: 1 hr/ac @ $9/hr</td>
<td>$9.00</td>
</tr>
<tr>
<td></td>
<td>Labor: 1 hr/ac @ $14.50/hr</td>
<td>$14.50</td>
</tr>
<tr>
<td>Mowing</td>
<td>Machine: ($7/ac)(1.0x/wk)(16 wk/yr)</td>
<td>$616.00</td>
</tr>
<tr>
<td></td>
<td>($7/ac)(2x/wk)(36wk/yr)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Labor: ($8.50/ac)(1.0x/wk)(16 wk/yr)</td>
<td>$748.00</td>
</tr>
<tr>
<td></td>
<td>($8.50/ac)(2x/wk)(36wk/yr)</td>
<td></td>
</tr>
<tr>
<td>Aerification</td>
<td>Machine Usage: ($5/hr)(2 hr/ac)(3x/yr)</td>
<td>$30.00</td>
</tr>
<tr>
<td></td>
<td>Labor: ($9.50/hr)(2 hr/ac)(3x/yr)(2 people)</td>
<td>$114.00</td>
</tr>
<tr>
<td>Seeding</td>
<td>Not done (Bermuda grass)</td>
<td>$0.00</td>
</tr>
</tbody>
</table>

TOTAL COST = $1568.43/ac/yr

The estimates generated in Table 3.2 are based on information obtained from Tim Hiers, Head Superintendent of the course. This course has approximately twenty acres of rough planted with Bermudagrass. The grass in the roughs are maintained at approximately a 1-1.5 inch mowing height and are mowed two times per week from March
to October and once per week from November to February. Pesticides are only applied to the rough in spot treatments. The total annual pesticide budget for Collier's Reserve is less than $20,000, most of which is applied to the fairways, tees, and greens. This value is considered quite small for a Florida course which is open throughout the year.

**Devil's Paintbrush Golf Course: Caledon, Ontario, Canada**

This is a private eighteen hole golf course near Toronto operated in conjunction with an adjacent private course named Devil's Pulpit. Both courses were designed by Michael Hurdzan, noted architect and author of *Golf Course Architecture: Design, Construction, and Restoration* (1996). Devil's Pulpit is a high-maintenance complex that was completed in 1990. The Paintbrush course was completed in 1993 and was designed as a low-maintenance course, primarily through its extensive use of Fescue grasses on the fairways, roughs, and out-of-play areas.

The estimates generated in Table 3.3 are based on information obtained from Ken Wright, Head Superintendent of both Devil's Paintbrush and Devil's Pulpit. Devil's Paintbrush has approximately 75 acres of fairways and roughs that are planted in Creeping Red Fescue. The secondary rough is a mixture of 50% Creeping Red Fescue, 40% Tall Fescue, and 10% Kentucky Bluegrass. The grass in the fairways and roughs are maintained at the same 0.75-1.0 inch mowing height and are mowed two times per week. The source of irrigation for the course is well water, and the total cost of irrigation for the fairway and rough areas is approximately $2169 each year.

**Table 3.3:** Estimated per-acre, per-year cost of maintaining golf course rough at Devil's Paintbrush Golf Course

<table>
<thead>
<tr>
<th>Maintenance Item</th>
<th>Description</th>
<th>Cost (per acre per year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irrigation</td>
<td>Well water: 75 acres @ $2169 per year</td>
<td>$28.92</td>
</tr>
<tr>
<td>Chemical and Fertilizer Use</td>
<td>One application of fertilizer @ $69.40/ac</td>
<td>$69.40</td>
</tr>
<tr>
<td></td>
<td>One application of pesticide @ $10.84/ac</td>
<td>$10.84</td>
</tr>
<tr>
<td></td>
<td>Machine Usage: 1 hr/ac @ $7/hr (2 applic.)</td>
<td>$14.00</td>
</tr>
<tr>
<td></td>
<td>Labor: 1 hr/ac @ $7.25/hr (2 applications)</td>
<td>$14.50</td>
</tr>
<tr>
<td>Mowing</td>
<td>Machine: ($5/hr)(2hr/ac)(2xwk)(24wk/yr)</td>
<td>$480.00</td>
</tr>
<tr>
<td></td>
<td>Labor: ($7.25/hr)(2hr/ac)(2xwk)(24wk/yr)</td>
<td>$696.00</td>
</tr>
<tr>
<td>Aerification/Seeding</td>
<td>Not done</td>
<td>$0.00</td>
</tr>
</tbody>
</table>

**TOTAL COST = $1313.66/ac/yr**
Summary

Since the courses selected for this study represent different climates and are open for different lengths of time each year, their maintenance costs can be more effectively compared by dividing the costs obtained on a per acre per year basis by the number of weeks they are open for play. Table 3.4 shows that Collier’s Reserve operates with the lowest maintenance costs for the maintained rough areas, followed by Devil’s Paintbrush and Veenker Memorial, respectively.

Table 3.4: Weekly per-acre costs of maintaining rough at three golf courses

<table>
<thead>
<tr>
<th>Course Name</th>
<th>Maintenance Cost Per Year</th>
<th>Length of Season</th>
<th>Maintenance Cost Per Week</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Veenker Memorial</strong></td>
<td>$1245.55/ac/yr</td>
<td>30 weeks per year</td>
<td>$41.52/ac/week</td>
</tr>
<tr>
<td><strong>Colliers Reserve</strong></td>
<td>$1568.43/ac/yr</td>
<td>52 weeks per year</td>
<td>$30.16/ac/week</td>
</tr>
<tr>
<td><strong>Devil’s Paintbrush</strong></td>
<td>$1313.66/ac/yr</td>
<td>24 weeks per year</td>
<td>$54.73/ac/week</td>
</tr>
</tbody>
</table>

All of these courses use different types of turfgrass management strategies and have differing labor costs which then affect their total maintenance costs. Table 3.5 shows a comparison between the costs of irrigation, chemical and fertilizer usage, mowing, aerification, and seeding for the three courses. Veenker Memorial maintains extensive areas of cool-season Kentucky Bluegrass rough with no supplemental irrigation and a fairly heavy pesticide and fertilizer program. The main costs involved in management of rough at Veenker were mowing and chemical/fertilizer usage, which accounted for 50.6% and 31.7% of the total cost per acre per year, respectively.

