Water Use on Ontario Golf Courses

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

The golf industry is an important sector of the recreation and tourism economy in Canada. In 2009, the Canadian golf industry generated an estimated total direct economic activity of CND$29.4 billion dollars and created over 300,000 jobs for Canadian residents. Within Canada, Ontario is the dominant province with regards to golf's gross domestic product (GDP). In 2009, the 848 golf courses in Ontario generated $11.5 billion, which equates to 38.7% of Canada's golf GDP (Strategic Networks Group, 2009). Due to the economic and employment benefits of the Ontario golf industry and its sizeable land use, it is important to fully understand the environmental impacts of golf courses.

While concerns have been raised regarding water consumption by the Ontario golf industry, the golf industry in Ontario has never responded to these criticisms with actual water taking data to support their claims of environmental sustainability. Water withdrawals and water use efficiency among golf courses have yet to be quantified by the Province, the golf industry or its critics. This study uses daily water withdrawal data, self reported by 129 golf courses, to the Ministry of Environment (MOE) from 2007 to 2012. The water taking data is used to examine biophysical golf course characteristics that influence water use, to estimate annual water use by golf courses in Ontario, to identify the potential for water use reductions through best management practices (BMPs) and to explore how climate change may influence future golf course water use in Ontario.

This study provides a first approximation of water use by irrigation for golf courses in Ontario. The analyses that examined the biophysical characteristics of golf courses indicated that soil type and golf course type influenced water use. During a dry season, golf courses composed of sand and silt dominated soils were found to require more water than they did during a climatically normal season. With regards to golf course type, premier private and private golf courses were found to use a greater quantity of water during both normal and dry seasons when compared to public and semi-private golf courses. The provincial water use analysis revealed that during a climatically normal season, 50.5 billion L of water is used to irrigate Ontario golf courses. Irrigation increased (58%) to 79.9 billion L during a season that was 1.2°C warmer and 29% dryer than normal. This finding indicates that under anticipated climate change by the 2050s, water use on golf courses in southern Ontario could increase by 151% current levels.

The analysis for potential water savings for Ontario golf courses revealed that water use reductions of 35% are possible if golf courses adopt similar maintenance and irrigation practices to more efficient golf courses (80th percentile) in Ontario. Further research regarding maintenance practices on golf courses should be carried out to understand what best management practices result in water efficiency among courses. Also, due to the self-reporting nature of the water taking program with the MOE, it has been recommended that a more strict and automated monitoring system be implemented. Lastly, it is strongly believed that in order for the province wide water savings to be achieved, collaboration between the government and the golf industry will be needed. This study is the first approximate of water use for Ontario golf courses, however, more research is needed to examine the MOE's water taking data in detail to better understand the determinants of water use among similar golf courses.

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List of Abbreviations

PTTW: Permit to Take Water

MOE: Ministry of Environment

BMPs: Best Management Practices

GDP: Gross Domestic Product

ECO: Environmental Commissioner of Ontario

GCSAA: Golf Course Superintendents Association of America

CAA: Conservation Authorities Act

ESA: Environmentally Sensitive Areas

EIA: Environmental Impact Assessment

IPCC: Intergovernmental Panel on Climate Change

VEPs: Voluntary Environmental Programmes

ACSP: Audubon Cooperative Sanctuary Program

GRCA: Grand River Conservation Authority

GLRWUD: Great Lakes Regional Water Use Database

Chapter One: Introduction

1.1 Introduction

Environmental awareness of golf course development and management was minimal prior to the 1970s, particularly in North America (Air Force Center for Engineering and the Environment , 2008). Due to a lack of interest in environmental protection by the golf course management, the public, and the government, golf course development often created negative impacts on the environment. Smart and Peacock (2000) and Mankin (2000) report that golf courses that are poorly designed and managed can create adverse environmental impacts that include the contamination of surface water and runoff water adjacent to the golf course, increased pest populations and their resistance to chemicals, high levels of toxicity in non-target plants and animals, and excessive usage of freshwater resources (Mankin, 2000; Smart and Peacock, 2000).

However, since the development of the Environmental Protection Act in Canada in 1990, and the 'Environmental Guidelines for Canadian Golf Courses' in 1993, Canadian golf courses have sought to minimize negative environmental impacts by incorporating natural ecological features into the design of the golf course and by integrating sustainability criteria and design (Air Force Center for Engineering and the Environment, 2008; Duncan, 1996; Gössling et al., 2012; Government of Canada Justice Laws Website, 2013h; Kiss, 1998; Minoli and Smith, 2011; Ontario Allied Golf Associations, 2007; Rodriquez-Diaz, Weatherhead, Garci Morillo, and Knox, 2011; Warnken, Thompson, and Zakus, 2001). Mankin (2000) demonstrates through an integrated modeling framework that golf courses that properly apply pesticides, fertilizers, and irrigation, and maintain appropriate vegetation can produce low environmental impacts while generating important economic activity and employment opportunities. One of the most pressing concerns regarding the golf industry and its recent growth relates to the amount of freshwater used to maintain the turfgrass. As a water-intensive industry (Blette, 2012; Lyman, 2012; Throssell, Lyman, Johnson, Stacey and Brown, 2009), it is very important for both the environment and society that irrigation is sustainably applied to golf courses and not used in excess. The public's concern over excessive irrigation on golf courses, especially in arid or water scarce areas, will likely be amplified as climate change is expected to lead to water shortages, reduced soil moisture and extreme temperatures (de Loë and Berg, 2006). Studies conducted by Scott and Jones (2007) and reviews completed by Lemmen and colleagues (2008) suggest that the golf industry in Canada will experience changes to their irrigation water consumption due to warmer average temperatures and more variable precipitation under climate change.

Little is known about total water consumption from irrigation for golf courses in Ontario or the biophysical characteristics that influence water use efficiency. Nonetheless, some organizations, such as the Sierra Club, Friends of the Earth, Earthroots and the Nature Conservancy have expressed concerns about water use by the golf industry in Ontario (Air Force Center for Engineering and the Environment, 2008; Garfinkel, Kohler, Lintner and Wilkins, 2008). This thesis examines a water withdrawal dataset of irrigation water consumption for Ontario golf courses, provided by the Ministry of Environment (MOE), to examine if biophysical golf course characteristics influence golf course water use, to estimate total annual water use by golf courses in Ontario, to predict how climate change may influence golf course water use in Ontario and to estimate the potential water savings through best management practices (BMPs). The following research questions guided the study:

1. What sustainability initiatives, both voluntary and mandatory, are in place that regulate irrigation water consumption on golf courses both globally and in Ontario?
2. What biophysical characteristics influence golf course water use in Ontario?
3. What is the average annual water use for golf courses in Ontario?
4. How may predicted climate change influence future golf course water use in Ontario?

Based on the available literature, several hypotheses were generated for research question two:

- Golf courses underlain by sandy soils require more water use than golf courses with clay soils due to increased infiltration rates in sandy soil;
- Golf courses in the oldest age category require more irrigation than newly constructed golf courses (i.e. golf courses in the youngest age category) due to outdated and inefficient irrigation systems and golf course design;
- Private golf courses consume greater amounts of water than public golf courses, or daily fee golf courses, since private clubs have more demanding members with regards to golf course aesthetics and conditions;
- Above average daily temperatures require more irrigation due to high rates of evapotranspiration and therefore water use will be higher during warmer summers; and

- Precipitation will naturally irrigate the golf course and therefore, water use will be increased during dry summers.

These water use influencing characteristics are thoroughly examined and discussed in Chapter Four.

No regional quantification of water use for Ontario golf courses exists. However, water use research was calculated on golf courses in the Northeast agronomic region of the United States, which is a region that is climatically similar to Ontario (Throssell et al., 2009). They found that the Northeast agronomic region of the United States had an average annual water use of 52 million L for an average sized 18-hole golf course. It was therefore estimated that standard 18-hole golf courses in Ontario are likely to use similar amounts of water annually. With an estimated 848 golf courses in Ontario, total annual water use could exceed 44 billion L if all golf courses irrigate for average sized 18-hole courses.

Due to the lack of water use profiles for Ontario golf courses, a numerical hypothesis could not be made to estimate a change in water use due to climate change. Rather, it is simply hypothesized that warmer average temperatures and reduced summer precipitation would increase water use on Ontario golf courses.

1.2 Research Rationale

The purpose of this research is to develop a baseline estimate of water consumption by golf courses in Ontario. Due to a lack of water use data for golf courses in most jurisdictions globally, concerns regarding the improper use of water on golf courses persist and are intensified with predicted population growth and climate change

(Colombo, McKenney, Lawrence and Gray, 2007; Ontario Ministry of Finance, 2006). Considering the water criticisms aimed at the golf industry, it is now more important than ever for the industry to respond with improved water conservation practices.

The Ontario golf industry was chosen as the focus for this study since water taking data has only recently become available due to the Permit to Take Water (PTTW) program. As discussed in section 2.2.3, the PTTW program was introduced to Ontario golf courses between 2005 and 2007 (Ministry of Environment, 2005). With this new monitoring program, the golf industry is now able to track water use, capacity it did not have ten years ago. Today, there are enough golf courses in the program reporting their annual water use that allows for data analysis of water use by courses with different characteristics and during variable weather conditions. As this data is newly available and growing, there has yet to be any systematic analysis of water use on Ontario golf courses. Organizations and groups that have criticized the water use of the Ontario golf industry were not informed by a systematic evidentiary basis, such as the MOE dataset. However, they have encouraged the industry to create informative documents educating the public about their water use and environmental protection initiatives.

The research questions of this thesis were specifically chosen to address the identified knowledge gaps associated with irrigation water use on golf courses in Ontario. In order to successfully reduce the knowledge gaps, an extensive literature review and secondary data analysis was completed. Assessing current water use and water conservation initiatives will assist both the golf industry and the government (local and provincial) to work together to advance sustainable water use in the golf industry.

Furthermore, by predicting the impacts climate change may have on the golf industry, particularly as it relates to water use, the industry's awareness to climate change will increase. Identifying both the current water use and the potential changes to water use due to climate change will allow the golf industry to adopt practical and affordable water conservation strategies. Increasing the awareness of golf course owners, managers and superintendents to the impacts of climate change will enable the golf industry to plan for and mitigate anticipated changes by adapting several BMPs, and perhaps even enforcing BMPs, to help reduce negative environmental impacts. Additionally, the results of this research could be used to further develop mandatory rules and regulations within regions and municipalities where efficient sustainable golf course irrigation is most needed due to high demand among multiple users.

Chapter Two: Literature Review

2.1 The Golf Industry

Over the past two decades, the global golf industry and golf tourism markets have been expanding rapidly around the world. In the last five years alone, the number of golf courses have increased by an estimated 15% (Berenberg, 2012). Today, it is estimated, since the number of golf courses is always changing due to constant developments and closures, that there are more than 40,000 golf courses in 119 countries catering to 80 million active golfers (Berenberg, 2012; Briassoulis, 2007; HSBC, 2012). North America, Europe and Asia are home to 91% of the world's golf courses; 59% are situated in North America, 20% in Europe, and 12% in Asia (Briassoulis, 2007). The dominant country in North America contributing to the golf economy is the United States. In 2011, SRI International (2012) estimated that the golf industry in the United States directly generated $76.4 billion in goods and services (all monetary values in this thesis are in Canadian dollars). In addition, the estimated total economic impact was $192.2 billion, creating 1.98 million jobs with a total household income of $61.7 billion (SRI International, 2012). Canada will be discussed in section 2.1.1.

In Europe, Spain is the most dominant country with regards to the golf economy, having over 300 golf courses and nearly 250,000 resident golfers (Tapias and Salgot, 2006). In Catalonia alone, the golf industry produces an economic impact of $30 million each year (Salgot, Priestley, and Folch, 2012; Tapias and Salgot, 2006). Golf popularity and participation rates have grown significantly since 2000, particularly in Germany, the Netherlands and the Czech Republic by 74%, 146% and 650% respectively (HSBC, 2012). This growth in popularity and golf participation rates shows great promise for the golf economy in Europe (HSBC, 2012). Asia has also experienced pronounced growth in golf popularity. China in particular has been experiencing a boom in the golf industry since 2004, tripling the number of golf courses from 170 to over 600 by 2011 (HSBC, 2012). These golf courses generate revenues greater than $9.6 billion a year from more than 3 million golfers (Gould, 2010). The economic figures presented above strongly show the importance of the golf industry in the global economy. Although Canada's economic figures are more subordinate than the economic figures of the United States, Spain, China and Japan, on a per capita basis, Canada has "one of the highest golf participation rates [in] the world" (Royal Canadian Golf Association, 2011).

2.1.1 Canadian Golf Industry

The Canadian golf industry has estimated that there are 6 million resident golfers playing 70 million rounds each year at 2,500 golf courses (National Allied Golf Associations (NAGA), 2012; Stategic Networks Group (SNG), 2009). There is an estimated 200,000 hectares (Ha) of land designated to golf courses in Canada. Of this area, roughly 160,000 Ha is managed green space and 40,000 Ha is unmanaged wildlife habitat under golf course stewardship (SNG, 2009). From an economic standpoint, the Canadian golf industry in 2009 was estimated to have a gross production of $29.4 billion, $13.6 billion of which was generated through total direct sales (SNG, 2009). The golf tourism industry alone accounts for $11.3 billion of Canada's Gross Domestic Product (GDP). As of 2009, the industry created 341,794 jobs resulting in $7.6 billion in household income (SNG, 2009). Additionally, it has been estimated that Canadian golfers spend $13.1 billion each year on golf equipment, apparel, memberships and golf travel within Canada (SNG, 2009). Total revenues for golf courses, driving and practice ranges, as well as their associated facilities, was $4.7 billion in 2009, whereas the combined revenues of all other participation sports combined was $4.8 billion (ski facilities, fitness centres and amusement parks generated $0.9 billion, $1.7 billion and $0.4 billion respectively) (SNG, 2009).

The Consumer Behaviour Study conducted by the National Allied Golf Associations (2012), suggests that since 2009, golf participation rates have remained stable, meaning there is no current growth. However, future predictions suggest that by 2020 there will be positive growth due to an increase in Canadian golf tourism and an increase in engagement among the current population, partly due to sustainability efforts (Beditz and Kass, 2010; NAGA, 2012). The data collected by NAGA (2012) indicates that only 25% of the Canadian golfing population is "actively engaged" in the sport, meaning that they participate in at least four of the following categories: learn, volunteer, follow, subscribe, practice, attend tournaments or talk about the game of golf. The principal finding of the research conducted by NAGA (2012) shows that the majority of Canadian golfers are considered to be unengaged in golf, playing 25 rounds or less each year. NAGA (2012) suggests that there is an enormous window of opportunity for the number of rounds played by the 75% of "un-engaged" golfers to increase and create positive growth if marketing, participation and engagement strategies are proven successful (NAGA, 2012).

