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CRC TOURISM WORK-IN-PROGRESS REPORT SERIES : REPORT 7

INTEGRATED TURFGRASS MANAGEMENT SYSTEMS

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CRC for Sustainable Tourism

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Editors

Production editor • Sharon Solyma

Design & layout • Debbie Lau

Printer • Rolf Bernklev, Document on Demand

National Library of Australia Cataloging in Publication data

National Library of Australia Cataloging in Publication data

Integrated turfgrass management systems in golf courses.

Bibliography.
ISBN 1 1876685 24 7.

1. Turf management - Australia. 2. Turfgrasses - Fertilisers - Australia. 3. Turfgrasses - Irrigation - Australia. 4. Turfgrasses - Diseases and pests - Australia. 5. Golf courses - Maintenance - Australia. I. Hu, Xiandeng. II. Cooperative Research Centre for Sustainable Tourism. (Series : Work-in-progress report series (Cooperative Research Centre for Sustainable Tourism) ; no. 7).

635.9642

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Introduction

As stated in the project proposal, a survey was required regarding the grass species, irrigation and fertilisation practices, common pests and the current pest management practices for turfgrasses. The survey was started with interviewing some key persons in the industry. It was found that four recent surveys have been carried out in relation to this topic:

- golf course administration - by Australian Golf Union (1995),
- environmental impacts of turf industry - by former Australian Turfgrass Research Institute (1997),
- turf dieback - by Queensland Superintendents Association and Queensland Golf Union (1998),
- effluent irrigation - by Queensland Department of Natural Resources (1998).

These surveys covered most of the information relevant to turf management. It was therefore unnecessary to undertake additional surveys as part of this project.

The objectives of this project are to develop a set of practical and cost-effective techniques for the integrated turfgrass management systems (ITMS) on irrigation scheduling, fertiliser application planning, and pest control. It is necessary to develop a working definition for the ITMS and a strategic framework to guide future research. An extensive literature review on turf management practices and interactions between the practices was conducted. The working definition and framework were developed and are reported in Chapters 2 to 5 of this report. The site specific ITMS strategies will be developed in future field experiments.

Irrigation, fertilisation, and pest control along with mowing are the key practices in turf management and are closely related to each other. These practices will be studied separately first, in order to develop individual management techniques. Once the techniques are developed, they will be used to develop the strategies of the ITMS. In 1998, the fertilisation and pest management practices were studied only at a preliminary level. As yet there are no final results to be reported. The irrigation component has been studied to such a level that some methods for irrigation scheduling and cost analysis have been developed. The methods are reported in Chapter 6.

2 chapter two

Management practices of turfgrass

The objective of turf management is to maintain the quality of turfs based on aesthetics and playability. Turf quality includes visual quality and functional quality. The visual quality of a turf can be described using the six parameters listed below (Beard 1973, Turgeon 1996):

- Uniformity: a high quality turfgrass should be extremely uniform in appearance. The presence of bare areas, weeds, blemishes due to insect or disease injury, or an irregular growth habit lower the level of turfgrass quality.
- Density: is one of the more important components of turfgrass quality. Visual quality ratings are positively correlated with density. A high turfgrass shoot density or plant population is desired because of the increased competition to invading weeds.
- Texture: turfgrass texture is a function of the width of individual leaves. A medium-fine to medium texture, ranging from 1.5 to 3 mm in width, is generally preferred for most turfgrass uses.
- Growth habit: an upright or vertical positioning of turfgrass leaves is preferred on greens.
- Smoothness: is a component of turfgrass quality that is particularly important on greens. Greens should be free of obstructions or depressions.
- Colour: one of the best indicators available concerning the general condition of a turf is colour. A loss of green colour may indicate the development of nutritional, disease, insect, nematode, excessive water, wilt, or other environmental stress problems.

The functional quality is described using following eight parameters (Turgeon 1996):

- Rigidity: the resistance of the turfgrass leaves to compression, rigidity is related to the wear resistance of a turf. It is influenced by the chemical composition of the plant tissue, water content, temperature, plant size, and density.
- Elasticity: the tendency of the turfgrass leaves to spring back once a compressing force is removed. This is an essential property of any turf since some traffic is inevitable with playing, mowing and other maintenance activities.
- Resiliency: is the capacity of a turf to absorb shock without altering its surface characteristics.

- Ball roll: is the average distance a ball travels upon being released to a turf surface. Mechanical devices may be used to release the ball at a consistent speed to obtain reliable measurements.
- Yield: is a measure of clipping removed with mowing. It is an indication of turfgrass growth as influenced by fertilisation, irrigation, and other cultural as well as natural environmental factors.
- Verdure: is a measure of the amount of aerial shoots remaining after mowing. Within a particular turfgrass genotype, increasing verdure is correlated with increasing resiliency and rigidity.
- Rooting: is the amount of root growth evident at any one time during the growing season. It can be estimated visually by extracting a turf core with a soil probe or knife and carefully working the soil free with the fingers to expose the roots.
- Recuperative capacity: is the capacity of turfgrass to recover from damage caused by disease organisms, insects, traffic, and the like. Recuperative capacity varies with different turfgrass genotypes and is strongly influenced by cultural and natural environmental conditions.

Turf quality is maintained through a series of management practices. The main management practices include irrigation, fertilisation, pest management, mowing, cultivation and selection of grass species and cultivars (Beard 1973, Turgeon 1996). An outline of these management practices is provided below. The interaction between the management practices will be discussed in the next chapter.

Irrigation

Water is a vital constituent of all living plants. The water content of actively growing plants is generally 75 to 85% by weight. Young tissues are higher in water content than mature tissues because of lower dry matter contents, thin cell walls and highly hydrated protoplasm. The roots are lowest in water content, the leaves, intermediate, and stems being the highest. Water is a vital constituent of protoplasm. Death occurs if the water content of the protoplasm decreases below a critical level. The lethal water content varies with the physiological conditions of the turfgrass plants. A 10% reduction in water content from 80% to 70% may be sufficient to cause death. The water also functions as a transport medium or solvent by which nutrients, organic compounds and gases enter and move through turfgrass plants. The water is also required by the beneficial bacteria and fungi involved in thatch decomposition (Beard 1973).

Rainfall provides a significant amount of water for turf growth. However, rainfall does not fall evenly during a year and in arid regions may not provide sufficient water for turf requirements. Irrigation is required to provide the water for turfgrass during the dry period between rainfalls, ensuring an adequate supply of moisture for turfgrass growth. Turf is also irrigated to wash in fertilisers and some pesticides following their application. This maintains sufficient surface moisture to promote germination of interseeded turfgrasses, and to modify turfgrass tissue temperatures on hot days (Turgeon 1996). Irrigation also provides water to wash soluble salts out of the root zone, and controls salinity.

Irrigation practices represent one of the most difficult aspects of turfgrass culture. Important considerations in developing an irrigation program include:

- When to irrigate
- Irrigation frequency
- Quantity of water to apply
- Water source
- Water quality
- Method of irrigation

These will be discussed in detail in Chapter 5 and separate reports.

fertilisation

Turfgrass requires a number of macro- and micronutrients to function properly. Macronutrients include:

- Nitrogen
- Phosphorus
- Potassium
- Calcium
- Magnesium
- Sulfur

Micronutrients include:

- Iron
- Manganese
- Copper
- Zinc
- Molybdenum
- Boron
- Chlorine

The nutrients have a number of vital functions in plant growth and development such as (a) constituents of living tissues, (b) catalysts in certain biochemical reactions, (c) influencing the cell osmotic pressure, (d) influencing the acidity of plant tissues, and (e) affecting membrane permeability to nutrient uptake and transport (Beard 1973). A deficiency of any one nutrient element can seriously impair the overall growth and developmental processes.

Natural soils are usually not able to provide adequate levels of all nutrients for turfgrass growth. Fertilisers are therefore required to supplement the nutrient deficit. Fertilisation ranks with mowing and irrigation as a primary determinant of turfgrass persistence and quality.

Fertilisers of turfgrass include all materials containing one or more essential plant nutrients that are added to the soil to increase the supply of available plant nutrients for the purpose of maintaining satisfactory turfgrass quality. They may be the fertilisers from factories, reclaimed water, or from organic material.

The role of each essential nutrient in plant growth and development is quite different. For example (Beard 1973):

- Nitrogen nutrition can affect a turf in (a) shoot growth, (b) root growth, (c) shoot density, (d) colour, (e) disease proneness, (f) heat, cold, and drought hardiness, (g) recuperative potential, and (h) composition of the turfgrass community.
- Phosphorus affects turf in (a) establishment, (b) rooting, (c) maturation, and (d) reproduction. It is particularly vital during the seedling stage of turfgrass growth and development. It also stimulates root growth and branching. Higher phosphorus levels hasten maturity, while a phosphorus deficiency delays maturity. Seed setting is also enhanced by higher phosphorus levels. A phosphorus deficiency causes a reduction in the tillering, shoot growth, and moisture content of ryegrass shoots.
- Potassium influences turfgrass (a) rooting; (b) drought, heat, and cold hardiness; (c) disease proneness; and (d) wear tolerance.
- Calcium affects meristematic activity. Nonlimiting calcium levels enhance root growth, particularly root hair development. Calcium ions also exert a strong influence on the absorption of other ions by turfgrass plant. Specially, the uptake of potassium and magnesium is modified by the concentration of calcium ions. A calcium deficiency results in increased proneness to red thread and Pythium blight.
- Magnesium functions in several vital physiological processes within the plant such as (a) being a constituent of chlorophyll, (b) the translocation of phosphorus, and (c) cofactors of many plant enzyme systems.
- Sulfur works primarily as a constituent of certain essential amino acids such as cystine, cysteine, and methionine, which are required for protein synthesis. It is also a constituent of certain other important organic compound in plants such as thiamine and biotin. A sulfur deficiency in Kentucky bluegrass increases powdery mildew disease development.

With the exception of molybdenum and chloride, micronutrients become highly insoluble in alkaline soils, while, under acidic conditions, solubility is so high that many micro-nutrients are actually toxic to turfgrass. Other conditions that promote micronutrient deficiencies include high soil-phosphate levels, high concentrations of soil organic matter, excessive thatch accumulation, and poor drainage (Turgeon 1996). Usually, the best ways to avoid micronutrient deficiencies are to ensure that the soil is maintained within a suitable pH range and to limit applications of lime and phosphates to levels necessary for sustaining optimum turfgrass growth (Turgeon 1996).

The primary objective in applying fertilisers is to supply nutrients that are deficient in the soil in order to maintain turfgrass quality. In addition, fertilisers influence other soil properties including the soil reaction and indirect effects on the structure and micro-organism population. The indirect effects are usually related to increases in the soil organic matter content. An effective fertiliser program involves determination of the fertility requirement followed by selection of appropriate fertiliser carriers, application rates, and the time of application (Beard 1973).

Pest management

Even if turf is provided with enough water and nutrients, its quality can be damaged significantly by pests. One of the most important components of turfgrass quality is uniformity. The presence of weeds in a turfgrass community disrupts the uniformity due to the variability in leaf width, colour, and growth habit. Similarly, turfgrass injury caused by diseases, insects, nematodes, and other small animals both disrupts the uniformity of the turf and may result in a substantial reduction in shoot density. Because of the objectionable nature of these turfgrass pests, pest management practices are implemented to discourage them.

Pests are any organisms causing a measurable deterioration in the aesthetic or functional value of a turf, including weeds, disease-causing organisms, some insects, and other destructive organisms. The means for controlling different pests vary. For example, weeds are visual plant species that can be removed by physical methods such as hand removal or by chemicals that kill the weeds. Diseases are usually controlled by chemicals.