Devil’s Paintbrush’s use of Creeping Red Fescue allows it to avoid seeding and aerification costs and requires little chemical and fertilizer usage. The main expenditure on this course is mowing, which accounts for 89.5% of the total maintenance cost for the rough areas. The values calculated for mowing and irrigation are a bit deceiving in that the course doesn’t differentiate between rough and fairway, so the calculations performed are actually for fairway conditions rather than primary rough as for the other courses. Maintaining slightly wider areas of fairway/rough allows more room for errant shots before encountering the longer, unmaintained secondary rough.
Table 3.5: Annual per-acre costs of specific maintenance practices employed on the rough at three golf courses

<table>
<thead>
<tr>
<th></th>
<th>Veenker Memorial</th>
<th>Collier’s Reserve</th>
<th>Devil’s Paintbrush</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TOTAL COST</strong></td>
<td>$1245.55/ac/yr</td>
<td>$1568.43/ac/yr</td>
<td>$1313.66/ac/yr</td>
</tr>
<tr>
<td><strong>Irrigation Cost</strong></td>
<td>$0.00</td>
<td>$0.00</td>
<td>$28.92</td>
</tr>
<tr>
<td>% of total cost</td>
<td>0.0%</td>
<td>0.0%</td>
<td>2.2%</td>
</tr>
<tr>
<td><strong>Chemicals/Fertilizer</strong></td>
<td>$395.20</td>
<td>$60.43</td>
<td>$108.74</td>
</tr>
<tr>
<td>% of total cost</td>
<td>31.7%</td>
<td>3.9%</td>
<td>8.3%</td>
</tr>
<tr>
<td><strong>Mowing</strong></td>
<td>$630.00</td>
<td>$1364.00</td>
<td>$1176.00</td>
</tr>
<tr>
<td>% of total cost</td>
<td>50.6%</td>
<td>87.0%</td>
<td>89.5%</td>
</tr>
<tr>
<td><strong>Aerification</strong></td>
<td>$27.00</td>
<td>$144.00</td>
<td>$0.00</td>
</tr>
<tr>
<td>% of total cost</td>
<td>2.2%</td>
<td>9.2%</td>
<td>0.0%</td>
</tr>
<tr>
<td><strong>Seeding</strong></td>
<td>$193.35</td>
<td>$0.00</td>
<td>$0.00</td>
</tr>
<tr>
<td>% of total cost</td>
<td>15.5%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
</tbody>
</table>

Collier’s Reserve also spends more of the total cost of maintenance on mowing (87%) than on any other item. In general, Collier’s Reserve and Devil’s Paintbrush use much less water, fertilizer, and pesticides and require less maintenance than many other courses in the U.S. (including Veenker Memorial) because they utilize extensive areas of native vegetation. Both courses maintain approximately 70 acres of combined fairway and rough area compared to the national average (based on a survey of 1024 courses) of 130 acres ("Maintenance Budgets," 1994). Veenker exceeds this average with its 137 acres of rough alone, which demonstrates the opportunities available at this course for the use of native vegetation to decrease maintenance costs. Collier’s Reserve has only 20 acres of rough, and its use of strong IPM practices and effluent water further decrease its impact upon the environment.

**Economic Impacts of Irrigation Costs**

Table 3.5 lists the cost of irrigation for rough areas at each of the three golf courses. Since Veenker Memorial pays a flat rate of $25 every ten years for their use of well water, the amount of cost from this payment on a per acre, per year basis is insignificant. Therefore, the only cost associated with water usage for irrigation on this course is for the energy needed to pump the water from the well and maintain irrigation equipment. Since the rough areas are not irrigated at Veenker, this value remains zero. The Devil’s
Paintbrush course also uses well water for irrigation, at a cost of approximately $29 per acre per year.

Many other courses in the U.S., however, rely upon municipal sources of water for irrigation, which is much more expensive than using well water. For many years, inexpensive sources of water have been taken for granted in this country. The growing water shortage and high cost of producing and delivering water has increased the cost of municipal water in many areas to over $350 per acre foot ("Irrigation," 1997). Los Verdes Golf Course in Los Angeles pays $710 per acre foot for irrigation water ("Finding effective ways," 1990).

In order to understand the impact these charges for water use would have upon the maintenance budget at Veenker, it is necessary to make a few assumptions. First, it will be assumed that Veenker needs to irrigate their rough areas with an average of one inch of water per week. This would mean that, for the thirty week growing season at Veenker, thirty inches of irrigation are applied. Veenker has approximately 137 acres of rough, so these areas would require 11.42 acre feet of water per week or 342.5 acre feet of water per year.

If it is further assumed that Veenker is required to pay $350 per acre foot of water, this translates into a total yearly expenditure of $119,875 for irrigation water, or about $875 per acre of rough per year. For comparison, the $710 rate charged to the Los Verdes Golf Course would cost Veenker $243,175 total or $1,775 per acre per year. These two charges for water would push the total maintenance costs for the rough areas from $1245 to $2,120 and $3,020 per acre per year, respectively.

Collier's Reserve avoids any significant irrigation costs by utilizing effluent water and collected water from holding ponds. This is important when one considers that fifty-two inches of water per year are applied to each acre of rough, or 86.67 acre feet for the twenty acres that are irrigated. At the municipal rate of $350 per acre foot of water mentioned previously, this would translate into a total yearly expenditure of $30,300 for irrigation water, or about $1516 per acre of rough per year. Similarly, the $710 rate charged to the Los Verdes Golf Course would cost Collier's Reserve $61,500 total or $3077 per acre per year. These two charges for water would push the total maintenance costs for the rough areas at Collier's Reserve from $1568 to $3085 and $4645 per acre per year, respectively.
These calculations demonstrate the effects of irrigation costs on turfgrass maintenance expenditures. All three of these courses benefit from the small fees that they pay for irrigation water compared to the municipal water fees described. As the costs for water and chemicals continue to rise, there will be more of a need to find alternative solutions for management of these areas in order to keep the price of playing golf affordable. One of the key methods for doing this is the conversion of turfgrass to native vegetation.

Costs for the Establishment and Management of Native Vegetation

The benefits of the use of native vegetation include lower cost of establishment per acre (versus turf), reduced maintenance costs (equipment and labor), fewer (if any) chemicals applied, and elimination of irrigation (Weston, 1990). They don’t require mowing, fertilizers, irrigation, or chemicals, and they provide wildlife with habitat (cover and food from plants and seeds) and safe travel routes. These areas also act as buffers and filters that prevent chemicals and silt from leaving the turfgrass areas (Ciekot, 1996). Native grasses are able to tolerate these low-maintenance conditions because they are acclimated to local soil conditions, temperature extremes, and less susceptible to damage from pests in that area (Voyt, 1996).

The management section of Chapter II outlined the procedures for seed selection, site preparation, and establishment of prairie plantings. Prairie plants were selected for use in this analysis because their wide range of adaptation makes them practical for use on the widest array of golf courses. The genetic stability of these plants and diverse seed mix makes it possible for them to continue to grow without the need for continual maintenance ordinarily required for wildflower or grass mixtures with just a few species of plants. Prairies are also highly valued wildlife habitat, particularly when planted adjacent to other edge conditions such as wetlands or forests (Thompson, 1992).