2.1.2 Ontario Golf Industry

Based on the findings of the Economic Impact Study conducted by SNG (2009), the province found to generate the highest percentage of golf associated GDP was Ontario. The Ontario golf industry alone accounts for $11.5 billion of Ontario's GDP, which is 38.7% of Canada's golf GDP (Figure 1) (SNG, 2009).

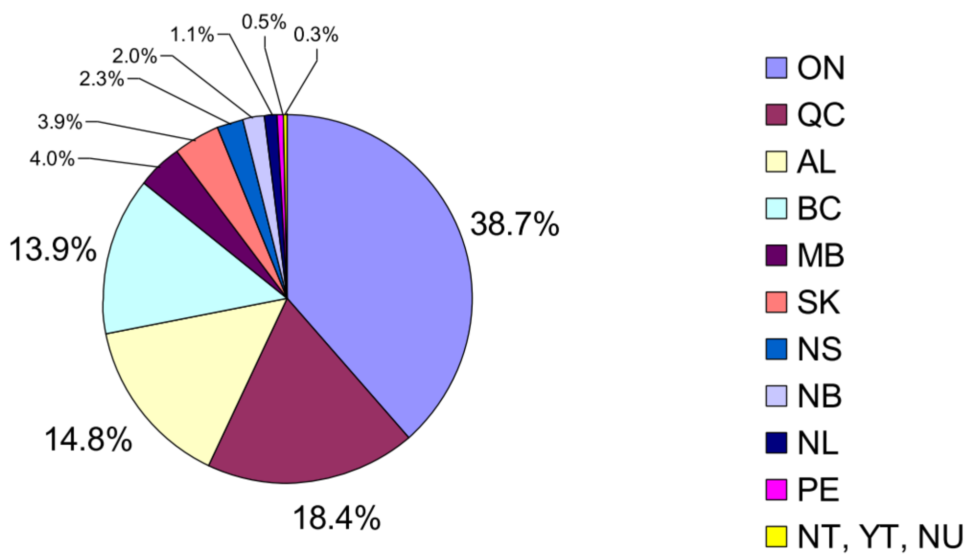

Figure 1: Golf GDP By Province

(SNG, 2009).

Through direct, indirect and induced spending, the Ontario golf industry generated a total of $11.5 billion in 2009; $1.66 billion of which was generated directly by golf courses and their accompanying facilities (SNG, 2009). As of 2009, the Ontario golf industry created 123,566 jobs generating $2.97 billion in household income (SNG, 2009). The Economic Impact Study of golf for Canada, conducted by the Strategic Networks Group (2009), also verified that there are 2.32 million resident golfers playing at 848 golf courses in Ontario. The majority of golf courses located in Ontario are 18-hole golf courses, with an average area of approximately 81 Ha each, 57 Ha of which tends to be maintained and irrigated (Carrick, 2013; Peister, 2012). Due to the temperate climate in

Ontario, the golf season length is normally shorter than 250 days, lasting from May to October. However, season length is inconsistent each year since it is directly influenced by climate variability (Scott and Jones, 2007).

The Ontario golf industry is likely to experience new hardships with regards to reduced freshwater availability. For as long as the Ontario golf industry has been in existence, there has been a copious supply of freshwater resources from the Great Lakes with little to no regulations on water withdrawals. The abundance of freshwater resources and a lack of water withdrawal regulations may have influenced water managers to disregard sustainable management, however, the need to sustainably manage Ontario's freshwater resources is now prominent. de Loë and Berg (2006) and Lemmen and colleagues (2008) suggest that climate change occurring in Ontario, particularly in the Great Lakes basin, will likely result in intensified water shortages, reduced water levels in the Great Lakes, decreased annual runoff, reduced groundwater recharge, reduced soil moisture during the summer months, reduced crop growth, increased summer temperatures and increased evaporation rates. Additionally, population growth is expected to increase particularly in southern Ontario, where golf course density is greatest (Lemmen et al., 2008; Ontario Ministry of Finanace, 2006).

The need to reduce freshwater consumption and preserve Ontario's freshwater resources is of the utmost importance. The Ontario golf industry will become more vulnerable to the impacts of climate change in the following years and be forced to experiment with sustainable water practices that have not been previously incorporated. Generating a baseline dataset of current irrigation water consumption is the first step in standardizing sustainable irrigation practices. Educating the Ontario golf industry on their current water use profiles will enable them to plan for the future, mitigate negative environmental impacts and reduce golf course expenditures to ensure future prosperity.

2.2 Golf and Environmental Sustainability

The literature shows that beginning in the 1970s, the rapid expansion of the golf industry created public concerns regarding the adverse environmental, social and health impacts associated with the development and management of golf courses (Briassoulis, 2007; Briassoulis, 2010; Winter, Dillon, Paterson, Reid and Somers, 2003). The main concerns raised by the public were regarding the long-term impacts associated with the use of pesticides and chemicals on human and wildlife health; the high level of irrigation water consumption on freshwater resources; and the destruction and management of the natural environment on ecosystems (Winter et al., 2003). Prior to 1970, golf course development used, in today's view, unsustainable methods to design, construct and manage golf courses, which was found to produce deleterious impacts towards the environment (Air Force Center for Engineering and the Environment, 2008). This ultimately led to environmental degradation mainly through ground and surface water contamination and land degradation (Wheeler and Nauright, 2006). In turn, publicly voiced environmental concerns and criticisms, such as: "golf course construction devours vast stretches of land [and wastes] scarce water resources" (Pleurom, 2007); "golf development is [one] of the most unsustainable and damaging activities to people and the environment" (Walsh, 1997); and "environmentally friendly golf courses are an oxymoron" (Yorba, 2005), evolved into organizations, such as the Global Anti-Golf Movement, designed to challenge and inhibit the development of golf courses by exposing the negative impacts associated with golf course development and management (Wheeler and Nauright, 2006).

In response to the criticisms, the golf industry has increased its environmental awareness, particularly over the last 30 years, and is acknowledging the potential negative environmental impacts of construction and operations, mainly in regards to freshwater impacts and use, and is therefore voluntarily implementing more sustainable development practices. In general terms, sustainable development is "…development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Mitchell, 2002, p.73). In order to create sustainable development practices on the golf course, several organizations such as Audubon International, GEO, and Beyond the Green are creating programs for golf courses that focus on eco-friendly management practices. Some of the programs available to golf courses today include Voluntary Environmental Programmes (VEPs), the Audubon Cooperative Sanctuary Program (ACSP) and best management practices (BMPs). All of these programs can be easily integrated into the current management practices of the golf course. The modern form of golf course development and management we see today has shown to significantly reduce negative environmental impacts while enhancing natural environmental features. The environments created on the golf course through these eco-friendly management practices encourage animal habitat and wildlife populations, enhance surface and groundwater movement, increase green space in urban communities and encourage human recreation within its ecosystem (Bruneau, Williams, Lucas, Peacock and Bowman, 2005; Michalska, 2005; Minoli and Smith, 2011).

VEPs are site specific and are encouraged to be maintained throughout the life cycle of the golf course. VEPs are often implemented during the construction phase of the golf course, focusing on natural and eco-friendly designs that rehabilitate degraded landscapes, establish water resource protection and enhance wildlife communities beyond preexisting legal regulations (Morgenstern and Pizer, 2007; Rivera and DeLeon, 2008). A study conducted by STRI (2010) concluded that 75% (or 153/204) of global golf courses participating in VEPs have reduced their environmental impacts via:

- Reintroducing native vegetation and removing undesirable vegetation;
- Increasing animal habitat and wildlife corridors;
- Increasing heathland;
- Improving existing, and creating new, ponds;
- Extending buffer zones around ponds and ditches; and
- Increasing compost facilities

(STRI, 2010).

Furthermore, golf courses around the world are participating in the Audubon Cooperative Sanctuary Program. The ACSP assists golf courses in protecting the environment while preserving the game of golf by developing site-specific sustainable management practices for individual golf course needs (Audubon International, 2013). In order for golf courses to be fully certified by Audubon International, the golf course must appropriately plan, integrate and document their efforts with regards to the following criteria:

1. Environmental Planning;
2. Wildlife and Habitat Management;

3. Chemical Use Reduction and Safety;
4. Water Conservation;
5. Water Quality Management; and
6. Outreach and Education

(Audubon International, 2013; Michalska, 2005).

The benefits associated with being a designated certified Audubon Cooperative Sanctuary golf course includes constantly improving, maintaining and conserving environmental resources; reducing golf course liabilities; improving community relationships; growing capital; and improving the golf course's stature and reputation (Audubon International, 2013).

BMPs on the golf course are mainly considered voluntary initiatives, however, government policies and regulations do influence certain maintenance practices, such as the use of chemicals. BMPs are extensive, encompassing a wide range of practical processes that aim to protect the ecosystem from negative environmental impacts associated with golf course development and management. Due to the fact that golf courses are vast man-made ecosystems with various microclimates and interactions between soil, water, air, climate and humans, BMPs are implemented based on site-specific analyses (Carrow and Duncan, 2007). Examples of BMPs include water conservation strategies; integrated pest management; stormwater management; turfgrass maintenance; fertilizer and pesticide management; vegetation and wetland management; and golf course operation monitoring programs (Gartner Lee Limited, 2001). Due to the water criticisms impinged on the golf industry, along with the fact that there are cost savings associated with decreased water use, water conservation strategies are commonly implemented forms of BMPs.

In addition to VEPs, the ACSP and BMPs, the global golf industry is proactively creating a sustainable future by investing in sustainable development research. Since 1993, the Canadian golf industry has raised over $1.2 million to fund sustainable development research projects (Ontario Allied Golf Associations, 2007). Global sustainability projects show that BMPs, when incorporated into the design and management of golf courses, can reduce pesticide use by up to 50% (Ontario Allied Golf Associations, 2007), reduce irrigation requirements by up to 50% (Cisar, 2004), reduce stream sedimentation during the construction phase (Mankin, 2000), reduce surface runoff (Mitra et al., 2006), preserve up to a minimum of 70% of the natural habitat (Terman, 1997) and reduce fertilizer requirements by up to 25% (Cisar, 2004).

Based on studies conducted by the Golf Course Superintendents Association of America (GCSAA), (1999), HSBC (2012), National Allied Golf Associations (2012), SNG (2009), and Tapias and Salgot (2006), it is clear that the global golf industry plays an important role in the global economy. Often the economic importance of golf is overlooked because of publicly voiced concerns regarding the negative impacts golf course development and management can have on the environment and society. However, it is the publicly voiced environmental concerns that informed the golf industry of its lack of progress in environmental sustainability pre-1970s. Today, the golf industry is focused on increasing its environmental awareness and strengthening its environmental stewardship (Hartwiger, 2012; Ontario Allied Golf Associations, 2007; Scottish Golf Environment Group (SGEG), 2004).

2.2.1 Policies that Govern Sustainable Golf Course Development

Environmental rules and regulations have been imposed on the golf industry since the 1930s, particularly in North America and developed countries (Fazio and Brown, 2000, p.50). These rules and regulations continuously influence and promote the sustainability of the location, design and management of golf courses (Fazio and Brown, 2000, p.50; Salgot et al., 2012; Warnken et al., 2001). Mandatory initiatives that are set forth by governments and environmental agencies can actually create benefits for the golf industry by creating better playing conditions; creating unique and aesthetically pleasing golf courses; protecting environmentally sensitive areas; reducing maintenance requirements and costs, particularly with regards to water and chemical application; and improving water quality and quantity (Duncan, 1996; Kiss, 1998; Moeller, 2013; Terman, 1997; Waltz, Carrow, Broomhall and Duncan, 2002).

The policies involved with developing and managing a golf course vary depending on country and location. Environmental Impact Assessments (EIA) are often required prior to golf course development in order to expose potentially adverse impacts that may occur to any biophysical and/or socio-economic factors associated with the golf course (Minoli and Smith, 2011). By exposing potential adverse impacts that may result from the proposed development, the EIA allows these impacts to be mitigated prior to development, thus creating a preventative and proactive approach to development and environmental protection (Government of New Brunswick, 2013; Hanna and Slocombe, 2007, p.45; Minoli and Smith, 2011).

After golf course development, it is common practice for environmental agencies to monitor and evaluate management and maintenance operations, such as land contamination; fertilizer and pesticide use; hazardous waste storage and removal; fuel storage; water use and discharge; as well as the golf course's impact on wildlife, wetlands, vegetation and hydrogeology (Gartner Lee Limited, 2001; Minoli and Smith, 2011). Based on the environmental impacts associated with a golf course's operations, environmental agencies will often integrate what they call "rigid regulations", where particular management operations are banned for either short-term or long-term periods. For example, environmental agencies may ban maintenance on particular areas of turfgrass, ban particular species of turfgrass from being integrated onto the course or ban all golf course irrigation in short-term and long-term increments (Carrow, Duncan and Waltz, 2007). Failure to comply with environmental regulations set forth by environmental agencies can result in charges or fines, loss of operating license or even course closure (Gartner Lee Limited, 2001; Minoli and Smith, 2011). The enforced regulations and policies implemented are primarily country specific. In Canada, the environmental legal requirements has changed golf course development into an integrated watershed management process that involves many stakeholders, decision makers, as well as public and private authorities to mitigate negative environmental impacts (Farrally et al., 2008; Warnken et al., 2001).

2.2.2 Policies and Acts that Govern Golf Course Development in Ontario

Golf course development and management in Ontario is governed by municipal and regional by-laws, as well as by Federal and Provincials Acts and Regulations (Fraser River Action Plan, n.d.). In Ontario, the location for golf course development is primarily controlled via the Provincial Planning Act and the Conservation Authorities Act (CAA). In general, the Planning Act sets forth ground rules for land use planning in

Ontario by describing how land uses are controlled and who controls them (Ministry of Municipal Affairs and Housing, 2010). Similarly, the CAA regulates land developments that either interfere with wetlands and/or alter shorelines and watercourses (Ministry of Environment, 2011). The CAA promotes environmental protection by inhibiting development in environmentally sensitive areas (ESA), which extensively includes wetlands, hazardous areas and lands adjacent to or close to the shoreline of the Great Lakes – St. Lawrence River System (Ministry of Environment, 2011; Ministry of Municipal Affairs and Housing, 2010; Ministry of Natural Resources, 2013a; Ontario Nature, 2004). Furthermore, land uses/developments are regulated and controlled by municipal zoning by-laws, which deliberately promote sustainable management of natural resources in Ontario (Ministry of Municipal Affairs and Housing, 2010). The zoning by-laws in Ontario restrict golf course development to areas that are zoned open space or recreational. If a developer wishes to build a golf course in an area that does not have compatible zoning, the developer must formally request a zoning by-law amendment to the municipality (Garnter Lee Limited, 2001). In order for the zoning by-law amendment to be approved, municipalities often require a range of studies to be conducted by the applicant, which include:

i. Environmental Impact Assessments (EIA);
ii. Feasibility Studies;
iii. Hydrogeology Reports;
iv. Stormwater Reports;
v. Traffic Studies;
vi. Noise Studies;

vii. Golf Course Management Plans;

viii. Construction Mitigation Practices;

ix. Cut and Fill Plans;

x. Site Design; and

xi. Compatibility with Surrounding Uses

(Gartner Lee Limited, 2001).