Pesticides are considered as important means for achieving pest control. Pesticides refer to manufactured organic compounds and biochemical control agents for use in turfgrass management. They include all insecticides, fungicides, herbicides, nematicides, miticides, rodenticides, fumigants, and other organic chemicals used to control or reduce the adverse effects of pests. In the last 40 years, these chemicals have become a major component of agricultural, forestry and turfgrass management systems. The use of chemical control of turfgrass pests in conjunction with nutrient and cultural practices has had tremendous effects on the function and quality of turfgrass grown for golf courses and lawns. The chemical control of pests is the primary technique used on golf courses to promote sustained turfgrass quality and to reduce labour and energy costs. Under conditions of massive insect, disease or weed infestation, chemical pest control is often the only effective option.

Pesticides are valuable components of a turfgrass cultural program and the importance of pesticides for protection of high-quality turfgrass on golf courses and lawns has been well documented. The use of pesticides has however created concerns based on environmental issues and human health risks. Although the turf industry has not yet been targeted, the Australian cotton industry was recently audited on its pesticide application and economic impacts of this. Therefore, pest management includes more than simply selecting and applying the appropriate pesticide to control specific organisms. A properly maintained and healthy turfgrass will tolerate the presence of low-level pest populations without suffering permanent damage. It is possible to reduce pesticide application without reducing turf quality. Integrated pest management (IPM) is an approach now strongly recommended for pest control in agricultural and turfgrass systems to minimise pesticide application.

The IPM is an approach that utilises the most appropriate cultural, biological, and chemical strategies for managing plant pests. There are still no mature techniques that can be used to develop an IPM for a specific golf course. An IPM strategy may consist of a range of tactics, including selecting turfgrass species that are well adapted to prevailing environmental conditions, following proper establishment procedures, and conducting a cultural program that favours healthy turfgrass growth.

Mowing

Mowing is a defoliation process in which a portion of turfgrass leaf is removed. Mowing is the most fundamental and universal practice utilised in turfgrass culture. It provides a uniform surface for ornamental beautification and for many outdoor sport and recreational activities. Several variables in the mowing program influence turfgrass quality. These include the height, frequency, and pattern of mowing. Each type of turfgrass has a mowing tolerance range that is expressed as the lowest and highest tolerated mowing heights. In addition, turfgrass quality and cultural requirements can be affected by the removal or return of clippings during mowing (Turgeon 1996).

There are three principal types of mowers (Turgeon 1996): the reel, rotary, and flail. The reel mower consists of a rotating reel cylinder equipped with blades and a stationary bedknife. The reel blades guide leaves toward the bedknife, where they are cut by a shearing-type action. The rotary cuts by impact as the horizontally mounted blades rotate about a vertical shaft. The flail mowers consist of numerous small knives hinged to a horizontal shaft. When the shaft rotates, the knives are held out by centrifugal force. Due to the small clearance between the knives and the mower housing, cut debris is recut until it is small enough to clear the housing.

The reel mowers can cut turfgrass at the highest possible mowing quality and are widely used on golf courses, athletic fields, parks, sod farms, and many commercially maintained lawn sites. The rotary mowers can cut high and rough grasses although the cut may not be as sharp as with a reel mower. The rotary mowers are usually used on utility turfs. The flail mowers are impact-type cutting facilities and are used on utility turfs only.

Cultivation

Cultivation refers to mechanical methods of selective tillage that modify physical and possibly other characteristics of a turf. Cultivation practices are primarily designed to reduce problems associated with excessive thatch and soil compaction; however, some practices are also effective in reducing grain in greens. The principle types of cultivation are coring, slicing, spiking, vertical mowing, and water injection cultivation (Turgeon 1996).

Selection of turfgrass species

Turfgrasses are selected for planting based on a variety of considerations. The anticipated persistence and quality of the turf and the rate of establishment are of primary importance.

The characteristics of some common turfgrass species are listed in Tables 1 and 2. The tables can be used to select the required species following these steps:

- Identify the climate conditions (temperature, rainfall)
- Identify the growth environment (shade, water table, flood)
- Identify the water sources for irrigation and its quality (salinity, acidity, fertility)
- Identify the required turf quality
- Arrange the priority of above parameters for species selection
- Find the best turfgrass species in the table

Table 1

COOL-SEASON TURFGRASS PROPERTIES (DATA FROM TURGEON 1996)

	Colonial bentgrass	Fine fescues	Kentucky bluegrass	Perennial	ryegrass	Tall fescue
Establishment rate (1 - fastest)	5	4	3	6	1	2
Leaf texture (1 - coarsest)	4	5	6	3	2	1
Short density (1 - highest)	2	1	3	4	5	6
Cold tolerance (1 - highest)	3	1	4	2	5	6
Heat tolerance (1 - highest)	4	2	5	3	6	4
Drought tolerance (1 - highest)	5	6	3	1	4	2
Shade tolerance (1 - highest)	2	4	1	5	6	3
Soil acidity tolerance (1 - highest)	3	4	2	6	5	1
Submersion tolerance (1 - highest)	3	1	6	4	5	2
Salinity tolerance (1 - highest)	6	1	4	5	3	2
Mowing height adaptation (1 - highest)	5	6	2	4	3	1
Mowing quality (1 - best)	2	3	5	1	6	4
Fertility requirement (1 - highest)	2	1	6	3	4	5
Disease potential (1 - highest)	2	1	3	4	5	6
Thatching tendency (1 - highest)	2	1	4	3	5	6
Wear resistance (1 - highest)	6	5	4	3	2	1
Recuperative capacity (1 - highest)	6	1	5	2	4	3
	Colonial bentgrass	Fine fescues	Kentucky bluegrass	Perennial	ryegrass	Tall fescue

Note: rated within a range of 1 - 6, with 1 being the most favourable.

Table 2

WARM-SEASON TURFGRASS PROPERTIES (DATA FROM TURGEON 1996)

	Bahia-grass	Bermuda-grass	Carpet-grass	Centipede-grass	St Augustine-grass	Zoysia-grass
Establishment rate (1 - fastest)	3	1	5	4	2	6
Leaf texture (1 - coarsest)	3	6	1	4	2	5
Short density (1 - highest)	6	1	5	4	3	2
Cold tolerance (1 - highest)	3	2	5	4	6	1
Heat tolerance (1 - highest)	6	2	3	4	5	1
Drought tolerance (1 - highest)	3	1	6	5	4	2
Shade tolerance (1 - highest)	5	6	4	6	1	2
Soil acidity tolerance (1 - highest)	6	3	1	2	5	4
Submersion tolerance (1 - highest)	2	1	4	6	3	5
Salinity tolerance (1 - highest)	4	1	5	6	3	2
Mowing height adaptation (1 - highest)	1	6	3	4	2	5
Mowing quality (1 - best)	6	2	4	3	1	5
Fertility requirement (1 - highest)	6	1	5	4	2	3
Disease potential (1 - highest)	5	2	4	6	1	3
Thatching tendency (1 - highest)	6	1	5	4	2	3
Wear resistance (1 - highest)	3	2	5	6	4	1
Recuperative capacity (1 - highest)	3	1	4	5	2	6
	Bahia-grass	Bermuda-grass	Carpet-grass	Centipede-grass	St Augustine-grass	Zoysia-grass

Note: rated within a range of 1 - 6, with 1 being the most favourable.

3 chapter three

Interaction between management practices

The main turf management practices have been outlined and briefly discussed in Chapter 2. These practices are closely interrelated. In this chapter, the relationships between different management practices and their effects on turf quality are discussed. As this project concentrates on irrigation, fertilisation and pest management only, the interactions of these management practices with each other and with other practices (mowing, cultivation and grass species) are the main concerns of this chapter.

i Irrigation and fertilisation

Nutrients can change the water performance of turf systems. Nitrogen fertilisation stimulates rapid shoot growth, enlarges cell size, increases tissue hydration, and finally increases the total water use of turfgrasses. Nitrogen deficiencies result in reduced hardiness. High nitrogen levels increase proneness to wilting and desiccation. Potassium deficiency will reduce drought hardiness.

On the other hand, irrigation affects nutrient dynamics and transport within and outside of the turfgrasses. The soil moisture content influences the ion diffusion rate into the "outer space" of roots. Turfgrasses can only take up nutrients present in soil solution, not those adsorbed by soil colloids. Consequently, it is important to have adequate but not excessive concentrations of nutrients present in soil solutions. Water enables nutrients to enter and move through the turfgrass. Irrigation provides the water as the transport medium or solvent for nutrients to function properly in the turf during the dry season. Irrigation also provides the major medium by which nutrients transport out of a target site through surface runoff, leaching and volatilisation as nutrient losses.

Runoff loss of nutrients includes those nutrients dissolved in water and those absorbed by soil particles moved by the runoff and suspended as sediment. The runoff losses can be greatly reduced if:

- Occurrence of runoff is delayed after nutrient application
- Rainfall or irrigation leaches the nutrients beneath the soil surface prior to occurrence of runoff
- Nutrient sources are incorporated into the soil
- The application rate is limited by the amount required for turf productivity, as determined by soil testing and nutrient budgets
- Nutrient sources are applied at the time required for crop growth
- Residue and cultivation are implemented to reduce the volume of both runoff sediment and water.

Nutrients lost by leaching are mainly in a dissolved format. The nutrients are dissolved in soil water moving below the rooting zone, which shifts the nutrients to ground water. Leaching losses can also be a diffusive transport of solutes from higher to lower concentration locations within the soils. The nonadsorbed anion, nitrate, is the principal nutrient concerned in leaching losses. Even nutrients with a high potential to be adsorbed by soils such as phosphorus may be lost in soils with high permeability. Since potassium salts are readily soluble in water, leaching losses can be substantial in sandy soils of low cation exchange capacity. Many calcium minerals are fairly soluble and adequate moisture favours continual dissolving and leaching. Magnesium is susceptible to leaching in sandy soils, but losses are usually not as rapid as calcium due to the relatively low solubility of magnesium minerals. The extent of leaching losses depends on the amount of precipitation and irrigation, temperature, and soil texture. Excessive application of water-soluble nitrogen fertilisers should be avoided to minimise the leaching of nitrates that can contribute to nitrate pollution of ground water, streams, and lakes.

Volatilisation losses occur when nutrients are converted into gaseous forms and lost to the atmosphere. Ammonia is the nutrient of main concern with respect to volatilisation losses, and the extent of loss is influenced by N fertiliser type, fertiliser placement and post-application position as determined by precipitation and irrigation. It was found that 36% of applied ammonia volatilised when no irrigation followed the surface application. Whereas 1-4 cm of water within 5 min of application can reduce ammonia volatilisation from urea to between 8 and 1%. Irrigation after application also affects the urea position in the turf. Movement of urea into the soil and conversion to ammonium and nitrite can reduce initial volatile losses of nitrogen.

Therefore, nutrient and irrigation management practices are especially important for increasing nutrient use efficiency and reducing nutrient losses from the turf.

Irrigation and pest management

Water is a significant factor in weed seed germination. Excessive irrigation beyond the requirement of the turfgrass plant is undesirable as it can stimulate weed encroachment. A waterlogged soil condition restricts turfgrass growth and vigour due to the lack of soil aeration. Some turfgrass weeds, however, are more tolerant of these conditions. For example, germination of annual bluegrass, crabgrass, chickweed, and sedge is favoured by very moist conditions. Subsequent shoot growth of these weeds is substantially enhanced by moist to wet soil conditions. In contrast, weeds such as the cinquefoils and quackgrass can compete more favourably with the desirable turfgrass species under droughty conditions (Beard 1973).