The first year of prairie establishment requires the greatest maintenance expenditure. Weeds, quick to establish themselves, will require mowing once every three weeks at first if they are growing quickly (use of herbicides should be avoided). This will knock back weeds and allow sunlight to penetrate which will give the native plants a good start. During the second year, mowing may be required occasionally, depending upon how
well the vegetation is becoming established. Most weed management can be accomplished by pulling or careful spot-treatment with herbicides. The third year will only require a spring burning, which will stop the encroachment of woody vegetation and enhance the growth of native grasses and forbs. After that, burning should take place on a rotational basis every three to five years in order to preserve some areas as wildlife habitat while other areas are burned. No additional maintenance should be required other than burning.

Table 3.6 estimates the costs for the first three years of establishment of a prairie planting. Prices for prairie seed vary throughout the country. Pure live seed (clean seed that doesn’t contain other plant materials from harvesting) with 25-35 different species of plants can be obtained from seed nurseries for approximately $30-95 per pound. When seeded at a rate of 10 pounds per acre, this amounts to a seeding cost of $300-950 per acre (Kurtz, 1997). However, as the number of prairie seed distributors increases, more economical alternatives are becoming available. This analysis is based on seed mix from a local distributor with over 50 species of plants at $10 per pound. This mixture contains dead plant material gathered during harvesting that raises the application rate to 15 pounds per acre. Even at this higher application rate, the cost of seeding is $150 per acre. Alternative seed sources include harvesting from roadsides, railroad right-of-ways, and pasture lands.

Table 3.6: Estimated per-acre cost of establishing prairie plants in Ames, Iowa

<table>
<thead>
<tr>
<th>Timeline and Description</th>
<th>Cost (per acre per year)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FIRST YEAR:</strong></td>
<td></td>
</tr>
<tr>
<td>Seedbed Prep. (Roundup+ labor &amp; machine): ($60/ac)+ ($35/ac)</td>
<td>$95.00</td>
</tr>
<tr>
<td>Prairie Seed (two applications @ $150 per acre)</td>
<td>$300.00</td>
</tr>
<tr>
<td>Machinery: ($10/hr)(2hr/ac)</td>
<td>$20.00</td>
</tr>
<tr>
<td>Seeding Labor: ($22/hr)(2hr/ac)</td>
<td>$44.00</td>
</tr>
<tr>
<td>Mowing Machine: ($7/hr)(1hr/ac)(10x/yr)</td>
<td>$70.00</td>
</tr>
<tr>
<td>Mowing Labor: ($7/hr)(1hr/ac)(10x/yr)</td>
<td>$70.00</td>
</tr>
<tr>
<td><strong>TOTAL COST OF FIRST YEAR (per acre)</strong></td>
<td><strong>$549.00</strong></td>
</tr>
<tr>
<td><strong>SECOND YEAR:</strong></td>
<td></td>
</tr>
<tr>
<td>Mowing Machine: ($7/hr)(1hr/ac)(3x/yr)</td>
<td>$21.00</td>
</tr>
<tr>
<td>Mowing Labor: ($7/hr)(1hr/ac)(3x/yr)</td>
<td>$21.00</td>
</tr>
<tr>
<td>Hand pulling and spot treatment of weeds ($7/hr)(2hr/ac)</td>
<td>$14.00</td>
</tr>
<tr>
<td><strong>TOTAL COST OF SECOND YEAR (per acre)</strong></td>
<td><strong>$56.00</strong></td>
</tr>
<tr>
<td><strong>THIRD YEAR:</strong></td>
<td></td>
</tr>
<tr>
<td>Labor (spring burning, selective weeding): ($7/hr)(2hr/ac)(3x)</td>
<td>$42.00</td>
</tr>
<tr>
<td><strong>TOTAL COST OF ESTABLISHMENT</strong></td>
<td><strong>$647.00/acre</strong></td>
</tr>
</tbody>
</table>
Conversion of Turfgrass to Native Vegetation

Up-Front Costs Versus Long-Term Savings

In assessing the feasibility of converting turfgrass areas to native vegetation, it is important to compare the up-front costs of establishment of native vegetation with the costs of long-term maintenance of the turfgrass. When can the changes be expected to pay for themselves? The answer to this question is highly variable, since it depends upon many different site-specific factors. Some of these include the climate, the types of plants being established, the type of turfgrass being replaced, and the management practices employed on the course.

Based on the data collected and summarized above, there is a strong economic benefit for the conversion of turfgrass to native vegetation. The estimate for cost of prairie establishment generated in Table 3.6 is clearly less than the yearly turfgrass maintenance expenditure for any of the three golf courses analyzed in this study. It should be noted that this comparison does not take into consideration the cost for establishment of turfgrasses, which would further increase these savings for conversion to native vegetation. Using the higher costs for pure live seed of $300 to $900 per acre described previously, the total three-year cost of establishment would become $903 to $2203 per acre. Even at the highest cost for seed, establishing a prairie planting would pay for itself within two years of conversion from turfgrass for all three of the courses studied. Ongoing maintenance of the prairie plantings is minimal due to their genetic diversity, requiring a small expenditure for labor during burning of these areas (approximately $40 per acre per year). These calculations do not even take into consideration the cost of establishing turfgrass nor the irrigation cost savings that would be encountered at many golf courses in the U.S., particularly those dependent upon municipal water sources.

To illustrate the maintenance costs savings available to Veenker Memorial, it will be assumed that 30% (41 acres) of the 137 acres of rough can be converted to native vegetation without a significant impact upon the playability or speed of play on the course. Subtracting the cost of establishing prairie ($647 per acre or $26,527 for the first three years) from the cost of turf maintenance ($1246 per acre per year or $153,258 total for the first three years) produces a maintenance savings of $126,731 for the first three years.
After that, maintenance of the prairie areas is reduced to about $42 every three years for burning, so the costs savings would be even more significant.

**The Influence of Rising Water Costs**

Many critics of the golf industry justifiably assert that courses should be held accountable for the amount of water they use for irrigation. It appears from the literature that the best way to do this is to make it economically necessary for them to alter their management strategies through the use of nominal fees for water use. Because the marginal value of the resource will no longer exceed the cost, it is anticipated that many courses will reduce their maintenance costs by converting some of the rough areas currently planted with turfgrasses to native vegetation. Based on the calculations performed in this chapter, this is a cost-effective strategy even without the addition of charges for irrigation water. The cost savings generated by the elimination of chemical and fertilizer use, mowing, and aerification are enough to warrant decreases in maintained turf. Conversion of these areas to native vegetation would also provide substantial opportunities for the creation of wildlife habitat and visual interest.