If the requested study/studies show potential environmental or social disruption, the municipality may reject the zoning by-law amendment and a golf course will not be developed in that location. On the other hand, if the requested study/studies show that little to no disruption will occur during the development and management of the golf course, municipalities will frequently offer a conditional approval in which reporting mechanisms must be maintained throughout the lifecycle of the golf course. Conditional approvals may include (but are not limited to) developing:

i. Monitoring Programs and Contingency Plans (i.e. surface and groundwater quality and quantity);

ii. Comprehensive Stormwater Management Plans;

iii. Erosion Control Plans;

iv. Nutrient Management Programs;

v. Environmental Remediation Programs;

vi. Operational Manual for Staff Training Protocols; and

vii. Application and Management Plans (for irrigation and chemicals)

(Gartner Lee Limited, 2001).

By requesting impact studies and offering conditional development approvals, municipalities are given primary authority over golf course development and management operations. This authority promotes environmental protection of areas by rejecting development in ESA; promotes sustainable golf course development and management since environmental impacts are acknowledged; and administers mitigation efforts, such as BMPs, into the development and management of the golf course.

The Planning Act and the Conservation Authorities Act in Ontario work in conjunction to restrict the location of golf courses to ecologically viable lands. Additional Acts and Regulations of particular importance for golf courses include the Fertilizers Act, the Pest Control Products Act, the Pesticide Act, the Weed Control Act, the Clean Water Act, the Ontario Water Resources Act and the Environmental Protection Act (Table 1.1). Although these Acts are not golf course specific, they are consulted and enforced regularly during golf course management in order to minimize negative environmental impacts. The Ontario Water Resources Act is of particular importance for this research as it is the only Act that addresses sustainable water extraction for golf course irrigation with its Permit to Take Water (PTTW) program.

Table 1.1: Federal and Provincial Acts and Regulations that Help Regulate the Environmental Impacts of Golf Course Development and Maintenance

Federal Acts and Regulations	Description
Fertilizers Act/ Regulation (Government of Canada Justice Laws Website, 2013a)	Regulates agricultural fertilizers
Fisheries Act (Government of Canada Justice Laws Website, 2013b)	An Act that governs fisheries
Migratory Birds Convention Act/ Regulation (Government of Canada Justice Laws Website, 2013c)	Implements a Convention for the protection of migratory birds in Canada and the United States
Pest Control Products Act/ Regulation (Government of Canada Justice Laws Website, 2013d)	Protects human health and the environment by regulating products used for the control of pests
Transportation of Dangerous Goods Act (Transport Canada, 2013)	Develops and enforces safety regulations and standards for transporting dangerous goods such as pesticides
Canadian Environmental Assessment Act (Gartner Lee Limited, 2001)	Establishes a federal environmental assessment process
Conservation Authorities Act (Ministry of Environment, 2011)	Inhibits development in or on the areas within the jurisdiction of the Authority that interfere with wetlands, shorelines and/or watercourses
Provincial Acts and Regulations	
Environmental Management Act (Ministry of Environment, 2013a)	Empowers the Minister of Environment to manage, protect and enhance the environment while preventing detrimental environmental damage
Planning Act (Ministry of Municipal Affairs and Housing, 2010)	Creates guidelines for land use planning in Ontario and depicts how land uses may be controlled and who controls them
Pesticide Control Act/ Regulation (Government of Canada Justice Laws Website, 2013e)	Enforces the safe transportation, storage, preparation, application and disposal of pesticides
Waste Management Act/ Special Waste Regulation (Ministry of Environment, 2013b)	Establishes the rules for operating, altering, managing or improving landfill waste disposal sites and persecutes those without a permit or compliance with relevant regulations
Ontario Water Resources Act (Ministry of Environment, 2013c)	Considers the conservation, management and protection of Ontario's water resources as it relates to efficient and sustainable use
Weed Control Act (Government of Canada Justice Laws Website, 2013f)	Attempts to regulate noxious weeds, weed seeds, and prohibited noxious weeds via various control measures
Wildlife Act (Government of Canada Justice Laws Website, 2013g)	Ensures the respect of wildlife in Canada
Endangered Species Act (Ministry of Environment, 2013d)	Identifies species at risk, aims to protect the species and their habitats and promotes stewardship undertakings to assist in protecting and recovering the species
Environmental Protection Act (Government of Canada Justice Laws Website, 2013h)	Specifies protection and conservation of the natural environment
Lakes and Rivers Improvement Act (Ministry of Natural Resources, 2013b)	Manages, protects, preserves and dictates the use of water in lakes and rivers in Ontario

2.2.3 Permit to Take Water (PTTW)

The Ministry of Environment (MOE) established the PTTW program in 1960 to conserve and protect Ontario's freshwater resources; to ensure fair sharing while minimizing competition among water users; to increase public knowledge of water taking activities; and to ensure water conservation initiatives are implemented by water users (Ministry of Environment, 2013e). The PTTW program requires that anyone withdrawing "more than 50,000 litres of water a day from a lake, river, stream or groundwater source" is obligated to have a PTTW (Ministry of Environment, 2013e). The MOE will reject permits if the proposed water extraction is expected to adversely impact Ontario's water resources. In order to ensure water conservation in Ontario, all permit holders are obligated to keep record of their daily water takings and report their totals to the ministry annually (Ministry of Environment, 2013e; Ministry of Environment, 2005).

Ontario golf courses were phased into this program between 2005 and 2007, and are therefore required to obtain a PTTW if they use more than 50,000 L of water each day to irrigation their turfgrass. Since golf courses have only recently been integrated into this program, water taking recordings are sporadic throughout the 2005 to 2007 reporting years. In addition, various golf courses in Ontario are excluded from this requirement due to grandfathering. Grandfathering exempts some golf courses, particularly very old golf courses, from adhering to the requirements of the PTTW program due to legal arrangements agreed upon before the PTTW program was established. Nevertheless, golf courses that have a PTTW are subject to specific terms and conditions regarding water taking activities, with particular restrictions occurring during low flow or drought periods.

In order to minimize adverse environmental impacts during drought periods, the MOE, in association with the Ontario Ministry of Natural Resources and several other associations, has developed a low water response program. This program has been developed “to ensure provincial preparedness… in the event of a drought” (Regional Operations Division, 2010). The Ontario low water response program has categorized drought severity, or “low flow” into three different classes, level I, II and III, each with its own drought response. During level I low water response, the MOE develops recommendations and targets for water taking reductions, however, golf course compliance is strictly voluntary. During a level II low water response, ways to reduce water use is broadcasted and compliance becomes slightly more regulated. Lastly, during a level III response, the MOE is fully authorized to restrict water taking for existing permits and to perform random inspections of the facility to check for compliance (Regional Operations Division, 2010). By enforcing water taking restrictions during low flow periods, the MOE protects Ontario’s freshwater resources. Golf courses that fail to comply with the rules of the PTTW program can be prosecuted by means of fines and permit cancellations (Ministry of Environment*,* 2013e).

Despite the good intentions of the PTTW program for Ontario golf courses, in 1999, the Environmental Commissioner of Ontario (ECO) criticized the PTTW program due to concerns regarding the self-reporting nature of the program, inconsistent and inaccurate descriptions of water sources and wrongfully reported water withdrawals. The ECO suggested that the PTTW program was not a reliable source of information, and that it should not be solely used to develop water taking trends and allotments (Environmental Commissioner of Ontario, 2001; International Joint Commission, 2000). In order to create golf course specific regulations on both a global and local scale, it is imperative that governments and the golf industry enforce reliable, accountable and accurate reporting mechanisms for all golf courses in order to establish a baseline of current water use. Although environmental agencies attempt to control and create sustainable water consumption regulations, there has yet to be a well defined, consistent and enforced approach to promote widespread water conservation on golf courses in Ontario (Carrow et al., 2007).

2.3 Golf and Water

Briassoulis (2010) conducted a study in Europe to better understand the public's perception of golf courses. The findings of this research suggest that there is a widespread negative public perception of golf courses, mainly as a result of high water use, as is demonstrated through the following statements from participants: "people cannot be left to die due to [a] lack of potable water while others will be playing golf!"; "golf courses, with their intensive water and herbicide use and association with elite groups of society, are clearly antithetical to the spirit of Crete"; "golf courses now try to keep green all through the year, even during the rainless summers of the Mediterranean, and use immense quantities of water and polluting chemicals"; and "unsustainable water use is environmentally unacceptable" (Briassoulis, 2010). It is uncertain if such public perceptions extend to other parts of the world. Nevertheless, the global golf industry must better inform the public of their actual water quantity and quality impacts and the improvements they have made over the last two decades.

2.3.1 Golf and Water Quantity Reductions

In 2004, it was estimated that 9.5 billion L of water was used each day to irrigate the world's golf courses (Wolbier, 2004). Although this estimation is published in a Worldwatch magazine, which focuses on international environmental sustainability, how robust this estimate is remains highly uncertain. The magazine does not provide any background information as to how this estimate was calculated, nor does it provide any sources to support its methodology. More recent studies have been conducted to estimate annual irrigation water consumption of golf courses in individual countries (Table 1.2). However, the number of studies conducted and the number of countries is limited, precluding an update of the 2004 estimate.

Table 1.2: Estimated Annual Irrigation Water Consumption for a Standard 18-hole Golf Course in Morocco, Spain, France, and the United States (US)

Studies and Supportive Literature	Year Analyzed	Annual Irrigation Water Consumption (Million L)	Country
+MEDSTAT II, 2009	2006	1,300	Morocco
Rodriquez-Diaz et al., 2011; Salgot et al., 2012	2011	320	Spain
Gössling et al., 2012	2012	200	Southern France
Throssell et al., 2009	2009	52	Northeast Region of US
		95	North Central Region of US
		298	Southeast Region of US
		566	Southwest Region of US
Gössling et al., 2012	2012	100	Northern France

+Assumes irrigation occurs 365 days a year therefore daily water use was multiplied by 365

The purpose of golf course maintenance is to uphold healthy, firm and aesthetically pleasing turf. In order to do so, irrigation, in the form of either natural precipitation or sprinkler systems, must be applied to the turfgrass. Irrigation quantity is influenced directly by climatic variables, such as temperature, wind, relative air moisture and rain, as well as soil type and golf course size. In general, sandy soils require more frequent irrigation, and thus a greater quantity of water, than clay soils due to faster drainage and infiltration rates (Gössling et al., 2012; Tapias and Salgot, 2006). Reducing the overall amount of irrigation is sometimes practiced and referred to as deficit irrigation, however, this can lead to turfgrass diseases and salt imbalances (Tapias and Salgot, 2006). As an alternative to deficit irrigation, golf courses incorporate several water sources, such as reclaimed wastewater and rain/runoff water as primary sources for irrigation (Foy, 2006; Hawes, 1997; Rodriguez-Diaz et al., 2007; Snow, 2001; Tapias and Salgot, 2006; Waltz et al., 2002). Although incorporating several water sources does not reduce the overall water quantity applied to the course, it does preserve existing freshwater resources and reduces competition among water users (Fraser River Action Plan, n.d.; Gartner Lee Limited, 2001; Gössling et al., 2012). There are several attainable BMPs golf courses can voluntarily implement in order to decrease the overall demand for water, thus reducing irrigation water consumption. Water conservation BMPs include, but are not limited to:

1. *Integrating drought-tolerant turfgrass*: reduces water requirements as these turfgrasses can withstand drier conditions with minimal damage.
2. *Utilizing existing native vegetation*: reduces water requirements as the vegetation is acclimatized to the local climate and weather conditions.

3. *Harvesting rainfall and/or stormwater*: reduces dependency on freshwater resources and reduces competition among freshwater users.
4. *Incorporating multiple water sources for irrigation*: reduces dependency and extraction rates from freshwater resources, especially during times of drought and low water flow.
5. *Applying wetting agents*: increases soil moisture for an extended period of time, reducing irrigation requirements.
6. *Performing irrigation audits:* improves irrigation distribution efficiencies, which may allow for a reduction in irrigation frequency and/or quantity.
7. *Using soil moisture sensors*: reduces overwatering by measuring and optimizing soil moisture.
8. *Optimizing irrigation scheduling*: improves the probability of successful target irrigation if scheduled during the early morning or late night, thus decreasing wasteful and excessive irrigation.
9. *Practicing soil cultivation techniques*: improves the ability of water to infiltrate the soil thus improving soil moisture and decreasing irrigation requirements.
10. *Integrating hand-watering practices*: increases irrigation efficiency by target irrigation thus reducing overwatering and large-scale saturation.
11. *Practicing appropriate fertilizer management*: reduces the water needs of the turf and improves drought and disease resistance.
12. *Installing efficient irrigation systems:* reduces water use by increasing the proficiency of the irrigation system to ensure water reaches designated turf areas.

13. *Practicing "Maintenance Up the Middle":* restricts irrigation in the rough and in out-of-play areas thus reducing irrigation application.
14. *Increasing education of turfgrass managers.*

(Compiled from: Carrow and Duncan, 2007; DaCosta and Huang, 2006; Fraser River Action Plan, n.d.; Gartner Lee Limited, 2001; Hartwiger, 2012; Mccarthy, 2006).

The studies in Table 1.3 have concluded that incorporating water conservation strategies, such as those listed above, can reduce water usage and maintenance costs, as well as create additional environmental benefits on the golf course. Often, the more water conservation strategies implemented, the greater the savings and environmental benefits (Carrow et al., 2007; Gartner Lee Limited, 2001; Mccarthy, 2006). As previously mentioned, the simplest way to reduce irrigation water consumption is to practice deficit irrigation, which is "… deliberate under-irrigation of a plant to below its maximum potential water demand" (DaCosta and Huang, 2006). DaCosta and Huang (2006) performed a regional study in the United States that found certain types of drought-tolerant turfgrass cultivars to persevere and maintain a higher turf quality than other turf types during deficit irrigation. The outcome of pairing an appropriate turf type with deficit irrigation is possible irrigation savings of 20-40% in the summer and 60% in the fall (DaCosta and Huang, 2006). However, deficit irrigation can lead to an increase in turf disease and an imbalance of salt in the soil if improperly managed.

