Water Management at Golf Courses –

Algae and Macrophytes

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Water management on a golf course is one of the significant keys to the success of course management. Properly managed water resources provide good quality irrigation water, aesthetically pleasing ponds and streams, appropriate stormwater treatment, and no offsite surface or ground water pollution problems.

Improperly or poorly managed water resources can cause great problems for the golf course; for example, poor quality irrigation water may injure or even kill greens, while pond algal blooms can cause aesthetic and odor problems. Understanding the ecology of aquatic plants, algae and macrophytes, as an important component of the golf course water resources is paramount to making certain they only positively impact the golf course environment.

Incorporation of aquatic management strategies should be part of the courses overall environmental management program (Peacock and Smart 1995).

Algae are particularly well adapted to take advantage of high nutrient concentrations (particularly phosphorus), warm water, and sunshine as they reproduce in exponential fashion.

1.0 Algae and Aquatic Macrophytes. Aquatic algae are plants generally classified as either attached (periphyton) or free-floating (phytoplankton). Attached aquatic macrophytes are generally classified by their growth form - floating, emergent, and submergent. Each water body has algae and aquatic macrophytes that occur naturally.

Aquatic plants are an important component of the ecosystem. Like other plants they produce food through photosynthesis and are thus the base of the aquatic food chain, and they provide cover for animals. The algal community is comprised of many different types of algae that may change throughout the growing season. Some of the common groups include blue-green algae, green algae, dia-

Table 1. Mean and range of nutrient and chlorophyll concentrations associated with various water quality conditions (Modified from R.G. Wetzel, 1983).

Nutrient	Pristine Water (Oligotrophic)	Moderately Enriched (Mesotrophic)	Enriched (Eutrophic)	Highly Enriched (Hyper-eutrophic)
Total Phosphorus (μg/L or ppb)	8.0 3.0-17.7	26.7 10.9-95.6	84.4 16-386	750-1200
Total Nitrogen (μg/L or ppb)	661 301-1630	753 361-1387	1875 393-6100	—[a]
Chlorophyll a (μg/L or ppb)	1.7 0.3-4.5	4.7 3-11	14.3 3-78	100-150

[a] No Data

toms, dinoflagellates, and euglena. The body shapes of algae are highly varied and include unicellular, multicellular, colonial, and filamentous.

The distribution and abundance of algae and macrophytes in a water body is subject to considerable spatial and temporal variation. Among the many factors that determine their presence, distribution and density are light, temperature, water turbidity, water currents, hydraulic residence time, nutrient concentrations, nutrient loading from watersheds, water chemistry, water depth, sediment quality, herbivore grazing, and human activities. Aquatic sites are thus dynamic and responsive and as the availability and nature of the resources change, so will the species diversity and/or amounts of aquatic vegetation. However, at some point a healthy algal or macrophyte population may actually become an "algal bloom" or "weed infestation" that may impair the usefulness of a water body for its intended uses.

The result is an algal bloom, often distinguished by the "pea-soup" appearance of water that results from large quantities of algae.

2.0 Aquatic Algae and Algal Blooms. Although many factors influence the abundance of algae, algal blooms are most often associated with an increase in nutrients (primarily phosphorus and nitrogen) in the water. Through much research, phosphorus was identified as the critical element in causing algal blooms in water bodies (Vollenweider, 1971; Jones and Bachmann, 1976; Wetzel, 1983). Phosphorus is therefore generally considered the limiting nutrient in freshwater ecosystems; that is, phosphorus is a required nutrient for plant growth that is most often in short supply.

Algae are particularly well adapted to

Table 2.

Effectiveness of herbicides for aquatic plant control in irrigation watersupplies (Langeland, 1994).