A high atmospheric water vapour content favours the penetration and infection of certain turfgrass pathogens. Most fungi require a high relative humidity for mycelial growth and the production of spores. The activity of brown patch, Fusarium patch, powdery mildew, slime mold, Pythium blight, copper spot, dollar spot, red thread, and Typhula blight is stimulated by a high atmospheric water vapour content (Beard 1973).

Disease development in certain turfgrasses is influenced by plant water deficits. For example, the Pythium blight susceptibility of Highland colonial bentgrass increases under soil moisture stress. Similarly, soil moisture stress increases the dollar spot susceptibility of Kentucky bluegrass. The crown and root rot phases of many Helminthosporium diseases are favoured by water stress. In contrast, soil moisture stress reduces the leaf spot phase of Helminthosporium sativum on Kentucky bluegrass. Also, Rainier red fescue is more tolerant of red thread when grown under soil moisture stress (Beard 1973).

Since surface and subsurface drainage and irrigation are directly related to the atmospheric water vapour content near soil surface and soil moisture condition, proper drainage and irrigation practices should be maintained to minimise disease development in turfgrass systems. A proper frequency and intensity of irrigation will provide a controlled shoot growth rate that enables the turf to resist and rapidly recover from disease. Applying an excessive amount of water or irrigation too frequently increases susceptibility to disease.

The timing of irrigation may also influence disease development. If possible, turfs should be irrigated when the evaporation of water droplets from the shoots is most rapid. Irrigation during the evening period usually permits the water droplets to remain on the leaves for an extended period of time compared to early morning irrigation. As a result, evening irrigation may increase the likelihood of spore germination, growth, and penetration into the host (Beard 1973).

Excessive water irrigation applications that saturate the soil cause an increased frequency and intensity of leaf exudate formation. Early morning syringing is beneficial because it removes the leaf exudates and disperses dew droplets so that the leaf surface dries more rapidly. Thus, syringing can be used to minimise conditions favourable for spore germination and mycelial growth. Midday syringing, which lowers turfgrass temperatures, can be used to reduce the likelihood of infection from high temperature pathogens (Beard 1973).

When pesticides are used for controlling pests, their fate and persistence are greatly influenced by water management practices. Pesticides begin to disperse from the target area immediately after application. Dispersal occurs through the action of air, water and degradation. The entry of pesticides into environment and the partitioning of pesticides to soil, atmosphere, groundwater, and surface water is determined by innumerable interacting factors and conditions. The critical factors may be classified by their impact on four dominant processes (Balogh and Anderson 1992):

- Volatilisation
- Adsorption
- Decomposition
- Water transport

All of these processes are closely related to water and are summarised below.

Volatilisation: irrigation and precipitation indirectly influence the volatilisation of pesticides. The water from irrigation and rainfall will transport pesticides away from the soil surface and volatilisation sites. Volatilisation of soluble pesticides is limited by the degree of chemical leaching into the soil. The intensity and spacing between irrigation periods will affect the duration of the evaporation cycle. This in turn affects the upward transport and deposition of pesticides at the soil surface. High-frequency irrigation will most likely significantly decrease volatilisation of incorporated pesticides (Balogh and Anderson 1992).

Adsorption: soil water content influences the extent of adsorption by:

- Modifying the solution pathway leading to adsorptive surface and
- Modifying the solution concentration in comparison to the concentration on the adsorptive surfaces.

Usually, the influence of soil water content on adsorption is not strong until the soil is very dry. Pesticide adsorption increases dramatically when soils are very dry (Balogh and Anderson 1992).

Decomposition: water is required for the growth of micro-organisms responsible for degradation of pesticide residue. An over supply of soil moisture will reduce gas exchange, limit soil oxygen content by microbial depletion, and thus reduce aerobic microbial activity and create anaerobic soil conditions. Soil water content also influences the concentration of soluble pesticide in solution. Decreasing levels of soil moisture increase adsorption and sequestering of residues from degradation. Increasing moisture levels will decrease pesticide concentration in solution, possibly reducing the rate of biotransformation. However, decreased solution concentration will dilute the concentration of toxic levels of pesticide residues, potentially increasing the rate of degradation (Balogh and Anderson 1992).

Transport: the highest concentration of pesticides in runoff occurs during the first event after pesticide application. After initial losses, pesticide concentration and availability at the soil and turfgrass surfaces dissipate, often exponentially with time. The intensity, duration, amount and time of rainfall or irrigation are very important in affecting pesticide entrainment and transport in runoff. Increasing intensity increases the rate of runoff water and energy available for pesticide extraction and transport. Duration and amount affects runoff volume, subsurface soil leaching and pesticide wash-off from foliage. Runoff concentrations increase as time to runoff decreases (Balogh and Anderson 1992).

Irrigation and mowing

Within the mowing tolerance range of a turfgrass, reducing the mowing height results in substantial physiological and morphological changes in the turfgrass. Some effects of closer mowing include stimulated aerial shoot growth, increased shoot density and smaller shoot size, decreased root and rhizome growth, decreased synthesis and storage of carbohydrates, and increased plant succulence. Closer mowing thus produces a turf that is esthetically more pleasing but that is less tolerant of environmental stresses, more disease prone, and generally more dependent on a carefully implemented cultural program. The shorter root system requires more frequent irrigation and fertilisation to compensate for the plants' reduced ability to secure moisture and nutrients from the soil. The larger number of smaller shoots are under considerably greater competitive stress and thus are less tolerant of other stresses, including heat, cold, drought, pathogens, insects, traffic, and an array of chemicals applied as part of the cultural program. Closely mowed turfs can be successfully sustained, but the technical expertise required of the turf manager is greater than for the same turfs maintained at higher mowing height (Turgeon 1996).

The water use rate increases as the cutting height is raised. A reduction in the leaf area causes a decrease in the total transpiration rate per plant, but the water loss rate per unit of leaf area actually increases. Cutting with a dull, improperly adjusted mower mutilates the leaf tissue and increases the water use rate of the turf (Beard 1973).

Irrigation and cultivation

The water that falls on the turf surface from irrigation or rainfall will separate into two parts: runoff and infiltration. The runoff is determined by the water falling intensity and maximum infiltration rate. If the falling intensity is greater than the infiltration rate, runoff will occur. A regular and deep cultivation will increase the infiltration rate and reduce runoff. The water storage capacity of soils will increase as a result of the cultivation. With higher soil water storage capacity, irrigation frequency and evaporation loss can be reduced, increasing total water use efficiency.

Excessive irrigation may result in waterlogged turfs and elevate the water vapour content within or near the turf. A higher drainage capacity is required to move the water out of the root zone in an excessive irrigation situation.

Irrigation and grass species

Turfgrass species and cultivars vary in the amount of water required. The water use rate of a chewing fescue turf is much less than Kentucky bluegrass, while the rate for Washington creeping bentgrass is slightly less than for Kentucky bluegrass (Beard 1973). An irrigation program should be designed to match the water use of different turfgrass species.

Drought tolerance is an extremely important criterion for selecting a turfgrass where irrigation cannot be provided during extended periods of inadequate rainfall. Within the zones of cool season turfgrass adaptation, fine fescues provide excellent drought tolerance in cool regions while tall fescue is preferred in warmer regions. Bentgrass is highly dependent on a frequent irrigation regime during dry periods, especially when temperatures are high. Warm-season turfgrasses may lose colour during an extended drought, but they will usually survive within their zones of adaptation (Turgeon 1996).

Turfgrasses are frequently planted on flood plains and on slopes adjacent to water bodies where temporary submergence under water occasionally occurs. This condition frequently results in the loss of Kentucky bluegrass and zoysiagrass turfs. However, creeping bentgrass is quite tolerant to flooding, and tall fescue is valuable for use in drainage ditches along roadsides. Among the warm-season grasses, bermudagrass and bahiagrass are outstanding in their submersion tolerance (Turgeon 1996).

Along highways and sidewalks, calcium and sodium chlorides are sometimes used to melt snow and ice, and subsequent runoff of these salts may result in the death of adjacent turfgrasses. Some sources of irrigation are high in salts, resulting in saline soil conditions in the irrigated turf. In dry climates, salts are brought to the soil surface in conjunction with upward water movement in response to evaporation and transpiration. Turfgrass tolerance of soil salinity varies with species and cultural factors. Creeping bentgrass and tall fescue are cool-season grasses with good salinity tolerance. Among the warm-season species, seashore paspalum, bermudagrass, zoysiagrass, and St. Augustinegrass are quite tolerant of saline soil conditions (Turgeon 1996).

fertilisation and pest management

The development of weeds, diseases and nematodes in turfs is closely related to nutrient management. A nutrient deficiency favours the invasion of broadleaf weeds due to the thin turf and resulting lack of competition. On the other hand, intensive fertilisation and irrigation practices encourage the encroachment of certain weeds such as annual bluegrass, bermudagrass, crabgrass, and creeping bentgrass (Beard 1973).

Turfgrasses need a minimum level of essential nutrients in the proper balance to resist and recover rapidly from disease. A balanced level of nutrition should provide a controlled shoot growth rate, a deep extensive root system, and good recuperative potential. The timing of fertiliser applications should also be considered in relation to potential disease development. For example, early autumn applications of nitrogen fertiliser can cause an increased incidence of Typhula blight compared to earlier or later nitrogen applications. The type of nitrogen carrier used can also influence the degree of disease development. Fertilisation with activated sewage sludge reduces the severity of dollar spot on bentgrass and Pythium blight on ryegrass in comparison to the use of soluble nitrogen carriers (Beard 1973).

Excessively high nitrogen levels may increase the susceptibility of turfgrasses to certain pathogens such as Fusarium, Helminthosporium, Ophiobolus, Piricularia, Rhizoctonia, and Typhula. Fasarium patch and brown patch are particularly destructive at excessive nitrogen levels, because the cell walls of the turfgrass hosts are thinner and more easily penetrated by fungal hyphae. Excessive nitrogen fertilisation in summer can predispose Kentucky bluegrass, bentgrasses, and other turfgrasses to severe incidences of Pythium blight (Turgeon 1996). Excessive amounts of nitrogen also increase the succulence of the tissue, as well as the glutamine content and frequency of leaf exudates (Beard 1973).

In contrast, the development of other turfgrass diseases caused by such fungal pathogens as Corticium, Puccinia, and Sclerotinia is particularly severe at low levels of nitrogen nutrition. Dollar spot is most severe on inadequately fertilised turfgrasses; besides regular fungicide use on greens, a major control measure being the implementation of an adequate nitrogen fertilisation program (Turgeon 1996). Generally, rust is more serious on turfgrasses with reduced rates of growth due to inadequate nitrogen fertilisation, insufficient water, or other growth-limiting factors (Turgeon 1996).

Potassium, phosphorus, calcium, and iron levels also influence turfgrass disease development. Adequate potassium levels are important in reducing the disease proneness of turfgrasses. For example, high potassium levels apparently reduce the incidence of brown patch, dollar spot, Fusarium patch, Helminthosporium species, Ophiobolus patch, and red thread. Optimum phosphorus levels stimulate root development and reduce the susceptibility of turfgrasses to seedling damping-off diseases. High calcium levels tend to reduce the susceptibility of turfgrasses to certain diseases including Pythium blight and red thread. An application of iron is reported to reduce the severity of Fusarium patch (Beard 1973).

The type of nitrogen carrier used is reported to affect nematode populations. Activated sewage sludge causes a reduction in the nematode population when compared to inorganic nitrogen carriers. It is thought that the organic nitrogen carrier enhances the development of predators that kill or are antagonistic to parasitic nematodes (Beard 1973).

Soil chemistry can be an important factor in the encroachment of certain turfgrass weeds. Soils with a neutral pH favour annual bluegrass. Red sorrel and bentgrass grow best on relatively acidic soils. Certain other species such as knotweed can grow under relatively wide ranges of pH levels (Beard 1973).