The golf courses analyzed in this study are fortunate to have inexpensive sources of water available for irrigation. If courses with expansive areas of turfgrass rough such as Veenker Memorial were faced with the high costs of irrigation water found in other parts of the country, they would most likely have to consider alternative management practices and higher greens fees in order to remain economically viable. Higher greens fees would then bring the impact of water use directly to the user of the golf course. Consequently, golfers would probably be more likely to tolerate more natural areas (making the course slightly more difficult) and would be less worried about the aesthetic appearance of the turfgrass, since the burden of the maintenance costs will have been transferred to them more directly. Education of the golfer will be an important part of this process so that they understand the reasons for these rising costs and the benefits of turfgrass conversion to native vegetation.

Quantifying the value of irrigation water used on golf courses is not as simple as it seems, however. Besides providing recreational opportunities, golf courses provide other benefits for the surrounding community such as golf-related jobs, income to the community through purchases, wages, and taxes, indirect jobs and income, and an increasing
community tax base (Beard, 1994). Additionally, a golf facility usually elevates the quality of life, improves the business climate and surrounding property value, induces tourist traffic, and preserves open space for the surrounding community. Golf courses are also valuable methods of restoring damaged landscapes such as landfills, industrial waste dumps, abandoned sand and gravel mines, rock quarries, and coal mines. Funds generated by golf make it economically feasible to convert these abandoned lands when nothing else will work (Osmun, 1992). They can also be used for treatment of effluent water, as discussed in Chapter II. These and other benefits are very difficult to quantify, but they must be considered during any discussion of water allocation and pricing for golf course irrigation.
CHAPTER IV: CONCLUSIONS AND RECOMMENDATIONS

Research Summary

The purpose of this study was to synthesize current environmental research to develop a set of principles for sustainable golf course development and management and, in particular, to examine the economic and environmental benefits of using native vegetation on golf courses. This particular study focused more on issues of water quality, soil protection, and the use of native vegetation but less directly on wildlife ecology.

The golf course design, construction, and management principles presented in Chapter II represent a synopsis of the current environmental research that has been published in a variety of journals (both refereed and non-refereed), books, and other sources. The general goals of these principles were to create methods for maintaining playability, aesthetic value, and keeping costs down while minimizing environmental impacts (i.e. reduction of fertilizer and pesticide usage and runoff, reduced water consumption, and improved water quality). Each section discusses a separate topic and draws conclusions based upon the information that could be gathered on that subject.

Water Quality

The substantial body of recently published research on turfgrass has greatly expanded the understanding of the effects of establishment and management practices on turfgrass health and water quality. Collectively, they point to three major factors which must be well understood if risk of water contamination is to be avoided: specific site and soil conditions, characteristics of turfgrass species planted, and chemical properties of fertilizers and pesticides used. Chemical properties such as high water solubility, low soil adsorption, long half-life (indicating longer persistence), and low volatility create conditions in which fertilizers and pesticides are more likely to leach into the soil profile or be transported into adjacent surface waters. Therefore, pesticide selection is a very important indicator of potential contamination.

Highly sandy sites are most susceptible to nutrient and pesticide leaching due to high permeability, low organic carbon content, and low cation exchange capacity (CEC). Golf course greens and tees are usually constructed using a sand base because of the
importance of drainage in these areas, and are therefore areas of concern. Drainage from these tees and greens should be treated in filtration trenches or retention ponds and not allowed to directly enter adjacent surface waters. Leaching is of particular concern on newly established turfgrass and in areas with shallow water tables and sandy soils. Many golf courses are built on these types of sites, particularly in the southern and coastal regions, so extensive evaluation of these areas should be done to identify potential problems from contamination. Volatilization levels and dislodgeable residues from pesticides are highest immediately after application and higher with emulsified application than with granular. However, irrigation after application greatly reduces safe entry times and possible exposure to animals and humans.

Several of the articles identified in this study confirmed that large amounts of pesticides are used on golf courses. Though the pesticide usage levels on golf courses may seem excessive, they fail to reflect the efficiency with which turfgrass is able to utilize these nutrients. Leaching is less from turfgrasses than from agricultural fields due to the higher shoot density, thatch layer, and active root zone microbial layer in turfgrasses. Most of the studies (Shirk, 1996; Carville, 1991; Grossmann, 1993; Snow, 1996; Cohen et al., 1990; Horst et al., 1995; Petrovic et al., 1993; Smith et al., 1993; Snyder et al., 1995; Starrett and Christians, 1995; Yates, 1995) were unable to find significant levels of these pesticides or fertilizers in groundwater or leaching samples. Pesticide and fertilizer levels measured in these studies were almost always less than the “Maximum Contaminant Levels” set by the EPA for drinking water.

There is a concern, however, for potential chronic or sublethal toxicity from chemical usage on golf courses because it has not been well documented in past studies. Even though nitrate-nitrogen levels less than 10 mg/L (as most water quality tests have shown) are not much risk to potable drinking water, concentrations of nitrogen and phosphorus have been measured high enough to trigger eutrophication (over-enrichment) in nutrient-sensitive surface waters (Barth, 1995a). These concerns merit further investigation and research. There is also the issue of raw consumption of resources for the production, distribution, and application of pesticides and fertilizers. The off-site costs for the use of materials on golf courses are an area of concern in any discussion of future sustainability of these areas. Because of the environmental concerns and economic implications of
pesticide use (both on and off site), golf courses should seek to minimize chemical usage, particularly where opportunities may exist for the conversion of turfgrass to native vegetation.

Current research generally supports the notion that turf grown on finely textured soils with moderate inputs of nitrate fertilizer and irrigation doesn’t have the nitrate leaching potential of row crops, nor does it pose a significant risk to potable water supplies. The key exception to this is over-watered lawns on sandy soils, where leaching may be a concern and more care must be taken in management (Schueler, 1995a). Turfgrass root-zone and thatch layers have a high level of biological activity which enables turf to work like a filter when pesticides and fertilizers are applied. Fertilizer applications should be based on plant tissue and soil tests to prevent over-fertilization of the turfgrass, providing just enough nutrients for the plants so that they will be slightly stressed but will not become chlorotic (yellowing of the tissues that indicates nutrient deficiency). That way, the turf will develop more extensive root systems and will tolerate stress such as drought or disease more readily than will the succulent growth caused by over-fertilization. Use of fertilizer on steep slopes and near surface waters should be avoided to prevent nitrogen from traveling in surface water runoff.

