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);
- *Volatilization 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. (1996) 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, their 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 meprop (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 dislodgeable 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 (K_d) greater than five, normalized partition coefficient (K_OC) 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**—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 mean 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 areas 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., 1996).

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.
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. Annuals 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 drop spreader 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).