THE EFFECTS OF GOLF COURSES IN THE AUSTIN-SAN ANTONIO REGION ON LOCAL WATER SUPPLIES

THESIS

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By

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This thesis is dedicated to my parents and my wife.

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CHAPTER ONE

INTRODUCTION

Context of the Issue

The Austin-San Antonio growth corridor is experiencing water shortages because in most years more water is withdrawn from its major source, the Edwards Aquifer, than nature replaces (Sharp 1991). Amid the water shortages, still standing tall, is the Texas 'Law of the Biggest Pump,' which dictates that whoever can withdraw groundwater first or fastest is the rightful owner of that water. Citizens have not been inclined to question aquifer depletion when it is due to such key uses as agriculture, industry, and municipalities. Until recently, the general public has paid little attention to recreational activities that utilize substantial quantities of water from an increasingly finite source. However, recent predictions of potentially serious water shortages in the Austin-San Antonio growth corridor have led to a new public awareness and concern.

The public also tends to accept agriculture's use of chemicals such as insecticides, fungicides, herbicides, and fertilizers for the same reasons they accept agriculture's massive use of water. They believe it is necessary for providing low-price domestic food supplies, and they are relatively uninformed about any negative effects. Considering that golf courses serve primarily recreational interests, will the public maintain its acceptance of their use of chemicals?

This paper will measure the water needs of golf courses in the Austin-San Antonio growth corridor. It will look specifically at the region's golf courses and their utilization of water as a proportion of the total water supply available for consumption. The research will also focus on water conservation techniques and their application by golf course superintendents. Finally, the paper will analyze measures being taken to preserve environmental quality through prudent use of chemicals in golf course management.

Background of the Issue

The golf course's origins lie in fourteenth century Scotland, where the first permanent courses were established (Pearce 1993; Rooney 1992). Participants played on the naturally occuring terrain of the coastal sand dunes (Pearce 1993; Rooney 1992; Edmonson 1987). These courses were known as links. The native grasses of Scotland were ideal golf course turfgrasses. They did well enough to allow for them to be cut very short with minimal care (Edmonson 1987; Pleumarom 1995). The marine west coast climate of Scotland was crucial to the natural thriving of links. Precipitation was abundant every month, with annual totals averaging over 50 inches (1460 mm). The soil-water shortage, which is the total amount of irrigation water necessary to ensure maximum growth of plants, was minimal (Strahler 1989). By virtue of this native climate, links did not require irrigation--enough rain fell to ensure maximum growth of the grass on the course. The traditional links courses spread throughout Great Britain, and in the late 1800s, American tourists traveling in the region came into contact with the game.

Americans returning from Europe who had played golf there wished to take it up in the States; this led to the first permanent United States golf course in 1888 at Yonkers, New York (Rooney 1992). "The nature of the game has always rendered certain natural settings preferable to others ..." comments Rooney in his book, *Atlas of American Sport* (1992, 74). With the game's rapid diffusion to and throughout the U.S., its growth did not halt where natural conditions were no longer ideal. The phenomena of massively altering the landscape in order to build a course started in the Florida swamplands (Pearce 1993). There, builders had to find a way to make fairways flood-proof and bunkers alligator-proof. Thus major civil engineering became involved in the building of the type of course which dominates the golf world today: that which transforms the landscape instead of blending in with it (Pearce 1993). This type of course became the norm wherever courses were built. Golf courses abound even in arid regions. Anyone who sees a golf course in the middle of a desert perceives a geographical anomaly, whether their cognition is of an amazing example of modern technology or an aberration. Inherent in their perception is the fact that the course's vegetation would never naturally occur in such a place. Alteration of the natural landscape in Scotland is rare, but it is a common characteristic of golf courses in the United States.

Another typical characteristic of U.S. golf courses seldom found in Scottish courses is the immaculate, intricate grooming which evolved hand in hand with the bulldozer-created course. The average U.S. golf course sports a highly groomed carpet of grass which requires high doses of fertilizers, pesticides, and water in order to maintain it. In Scotland, golfers played on courses which were much less manicured than their U.S. counterparts, and consequently required fewer chemicals (Selcraig 1993). The only reason that some Scottish courses now require chemicals is that the American-style golf course has diffused to Great Britain, replacing many traditional links, and becoming the norm for new courses. By a strange twist of history and geography, in emulation of the American golf course ideal, the Scottish and English are increasingly cultivating U.S.-style grasses which are not native to Great Britain. The U.S. golfer is accustomed to carpet-like grass conditions, as opposed to Scottish and English traditional standards. Edmondson, in his 1987 article, 'Hazards of the Game,' comments, "He [the U.S. golfer] wants his fairways verdant and velvety, his greens looking like emerald oases. The slightest blemish and he gets ornery" (1987, 33).

Some 14,000 golf courses exist in the United States (Grossmann 1993; Rooney 1997; Wheat 1993). With a total U.S. population of 256 million, the 18 hole course (or equivalent) per capita is approximately 1:18,000. Environmentalists have increasingly fought the ever-expanding golf course industry's high demands for and abuse of precious resources such as land and water, especially as the industry has attempted to move abroad. Golf is at such a premium in Japan that the Japanese are building courses at a frenzied rate in Indonesia, Australia, and the Philippines (Pleumarom 1995). It is cheaper for a Japanese golfer to fly to one of these foreign courses for the weekend than to pay for a membership at a Japanese golf club. Many of the foreign course developers have been criticized for their lack of ethics in acquiring land for constructing golf courses in developing countries. In the Philippines, many farmers have been either forced to sell out at absurdly low prices or evicted from their land by government military troops (Wheat 1993). Hence, it is not surprising that the first organized network against golf, the Global Anti-Golf Movement (GAG'M), was born in Japan. This also highlights the fact that golf is presently a bonafied global phenomena. Some 11,000 golf courses exist worldwide in addition to the 14,000 in the United States. Most of these courses are in southeast Asia and Europe.

Statement of the Issue

In the mid-1990s, the Austin-San Antonio growth corridor experienced its most recent episode of drought, complete with the resulting political battles over Edwards Aquifer water usage. One controversial problem with golf courses in the area during droughts is that each one may use the same amount of water in a day as do several thousand people (Wheat 1993; Selcraig 1993; Shi 1993). It stands to reason that citizens in the Austin-San Antonio area will become increasingly irate in times of water shortages, if, upon being forced to limit their water usage, they witness golf courses' continued use of vast amounts of water. In situations such as these, golf courses emerge as manifestations of the social imbalance of wealth.

Courses located in climates with less rainfall have a higher soil-water shortage, i.e. the drier the climate, the more a course must depend on irrigation to achieve optimum growth of its grasses. The climate in central Texas is in a transition zone between humid subtropical (Koppen Cfa) and semiarid subtropical (Koppen BSh) climates. In a humid subtropical climate, the annual water shortage is relatively small. However, in a semiarid subtropical climate, the annual water shortage is nearly equal to the precipitation (Strahler/Strahler 1989). In comparison to the soil-water shortages in Great Britain's marine west coast climate, this is nearly at the other end of the spectrum.

The cyclical occurrence of droughts in central Texas amplifies the precariousness of the water situation (Earl and Kimmel 1995). In non-drought years, people are lulled into a false sense of immunity to water scarcity, and use water as if its supply were unlimited. When a drought comes, they must abide by water restrictions, which are the standard after-the-fact measures in such circumstances. It is more practical to save as much water as possible in plentiful years in order to prepare for the inevitable drought years than consume excessively in times of plenty, only to have to face drastic and disruptive restrictive measures when drought returns. Golf course water issues are worthy of study because the amount of water consumed by courses will increase not only quantitatively, but also as a proportion of the total water available for use. Population geographers project that the population in the region will double by 2020 (Population Estimates and Projections Program and The Center for Demographic and Socioeconomic Research and Education 1996). But the amount of available water will not multiply along with it. As such, the principal question that this study will attempt to answer is how much water golf courses in the study area are using currently and will be using in the future.

Another potential threat the courses pose is their use of agricultural chemicals for fertilization and pest-control. Pesticides are chemicals or other agents used to cause the destruction of non-human organisms considered to be pests (Grad 1996). Pesticides is a general term which includes insecticides, herbicides, fungicides, plant-growth regulators, and defoliants. Before it was banned in 1972, golf courses frequently used DDT; phenol mercury was used on greens well into the nineteen-eighties (Finger 1997; Grossman 1993; Papadolias, telephone interview, 11 November 1996). Estimates place golf course chemical use at three to twenty times the per square foot usage of farming (An and Sage 1992; Selcraig 1993). This use also depends on the course's host climate. Through run-off, high concentrations of fertilizers such as nitrates can end up in surface and ground water. Nitrates are prime catalysts in eutrophication, which is the excess of nutrients in bodies of water that can cause algae blooms. Thus, additional issues this study will explore are the precautions golf course superintendents are taking to prevent the contamination of water supplies through their use of fertilizers and pesticides.

Purpose of the Study

The purpose of this study is to provide a current assessment of the impact of golf courses in the I-35 Primary Growth Corridor (I-35PGC) on water, as well as projections of what their impact on water use may be in

2020. The study will determine the number of golf courses in the I-35PGC presently, and, using demographic data, make minimalist and maximalist projections of the number of golf courses that will exist in 2020 for the same domain. Concordantly, the study will assess the amount of water consumed in average and drought years at the golf courses in question, and predict future water use based upon predicted population increases.

A comprehensive discussion of water supply must include water quality considerations. Water quantity is no longer merely a question of supply and demand (Tobin et al. 1989). Water quality ultimately affects the amount of water available, since polluted water is effectively unavailable for use until treated. For this reason, in its examination of golf courses' effects on water quantity, this paper also examines the potential effects of golf courses on water quality, especially those effects which are specific to the region.

The study's subjects include the golf courses in the I-35 Primary Growth Corridor (I-35PGC). Within what Boehm and Visser define as the I-35 Growth Corridor, the I-35 Primary Growth Corridor is the area with the highest population growth rate (1996). Six of the I-35 Growth Corridor's twelve counties comprise the primary growth area: Bexar, Comal, Guadalupe, Hays, Travis, and Williamson (Fig. 1). This study will assess golf courses' effects on water quantity and quality in this region.

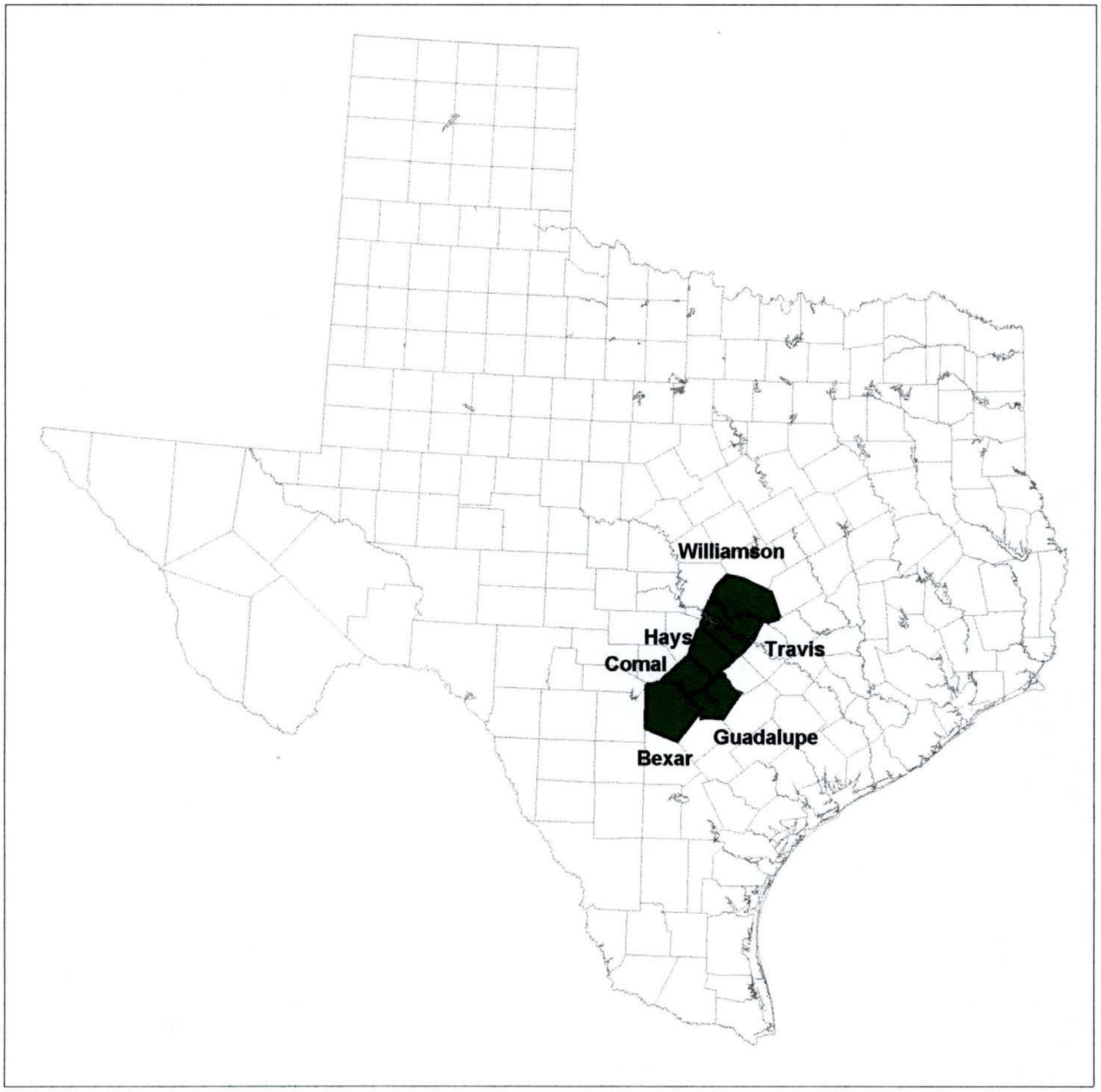

Fig. 1. Counties of the I-35 Primary Growth Corridor (I-35PGC)

CHAPTER TWO

LITERATURE REVIEW

General Integrative Reviews

Many people view environmental sustainability and economic prosperity as diametrically opposed. Simpson, in his article, 'Sustainability and Environmental Assessment,' comments that "where there is a significant conflict between economic and environmental objectives, the application of principles of sustainability is much more likely to be acceptable if there is quantitative information on what environmental damage is likely to occur" (1996, 207).

The concept of sustainability is unclear. In general, the public views practices dubbed as sustainable as being perpetually sustainable. Simpson points out that "[m]any, if not all, development proposals of any significant scale will involve the use of some resources which are, on anything less than a geological time scale, non-renewable. We are really dealing in degrees of sustainability (or unsustainability)" (1996, 206). The term sustainability is relative.

Simpson also emphasizes that geographical scale must be considered in environmental assessment. Local and regional communities, together with the global community, should pursue sustainablility. What is sustainable on one level may not be sustainable on another (Simpson 1996).

For example, consider the difference in sustainability between a golf course at an oasis in the desert (a local level) and golf courses throughout a desert region (a regional level).

Many people's sense of right and wrong is equivalent to their sense of what is legal and illegal, and extends no further. In his article, "Business Ethics and Tourism: From Micro to Macro Perspectives," Walle (1995) discusses Milton Friedman's advocacy that a business's sense of right and wrong should not extend beyond the legal realm. Friedman's opponent, Keith Davis, argues that businesses' responsibilities extend far beyond the legal realm, well into the social and ethical domain (Walle 1995). Curiously enough, Walle (1995) argues that tourism is a special case, which fits into Davis's framework for reasons specific to tourism, which include:

1. "The concept of 'progress' is not a central or unifying concept within tourism theory and ethics" (1995, 264). It could be argued that the concept of 'progress' as we know it must no longer remain a central or unifying concept within any business theory and ethics, including golf's.
2. "The product which tourism provides may be destroyed or undermined by pressures created by the industry" (1995, 264). However, the product any business provides ultimately comprises some combination of resources, and hence also may be destroyed or undermined by pressures created by that industry. Golf is no exception;

courses could potentially play a part in polluting water to such a degree that they could no longer afford water for irrigation because of high treatment costs.

3. "The needs of all relevant stakeholders must be addressed when tourism strategies are being forged" (1995, 264). Here, the argument could be extended that the needs of all relevant stakeholders, who are initially everyone affected by the externalities of the business in its region, must be addressed when any business strategies are being created. Golf, a game played by a very small percentage of the U.S. population, can play a part in polluting the water supply of a much larger percentage of the U.S. population.

Hence golf, as well as tourism, falls under Davis's parameters, not because of anything specifically inherent to its nature, but because of a definitive penchant of any business: it will perpetrate negative externalities to some degree.

Walle (1995) discusses the 'Globalization of Markets' theory advanced by Harvard's Theodore Levitt, which concludes that "the optimum strategy of the [business] firm is ... to force homogeneous consumption patterns upon customers even in cases where markets resist such tactics" (1995, 265). This stems from the views of proponents of western-style progress, who inevitably consider nearly all economic development to be moral because it brings some benefits to a region (Walle

1995). The obvious rebuttal to this is that the benefits of economic development not occuring may outweigh the benefits of its implementation.