Effectiveness of control is as follows: * = Not recommended; F = Fair; G = Good; E=Excellent

Aquatic Plant	Diquat	2,4-D	Copper	Fluridone	Glyphosate
Floating Plants					
Duckweed	G	F	*	E	*
Watermeal	*	*	*	G	*
Alligatorweed	*	F	*	F	G
Submersed Plants					
Bladderwort	G	F	*	G	*
Brazilian elodea	E	*	F	G	*
Coontail	E	F	*	E	*
Hydrilla	E	*	F	E	*
Parrotsfeather	G	*	*	F	*
Pondweed	G	*	*	F	*
Slender naiad	E	*	*	E	*
Southern naiad	E	*	*	G	*
Spikerush	*	*	*	G	*
Variable leaf milfoil	G	E	*	G	*
Emersed Plants					
American lotus	*	G	*	G	G
Cattail	G	F	*	F	E
Fragrant waterlily	*	G	*	G	E
Rush	*	F	*	*	G
Spadderdock	*	F	*	G	E
Waterpennywort	F	G	*	*	E
Filamentous Algae	G	*	G	*	*

take advantage of high nutrient concentrations (particularly phosphorus), warm water, and sunshine as they reproduce in exponential fashion. The result is an algal bloom, often distinguished by the "pea-soup" appearance of water that results from large quantities of algae. Concentrations of nutrients and chlorophyll a associated with different levels of water quality are given in Table 1 (*Page 74*). Chlorophyll a is used as a measure of the algal biomass in water.

Algal blooms cause many different problems. Two of the primary concerns on golf courses are aesthetics (looks bad and smells when they die) and die-off (die-off is when most of the algae die at nearly the same time). Die-off occurs for many different environmental reasons (overcast skies reducing light intensities and a cold snap are among the two most common) and may also occur when chemicals are applied for algal control. A die-off is easily observed - one day the water is green, and the next day the water is brown. The intense green of the algal bloom is from the chlorophyll in the

Table 3.
Waiting period in days before using water after application of herbicides for aquatic plant control.

Common name	Irrigation	Fish Consumption	Swimming
Copper Compounds	NR*	NR	NR
2,4-D	+	+	+
Diquat	14	NR	NR
Fluridone **	7-30	NR	NR
Glyphosate	NR	NR	NR

* NR = No Restrictions
** See label for specific information.
\+ Water use retrictions vary by formulation and manufacturer. In general, if water is used for irrigating sensitive plants, 2, 4-D should not be used.

algae. The mass die-off of algae places a large oxygen demand on the water; that is, large amounts of dissolved oxygen are required to decompose the dead algae.

If oxygen demand is large enough, dissolved oxygen concentrations can fall to levels that cause changes in the biological and chemical characteristics of the water body.

Four mg/l of dissolved oxygen is generally the minimal amount of oxygen that is desirable for maintanence of aquatic life. Thus, if dissolved oxygen levels fall below this level aquatic biota may die (e.g., a fish kill may occur). In many states, 4.0 mg/l is the water quality criteria for warm water fisheries and 5.0 mg/l is the criteria for cold water fisheries. It is important to maintain these levels of oxygen in the water column. The lack of dissolved oxygen also sets in motion a series of chemical reactions that reduces water quality.

2.1 Prevention of Algal Blooms. The factors that control the abundance of algae, form the basis for managing them. Frequently, prevention of algal blooms requires controlling nutrient loadings to the water body. This means that sources of nutrients in the watershed or basin that have the potential of reaching the water must be controlled, or at least, reduced to the lowest quantities possible. The alternative to controlling nutrients before they enter the water, is to undertake restoration of the water body after nutrients have reached levels great enough to cause blooms and water quality has deteriorated. Restoration is expensive and time consuming and includes not only controlling external nutrient loadings, but also internal nutrient cycling. The larger the water body, the greater the costs. Restoration generally requires years to successfully complete.

Prevention of algal blooms is the best approach to maintaining water quality, and prevention of algal blooms require reductions in nutrient supplies to the water.

Implementing Best Management Practices (BMPs) to control nutrient movement from the golf course and into surface waters is the most cost effective solution.