Some of the research demonstrated that the form of fertilizer applied (inorganic versus slow-release) has little direct effect on the concentrations of leached nitrate (in the absence of over-watering). It appears that the critical factor in terms of nitrogen leaching is the amount of irrigation and rainfall that the site experiences, and care should be taken to avoid excessive amounts of water following application. Light applications of slow-release nitrogen sources on frequent intervals are better for leaching protection. According to seven university studies on nitrogen leaching, very little occurred when these materials were applied as appropriate for the needs of the turf, the soil type of the site, and when irrigation levels were correct according to rainfall amounts.

Fewer studies have been conducted on fertilizer runoff than on fertilizer leaching. Most of the experiments on fertilizer runoff have shown that nitrogen runoff can be minimized by having a dense, mature turf cover, avoiding compacted soil conditions, avoiding high soil moisture levels, using buffer strips in drainage ways and along surface waters, and using slow-release products (sulfur-coated urea, for example) rather than water
soluble products such as urea (Snow, 1996a). Measurements of fertilizer runoff revealed that, even on newly established stands of turf, nitrate-nitrogen concentrations were usually less than 10 mg/L and the leaching and runoff concentrations measured were less than those measured in the irrigation water alone. Phosphate-P leachate and runoff concentrations measured were also less than those present in the fertilizer and irrigation water.

Fertilizer and pesticide runoff studies revealed that it is difficult to generate adequate runoff amounts from turfgrass areas in order to observe any movement of nutrients. It appears that well-maintained turfgrass seldom produces surface runoff, except from uncommonly large storm events. There is, however, concern for highly compacted soils or when there are short travel distances to impervious areas (Barth, 1995a). Where this is the case, measures should be taken to alleviate compaction, provide vegetative buffers along surface water areas, and redirect drainage away from these areas.

Golf Course Design and Construction

The analysis of the site selected is the most important step in evaluating the potential environmental impacts of the golf course development and anticipating ways of mitigating these impacts. It is important that the development of the course involves a multidisciplinary team including an owner, engineer, ecologist, botanist, archaeologist, golf course architect, land planner, golf course superintendent, lawyer, and planning team coordinator (Hurdzan, 1994). By taking part in the design and construction process, the superintendent will be able to understand how the course has been built and will know how to best care for the course once it is completed. When minor modifications need to be done to the course in the future, they can then be done in a manner that is efficient and in keeping with the original concept of the intended design.

In general, the best soil and topography conditions for a site seem to be those with a gently rolling topography and a soil profile that is consistent throughout the site. These factors will decrease construction and maintenance costs because a minimal amount of soil will need to be moved during construction and the conditions for maintenance will be relatively consistent throughout the course. The best soil types seem to be well-drained soils, such as sandy loam, that will be resistant to compaction but will be able to retain
enough moisture for plant growth. Greens and tees require separate construction methods and soil distributions because of the intense traffic and maintenance conditions required in these areas. Porous soils (particularly high in sand content) with low levels of organic matter are considered more susceptible to downward movements of chemicals, and sites with these characteristics should be carefully treated (particularly in coastal areas). Sites with a shallow water table on sloping land are also areas of concern, particularly those near surface water bodies and those that may have sink holes or abandoned wells present within the area which would allow more rapid movement of chemicals.

From an environmental standpoint, the most important factors related to soils are protection from erosion, avoidance of areas not intended for development (keep native vegetation as a covering), and proper soil preparation (amend soils as needed for pH, CEC, sodium, and other nutrient levels) that will maximize the efficiency of future turfgrass needs for water and chemical applications. Disturbance of steeply sloped terrain (especially those exceeding fifteen percent) should be avoided if possible due to the difficulty of machinery operation and erosion control in these areas. For any areas that will be disturbed during construction, dikes, diversions, and waterways should be established before clearing and grading takes place. This will divert runoff waters from disturbed areas and greatly decrease the threat of erosion. Silt fencing should be erected in all work areas adjacent to river and stream corridors, especially in adjoining drainage swales. Vegetative buffers should be preserved around sensitive areas, particularly surface water bodies on the site. Vegetation can be selected that will rapidly re-vegetate exposed soils and hold them in place, and exposed soils can also be protected during construction through hydroseeding, sodding, or using mulch. Construction scheduling should also protect soils by minimizing the exposed area and the amount of time the ground is left without cover.

Whenever possible, earthwork should be kept to a minimum in order to protect existing soils from potential erosion during construction and to keep construction costs down, thereby providing cost savings to golfers that will play the course in the future. This will also allow the preservation of the greatest amount of existing vegetation, which is particularly important for previously undisturbed sites. Qualified professionals should be on site during staking and clearing to identify (tag) endangered and sensitive flora. A very
effective method for protecting these areas is by fencing off areas that will remain undisturbed and avoiding them during construction.

Most of the criticisms that have been raised concerning golf course impacts upon the environment have dealt with water quality degradation and excessive water use. Therefore, it is very important to identify any possible surface or groundwater impacts before construction begins. Perennial and intermittent streams, floodplains, steep slopes, forest stands, and habitat features for a proposed course should be identified and evaluated prior to the design of the course so that it can be configured to avoid or minimize disturbance of such areas. Any presence or likelihood of groundwater discharges to sensitive surface water bodies should also be identified and protected prior to construction. In addition to these elements, soil characteristics and the proximity of the water table to the surface are important factors in determining potential groundwater impacts.

Surface and groundwater resources must be carefully identified and evaluated prior to construction of the course. Any use of these resources should be planned and monitored in order to avoid water quality degradation and excessive water use. One guideline for water usage identified in the literature was that sufficient water must be available to meet the irrigation needs of the golf course without either causing a decrease of more than five percent of the seven day, ten year low-flow level of any waterway in the vicinity or substantially reducing the yield of existing wells in the area (Klein, 1994). Following this guideline will provide the irrigation water necessary for turfgrass maintenance without negatively impacting the water resources of the surrounding ecosystem.

Additional planning requirements and restraints may include wetlands or other sensitive surface waters that require buffers for protection and potential and existing habitats (nesting and breeding areas), particularly those used by endangered species identified on the site (Hurdzan, 1994). Once these areas have been identified, the site analysis should also assess the possibility of enhancing existing habitat and creating a more sound ecological plan for the development. For instance, the inclusion of large contiguous patches of native vegetation can be connected together to form a matrix of habitat and travel corridors for wildlife. Preservation of these connections during the design and construction of the course will make it possible for wildlife to travel through the site and will
encourage the health and growth of a wider range of animals, thereby promoting the biodiversity of the site.