Incorporating modified turfgrasses can also lead to a 50% reduction in irrigation requirements since modified turfgrasses often have a high tolerance to drought and drought injury, salt imbalances, and low temperatures (Cisar, 2004). Additionally, modified turfgrasses often maintain below normal growing heights and have fewer nutrient requirements than traditional turfgrasses thus, maintenance requirements and costs are reduced (Cisar, 2004; Foy, 2006; Fraser River Action Plan, n.d; Moeller, 2013).

Additional reductions in irrigation water consumption are obtainable by incorporating soil moisture sensors and wetting agents into management techniques. The use of soil moisture sensors informs superintendents when irrigation is needed based on quantitative measurements of soil moisture in the root zone. Using this technique to assess irrigation requirements has proven to reduce water usage from a minimum of 20% to a maximum of 95% on select turfgrasses, while also improving the health and quality of the turf (Augustin and Snyder, 1984; Bremer and Ham, 2003; Peister, 2012). The use of wetting agents, particularly during a dry season, can reduce irrigation requirements by up to 50% and increase the overall turfgrass health by promoting photosynthesis, soil moisture and turf growth (Cisar, 2004).

Investing in water conservation strategies is beneficial for the golf industry as it can generate large-scale cost savings. Reducing overall irrigation can occur by naturalizing golf course areas, practicing deficit irrigation and/or practicing "maintenance up the middle" (Hartwiger, 2012). Incorporating naturally occurring features, such as native grass fescue and environmentally sensitive areas, and practicing "maintenance up the middle" reduces the overall managed/maintained area of the golf course, while deficit irrigation reduces water use and tends to reduce turfgrass growth. By minimizing the total irrigated area and reducing turfgrass growth, long-term cost savings are expected due to lower labour costs, reduced fuel costs, and reduced upkeep costs of maintenance equipment. Additionally, energy costs are reduced when irrigation pumps are used less often and/or for shorter periods of time. Therefore, reducing overall irrigation water consumption results in greater golf course profitability (Air Force Center for Engineering and the Environment, 2008; Augustin and Snyder, 1984; Cisar, 2004; Foy, 2006; Gartner Lee Limited, 2001; Hartwiger, 2012; Kiss, 1998; Mccarthy, 2006; Minoli and Smith, 2011; Moeller, 2013; Mitra et al., 2006; Osborn, Letey and Valoris, 1969; Park, Cisar, McDermitt, Williams, Haydu and Miller, 2005; Terman, 1997).

Table 1.3: Best Water Management Practices and the Associated Environmental Benefits

Studies and Supportive Literature	Best Water Management Practice	Environmental Benefits
(Mccarthy, 2006; Tapias and Salgot, 2006; Terman, 1997)	Incorporating natural features of the landscape	• Preserves plant, animal and ecosystem diversity • Reduces the amount of irrigation, fertilizers, pesticides and maintenance needed
(Carrow and Duncan, 2007; Mccarthy, 2006)	Incorporating drought-tolerant turfgrass	• Aids in water resource protection • Reduces the amount of water and maintenance needed
(Carrow and Duncan, 2007; Mitra et al., 2006; Park et al., 2005; Osborn et al., 1969)	Wetting agents	• Increases soil moisture content for longer periods of time, reducing irrigation needs thus aiding in the preservation of freshwater resources
(Carrow and Duncan, 2007; Mccarthy, 2006; Mitra et al., 2006)	Soil cultivation techniques	• Improves the ability of water to infiltrate the soil thus decreasing runoff (and possible contamination) and irrigation requirements
(Carrow et al., 2007; Tapias and Salgot, 2006)	Appropriate irrigation design and cycle	• Improves irrigation efficiency thus decreasing water waste and preserving freshwater resources
(Tapias and Salgot, 2006; Winter and Dillon, 2005)	Irrigating with effluent and stored stormwater	• Protects freshwater resources • Reduces nutrient outputs to surrounding streams
(Snow, 2001)	Design	• Decreases water-demanding landscapes, on-course flooding potential, runoff and erosion potential thus protecting natural landscapes and ecosystem components from contamination
(Augustin and Snyder, 1984; Bremer and Ham, 2003; Peister, 2012)	Soil Moisture Sensors	• Reduce over watering, improve irrigation efficiency and protect freshwater resources; can result in irrigation savings of 20% to 95%
(Davis and Lydy, 2002)	Minimizing chemical application	• Improves soil and water quality, decreases contaminated runoff and improves taxa richness in nearby water bodies
(Davis and Lydy, 2002; Winter and Dillon, 2005)	Maintaining vegetated buffer systems	• Runoff is diluted and filtration is increased which reduces nutrient concentrations and total suspended solids in surrounding water bodies

Integrating BMPs and VEPs has the potential to reduce management and maintenance costs while also reducing negative environmental impacts. It is also possible that implementing BMPs will enhance a golf course's reputation as an environmentally friendly business, which can lead to an increased number of customers and a stronger bottom line (Minoli and Smith, 2011). Although there is a lack of studies that demonstrate the relationship between reduced irrigation water consumption and cost savings, the importance of reducing irrigation water consumption is apparent. Since the golf industry is currently experiencing economic hardships in North America, it is more important than ever for the industry to become more economically efficient (HSBC, 2012; National Allied Golf Associations, 2012). Furthermore, the golf industry is expected to undergo further challenges in many regions due to climate change. Climate change could pose a threat to preexisting environmental protection advancements, particularly with regards to irrigation water consumption. In order to prepare for these climate shifts, it is essential that the golf industry has a more comprehensive understanding of their current water use profiles and water conservation strategies in order to mitigate future impacts of climate change and increased water use competition with other users.

2.3.2 Golf and Water Quality Improvements

With regards to water quality, golf course turfgrass absorbs pollution, such as pesticides, chemicals, dust and fertilizers, from water resources and stores the pollution in the soil for future decomposition. Due to the unique root system of turfgrass cultivars, the turfgrass ecosystem is high in microbial biomass, having up to 42% more microorganisms than other plant-soil ecosystems such as grassland, cropland and/or forests (Beard and Green, 1993). This creates a unique environment for filtering and cleansing water not only from the golf course, but from surrounding areas as well. The natural ability of the turfgrass to filter the water results in enhanced groundwater quality (Beard and Green, 1993; Bruneau et al., 2005). In addition to filtration benefits, golf course turfgrass protects soil from wind and water erosion (Beard and Green, 1993; Carrow et al., 2005), reduces urban runoff (Beard and Green, 1993; Carrow et al., 2005; Ling, 1992), and can possibly reduce fire hazards due to the "low fueling" characteristics of turfgrass (Beard and Green, 1993). Although Beard and Green (1993) suggest golf courses can reduce fire hazards, it is likely that the turfgrass on golf courses will only slow down the spreading process of advancing wildfire. Wet detention ponds are another aspect on the golf course that improves water quality. When incorporated into the design of the golf course, stormwater and runoff can be captured and stored short term in wet detention ponds. Short-term storage of stormwater and runoff allows for up to 90% of unwanted particulate found in the water column to be removed thereby improving water quality (Fraser River Action Plan, n.d.).

2.3.3 Estimated Annual Golf Course Irrigation Water Consumption

Golf courses globally are considered to be recreational and tourism land uses, without regard for the wide scale benefits of employment opportunities, economic activity and ecological preservation. As is discussed in section 2.3.1 and in Table 1.2, the number of countries, and the number of studies conducted, to estimate annual golf course irrigation water consumption is very limited. The lack of current water use profiles is preventing the golf industry from comparing their annual water use and economic value generated per unit of water to other water-intensive industries and thus, the public perception remains that the golf industry is a very water-intensive industry. The number of golf courses improving the efficiency in which water is distributed on the golf course is increasing annually, which is demonstrated through innovative golf course design and new sustainable management techniques (HSBC, 2012). Golf courses that are able to distribute water more efficiently are preserving freshwater resources by eliminating waste and reducing overall water needs on the golf course (Carrow, Wienecke and Duncan, 2005; HSBC, 2012). If the global golf industry wants to minimize the negative public perceptions of golf, the industry must conduct more studies to estimate annual irrigation water consumption to allow for comparisons between current and future water use. This will allow the golf industry to show how water use reductions are possible through the integration of BMPs.

2.4 Climate Change and Golf in Canada

Climate change is a term that is commonly known, used and integrated in discussions between the general public, governments, academics and scientists. The Intergovernmental Panel on Climate Change (IPCC) (2013) defines climate change as "a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or variability of its properties, and that persists for an extended period, typically decades or longer". As climate change science further develops, many public and private sectors are developing mitigation and adaptation plans to prepare for expected impacts of higher maximum and minimum temperatures, increased frequency of warm spells, increased precipitation, increased drought events, changes to tropical cyclone patterns, and sea level rise (IPCC, 2013). Since the 1950s, the global average of carbon dioxide (CO_2), methane (CH_4), and nitrate (N_2O) has increased exponentially, thereby impacting physical and biological aspects of the earth in both positive and negative ways. The IPCC (2013) suggests that the rapid and extreme fluctuations in temperature we are observing today are due to the rapid increase of CO_2, CH_4 and N_2O.

Golf courses encounter changes to weather on a daily basis. Weather refers to the atmospheric state, including temperature, humidity, evapotranspiration and wind conditions in a particular location (Aguado and Burt, 2010; IPCC, 2013). Based on daily weather changes, superintendents of golf courses alter management practices to meet the needs of the golf course (SGEG, 2004). This involves shortening or lengthening an irrigation cycle, aerating the turf to increase infiltration rates or even applying fertilizer to provide extra nutrients to the turf. In comparison to short-term daily weather, the term climate refers to expected or typical conditions averaged over a period of time in a particular location (Aguado and Burt, 2010; IPCC, 2013). When it comes to golf course management, climate variability is the one uncontrollable factor having the greatest effect on the condition of the golf course (SGEG, 2004).

In order to prepare for climate change, golf course management practices have to be adaptable and flexible, and both proactive and reactive (SGEG, 2004). This means that individual golf courses will have to predict climate change impacts and create management strategies to mitigate these predicted impacts. The SGEG (2004) suggests that golf courses should consider impacts that could occur to the greens, fairways, tee decks, rough and bunkers and create several management strategies that will be proactive and reactive in mitigating the impacts. Management strategies could include creating drainage and irrigation plans, integrating appropriate turfgrass on the golf course and creating suitable disease, pest and fertilizer management programs (SGEG, 2004). Creating and integrating these plans will quite possibly require research, technological upgrades, retrofitting, greater time investments and possibly consultation services that will increase the golf course's short-term expenditures but reduce their long-term vulnerability to climate change. Although these management strategies can be adopted to reduce negative impacts, climate variability can still uncontrollably create "brown fairways, [bake] greens and [create] more firm conditions" (Agostini, 2014).

In Canada, climate change is expected to change water quality, quantity and availability; plant productivity; ecosystem health; and the distribution of animal species (Cohen and Waddell, 2009; Lemmen et al., 2008). As stated in the Government of Canada report, "From Impacts to Adaptation: Canada in a Changing Climate 2007", future predictions of climate change suggest an increase in climatic variability, particularly with regards to changes in average temperature, evaporation rates, soil moisture and precipitation rates. It is expected that more areas throughout Canada will become water-stressed as a result of this climatic variability. The expected water shortage will intensify the need to better manage water resources, since many sectors including agriculture, energy production, tourism and recreation will be sharing and competing for a reduced supply of freshwater (Lemmen et al., 2008; Rodriquez-Diaz et al., 2011). Globally, climate change is pushing the golf industry to adopt new golf course management strategies (Rodriguez-Diaz et al., 2011; Rodriguez-Diaz et al., 2007; SGEG, 2004). As a water-intensive industry, it is important that the Canadian golf industry better understand how changes to average temperature and precipitation rates may influence the environmental and economic sustainability of the industry.

2.4.1 Predicted Changes to Average Temperature and Its Impact on Canadian Golf

Between 1950 and 2010, the average national temperature of Canada warmed by 1.5°C (Vincent, Wang, Milewska, Wan, Feng and Swail, 2012). A2 climate change projections suggest that over the next 80 years and beyond, temperatures will continue to rise if mitigation efforts are unsuccessful, with particular warming occurring in the northern provinces during the winter and spring months (Colombo et al., 2007; IPCC, 2013; Lemmen et al., 2008; Vincent et al., 2012). In Ontario, A2 predictions suggest an increase in extreme weather events such as heat waves and smog episodes; ecological changes; an increase in summer temperatures by up to 6°C; an increase in evaporation rates; decreased groundwater recharge; reduced soil moisture during the summer months and reduced water levels in the Great Lakes (Colombo et al., 2007; de Loë and Berg, 2006; Lemmen et al., 2008).

The golf industry is particularly vulnerable to changing weather patterns with respect to average daily golf participation rates. Both above and below normal temperatures have been shown to reduce daily rounds if the golfers find it too hot or too cold (Farrally et al., 2008, Minoli and Smith, 2011; Scott and Jones, 2007). In Canada, as is discussed by Scott and Jones (2007), the number of daily rounds played begins to decline at temperatures above 30°C and below -6°C, and at wind speeds greater than 20kph. Above normal seasonal temperatures also hinder golf course aesthetics and playability by hardening the putting surfaces and browning the turfgrass (Farrally et al., 2008). Furthermore, since golf is an outdoor recreational activity, daily temperatures highly influence the season length of golf. Climate change that will result in warmer weather throughout the summer season will likely extend the Ontario golf season (Scott and Jones, 2007; Scott and Jones, 2006; WeatherBill Incorporation, 2007). The current season length for golf courses in Ontario is roughly six months, lasting from May to October. In southern Ontario, where golf course density is greatest, warming summer temperatures are expected to lengthen the golf season by up to seven weeks by 2020 and by up to 12 weeks by 2050 (Scott and Jones, 2007). An increase in season length will be paired with an increase in annual rounds and thus, an increase in golf course revenue; a seven-week increase in season length is expected to result in a 23% to 37% growth rate while a 12-week increase is expected to result in a 27% to 61% growth rate in annual rounds (Scott and Jones, 2007).

While climate change predictions are spatially variable, several studies conducted by Assel, Quinn and Sellinger, (2004); Cohen and Miller, 2001; de Loë and Berg (2006); Fernandes, Korolevych and Wang, (2007); Kling, Hayhoe, Johnson, Magnuson, Polasky, Robinson…Wilson (2003); Lofgren, Quinn, Clites, Assel, Eberhardt, and Luukkonen (2002); and Mortsch, Hengeveld, Lister, Lofgren, Quinn, Slivitzky and Wenger (2000) suggest that the water levels in the Great Lakes will decline in the future due to warmer temperatures and greater evaporation rates. In southwestern Ontario, an increase in 1°C in average temperature is associated with a 7% to 8% increase in actual evapotranspiration rates (Fernandes et al., 2007). It is therefore believed that southern Ontario will face drought and dry conditions particularly during the summer months, despite the current abundance of freshwater resources (Mortsch et al., 2000).