Walle (1995) criticizes the typical business practice of focusing exclusively on the customer's needs in order to advance economic goals. He favors the macro-marketing perspective, which concentrates on the long-term impacts and all relevant stakeholders. This view is of great utility in regard to environmental issues, "... transcending a myopic focusing upon customer needs as the be-all and end-all of organizational strategy" (1995, 267). Golf courses would certainly prosper, at least in the short run, if they continued to focus solely on customer needs; their customers tend to be wealthy and capable of paying for the fulfillment of their desires. However, political and public pressure brought on by negative perceptions of golf courses' effect on the environment could ultimately cut the golf industry's profits more than if it worked towards objectives aimed at the goal of sustainability.

The geographer who is the foremost authority on golf as a sport is John F. Rooney. Within human geography, Rooney (1985, 1989, 1992, 1997) is a sports geographer who has focused on the spatial per capita distribution and regionalization of golf course diffusion in order to discover market areas for new golf course construction. However, he has not focused on physical geography or the interface of physical and human geography as they relate to golf courses.

General Positive and Negative Aspects of Golf Courses

One of the criticisms of golf courses concerns the death of wildlife--especially avian mortality--due to contact with, or the ingestion of chemicals used to treat turfgrass (Balogh et al. 1992; Rainwater et al. 1995; Stevens and Stevens 1996; Tietge 1992). Those who argue in counter to this criticism assert that golf courses are wildlife habitats/sanctuaries (Balogh and Walker 1992; Dodson 1996 and 1997; Finger 1997; Miller et al. 1995; Stevens and Stevens 1996; Tietge 1992; USGA 1997). Another criticism of golf courses is that they occupy valuable space which could be used for agriculture or other uses. The three rebuttals to this criticism are:

1. Golf courses are greenbelts which in addition to providing oxygen have recreational value.
2. Golf courses entail an increase in surrounding land values (Balogh and Walker 1992), and thus an increase in local tax bases (Finger 1997). [The average revenue generated per Texas course in 1993 was $630,000 (Sharp 1997).]
3. Golf courses can be located on sites which for other uses are either undesirable, such as closed sanitary landfills (Miller et al. 1995), abandoned quarries and mines (United States Golf Association {USGA} 1997), and toxic waste sites (Sinclair 1997), or naturally impractical, such as floodplains (Hind et al. 1995).

Two of the more positive aspects of golf courses relate to older sports enthusiasts and job creation. Golf courses provide an opportunity for older athletes who are less capable of participating in more rigorous sports (Finger 1997). On the other hand, the pesticides used on golf courses are potential human carcinogens (Balogh and Anderson 1992). Golf courses also create jobs in three ways. In addition to the golf course grounds maintenance staff, most golf courses have restaurant and bar facilities which provide additional employment. Private golf courses often contain tennis courts and swimming pools which mean additional job opportunities. Tourists and business people who are golfers have a tendency to choose a travel destination depending on its proximity to a golf course. A golf course attracts tourists who are golfers to the hotels and restaurants in the course's area. Golf courses may also create jobs by being a contributing factor in corporate location. In a study done by the City of Waco on the amenities which attracted corporations, golf ranked third after hospitals and schools on the list of the most important factors companies considered when moving to a new location. Companies want their employees to have nearby recreational opportunities. They also have an interest in providing recreational outlets for visiting business contacts (Finger 1997).

James C. Balogh and William J. Walker (1992), Ph.D.s in soil science and in soil and water chemistry, respectively, are the editors of one of the most extensive (900 plus pages) and comprehensive (over 2,000 references) books on the environmental issues concerning golf courses. These researchers 'wrote the book' on golf course-related environmental concerns. The United States Golf Association (USGA) copyrighted the publication. In addition to the recreational and aesthetic value of golf courses, Balogh and Walker (1992) list the positive and negative environmental effects of turfgrass. Some positive environmental effects not already mentioned in this paper include erosion control, adsorption of atmospheric pollutants, dust control, cooling effects, and noise abatement (Balogh and Walker 1992). Other positive environmental effects they mention relate to water and will be discussed later in this chapter. In the first chapter on the background and overview of environmental issues, Balogh et al. (1992) identify the environmental impacts and nonpoint pollution problems in turfgrass systems:

1) Contamination of surface water with sediment and nutrients during turfgrass construction
2) Potential contamination of runoff water and groundwater with applied nutrients and pesticides
3) Development of pest populations with increasing resistance to chemical control
4) Potentially negative impacts of chemical management on beneficial soil and non-target organisms
5) Potentially toxic effects of applied chemicals to non-target plants and animals
6) Excessive use of water resources during drought conditions and in semiarid and arid climatic zones
7) Loss or degradation of wetland resources during construction and turfgrass maintenance (p. 22)

However, Balogh and Walker (1992) do not apply their examination of the use of water resources and potential water contamination to the golf courses of any region in particular.

Golf Course Water Consumption

Negative and Positive Impacts of Water Consumption

Perception plays a fundamental role in the controversy surrounding golf course water consumption. Some items which typically make the news are sensational highlights. One such example is the witnessing by Peter Raine, Director of the Kent Trust for Nature Conservation, of the irrigation of golf courses on the outskirts of Harare, Zimbabwe, while people in the region were quite literally dying of thirst (Wheat 1993; Pearce 1993). The press heavily influences public perception. As such, a review of the popular press's coverage of this issue is in order.

One of the potential problems that golf courses pose is their high consumption of water, which often involves use of public water supplies (Boss 1994; Grossman 1990; Pearce 1993; Platt 1994). Edmondson (1987) identifies water as the most pressing problem confronting golf courses in arid regions. Central Texas is in a transitional climatic region between humid subtropical and semi-arid subtropical; during droughts it faces water shortages similar to those of arid regions. To present the amounts of water used by golf courses in laypersons' terms, estimates in the popular press are often couched in terms of equivalents in per family or per person daily usage. Sometimes the specifics of this comparison are unclear. Selcraig (1993) states a figure for the Palm Springs Golf Course in Phoenix, Arizona, as the equivalent to the water used by 11,000 people on a daily basis (1993). Robbins (1992) places the average figure for each of Jarkarta's golf courses as equal to the water use of 1,000 families. Wheat (1993) states that 2,000 families could satisfy their water requirements with the amount of water used on a Thailand golf course. Shi (1993) also places the estimate of per-course daily needs as equal to that of 2,000 families. Clearly, these figures depend on the climate, family size, and the average per capita water use specific to a given country.

Similarly formulated estimations by academics concur. Pleumarom's (1995) estimates of golf course water use are similar to those previously mentioned, placing the amount of water used per course as an equivalent to the quantity used by 6,000 Bangkok residents. This figure changes, when industry and agriculture are excluded, to 15,000 townspeople, or 60,000 villagers. One might assume that all the figures given by the aforementioned authors in reference to the amount of water expended per capita, or per family, include agricultural, industrial, as well as municipal uses. In either case, the figures are substantial, especially considering that they are per course.

Balogh and Watson (1992) do not make comparable estimates. They do provide a comprehensive review on the core of knowledge related to golf course water consumption in the United States. Water is an invaluable resource in the U.S., supplying recreational and aesthetic value, transportation, and providing for public, agricultural, and industrial consumption. Recent droughts in the United States have emphasized the need to formulate a logical water resource policy. As the demands of many urban and rural constituents continue to increase, water surpluses stored during wet years are no longer reliable sources for allocation of groundwater and surface water during dry years. Turfgrass water consumption is relatively small compared to agricultural and industrial uses. Nonetheless, certain sectors of the public have considered highly visible irrigation of recreational and leisure turfgrass facilities as a luxury. Historically in the U.S., policy-makers and turfgrass managers alike have treated water as if its supply were inexhaustible (Balogh and Watson 1992).

Golf course proponents' answer to the criticism concerning high water consumption is that golf reaps the highest dollar return per volume of water used when compared to industry and agriculture in general, with the exception of a small number of specialty crops. The average revenue generated per Texas course in 1993 was $630,000 (Sharp 1997). The 827 golf courses in Texas by 1997 (Sharp 1997) could be projected to generate more than half a billion dollars in revenue.

Potential Solutions to High Water Consumption

Research has proven that total water consumption by turfgrasses is related to water supply and evaporation demand, length of the growing season, turfgrass species and cultivars, amount and rate of vegetative growth, and turfgrass cultural practices (Balogh and Watson 1992). The amount of water supply affects turfgrass water consumption in that turfgrass is capable of ingesting higher amounts of water than are necessary for optimum growth. Golf course superintendents must be careful to not provide more water than is actually necessary for reasonably acceptable growth. Plants can absorb more water than they need. In general, the higher a turfgrass's evapotranspiration rate, the more water it will consume. Turfgrasses which are drought resistant and have low evapotranspiration rates consume less water than those that are not drought resistant and have higher evapotranspiration rates (assuming equal mowing heights). The more vegetative growth a grass exhibits, and the faster its growth rate, the more water it will consume (Balogh and Watson 1992). Cultural practices used to conserve water on golf courses involve mowing, timing and duration of irrigation, fertilization scheduling, soil cultivation, and the use of anti-transpirants and growth regulators (Balogh and Watson 1992).

Increasing mowing frequency and honing in on the most efficient turf height can aid in increasing water use efficiency. The deeper and more extensive a grass root, the more water it can absorb, because water from a greater portion of the soil profile is available. Generally speaking, the less exposed canopy surface area there is, the lower the evapotranspiration rate, and hence the lower the water deficit. However, the shorter the grass, the more difficult it is to maintain a deep root. The essence of increasing water use efficiency and conservation through mowing is to aim for the point of equilibrium between root depth and canopy surface area, such that overall applied water be as little as possible. The stock expectation of golfers in the United States, that golf course turfgrasses be carpet-like, complicates saving water. Greens provide a perfect example of turf that is out of balance in this sense (in regard to the mowing height/root depth dichotomy), because of the requirement of such short grass. Because evapotranspiration rates from greens are lower than anywhere on a golf course, they would seem to be ideally suited to conserving water. But because their root systems are so shallow, they are incapable of ingesting water efficiently (Balogh and Watson 1992). As a result, greens use more water per area than tees, fairways, or roughs.

Another water-saving practice is watering at night or in the early morning. This conserves water because wind and solar radiation are at a minimum at these times. Water conservation occurs because there is less evaporative loss from the water stream emitted by the sprinkler, from the soils, and from the turfgrass itself (Balogh and Watson 1992).

In comparison to fixed calendar scheduling, irrigation based on visual indicators saves substantial amounts of water. The combined use of visual indicators and pan evaporation saves an even larger amount of water. The accepted practice for irrigation is deep and infrequent watering. This practice leads to deeper and more extensive root systems which are able to absorb more water. Therefore, although less water is made available to the plant for absorption, since the plant absorbs what water is available to it more efficiently, irrigation requirements decrease. Computer irrigation systems which are properly designed, programmed, and installed conserve significant amounts of water by irrigating according to a course's specific needs (Balogh and Watson 1992).

Features of computer systems which further increase water conservation include single-head controls, water recycling capabilities, solid state valve timers, devices which measure the infiltration capacity of soils, and on-site weather stations. Single head controls are advantageous in that if a dry spot exists which needs more irrigation, operators can turn on the one sprinkler head that waters that dry spot. With standard manual systems, one valve typically opens at least two, if not several sprinklers on one line at a time. Thus, upon irrigation of a dry spot with standard manual systems, already saturated areas under accompanying sprinkler heads also receive water. These conditions easily lead to runoff and the potential environmental consequences which accompany it. Solid state timers have a margin of error of one minute, which is significantly less than that of electro-mechanical timers, which is one to four minutes. Also essential to maximum conservation of irrigation water is maintenance of irrigation systems to avoid leaks and improper irrigation timing is (Balogh and Watson 1992).

Over-fertilizing, especially with nitrogen, decreases water use efficiency. Over-fertilization causes excessive growth in a turfgrass, which in turn requires a greater amount of water for its maintenance. The cultivation of healthy soils is critical to the reduction of water irrigation requirements. For example, soil compaction reduces aeration and water retention capacity. Due to these reductions, a plant in compacted soil requires more irrigation water in order to ingest the same amount of water that a plant in a non-compacted soil can ingest with less irrigation water (Balogh and Watson 1992).

Chemicals which inhibit water-requiring tendencies of plants have also proven to save water. Anti-transpirants decrease turfgrasses' natural evapotranspiration rate. Wetting agents increase infiltration rates in hydrophobic soils by breaking down wax-like substances that can coat the surface of soil particles. Additional water conservation occurs when growth regulators are used to stunt the growth of turfgrass. However, the current social and environmental disadvantages of chemical strategies for water conservation limit their potential for development (Balogh and Watson 1992).

Conservation-minded golf course design can save water. Drainage systems which recapture irrigation water in retention ponds for reuse can cut overall water needs by taking maximum advantage of the total water applied to turfgrass. Similarly, irrigation from ponds which capture natural rainfall has obvious advantages, even though the ponds are not an integral part of a drainage system. Many golf courses maintain out-of-play areas in lawn-like conditions. By converting out of play areas to natural landscapes, irrigation is no longer necessary for out-of-play areas (Hartwiger 1995). Along similar but more innovative lines, golf course architect Joe Finger (1980) suggests saving water by redesigning golf courses with significantly reduced fairways that consequently require much less irrigation (Figure 2).

Currently in the United States, tee-to-green manicured grass is the norm, as is relatively hydrophilic turfgrass in the rough. Future courses could have reduced fairways and roughs which are not irrigated (Finger 1980). By reducing fairways to the size and place only where a reasonably well hit drive would land, fairway sprinklers could be cut by a third. The distance to these "landing areas" could be calculated, and multiple, carefully placed tees could be installed for different levels of abilities. Future course's roughs could employ native grasses which required

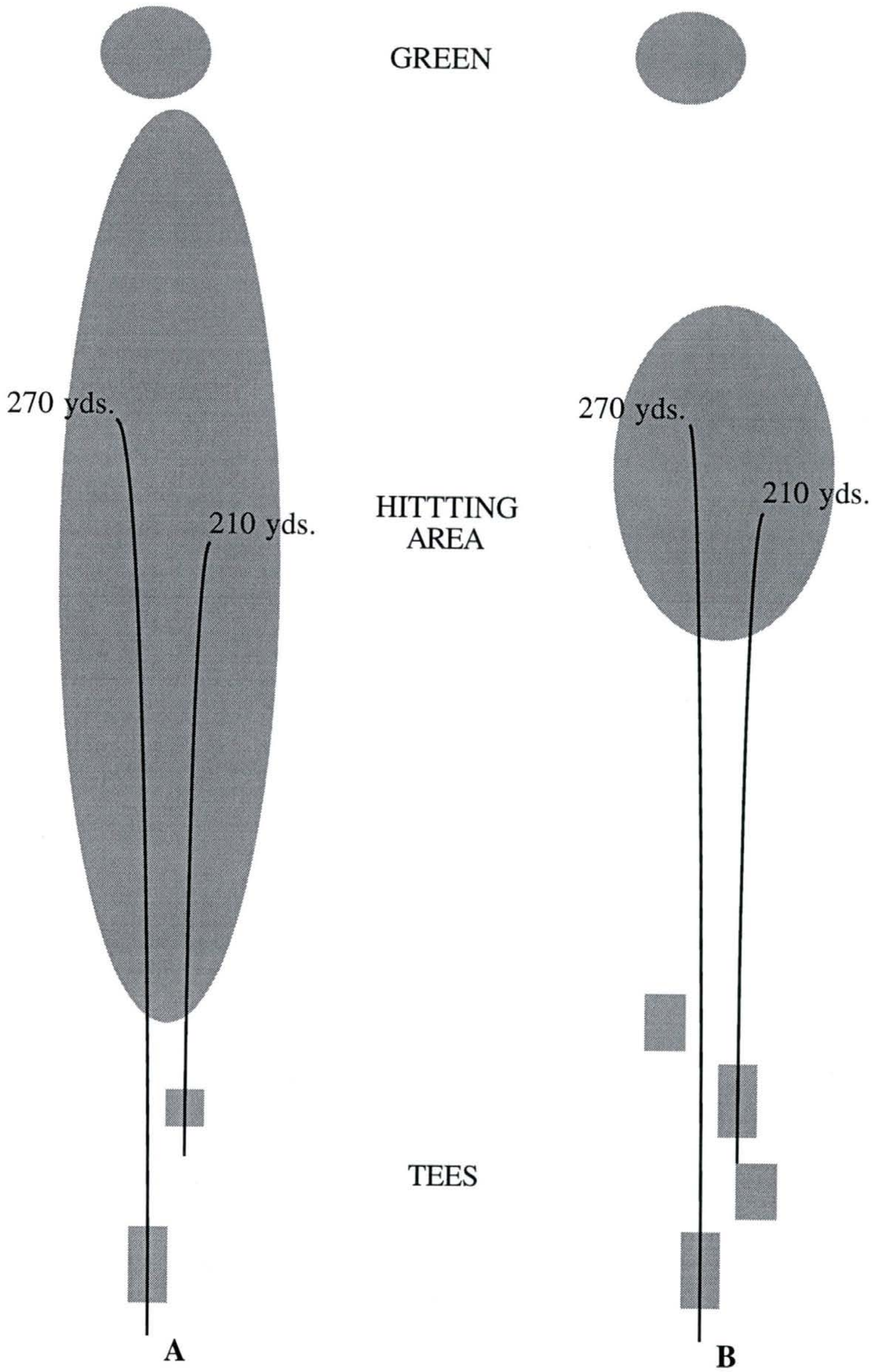

Fig. 2. Basic Hole Layouts: Current (A) and Future Water-Saving (B)
(Adapted from Finger 1980)

limited water, allowing natural rainfall to dictate the conditions of the rough (Finger 1980). Finger (1980) advocates maintaining the future courses' 'landing areas' with the same intensity as entire fairways are maintained currently. He also envisions current maintenance practices of tees and greens to continue. A course designed in such a way could save as much as 80 million gallons (246 acre feet) of water per year, which is approximately equal to the yearly water needs of 800 families of three (Finger 1980).