There is ample evidence that golf courses provide habitat for a wide variety of plants and animals (USGA report, 1996; Borland, 1988; Carrick, 1994; Danielson, 1993; Etchells and Rinehimer, 1994; Harker et al., 1993; Hawes, 1996), though concerns still exist that the types of habitats which they provide favor edge species rather than a broader range of wildlife types. Continued evaluation of wildlife habitat impacts is needed in order to assess the quality of these habitats and determine the future goals of development. Funds generated by golf course development also make it economically feasible to reuse degraded sites such as landfills, industrial waste dumps, abandoned sand and gravel mines, rock quarries, and coal mines. Examples of this include the TPC of Michigan (Hawes, 1996), Harborside International in Chicago (Thompson, 1996), Old Works Golf Course in Anaconda, Montana (Duthie, 1996), and Widows Walk in Scituate, Massachusetts (Hurdzan, 1996; Whitten, 1996). These types of development offer tremendous opportunities for the future problems associated with waste disposal from the excessive resource use of our society. The impact of golf course development upon existing flora and fauna in previously undisturbed sites, however, has yet to be fully evaluated. More research needs to be conducted in this area in order to assess potential impacts and opportunities for improving habitat. If a previously undisturbed site is going to be developed, the design and construction of the course should be carried out with minimal disturbance to the out-of-play areas and with very careful consideration of potential ecological impacts.

Avoidance of surface water effects can be accomplished through the integration of wetlands into the design, minimization of stream crossings and alterations in streamflows, construction of drainage swales and retention ponds away from the stream to capture surface runoff for reuse in irrigation, and the use of buffer plantings. Based on the research, it appears that a minimum of 50 feet of native vegetation should be planted as a buffer to surface water areas. Widths closer to 100 feet will provide even more opportunities for wildlife habitat and ecological health for the site. If widths less than this are required, steps should be taken to route storm water runoff away from the surface water bodies through the use of berms and swales.
In addition to these design strategies, efforts should be made to raise mowing heights and lower green speeds in the interest of increased turfgrass health and decreased water and chemical usage. This will mean the return of increased slopes to golf greens in order to maintain the same level of playability. Continued research may reveal better methods of green construction, better root-zone mixes, and better varieties of turfgrasses for use at low mowing heights. Based on a review of the literature, the USGA method of green construction seems to be the best available in terms of water conservation and improved turfgrass health. It is important that superintendents understand the lower water requirements of greens built according to USGA specifications so that overwatering can be avoided. For areas with higher amounts of precipitation, the California method may be a better solution because of its drainage characteristics, but the same principles of proper treatment of collected drainage water should be used no matter which construction method is chosen.

Perhaps no other single factor has more of an impact upon golf course development than the expectations of the golfer. The demands for all-green turf areas without signs of wear or disease and lightening quick greens have caused increases in water and chemical usage due the stresses related to shorter mowing heights and reduced drought and stress tolerance. More water and nutrients must be applied because there is inadequate root growth, and more chemical pesticides must be applied because the plants are no longer as resistant to diseases and pests. Playing equipment should be regulated as it is for the game of baseball to reduce amounts of land required for golf courses and make it possible for older, shorter courses to be played the way they were designed to be played. By changing golfer expectations about equipment and maintenance standards, less water and chemicals would be required, shorter courses could be developed, and the firmer conditions would produce more shotmaking skill in golfers because they would be required to think more about how to approach each hole.

This research also proposed some innovations for golf course design. The use of artificial playing surfaces for greens and tees would have many potential benefits, particularly in situations where environmental impacts (chemical leaching and runoff) are a concern or in conditions where turfgrasses are more difficult to maintain such as inadequate soils, inaccessibility to quality irrigation water, and limited sunlight, drainage, and air
circulation. Irrigation with wastewater is another issue that was discussed for its importance in creating multiple uses for land dedicated to golf courses and for providing a lower cost source of water. Multiple use of the land can also be accomplished by building golf courses on abandoned lands such as quarries, landfills, and other damaged landscapes. The benefits of the reuse of damaged lands and treatment of wastewater can then be added to the economic benefits that golf courses provide to the community.

One of the key issues identified in this research was the opportunities available for the expanded use of native vegetation on golf courses. Irrigation restrictions currently placed on desert golf courses may one day be applied elsewhere as well, a change that will impact future course design and management strategies. Perhaps concepts related to water conservation should be implemented before water resources become a greater concern. One method would be the use of the “target” course design philosophy in the non-arid regions of the country. Because of the smaller areas dedicated to maintained turf, the out-of-play areas on the course could be protected during the development of the site. This would be especially beneficial for those developments taking place on previously undisturbed sites. Existing natural areas could be preserved and the golf course would have less of an impact upon the land. Also, because of the enlarged areas devoted to native vegetation, more habitat and travel corridors would be provided for wildlife, enhancing the suitability of the site for more diverse species types. This has value for both previously undeveloped sites and for courses built on highly modified landscapes.

Target course design makes it possible to build shorter courses which will rely more on accuracy and finesse than on distance. This type of development would reduce construction and maintenance costs since courses would be shorter and only the greens, tees, and fairways would be need to be developed and maintained. Lower water consumption, because of the decreased amount of maintained turf, reduces water use and lowers water costs by requiring less water and smaller pumps and irrigation lines. Decreased amounts of fertilizers and pesticides will mean additional maintenance cost savings and reduced environment impacts.

Another strategy that has been used for water conservation is the design of courses with internal collection of rainwater and irrigation runoff into holding ponds for reuse. This not only decreases the demand for potable water for irrigation of the course, it decreases
the likelihood of off-site transport of nutrients and chemicals from turfgrasses. The use of effluent water is another concept that has been implemented successfully on several courses in the U.S. (Frye, 1994; Salvesen, 1996; Poellot, 1992) and may provide promise for future golf course irrigation and water treatment needs in this country.

Golf Course Management

Integrated Pest Management (IPM) describes efforts underway by superintendents to balance the costs, benefits, public health concerns, and environmental quality concerns of managing golf courses. IPM relies on ecological principles and uses both biological and chemical approaches. It aims at the development of healthy turf that can withstand pests and the judicious and efficient use of chemicals. This depends on strengthening natural organisms that benefit turfgrasses and on timing pesticide control measures to coincide with the pest’s most vulnerable stage so that less pesticide is required.

Turfgrass species selected for use on golf courses should be appropriate for the region and particular site characteristics such as shade, typical pests, and disease tolerance. Slow growers, dwarf cultivars, those that require less fertilizer and water, and endophyte-enriched (to battle disease) species are preferred when applicable. Proper site preparation is also very important, including irrigation and drainage systems that provide precise water management, planting turf in soil which is free of pests, adequate sunlight, proper ventilation, proper drainage on fairways, greens large enough to support anticipated traffic, and an adequate supply of good quality irrigation water.