Turfgrass that does not receive ample irrigation (either artificial or natural) will enter a dormant state. Turfgrass in a dormant state is especially vulnerable to disease and weed infestation as grassless pores in the soil expand to increase nutrient and water uptake (Barratt et al., 2000). Failure to meet the increased water needs of the golf course due to reduced water availability or rigid regulations regarding water use will likely reduce golf course playability because of hardened playing surfaces; reduced turf and vegetation productivity; increased weed infestation; increased turf stress; and more shallow root zones. If golf course superintendents attempt to maintain an aesthetically pleasing golf course during summer droughts in order to sustain annual rounds, irrigation water consumption rates could be pushed well beyond current water use levels, thus making golf course maintenance uneconomical. The extent of additional irrigation needs under climate change remains an important uncertainty.

2.4.2 Predicted Changes to Precipitation Rates and Its Impact on Canadian Golf

During the last half-century, precipitation rates in Canada increased by 12%, making the country, on average, wetter; however, the increased precipitation mainly occurred in northern Canada while southern Canada experienced decreased precipitation rates (IPCC, 2013; Lemmen et al., 2008, Mekis and Vincent, 2011). A2 Climate change scenarios suggest that by 2050, precipitation rates are expected to decrease during the summer and fall months by up to 10% in southern Ontario, and increase during the winter months by up to 10% in the south and up to 50% in the north (Lemmen et al., 2008). However, as discussed in the previous section, section 2.4.1, when paired with elevated average temperatures, the likelihood of enhanced evaporation is highly probable. Reduced precipitation and increased evapotranspiration will reduce the soil moisture content thereby increasing the crop water demand (Laporte, Duchesne and Wetzel, 2002). de Loë and Berg (2006) suggest that during the 21st century in the Great

Lakes basin, soil moisture will likely increase by up to 80% during the winter months and decrease by up to 30% during the summer and fall months.

Golf courses that receive below normal precipitation will experience moisture deficit, encounter low water levels in golf course water features and have a reduced level of water availability. Due to the PTTW program, as discussed in section 2.2.3, golf courses in Ontario may be requested to reduce or discontinue irrigation as a result of reduced water availability. It is during these drought periods, however, that irrigation need is highest and failure to irrigate can result in long-term turf damage. Summer droughts frequently result in decreased turf and vegetation productivity, browning turfgrass, hardened putting surfaces and thus, reduced playability. Reduced aesthetics of the golf course due to summer drought can reduce the overall enjoyment for golfers which extends to a decrease in the number of annual rounds played (Rodriquez-Diaz et al., 2011).

During the 20th century, the IPCC (2013) observed an increase in the frequency of heavy precipitation events, especially over the Northern Hemisphere. Golf courses receiving high amounts or excessive precipitation are likely to experience physical damage, including degradation of turf quality and aesthetics of the golf course; soil compaction; erosion of soil and turf; reduced soil health; reduced root density; damages to infrastructure; submersion injury, which is turf damage as a result of prolonged submersion; soil deposition, which can result in long-term drainage problems; an increased likelihood of turf disease and pests; and even course closures (Farally et al., 2008; Hartwiger, 2000; Minoli and Smith, 2011; SGEG, 2004). From an economic standpoint, the physical impacts from excessive precipitation will likely increase golf course expenditures in order to repair golf course damage (Cyr, Kusy and Shaw, 2010). Furthermore, golf course revenue will likely decline due to the excessive precipitation reducing the number of annual rounds (Cyr et al., 2010). Scott and Jones (2007) found that a rainy spring in 2002 reduced golf rounds in Ontario by 20% from the previous year, and that the number of golf rounds in Canada could decrease by as much as 45% if average daily precipitation rates reached 5mm to 10mm during the day. Due to the various climate change predictions, it is imperative that the Canadian golf industry, and more specifically the Ontario golf industry due to its high golf GDP, understands the potential climate-induced impacts and understands their current water use profiles in order to mitigate the impacts in a sustainable and profitable manner.

2.5 Summary of Literature

The global golf industry is regionally important in terms of employment and economic activity. In Canada, Ontario generated 38.7% of Canada's golf GDP in 2009, the majority of which was generated in the densely populated southern Ontario region (SNG, 2009). The golf industry has faced criticisms regarding the unsustainable management and use of freshwater for irrigation purposes and for the potential environmental damage golf course development and management can have on ecosystems and environments. In response to these criticisms, the Ontario golf industry has invested in research that has led to more sustainable management practices that reduce the use of chemicals on the golf course, reduce irrigation water consumption and preserve greater natural areas. Furthermore, the Ontario golf industry, with support from scientific studies, universities, golf agencies and governments, are producing educational material and reports to inform the public of sustainability initiatives that reduce irrigation water consumption and protect the natural environment. Much of the environmental protection initiatives are voluntary, such as VEPs, BMPs and the ACSP. However, there are Federal and Provincial Acts and Regulations, such as the Permit to Take Water program in Ontario, which regulates golf course development and management and aids in environmental protection. Although the purpose of the PTTW program is to aid in the conservation of Ontario's freshwater resources, the ECO has publicly criticized the validity and accuracy of the program, suggesting that water withdrawals are being recorded inaccurately. It is believed by the ECO that the MOE staff are making major decisions regarding Ontario's water use based on improper data.

A particular focus for the golf industry is sustainable irrigation water consumption. This is not only due to public scrutiny regarding large water use, but also due to the numerous management practices available that can reduce water use while also improving golf course ecology, enhancing beneficial relationships between golf and the environment and reducing golf course expenditures. Irrigation water consumption is mainly reduced via voluntary BMPs that are implemented based on a site-specific analysis. It is important to understand the performance of BMPs in order to maximize water savings and advance environmental protection. Although there are environmental protection initiatives in place in the golf industry, climate change is expected to push past the economic benefits of increased season length and thus increased revenue and create economic hardships within the Ontario golf industry. Climate change is likely to increase the crop water demands of turfgrass, increase operating and labour costs and reduce golf course aesthetics and playability (Hartwiger, 2012; Scott and Jones, 2007).

Chapter Three: Methodology

3.1 Introduction

An extensive literature review, presented in Chapter Two, identified sustainability initiatives, both voluntary and mandatory, that are in place that regulates irrigation water consumption on golf courses both globally, and in Ontario. A variety of secondary data were obtained from online public sources and the MOE's Permit to Take Water program, which enabled the remaining research questions, two through four, to be addressed. The following sections discuss how the water taking data, golf course area and biophysical golf course characteristics were collected and processed. Finally, the methods used to calculate average annual water use and potential water savings for Ontario golf courses and data limitations are discussed.

3.2 Water Taking Data Collection

In 1960, the Ministry of Environment developed the PTTW program. However, Ontario golf courses have only recently been phased into this program (Ministry of Environment, 2005). Since 2007, golf courses that take more than 50,000 L of water per day are required to record their daily water takings (in L) and report both their daily water takings and their total annual water taking once every calendar year to the MOE (Ministry of Environment, 2005). The PTTW database, which is available online through the MOE's data downloads website (http://www.ene.gov.on.ca/environment/en/resources/collection/data_downloads/index.htm#PTTW) includes the permit number, the major water taking category (i.e. commercial, agriculture, industrial, etc.), the specific purpose water taking category (i.e. golf course irrigation, aquaculture, campgrounds, etc.), the water taking type/source (i.e. ground or surface water), the location of water extraction (i.e. an irrigation pond(s), well, creek, river, reservoir, etc.), the date the permit was issued, the date the permit will expire, the organization/client name and the municipality in which the organization is located. However, actual water taking data is not available online.

In order to create a baseline dataset of current irrigation water consumption for golf courses in Ontario, annual water taking reports were obtained as secondary data from the MOE's PTTW program. In order to obtain the water taking data for all golf courses in Ontario, a Freedom of Information (FOI) request was submitted to the Freedom of Information and Protection of Privacy Office in Toronto, Ontario. In this case, the requested dataset included total annual water taking data for all Ontario golf courses with permits from 2007 to 2012. Since water taking reporting occurs only once a year in March, the MOE has a lag time of one year in reporting. Therefore, at the time of the data collection process in 2013, the most recent water taking data available was for 2012. After the Freedom of Information and Protection of Privacy office confirmed the request, and the PTTW records were compiled by the MOE, the data was loaded onto a CDROM and mailed to the researcher.

The data obtained by the MOE's PTTW database included the golf course/organization name and its associated self-reported annual water taking total, permit number, municipality, number of water taking days and the effective date and expiry date of its permit, for all golf courses in Ontario, from 2007 to 2012, with active permits. Although the online database indicates the exact location of water taking, for example well #1 or ponds 4 and 5, and the water taking type/source, such as ground or surface water, for each golf course with a permit, the PTTW records obtained from the MOE for this research did not include these identifiers. Since the location and type of water extraction was excluded for each golf course in the sample size, the researcher was unable to say with complete certainty that the water withdrawn was strictly for irrigation purposes and not also for water use in golf course facilities (i.e. potable water for guest services, bathrooms, etc.). It is therefore believed that further research is required to identify if the water withdrawn for the special purpose of golf course irrigation is strictly for golf course irrigation or if it includes all water use for the golf course.

The PTTW program is based on issued permits, which have an effective date and an expiry date. During the period of 2007 to 2012, several permits were issued and expired. In 2007, 351 golf courses had permits and by 2012, this number increased to 600 (Table 2.1). Due to the expiration dates of the permits, some of the golf courses in the database have 6 years of water takings recorded while some only have one or two years of water takings recorded. Furthermore, various golf courses in the sample size reported their water takings for one year but failed to report their water takings the next year, while their permit was still effective. This suggests that there is missing data within the PTTW dataset. Although there is missing data within the dataset, the percent of golf courses complying with the PTTW program is quite high, as is shown in Table 2.1. Since golf courses have only recently been integrated into the PTTW program and reporting compliance is high, the MOE does not respond to non-compliance in an aggressive manner, which means that fines are not normally given to golf courses that fail to report water use. Instead, the MOE encourages non-compliant golf courses to recommit to the program voluntarily (Schraeder, 2014).

Table 2.1: The Number of Golf Courses in the Permit to Take Water Database (2007 to 2012)

	2007	2008	2009	2010	2011	2012
Number of Golf Courses in the PTTW Database	351	478	582	620	643	600
Number of Golf Courses in the PTTW Database with Recorded Water Takings	310	434	517	543	563	550
Percent Compliance	86%	91%	89%	88%	88%	92%

Compiled from the PTTW Database

One last aspect of the PTTW program that is worth mentioning, which was also criticized by the ECO, is what appears to be its lack of awareness regarding water availability and quantity when issuing and renewing permits (Environmental Commissioner of Ontario, 2001). The ECO strongly believes that "ecosystem protection may be threatened because MOE staff are issuing permits for new water takings without access to fully complete or accurate information on existing water takings" (Environmental Commissioner of Ontario, 2001). It is therefore believed that the general purpose of the PTTW program, which is to protect Ontario's freshwater resources, is not being upheld due to inaccurate reporting of water withdrawals.

3.2.1 Water Taking Data Processing

The data obtained from the PTTW database was formatted in Excel. Several steps were taken to create the final sample size for this thesis. As is shown in Table 2.1, in 2007, 351 golf courses were in the PTTW database, however, only 310 of these golf courses had recorded water takings. The first step in creating the sample size, which is based on the number of golf courses in the PTTW program in 2007, was to remove the 41 golf courses with missing data from the sample size. The second step was to identify which of the 310 golf courses had active permits throughout the time span of 2007 to 2012. Although each year more and more golf courses join the PTTW program, in order to have a consistent sample size with the same group of golf courses from 2007 to 2012, each golf course in 2007 had to be identified in the subsequent years to be included in the sample size. If a golf course was removed from the program during the time span of 2007 to 2012 due to permit expiration or non-compliance, it was removed from the sample size.

Due to permit expiration dates and non-compliance, several of the 310 golf courses in 2007 failed to report water takings in each of the subsequent years and were therefore removed from the sample size. This second step reduced the sample size from 310 golf courses to 192 golf courses. The 192 golf courses remaining were analyzed to identify if there was any unreliable water taking data. Golf course water taking data was considered to be unreliable by the researcher if:

- The number of water taking days exceeded 300, which is far longer than the golf season in Ontario, and therefore the water takings could not strictly be for golf course irrigation but also for facilities on the golf course;
- The golf course/organization name was unrecognizable or coded, for example "*1097739 Ontario Limited*", thereby preventing the identification of its location and characteristics such as age, soil type and golf course type; and
- The total annual water taking outliers far exceeded the lowest or highest values of the sample (i.e. if the difference in water use between the minimum value and the maximum value was greater than 500%).

Excluding the outliers and unreliable data reduced the sample size from 192 golf courses to 132 golf courses. The last step in creating the sample size occurred after golf course characteristics were identified and the climatically normal and dry seasons for golf courses in Ontario was completed (this process is discussed in section 3.4 and 3.4.1). Once the golf courses were separated into their climate locations and the climatically normal and dry seasons for each location were identified (Table 2.8 in section 3.4), the sample size was manipulated to exclude golf courses that had missing water taking data for their normal and dry seasons. This step had to be completed so that water use could be compared among climatically normal golf seasons and climatically dry golf seasons for a consistent group of golf courses. Identifying the climatically representative seasons also identified regions in Ontario that did not need water taking data for the 2007 year. Climate stations that did not need 2007 water taking data included the Barrie, Ottawa, Petawa, Sudbury, Thunder Bay and Windsor climate stations. This allowed 13 golf courses that were removed from the sample size initially, due to missing water taking data in 2007, to be added to the sample size since their water taking data during the climatically representative seasons was complete and reliable.

This final step removed 16 golf courses and added 13 golf courses, changing the sample size from 132 to 129. The finalized sample size of 129 golf courses was used for all the analyses of this thesis. Table 2.2 identifies the 40 regions, and the number of golf courses within those regions, that the golf courses in the sample size are located in.

Table 2.2: The Distribution of Golf Courses in the Sample Size

Region	Number of Golf Courses	Region	Number of Golf Courses	Region	Number of Golf Courses
Algoma	1	Huron	2	Peel	7
Brant	1	Kawartha Lakes	1	Perth	1
Brantford	1	Lambton	5	Peterborough	2
Bruce	2	Lanark	1	Prince Edward	2
Chatam-Kent	3	Leeds and Grenville	1	Renfrew	3
Elgin	1	Lennox and Addington	1	Simcoe	10
Essex	3	Middlesex	7	Stormont, Dundas and Glengarry	1
Frontenac	1	Muskoka	5	Sudbury	3
Greater Sudbury	1	Niagara	4	Thunder Bay	1
Haliburton	1	Norfolk	3	Toronto	7
Halton	5	Northumberland	3	Waterloo	6
Hamilton	4	Ottawa	6	Windsor	2
Hastings	2	Oxford	4	Wellington	5
				York	10

3.3 Golf Course Area Data Collection

To compare water use among golf courses in this study, golf course area was calculated for each golf course. This enabled all golf courses in the sample size, which included 9, 18, 27 and 36-hole golf courses, to have their total annual water use (in L) be averaged on a per hectare basis.