Annual bluegrass, bermudagrass, and creeping bentgrass are turfgrass weeds that respond to a high soil fertility level. The level of specific nutrients can also influence weed encroachment. Clover is favoured by high potassium levels, while annual bluegrass responds to high phosphorus levels. Soil aeration is also a factor in the encroachment of certain turfgrass weeds. Annual bluegrass and knotweed are adapted to compacted soils with poor aeration (Beard 1973).

The degree of soil acidity can affect pathogens directly and in turn, influence turfgrass disease development. Most parasitic soil fungi are favoured by an acidic soil pH of less than 6. Neutral and alkaline soil pH's increase the incidence of some diseases such as Ophiobolus patch and Fusarium Patch (Beard 1973).

Soil chemistry also directly influences the disease susceptibility of turfgrasses. The turfgrass root system is restricted under extremely alkaline or acidic soil conditions, and the availability of essential nutrients is reduced to the extent that the plant is weakened and susceptible to fungal infections. Soil pH also influences the activity of saprophytic soil organisms that directly or indirectly affect the pathogen population (Beard 1973).

Fertilisation and pest management

Mowing height affects the growth of roots and other organs of turfgrass plants as well as the consequent capacity of the plant community to absorb available nutrients from the soils. Turfgrasses that are closely mowed (ie. at a height near the lower limit of their mowing tolerance range) should receive smaller quantities of quickly available nitrogen. Closely mowed grass is often so dense that fertiliser particles cannot fall into the turf; instead, they are retained on the foliage (Turgeon 1996). More frequent fertilisation is also required by closely mowed grass as its roots are shorter.

Turfgrass biomass contains all the nutrients required for turfgrass growth. When clippings are retained on site, the biomass decomposes and releases a range of nutrients. Clipping removal, where practiced, is an important nutrient output avenue, and additional nutrients from fertilisation are required to compensate for the loss (Turgeon 1996).

Excessive fertilisation increases grass growth and yield, thus necessitating more frequent mowing.

fertilisation and cultivation

Deep cultivation permits greater penetration of the more immobile fertiliser and lime materials into the soil, which encourages deeper, more extensive rooting. Deep cultivation can however, substantially influence nutrient movement below the root zone as a leaching loss, resulting in more fertiliser requirements.

fertilisation and grass species

The frequency and intensity of fertilisation and the composition of a turfgrass fertilisation program depend on numerous genotypic and environmental factors. The particular turfgrass genotype (species and cultivar) influences the amount of nitrogen and other nutrients required to sustain the growth. Some turfgrasses, such as red fescue and centipedegrass, have relatively low fertilisation requirements; others grow best where moderate to high rates of fertiliser nutrients are applied (Turgeon 1996).

The composition of a turfgrass community is sometimes influenced by the level of nitrogen nutrition. A typical example is a Kentucky bluegrass-red fescue community where Kentucky bluegrass tends to dominate at higher nitrogen levels while red fescue becomes dominant under minimal levels of nitrogen nutrition. Similar responses occur within blends as well as mixtures. For example, Merion Kentucky bluegrass is favoured by a higher nitrogen fertility level, while Kenblue responds more favourably to a lower nitrogen level (Beard 1973).

Turfgrasses vary in phosphorus absorption. Kentucky bluegrass ranks quite high, whereas cartpetgrass, bahiagrass, and bermudagrass are relatively low (Beard 1973). The zinc content of Kentucky bluegrass seeds is quite high (Beard 1973).

Pest management and mowing

Mowing generally enhances disease development. Wounds produced at the leaf tips serve as major avenues for the penetration of many fungal pathogens such as Rhizoctonia and Fusarium. Exudations from the wounds form droplets containing nutrients that enhance spore germination and mycelial growth. Disease development increases with an increased mowing frequency. Spore dissemination is also facilitated by mowing, particularly when greens are mowed in early morning. The pattern of Pythium disease development is affected by the mowing direction (Beard 1973).

Height of cut is another aspect of mowing that may affect the development of turfgrass disease. A close cutting height that weakens the turf frequently results in increased weed problems, due to the reduced competitive ability of the turf. For example, creeping bentgrass, bermudagrass, and annual bluegrass encroachment into Kentucky bluegrass or St. Augustinegrass is significantly enhanced by close cutting. Close mowing also assists in seed germination and seedling growth of crabgrass and goosegrass since it increases light penetration to the soil surface (Beard 1973). Thus, increased cutting heights and adequate fertility levels maintain high shoot densities and active growth rates for turf. This impairs weed encroachment due to limited light penetration to the soil surface (Beard 1973). A close cutting height frequently results in increased susceptibility to disease injury, particularly from Helminthosporium, Puccinia, Phizoctonia, and Sclerotinia species. The increased shoot density occurring at short cutting heights contributes to a higher water vapour content within the plant community. Also, individual plants within a closed cut turfgrass community are relatively small, have a restricted rooting depth, and are reduced in overall plant vigour. The net result is increased susceptibility to disease injury. In addition, bridging of mycelium from leaf tip to leaf tip across a turf is generally much more rapid under close, frequent mowing than in comparable, higher cut turfs (Beard 1973).

Defoliation resulting from mowing can be beneficial to turfs having a rapid rate of vertical leaf extension. Some parasitic fungi that penetrate through wounds at the leaf tip have a relatively slow rate of downward infection to the meristematic tissues. In such cases, the infected leaf tips may be removed by mowing while the lower, disease-free tissues continue to grow (Beard 1973).

The removal of diseased clippings from a turf can reduce the amount of inoculum available for current and future pathogen activity. This does not imply that the inoculum supply will be eliminated, but only that the relative amount of inoculum present can be substantially reduced under certain conditions. This may reduce the likelihood of severe disease development, especially for fungi that are unable to grow in the thatch, but can survive on the clippings as dormant structures. A typical example occurs with Helminthosporium species. The removal of disease-free clippings may also be important, especially for soil-inhabiting pathogenic fungi that are able to colonise these substrates for readily decomposable sugar-containing compounds. Pythium and Rhizoctonia are common examples of the latter situation (Beard 1973).

Pest management and cultivation

Soil factors influencing weed survival and competitive ability are (Beard 1973):

- Soil reaction
- Water content
- Fertility
- Aeration
- Temperature

Cultivation practices such as coring, which improve soil aeration and encourage the growth of desirable species, impair the relative competitive ability of such turfgrass weeds as annual bluegrass and knotweed. The timing of cultivation and vertical mowing practices in relation to the optimum weed seed germination periods is particularly important. For example, vertical mowing in early autumn when annual bluegrass seed germination is quite intense results in a substantial increase in annual bluegrass encroachment (Beard 1973).

Pest management and grass species

Disease proneness, in particular, must be considered in selecting a turfgrass species for use on a specific site. Grasses that have a high potential for disease incidence may require frequent treatment with various fungicides. Closely mowed creeping bentgrass and bermudagrass turfs may require fungicide spraying to prevent the occurrence of dollar spot, brown patch, and other diseases. Tall fescue and centipedegrass are relatively disease free (Turgeon 1996).

Where disease resistant cultivars are available, they can be substituted for susceptible ones. For example, substituting Warren's A-20 Kentucky bluegrass for Merion can result in a reduction of stripe smut, powdery mildew, stem rust, and possibly summer patch diseases (Turgeon 1996).

Cultivars within certain turfgrass species may differ substantially in their relative susceptibility to various diseases. Converting from Kentucky bluegrass to perennial ryegrass may result in reduced problems from summer patch, Drechslera leaf spot, powdery mildew, stem rust, and smuts, but increased problems are likely from anthracnose, Drechslera brown blight, Phythium blights, brown patch, crown rust, and Typhula blight (Turgeon 1996).

The use of shade-adapted turfgrass species and cultivars is preferable for sustaining powdery mildew-free turf (Turgeon 1996).

4 chapter four

Environmental impact of the turfgrass industry

Turfgrasses are frequently maintained in highly populated areas and involve significant land use and intensive management practices. Previous discussion has indicated that numerous cultural, physical, and chemical management strategies have been used as cost-effective tools to meet the requirements for facilities with high-quality turfgrasses. Statistical data indicated that US$24,552.4 million had been spent in 1982 on

Table 3

SUMMARY OF EXPENSES ON FLORDIA GOLF COURSES (FROM HAYDU ET AL 1997)

	1974				1994			
Expenses Category	9 holes	18 holes	18+ holes	Total	9 holes	18 holes	18+ holes	Total
	MILLIONS OF DOLLARS							
Materials	0.60 (18%)	7.02 (17%)	2.23 (16%)	9.85 (17%)	1.27 (18%)	115.67 (22%)	58.02 (24%)	174.96 (22%)
Equipment	0.93 (27%)	13.31 (32%)	4.43 (32%)	18.67 (32%)	0.55 (8%)	38.28 (7%)	19.22 (8%)	58.05 (7%)
Labour	1.55 (45%)	20.08 (48%)	6.7 (48%)	28.33 (48%)	4.55 (64%)	319.30 (60%)	138.30 (58%)	462.15 (53%)
Services	0.20 (6%)	0.15	0.20 (1%)	0.55 (1%)	0.61 (8%)	41.97 (8%)	13.21 (6%)	55.79 (7%)
Other	0.14 (4%)	1.07 (3%)	0.33 (2%)	1.54 (2%)	0.07 (1%)	19.80 (4%)	8.73 (4%)	28.06 (4%)
Total	3.42	41.63	13.89	58.94	7.05	535.02	273.48	779.55

Table 4

AVERAGE NUTRIENT APPLICATION RATES IN FLORIDA'S GOLF COURSES (FROM HAYDE ET AL 1997)

Year	Nitrogen	Phosphorus	Potassium	Total
	kg/ha			
1974	828	207	484	1519
1997	265	92	258	615
Ratio	0.32	0.44	0.53	0.40

turfgrass maintenance within the United States, with approximately 12.327 million pounds of pesticides being added (Balogh et al. 1992a). In Florida, expenditures for the golf industry as a whole grew from US$58.94 million in 1974 to US$779.55 million in 1994, about a 13-fold increase within 20 years (Haydu et al. 1997). The expense figures are broken down into their major components as shown in Table 3.

The figures in Table 3 show that the cost of materials increased from 17% in 1974 to 22% in 1994. Table 4 shows that nutrient application decreased from 1519 kg/ha in 1974 to 615 kg/ha in 1994. This means that the pesticide application must have increased, as the material costs increased and the nutrient application decreased.

Cultivation and chemical application techniques in turfgrass systems can be quite different from those employed in agricultural systems. As turfgrass chemicals are frequently added to the surface with less mixing than in agricultural systems, turfs may contribute significantly to the quality of surface water. The heavy application of pesticides and fertilisers also threatens the quality of ground water.

Few years ago, the US-EPA completed a national survey of pesticides in drinking water wells. The results are listed in Table 5. Fertiliser nutrients and pesticides appeared in the drinking water wells of many locations. It is believed that turfs and gardens in urban areas have a significant contribution to the pesticides in ground water.

Pesticide residues have been associated with adverse environmental and potential human health effects including (Balogh and Anderson 1992):

- reduction of certain predator bird populations
- appearance of detectable residues in aquatic ecosystems on a global scale
- implication of many pesticides as potential human carcinogens
- long-term contamination of soils with persistent pesticides
- contamination of drinking water, surface water, and groundwater
- destruction of nontarget organisms (fish kills and beneficial soil organism
- elevation of nonpest species to pest status
- evolution of resistant insect strains

The nitrate levels are toxic to humans and animals. The combined nutrients will contribute to blue-green algae blooms (NSW Blue-Green Algae Task Force 1992).