A common strategy employed by golf courses to limit water use is irrigating with treated wastewater. This practice saves water, and is a viable standard irrigation technique for golf courses (Barnhart 1992; Hayes 1995; Joerns and Moriaty 1988; Long 1994; Mujeriego et al. 1996; Ninemire 1997). In addition to reducing water costs, another advantage of irrigating with wastewater effluent is the reduction of fertilizer expenditures between 6 to 8 cents per cubic meter of reclaimed effluent (Mujeriego et al. 1996). One golf course in New Mexico not only uses treated wastewater, but is located directly on the grounds of a water treatment facility; it also incorporates an alfalfa farm and tree nursery (Meiner 1993).

The possible disadvantages of wastewater irrigation for golf courses are many: contamination of soils with toxic levels of micro-nutrients, reduction of available oxygen, silting of water storage areas, and increased damage to irrigation equipment caused by high levels of suspended solids (Balogh and Watson 1992). Careful monitoring of soil conditions and flushing irrigation equipment with 'normal' water can help mitigate possible detriments. Another disadvantage of wastewater irrigation is that like fertilizers, it poses a potential threat to water quality through runoff (Barnhart 1992). However, even if wastewater irrigation solved the water consumption matter and posed no threat to water quality, it would not entirely solve all the water quality problems posed by golf courses.

Golf Courses' Potential Impacts on Water Quality

Negative and Positive Effects on Water Quality

Golf courses may threaten water quality through the use of chemicals and organics to fertilize turf and kill pests. Such chemicals can become integral parts of the hydrological cycle (Platt 1994; Pearce 1993: Grossmann 1990). An and Sage (1992), in their study, "The Golf Boom in South Korea," identify pollution of drinking water as a main source of criticism of golf courses. Selcraig describes one case in the area of Orlando, Florida where the runoff from a golf course severely degraded one of the clearest lakes in the state (1993). Robbins (1992) and Grossman (1990) cite instances in which golf course runoff contaminated nearby surface and groundwater.

Researchers have delineated two processes through which pesticides and fertilizers can become a detriment to water quality: surface runoff and leaching. Water which does not infiltrate into a soil or evaporate will flow across turfgrass into local drainage systems, streams, and lakes. Water which does infiltrate into the soil but is not absorbed by the soil is subject to leaching. Factors affecting the amount and rate of surface runoff include

1) precipitation duration, intensity, and spatial extent;

2) size, shape, orientation, topography, and geology of the golf course watershed;

3) soil physical and chemical properties, infiltration capacity, and antecedent soil moisture conditions;

4) type and extent of grass cover (sod vs. seed); and

5) cultural practices. (Balogh and Watson 1992, p. 49)

Runoff is a more serious problem on sites with thatched turfgrass, fine-textured soils (e.g. silt loam and clayey soils), compacted soils, slopes, and precipitation or irrigation rates exceeding the infiltration rate (Balogh and Watson 1992).

The mechanisms by which runoff water transports turfgrass fertilizers and pesticides to surface water are their dissolution in the runoff water itself, and their absorption into, adsorption onto, or desorption from eroded sediment particles being carried in the runoff water. To which one of these runoff transport processes a certain chemical compound tends to be most subject depends on its chemical characteristics, water solubility, ionic charge, the qualities of the adsorbing surfaces of the sediment, and the duration and intensity of the runoff event (Balogh and Watson 1992).

Fertilizers and pesticides leach into groundwater almost exclusively in solution with water percolating through the soil (The most notable exception is karst topography). Substantial solute leaching occurs only when soils are wetter than field capacity. The potential for leaching into groundwater varies seasonably. In dry months, lower water tables are less subject to leached chemicals. In wet seasons, higher water tables are more prone to leaching nutrients and pesticides. Clay soils, except in cases where shrink/swell cracks are present, have reduced potential for subsurface transport. Conversely, clay soils have increased potential for runoff (Balogh and Watson 1992).

No topography has greater potential for contamination of water through runoff and leaching than karst topography. The large channels and underground caves in its limestone rock permit rapid conveyance of water underground. Where these openings are exposed at the surface, expeditious transport of runoff occurs with negligible dilution. The sinkholes, disappearing streams, and disappearing valleys which characterize karst topography are direct conduits for runoff into underground channels and caverns in limestone aquifers (Balogh and Watson 1992). Karst aquifers, in addition to being subject to leaching through its normal agent, solute transport, are subject to leaching through all agents of runoff transport (adsorption, absorption, desorption). Golf courses located in karst topography are especially prone to contaminate groundwater with fertilizers and pesticides through runoff and leaching (Balogh and Watson 1992).

Conversely, golf course proponents highlight that turfgrass has positive effects on water quality because of both its filtering and anti-erosional qualities. Turfgrass, having no impervious cover, acts as a water filter. Turfgrasses' potential for runoff is low compared to parking lots and other similar urban settings. Moreover, turfgrass impedes erosion through

1) interception of rainfall,
2) reduction of the magnitude and velocity of surface runoff,
3) physical binding of soil particles,
4) improvement of soil physical properties involved with structural stability and particle cohesiveness, and
5) reduction of soil moisture by transpiration resulting in increased water holding capacity. (Balogh and Watson 1992, p. 50)

Grass cover's average annual sediment losses, among the lowest of any land cover, are comparable to those of forest cover. Grass cover's average annual sediment losses range from less than one tenth of one percent (of those of agricultural fields in rotation) to 11 percent (of the average annual sediment losses of agricultural fields with fallow cover) of those of other land cover systems, depending on the soil (Balogh and Watson 1992).

Methods of Limiting Potential for Water Contamination

The current buzzword for environmentally friendly use of pesticides and fertilizers is Integrated Pest Management (IPM). IPM bases its practices on the idea that healthy, growing turf is the best defense against pest problems. IPM promotes healthy, growing turf through cultural and biological practices; by doing so, IPM avoids superfluous pesticide treatments (Dinelli 1997). Integrated Fertilizer Management (IFM) is the same idea applied to fertilizers. Best Management Practices refers to the techniques used in IPM, IFM, and in the reduction of water use. BMP stresses methods that have been used for years by golf course superintendents, only today superintendents place much more importance on these methods because of increased environmental concerns (Clark 1997). Some methods for the reduction of the use of fertilizers and pesticides' potential for harming water quality are as follows.

1. methods to avoid both leaching and runoff of both fertilizers and pesticides:
    a. judicious, minimal, less frequent use (this includes means to this end, such as redesign of courses by conversion of out of play areas to natural landscapes and reduction of fairways to minimal landing areas)
    b. limitation of irrigation to quantities and rates that do not exceed plant use, evaporation, and soil storage
    c. applications timed in relation to potential runoff and leaching events (rain storms)
    d. management of traffic patterns in order to control factors such as soil compaction, which should be low enough to avoid surface runoff
    e. maintenance of a vegetative buffer zone between surface water and treated areas

f. special care in regions of karst topography to avoid direct entry into fractures and sinkholes

g. proper equipment maintenance and calibration for even applications

h. chemical selection according to site conditions such as soil properties, local and regional geology, depth to groundwater, proximity to well heads and surface water, topography, and climate

i. retention ponds which capture runoff or drained irrigation

2. methods for environmentally-sensitive pesticide management:

   a. application in strict compliance with labels and all regulations

   b. establishment of action thresholds (the levels at which pests need to be in order to act to limit them)

   c. proper disposal of unused chemicals and containers

   d. proper chemigation techniques including anti-backsiphoning devices and flushing of injection and irrigation systems

e. selection of less toxic, less mobile, less persistent pesticides with greater selective control of pests

f. light, post-application irrigation to incorporate chemicals into soil, thus making them less subject to runoff

g. spot application (as opposed to blanket application)

h. selection of pesticides according to how their solubility, formulation, degradation rate, volatility, and adsorption properties correspond with site conditions (1.h.)

3. methods to reduce the possibility of contaminating water with fertilizers:

a. timed applications using amounts which are no more than the plant can use at that time in the plant's growth stage

b. frequent applications of reduced amounts

c. use of slow-release sources of nutrients (such as many organic fertilizers)

d. maintenance of good growing conditions (Balogh and Anderson 1992; Finger 1980; Hartwiger 1995)

Since chemicals leach almost exclusively in solute form, within the context of an overall effort to reduce total chemical use, maximizing the use of insoluble fertilizers and pesticides can help avoid contamination of groundwater through leaching. Considering that substantial drainage and solute leaching occurs almost entirely when soils are wetter than field capacity, not irrigating beyond a soil's field capacity should also limit leaching. However, for aforementioned reasons, both of these strategies are of limited value for courses located on karst topography.

Summary of Literature Review

Although golf course turfgrasses consume a small percentage of the water supply, their total water use is substantial in and of itself. Consideration of both water conservation's cost benefit and water planning authorities' (TWDB 1990) recommendation of water conservation as a priority method to meet demand will require research in the Austin-San Antonio area regarding the development of water conservation strategies. Through leaching and runoff, the use of fertilizers and pesticides on golf course turfgrass is a potential threat to the quality (and thus the quantity of available supply) of surface and groundwater. The need exists for quantitative studies that measure the environmental impact of economic development (Simpson 1996). Water use issues in regions with periodic drought conditions require the attention of turfgrass researchers. Water consumption and conservation of water quality are important considerations in integrated management of turfgrass. Due to regional concerns regarding the impacts of consumptive use of water, irrigation, and chemical management of turfgrass, regionally specific information on water management guidelines for practices to conserve water quality and quantity should be developed at a regional level. Such information would be useful in the development of consistent guidelines and recommended practices (Balogh and Watson 1992).

CHAPTER 3

LEGAL BACKGROUND

This chapter addresses the federal, state, and local laws, regulations, and court decisions that apply to the use of water and chemicals by golf courses in the study area. The first part of the chapter addresses water quantity. The second part deals with water quality, especially the effects of runoff and leaching of pesticides and fertilizers from turfgrass. The last part covers reclaimed water use.

Water Quantity

Since water quantity problems are usually local in scale, federal law relegates this issue to the states. In Texas, the state owns surface water, which is allocated by a permit system based upon prior appropriation. This allocation is carried out by the state, through the Texas Natural Resource Conservation Commission (TNRCC), by granting permanent permits for a quantity of water which equals the "firm annual yield." The firm annual yield is a quantity of water equal to the streamflow of all Texas streams in the drought of record. Recent legislation also requires the TNRCC to maintain in-stream flows that meet the environmental needs of bays and estuaries. All new permits granted in excess of the firm annual yield are temporary (Kaiser 1985).

In contrast, land owners have absolute ownership of groundwater under Texas state law. Rights to groundwater, enhanced by the 'Rule of Capture'--also known as the 'Law of the Biggest Pump'--are one 'stick' in the 'bundle' of property rights. Property owners have absolute ownership of any and all groundwater they can pump from a well on their property (Kaiser 1985). This leads to the paradoxical circumstance that property owners effectively have rights to more than just the groundwater beneath their property. Because of the nature of the flow of water in aquifers, they may have access to groundwater which would normally move beneath their neighbors' property.

The landmark court case that affirmed the Rule of Capture was *Houston & T.C. Ry. Co. v. East, 98 Tex. 146, 81 S.S. 279* (1904). The Houston railroad's pumping of groundwater caused subsidence on East's property. However, the court did not hold the railroad liable since it had caused the subsidence unintentionally through the exercise of a vested right. Exceptions to this law do exist today; one such exception is the Edwards Aquifer Authority (EAA). Senate Bill 1477 (1993) created the Edwards Aquifer Authority and authorizes it to issue permits in order to regulate the pumping of water from the aquifer. Both existing users and those who wish to drill a new well must apply for a permit from the EAA (31 TAC § 701.1-701.212).

Ironically, water conservation was not the focus of what led to the EAA, which was one of the first restrictions on the Rule of Capture. Rather, the EAA was created in response to a court order pursuant to the Endangered Species Act of 1973 (ESA). Among other things, this act mandates the protection of the critical habitats of endangered species. It was through this act, which grants standing to environmental groups, that the Sierra Club sued the City of San Antonio in order that it do its part to maintain the flow of springs at San Marcos and New Braunfels. San Marcos Springs and Comal Springs (the spring in New Braunfels) are critical habitats of several endangered species.

Texas Senate Bill 1477 required the EAA to prepare and implement a critical period management plan for droughts. From *Sierra Club v. San Antonio et al.* came the August 23, 1996 ruling of Judge Lucius Bunton, which included an emergency withdrawal reduction plan for the Edwards aquifer. In essence, this plan was an ad hoc substitute for the critical period management plan that the EAA, in Judge Bunton's estimation, had failed to implement at that point. Among other things, Judge Bunton's plan restricted golf course water use to 11.2 million gallons (34.4 acre feet) per month per 18-hole golf course. The plan also required golf courses to install meters to measure aquifer pumping (Express-News Online 1997). However, this plan never went into effect since the appropriate authorities never declared the beginning of a critical period. Since January 1, 1998, those portions in the study area within the San Antonio section of the Edwards Aquifer have been subject to pumping limits by means of a prior appropriation system similar to that of surface water (Texas Legislature 1993, SB1477).

Conserving water is the least expensive way to obtain 'new' water, followed by other methods such as aquifer storage and recovery, water reuse, purchase, water development projects (dams and transfers), and desalinization of ocean water. Currently, the Texas Water Development Board (TWDB) recommends conservation as a key method to meet Texas' water demand. Until the early 1980s, the traditional approach to meeting the water demand in Texas was to identify surface and groundwater supplies for development (TWDB 1990).

The use of reclaimed water is both a water quantity and quality issue. The Texas Water Development Board (1990) recommends the use of reclaimed wastewater as a viable method of increasing the usefulness of a limited water supply. In 1985, the 69th Texas Legislature included water recycling and reuse in its refined definition of water conservation. One of the priority recommendations of TWDB in 1990 regarding alternative water supplies was that the state adopt an official policy to guide state water reuse and recycling (TWDB 1990). Although the purpose of wastewater reuse is to effectively increase the water supply, the heart of the regulations regarding reclaimed water use deal with its effect on water quality.

Water Quality

The federal laws which are most pertinent to golf courses' potential threat to water quality are the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) and the Clean Water Act (CWA), along with their respective amendments. FIFRA is the federal law which most directly addresses pesticides. The Toxic Substances Control Act (TSCA), in § 3(2)(B)(ii), specifically excludes pesticides as defined by FIFRA from TSCA's definition of chemical substances (Landfair 1997). The Comprehensive Environmental Response, Compensation and Liability Act-

1980 (CERCLA) also addresses pesticides under its cleanup provisions, but in § 107(i) specifically exempts from its coverage the damage resulting from the application of a pesticide product registered under FIFRA. However, this does not relieve a person from liability under CERCLA for the release of pesticides classified as hazardous substances (Grad 1996).

Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA)

The intent of the original FIFRA, passed in 1947, became a reality in 1972 with the Federal Environmental Pesticides Control Act (FEPCA). FEPCA added health and environmental concerns to FIFRA's focus on labeling and efficacy; it also strengthened FIFRA's enforcement provisions. Further amendments in 1975, 1978, 1980, 1988, and 1996 are indicative of an ongoing battle between environmentalists and pesticide interests (Miller 1997).

FIFRA defines a pesticide as any substance intended for "preventing, destroying, repelling or mitigating any pest," and substances intended for "use as a plant regulator, defoliant, or desiccant." The standard definition of pest includes insects, rodents, worms, fungus, weeds, plants, virus, bacteria, micro-organisms, and other animal life (Miller 1997). Note that pesticide is a general term that denotes insecticides, fungicides, and herbicides, which are all distinct in that their target pests (insects, fungi, and weeds, respectively) differ.

The core of FIFRA since 1972 has been its pesticide registration program. The United States Environmental Protection Agency (EPA) must approve a pesticide before it can be manufactured, distributed, or imported.

Obtaining the data required to apply for registration with the EPA can take several years and millions of dollars, and the subsequent application and approval process by the EPA can take another several years. In order for the EPA to approve a pesticide, the pesticide must not have unreasonable adverse effects on the environment. Another requirement is that the pesticide not cause unreasonable adverse effects on the environment when used in accordance with widespread and commonly recognized practices. The operative phrase "unreasonable adverse effects on the environment" means "any unreasonable risk to man or the environment, taking into account the economic, social, and environmental costs and benefits of the use of the pesticide" (Miller 1997, 289).

Until 1996, registrations were good for five years, at which time they expired unless an interested party petitioned for renewal. The 1996 amendments extended this period to 15 years. At time of expiration, the EPA may require further testing. Due to the realization that many of science's previous assumptions about pesticides have been wrong or at least over-simplified, the EPA has recently attempted to accelerate reviews of hundreds of chemicals that were registered earlier under less strict standards. The 1988 amendments addressed the inadequacy (by contemporary scientific standards) of the safety data underlying the registrations. These amendments deemed all data submitted prior to 1970 as invalid for re-registration purposes. However, the near-collapse of the EPA's registration process in the mid-1970s, symptomatic of the fact that the review of all pesticides pending registration or re-registration could take well into the next century, gave way to a conditional registration and conditional re-registration process. Consequently, a substantial amount of pesticides in use have only been registered or re-registered conditionally, pending the submittal and/or evaluation of information regarding their unreasonable adverse effects on the environment (Miller 1997).