The area of each golf course in the sample was calculated using two sources: 1) the municipal property assessment corporation (MPAC, 2013) website, https://www.aboutmyproperty.ca; and 2) Google Earth Pro. The MPAC program allowed the researcher to search each golf course property. Once identified on a satellite image, the property was delineated and the area was calculated. Google Earth Pro was used when MPAC included large regions of non-golf course property in the total area, such as forests or adjacent fields, in order to calculate strictly golf course area that is likely irrigated. Google Earth Pro allowed the researcher to create a perimeter around the golf course property that is likely irrigated (i.e. tees, greens, fairways, rough, clubhouse property, etc.). Based on the chosen perimeter, the area was automatically calculated by Google Earth Pro.

3.3.1 Golf Course Area Data Processing

Once the area of all the golf courses in the sample size was calculated, the total annual water use, provided by the PTTW database, was changed from L/yr to L/Ha.

3.4 Golf Course Characteristics Data Collection

The golf course characteristics examined in this study included the soil type, the age, the golf course type and premier status (those golf courses in the sample that are ranked in the top 100 golf courses in Ontario), the location, and the average seasonal temperature and average seasonal precipitation for individual golf courses in the sample. Soil types were identified using scholars geoportal via the University of Waterloo website. The geoportal map was manipulated to include two data layers: Ontario's soil survey complex and Canadian golf courses. Each golf course in the study sample was individually searched on the map, and once located, the dominant soil type for that location was identified based on the soil survey complex. Due to the inability to locate five of the 129 golf courses in the geoportal program, soil types were only recorded for 124 of the golf courses in the sample. Further analysis with a USDA textural triangle (or soil type triangle) enabled the researcher to categorize the soil types into sand, silt and clay dominated soils (Ward and Trimble, 2004, p.56). Sand dominated soil included soils made of fine sand, sand, sand gravel, clay sandy loam, sandy loam, fine sandy loam and very fine sandy loam. Silt dominated soil included soils made of loam, organic loam, gravel loam, silt loam, organic silty loam, silty clay and silty clay loam. Clay dominated soil included soils made of clay and clay loam.

The number of holes, golf course type (including premier ranking), age and estimated season length (based on the location of the golf course) were gathered from the online resources of World Golf (2013) and Golf Max (2013) for each individual golf course. However, since this data was gathered via online resources, some data was unavailable (Table 2.3).

Table 2.3: Missing Golf Course Characteristics Within the Sample Size

	Soil Type	Age	Number of Holes
Missing Data for '*x*' Number of Golf Courses	5	26	1
The Altered Sample Size for Individual Analyses	124	103	128

The average seasonal temperature and average seasonal precipitation data was collected for the sample years 2007 to 2012 from 19 climate stations in the study area (Table 3.1 and 3.2 in section 4.2.1) for the length of the golf season (May 1st to October 31st). The climate data included mean daily maximum temperature (°C), mean daily minimum temperature (°C), mean daily temperature (°C), and total precipitation (mm) for the years when water data was available. In addition, climate normals, or meteorological averages observed over a long period of time, from 1981-2010 were collected (Kin-wai, 2012). The climate normals enabled the researcher to indicate two years during the 2007 to 2012 study period at each of the climate stations that had an average temperature and average precipitation most similar and most dissimilar to the 1981-2010 data. These years were categorized as a climatically normal season (most similar) and a climatically dry season (most dissimilar).

3.4.1 Golf Course Characteristics Data Processing

To identify characteristics that influence golf course water use in Ontario, the golf courses in the sample size were classified, along with their associated water use, based on their individual characteristics. For example, golf courses comprised of sand dominated soils were separated from golf courses comprised of clay and silt dominated soils, and their average seasonal water use (in L/Ha) and percent difference in water use from a climatically normal season to a climatically dry season was recorded. This process was replicated for each characteristic of soil type, age, golf course type and premier status. The location of the golf courses was identified to estimate the season length at each golf course in order to identify if season length plays a role in how much water is used each season. However, the season length for 55 golf courses was unidentifiable through online resources. In addition, the estimated season length for golf courses in southwestern, central, eastern and northern Ontario had very similar season lengths, suggesting that golf courses across Ontario have similar growing seasons (Table 2.4, 2.5, 2.6 and 2.7). Because of missing data and the limited variability in season length, season length was not considered to be an important determinant in water use and therefore water use was not further analyzed.

Table 2.4: Estimated Season Length of Golf Courses in Southwestern Ontario

Region	Total Average Annual Water Use L/Ha from 2007-2012	Estimated Season Length	Number of Golf Courses in the Region
Brant	741,523	210	1
Brantford	1,451,107	195	1
Bruce	1,161,977	218	2
Chatam-Kent	1,326,129	210	3
Elgin	1,034,312	N/A	1
Essex	1,253,299	210	3
Hamilton	1,157,773	223	4
Huron	860,835	180	2
Lambton	1,258,684	200	5
Middlesex	1,220,405	220	7
Niagara	1,300,944	262	4
Norfolk	1,303,758	202	3
Oxford	1,773,408	222	4
Perth	1,121,130	N/A	1
Waterloo	1,279,562	219	6
Wellington	1,220,788	222	5
Windsor	843,006	N/A	2
Average Season Length in Days:	214	Total Number of Golf Courses:	54

Table 2.5: Estimated Season Length of Golf Courses in Central Ontario

Region	Total Average Annual Water Use L/Ha from 2007-2012	Estimated Season Length	Number of Golf Courses in the Region
Haliburton	1,321,579	165	1
Halton	1,253,297	220	5
Hastings	1,159,444	202	2
Kawartha Lakes	819,274	195	1
Muskoka	1,186,376	222	5
Northumberland	1,246,353	222	3
Peel	1,215,989	210	7
Peterborough	1,254,369	219	2
Prince Edward	2,629,560	195	2
Simcoe	1,263,823	212	10
Toronto	1,778,531	223	7
York	1,207,353	222	10
Average Season Length in Days:	208	Total Number of Golf Courses:	55

Table 2.6: Estimated Season Length of Golf Courses in Eastern Ontario

Region	Total Average Annual Water Use L/Ha from 2007-2012	Estimated Season Length	Number of Golf Courses in the Region
Frontenac	1,205,492	180	1
Lanark	111,271	N/A	1
Leeds and Grenville	612,010	223	1
Lennox and Addington	1,516,807	180	1
Ottawa	1,181,300	205	6
Renfrew	1,189,833	225	3
Stormont, Dundas and Glengarry	399,220	195	1
Average Season Length in Days:	201	Total Number of Golf Courses:	14

Table 2.7: Estimated Season Length of Golf Courses in Northern Ontario

Region	Total Average Annual Water Use L/Ha from 2007-2012	Estimated Season Length	Number of Golf Courses in the Region
Algoma	291,186	219	1
Greater Sudbury	277,175	210	1
Sudbury	1,236,812	210	3
Thunder Bay	515,085	240	1
Average Season Length in Days:	220	Total Number of Golf Courses:	6

With regards to the weather and climate data, representative seasons were created for each climate station that indicated a climatically normal season and a climatically dry season (Table 2.8). The normal representative season, or the climatically normal season with regards to usual irrigation needs, was chosen by identifying the year that had the closest to normal precipitation (based on the 1981-2010 climate normal), within 40-50mm, and the year that had the closest to normal temperature. On average, the normal representative season received 1% more precipitation and was 0.2°C warmer than the 1981-2010 climate normals.

The dry representative season, or the climatically dry season that should require the greatest amount of irrigation, was chosen by identifying the driest year (which was clearly identifiable in 17 of the 19 climate stations since the other years had at least 40-50mm, or 10% more precipitation than a normal year). However, if two years were within 40-50mm of precipitation, the warmer of the two years (with greater evaporation) was chosen to be the representative season. Further analysis of the dry representative season shows that the dry season received 29% less precipitation and was 1.2°C warmer than the 1981-2010 climate normals.

It was important to identify these climatically representative seasons to examine how irrigation needs differ in seasons when climate conditions are normal and anomalously dry. The representative seasons had to be identified for each station individually since conditions vary year to year across the province. For example, the driest season for most golf courses in southern Ontario was 2007, while the golf courses in northern Ontario experienced their driest season in 2012. Identifying the two representative seasons provided a range of climatic conditions found in the 2007 to 2012 period at each of the 19 climate stations. Once the climate representative seasons were identified, analyses occurred for each golf course characteristic (soil type, golf course type and the age of the golf course) to recognize if golf course characteristics influence water use particularly during climatically dry seasons.

Table 2.8: Climatically Representative Seasons at Each Climate Station

Climate Station	Number of Golf Courses at the Station	Dry Season	Normal Season
Barrie-Simcoe-Georgina	13	2011	2008
Chatham-Kent	3	2007	2008
Grey-Bruce	2	2007	2008
Hamilton-Burlington-Brant-Haldimand	6	2007	2012
Kingston-Frontenac-Napanee	2	2007	2012
London-Middlesex-Elgin-Oxford	12	2007	2009
Muskoka-Haliburton-Parry Sound	6	2007	2010
Niagara	4	2007	2011
Ottawa	9	2012	2008
Petawa-Renfrew	3	2012	2008
Peterborough-Kawarthas-Northumberland	6	2007	2010
Sarnia-Lambton	5	2007	2012
Sudbury	5	2011	2008
Thunder Bay	1	2011	2007
Toronto-Etobicoke-Halton-Peel (GTA West)	12	2007	2009
Toronto-York-Durham (GTA North and East)	17	2007	2009
Trenton-Belleville-Quinte	4	2007	2010
Waterloo-Guelph-Wellington	14	2007	2010
Windsor-Essex	5	2012	2008

Table 2.9: The Average Difference Between the Representative Seasons and the Climate Normals at All 19 Climate Stations

	Dry Representative Season	Normal Representative Season
Average Temperature Difference from 1981-2010 Climate Normals	+1.2°C	+0.2°C
Average Precipitation Difference from 1981-2010 Climate Normals	-29%	+1%

3.5 Calculating Average Annual Water Use for Golf Courses in Ontario

To calculate the average annual water use for all golf courses in Ontario, several assumptions were made. It was assumed that golf courses in Ontario have the same proportional characteristics as the 129 course sample, suggesting that:

1. 47% of all golf courses are comprised of sand dominated soil, 31% of all golf courses are comprised of silt dominated soil and 22% of all golf courses are comprised of clay dominated soils;
2. 46% of all golf courses are public or daily fee golf courses, 17% of all golf courses are semi-private golf courses, 15% of all golf courses are private golf courses and 22% of all golf courses are ranked as premier golf courses;
3. 15% of all golf courses are aged 0-19, 17% of all golf courses are aged 20-39, 55% of all golf courses are aged 40-99 and 13% of all golf courses are aged 100 and above;
4. 12% of all golf courses are 9-hole courses, 74% of all golf courses are 18-hole courses, 12% of all golf courses are 27-hole courses and that 2% of all golf courses are 36-hole courses; and
5. The average area for a 9-hole golf course is 32 hectares, the average area for an 18-hole golf course is 57 hectares, the average area for a 27-hole golf course is 81 hectares and the average area for a 36-hole golf course in 98 hectares.

The first step in calculating the average annual water use for golf courses in Ontario was to create an 18-hole equivalent water use for each golf course in both the climatically normal and dry seasons. This was done by first calculating the 18-hole equivalent area for each golf course in the sample size (Table 2.10).

Table 2.10: Calculating the 18-hole Equivalent Area for Golf Courses in the Sample Size

Number of Holes	Number of Courses	Percent of Sample	Average Hectares	Hectares/ Hole	Average Water Use (L/Ha) for a Normal Season	18-Hole Equivalent Area
9	16	12%	32	3.55	960,000	64
18	95	74%	57	3.19	1,000,000	57
27	15	12%	81	2.98	680,000	54
36	2	2%	98	2.72	1,100,000	49

After the 18-hole equivalent area was calculated, the total water use was calculated. To calculate the total water use, the following steps were taken:

1. Multiply the number of golf courses in the sample that are 9-hole by the 18-hole equivalent area for 9-hole golf courses multiplied by the average water use by 9-hole golf courses in a 'normal' season;
    - Example: 16 x (64 Ha x 960,000 L/Ha) = 980 million L
        - 16 = the number of 9-hole golf courses in the sample size
        - 64 hectares = the 18-equivalent area (Table 2.10)
        - 960,000 L/Ha = the average water use by 9-hole golf courses in a 'normal' season
2. Repeat step 1 for 18-hole, 27-hole and 36-hole golf courses;
3. Add together the totals from step 1 for all 9, 18, 27 and 36-hole golf courses and divide that total number by the number of golf courses in the sample size (in this case the sample size is 128 due to missing data). This calculated the 18-hole equivalent total water use, in L/yr/18-hole equivalent, for Ontario golf courses in a 'normal' season;

4. Repeat steps 1 through 3 for the climatically dry season.

After the total water use for 18-hole equivalents in Ontario was calculated, it was possible to create a provincial estimate for water use in the two seasons (normal and dry). To do so, the 18-hole equivalent total water use, in L/yr/18-hole equivalent was multiplied by 848, the number of 18-hole equivalent golf courses reported to be in Ontario (SNG, 2009). Calculating the total water use and the provincial estimate for the two climate seasons allowed the researcher to see a range of water use and to see how temperature and precipitation can influence water use.

3.6 Calculating Potential Water Savings for Ontario Golf Courses

To estimate potential water savings for golf courses with particular characteristics, the golf courses in the sample were separated based on the following key characteristics of soil type and golf course type:

- Public sand, public silt, public clay, premier public sand, premier public silt, premier public clay;
- Semi-private sand, semi-private silt, semi-private clay, premier semi-private sand, premier semi-private silt, premier semi-private clay; and
- Private sand, private silt, private clay, premier private sand, premier private silt and premier private clay

Once the separations occurred, the median seasonal water use during a climatically normal season was identified and recorded for each key characteristic in the sample. The median seasonal water use was used since a brief analysis revealed a few remaining outliers in the data; for some key characteristics the difference in water use between the minimum value and the maximum value was as high as 9,719%. Due to these outliers, the median seasonal water use and the water use of the golf course in the 80th percentile for each key characteristic were used to estimate potential water savings. This enabled the researcher to create a more accurate representation of the average water use for golf courses in the sample and create a more realistic value for potential water savings.