Table 5

SURVEY RESULTS OF US WATER WELLS CONTAINING NITRATE OR PESTICIDES (FROM BALOGH AND ANDERSON 1992)

Chemical	Estimated number*	Estimated percent*	Minium reporting limit
Nitrate	49,300	52.1	0.15 mg/L
DCPA acid metabolites	6,010	6.4	0.10 mg/L
Atrazine	1,570	1.7	0.12 mg/L
Simazine	1,080	1.1	0.38 mg/L
Prometon	520	0.5	0.15 mg/L
Hexachlorobenzene	470	0.5	0.06 mg/L
DBCP	370	0.4	0.01 mg/L
Dinoseb	25	<0.1	1.3 mg/L

*Estimates based on a nation-wide sample of 1300 community water wells and rural domestic wells representing a total of 94,600 drinking water wells at 38,800 community water systems.

A survey by the Australian Golf Union and Turfgrass Research Institute (Kaapro 1997) found the main concerns about golf courses in Australia to be:

- water pollution by nutrients and pesticide residues
- destruction of native vegetation
- excessive water use

Turfs therefore require judicious management practices to prevent the transport of sediment from urban runoff surfaces, as well as to prevent excessive fertilisation and improper pesticide application, which may lead to high a concentration of chemicals in storm-water runoff and ground water.

5 chapter five

Integrated turfgrass management systems (ITMS)

As previously discussed, numerous management practices are involved in the maintenance of turfgrass systems, all of which are closely interrelated. Some practices are good for turfgrass growth, but not for pest management and environmental pollution control. Coordination between the practices is required to maximise turf quality, and to minimise costs and environmental pollution. This is the principal idea behind integrated management systems for turfgrasses.

Integrated turfgrass management systems (ITMS) are approaches that would coordinate all management factors together to maintain the long-term productivity and quality of turfgrasses, golf course profitability, and ecological soundness of selected management options. When implementing the ITMS, the construction and management strategies of turfs are no longer employed separately, instead, they are co-ordinated to achieve the goal of the ITMS. Integrated systems approaches are the latest and most complete attempt to reduce detrimental environmental and water quality impacts (Balogh et al. 1992a).

The concepts developed for integrated crop management systems (ICM) in agriculture have been adopted for the development of ecologically sound management practices for turfgrasses. Integrated crop management is an important conceptual expansion of integrated pest management (IPM). The IPM programs developed for turfgrasses are a significant component of turfgrass management. However, traditionally defined IPM protocols are only a part of the expanded functional concept of ITMS.

The goal of the ITMS approach is to manage golf courses and turfgrasses by balancing turfgrass quality, costs, benefits, public health, and environmental quality. Critical components of integrated management systems include:

- Proper design and construction of golf courses
- Selection of appropriate turfgrass species and cultivars
- Soil management practices
- Clipping and cultivation practices
- Nutrient management
- Irrigation and drainage management
- Chemical, biological, and cultural pest management
- Soil, water, energy, and natural resource conservation during construction and maintenance

Use of integrated water, pest, and nutrient management strategies will ultimately resolve the issue of maintaining high quality turfgrasses with minimum environmental disturbance (Balogh et al 1992d).

Development of economically feasible programs compatible with long-term environmental and social goals is an essential ingredient for the success of the ITMS. Development of the ITMS programs should progress through three iterative phases:

- Basic and applied research
- Development of field programs
- Implementation and economic assessment of the field programs

Eight basic components of the ITMS have been identified as (Balogh et al. 1992d):

Role definition: Definition of the roles of all people involved in the management of turfgrasses ensures understanding of goals and promotes communication. Important individuals in the development of the ITMS on a golf course are the superintendent, members of the green and golf committees, the golf professional, the golfers, and possibly adjacent landowners. During golf course design and improvements, the golf course architect should be informed of site-specific conditions required for systematic development of the ITMS programs.

Objective establishment: Objectives for realistic cultural, water, nutrient and pest management on specific areas on the course should be established for the ITMS program. These objectives serve as the basis for establishing control methods and action thresholds. Management of tees and greens require different control strategies to those of fairways and rough. Integration of irrigation, fertilisation, pest and other cultural control methods is essential even for the preliminary development of ITMS programs.

Action thresholds: Action thresholds for fertilisation, irrigation, and other cultural practices should be established, based upon regional research and prevailing economic conditions. In ITMS programs, action thresholds are expanded beyond the traditional definition used for IPM practices. They are based on:

- Pest populations
- Turfgrass/soil nutrient tests
- Soil water conditions
- Soil and thatch physical properties
- Turfgrass playing conditions
- Environmental conditions

All of these conditions indicate whether an action must be taken to maintain turfgrass quality. No action, whether chemical, physical, or cultural, is taken until the predetermined action point is reached. Actions are taken when the pest population, or nutrient/water deficiency affect turfgrass quality sufficiently to threaten the biological and economic viability of the turfgrasses. These effect levels are defined by ITMS objectives.

Monitoring: Close monitoring of golf course climatic conditions, soil conditions, pest populations and turfgrass quality on a periodic and consistent basis is necessary to determine when the action thresholds are reached. Monitoring also may be used to determine whether a specific set of practices has been successful. Monitoring and identification of pests and deficiencies are the cornerstones of integrated management technologies. Use of automatic monitoring equipment, innovative identification techniques, climatic phenological indicators, and use of computer simulation models provide assistance in determining when action thresholds have been reached.

Management practices: Specific management practices to suppress pest populations, reduce nutrient and water deficiencies, or maintain turfgrass quality for playability should be selected from a range of options. Dependent on site-specific conditions, management options may include physical, biological, or chemical treatment. Understanding the relationship between nutrient, water, and climatic conditions is especially important for control and prevention of conditions conducive to pest and disease infestations. Use of alternate nutrient and pest control options should always be considered.

Chemical usage: When chemical use is necessary, appropriate chemical control, alternate control, irrigation or cultural action should be taken. Preferred chemical practices would reduce the movement of the applied chemicals off the target site and provide maximum contact with the intended pest (pesticide) or root system (fertiliser), while presenting the least possible hazard to non-target organisms. Chemicals should be applied on the basis of need. Fertilisers should be applied during the period of active uptake (growth), and pesticides should be applied when the pest or disease is at its most vulnerable life stage. Calendar, global broadcast, and preventative applications are not always consistent with integrated systems, economic sustainability, environmental quality, or societal goals.

Record: Maintaining written records of course management objectives, monitoring methods, data collection, management actions and the results of management practices are essential for the evaluation of the ITMS, and for the development of future plans.

Evaluation: Evaluation of the results of pest habitat alteration, pesticide application, alternative control options, fertilisation and water management practices (irrigation/drainage), should be conducted periodically to assess the success of ITMS programs. Results of the evaluation are used to modify the initial program to meet changing environmental, cultural, and pest conditions. Flexibility and economic feasibility ultimately determine the long-term success of the ITMS (Balogh et al 1992d).

The ITMS combines all the activities of pest and nutrient control, irrigation scheduling, other cultural practices, and golfer use patterns together to maximise turf quality and minimise costs and environmental pollution. When properly implemented, the systems approach produces turfgrass management programs that are economically feasible, profitable, and acceptable to turfgrass managers. Use of the ITMS for growing high-quality turfgrasses and for reducing potential environmental impacts is very effective (Balogh et al 1992d).

6 chapter six

Management techniques - irrigation

The turf management practices, relationships between the practices, philosophy and components of the ITMS have been discussed in previous chapters. The techniques for determining action thresholds and selecting turf management practices will be discussed in a series of milestone reports throughout the project. As planned in the project proposal, only the irrigation techniques are discussed in this report.

Irrigation water sources

The selection of water sources for irrigation is one of the key components of irrigation system design. Generally, there are four possible sources of water:

- Surface water
- Ground water
- Municipal supply water
- Effluent

The two surveys outlined below give a good estimate of water sources used for turf irrigation in Queensland.

Survey by the Queensland Golf Union

Sponsored by the Queensland Golf Union (QGU) and the Golf Course Superintendents Association of Queensland (GCSAQ), a 1998 survey was conducted by Dr Walter Scattini in order to identify the causes of severe dieback on putting greens experienced on some golf courses during the 1997/98 summer. The survey was a questionaire completed by golf course superintendents.

The questionnaires were mailed to 134 clubs (94 members of Australian Golf Course Superintendents

Association and 40 non-members) by the QGU. Sixty-four clubs from Cairns to Coffs Harbour responded to the survey. Eleven respondent clubs were north of Gympie, seven were in New South Wales and forty-six were in South-East Queensland. Club superintendents were asked to submit separate survey forms for each grass variety on greens.

A database of the survey results was assembled and analysed. The database comprises of more than 180 variables, including grass varieties, number and range in ages of greens, summer cutting height, root depth and density, type and timing of renovation treatments, chemicals used, water source and watering frequency in spring and summer, dieback occurrence, number of greens affected, ages of greens affected, when the condition was first noticed, weeks for greens to recover, pests and diseases identified, superintendents' opinions on the cause of the problem, remedial treatments used and strategies for the 1998/99 summer.

Out of 56 courses that provided irrigation information, there were 23 courses (41%) irrigated with effluent, 19 courses (34%) with surface water, 9 courses (16%) with ground water, and 5 courses (9%) with municipal supply water.

Survey by Queensland Department of Natural Resources

In 1998, Mr David White of the Queensland Department of Natural Resources, conducted a survey to document the effluent irrigation status in Queensland. The survey results indicated that more than 70 golf courses in Queensland use effluent for irrigation. There is likely to be a continued increase in this figure, due to high water costs and government regulation. The golf industry is the biggest third party re-user of effluent, consuming around 14600 ML of effluent per year in Queensland (42% of total reused effluent including local authorities). Approximately 10.7% of municipal sewage effluent was reused over the last 12 months in Queensland.

Within the golf courses irrigated with effluent, 61% conduct soil monitoring, 54% water chemical monitoring, and 11% water micro-organism monitoring. Only 50% of golf courses had some level of design and planning on the effluent irrigation systems. The issues identified relating to effluent irrigation included odour, pipe blockage, salinity and contamination of ground water.

Survey conclusions

The following conclusions can be drawn from the above surveys:

- About half of the golf courses in Queensland have used or will use effluent as the water source for irrigation. The Queensland golf industry will play a critical role in water recycling.
- Design and planning of the effluent irrigation systems are very poor. One reason for this is that available techniques for design and operation of effluent irrigation systems are poor. In Queensland, the only available guidelines for effluent irrigation design were published in 1996 and the calculation procedures in the guidelines are not sufficiently detailed (Beavers 1996).
- To enable the sustainable use of effluent for irrigation, a great amount of research needs to be undertaken in understanding the nutrient content of effluent and the potential environmental impacts of its use.

Irrigation scheduling

In most situations, water loading per irrigation is controlled by avoiding runoff rather than by deep irrigation. Experience in California, USA, indicated that surface runoff would occur after 15 minutes of irrigation, resulting in daily irrigation at the evapotranspiration rate, plus 1-2 mm per irrigation. However, this is not enough for the ITMS, as more theoretically solid methods for scheduling must be developed.

Methods of irrigation scheduling

Irrigation schedules are the critical component of water management. The amount of water required for irrigation is usually determined using the water balance method that is expressed as (Singh et al.1995):

$$IR = ET \quad Ro \quad Dc \quad s - P \qquad (1)$$

where IR is the amount of irrigation water; ET is turfgrass evapotranspiration; Ro is the amount of surface runoff into (-) or out of (+) the field in question; Dc is the amount of capillary drainage toward the surface (-) or into the subsurface (+); s is residential moisture in the soil, and P is the amount of precipitation.