Other laws in addition to FIFRA enter into the picture regarding pesticide regulation; the overlap can be conflicting. Guillebeau (1995) examines the phase-out of the pesticide methyl bromide by golf courses, which is one of the consequences of the Clean Air Act (CAA). Methyl bromide is unique due to the distinct evaluation criteria of the CAA and FIFRA. Both acts require the EPA to determine the risks of pesticides; however, under FIFRA, the EPA weighs risks with benefits before taking regulatory action, whereas under the CAA, the EPA typically removes a pesticide from the market if it exceeds certain risk criteria, regardless of the benefits (Guillebeau 1995).

Historically, FIFRA has permitted the use of methyl bromide on golf courses by superintendents, who applied it as a fumigant against a wide range of pests. Under FIFRA, after the EPA examines a pesticide's risks to both humans and the environment, the most common resolution is to allow a pesticide's continued use with increased safety regulations. Once methyl bromide was identified as an ozone-depleting substance, the CAA dictated that it be phased out in the U.S. by January 1, 2001. On that date the production and importation of methyl bromide will be banned altogether. Guillebeau makes note of the fact that the CAA's ban is on the production and importation of methyl bromide, not its use. The use of pesticides is FIFRA's jurisdiction; its policy regarding methyl bromide may or may not change. Thus Guillebeau, inadvertently or otherwise, implicitly points out that golf courses could stockpile methyl bromide in order to use it after the CAA ban is in effect. The possible substitutes are either less effective or otherwise unsatisfactory (Guillebeau 1995).

The quality of any regulatory decision is no better than the data upon which it is based; unfortunately the EPA does not have the resources to test all the pesticides submitted for approval (Guillebeau 1995). Guillebeau (1995) appeals to all interested and concerned parties to provide information on which regulatory decisions can be based.

The basis for regulation of pesticide usage resides in the fact that a pesticide which is safe for use on one plant may leave dangerous residues on another. Likewise, a pesticide safe for use on a dry area may pose a hazard if applied to a marshy environment. Also, certain chemicals may be too dangerous for general use, but reasonably safe if applied by trained personnel. Hence FEPCA created general and restricted use categories for pesticides, the latter available only to Certified Applicators. A pesticide's label for use only under the direct supervision of a Certified Applicator does not mean that a Certified Applicator need be physically present when the pesticide is applied, but rather that the chemical is to be applied under the instruction and supervision of a Certified Applicator (Miller 1997). Different types of applicators exist. In the situation of a golf course, the proper type is commercial applicators, who use or supervise the application of pesticides on property other than their own. The EPA prescribes certification standards, but any state wishing to do so may establish their own certification program, as long as it adheres to EPA guidelines and federal statutes (Miller 1997).

Texas has established its own certification program within the Texas Department of Agriculture (TXDOA), the agency that has the responsibility to regulate the registration and use of pesticides in Texas (Grad 1996). Until the 1978 FIFRA amendments, states could not impose stricter standards on pesticide use within their jurisdiction (Miller 1997). Since then, state agencies like the TXDOA have had the authority to declare 'state-limited-use' pesticides. In classifying a pesticide as such, the TDOA must take into account the chemical's effect on water quality (V.T.C.A., Agricultural Code § 76.003). The state-limited-use classification, based on state-specific economic, social, and environmental costs and benefits of the use of the pesticide, is more strict than the federal restricted-use pesticide standard. The head of each state regulatory agency may, after notice and public hearing, adopt rules that

1) prescribe methods to be used in the application of a restricted-use or state-limited-use pesticide;
2) relate to the time, place, manner, method, amount, concentration, or materials used in pesticide application; and
3) restrict or prohibit use of a restricted-use or state-limited-use pesticide in designated areas during specific periods of time (V.T.C.A., Agricultural Code § 76.008).

Any rules established under this clause have immense potential to protect the quality of surface and groundwater from the threats that pesticides pose through leaching and runoff.

Texas requires licenses and certification for commercial applicators. The state obliges commercial applicators who apply restricted-use pesticides to have additional certification specific to this task (Grad 1996). However, an unusual provision states that the licensing of commercial applicators is contingent on the availability of federal funding, and will be discontinued if federal funds are not adequately available (V.T.C.A., Agriculture Code § 76.103). Certified Applicators must keep two-year back-dated records of their use of pesticides. If an agency requests these records in writing, a licensee must comply (V.T.C.A., Agriculture Code § 76.114).

The Clean Water Act

The Clean Water Act (CWA, 1977) is one of several amendments to the Water Pollution Control Act (1948). The Water Pollution Control Act required the states to first determine which water bodies were polluted, and then set pollution-preventing standards accordingly. After this proved to be logistically impossible, amendments to the law in 1972 took a different tack, setting a-priori standards for effluent. The next amendment to the Water Pollution Control Act, in 1977, changed the law's name to the Clean Water Act (CWA), which established a "fishable and swimable" objective for all U.S. waters. The amendment to the CWA a decade later, the Water Quality Act of 1987, was the first major law to address non-point source pollution (Gallagher 1997).

The Clean Water Act contains provisions which directly apply to golf courses. During golf course construction in the past, it has not been uncommon to fill in wetlands with bulldozers. Today, Section 301 of the CWA prohibits such actions unless they are carried out with a permit issued by the U.S. Army Corps of Engineers (COE) under Section 404 of the CWA. The COE has two requirements in order that it grant a fill permit. First, the permit applicant must reduce the extent and adverse effects of filling in the wetlands as much as practicably possible. Second, under Section 404, which contains what is known as the No Overall Net Loss (NONL) provision, the applicant must mitigate whatever damage remains by restoring or creating wetlands at a 1:1 ratio. The applicant must replace wetlands on-site if possible, or if not, in the same watershed. Like breaches of other parts of the CWA, violations of Section 404 may result in fines of up to $25,000 per day (Gallagher 1997). Section 301 and 404 of the CWA force golf course developers to put more effort and money into siting considerations and construction logistics. Both Sections have the potential to reduce golf courses' negative effects on water quality, since by protecting wetlands, they are conserving massive natural water filters.

The Water Quality Act of 1987 directly impacts golf courses. It requires the EPA to establish regulations and issue permits for storm water discharge "associated with industrial activities." The definition of "storm water discharge associated with industrial activity" does not include discharges from facilities engaged in wholesale, retail, service, or commercial activities (Gallagher 1997). However, the EPA and the state retain the authority to require a permit for discharges falling outside this definition that contribute to water quality violations or are significant contributors of pollutants to water bodies (Gallagher 1997). Golf courses may possibly be one such exception.

The major contributor to nonpoint source pollution is agricultural runoff. Siltation, salinity, pesticides, and nutrient discharges are the primary nonpoint sources of pollution of surface waters (Gallagher 1997). During construction, golf courses may impact water quality in all four of these ways. The main post-construction source of water pollution by golf courses is runoff of pesticides and nutrients (Balogh et al. 1992). Section 319 of the Water Quality Act of 1987 requires states to develop plans to control nonpoint sources of pollution. These plans must include an assessment of which bodies of water cannot reasonably be expected to obtain water quality standards without controls on nonpoint source pollution. The plans must also include both the specific measures to be used to control nonpoint source pollution and the programs to implement these measures, as well as a schedule of their implementation. Congress authorized up to $400 million over four years to fund these statutory provisions. However, Congress has failed to appropriate the money for its implementation. Furthermore, there is no penalty for failure of a state to submit an adequate plan (Gallagher 1997).

The 'Edwards Rules'

At the state level, the Edwards Aquifer Rules promulgated by the TNRCC in 1997 regulate activities having the potential for polluting the Edwards Aquifer. The purpose of the 'Edwards Rules' is to protect groundwater quality and maintain Texas Surface Water Quality Standards in hydrologically connected surface streams (30 TAC § 213.1). The counties in the study area to which the Rules apply are Bexar, Comal, Hays, Travis, and Williamson. The Rules do not apply to the other county in the study area, Guadalupe, because this county is not located over the Edwards Aquifer. The Rules require that the owner of an existing or proposed site who proposes to carry out new or additional regulated activities file an application with, and receive approval from the TNRCC before commencing the construction of said activities (30 TAC § 213.2).

Golf course activity is a "regulated activity", as the definition of regulated activities under the Rules includes

> [a]ny construction-related activity on the recharge zone of the Edwards Aquifer, such as, but not limited to: construction of buildings...[or] roads; clearing, excavation or any other activities which alter or disturb the topographic, geologic, or existing recharge characteristics of a site; any installation of aboveground or underground storage tank facilities [common for golf cart fuel storage] on the recharge or transition zone of the Edwards Aquifer; or any other activities which may pose a potential for contaminating the Edwards Aquifer and hydrologically connected surface streams. (TAC § 213.3)

Worthy of note is the definition of a site of a regulated activity; it includes sites which are partially located on the recharge zone. The definition also includes sites which are located on the transition zone, which is the area whose drainage flows back to the recharge zone (30 TAC § 213.3). This type of area is commonly referred to as the contributing zone.

An Edwards Aquifer Protection Plan, one of the principal provisions of the Edwards Aquifer Rules, includes any water pollution abatement plan, organized sewage collection system plan, underground storage tank facility plan, and aboveground storage tank facility plan. Water pollution abatement plans must contain detailed site location maps and data, an assessment of area geology, and a technical report on specific measures the applicant proposes taking to lessen adverse effects on Edwards Aquifer water quality (30 TAC § 213.5).

Regulated activity does not include single-family residences on lots larger than five acres where no more than one single-family residence per lot exists (30 TAC § 213.3). Considering this, it is interesting to note that the use of sewage holding tanks as part of an organized sewage collection system is a prohibited activity on the recharge zone (30 TAC § 213.8). It seems, then, that the use of a sewage holding tank as part of an unorganized sewage collection system may not be prohibited. Neither is it clear if, in the common case of golf courses which double as subdivisions, the construction of a residence which formed part of the golf course would be considered a regulated activity in the case that the residence was the only single-family residence located on a larger than five acre lot. In other words, do the residences in golf course subdivisions count as individual entities, or as part of the golf course development--as they do in at least some legal respects?

The Edwards Aquifer Rules also take into consideration those wastewater disposal systems which are located on the recharge zone and use land application methods such as irrigation--as do some golf subdivisions'. These systems are to be considered on a case by case basis. At minimum, these systems must attain secondary treatment as defined in Chapter 309 of the title, which covers effluent limitations (30 TAC § 213.6).

Reclaimed Water Use

In most states, the issue of water rights to reclaimed water is still an unsettled area of the law. Traditional water rights systems do not easily accommodate reclaimed water use. Conflicting mandates, such as the implementation of the Clean Water Act and the promotion of wastewater use, complicate the problem. The right to ownership of treated wastewater is generally held by the treating entity, as opposed to the supplier of deficient water to the treatment plant; but this does not resolve the ownership issue between the treating entity and downstream users. Thomas (1994) advises golf courses considering wastewater reuse to both find out the legal status of wastewater in their state and make sure that a treatment plant can demonstrate clear ownership of the wastewater in question. General legal conditions that golf courses should take into consideration before using reclaimed water are maintenance of downstream water quality and absence of three encumbrances: detrimental health effects, adverse effects on downstream water users, and injurious effects on plant life, fish, and wildlife (Thomas 1994).

The statutory framework for use of reclaimed water involves both federal and state laws. The application of the Clean Water Act requirements may require flexibility for certain streams. The 1986 amendments to the Federal Safe Drinking Water Act contain groundwater-protecting clauses which may also apply to wastewater use. Interested golf courses should become familiar with any regulations governing the use of wastewater in order to understand their own obligations and to assure themselves that their supplier is in compliance--with, for example, National Pollutant Discharge Elimination System (NPDES) requirements (Thomas 1994).

To date, discussion of legal liability for injury caused by the use of reclaimed water is hypothetical, as no such reported cases seem to exist (Thomas 1994). Since the possibility exists that golf courses could be liable for injury caused by on-site wastewater use, Thomas (1994) suggests that golf courses, in their contract with the wastewater supplier, try to stipulate that the supplier be liable for any harm caused by its failure to meet state regulatory or NPDES requirements (Thomas 1994).

No federal standards governing water reuse exist; regulations that do exist are at the state level. In 1992, the EPA did issue official guidelines on water reuse for states with fledgling programs. Along with other states where reuse has been common, such as Arizona, California, and Florida, Texas had already developed comprehensive water reclamation and reuse regulations prior to the publication of the EPA guidelines (Crook 1994). State regulations with respect to reclaimed water use will become increasingly important in the study area as golf course wastewater irrigation increases.

In Texas, the regulations regarding the use of reclaimed water pertain to both the provider and the user of the reclaimed water (TAC § 310.3). Some general requirements which are especially applicable to golf courses include the following. No surface runoff of reclaimed water may occur without a permit, except in the case that it flow to a wastewater treatment collection system. Reclaimed water cannot be used in such a way that it threatens groundwater quality. If storage areas, hose bibs, and faucets are not secured so as to prevent access by the public, signs in both English and Spanish must be posted which convey the meaning of "Reclaimed Water, Do Not Drink" (TAC § 310.6).

More specific requirements concerning golf course wastewater use include those regarding storage requirements, transfer of reclaimed water, and irrigation. If natural conditions allow for the reclaimed water to leach while stored, golf courses must construct ponds with impervious materials such that the reclaimed water be contained. Users must not allow storage/holding ponds which capture stormwater to overflow, unless the volume ratio of reclaimed water to stormwater is less than or equal to 1:10. Users can also store reclaimed water in leak-proof tanks (TAC § 310.7). The party that provides reclaimed water must make transfers on a demand-only basis. In other words, the reclaimed water user may refuse delivery of such water at any time (TAC § 310.14).

TAC § 310.8 provides water quality parameters for all types of irrigated areas, including unrestricted landscape areas and restricted landscape areas. For the purposes of reclaimed water use, Texas defines golf courses as restricted landscaped areas. For irrigation on restricted landscaped areas, the reclaimed water transferred by the provider must meet the following quality parameters on a 30-day average. The five day biochemical oxygen demand (BOD5), other than a pond system, must be 20 mg/l. The BOD5 in pond systems must be 30 mg/l. The fecal coliform level must not exceed 800 CFU/100 ml. Moreover, the reclaimed water user must determine application rates based on a detailed water balance formula using indicators such as average precipitation, average runoff, average infiltrated rainfall, evapotranspiration, required leaching, and total water needs (TAC § 310.8).

Wastewater irrigation embodies the complexity of water issues. While being a part of the solution to water shortage, at the same time it is a potential threat to water quality. If enforced, regulations can aid in reducing the potential harm golf courses pose to water quality through reclaimed water use. In his article, "Barton Creek Wastewater Case Study," Golf Course Superintendent Tim Long (1994) concludes that golf course irrigation using effluent is a viable solution to his golf course's water needs in the future. Barton Creek is a 4,500 acre master-planned community whose design originally included a scheme to irrigate golf courses with all of the treated sewage water it generated. Requirements to irrigate with storm water in order to protect Barton Springs jeopardized the plan. At the time of the study, the Texas Water Commission (TWC) regulated effluent irrigation, and both the Lower Colorado River Authority (LCRA) and the City of Austin regulated storm water runoff and non-point source pollution abatement. A 1991 City Council ordinance discouraged effluent irrigation (Long 1994).

The LCRA required the Barton Creek project engineers to complete a Non-Point Source Pollution Abatement Plan that detailed water monitoring, integrated pest management (IPM), and education and golf course maintenance practices. The golf course is seven miles upstream of Barton Springs, where the most recent ordinance exempts residential units of 5 acres or more from water quality regulations, thereby encouraging the use of individual septic tank/field systems. Inspections have revealed the water quality levels in the golf course's holding ponds to be within federal standards. The only problem to date has been the detection of low levels of phosphates in storm water runoff, which the course is addressing by upgrading its treatment plant (Long 1994).

Long (1994) believes that even with the numerous regulations and additional maintenance requirements associated with effluent irrigation, its benefits far outweigh the negatives regarding costs, water conservation and protection of water quality. The golf course pays nothing for the effluent water. Normal water costs are ninety cents per thousand gallons (Long 1994).

Summary of Legal Background

The Endangered Species Act is the most important federal law impacting golf courses' water consumption in the I-35 Primary Growth Corridor (I-35PGC). Implementation of this act, to protect endangered species dependent upon spring flow, has resulted in restrictions of groundwater use in the region governed by the Edwards Aquifer Authority (EAA). Regulations governing the use of reclaimed water reflect an effort by the state to promote wastewater use as an alternative water supply.

FIFRA, by way of its pesticide registration and applicator certification program, is one of the two most important federal laws which apply to the study area's golf courses effects on water quality. The other major water quality laws are the Clean Water Act and its amendment, the Water Pollution Control Act. Regulations on the use of reclaimed water are an effort to mitigate the potentially harmful effects on water quality posed by wastewater irrigation of golf courses.