The difference in water use from the golf course in the 80th percentile and the median seasonal water use for the golf courses in each category was calculated. The difference in water use indicated the potential water savings that could be possible if golf courses in their associated category or key characteristic type (i.e. public sand or private silt) were able to adopt similar management practices to that of the golf course in the 80th percentile. Once these differences were calculated for all golf courses of key characteristics, the differences in all categories were averaged to provide a total potential water savings estimate for the province.

Using the water use of the golf course in the 80th percentile instead of using the golf course with the lowest average water use not only eliminated outliers that could be caused by reporting problems, but it also eliminated any 'low end' golf courses in the sample that are very poorly managed and rarely irrigate. Eliminating these golf courses are important for estimating potential water savings since the average golf course in Ontario irrigates not only to maintain healthy turf but to maintain an aesthetically pleasing appearance. By using the 80th percentile to calculate potential water savings, it eliminated these golf courses from the estimation and provided a more realistic estimation of water savings.

3.7 Limitations to the Data

There were several limitations to the water taking data provided by the MOE that significantly reduced the sample size for all the analyses in this thesis. First, the water taking data is all self-reported, and therefore, there is the chance of human error in reporting incorrect water use data or forgetting to report water use data. It is believed, due to the outliers found in the dataset, that water withdrawals are recorded and reported incorrectly to the MOE. For example, one golf course that was excluded from the sample size had recorded a difference in their water takings from 2009 to 2012 of over 21,421%, which cannot be accurate.

Second, not all golf courses in Ontario are compliant with the PTTW program due to grandfathering, (see section 2.2.3). Because of grandfathering, an unknown number of golf courses in Ontario are exempt from recording and reporting their water use to the MOE. Therefore, the number of accessible golf courses for this study is reduced. Third, due to the ambiguity, or coded organization names, of numerous golf courses in the water taking database, golf course characteristics could not be identified and thus, their recorded water takings were excluded from the sample size and all the analyses. Fourth, each year there were discrepancies for some golf courses between golf course/organization name and the location of those golf courses. Although the data does not explain these discrepancies, it could be due to reporting errors or changes in golf course ownership. Whatever the case, the discrepancies created identification uncertainty and precluded a multi-season water use comparison for the climate change analogue analysis. Therefore, these golf courses were excluded from all the sample size and analyses.

Lastly, the raw dataset provided by the MOE did not indicate if any irrigation upgrades, golf course expansion or even a change in superintendent occurred during the study period. If this information was provided in either the MOE dataset or online resources it could explain some of the outliers in the data. However, for this thesis it is assumed that no changes occurred to any of the golf courses in the sample. If significant changes did occur to the golf course during the study period from 2007 to 2012, particularly with regards to an expansion of the irrigated area (i.e. new holes were constructed) or irrigation upgrades such as additional irrigation heads being added to the current system, the relationship between water use and area may change. Since this is the first research completed with this dataset, it has identified similar problems within the dataset that the ECO identified in 1999, which if corrected, can create multiple opportunities to better this research and further develop sustainability programs that can achieve golf course water savings in Ontario.

Chapter Four: Results

4.1 Overview

This chapter summarizes the analysis of the secondary data obtained for this thesis. Section 4.2 discusses the climate data and identifies how weather can influence irrigation practices on golf courses in Ontario. Furthermore, it identifies key golf course characteristics of soil type, golf course type and golf course age for the courses in the sample, and analyzes each characteristic to identify how they can influence water use on Ontario golf courses. Section 4.3 of this chapter calculates and discusses the provincial water use estimate for Ontario golf courses.

4.2 Inter-Annual (Year to Year) Variability in Water Use

Climate data was gathered from May 1st to October 31st at 19 climate stations in Ontario for the period 2007 to 2012 to determine average seasonal temperature and precipitation. Tables 3.1 and 3.2 display the climate data collected at the 19 climate stations. In addition to the obtained climate data during the study period, climate normals from 1981-2010 were also obtained to identify dry anomalous years in the 2007 to 2012 data set. The average May to October temperature (normal) from 1981-2010 is 15.6°C and the average precipitation (normal) from 1981-2010 is 504.4mm. The average value for both the climate normals and the individual seasons (2007-2012) were calculated by averaging the temperature and precipitation recordings from each of the 19 climate stations.

Table 3.1: Mean Seasonal Temperature (°C) from May 1st to October 31st for 19 Climate Stations Across Ontario

Climate Station	Number of Golf Courses Represented at each Climate Station	Mean Seasonal Temperature (°C) From May 1st to October 31st 2007	2008	2009	2010	2011	2012	**1981-2010 Climate Normal**
Barrie-Simcoe-Georgina	13	15.3	13.9	13.2	15.6	15.8	15.7	**15.5**
Chatham-Kent	3	17.9	16.8	16.1	18.0	17.6	17.8	**16.7**
Grey-Bruce	2	15.9	14.2	13.7	15.5	15.3	15.9	**14.5**
Hamilton-Burlington-Brant-Haldimand	6	17.7	15.7	15.2	16.9	17.0	17.1	**16.2**
Kingston-Frontenac-Napanee	2	17.2	15.7	15.1	16.8	16.9	16.9	**15.8**
London-Middlesex-Elgin-Oxford	12	17.6	16.1	15.5	17.4	17.2	17.5	**16.1**
Muskoka-Haliburton-Parry Sound	6	14.4	13.1	12.5	14.3	14.6	14.5	**13.7**
Niagara	4	18.2	16.7	16.5	17.9	17.6	18.0	**16.9**
Ottawa	9	16.5	15.7	15.0	16.6	17.2	17.1	**15.9**
Petawa-Renfrew	3	14.9	14.0	13.5	15.2	15.6	15.9	**15.2**
Peterborough-Kawarthas-Northumberland	6	15.6	14.5	14.0	15.9	16.0	15.6	**14.7**
Sarnia-Lambton	5	17.8	16.5	15.3	18.1	17.4	17.4	**16.4**
Sudbury	5	15.1	13.6	13.1	14.9	15.2	15.1	**13.9**
Thunder Bay	1	13.4	12.4	11.8	13.3	13.3	13.3	**12.3**
Toronto-Etobicoke-Halton-Peel (GTA West)	12	18.6	16.4	16.0	17.9	18.0	18.3	**16.6**
Toronto-York-Durham (GTA North and East)	17	17.8	16.1	15.5	17.4	17.5	17.7	**16.3**
Trenton-Belleville-Quinte	4	16.9	15.8	15.4	17.2	17.1	17.5	**15.8**
Waterloo-Guelph-Wellington	14	16.4	14.9	14.4	16.0	16.1	16.4	**15.8**
Windsor-Essex	5	20.0	18.9	17.8	19.8	19.1	19.4	**18.3**
19 STATION AVERAGE	129	16.7	15.3	14.7	16.6	16.6	16.7	**15.6**

Table 3.2: Total Precipitation (mm) from May 1st to October 31st for 19 Climate Stations Across Ontario

Climate Station	Number of Golf Courses Represented at each Climate Station	Total Precipitation (mm) From May 1st to October 31st: 2007	2008	2009	2010	2011	2012	**1981-2010 Climate Normal**
Barrie-Simcoe-Georgina	13	462.3	523.9	481.4	702.0	468.0	540.0	**498.2**
Chatham-Kent	3	380.0	493.6	446.0	538.0	777.0	599.0	**527.4**
Grey-Bruce	2	411.8	554.5	467.6	587.1	690.0	592.7	**507.6**
Hamilton-Burlington-Brant-Haldimand	6	262.6	591.7	612.2	620.0	582.0	503.2	**503.3**
Kingston-Frontenac-Napanee	2	393.0	558.0	551.4	571.8	487.3	508.4	**515.7**
London-Middlesex-Elgin-Oxford	12	311.2	473.2	483.0	592.6	593.8	434.2	**531.4**
Muskoka-Haliburton-Parry Sound	6	437.7	571.7	524.2	613.1	647.8	481.4	**599.6**
Niagara	4	329.8	638.0	637.4	576.9	542.8	482.9	**522.4**
Ottawa	9	473.4	505.6	655.8	614.6	485.2	435.8	**526.6**
Petawa-Renfrew	3	534.2	507.9	436.4	445.7	482.5	371.2	**511.8**
Peterborough-Kawarthas-Northumberland	6	327.2	654.2	542.7	459.9	548.3	521.5	**471.1**
Sarnia-Lambton	5	378.3	593.5	470.9	464.8	534.7	475.8	**500.6**
Sudbury	5	466.6	542.8	584.6	455.3	425.1	499.7	**517.9**
Thunder Bay	1	423.1	508.0	384.0	415.1	349.3	524.8	**464.4**
Toronto-Etobicoke-Halton-Peel (GTA West)	12	254.8	588.0	471.0	536.2	509.8	520.6	**435.2**
Toronto-York-Durham (GTA North and East)	17	248.4	523.0	514.7	609.6	545.8	649.3	**467.3**
Trenton-Belleville-Quinte	4	306.5	579.3	541.7	470.0	580.8	496.5	**472.6**
Waterloo-Guelph-Wellington	14	245.1	586.1	490.0	545.1	556.7	471.0	**506.9**
Windsor-Essex	5	522.6	496.4	459.0	567.6	859.8	441.4	**503.6**
19 STATION AVERAGE	129	377.3	552.1	513.4	546.6	561.4	502.6	**504.4**

To identify how climate influences water use among the golf courses in the sample, the difference in water use from the climatically normal season to the climatically dry season was identified (Figure 2). In general, the climate data found the average daily temperature to be 15.8°C during the normal season and 16.8°C during the dry season. Furthermore, the climate data found the average annual precipitation to be 509mm during the normal season and 358mm during the dry season. The analysis of water use during the climatically representative seasons found that, on average, water use from a normal season to a dry season increased by 93%.

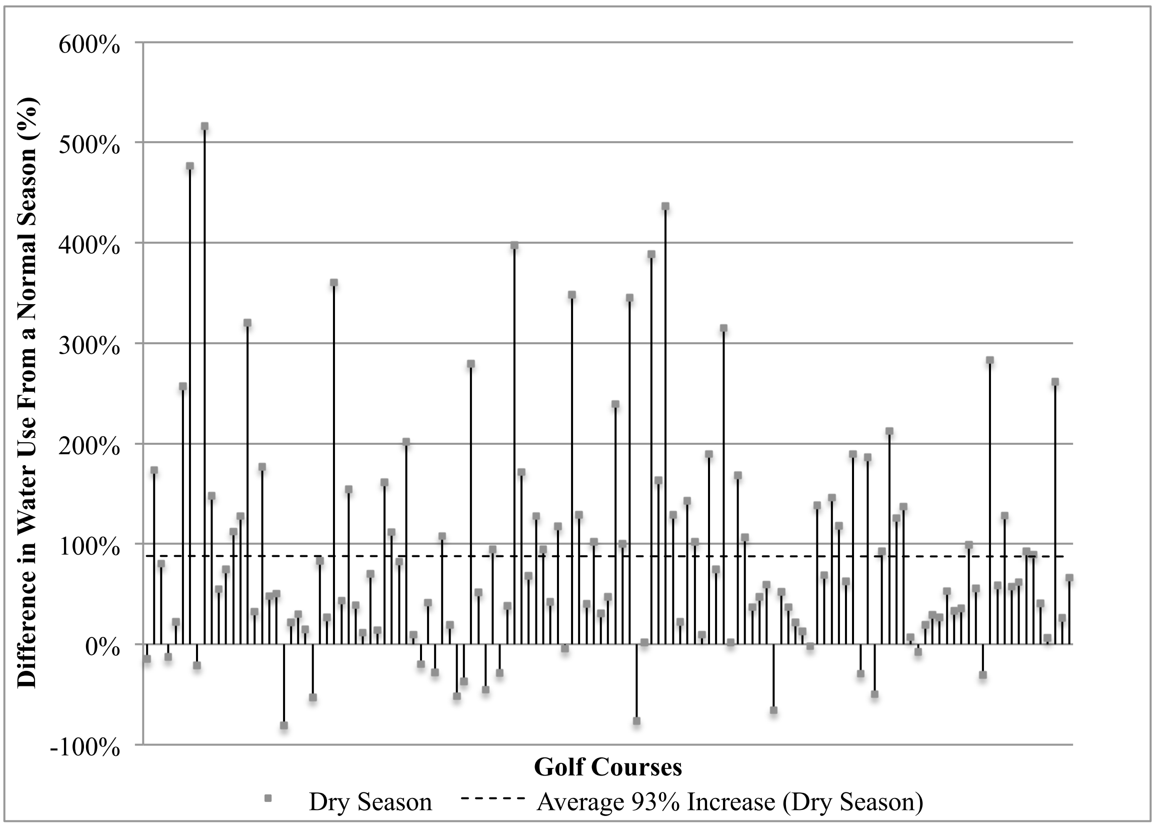

Figure 2: The Difference in Water Use From a Climatically Normal Season (0%) to a Climatically Dry Season For Each Golf Course in the Sample

4.2.1 Identifying Characteristics that Influence Golf Course Water Use in Ontario

As discussed in section 1.0, several hypotheses were made regarding characteristics that may influence golf course water use in Ontario. Characteristics that were investigated include the dominant soil type, the type of the golf course and the age of the golf course. The following sections will discuss the difference in water use between the representative seasons for golf courses in the sample based on their individual characteristics to identify if characteristics influence golf course water use.

4.2.1.1 Soil Type and Its Influence on Golf Course Water Use

The golf courses in the sample are comprised of three main types of soil: sand dominated soil, silt dominated soil and clay dominated soil. Due to missing data, the number of golf courses in the sample size for this analysis is 124. Of the 124 golf courses, 47% are comprised of soils dominated by sand, 31% are comprised of soils dominated by silt and 22% are comprised of soils dominated by clay.

To understand how weather influences water use on golf courses comprised of different soil types, the difference in water use for the representative seasons was analyzed (Figure 3). When analyzing the difference in water use from a normal season to a dry season for the golf courses on the three soil types, the data illustrates that, on average:

- Golf courses comprised of sand dominated soils use 95% more water during a dry season than they do during a normal season;
- Golf courses comprised of silt dominated soils use 95% more water during a dry season than they do during a normal season; and

- Golf courses comprised of clay dominated soils use 82% more water during a dry season than they do during a normal season.