Timing of application is one of the key factors in a successful IPM program. Pesticides are best applied during a particular stage in the life-cycle of weeds and insects (usually the early stage of development) or during certain weather conditions, and every effort should be made to coordinate the application times with these conditions of increase susceptibility. Efforts should also be made to select chemicals that will be the most effective treatment but the least toxic to non-target organisms (and least persistent). Whenever possible, chemical treatments should be curative rather than preventive (spot-treat problem areas rather than use chemicals as a blanket application). Applications should be made after problems have exceeded damage thresholds set for the turf or when conditions are likely for this to occur.
It is also important to select disease and pest resistant turfgrasses and to use correct management levels for irrigation, fertility, mowing, and aerification. Watering less often and more deeply (to encourage deeper root growth) and early in the morning (to minimize evaporation losses) is part of this approach. Irrigation water should be applied at intervals that will balance the needs of the turf (water deep enough to encourage root growth and infrequent enough to increase tolerance to stress) and concerns for groundwater protection (avoid watering too deeply, where there may be concerns for leaching of chemicals and fertilizers through the soil profile). Chemicals should not be applied during conditions of high winds or when rain is in the forecast, and low-volume sprayers should be used in order to reduce drift. Careful records need to be kept that contain a specific history of pest emergence and control throughout the golf course, and maintenance workers should be extensively trained in the proper use, storage, and handling of pesticides.

Cultural practices of management also impact potential risk of contamination to surface and groundwaters. Incomplete planning, misapplication (applying excessive amounts or using the wrong materials), poor timing (applying in high winds or prior to storm events), and over-irrigation following application of chemicals are practices that increase the potential for contamination. There is also concern that, although golf courses have licensed maintenance personnel, the application of pesticides may be delegated to those who do not understand proper application techniques or the dangers of misuse. All of these conditions need to be avoided in order to control the influence of chemical treatments and to ensure that golf courses maintain their utility in providing recreation while functioning as part of a healthy ecosystem.

Economic Benefits of Turfgrass Conversion

As an example of a more sustainable golf course design and management strategy, the expanded use of native vegetation in out-of-play areas was discussed for three existing golf courses in an effort to evaluate the environmental and economic benefits of turfgrass conversion in these areas. Prairie plants were selected for this analysis because their wide range of adaptation makes them practical for use on the widest array of golf courses. The
costs of maintaining turfgrass rough was calculated for each of the three courses and compared with the cost of establishment and management of prairie plants.

Establishment of prairies in out-of-play areas on golf courses should involve at least thirty species of grasses and forbs in order to create a dynamic system of plants that will be able to sustain itself. The greater the diversity of the plants used, the greater will be the long-term sustainability of the planting (Kurtz, 1997). This concept is commonly misunderstood in the establishment of low maintenance vegetation, and many golf courses select wildflower mixtures or grass species that have less than ten species of plants. This lack of species diversity makes it possible for weeds to invade the planting and requires continual maintenance for weed control. Use of seed mixtures with a higher diversity of native plants will be more expensive during establishment, but will produce a more stable plant community and will reduce maintenance costs in the long run. The native vegetation is more acclimated to the local conditions and will out-compete the weedy invaders and require little or no maintenance once they become established.

The results of this study, presented in Chapter III, illustrate the maintenance savings available through the use of native vegetation such as prairies. For all three of the courses studied, the conversion of turfgrass rough to prairie plants would pay for itself in reduced maintenance cost within the first two years, even using the highest priced prairie seed. In addition to making playing the game more affordable, these areas would provide tremendous opportunities for wildlife habitat and decreased chemical, fertilizer, and water usage, all of which will be important characteristics of future golf courses as maintenance costs and political pressures continue to rise.

**Recommendations for Future Study**

**Areas of Need**

Although many community benefits can be attributed to golf courses (see Chapter I), and extensive research supports the idea that a properly designed and maintained golf course has minimal environmental impact, there are clearly still unanswered questions and criticisms related to golf course development and its impact upon the environment. Several areas identified in the research merit further study.
Runoff and Leaching

A review of the research literature outlined in the management section of Chapter II reveals that experiments on fertilizer and pesticide leaching and runoff have been conducted with a wide variety of soil types, turfgrass species, and management conditions. Leaching and runoff studies for golf course greens have been particularly thorough in their use of warm and cool season grasses and a variety of root-zone mixtures. There are, however, some situations that have not been adequately addressed. For example, Cohen et al. (1990) recommend that further leaching studies be conducted on a wider variety of pesticides and hydrologic environments, especially for courses in southern climates that use nematicides, which are more mobile and persistent than other chemicals.

Potential concerns related to the chronic or sublethal toxicity of pesticides in surface and groundwaters should be addressed in future research because it has not been well documented in past studies. Experiments could also be conducted to determine how turf compares with forests and prairies for runoff and leaching of fertilizers, chemicals, and water. If runoff (sediment or chemicals) only occurs during infrequent, intense rainstorms, as the research has demonstrated, need we be concerned about runoff from turfgrasses? It would also be helpful to determine the extent to which turf intercepts applied chemicals, which would make it possible to identify the limit of original quantity of chemicals that can be applied to turfgrasses and still achieve “safe” runoff (Schueler, 1995c).

Direct Study of Golf Courses

Much of the literature reviewed for this thesis involved research results from experiments conducted under golf course conditions in a laboratory. Although the data gathered has been helpful in beginning to evaluate the environmental impacts of golf courses, more studies need to be conducted on the courses themselves because of the difficulty in simulating turfgrass stresses caused by golfer traffic. Simulating the effects of foot traffic, ball marks, and divots cannot be done practically in a laboratory. Golf courses also tend to have shorter mowing heights, off-hours irrigation, early morning mowing, restrictions on the timing of pesticide and fertilizer applications, and a more intense desire for perfect green turf than do research plots, although these conditions are somewhat easier to simulate.
Foot traffic is particularly important where tees and greens are concerned because of their heavy use each day by golfers. The USGA has recently initiated a program that will enlist golf courses from around the country in a direct study of these effects. The program involves the use of practice greens for testing of different grasses and maintenance practices under golf course traffic and management conditions. Data collected from these experimental areas can then be compared to research data already obtained in order to evaluate these effects. Hopefully, this program can also be extended to testing of practice tees and fairway conditions as well. Development of additional courses as research laboratories, as has been done with Widow's Walk in Scituate, Massachusetts, will also be helpful in generating data for the evaluation of golf course impacts upon the environment.

Water Quality Monitoring

The management section of Chapter II outlined procedures for establishing water quality monitoring programs and discussed some of the research results that have been obtained for several golf courses. The data collected thus far on water quality impacts of golf courses has done much to discredit criticisms related to water quality. Courses such as Queenstown Harbor in Queenstown, Maryland and Squaw Creek Resort in Olympic Valley, California demonstrate that golf courses have actually caused an improvement in water quality within their respective watersheds. Streams exiting these courses were found to have lower levels of nitrates and pesticides than samples drawn from the stream before it entered the course (Shirk, 1996; Thompson, 1993; Carville, 1991).