In the settings where the surface is flat, surface runoff (Ro) is negligible. Otherwise the water should be applied at a proper rate to avoid runoff. Also, in situations where the ground water table is well beneath the rooting depth of the soil, capillary rise (-Dc) is negligible. P is equal to zero if no rainfall occurs between two irrigations. Since each irrigation usually starts when soil moisture is reduced to a given water content, s can be taken as zero. Therefore Eq. (1) is reduced to:

IR = ET + Dc (2)

This means that irrigation inputs should equal the water loss through evapotranspiration and drainage. Since evapotranspiration is supplied by the upward movement of water stored in the soil, the frequency and amount of irrigation depends on how much water the soil in the root zone can hold, and how deep the soil water deficit (SWD) is permitted. Drainage water is needed for leaching salt accumulated in the root zone. The amount of each irrigation can also be expressed as follow:

IR = SWD + LR IR (3) or

IR = (4)

SWD = EW DR(5)

LR = (6)

where SWD is the total soil water deficit in the root zone where irrigation should occur (mm); LR is leaching requirement expressed as a portion of the infiltrated water, that is equal to IR when no runoff takes place; EW is the unit soil water deficit permitted (mm/cm); DR is the depth of root zone (cm); ECw is salinity of the irrigation water (dS/m); ECe is maximum soil salinity tolerated by the specific turfgrasses (dS/m). The value of both EW and ECe can be found in Handreck and Black (1994).

The frequency of irrigations can be estimated by the following formula:

d = = (7)

where: ET is daily evapotranspiration of turfgrass system (mm); PET is the evaporation rate of open Class A pan (mm); and f is a crop factor that is related to the turfgrass species and growth appearance needed. This can also be found in Handreck and Black (1994).

Therefore, every d days, the irrigation requirement (IR) must be supplied to the turf for balancing the water deficit in the soil reservoir and salt leaching.

Examples of irrigation scheduling

To demonstrate an application of the above irrigation scheduling methods, an example is provided in this section.

Assume there is a golf course that is growing warm-season turfgrasses. Core samples show that a major portion of the root system is located in the upper 40cm of the soil, but its root penetration has been observed at a soil depth of 150cm. The grass is to be kept growing strongly, but it does not need to be very lush. The soil is a sandy loam. During summer, the evaporation from the open Class A pan near the golf course is 10mm per day on average. The water used for irrigating the golf course has an ECw of 1.0dS/m. The turfgrasses are sensitive to salinity. No more than 10% reduction in growth is allowable.

Since the major portion of the root system is located in the upper 40cm of the soil and roots extend very deeply, it is proper to choose DR = 50cm. For the sandy loam soil in this golf course, field capacity (FC) is chosen as 2.1mm/cm and permanent wilting point (PWP) is 0.8mm/cm. The maximum available soil water (MAW) is

MAW = (FC-PWP) DR = (2.1-0.8) 50 = 65 mm

As the turfgrasses are to be kept growing strongly, the amount of water that can be removed from the sandy loam soil is about 1.0mm/cm, starting at field capacity of 2.1mm/cm (see Table 22.6 in Handreck and Black, 1994). The soil water deficit for irrigation is

SWD = EW DR = 1.0 50 = 50 mm

ET from the turfgrasses are calculated from PET, which is 10mm. From Table 22.8 in Handreck and Block (1994), f is chosen as 0.5. So;

ET = PET f = 10 0.5 = 5mm

The irrigation frequency should be

d = = =10 (days)

The results from above calculations mean that 50mm water is needed every 10 days, to refill the soil water reservoir and satisfy evapotranspiration requirements. Turfgrasses are sensitive to salinity and no more than a 10% reduction in growth is allowable. The maximum allowable ECe of irrigation water is 2.0dS/m (see Table 21.4 in Handreck and Block, 1994). However, the water used for irrigation has an ECw of 1.0dS/m. Leaching water is required and calculated as follows.

LR= = = 0.11

The total irrigation water required should be:

IR = = = 56.2mm

This means 56.2mm water should be irrigated to refill the soil water reservoir and leach salts every 10 days in order to keep turfgrasses growing strongly.

Table 6

SIMULATION RESULTS FOR OPTION ONE (MM)

Period (day)	Water content			Irrigation	Runoff	Infiltration	Drainage	ET
	Initial	Final	Difference					
1-10	54.99	69.44	14.45	56.20	0.00	56.20	0.26	41.52
11-20	69.44	77.93	8.50	56.20	0.00	56.20	2.81	44.86
21-30	77.93	81.10	3.14	56.20	0.00	56.20	6.50	46.52
31-40	81.10	81.98	0.87	56.20	0.00	56.20	8.36	46.96
41-50	81.98	82.19	0.21	56.20	0.00	56.20	8.91	47.06
51-60	82.19	82.24	0.05	56.20	0.00	56.20	9.06	47.08
61-70	82.24	82.25	0.01	56.20	0.00	56.20	9.09	47.08
71-80	82.25	82.25	0.00	56.20	0.00	56.20	9.10	47.09
81-90	82.25	82.26	0.00	56.20	0.00	56.20	9.10	47.09
91-100	82.26	82.26	0.00	56.20	0.00	56.20	9.10	47.09

Note: 1. Water content is the total water content of the root zone (50cm). Initial is the water content at the beginning of the calculated period, or just before the irrigation. Final is the water content at the end of the calculated period, or just before the next irrigation 2. The total water content corresponding to FC (2.1 mm/cm) and PWP (0.8mm/cm) is 105mm and 40mm respectively

Soil water dynamic under different irrigation schedules

Previous studies found that irrigation not only provides water for turf growth, it also affects turf quality. Beard (1982) recommended that, whenever possible, the irrigation should be as deep and as infrequent as possible in relation to the rooting depth of the desirable turfgrass species. Deeper rooting depth can:

- Protect weed invasion
- Increase drought tolerance
- Reduce insect damage

The irrigation frequency calculated in the previous section is quite different from daily irrigation. What is the effect of this scheduling on turf quality and the environment? It is necessary to develop an understanding of the water dynamic in the soil profile under different irrigation schedules. To do that, the SWIM model

Table 7

SIMULATION RESULTS FOR OPTION TWO (MM)

Period (day)	Water content			Irrigation	Runoff	Infiltration	Drainage	ET
	Initial	Final	Difference					
1-10	54.99	66.86	11.87	56.20	0.00	56.20	0.00	44.32
11-20	66.86	76.28	9.42	56.20	0.00	56.20	0.03	46.74
21-30	76.28	83.63	7.34	56.20	0.00	56.20	0.38	48.47
31-40	83.63	88.86	5.24	56.20	0.00	56.20	1.34	49.63
41-50	88.86	92.46	3.60	56.20	0.00	56.20	2.68	49.93
51-60	92.46	94.70	2.24	56.20	0.00	56.20	4.00	49.97
61-70	94.70	95.93	1.23	56.20	0.00	56.20	4.99	49.98
71-80	95.93	96.55	0.62	56.20	0.00	56.20	5.60	49.98
81-90	96.55	96.85	0.30	56.20	0.00	56.20	5.92	49.98
91-100	96.85	96.99	0.03	56.20	0.00	56.20	6.08	49.98
101-110	96.99	97.05	0.06	56.20	0.00	56.20	6.15	49.98
111-120	97.05	97.08	0.03	56.20	0.00	56.20	6.19	49.98
121-130	97.08	97.09	0.01	56.20	0.00	56.20	6.20	49.98
131-140	97.09	97.10	0.01	56.20	0.00	56.20	6.21	49.98
141-150	97.10	97.10	0.00	56.20	0.00	56.20	6.21	49.98

developed by Ross (1990a and 1990b) is used to simulate following three schedule options:

Option one: Turfgrasses are irrigated every 10 days, a total amount of 56.2mm water is applied evenly from 0:00am to 10:00am on the morning of the first day with the turfgrasses unwatered for the remaining 9 days;

Option two: Turfgrasses are irrigated every 5 days. An amount of 28.1mm water is applied evenly from 0:00am to 5:00am on the morning of the first day with the turfgrasses unwatered for the remaining 4 days;

Option three: Turfgrasses are irrigated every 2 days. An amount of 11.24mm water is applied evenly from 0:00am to 2:00am on the morning of the first day with no water applied on the second day.

SWIM is run to simulate the water movement for 100 days for option one and 150 days for both options two and three. Assume that at the beginning of the simulated period, the soil water content in all root depth is at the minimum removable point before the growth rate becomes unacceptable, which is 1.1mm/cm. The results are presented in Tables 6 to 8.

Table 8

SIMULATION RESULTS FOR OPTION THREE (MM)

Period (day)	Water content			Irrigation	Runoff	Infiltration	Drainage	ET
	Initial	Final	Difference					
1-10	54.99	62.79	7.80	56.20	0.00	56.20	0.00	48.41
11-20	62.79	69.21	6.42	56.20	0.00	56.20	0.00	49.78
21-30	69.21	75.47	6.26	56.20	0.00	56.20	0.00	49.93
31-40	75.47	81.69	6.21	56.20	0.00	56.20	0.02	49.96
41-50	81.69	87.79	6.10	56.20	0.00	56.20	0.12	49.98
51-60	87.79	93.58	5.79	56.20	0.00	56.20	0.44	49.98
61-70	93.58	98.59	5.02	56.20	0.00	56.20	1.20	49.99
71-80	98.59	102.37	3.78	56.20	0.00	56.20	2.43	49.99
81-90	102.37	104.79	2.42	56.20	0.00	56.20	3.79	49.99
91-100	104.79	106.10	1.31	56.20	0.00	56.20	4.87	49.99
101-110	106.10	106.77	0.67	56.20	0.00	56.20	5.52	49.99
111-120	106.77	107.10	0.33	56.20	0.00	56.20	5.88	49.99
121-130	107.10	107.39	0.29	56.20	0.00	56.20	5.92	49.99
131-140	107.39	107.40	0.01	56.20	0.00	56.20	6.20	49.99
141-150	107.40	107.39	-0.01	56.20	0.00	56.20	6.22	49.99

Conclusion

- Soil moisture before irrigation and evapotranspiration both increased as the irrigation frequency increased. Soil moisture was even higher than field capacity in frequent irrigation situations (e.g. every two days). This should be avoided.
- For the infrequent irrigation (every 10 days), evapotranspiration was lower than expected while deep drainage was higher. The soil water deficit for the irrigation trigger is about 56% of plant available water, which seems to be what the ITMS expects. However, excessively deep drainage and possible pollutant movement into ground water should be further investigated.
- A proper soil water deficit for the irrigation trigger is a function of the irrigation frequency only. Soil moisture before irrigation will be steady at the deficit whenever the initial soil moisture is set for the first irrigation.
- The above example considered only a single combination of soil and turfgrasses. An extensive simulation that covers different soils, irrigation frequency, irrigation depth, and turfgrass species should be undertaken to generate enough information for developing the best irrigation scheduling strategy under different site conditions.

Issues in effluent irrigation

Survey data presented in section 6.1 showed effluent irrigation to be the dominant option in Queensland. This is expected to extend throughout Australia as it has been recommended as the first choice for effluent disposal by Australian governments. Many local authorities such as the Thuringowa and Townsville City Councils are now investigating the possibility of reusing 100% of effluent for irrigation. It is necessary to develop a greater understanding of effluent irrigation in turf systems.

The most critical aspect of effluent irrigation design is determining the sustainable effluent loading rate. Guidelines produced by the Queensland Department of Natural Resources recommend that the nutrient loading should not exceed plant requirements in irrigation systems (Beavers 1996). A preliminary calculation is carried out in this report to identify possible issues related to using the guidelines.

Materials and methods

Sustainable loading rates were calculated for given climate and effluent data using the procedure recommended in the guidelines (Beavers 1996). Thirty-one locations were selected to cover different parts of Queensland. The climate data for the locations considered were long-term monthly records (50 to 100 years, depending on the data available).