CHAPTER 4

METHODOLOGY

Research Objectives

For the golf courses in the I-35 Primary Growth Corridor, this study proposed to determine and estimate the following for 1990 and the year 2020, respectively:

1. in general,
    a. the total number of golf courses
    b. the number of golf courses per capita
2. in relation to water quantity,
    a. the golf courses' total water demand
    b. the percentage of the area's total water demand the golf courses' water demand represents
    c. the percentage of the area's total water supply the golf courses' water demand represents
    d. the types of grasses used at the golf courses
    e. the methods used by the golf course superintendents to determine irrigation needs

3. in relation to water quantity and quality,
    a. the number and percentage of the courses that are irrigating with treated wastewater
    b. from what sources the courses obtain their irrigation water
4. in relation to water quality,
    a. the extent of the potential threat to ground and surface water posed through the runoff and leaching of pesticides, fertilizers, and wastewater irrigation, based on the physical geography of the region
    b. the measures the golf courses are taking to prevent runoff of fertilizers and pesticides
5. in relation to quantity and quality, but for 1990 exclusively,
    a. the location of the courses

Research Design

In order to accomplish these objectives, a questionnaire was sent to every golf course in the study region (65 courses). The survey results were compared with both estimates from turfgrass manuals (Duble 1996) and estimates based upon equations in irrigation engineering manuals (American Society of Civil Engineers 1990). By using the 1990 golf course per capita rate of the study area and population growth predictions for 2020, minimalist and maximalist scenarios were formulated concerning the number of possible golf courses in the region in 2020.

The survey was sent to every golf course superintendent in the study area, with a cover letter explaining the nature of the research (Appendix 1). The questionnaire (Appendix 2) was based on interviews with four golf course professionals and additional research materials. The interviews specifically dealt with the best way to pose questions in order to obtain the desired information. One interviewee was a prominent golf course architect, Joseph Finger. The other three interviewees were superintendents from different types of golf courses in the study area: Jay Cody, from a public course; Barry Carter, from a private course; and Bill Bedford, from an daily fee course. These four individuals, along with one other golf course superintendent, were also interviewed in regard to the central issues of this thesis.

Bill Bedford suggested sending out the surveys at the first of the year in 1998, to accommodate the golf course superintendent's busy schedule involving over-seeding (the practice of annually planting cool-season grasses). January would bring a relative lull in the workload. Following his offer for additional assistance, in mid-December of 1997 Bill Bedford also informed the Central Texas Golf Course Superintendents Association (CTGCSA) that they would be receiving a research questionnaire, and encouraged them to participate in the project. CTGCSA members, representing 58% of the courses surveyed, presumably increased the survey response level significantly.

The subjects of the survey were all the golf course superintendents in the primary growth area of the I-35 growth corridor. This included the golf courses in Bexar, Comal, Guadalupe, Hays, Travis, and Williamson counties. The golf courses in the six-county study area were identified by using the book, *Great Texas Golf* (Seelig 1994), which contains a comprehensive list of golf courses in Texas with their respective addresses.

Data Analysis (Calculation of Scenarios)

Based upon the data collected on the amount of water the golf courses currently consume and the measures the superintendents are taking to conserve water, four scenarios to evaluate the impact of the I-35 Primary Growth Corridor golf courses in 2020 were projected. The scenarios differ in their projected population growth rates, projected golf hole per capita rates, and projected conservation of water.

This study projects four scenarios, which range in order of magnitude from low to high case in regard to demand for water resources by golf courses. The scenarios' titles are, from low case to high case, Low Demand Scenario, Moderate Demand Scenario, High Demand Scenario, and Highest Demand Scenario. These four scenarios comprise three basic elements on which the majority of the rest of the study's figures are based: population growth, the golf course per capita rate, and water use.

The Low Demand Scenario assumes low population growth, the 1990 golf hole per capita rate, and maximum conservation of water. The Moderate Demand Scenario assumes moderate population growth, the 1990 golf hole per capita rate, and maximum water conservation. The High Demand Scenario assumes high population growth rates, the Southern Void Golf Supply Region's golf hole per capita rate (Rooney 1989), and the region's present golf course water use rates. The Highest Demand

Scenario assumes the highest probable population growth rates, the Western Golf Supply Region's golf hole per capita rate (Rooney 1989), and the present golf course water use rate in the region.

Calculation of Population Growth

In an effort to estimate the population growth as accurately as possible, the population projections are based on the most state-of-the-art, recent (1996) Texas population projections available. This data was produced by the Population Estimates and Projections Program together with the Center for Demographic and Socioeconomic Research and Education, both at Texas A&M University (1996). In contrast to straight-line population projections, which are based on total population growth, the Texas A&M project uses a cohort-component projection technique. The distinct fertility, mortality, and migration rates particular to each one of four ethnic groups--Anglo, Black, Hispanic, and Other--determine the projected populations (Population Estimates and Projections Program and The Center for Demographic and Socioeconomic Research and Education 1996).

The 1996 projections make adjustments to the 1990 Census, and for "special populations." Special populations do not follow the demographic patterns of the indigenous population of an area. One example of a special population is the "institutional" population: individuals residing in institutional settings such as colleges, prisons, and military bases. Unlike the indigenous population, this special population comes and leaves in fixed intervals. As such, using the cohort-component projection technique, the "institutional" population is subtracted from the base population before the fertility, mortality, and migration rates are applied to the base population to obtain a projection. Another special population subtracted from the base population before these projections were calculated was the large number of illegal immigrants admitted by the Immigration Reform and Control Act (ICRA) of 1986 under its amnesty provision (Population Estimates and Projections Program and The Center for Demographic and Socioeconomic Research and Education 1996).

Texas A&M's population projection scenarios are the Zero Migration (0.0) Scenario, the One-Half 1980-1990 (0.5) Scenario, the 1980-90 Migration (1.0) Scenario, and the 1990-94 Migration (90-94) Scenario. The Scenario 0.0 assumes in-migration and out-migration are equal. It represents growth due solely to increases through birth to death ratios in the indigenous population. It tends to project the lowest population figure for counties which have shown a growth tendency, as have the counties in the study area (Population Estimates and Projections Program and The Center for Demographic and Socioeconomic Research and Education 1996).

Scenario 0.5 uses a net migration rate half that of the 1980-1990 migration rate. It is representative of slow but steady growth patterns. Scenario 1.0 assumes that growth will continue at the same rate it exhibited during the 1980-1990 decade. Scenario 1990-94 projects future population figures based on the population growth rate from 1990-1994. It furnishes a good example of when the cohort-component projection technique adjusts population projections to specific ethnic patterns: the in-migration of Anglos from 1990-1994 was much greater than their in-migration in the 1980s, whereas the in-migration of minorities was slower during this period than in the 1980s (Population Estimates and Projections Program and The Center for Demographic and Socioeconomic Research and Education 1996).

Since three counties in the study area--Guadalupe, Hays, and Williamson--showed lower growth rates from 1990-1994 than from 1980-1990, their 1990-94 scenario projections are less than their 1.0 projections. In order for this study's demand scenarios to represent increased demand in order of magnitude, its four population scenarios must increase in order of magnitude. Hence, in order to fulfill said objective, the Low Population Growth to High Population Growth case scenarios for these three counties are in the following order: 0.0, 0.5, 1990-94, and 1.0. The other counties'--Bexar, Comal, and Travis'--Low Growth to High Growth population projections maintain Texas A&M's order: 0.0, 0.5, 1.0, 1990-94. The 1990 baseline total population of the six-county study area is the sum of the 1990 population figures for each county. The projected figures for total population of the six-county study area are the sum of Texas A&M's projections for each county, having inserted newly calculated projections for three of the six counties as indicated.

This study's population scenarios for the year 2020 (Table 1) are the Low Population Growth Scenario, the Moderate Population Growth Scenario, the High Population Growth Scenario, and the Highest Population Growth Scenario. The study's demand scenarios incorporate the Population Growth Scenarios accordingly: the Low Demand Scenario incorporates the Low Population Growth Scenario; the Moderate Demand Scenario incorporates the Moderate Growth Population Scenario; the High

Demand Scenario incorporates the High Population Growth Scenario; the Highest Demand Scenario incorporates the Highest Population Growth Scenario.

Table 1. 1990 Population and Projected 2020 Population for the I-35PGC, by County and Total

County/ Area	Baseline Population (1990)	Low Growth Scenario (2020)	Moderate Growth Scenario (2020)	High Growth Scenario (2020)	Highest Growth Scenario (2020)
Bexar	1,190,000	1,470,000	1,590,000	1,680,000	1,930,000
Comal	51,800	54,700	90,500	145,000	164,000
Guadalupe	64,900	74,400	104,000	105,000	143,000
Hays	65,600	89,700	121,000	137,000	169,000
Travis	576,000	738,000	779,000	813,000	1,130,000
Williamson	140,000	170,000	304,000	511,000	527,000
I35PGC	2,080,000	2,600,000	2,990,000	3,390,000	4,050,000

Projected Total Water Demand and Supply

The total water demand and supply projections for the I-35 Primary Growth Corridor for the year 2020 (Table 2) denote the precarious water situation of the majority of the counties in the study area. Potentially

Table 2. Total Water Demand and Supply (ROR rights) Projections for the I-35 Primary Growth Corridor (in acre-feet)

Case	Bexar	Comal	Guadalupe	Hays	Travis	Williamson	I-35PGC
1990 Use	303,000	15,400	15,000	13,000	131,000	28,200	506,000
1990 Supply	370,000	23,000	31,500	20,900	642,000	58,100	1,150,000
1990 Surplus/ Shortage	33,700	19,500	17,100	8,100	510,000	70,200	659,000
2020 Supply	337,000	34,900	32,100	21,100	642,000	98,400	1,170,000
2020 Low Projection: Demand	417,000	24,200	21,300	20,400	197,000	39,000	720,000
Surplus/ Shortage	-80,300	10,700	10,800	661	445,000	59,400	446,000
2020 Moderate Projection: Demand	443,000	32,400	26,400	25,800	206,000	65,900	799,000
Surplus/ Shortage	-106,000	2,510	5,660	-4,720	436,000	32,500	366,000
2020 High Projection: Demand	461,000	44,900	26,700	28,500	214,000	107,000	882,000
Surplus/ Shortage	-124,000	-9,980	5,420	-7,360	428,000	-8,640	283,000
2020 Highest Projection: Demand	514,000	49,000	33,200	33,900	282,000	110,000	1,022,000
Surplus/ Shortage	-177,000	-14,100	-1,110	-12,800	360,000	-11,700	143,308

Based on Trans-Texas Water Program figures (HDR Engineering 1994 and 1998)

serious water shortages for Bexar county are especially noteworthy. In 2020, Bexar county is projected to have significant water shortages even in the lowest case demand scenario. If demand reaches the highest case scenario in that year, Bexar County has a projected shortage of 177,000 acre-feet.

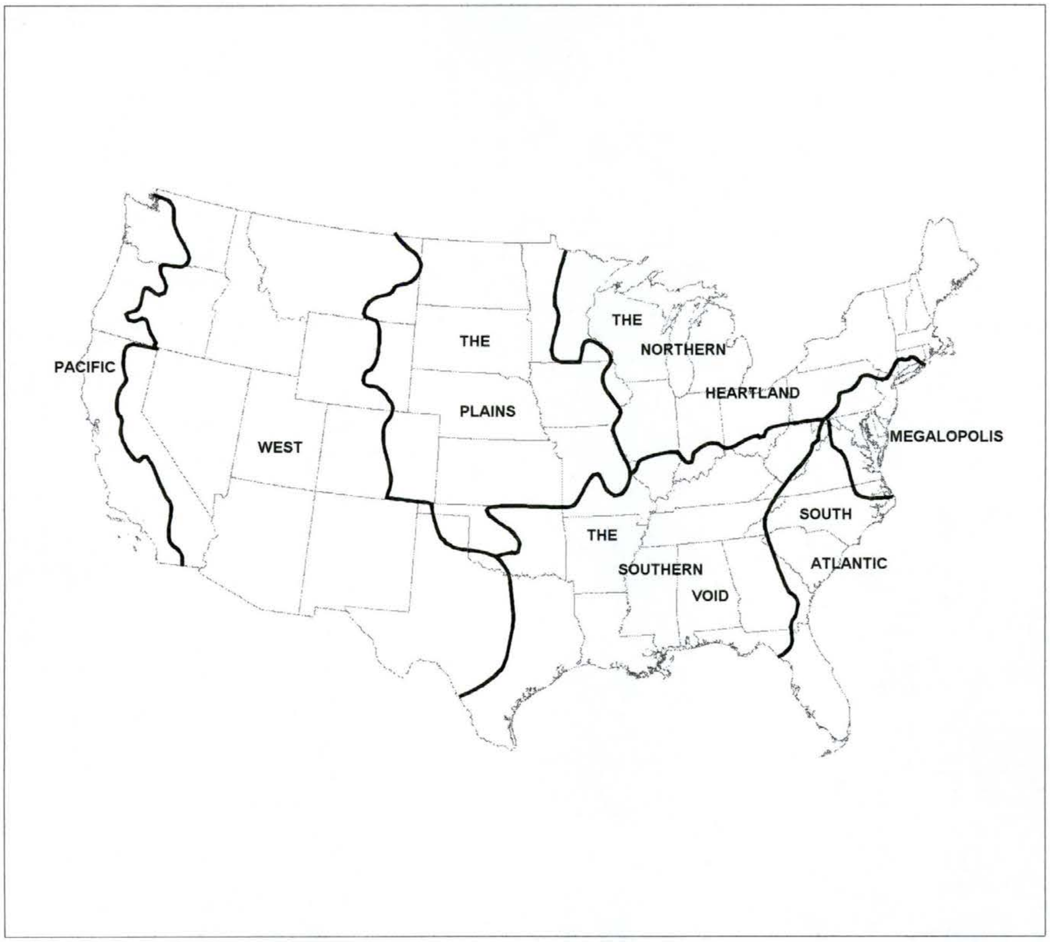

Fig. 3. Golf Supply Regions of the United States (Adapted from Rooney 1991)

Calculation of Golf Course Per Capita Rate

Golf course projections in the I-35 Corridor were calculated using the baseline--1990--golf course per capita rate (holes/100,000 pop.) for the low and moderate case scenarios for the year 2020. The high and highest case scenarios incorporate Rooney's (1989) Golf Supply Regions (Figure 3) and their respective rates (Table 3). The high case scenario assumes the I-35PGC's golf course per capita rate (holes/100,000 pop.) will attain the rate of the Southern Void Region. For both the high and highest projections, Rooney's Metropolitan County rate was used for Bexar and Travis counties, whereas his Non-Metropolitan County rate was used for Comal, Guadalupe, Hays, and Williamson. Finally, the highest case scenario was projected assuming the I-35 Primary Growth Region would reach the golf course per capita rate (holes/100,000 pop.) of the West Golf Supply Region. To obtain the total number of projected golf courses in the I-35 Primary Growth Corridor, the Golf Supply Regions' rates were applied to the I-35PGC as a whole, i.e. the projected number of golf courses in the I-35PGC is not a sum of the projections of the counties. Either way--using the Golf Supply Region rates applied to the study area as a whole, or adding up the county figures to attain the total for the study area--the two sets of total figures for the I-35 Primary Growth Corridor are within 5% of each other.

Table 3. Golf Supply Region Per Capita Rates

Region	# holes/ 100,000 pop.	Metro. Counties # holes/ 100,000 pop.	Nonmetro. Counties # holes/ 100,000 pop.	Metro. Pop. % of total pop.
Northern Heartland	96	85	147	81
Plains	132	90	164	52
South Atlantic	138	125	171	74
West	105	90	131	70
Southern Void	67	62	79	69
Pacific	50	47	95	94
Megalopolis	45	42	129	97

Adapted from Rooney 1989

Calculation of 1990 Golf Course Water Demand

To calculate the estimation of 1990 golf course water use (Table 10, p. 89), two sets of data were used. Some superintendents provided the total figures of how much water they use per season. Superintendents who did not know how much water they used provided information on their total number of sprinkler heads, the gallons per minute emitted by sprinklers, and the number of minutes per night and nights per season they irrigated. In order to calculate the yearly water use of a golf course in acre-feet based on this information, the number of sprinkler heads was multiplied by the number of gallons per night emitted by a sprinkler head, which was in turn multiplied by the number of nights sprinklers were running.

Calculation of Maximum Conservation Water Demand

The calculation of the estimation of water demand in the case that maximum water conservation occurred, for use in the two best case scenarios, was based on an equation for field irrigation requirements:

field irrigation requirement (inches) =

(evapotranspiration (Et) - effective rainfall) / irrigation efficiency

(American Society of Civil Engineers 1990)

where Et = PET x Tc x AS

(Texas Agricultural Extension Service 1998)

potential evapotranspiration (PET)

turf coefficient (Tc)

allowable stress coefficient (AS)

The values used for PET, Tc, and AS, along with the Et which results from them are listed in Table 4. The PET used is an estimate of the water requirements of a 4-inch grass growing in a deep soil under well-watered conditions (Texas Agricultural Extension Service 1998). The PET is calculated using the Penman-Monteith method (Texas Agricultural Extension Service 1998), which is generally accepted worldwide as the most accurate method for calculating PET (American Society of Civil Engineers 1990).

Table 4. Calculation of Et from PET, Tc, and AS

Month	Average Austin PET (inches)	Average San Ant. PET (inches)	Warm Season Tc	Cool Season Tc	Allowable Stress AS	Avrg. Austin Et (inches)	Avrg. San Ant. Et (inches)
Jan.	2.00	2.07		0.8	0.6	0.96	0.99
Feb.	2.66	2.77		0.8	0.6	1.28	1.33
Mar.	4.30	4.40		0.8	0.6	2.07	2.11
Apr.	5.27	5.33		0.8	0.6	2.53	2.56
May	7.55	7.58	0.6		0.6	2.72	2.72
June	8.28	8.21	0.6		0.6	2.98	2.98
July	8.12	7.96	0.6		0.6	2.92	2.92
Aug.	8.20	8.03	0.6		0.6	2.95	2.95
Sep.	6.22	6.19	0.6		0.6	2.24	2.24
Oct.	4.93	4.95		0.8	0.6	2.37	2.38
Nov.	3.08	3.14		0.8	0.6	1.48	1.51
Dec.	2.08	2.15		0.8	0.6	0.10	1.03
Year	62.69	62.78		0.8	0.6	25.5	25.70

The turf coefficient Tc accounts for the fact that turfgrasses on golf courses are normally shorter than the 4 inch grass used for the reference PET. With less canopy area exposed to weather conditions, the actual evapotranspiration of turfgrasses is less than this reference PET. The Tc for warm season grasses is 0.6; for cool season grasses it is 0.8 (Texas

Agricultural Extension Service 1998). The norm in the study area is to over-seed from October through April (Bedford, telephone interview, 27 March 1998). As a result, the Tc used for the months of October through April was 0.8, whereas 0.6 was the Tc used for the months of May through September.