2.2 Controlling Algal Blooms. The best approach to maintaining water quality against algal blooms is prevention. Prevention is best because causes of algal blooms are addressed. However, in water bodies at golf courses algae must often be controlled. Controlling algae at a golf course is an ongoing effort. The presence of algae should be 'scouted' as part of the Integrated Pest Management (IPM) program at the golf course. Scouting should begin in early spring, as water is warming, and thorough records kept of the time, location, and amount of algae observed. Obtaining and graphing water temperatures in each water body and noting when algae first appear is a simple but effective management tool. These records are a management tool and review of the records can indicate locations of problem areas on the golf course and suspected time of outbreak. Once known, BMPs can be implemented at the problem areas.

Chemical applications of copper sulfate materials are effective algicides (Table 2). Chemical treatment should begin as soon as algae are seen in the ponds. Applications are best for overall aquatic protection when they treat only approximately one-third (⅓) of a water body at a time. This is because chemical treatment resulting in algal die-off can cause oxygen to fall to very low levels and cause fish kills if treatment causes a die-off of an entire bloom. For small pond treatment, applications near the edge of the pond (approximately shore to 3 ft) are very effective control mechanisms.

3.0 Aquatic Macrophytes. Overabundant rooted or free-floating macrophytes can bea major nuisance to golf course water bodies. Macrophytes can interfere with irrigationintakes and detract from aesthetic values. They can also introduce significantquantities of nutrients and organic matter to the water, perhaps stimulating algalblooms and increasing consumption of dissolved oxygen. Light and nutrients tend tobe the dominant factors controlling distribution and abundance of macrophytes.

3.1 Aquatic Macrophyte Control. Growth habit, proper identification of the plantspecies, the relative abundance, location within the lake, and age of infestation areimportant considerations when dealing with macrophyte control. These are importantconsiderations because they may provide insight into the extent of the problem andhow and when to proceed with control measures. Use of the site and fate of the waterwill determine if many of the chemical control alternatives can be considered. Time ofyear will determine how effective different treatment approaches will be.

There are a number of distinct strategies for aquatic weed control. These include the following:

(1) prevention - this could be a very important consideration in the design and construction of new water bodies;

(2) mechanical - harvesting and removing, especially at critical developmental or reproductive stages could be considered;

(3) water management - such as seasonal drawdown, although this may have limited potential;

(4) chemical control - a variety of aquatic herbicides and algicides are available. However, various characteristics of these usually limit their use to specialized sites. Additionally, effects on nontarget species must be considered. Most of the limitations on chemical control are associated with the use or potential use of herbicide-exposed water;

(5) biological control - two biocontrols that directly attack or infest plants have found some success. The use of the South American alligator weed flea beetle and moths for control of alligator weed and the white amur ("grass carp"), a herbivorous fish, which is very effective for submersed weeds such as hydrilla.

4.0 Chemical Control. Chemical control of aquatic algae and macrophytes can beconsidered for certain plant species under specific conditions. Information on the effectiveness of herbicides for aquatic weed control is included in Table 2 (*Page 76*). While eachof the materials listed is legally labeled as an aquatic herbicide, specific restrictionsmay be imposed on each chemical or even by manufacturers on specific brand names. At all times, the label must be rigidly followed when using these materials. Additionally,even under specifically allowed and controlled conditions for application, restrictions onuse of the water subsequent to application may apply. Examples of these restrictionsare given in Table 3 (*Page 78*). However, additional or more specific information may be given onthe product label.

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cific questions about their impact on water quality. These materials have been shown not to accumulate in living organism norconcentrate in the food chain (SJRWMD, 1989). Dissipation of these materials fromphotochemical reaction, microbial breakdown, and dilution is rapid.

The application rate of each of the herbicides used for aquatic weed control will vary depending on the amount of active ingredient required to effectively control the targeted weeds and the formulation. Lake volume is also another consideration. Applications are best when they treat only approximately one-third (⅓) of a water body at a time. For small pond treatment, applications near the edge of the pond (approximately shore to 3 ft.) are very effective control mechanisms.