The calculation procedure in the guidelines has been programmed into a software package - Computer-Aided Design of Effluent Irrigation (CAD-Effluent) (Hu and Pigram 1998, Hu et al. 1998). Therefore, the CAD-Effluent was used to perform all the design calculations.

Three sets of effluent quality data were used for comparison. Data came from:

- Townsville Mt St. John Sewage Treatment Plant
- Caloundra, Queensland
- Feigin et al. (1991)

The nutrient concentrations in the effluent are presented in Table 9.

The nitrogen concentration of the Townsville plant (30.3mg/L) was very close to that found in Caloundra (31.3mg/L), both falling within the range cited in literature (Feigin et al. 1991). It was therefore assumed that it is reasonable to use 31mg/L to represent Queensland. The phosphorus concentration differed greatly between Townsville (21.5mg/L) and Caloundra (6mg/L). Townsville's phosphorus concentration was even higher than the maximum value cited in the literature. Therefore, three phosphorus concentrations were selected: 6mg/L (low), 10mg/L (medium), and 21.5mg/L (high). No potassium concentration data was available for the Caloundra. However, Feigin et al. (1991, p8) indicated that potassium added to effluent through domestic use will be between 7-15mg/L. Considering Queensland's industry and domestic combination, it was

Table 10

EFFLUENT NUTIRENT CONCENTRATIONS USED FOR THE PURPOSE OF THIS DISCUSSION (MG/L)

Effluent qualities	Nitrogen	Phosphorus	Potassium
Set 1	31	6	14
Set 2	31	10	14
Set 3	31	21.5	14

Table 9

NUTRIENT CONCENTRATIONS OF DIFFERENT EFFLUENT (MG/L)

Effluent sources	Nitrogen	Phosphorus	Potassium	Reference
Mt St John Sewage Treatment Plant, Townsville	30.3	21.5	14	Reference unpublished
Caloundra	31.3	6	not available	Cosser 1997
Literature	10-50	6-17	10-40	Feigin et al.1991, p24

considered reasonable to use a potassium concentration of 14mg/L (from Townsville) to represent the state. Therefore, the three sets of nutrient concentrations were used for the discussion and listed in Table 10.

Bluegrass is a common urban lawn in Queensland and was selected as the irrigated plant for discussion. Its nutrient removal capacities are: N=224kg/ha/yr, P=27kg/ha/yr, K=167kg/ha/yr (Beavers 1996).

Assimilation capacities of water and nutrients

The assimilation capacities of water and nutrients for three sets of effluent quality data are listed in Table 11. Nitrogen and potassium assimilation capacities were the same for the three effluent qualities. Phosphorus was

Table 11

ASSIMILATION CAPACITIES FOR DIFFERENT EFFLUENT QUALITIES

Location	Water Assimilation Capacity (mm/year)	Nitrogen Assimilation Capacity (mm/year)	Phosphorus Assimilation Capacity (mm/year) for following concentrations in effluent			Potassium Assimilation Capacity (mm/year)	Limiting Factor
Atherton	1450	764	475	134	286	1266	P
Beaudesert	796	764	475	134	286	1266	P
Bendigo	1015	764	475	134	286	1266	P
Brisbane	729	764	475	134	286	1266	P
Bundaberg	885	764	475	134	286	1266	P
Caboolture	669	764	475	134	286	1266	P
Caloundra	555	764	475	134	286	1266	P
Charleville	1929	764	475	134	286	1266	P
Charters Towers	1807	764	475	134	286	1266	P
Cleveland	629	764	475	134	286	1266	P
Coolangatta	539	764	475	134	286	1266	P
Dalby	1203	764	475	134	286	1266	P
Dubbo	1260	764	475	134	286	1266	P
Goondiwindi	1326	764	475	134	286	1266	P
Gunnedah	1199	764	475	134	286	1266	P
Gympie	799	764	475	134	286	1266	P
Ipswich	876	764	475	134	286	1266	P
Katanning	1006	764	475	134	286	1266	P
Longreach	2189	764	475	134	286	1266	P
Mackay	1175	764	475	134	286	1266	P
Maryborough	790	764	475	134	286	1266	P
Port Douglas	1320	764	475	134	286	1266	P
Rockhampton	1290	764	475	134	286	1266	P
Roma	1597	764	475	134	286	1266	P
Southport	554	764	475	134	286	1266	P
St Lawrence	1357	764	475	134	286	1266	P
Toowoomba	944	764	475	134	286	1266	P
Townsville	1571	764	475	134	286	1266	P
Wandering	1126	764	475	134	286	1266	P
Warwick	1062	764	475	134	286	1266	P
Yeppoon	1135	764	475	134	286	1266	P

the first limiting factor on effluent loading rates for three phosphorus concentrations. There were six locations where water assimilation capacity was the second limiting factor, and 25 locations where nitrogen was the second limiting factor. There were 10 locations where potassium was the third limiting factor. This means that most locations can assimilate more effluent if nutrient concentrations are low. This also means that:

- Fresh water is required to satisfy the water requirement for plant growth if the estimated sustainable loading rate is applied
- A larger area is required to dispose of a given volume of effluent
- Effluent reuse potential in urban areas is minimal

Limitations to phosphorus release potential

In Queensland's guidelines (Beavers 1996), the phosphorus loading rate into an effluent irrigation field is recommended to equal the crop removal capacity. In other references (Overcash and Pal 1979, Ryden and Pratt 1980, Broadbent and Reisenauer 1988), the phosphorus loading rate is estimated as the sum of plant removal capacity and soil adsorption. Limitations to the potential release of phosphorus may therefore exist if soil adsorption is considered. If the plant removal capacity is given, the required soil adsorption capacity can be estimated as

$$P_{adsorption} = P_{soil} = P_{input} - plant \quad uptake \qquad (8)$$

where *Padsorption* = phosphorus adsorption capacity required in kg/ha/yr

Psoil = phosphorus remaining in the soil after plant removal in kg/ha/yr

Pinput = phosphorus applied to the land by effluent irrigation in kg/ha/yr

Plant uptake = phosphorus taken up by the plant in kg/ha/yr

The phosphorus adsorption capacity can also be expressed as

$$x = \frac{P_{sorption} \times N}{soil \quad mass} = \frac{P_{sorption} \times N}{10 \times D \times r} \qquad (9)$$

where x = required adsorption capacity in g/kg of P in soil

N = the life period of the effluent irrigation system (years)

D = soil depth (or root zone depth) in metres

r = soil bulk density in kg/m3

If irrigation is based on the water assimilation capacity and on phosphorus removed by turf (bluegrass: 27kg/ha/year) (Beavers 1996), the required soil adsorption capacities for different locations are calculated and listed in Table 12. Laboratory analysis indicated that the adsorption capacity of Queensland soils varied from 0.05 g P/kg soil (low) to 1.8 g P/kg soil (very high) with a medium capacity of about 0.3 g P/kg soil (Reedman 1996). If phosphorus concentration in effluent is 6mg/L, 14 locations require medium or higher soil adsorption capacity so that the plant can be irrigated at water assimilation capacity. If the phosphorus concentration in effluent is 21.5mg/L, all locations require medium to very high soil adsorption capacity, which is impossible.

Conclusions

Following Queensland guidelines for calculations, analysis of the results indicated that phosphorus was the limiting factor for all Queensland areas. Further analysis showed that if the phosphorus concentration of effluent is greater than 10mg/L and the turf is irrigated at water assimilation capacity, phosphorus overload will occur in most locations, even if the soil adsorption is considered as a phosphorus removal pathway. A detailed investigation on soil phosphorus adsorption capacity should therefore be undertaken before an effluent irrigation system is installed in Queensland. For 25 locations out of 31, nitrogen was the second limiting factor of effluent loading rate. A further study on nitrogen transformation processes is required to understand the pathways of the nitrogen input through effluent irrigation. Water assimilation should not be the only factor considered in effluent irrigation design in Queensland. Nutrient transformation processes should be studied further to develop an understanding of the fate of nutrients and their impact on turf systems and the environment. Careful consideration and monitoring of nutrients is required during effluent irrigation.

Cost analysis of effluent irrigation

The survey results discussed in section 6.1 show that about half of the golf courses in Queensland still use fresh water for irrigation. In Australia, around two thirds of water used in urban areas is applied for the irrigation of turfgrasses. There is great potential for the turf industry to shift from fresh water irrigation to effluent irrigation. The Queensland water recycling strategy is initiating a range of research and pilot projects to encourage effluent irrigation practices. There still remain many factors that obstruct the progress of disseminating effluent irrigation. Costs and benefits need to be clarified. Unfortunately, economic analysis procedures are not provided in most Australian guidelines. A general discussion of economic analysis has been presented by Mills (1998). In Mills' procedure, the water volume is given a time value that decreases as money decreases in value. This concept conflicts with that of water becoming more scarce as its value increases. In addition, Mills did not give detailed methods for cost calculation which are critical for economic analysis. Richard (1998) presented some cost calculation methods for wastewater treatment facilities, but did not cover the on-site cost of effluent irrigation.

Table 12

REQUIRED SOIL PHOSPHORUS ABSORPTION CAPACITIES FOR DIFFERENT CONCENTRATIONS IN EFFLUENT

Location	Water assimilation capacity (mm/year)	Required soil P adsorption capacity (g/kg)		
		Concentration = 6 (mg/L)	concentration = 10 (mg/L)	concentration = 21.5 (mg/L)
Coolangatta	539	0.04	0.19	0.63
Southport	554	0.04	0.20	0.66
Caloundra	555	0.05	0.20	0.66
Cleveland	629	0.08	0.26	0.77
Caboolture	669	0.09	0.29	0.83
Brisbane	729	0.12	0.33	0.93
Maryborough	790	0.15	0.37	1.02
Beaudesert	796	0.15	0.38	1.03
Gympie	799	0.15	0.38	1.03
Ipswich	876	0.18	0.43	1.15
Bundaberg	885	0.19	0.44	1.17
Toowoomba	944	0.21	0.48	1.26
Katanning	1006	0.24	0.53	1.35
Bendigo	1015	0.24	0.53	1.37
Warwick	1062	0.26	0.57	1.44
Wandering	1126	0.29	0.61	1.54
Yeppoon	1135	0.29	0.62	1.55
Mackay	1175	0.31	0.65	1.61
Gunnedah	1199	0.32	0.66	1.65
Dalby	1203	0.32	0.67	1.65
Dubbo	1260	0.35	0.71	1.74
Rockhampton	1290	0.36	0.73	1.79
Port Douglas	1320	0.37	0.75	1.83
Goondiwindi	1326	0.38	0.75	1.84
St Lawrence	1357	0.39	0.78	1.89
Atherton	1450	0.43	0.84	2.03
Townsville	1571	0.48	0.93	2.22
Roma	1597	0.49	0.95	2.26
Charters Towers	1807	0.58	1.10	2.58
Charleville	1929	0.63	1.18	2.77
Longreach	2189	0.75	1.37	3.17

This report will extend Mills and Richard's methods to cover economic analysis methods for whole effluent irrigation systems. The discussion will deal specifically with effluent irrigation of golf courses and will address the effluent reuse option. The procedure is developed for the water users, not for the effluent generator.

Economic analysis can be done in two ways:

- Comparing the costs and benefits of a single project option- the project is viable if benefits are greater than costs
- Comparing the costs of different alternatives that are designed to do the same thing, the lowest cost alternative is the best option. This method is used for this discussion as water users should choose the most efficient from all available options, rather than considering a single option.

Economic analysis procedure

Economic analysis procedures for effluent irrigation can be separated into the following steps:

- Identify possible alternatives for irrigation
- Identify the components of the irrigation system for each alternative
- Estimate the capital and operation costs of individual components
- Calculate the total cost of each alternative
- Select the lowest cost alternative

These steps will be discussed in detail below.