The allowable stress coefficient (AS) accounts for the fact that even though a turfgrass would consume an amount of water equal to PET multiplied by that turfgrass's Tc, if the goal is to maintain a healthy, attractive turf with as little water as possible, less water can be used. The allowable stress coefficient would be 1.0 if the quantity of water equivalent to PET multiplied by Tc inches were applied. A low AS is 0.8; a normal AS is 0.6; a high AS is 0.5; and a very high AS is 0.4. The normal allowable stress factor (0.6) was used in the calculation of maximum water conservation demand, which is the factor that is generally accepted as stock (Texas Agricultural Extension Service 1998).

Effective rainfall is calculated as total rainfall minus runoff. Runoff was calculated as 30% of total rainfall (Duble 1996). Under low wind conditions, the percentage of overall irrigation efficiency of a sprinkler system ranges from .55 to .75 (Texas Agricultural Extension Service 1998). The intermediate irrigation efficiency value of .65 was chosen for this study. The values used for rainfall (Texas Agricultural Extension Service 1998) and effective rainfall, together with the field irrigation requirements which result from them are listed in Table 5.

The figure used for maximum conservation demand is 8 inches per year, which is the rounded average of Austin's and San Antonio's annual field irrigation requirements (the amounts of irrigation water needed) for golf course turfgrasses. The annual field irrigation requirement is the sum of the positive monthly field irrigation requirements, since superintendents cannot transfer excess monthly rain to the next month. In addition to serving as estimates of maximum water conservation demand for the study, Austin's and San Antonio's figures for annual field irrigation requirements (Table 5), 7.37 inches and 8.44 inches, respectively, also provide an informed approximation of how much irrigation water golf course turfgrasses in these cities need in an average year. The amount of irrigation water necessary (field irrigation requirement) or excess rainwater for each month for each city in an average year also appears (Table 5).

Table 5. Field Irrigation Requirements for Golf Course Turfgrass in the Austin-San Antonio Corridor

	Total Rainfall (inches)		**Effective Rainfall (inches)**		**Et minus Effective Rainfall (inches)**		**Field Irrigation Requirements (inches)**	
Month	Austin	San Ant.	Austin	San Ant.	Austin	San Ant.	Austin	San Ant.
Jan.	1.75	1.75	1.22	1.23	-0.27	-0.23	-0.41	-0.36
Feb.	2.50	2.10	1.75	1.47	-0.47	-0.14	-0.73	-0.22
Mar.	1.75	1.75	1.23	1.23	0.84	0.89	1.29	1.36
Apr.	3.25	3.00	2.28	2.10	0.25	0.46	0.39	0.71
May	4.25	3.75	2.98	2.63	-0.26	0.09	-0.40	0.14
Jun.	3.25	2.75	2.28	1.93	0.71	1.06	1.09	1.62
Jul.	2.00	2.00	1.40	1.23	1.52	1.70	2.34	2.61
Aug.	2.25	2.75	1.58	1.93	1.38	1.03	2.12	1.58
Sep.	4.00	4.00	2.80	2.80	-0.56	-0.56	-0.86	-0.86
Oct.	3.25	3.00	2.28	2.10	0.09	0.28	0.14	0.42
Nov.	2.25	2.25	1.58	1.58	-0.10	-0.07	-0.15	-0.10
Dec.	2.25	1.50	1.58	1.05	-0.58	-0.02	-0.89	-0.03
Yearly Totals	32.80	30.35	22.90	21.245	2.56	4.48	7.37	8.44

CHAPTER 5

RESULTS

Responses to Survey

Responses to Question 1

(How many holes is your golf course?)

The survey was sent to sixty-five golf facilities. The survey response was high, representing 40% of the total number of 18-hole equivalents in the study area. A total of twenty-six golf course superintendents responded to the survey. The surveyed courses comprised twenty 18-hole facilities, four 9-hole facilities, one 36-hole facility, and one 27-hole facility. One of the 9-hole facilities was a par-3 course which therefore was given "credit" for having seven holes in all of the subsequent calculations, due to its reduced yardage in comparison with a normal 9-hole course.

Responses to Question 2

(What is the length of your course?)

With a total of 172,060 yards, the courses surveyed averaged 6,882 yards per 18-hole equivalent. This is on the high end of the average range of golf course length, which is 6,000 to 7,000 yards (Sorensen 1976).

Responses to Question 3

(Type of course:)

Thirty-five percent of the courses that responded to the survey were public, and thirty-one percent of the responding courses were private. Thirty-five percent of the courses that responded were either daily fee or semi-private. Semi-private courses are essentially open to the public, as anyone may pay to play after the members of the club have taken their preferred tee times.

Response to Question 4

(How many acres does your golf course contain?)

The courses surveyed occupy a total of 4,317 acres, containing an average of 173 acres per 18-hole equivalent. In concordance with the comparatively long length of golf courses in the study area, this figure is larger than the 125 to 160 acres of land in a traditional U.S. golf course (Finger 1980; Sorensen 1976).

Response to Question 5

(How many acres of your golf course do you irrigate?)

The responses to this question revealed that the average surface area irrigated on an 18-hole equivalent in the study area was 106 acres. This figure represents approximately 60% of the total area of each golf course on average. If this figure was used to estimate the total number of irrigated acres on the sixty-two 18-hole equivalents in the six county study area, an area of approximately 6,572 acres would be involved in golf course irrigation.

Responses to Question 6

(Do you irrigate using ET rates or "Eye of the Greenskeeper?")

The answers to this question tell us that in order to determine irrigation needs, 69% of those sampled use the "Eye of the Greenskeeper" exclusively, whereas 31% use ET rates or both "Eye of the Greenskeeper" and ET rates.

Responses to Question 7

(What types of grasses or mixture of grasses do you use on tees, fairways, roughs, and greens?)

Common Bermuda, Bermuda hybrids, and combinations thereof are by far the most popular warm season turfgrasses used on the I-35PGC golf courses surveyed (Table 6). Some Bermuda hybrids and combinations thereof are more popular than others, but this depends on the area of the golf course for which they are used (Table 7).

Table 6. Overview of Warm Season Turfgrasses Used on I-35PGC Golf Courses (% of total response)

Turfgrass	Tees	Fairways	Roughs	Greens
Common Bermuda	19	31	50	4
Bermuda hybrid or mixture of Bermuda hybrids	68	50	19	92
Common Bermuda/Bermuda hybrid(s) mix	12	12	12	4
Buffalo/Common or Bermuda hybrid(s) mix	0	4	16	0
native grasses	0	4	4	0

Percentages may not add up due to rounding.

Responses to Question 8

(If you over-seed in the cool season, what types of grasses or mixture of grasses do you use?)

All superintendents surveyed over-seed tees and greens. However, only 58% and 19% over-seed fairways and roughs, respectively. Perennial Ryegrass is the most popular cool season grass for tees and fairways. Poa Trivialis is the most popular cool season grass for greens (Table 8).

Table 7. Specific Breakdown of Warm Season Turfgrass Species Used on I-35PGC Golf Courses (% of total response)

Turfgrass Species	Tees	Fairways	Roughs	Greens
Bermuda 419 (Tifway)	58	46	19	0
Common Bermuda	19	31	50	4
Tifdwarf Bermuda	0	0	0	42
Bermuda 328(Tifgreen)	0	0	0	38
Common Bermuda/419	8	12	12	0
419/328	8	4	0	0
Common Bermuda/Buffalo	0	4	4	0
native grass	0	4	4	0
419/Common Bermuda/Buffalo	0	0	8	0
Bermuda 427	4	0	0	0
Common Bermuda/328	4	0	0	0
419/ Buffalo	0	0	4	0
Tif Bermudas	0	0	0	4
CommonBermuda/ Tifdwarf Bermuda	0	0	0	4
Champion Bermuda	0	0	0	4
328/Tifdwarf Bermuda	0	0	0	4

Percentages may not add up due to rounding.

Table 8. Cool Season (Over-seed) Turfgrasses in the I-35PGC
(% of total response)

Turfgrass	Tees	Fairways	Roughs	Greens
Perennial Ryegrass	31	23	4	4
do not over-seed	0	42	81	0
Poa Trivialis	0	4	0	46
Rye	19	12	0	0
Poa Trivialis/ Perennial Ryegrass	4	4	0	23
Rye mix	4	8	4	4
3-blend Perennial Rye	15	0	0	4
Showboat Rye	8	0	0	4
Annual Rye	0	4	8	0
2-blend Perennial Rye	4	0	0	0
Scotts Winter Turf	4	4	0	0
70/30 Rye	4	0	0	4
Perennial/Annual Rye Mix	4	0	0	4
60/40 Perennial Rye mix	4	0	0	0
Dixie Green with Sabre	0	0	0	4
Rye/ Wildflowers	0	0	4	0
Poa Trivialis/ Bentgrass	0	0	0	4

Percentages may not add up due to rounding.

Responses to Question 9

(In an average year, how much water per season does your golf course use?)

The average annual water use per 18-hole equivalent in the survey sample is 226 acre-feet. Based upon an average irrigated area per 18-hole equivalent of 106 acres, that represents a water depth of 2.13 feet, or 25.6 inches. Using this figure to estimate the total water use for the sixty-two 18-hole equivalents in the study area in 1990 resulted in a figure of 14,000 acre-feet. By applying current U.S. consumption habits (220 gallons per person per day, or 0.25 acre-feet per year), this is the equivalent of the yearly municipal demand of a city of 56,000 inhabitants.

Responses to Question 10 and 10a

(Do you use wetting agents?), (If so, how often?)

Sixty-nine percent of those surveyed use wetting agents (see p. 22). Half of those who use wetting agents answered the frequency question precisely. They apply wetting agents an average of 18 times per year. The other half gave answers such as, "only as needed to help water infiltration into soils," "not often and then only on dry spots and greens," and "only in the summer."

Response to Question 11

(Do you use growth regulators?)

Fifty percent of those surveyed use growth regulators (see p. 23).

Response to Question 12

(What kind of terrain is the golf course built on?)

Fifty-six percent of the 18-hole equivalents of the survey have hilly terrain. Forty-four percent have flat terrain.

Response to Question 13 and 13a

(If you have a retention pond(s), how many do you have and what is their capacity?), (Do you irrigate with retention pond water?)

The sixty-five percent of the courses surveyed that have one or more retention ponds average four ponds per 18-hole equivalent. The ponds have an average capacity of 7 acre-feet per pond. Forty-seven percent of those who have retention ponds use them for irrigation needs.

Responses to Question 14

(What percentage of your water use comes from the following sources: treated wastewater, well, stream, municipal, reservoir?)

The courses surveyed obtain 35% of their irrigation water from wells, 34% from treated wastewater, 13% from retention pond water, 10% from stream water, 5% from municipal water, and 3% from reservoir water.

Responses to Question 15

(If you use treated wastewater, what are you charged for it?)

Approximately 77% of those who water with treated wastewater pay nothing for it. For the 23% who are charged a fee, the average cost per 1000 gallons is 27 cents. These figures do not include pumping costs.

Responses to Question 16

(If you have buffer zones next to or around water bodies,

how wide are they on average?)

Forty-six percent of the courses surveyed have buffer zones next to or around water bodies. The average buffer zone is 26 feet wide. However, a course next to Lake Austin has buffers which are 150 feet in width. If this statistic, which is arguably an outlier, is excluded, the average buffer width is 17 feet.

Response to Question 17 and 17a

(Is your course located west of I-35?)

(If so, is the course located in the Edwards Aquifer recharge zone, the contributing zone to the Edwards Aquifer recharge zone, or neither?)

Fifty-four percent of the courses surveyed are located west of I-35. Of these courses, 36% are located on the Edwards Aquifer recharge zone, 36% are located on the contributing zone to the Edwards Aquifer recharge zone, and 28% are not located in either zone.

Responses to Question 18

(Methods of fertilizer and pesticide application:)

_____ spot treat _____ blanket treat

_____ preventative _____ curative

The application method used the most frequently is spot treating, which was cited by 42% of the superintendents. Curative application was next with 35%, followed by preventative applications with 23% and blanket treatment by eight percent.

Responses to Question 19

(Type of fertilizers used: percentage of total use represented by liquid, organic, and synthetic fertilizers)

Overall, the courses surveyed cover an average of 66% of their fertilization needs with synthetic or synthetic-organic fertilizers, 17% with liquid fertilizers, and 17% with organic fertilizers. One superintendent out of all those surveyed, Lee Maddox of Lee's Par 3 in New Braunfels, uses organic fertilizer exclusively.

Responses to Question 20

(What are the most effective ways you conserve water?)

The most effective ways the golf course superintendents surveyed conserve water are through a combination of the following methods.

- (35%): the use of computer-controlled irrigation. The specific advantages of computer irrigation systems highlighted by the golf course superintendents were the following. Water-minimizing computer programs can provide such features as single-sprinkler head control, which allows sprinkler systems to water dry spots individually. With many non-computerized systems, the only way to turn on one sprinkler head is to turn on the line which feeds that sprinkler head, thereby necessarily turning on every other sprinkler head connected to the line. Lines traditionally have served a minimum of two heads--at termination points--and a maximum of dozens of heads--usually the nearer to the "trunk" of the irrigation system a line is, the more heads it will contain. Another advantage of computer irrigation is the possibility of connecting the system to an on-site weather station. Automated systems set to engage sprinklers at night will switch on regardless of the current ET rate or whether it rains. When the timed moment arrives to turn on the sprinklers, a computer irrigation systems linked to a weather station can stop them from engaging if it has rained or is raining. Such a system can also adjust the amount of water applied according to the daily ET the computer calculates from the weather station's data.

- (27%): watering only as necessary. This may seem evident, but it actually runs counter to customs which have been prevalent. One superintendent explained that he focuses on irrigating with the least amount of water necessary for healthy turf.
- (19%): hands-on, close-up, daily 'Eye of the Greenskeeper' monitoring (e.g. watching for wet spots and adjusting sprinkler times daily according to conditions, monitoring irrigation time in different areas)

- (19%): paying attention to local weather (e.g. watching the Weather Channel, not irrigating 1-4 days after a rain, not irrigating if there is a greater than 40% chance of rain)
- (19%): hand watering as necessary (e.g. hand watering greens, hand watering dry spots, and giving personnel time to hand-water as necessary)
- (19%): not irrigating in the daytime to reduce evaporative losses (e.g. irrigating "in the evenings," "at night," and "in darkness," or "as early in the morning as possible.")
- (15%): the use of ET rates (e.g. calculated by a weather station)
- (15%): irrigating with treated wastewater
- (15%): using drought-resistant grasses or proper grass types
- (15%): watering deeply and infrequently
- (15%): the use of wetting agents
- (12%): intense, up-to-date maintenance of irrigation equipment
- (8%): raising the cutting height of the grass
- (8%): proper soil types [soils with a good combination of water-holding and drainage capacities]
- (4%): not watering roughs
- (4%): irrigating with stormwater runoff

- (4%): the promotion of deep root growth
- (4%): the use of a moisture monitoring system
- (4%): not relying completely on an automated system [which implies that the survey participant bypasses automation when he thinks manually setting the sprinkler system will be more tailored to existing moisture conditions]
- (4%): keeping plants healthy and not stressed
- (4%): maintaining a dense, weed-free stand of grass
- (4%): utilizing what mother nature gives us
- (4%): the use of growth regulators
- (4%): the use of a strict drought-management plan
- (4%): eliminating overlapping sprinkler heads
- (4%): the use of a slow-release nitrogen fertilizer source
- (4%): requiring that golf carts remain on paths to reduce both the stress on turf and the correspondingly higher need for water such stress would entail due to compaction
- (4%): preferring turf to be on the dry side
- (4%): never allowing water to get to the point where it runs
- (4%): depending entirely on rainfall captured by holding ponds for irrigation [This was a par-three course.]

Responses to Question 21

(What are the most effective ways you control runoff of pesticides and fertilizers?)

The most effective ways the golf course superintendents control runoff of pesticides and fertilizers are through a combination of the following techniques.