With each herbicide information is available about use precautions and toxicological properties. Of primary concern is the effect of these materials on nontarget plants which may have been intentionally planted as wildlife habitat and the effect on nontarget wildlife. Effects on nontarget plants must be evaluated by a specialist in lake management who can accurately identify the vegetation and mechanism of action of the specific herbicide in question.

Each material listed in Table 2 will be discussed individually for effects on wildlife which inhabits or contact the aquatic environment. Data has been taken from the Herbicide Handbook of the Weed Science Society of America (1989), Weed Control Manual (1992), Farm Chemicals Handbook (1995), and "Acute and Chronic Toxicity of 75 Pesticides to Various Animal Species" (Kenaga, 1979). Values are either for LD50 - the dose (quantity) of a substance that will be lethal to 50% of the organisms in a specific test situation expressed in weight of the chemical (mg) per unit of body weight (kg); or for LC50 - the concentration of a substance in water that will kill 50% of the organisms in a specific test situation.

Fluridone. At recommended application rates concentrations in the water would range from 0.08 to 0.5 ppm. This material has been shown to be nonhazardous to birds (bobwhite oral LD50> 2000 mg/kg; bobwhite and mallard duck acute LC50 values are both >5000 mg/kg of diet). Fish have excellent tolerance at these concentration with an LC50 of 11.7 ppm for rainbow trout, 14.3 ppm for bluegill, and 10 ppm for channel catfish. Aquatic invertebrates also exhibit tolerances above these levels with values for daphnids at 6.3 ppm and midges at 1.3 ppm. No observed effect concentrations are 0.5 ppm for catfish and 0.48 ppm for fathead minnows. Communities of phytoplankton, zooplankton, benthic invertebrate organisms, and fish are unaffected at sites treated with these formulations.

Glyphosate. At recommended application rates the concentrations in the lake water would range from 0.36 to 1.8 ppm. This material has been shown to be extremely safe to wildlife. The LD50 for bobwhite quail is > 3850 mg/kg. The tolerance levels as LC50s for aquatic species are as follows: trout, 86 ppm; bluegill, 120 ppm; Daphnia magna, 780 ppm; harlequin fish, 168 ppm. None of these organisms would be especially sensitive to this material at proper application rates.

2,4-D. At recommended application rates the concentrations in the lake water would range from 0.36 to 1.5 ppm. General toxicity to wildlife and fish indicates that at 100 ppm there would be some slight mortality for fingerling bream and largemouth bass. Toxicity to rabbits is in the range of 300 to 1000 mg/kg. Some formulations are more toxic to aquatic animals and should not be introduced into aquatic environments unless specifically recommended on the label. The concentrations which would be found in lakes treated with the proper formulation of this material would not present a toxicity concern.

Copper sulfate. Calculated concentrations of copper in the water range from 0.155 to 0.4 ppm depending on the formulation. Environmental guidelines list the hazard to fish at > 1 ppm for rainbow trout and 0.884 ppm for bluegills and > 1000 ppm for pheasant. At the recommended rates this material should not pose a problem to wildlife.

Diquat. At recommended application rates concentrations in the water would range from 0.36 to 1.5 ppm. It is known to be generally safe to wildlife and fish with the LD50 for mallards at 564 mg/kg and the LC50 for bobwhite quail at 2932 ppm, rainbow trout at > 10 ppm and Daphnia at 7.1 ppm. Lake water concentrations at recommended rates would pose no environmental threat based on these tolerances.

The goal of the golf course should be prevention of unwanted algal blooms and infestations

Although algae and aquatic macrophytes can be controlled in an effective manner, the goal of the golf course should be prevention of unwanted algal blooms and infestations. Prevention is the most cost effective and environmentally compatible management practice. This requires the implementation of well-designed environmental management program that includes Best Management Practices and Integrated Pest Management strategies for protection of natural resources at the course.

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