Irrigation alternatives

Irrigation alternatives can be found by investigating the availability of water resources. Irrigation alternatives can be one or a combination of following:

- Surface water (withdrawn from rivers or storm water directly by the user)
- Ground water (withdrawn from the ground by the user)
- Municipal supply water
- Effluent irrigation

Components of irrigation systems

Components of irrigation systems will differ between alternatives. Figures 1 to 4 outline the systems for four alternatives with a single resource. Their components are summarised in Table 13. For multiple resource situations, the system should be the sum of the systems for each single resource.

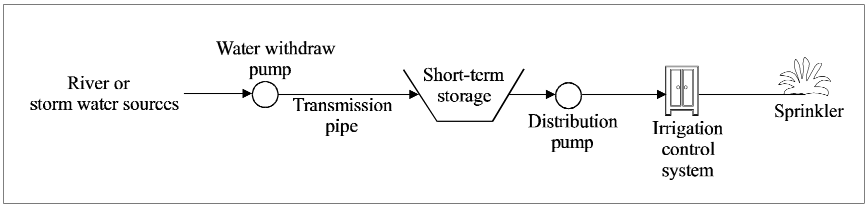

Figure 1 Outline of surface water irrigation system

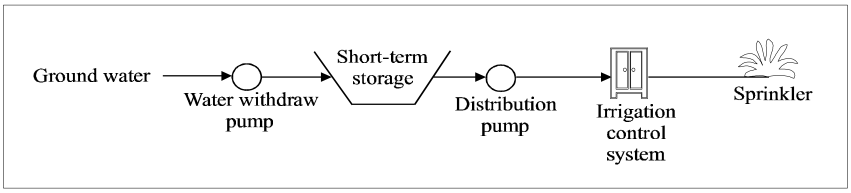

Figure 2 Outline of ground water irrigation system

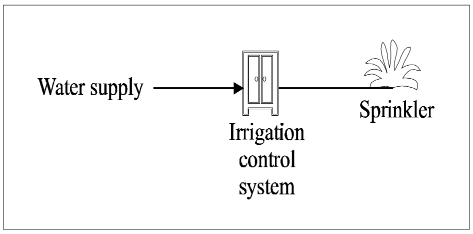

Figure 3 Outline of municipal water irrigation system

Figure 4 Outline of effluent irrigation system

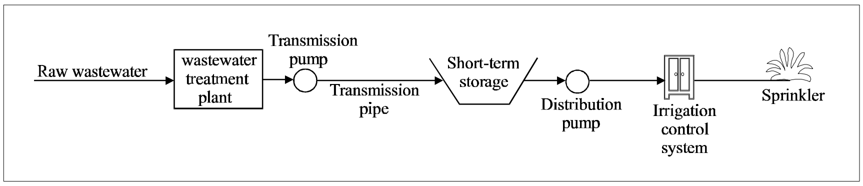

Table 13

COMPONENTS OF IRRIGATION SYSTEMS

No of components	Surface water irrigation	Ground water irrigation	Municipal supply water irrigation	Effluent irrigation
1	sprinkler irrigation system	Sprinkler irrigation system	sprinkler irrigation system	sprinkler irrigation system
2	irrigation control system	Irrigation control system	irrigation control system	irrigation control system
3	distribution pump station	Distribution pump station		distribution pump station
4	short term storage pond	Short term storage pond		short term storage pond
5	transmission pipes	Withdraw pump stations		effluent transmission pipes
6	withdraw pump stations			effluent transmission pump station
7				sewerage treatment plant

Cost calculations

Costs of irrigation systems consist of capital costs, as well as operation and maintenance costs, which are similar to other engineering systems. Methods for the cost calculations of individual components will not be discussed here, as they can be found in other references (e.g., Richard 1998). Important to consider are the varying costs of different water resources. The costs for some water resources such as storm water and effluent are minimal in Australia, and others such as water supplied by local authorities will be charged on a volume basis. Water costs can be calculated as the products of unit price and volume used.

Previous experience has found that the chemical costs of the effluent irrigation situation are higher than that of its alternatives, but the fertilisation costs are lower. Operation and maintenance costs (such as machinery rust, pipe blockage) may be also higher.

Calculation methods for total costs

Costs are usually expressed as present worth. All costs occurring at different times will be converted to the present worth at the reference time point. Assume that a cost (Fj) occurs in year n, then its present worth cost (Pj) is

$$P_j = F_j \frac{1}{(1+i)^n} \quad (10)$$

where i is interest rate per time period.

The useful life of some equipment may be longer than the planning period. The salvage value of the equipment with longer useful life than the planning period should be reduced from the capital cost. Straight-line depreciation from the first day of facility operation is assumed for determining salvage value (Mills 1998). The equation used to determine the salvage value is

$$SV_j = IC_j \frac{UL_j - PP}{UL_j} \quad (\text{ULj} > \text{PP}) \quad (11)$$

where ULj = useful life (year)
PP = planning period for use (year)
SVj = salvage value ($)   ICj = initial cost ($)

If a piece of equipment is replaced during the project life, the useful life of the equipment is the product of the replacement times and the actual useful life of the equipment.

The present worth of the total cost is calculated as

$$\text{Total cost (P)} = \sum_{j=1}^{M} \left(P_j - SV_j \frac{1}{(1+i)^{PP}} \right) \quad (12)$$

where M is the total number of costs.

Annual cost (A) is sometimes used for economic analysis and can be calculated from the present worth as:

$$A = P \frac{i(1+i)^n}{(1+i)^n - 1} \quad (13)$$

where A = Annual cost ($)
P = present worth cost ($)
i = interest rate per time period
n = number of time periods

Examples of economic analysis

Assume there is a golf course requiring 2.0 ML water per day for irrigation, if the water is of a high quality. There are three sources (river water, municipal supply water and effluent supplied by the local authority) from which water can be drawn. Each of the sources can supply enough water for the irrigation. The irrigation alternatives are therfore:

- Surface water
- Municipal supply water
- Effluent

The golf course manager wants to know which option is the most cost effective.

Estimated capital, and operation and maintenance costs for individual alternatives are listed in Table 15. Labour costs are considered as the same for all alternatives because the source of irrigation water should not change the operation of the system. Therefore, labour costs are set at zero, as they will not affect the results of alternative selection.

The present worth of the total cost is calculated as shown in Table 16 and the results are summarised in Table 14. The results indicate that municipal supply water irrigation is the most expensive option. There is not much difference between surface water and effluent irrigation.

Table 14

[redacted]

Irrigation alternative	Total present worth cost ($)	Annual cost ($)
Surface water	879,783	55,817
Municipal supply water	15,259,242	968,112
Effluent	963,321	31,117

Table 15

[redacted]

Items	Useful life (year)	Capital costs ($)			Operation and maintenance ($/yr)			Salvage value ($)		
		Surface water	Municipal supply water	effluent	Surface water	Municipal supply water	effluent	Surface water	Municipal supply water	effluent
Design										
Design	50	0	0	0	0	0	0	0	0	0
On-site systems										
Sprinkler	50	41,400	41,400	41,400	6,000	6,000	6,000	0	0	0
Distribution pipes	50	144,000	144,000	144,000						
Irrigation control system	15	855	855	855	130	130	130	285	285	285
Pump (from storage)	20	2,000	0	2,000	8,400	0	8,400	1,000	0	1,000
Pump station (from storage)	50	3,000	0	3,000	400	0	400	0	0	0
Short term storage	50	20,000	0	20,000	0	0	0	0	0	0
Water Transmission										
Transmission pipe (M)			0							
Pump station			0							
Pumps			0							
Wastewater treatment										
Sewerage treatment plant	50	0	0	0	0	0	0	0	0	0
Other costs										
Labour			0		0	0	0			
Fertilisers			0		5,000	5,000	0		0	
Chemicals in total			0		20,000	15,000	30,000		0	
Water (ML)					0	876,000	0			
Total		211,255	186,255	211,255	39,93	902,130	44,930	1,285	285	1,285

Table 16

CALCULATION OF PRESENT WORTH OF TOTAL COST

Assumption: Interest rate (%) = 6
Project name: Effluent irrigation in Willows Golf Club

Year	Capital cost & salvage ($)	Operation & maintenance ($)	Total net cost ($)	Present worth factor	Present worth of net cost
1	211255	44930	256185.00	1	256185.00
2		44930	44930.00	0.9434	42386.79
3		44930	44930.00	0.8900	39987.54
4		44930	44930.00	0.8396	37724.09
5		44930	44930.00	0.7921	35588.77
6		44930	44930.00	0.7473	33574.31
7		44930	44930.00	0.7050	31673.88
8		44930	44930.00	0.6651	29881.02
9		44930	44930.00	0.6274	28189.64
10		44930	44930.00	0.5919	26594.00
11		44930	44930.00	0.5584	25088.68
12		44930	44930.00	0.5268	23668.56
13		44930	44930.00	0.4970	22328.83
14		44930	44930.00	0.4688	21064.94
15	855	44930	45785.00	0.4423	20250.75
16	0	44930	44930.00	0.4173	18747.72
17		44930	44930.00	0.3936	17686.53
18		44930	44930.00	0.3714	16685.40
19		44930	44930.00	0.3503	15740.95
20	2000	44930	46930.00	0.3305	15510.98
21	0	44930	44930.00	0.3118	14009.39
22		44930	44930.00	0.2942	13216.40
23		44930	44930.00	0.2775	12468.30
24		44930	44930.00	0.2618	11762.55
25		44930	44930.00	0.2470	11096.75
26	0	44930	44930.00	0.2330	10468.63
27		44930	44930.00	0.2198	9876.06
28		44930	44930.00	0.2074	9317.04
29		44930	44930.00	0.1956	8789.66
30	855	44930	45785.00	0.1846	8449.93
31		44930	44930.00	0.1741	7822.77
32		44930	44930.00	0.1643	7379.97
33		44930	44930.00	0.1550	6962.24
34		44930	44930.00	0.1462	6568.15
35		44930	44930.00	0.1379	6196.37
36		44930	44930.00	0.1301	5845.63
37		44930	44930.00	0.1227	5514.74
38		44930	44930.00	0.1158	5202.59
39		44930	44930.00	0.1092	4908.10
40	2000	44930	46930.00	0.1031	4836.40
41		44930	44930.00	0.0972	4368.19
42		44930	44930.00	0.0917	4120.94
43		44930	44930.00	0.0865	3887.68
44		44930	44930.00	0.0816	3667.62
45	855	44930	45785.00	0.0770	3525.86
46		44930	44930.00	0.0727	3264.17
47		44930	44930.00	0.0685	3079.40
48		44930	44930.00	0.0647	2905.10
49		44930	44930.00	0.0610	2740.66
50	(1285)	44930	43645.00	0.0575	2511.58
				Total	$963,321.22

Conclusion

An economic analysis procedure for effluent irrigation has been developed, consisting of:

- identifying possible irrigation alternatives
- identifying the components of the irrigation system for each alternative
- estimating the capital and operation costs of individual components
- calculating the total cost of each alternative
- selecting the most cost effective alternative

An example was presented to demonstrate the application of this procedure. The procedure was used for the comparison of one irrigation option with its alternatives. Economic analysis of other irrigation systems can therefore be carried out using this procedure. Environmental benefits are not considered in the calculations. This is a difficult topic that should be studied separately in greater detail.

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acknowledgements

Authors wish to extend gratitude and acknowledgement in thanks for the support of the Golf Course Superintendents Association of Queensland, The Barron River Integrated Catchment Management Association, Chemturf Pty Ltd and the Daikyo Group of Companies.