- (38%): watching the weather (e.g. watching the Weather Channel; anticipating rain and not applying pesticides when heavy rain is expected; monitoring weather to ensure applications are not made prior to impending storms; applying when there is small percentage chance of rain; fertilizing or spraying when chance of rain is 20% or less; being weather-conscious: not applying fertilizers and pesticides if heavy rain or high wind--which augments drift--is probable)
- (31%): monitored irrigation (e.g. regulated water scheduling; minimizing irrigation following applications; not over-watering treated areas; multiple light shots of irrigation water to set product; controlling the amount of irrigation water in order to minimize runoff; light/frequent irrigation following application; watering in products right after application)
- (27%): application outside of buffer zones
- (19%): light applications

- (12%): use of timers on effluent pipe outlets to avoid accidental overflow of holding ponds
- (12%): maintaining a healthy stand of turf
- (12%): minimizing use on steep slopes
- (12%): injection or incorporation when possible
- (12%): use of organics
- (8%): use of proper Integrated Pest Management (IPM) techniques to decrease application rates; using IPM principles in which applications are made only when necessary
- (8%): use of slow-release fertilizer
- (4%): staying away from nitrates
- (4%): watering products in as directed on product labels
- (4%): employing good, licensed applicators
- (4%): having good employees that know their job
- (4%): the very limited use of pesticides
- (4%): frequent but low rate applications
- (4%): cultural practices to prevent the need for pesticide use
- (4%): using products only as necessary
- (4%): correct application
- (4%): computer irrigation to provide accurate water applications

- (4%): the use of syringe irrigation method when using chemicals
- (4%): controlling when and where pesticides and fertilizers are applied
- (4%): applying pesticides and fertilizers at a lower rate when runoff to a stream is possible
- (4%): being careful with when and how much water is applied according to the type of product that has been used
- (4%): use of non-leaching types
- (4%): use of half circle sprinkler heads along a creek
- (4%): recognizing and respecting the forces of mother nature, not the other way around: actual and potential weather conditions dictate applications no matter how badly they need to be done
- (4%): retention ponds
- (4%): getting maximum use out of all fertilizers and pesticides--a very tight budget demands this
- (4%): using the minimum required amount of pesticide or fertilizer
- (4%): the use of small amounts of pesticides, and only spot treating with the safest pesticide products available (organic)
- (4%): the use of amounts of fertilizers that plants can ingest at one time

- (4%): the use of slow release liquid and synthetic fertilizers that are microbial dependent and not broken down by water
- (4%): using preventative doses with pesticides and spoon feeding with fertilizers
- (4%): the use of short-term pesticides
- (4%): the use of pesticides with chemistry that breaks down into harmless elements
- (4%): researching new biological/natural solutions
- (4%): whenever possible using pesticides with natural bridges/dams [pesticides which target pests in a certain stage of life not present in human life, such as molting]
- (4%): use of modern "plant protectants" [a recently developed euphemism for pesticides] designed to 1. produce results in a short window, 2. have low to no volatilization, 3. not leach, 4. work on a specific pest or problem while not affecting the beneficial environment, and 5. break down quickly in soil into inert substances or elements

Completion of Research Objectives

Number (Total and Per Capita) of Golf Courses

The total number of 18-hole equivalents in the I-35 Primary Growth Corridor in 1990 was sixty two. Per capita, this equals 53 holes per 100,000 people, or one 18-hole equivalent for every 34,000 people. Table 9 summarizes these regional totals by county. In addition, the table provides projections for 2020 according to four population scenarios. For an idea of how these figures compare to other U.S. regions, see figure 3 and table 3 on pages 65 and 66, respectively.

Golf Course Water Demand Projections

Table 10 summarizes the study area golf courses' water demand as a net figure and as a percentage of the I-35 Primary Growth Corridor's total water demand and supply. The figure used for maximum conservation water demand was 70 acre-feet per year per 18-hole equivalent. This was derived by multiplying the maximum conservation demand field requirement estimate, 8 inches (averaged from Table 5, p. 69), by the average number of irrigated acres per course in 1990, which was 106. This produces a figure of 70.7 acre-feet per year per 18-hole equivalent, which was then rounded down to 70. This is reasonable since this figure aims at representing demand that assumes maximum possible water conservation. This figure, since rainfall is not evenly distributed within a month, would be realistic for an average year in which either a golf course superintendent allowed higher than normal stress on his turfgrass, or reduced fairways by a fraction of what Finger (1980) suggests.

Table 9. Projections for Total Number of Golf Courses and Golf Courses Per Capita in the I-35 Primary Growth Corridor (by county and total)

	Bexar	Comal	Guadalupe	Hays	Travis	Williamson	I35 Primary Growth Corridor
# of Holes 1990	424	36	61	45	455	90	1,111
# of Persons per 18-Hole Equivalent 1990	50,000	26,000	19,000	26,000	23,000	28,000	34,000
# of Holes/ 100,000 pop. 1990	36	69	94	69	79	64	53
# of Holes/ 100,000 pop. 2020 (Low Projection)	36	69	94	69	79	64	53
# of Holes/ 100,000 pop. 2020 (Moderate Projection)	36	69	94	69	79	64	53
# of Holes/ 100,000 pop. 2020 (High Projection)	62	79	94	79	79	79	67
# of Holes/ 100,000 pop. 2020 (Highest Projection)	90	131	131	131	90	131	105
# of 18-Hole Equivalents 1990	24	2	3	2	25	5	62
# of 18-Hole Equivalents 2020 (Low Projection)	29	2	4	3	32	6	77
# of 18-Hole Equivalents 2020 (Moderate Projection)	32	3	5	5	34	11	89
# of 18-Hole Equivalents 2020 (High Projection)	58	6	6	6	36	22	126
# of 18-Hole Equivalents 2020 (Highest Projection)	96	12	10	12	56	38	237

Table 10. Water Demand Projections for
I-35 Primary Growth Corridor Golf Courses
(% of total water demand)
(acre-feet)
(% of total water supply)

Case	Bexar	Comal	Guadalupe	Hays	Travis	Williamson	I-35PGC
1990 Use	2	3	5	4	4	4	3
	5,320	452	766	565	5,710	1,130	14,000
	1	2	2	3	1	2	1
2020 Low Projection	0.3	1	1	1	1	1	1
	2,050	148	272	239	2,270	425	5,390
	1	0.4	1	1	0.4	0.4	0.4
2020 Moderate Projection	1	1	1	1	1	1	1
	2,210	245	380	324	2,390	764	6,200
	1	1	1	2	0.4	1	1
2020 High Projection	3	3	5	5	4	5	3
	13,100	1,440	1,240	1,360	8,070	5,070	28,500
	4	4	4	6	1	5	2
2020 Highest Projection	4	5	7	8	4	8	5
	21,700	2,680	2,340	2,770	12,700	8,620	53,200
	6	8	7	13	2	9	5

The 1990 use of water by the golf courses was calculated by multiplying the number of 18-hole equivalents by the average water use per 18-hole equivalent in 1990, 226 acre feet. The low and moderate golf course water demand projections for 2020 were calculated by multiplying their respective projected number of 18-hole equivalents by the figure representing maximum water conservation demand for an 18-hole equivalent, 70 acre feet. The high and highest golf course water demand projections for 2020 were calculated by multiplying their respective projected number of 18-hole equivalents by the average use per 18-hole equivalent in 1990, 226 acre feet.

Impact of Location on the Potential for Water Quality Degradation

Figure 4 shows the location of the 65 golf courses in the study area. Taking I-35 as a proxy for the Balcones Escarpment, which is the dividing line between the clay soils of the Gulf Plain to the east and the karst topography of the Hill Country to the west, approximately two thirds of the golf courses are in the Hill Country. The most notable characteristic of the Hill Country's physical geography in regard to golf courses' potential for water contamination is its karst topography. The literature review revealed that no golf courses have a higher potential for leaching and runoff of fertilizers and pesticides than those located in karst topography (Balogh and Watson 1992).

Intense rainfall, another element which characterizes the physical geography of the region, results in enhanced runoff and leaching events. This factor increases the golf courses' potential for water contamination in the region. All of the courses in the region are subject to high rainfall intensity, although intense rainfall poses more of a threat on courses in karst topography.

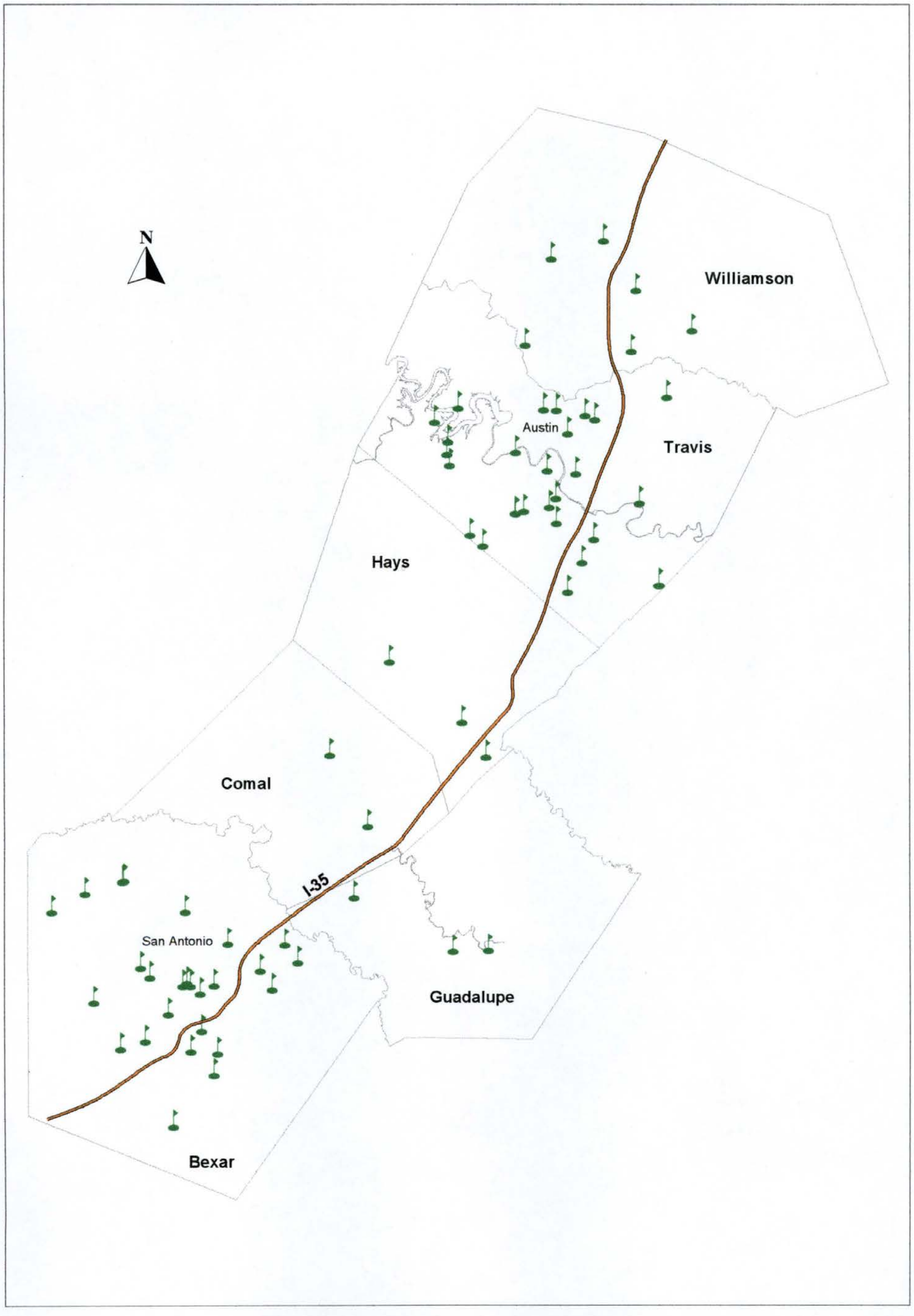

Fig. 4. Golf Courses in the I-35 Primary Growth Corridor circa 1990

CHAPTER 6

DISCUSSION

Water Quantity

The low, moderate, high, and highest 2020 water demand projections for the study area's golf courses in acre-feet (Table 10, p. 89) are 5,390; 6,200; 28,500; and 53,200; respectively. Assuming current U.S. municipal consumption rates (0.25 acre-feet/person/year), these are the equivalents of the municipal use of cities of 21,600; 24,800; 114,000; and 213,000 inhabitants; respectively.

Perception and the Blame for High Golf Course Water Use

Since golf course superintendents are generally considered to be the ones who decide how much to irrigate, a tendency exists to blame high water use by golf courses on them. However, often it is the greens committee, under pressure by members, which demands that golf course superintendents irrigate turfgrass so that it is aesthetically pleasing (green) and more easily playable (carpet-like). Golf course superintendents risk losing their jobs if they do not water enough to meet members' expectations for turfgrass color and 'playability' (Finger 1997).

However, golf course superintendents assert that this is seldom the case. First of all, they maintain that green color in grass can be achieved by other methods, such as soil amendments of iron and nitrates (Bedford 1997; Carter 1997; Williams 1998). They argue that over-watering is not in their interest because excessive irrigation can be detrimental to 1) turfgrass health, by promoting growth of fungus and 2) their budget, because of the resulting need for extra fungicide applications and mowing (Bedford 1997; Carter 1997; Cody 1997; Williams 1998). Nonetheless, the broad range of turfgrass irrigation necessities allows for the possibility that golf course members and committees force golf course superintendents to water more than necessary.

For example, Duble's (1996) estimate of the total water requirement (from rainfall and irrigation combined) for Bermuda grass survival on golf courses in Central Texas is approximately 23 inches per year. Achieving acceptable color requires 33 inches per year; adequate color and growth requires 43 inches per year (Duble 1996). The total water requirement estimates this study yields support Duble's (1996) figures. Duble's (1996) estimated total water requirement for survival of Bermuda grass, 23 inches, is comparable to the maximum conservation total water requirement estimate of the study area's golf course turfgrasses, 30 inches (the average of the effective rainfall of Austin and San Antonio--22 inches--plus the study's figure for maximum conservation irrigation demand--8 inches; see page 69). The study's figure is somewhat higher for two reasons:

(1) Duble's (1996) estimate is for Bermuda grass, whereas over-seeding with cool season grasses (which require more water) is still common in the study area, and

(2) the study's estimate for maximum conservation is conservative (i.e. still greater amounts of water could possibly be conserved), to avoid the impression that the figure is unrealistic in the sense that it would mean the golf courses' turfgrasses would be on the brink between surviving and perishing.

Duble's (1996) estimated total water requirement for adequate color and growth of Bermuda grass, 43 inches, is comparable to the total water use reported by the study area golf courses, 48 inches. The latter figure is larger due to the first or both of the following reasons:

(1) Duble's (1996) estimate is for Bermuda grass, whereas over-seeding with cool season grasses is still common in the study area, and

(2) Some of the golf courses in the area could be over-watering.

It is logically possible that during water shortages, in order to maintain conditions they perceive as ideal, members demand that superintendents irrigate in excess of what superintendents know to be an amount of water that ensures survival.

The question of perception is paramount. Most golfers today may not perceive the brown color of dormant Bermuda grass as pleasing. With a hypothetical, more environmentally sensitive constituency of golfers, perhaps aesthetic considerations would be secondary to environmental concerns. Golfers, with whom the blame for high water use at golf courses ultimately rests, could invalidate the 'necessity' of high water use.

Types of Grasses Used

The immense popularity of Common Bermuda and Bermuda hybrids denotes a widespread effort by superintendents in the area to reduce water consumption by choice of turfgrasses with low water requirements and drought resistance. Common Bermuda--commonly called Bermuda in the southern U.S.--does best in well-drained conditions. Curiously, agriculturists consider it to be one of the most troublesome weeds in crops such as cotton, sugarcane, corn, and vineyards (Duble 1996). Bermuda turfgrasses are highly drought resistant (Balogh and Watson 1992; Duble 1996). Within their region of climatic adaptation--in which the study area lies--no turfgrasses are more drought resistant (Balogh and Watson 1992). Bermuda turfgrasses also tolerates a wide pH range and saline conditions (Duble 1996), which makes it ideal for irrigation with treated wastewater.

Policy Implications

This study's estimate of the water requirements for an 18-hole golf course in an average year--70 acre-feet, or 5.83 acre-feet per month--are much lower than the per 18-hole course limit Judge Bunton (1996) set in the

Emergency Withdrawal Reduction Plan for the Edwards Aquifer--408 AF per year, or 34 AF/month. Also notably lower is the amount of water the golf courses surveyed reported using per 18-hole course in an average year--230 acre-feet, or 19 acre-feet per month. The root of this discrepancy presumably lies in the possibility that golf courses successfully lobbied for the highest figure they could, or that Judge Bunton attempted to account for the unusually high irrigation requirements which accompany drought conditions. However, the former possibility seems to be the more likely of the two explanations, considering the following postulation.

The normal minimum yearly rainfall of Austin and San Antonio is approximately 18 inches--based on National Weather Service (1998) Data from 1968-1997. This value is considerably lower than the actual average annual rainfall for the Austin-San Antonio area during the drought which ended in 1997 (which means the irrigation requirement it yielded would be considerably higher than the actual amount of irrigation water necessary). Inserting this value into the field irrigation water requirement equation (p. 66-69), the amount of irrigation water necessary for turfgrass survival in the study area during a drought is 20 inches per year. This yields an annual figure of 177 acre-feet per 18-hole course, or 14.7 acre-feet per month. Since it is representative of drought years, naturally this figure is higher than this study's figure--which represents an average year--of 70 acre-feet per year per course, or 5.83 acre-feet per month per course. However, this 'drought-adjusted' figure is still much lower than the 34 acre-feet per month limit allotted to golf courses by Judge Bunton (1996) in the Emergency Withdrawal Reduction Plan for the Edwards Aquifer.

Economic Considerations

The average revenue generated per Texas golf course in 1993 was $630,000 (Sharp 1998). Assuming the 1990 figure of 65 golf courses in the study area, a conservative estimate places their annual contribution to the Texas economy at 41 million dollars. Expanded to the projections, the courses' annual contribution to the Texas economy in 2020 could be anywhere from 50 million to 150 million dollars. However, their net contribution to the economy would be lower due to the use of a larger portion of the water supply and the resulting greater ecological tradeoff.