Care must be taken in the installation of these test sites and in the data collection to ensure accurate results. Some of the problems often encountered with these studies include that sampling is done too infrequently, the hydrology is not well understood, and the inputs (rainfall, irrigation, fertilizer, and pesticides) aren't well quantified (Petrovic, 1994). Evaluation of sampling results can be difficult because there is often uncertainty in the relationship between these results and the actual impacts from the golf course. Installation of upstream control sites is an important part of establishing how much of the contamination may be due to upstream effects such as urban or agricultural field runoff. It is also very difficult to relate testing results to other courses because each site varies based on climate, soils, management strategies, and other factors that influence test conditions. Installation of
monitoring wells on golf courses in varying hydrologic regions throughout the U.S. would enable researchers to gather and evaluate data that could form more solid conclusions about golf course effects on water quality.

Social Impact Assessment

One area of research that has received very little attention is the social impacts of different golf course design and management strategies such as the conversion of turfgrass to native vegetation. Evidence gathered from the current literature suggests that golfer attitudes toward expanded use of native vegetation have been increasingly positive. More golfers are beginning to enjoy the beauty of these areas and the opportunities that they provide for interaction with wildlife (Ciekot, 1996; Duffy, 1981; Seaberg, 1992).

The design section of Chapter II described the importance of golfer expectations upon golf course maintenance conditions. It seems clear that superintendents are willing to change management practices more readily than golfers are willing to accept reduced maintenance conditions. More accurate assessment of these attitudes will be helpful in directing education programs about the expanded use of native vegetation or reductions in water and chemical usage. There is also a growing need for a direct study on playability with more conservation-minded management practices. This could involve an evaluation of the playability effects of firmer and less green course conditions and the use of native vegetation in the rough areas.

Chapter II also discussed the playability impacts of changes in playing equipment (decreasing the length of golf ball flights), changes to the rules of golf (relief from environmental areas without penalty), scoring systems (Point-to-Point™ golf and the use of match play versus stroke play), and design practices (extended use of the target golf concept). Each of these proposals will impact golfers differently and will need to be evaluated in order to understand how these types of concepts can best be implemented for the good of the game and the environment.

Large-Scale Ecological Issues

- Ecological Context—Conventional development often increases fragmentation of the landscape, diminishing its ability to support a variety of plant communities and habitats.
Golf course developments should instead seek to create larger whole systems that will reconnect fragmented landscapes and establish contiguous networks with other natural systems both within the site and beyond its boundaries. In this way, golf courses can function as integrated parts of the larger context of the landscape. Possible strategies include using golf courses as a vehicle to acquire and preserve large habitat areas or limiting new course development to rejected landfills and urban fringe lands (Pearce, 1993).

- **Impacts of Course Development**—More extensive evaluation is required of existing golf courses as well as the impacts of future developments in terms of wildlife and vegetation, water quality, and chemical usage. This is particularly true for previously undisturbed sites, where extensive inventories of wildlife and plant species existing prior to development can be used to monitor changes caused by development of the course. This kind of pre- and post-development evaluation will be critical to the analysis of the actual environmental impacts of golf course developments.

- **Indirect Ecological Impacts**—Another issue raised during the literature review is the effects that golf course developments have on other sites as a result of the materials needed for construction and management of the course. Typical green and bunker constructions require sand and other soil amendments from external sites, and the production of the chemicals used to maintain the turfgrass also require inputs of energy elsewhere. These and other issues should be addressed in seeking to evaluate the potential sustainability of golf course developments in the future.

**The Goal: Approaching Sustainable Golf Course Development**

A truly sustainable golf course would be one that could function completely independent of the rest of the world for an indefinite period of time. The site would be capable of generating its own energy, recycling its own waste, supporting wildlife, producing food and other products, and performing all of these functions without detrimental impacts upon the environment. Many of the principles of sustainability can be used as guidelines for providing innovative solutions for growing environmental problems, and will be helpful to giving shape to future golf course developments. Sustainable golf course developments will include holistic, ecologically based strategies to create courses that do not impair but
instead repair and restore existing site systems such as plant and animal communities, soils, and hydrology.

One of the key criticisms identified in this research has been water and chemical usage on golf courses. Discussion of water and chemical usage involves evaluation of a very difficult question; how much water and chemical usage is acceptable? In an effort to approach sustainability, courses of the future will be looking to decrease water and chemical usage. Chapter III demonstrated the economic benefits of the conversion of turfgrass to native vegetation. This solution also has significant environmental benefits through the creation of wildlife habitat and the elimination of water usage, chemical usage, and labor required to maintain these areas. It is likely that there will be continual trend towards higher water and chemical costs and corresponding increases in costs for management of golf courses. Employment of the design, construction, and management principles discussed in Chapter II will have a large impact upon how well courses will perform economically and in protection of the environment.

Golf courses of the future will also function as multiple users of the land in their effort to approach sustainability. Chapter II described the opportunities that exist for the conversion of damaged lands such as landfills, industrial waste dumps, abandoned sand and gravel mines, rock quarries, and coal mines to golf courses (Dodson, 1996; Brown, 1994). Development of golf courses on these degraded sites can create new habitat that supports many species of wildlife where before it was uninhabitable. The funds generated by golf courses make this conversion economically feasible. Courses can also be used to preserve urban open spaces and provide a flexible use for floodplain areas where other types of development should be avoided. Expanded use of native vegetation will provide wildlife habitat and increased biodiversity within the region and will provide educational opportunities for golfers and non-golfers alike. Effluent irrigation can be utilized on the courses, thereby creating another use for the land through waste treatment and water quality enhancement. The future goal of sustainable golf courses will be the use of available precipitation for all of the water requirements of the development, including turf management, course operations, food production, waste management, and other needs. These courses will also use out-of-play areas to increase community benefits by producing
food (orchards or rotational crops) and energy (wind generators and solar collectors that harvest sustainable energy).

Continued research in the coming years will reveal more efficient irrigation systems and practices (expanded use of weather monitoring and computer software), better use of effluent for irrigation, new varieties of drought-resistant turfgrasses, and other developments that will change how golf courses are built and maintained. It is likely that mounting environmental and economic pressures related to water quality and water usage will also change the way golf courses do business in the future. So far, the golf industry as a whole has been quite receptive to these changes, as demonstrated by the commitment of the United States Golf Association to fund research related to water quality and improving golf course operations (they have funded over $11 million of research projects over the past seven years alone). Superintendents also continue to experiment with different management practices in an effort to decrease water and chemical usage and provide wildlife habitat on their courses. It is this kind of commitment to improvement that will keep the game of golf viable in the coming years as it faces rising costs of development and other environmental concerns.
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