The study's irrigation water requirement analysis shows that 70 acre-feet of irrigation water are needed per course in an average year. The survey results show that the average 18-hole course uses 226 acre-feet of irrigation water in an average year. Therefore, 156 acre-feet of irrigation water could be saved annually per 18-hole course. The study's irrigation water requirement analysis illustrates that 177 acre-feet of irrigation water is needed per 18-hole course in a drought year.

Water pricing in the Edwards Aquifer region is in its infancy. The water shortage situation in California indicates what future water prices for Edwards Aquifer water might be. California municipalities have paid between $40 per acre-foot in wet years and $175 per acre-foot in drought years such as 1991 (Keplinger and McCarl 1998). The 1997 Irrigation Suspension Program for the Edwards Aquifer, had not the Aquifer region had a wet spring in 1997, would have entailed a cost of about $99 per acre-foot of suspended irrigation water (Keplinger and McCarl 1998). Given these economic considerations, anyone with water to sell could reasonably expect to sell that water at a rate ranging from $40 per acre-foot to $175 per acre-foot. Obviously, the more pressing the drought, the more the price of water would increase.

Treated Wastewater

It is encouraging that over half of the courses surveyed use treated wastewater to some degree. However, overall, the courses surveyed only cover about one third of their irrigation necessities with treated wastewater. A consensus exists on the viability of the use of treated wastewater for irrigation. It saves both water and fertilizer. The use of treated wastewater by golf courses in the study area will most likely increase substantially between now and the year 2020. This will lighten the burden golf courses pose on the quantity of the region's primary water supply. On the other hand, golf course superintendents will have to take heightened care to limit this new form of irrigation's increased potential for nutrient-laden runoff.

Water Quality

Any suggestions concerning golf courses' effects on water quality beg questions related to the philosophical/policy aspects of environmental issues:

1. What are the appropriate measures of risk and safety?
2. When does science know enough about a particular practice in order to proceed safely?
3. Who will make judgments regarding risk and safety?

4. How is absolute safety or 'no risk' practices to be proven?

5. What constitutes an adequate ratio of risk to benefit? (Balogh et al. 1992, p. 24)

Science is still in the midst of ascertaining the definitive measures of risk and safety. Meanwhile, the U.S. Environmental Protection Agency (EPA) and the Texas Natural Resources Conservation Commission (TNRCC) have set water quality criteria for measures and compounds which runoff and leaching from golf courses may affect. Examples include dissolved oxygen, total dissolved solids (TDS), and certain toxic materials such as specific pesticides and nitrate nitrogen (30 TAC § 307.6).

It is difficult to pinpoint when science knows enough about a practice to proceed safely. It is safer to err in favor of caution than the contrary. Being too cautious is not necessarily less profitable monetarily for golf courses or the fertilizer industry. The golf courses would experience less opposition from environmentalists and find it easier to build new courses. The fertilizer industry could expand into more environmentally friendly products such as compost and organic fertilizers. Favoring caution could be detrimental to the pesticide industry, but perhaps more biological and biodegradable products would also spur a golf demand less inhibited by environmental concerns, leading to an increase in profits.

The question of who will make judgments regarding risk and safety is a large topic beyond the scope of this discussion, but whoever makes these decisions will almost certainly never be able to prove absolute safety or 'no risk' practices. Granting that no totally safe options exist is not paramount to condoning the historic or present methods of pesticide and fertilizer use. Many practices exist which greatly limit the risk of golf course turfgrass care. As a group, the golf course superintendents in the study area use a great variety of risk-limiting practices. Like society in general, the I-35PGC golf courses are in the process of making the transition to habits that help ensure clean air, water, and land.

Determining an adequate ratio of risk to benefit is complex. The choice of turfgrass provides a brief example. Common Bermuda and Bermuda hybrids help conserve water, but they have high nitrogen requirements compared to other turfgrasses (Duble 1996). Thus these turfgrasses' potential to contaminate water from runoff is higher than other, less water-efficient turfgrasses. Establishing the outcome of the tradeoff between these Bermuda grasses' beneficial water conservation traits and their comparatively higher potential threat to water quality is an effort which necessitates comparing mismatched components.

A Geographical Perspective

A geographical perspective yields new approaches to the resolution of the demand golf courses place on water resources. In Scotland, the place where the first permanent golf courses were located, a combination of natural rainfall, the lush vegetation it nurtured, and golfers' acceptance of the natural landscape as part of the challenge of the sport precluded the need for irrigation, fertilizers, and pesticides. Few golf courses in the world are more revered than many of Scotland's natural golf courses, such as St. Andrews. Golf courses in the Austin-San Antonio Corridor, and in the United States in general for that matter, could advance environmentally by regressing towards the natural conditions which characterized the first 400 years of golf courses' 500 year history.

The key to this changed attitude is geographical: instead of expecting courses to have standard conditions no matter where they are located, golf course conditions could vary according to where they were located. Far from detracting from the game, this would enrich the golfing experience. Currently, golf course play at different courses throughout the country resembles visiting suburbs throughout the country: a sameness dominates which makes it difficult to distinguish between them. Courses which were an integral part of their surrounding natural environment would become famous for much the same reason St. Andrews in Scotland is famous: the course is unique to that place, mainly because it is virtually synonymous with the physical environment of that place.

The particulars of these natural, place-specific courses would include the elimination of over-seeding, tees which resembled today's roughs, greens with subterranean designs akin to those of today's sanitary landfills, and fairways which depended primarily on natural rainfall. Bermuda turfgrasses in central Texas go dormant in the fall and winter months, in which stage their color is brown, as opposed to the green color they exhibit during the warm season. Over-seeding golf courses in central Texas is a practice carried out in order to maintain green color (Duble 1996). Green color is one of the aesthetic expectations of today's golfers. If golfers were to alter their perception to accept the geographical reality that seasons change and vegetation changes along with them, it would save immensely on water, pesticides, and fertilizers. Extensive fertilization would only be necessary upon the installation of turfgrass on a newly constructed golf course. The growth stage of a grass is when fertilizer, pesticide, and water requirements are highest. By simply accepting to play on brown turfgrass, golfers would save all the extra fertilizer, water, and pesticides it takes to grow the cool season grasses every year. This practice is already prominent in the area, as almost half of those surveyed do not over-seed fairways, and over three fourths of those surveyed do not over-seed roughs. But they all over-seed greens and tees, the latter of which is as unnecessary as over-seeding fairways and roughs.

Aesthetics aside, there is no reason tee areas have to have grass that is nearly as short as grass on the greens. The tee (i.e. the small, pointed, wooden or plastic golf ball holder) elevates the ball to the desired height. As long as the grass height is not so much above this desired height that it physically interferes with the club's path to the ball, it is short enough for all practical purposes. Tee areas with native grass as tall as the rough adjacent to the standard fairway today would have substantially reduced water, fertilizer, and pesticide requirements.

Greens, due to the difficulty of putting on anything but a carpet-like surface, could be maintained much in the same way they are today, with an emphasis on the use of less toxic, less persistent, less mobile pesticides, slow-release fertilizers, and techniques which capture leaching chemicals and runoff. Beneath greens, plastic liners with drainage systems which funneled leached liquid into a nearby holding pond--which itself had a plastic liner--could eliminate leaching into groundwater, excepting the case of leaks in the liner. Similarly, all runoff from greens could be diverted to paths which drained into a nearby holding pond, with plastic liners and like drainage underlying both path and holding pond.

Perhaps the most controversial of the suggestions proposed in this study is allowing natural rainfall to dictate the conditions of fairways. This would involve determining the grass height which needed the least amount of water due to the ideal combination of exposed canopy area and root depth. This height could be implemented on fairway turfgrasses, even if it was somewhat higher than currently typical heights. In dry years, enough irrigation water to ensure turfgrass survival could be applied. Another option would be to convert fairways to native grasses, which would be more capable of a higher level of dependence on natural rainfall. The problem (other than conflicting aesthetic expectations) with these two possibilities is that golfers in the United States expect carpet-like conditions on fairways.

Let us consider the golf course fairway. The rules of golf do not provide for the concept of a fairway; the nearest reference they make is to the area between the tee and the green, which is simply called "through to the green" (USGA 1998). The carpet-like fairway is a convenience initiated in the United States. Its main objective is to reward a golfer who makes a reasonably straight tee shot with a good lie from which to make their next shot. Evidently, this is an important objective in the United States.

But a much more environmentally sound means to attain this objective exists. By changing a rule, massive amounts of water and chemicals could be saved, and the potential threat posed by chemicals to water quality could be almost completely eliminated. Being able to improve one's lie in the fairway would achieve the same objective as an intensely-groomed fairway. If native grasses were so coarse that even an improved lie was unacceptable, golfers could use a tee in mid-fairway. The immediate reaction of the orthodox golf community to this is that the rules are the rules, and the rules say one cannot improve his or her lie. But those who made this rule played golf in a place where turf was naturally lush. Today golf is played in places whose physical geography is totally different than the physical geography of the place where the rules of golf were invented. To attempt to transfer the original setting and the rules which accompany it to wherever golf courses diffuse is to ignore geography entirely. Wes Jackson (1997), of the Land Institute, points out that since the onset of stationary agriculture 10,000 years ago, the time humans have spent learning to conquer nature dwarfs the time humans have spent learning to work with nature.

By learning to work with nature, golf courses, instead of being artificial 'natural' areas, could realize their potential for being truly natural areas, with negligible negative environmental consequences. Is not the purpose of a fairway more important than the fairway itself? What is the difference between getting a good lie by maintaining a heavily irrigated, chemically treated, carpet-like fairway and getting a good lie by improving one's lie in a 'rougher' fairway with limited or no irrigation or chemical treatment? The difference is the substantially declining stress the natural fairway places on the quantity and quality of water. If dogmatic golfers insist on not improving their lie, so be it. They can play the game on the natural grass surfaces on which the game was invented to be played.

Finger's (1980) reduced fairways are a step in the right direction. But one could essentially suggest substantially altering the fairway as we know it. The fairway envisioned could still be as big as pre-Finger fairways, but these fairways would only be irrigated as truly necessary. Changing the rule regarding improving one's lie, which would acknowledge the indigenous physical geography of the places to which golf courses have diffused, would eliminate virtually all of the potential threat golf courses pose to water quality.

CHAPTER 7

CONCLUSION

Summary of Results

The I-35 Primary Growth Corridor--Bexar, Comal, Guadalupe, Hays, Travis, and Williamson counties--had sixty-two 18-hole golf course equivalents in 1990. The survey response in this research was high, with a 40% return rate. Projections of the number of the study area's 18-hole equivalents in 2020 (Table 9, p. 88) range from 77 to 237. In 1990, there were 53 holes per 100,000 people in the region, with projections for the year 2020 ranging from the present rate to 105 holes per 100,000 people.

The water consumption of the average course in the study area is equivalent to the municipal demand of 900 people. In 1990, the golf courses in the study area used an approximate total of 14,000 acre-feet of water, which equals the municipal demand of an average city of 56,000 people. This was 3% of the area's total water demand, and between 1% and 2% of the region's water supply. The low projection for golf course water demand in 2020 is 5,390 acre-feet, which equals the municipal water demand of a city of approximately 21,600. This would be around 1% of the total water demand of the study area, and one third of 1% of the total water supply of the study area. The highest projection for golf course water demand is 53,200 acre-feet, which equals the municipal water demand of a city of over

200,000 people. This would be around 5% of the total water demand, and 5 % of the total water supply (Table 10, p. 89).

Common Bermuda and Bermuda hybrids are the most frequently used types of warm-season turfgrasses on golf courses in the I-35 Primary Growth Corridor. Considering the region's susceptibility to chronic drought, these grasses are logical selections since they consume comparatively low amounts of water and are drought resistant. The most common type of cool season turfgrass used to over-seed is Perennial Rye grass. Considering the controversy surrounding water supply in the area, it is encouraging that over one-half of the courses surveyed do not over-seed fairways or roughs.

About two-thirds of those surveyed rely exclusively on the "Eye of the Greenskeeper" to determine irrigation needs. About one third of those surveyed use either evapotranspiration rates or both "Eye of the Greenskeeper" and evapotranspiration rates. The most common methods golf superintendents use to save water are computer irrigation, followed by watering only as necessary, and irrigating in twighlight hours. The most popular source of irrigation water is well water (study area golf courses as a group cover 35% of their irrigation needs with it), followed closely by treated wastewater (34%), and then to a lesser degree by retention pond water, stream water, municipal water, and reservoir water.

In comparison to other types of topography, the risk of pollution of surface and groundwater through the runoff and leaching of pesticides and nutrients is highest in karst topography. The majority of golf courses in the study region are located on karst topography. Golf course superintendents in the study area are taking measures to prevent surface and groundwater contamination through the application of chemicals in accordance with close monitoring of the weather, monitored irrigation, and the use of buffer zones.

Suggestions for Further Research

This research has fortuitously coincided with the recent acquisition of Aquarena Springs Golf Course by Southwest Texas State University. The 9-hole course would be an ideal site to attempt the first 'totally natural' golf course in the region, as delineated in the Geographical Perspective section in chapter 6 of this thesis. As such, the course would pose much less of a potential threat to Aquarena Springs and the San Marcos River. With the claim of being the most environmentally sensitive golf course in Texas, Aquarena Springs Golf Course could draw heavily on the relatively large number of environmentally conscious people in the area.

APPENDIX 1: SURVEY COVER LETTER

Survey on Water and I-35 Corridor Golf Courses

January 2, 1998

(Name of Golf Course Superintendent)
(Name of Golf Course)
(Street Address of Golf Course)
(City, State, and Zip Code Address of Golf Course))

Dear Mr. (Name of Golf Course Superintendent),

We are asking that you please take a little time to tell us about your golf course in regard to water. We have included a self-addressed, stamped envelope for your convenience in returning the completed survey.

This survey is being conducted by a Southwest Texas State University graduate student studying applied geography under the supervision of Dr. Byron Augustin. The survey results will be included in a thesis, which is a requirement for completion of a Master of Applied Geography Degree at Southwest Texas State University. We would like to know about your golf course and several water issues in order to gather quantitative data on I-35 Corridor golf courses. We are interested in both the potential negative and positive effects of your course on water.

Your response will be strictly voluntary and confidential. However, we hope that after viewing the questionnaire, you will agree that this is a valid and valuable piece of research. If you participate in the study and would like to see a copy of the completed research, please let us know and include your return address; we would be pleased to share the results with you.

Due to time constraints at the university, we would very much appreciate it if the completed questionnaire could be returned by February 1, 1998. Thank you very much for your assistance with this project.

Sincerely,

G. Michael Lindner
M.A.G. Graduate Student

Dr. Byron Augustin, D.A.
Supervisor

APPENDIX 2: SURVEY QUESTIONNAIRE

Questionnaire

1. How many holes is your golf course?

18 9 36 27 other ____________

2. What is the length of your course?

____

3. Type of course:

_____ private

_____ public

_____ daily fee

4. How many acres does your golf course contain?

____

5. How many acres of your golf course do you irrigate?

____

6. You irrigate using:

_____ ET rates

_____ "Eye of the Greenskeeper?"

7. Types of grasses or mixture of grasses you use on

tees ____

fairways ____

roughs ____

greens ____

8. If you over-seed in the cool season, what types of grasses or mixture of grasses do you use?

tees ____

fairways _____________________________________

roughs _______________________________________

greens _______________________________________

9. In an average year, how much water per season does your golf course use? * (gallons or acre feet on average per month or year, or whatever units of measure are convenient for you)

spring ____

summer ____

fall ____

winter ____

* If you do not know, please answer the questions that follow.

9a. Number of sprinkler heads on

tees ___________________________

fairways _______________________

roughs _________________________

greens _________________________

9b. Gallons of water per minute emitted by average sprinkler heads on

tees ________________________

fairways ______________________

roughs _______________________

greens _______________________

9c. In an average year, how many nights a week do you irrigate with the sprinklers in each season? [see following table]

	spring	summer	fall	winter
tees				
fairways				
roughs				
greens				

9d. In an average year, number of minutes per night you irrigate with sprinkler heads on

	spring	summer	fall	winter
tees				
fairways				
roughs				
greens				

10. Do you use wetting agents?

_____ yes

_____ no

10a. If so, how often?

____

11. Do you use growth regulators?

_____ yes

_____ no

12. What kind of terrain is the golf course built on?

_____ hilly

_____ flat

13. If you have a retention pond(s), how many do you have and what is their capacity?

13b. Do you irrigate with retention pond water?

______ Do not have a retention pond.

14. What percentage of your water use comes from the following sources? [see table]

Type of Water	Percentage of Water Use
treated wastewater	
secondary	
tertiary	
well water	
stream water	
municipal water	
reservoir water	

15. If you use treated wastewater, what are you charged for it?

----

16. If you have buffer zones next to/around water bodies, how wide are they on average?

____

______ Do not have buffer zones

17. Is your course located west of I-35?

yes no

17a. If so, the course is located in

______ the Edwards Aquifer recharge zone

______ the contributing zone to the Edwards Aquifer recharge zone

______ neither

18. Fertilizer and pesticide use:

_____ spot treat _____ blanket treat

_____ preventative _____ curative

19. Type of fertilizers used:

Type of Fertilizer	Percentage of Total Use
liquid	
organic	
synthetic	

20. What are the most effective ways you conserve water?

21. What are the most effective ways you control runoff of pesticides and fertilizers?

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