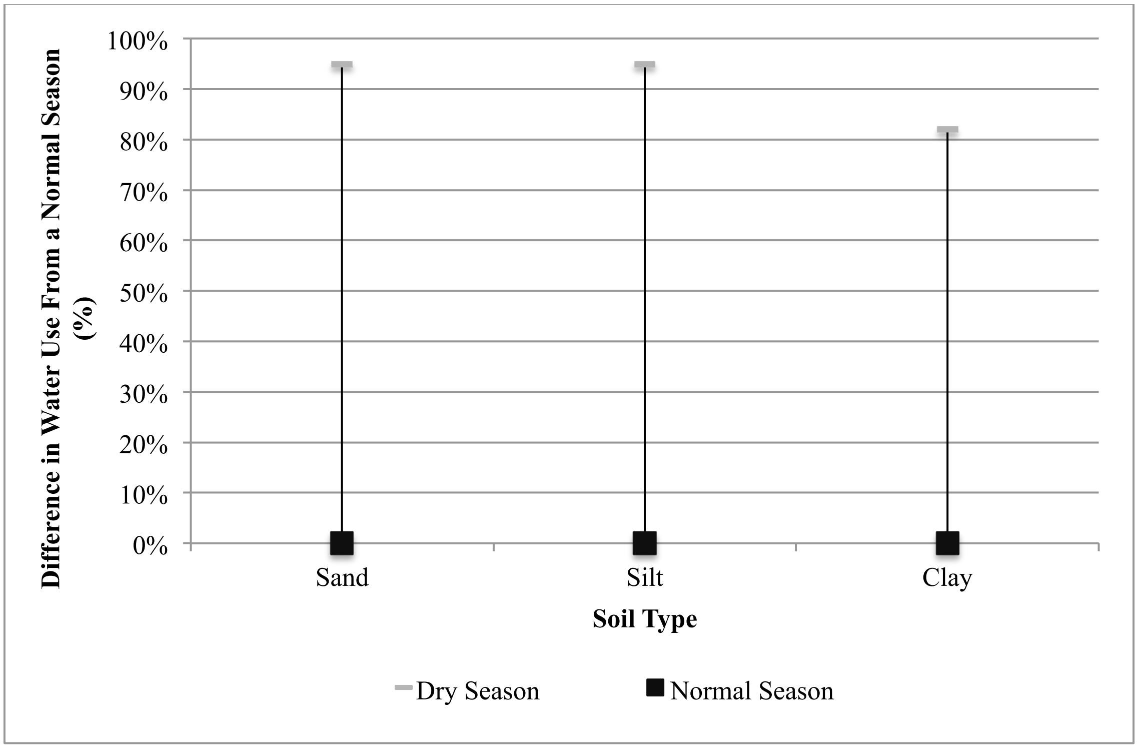

Figure 3: The Difference in Water Use From a Normal Season (0%) to a Dry Season For Golf Courses on Different Soil Types

These findings suggest that during a dry season, golf courses comprised of sand and silt dominated soils require similar irrigation inputs while golf courses comprised of clay dominated soils require lower irrigation inputs. On average, during a dry season, golf courses comprised of clay dominated soils require 13% less irrigation than golf courses comprised of silt and sand dominated soils.

These results are principally due to the particle size and soil texture of sand, silt and clay. The diameter of sand particles are much greater than silt and clay particles; sand particles range from 50 to 200 µm in diameter while silt particles range from 2 to 50 µm in diameter and clay particles are often less than 2 µm in diameter (Ward and

Trimble, 2004, p.436, 440 and 441). During golf course irrigation, the smallest pores in the soil fill first and maintain the greatest moisture content. When drainage or drying occurs, the soils with the largest pores empty first. Soils dominated with sand not only have the largest pores, but the soil texture of sand inhibits the soil moisture content to rise above 8% and creates a low suction for water, meaning water leaves sandy soils first and easily (Ward and Trimble, 2004, p.60). In contrast, clay has the smallest pores, the highest water content (25%) and the highest suction for water, meaning that soil moisture is easily maintained in this soil type. Silt particles have soil characteristics between that of sand and clay particles. Silt particles have medium sized pores, a water content of 20% and water suction between that of sand and clay (Ward and Trimble, 2004, p.60). It is believed that clay dominated soils have the lowest average seasonal water use during the representative seasons due to the soils' ability to maintain soil moisture. Similarly, it is believed that sand and silt dominated soils have the highest average seasonal water use during the representative seasons due to the soils' drainage efficiencies and their inability to maintain high levels of soil moisture.

4.2.1.2 Golf Course Type and Its Influence on Water Use

The sample was initially divided into three different categories of golf course type. The first category is referred to as a daily fee golf course or a public golf course, which is open to the public and does not require a membership or annual fees. The second category is referred to as a semi-private golf course. A semi-private golf course is open to the public but also has private members that pay some form of membership and/or annual fees. The third category is referred to as a private golf course, which is only open to the members of the club and their guests. In order to become a member at a private club, the member must pay an initiation fee, annual dues and a membership fee. In addition to a golf course being a public, semi-private or private golf course is the possibility of it being ranked as a premier golf course. In 2011, the Ontario Golf Magazine published a list of the top 100 golf courses in Ontario (Lancaster, 2011). 27 golf courses in the sample of 129 were identified on this list and are considered to be premier golf courses. In the sample of 129 golf courses, 46% of the golf courses are daily fee or public courses, 17% are semi-private courses, 15% are private courses, 2% are premier public courses, 1% are premier semi-private courses and 19% are premier private courses. The water use on premier golf courses was investigated because it was believed that the average seasonal water use would be highest on these golf courses due to their high ranking from their impeccable course conditions and aesthetics.

Before considering the influence premier golf courses and weather has on water use, the total average water use among public, semi-private and private golf courses was evaluated. The data shows that total average seasonal water use, over the 2007 to 2012 period, was higher among golf courses that were private; the total average seasonal water use for public golf courses was 1 million L/Ha; the total average seasonal water use for semi-private golf courses was 1.4 million L/Ha and the total average seasonal water use for private golf courses was 1.5 million L/Ha. During the 2007 to 2012 period, on average, semi-private golf courses used 39% more water than public golf courses and private golf courses used 45% more water then public golf courses.

The higher water use for private golf courses during the 2007 to 2012 period is likely due to the status of the golf course and due to member perception. Private golf courses often have high maintenance budgets due to expensive membership fees, which can cost anywhere from $15,000 to $100,000. It is believed that the expensive membership fees fund the large maintenance budgets of private golf courses, allowing for intensive maintenance practices. A study conducted on golf courses in the United States by Throssell and colleagues (2009) supports this finding. They found that as golf courses become more private, the maintenance budget and seasonal water use increased. Member perception is also likely to influence golf course irrigation since members expect their golf course to be kept in pristine conditions with vibrantly green turfgrass, tighter mowing heights and faster green speeds because of their expensive membership fees. This perception is sometimes referred to as the "Augusta National Syndrome" and has led many private golf courses to irrigate, manage and fertilize excessively, particularly during times of drought (Hiskes, 2010;Wheeler and Nauright, 2006). Based on this information, it is believed that golf course type does influence golf course water use.

To understand the influence of weather and golf course type on water use, the difference in water use during the climatically representative seasons was analyzed for different golf course types (Figure 4). In general, premier golf courses increased their average water use by 74% during a dry season, while non-premier golf courses were found to increase their average water use by 98% during a dry season. The data showed that premier golf courses have a higher total annual water use than non-premier golf courses. Because premier golf courses irrigate at a consistently higher rate during a normal season, there is less variability in their water use during the dry season than the water use variability for non-premier golf courses. Furthermore, the data showed that, on average, water use during a dry season increased by the greatest amount for public golf courses (Figure 4). This suggests that water use on daily fee or public golf courses is more highly influenced during warm and dry weather conditions than private golf courses (both premier and non-premier). To further understand the influence of golf course type on water use, soil type as well as the change in water use for each golf course type in the dry season was analyzed (Table 3.3).

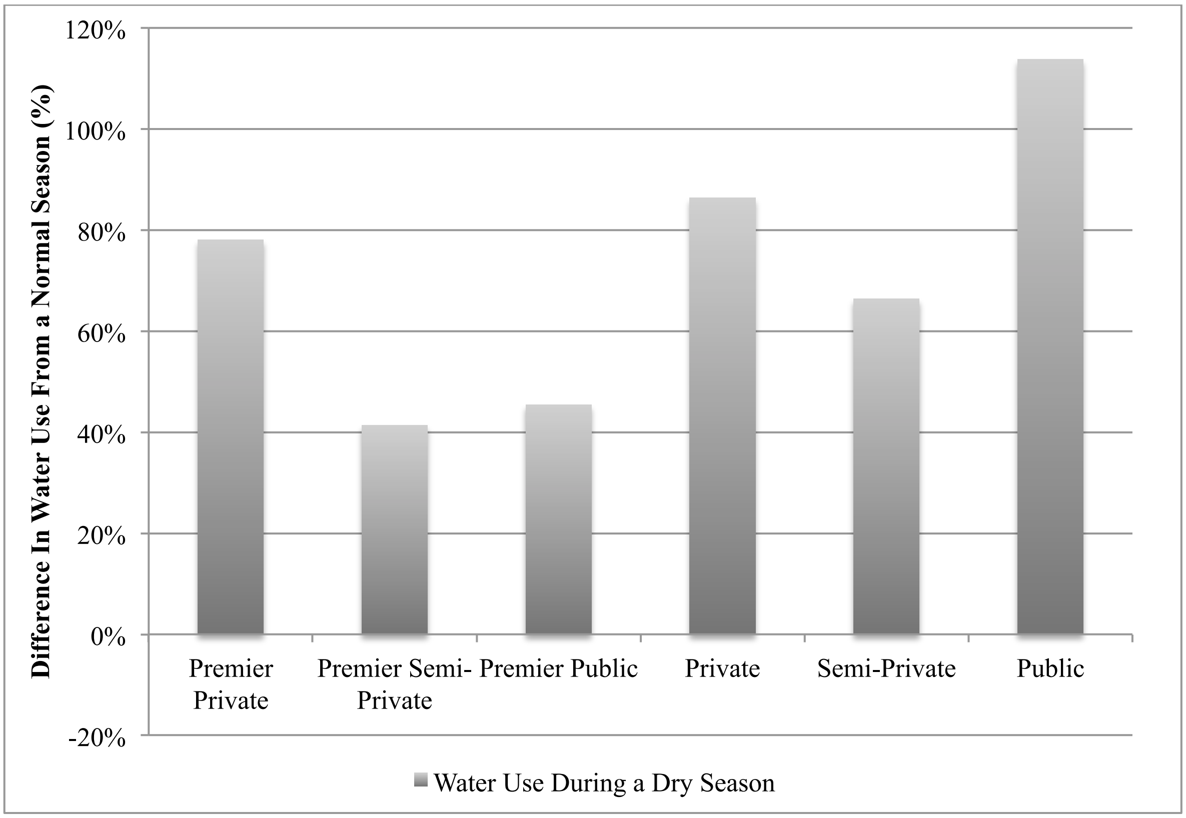

Figure 4: The Difference in Water Use From a Normal Season (0%) to a Dry Season For Different Golf Course Types

Table 3.3: Soil Type and Change In Water Use For Golf Courses of Different Golf Course Types During the Dry Representative Season

Golf Course Type	Number of Golf Courses	Soil Type						Increase in Water Use From Normal Season to Dry Season
		Sand		Silt		Clay		
Premier Semi-Private	1	1	100%	0	0%	0	0%	+41%
Premier Public	2	0	0%	2	100%	0	0%	+45%
Premier Private	24	14	58%	6	25%	4	17%	+78%
Semi-Private	22	10	46%	6	27%	6	27%	+66%
Private	20	8	44.4%	8	44.4%	2	11.2%	+86%
Public	60	26	46%	16	28%	15	26%	+114%
TOTAL	129	59	47%	38	31%	27	22%	

Due to the 114% increase in water use for public golf courses, an in depth analysis was done. This analysis identified seven outliers within the dataset that increased their individual water use by more than 300%. Removing the outliers from the dataset resulted in a water use increase of 78% instead of 114%. It is believed that the high increase in water use for public golf courses during a dry season is a result of more frequent irrigation since less natural precipitation occurs. During a normal season, public golf courses tend to irrigate only when necessary, taking full advantage of natural precipitation in order to save money and conserve water. This minimizes the total quantity of irrigation applied to the turf during a normal season. However, when a dry season brings little to no precipitation, irrigation is greatly increased to not only replace the quantity of precipitation that normally occurs, but also to replace the water that is lost to increased evapotranspiration rates. In addition, the high increase in water use by public golf courses is believed to be caused by lower maintenance budgets and thus older and less efficient irrigation systems. Literature states that when an irrigation system is inefficient, a greater quantity of water is used because of worn down sprinkler heads, leaky irrigation pipes and water distribution inefficiencies (Carrow, Duncan and Waltz, 2007).

Particular attention should be brought to the premier public and premier semi-private golf courses in the dry season. Although these golf course types have the lowest increase in water use, the results have low confidence since the data is obtained from only three golf courses. Due to the low confidence, the final conclusions of this analysis exclude water use on premier semi-private and premier public golf courses. Since the premier public and premier semi-private golf courses are all composed of silt and sand dominated soils, it is believed that the high efficiency of water use on these golf courses could be a result of three factors. First, the management strategies on the premier public and premier semi-private golf courses could be ecologically friendly practices focused on water conservation. Second, the irrigation system employed on these two golf course types could be very efficient. Third, it is likely that the irrigation systems on these golf courses run at full capacity during the normal season. Since these two golf course types likely irrigate heavily in climatically normal seasons, their water use will not increase by as much during the dry season as golf courses that only lightly irrigate in climatically normal seasons. These factors would enable the premier semi-private and premier public golf courses to use the least amount of water during the dry season. Although these golf courses only represent 2% of the sample size, it is believed that these three golf courses are highly efficient golf courses due to management practices and efficient irrigation systems rather than golf course type.

Private and premier private golf courses have a similar water use increases during the dry season; however, the premier private golf courses are more efficient during the dry season than the private golf courses. During the dry season, it is hypothesized that premier private golf courses have a lower water use than private golf courses because of the difference in soil type and more efficient irrigation systems. Premier private golf courses have more golf courses composed of clay soil than private golf courses. Based on the findings in section 4.2.1.1, golf courses composed of clay dominated soil require 13% less water than golf courses comprised of sand and silt dominated soil. Furthermore, it is likely that premier private golf courses have more expensive membership fees than private golf courses and thus more money is available to be spent on technologically advanced irrigation systems and manpower. Efficient irrigation systems, as discussed in section 2.3.1, result in reduced water use since water is more accurately applied to the turf through target irrigation.

After the outliers in the public and semi-private golf courses were removed and the water use data for premier semi-private and premier public golf courses were removed (due to low confidence) from the data (Figure 5), the results of this analysis suggest that, on average:

- Water use on premier private golf courses and private golf courses was the least efficient during a dry season;
- Water use on private golf courses increased by the greatest amount (i.e. it is the least efficient) during a dry season; and
- Water use on semi-private golf courses was the most efficient during a dry season.

The final conclusion of this analysis is that golf course type does influence golf course water use.

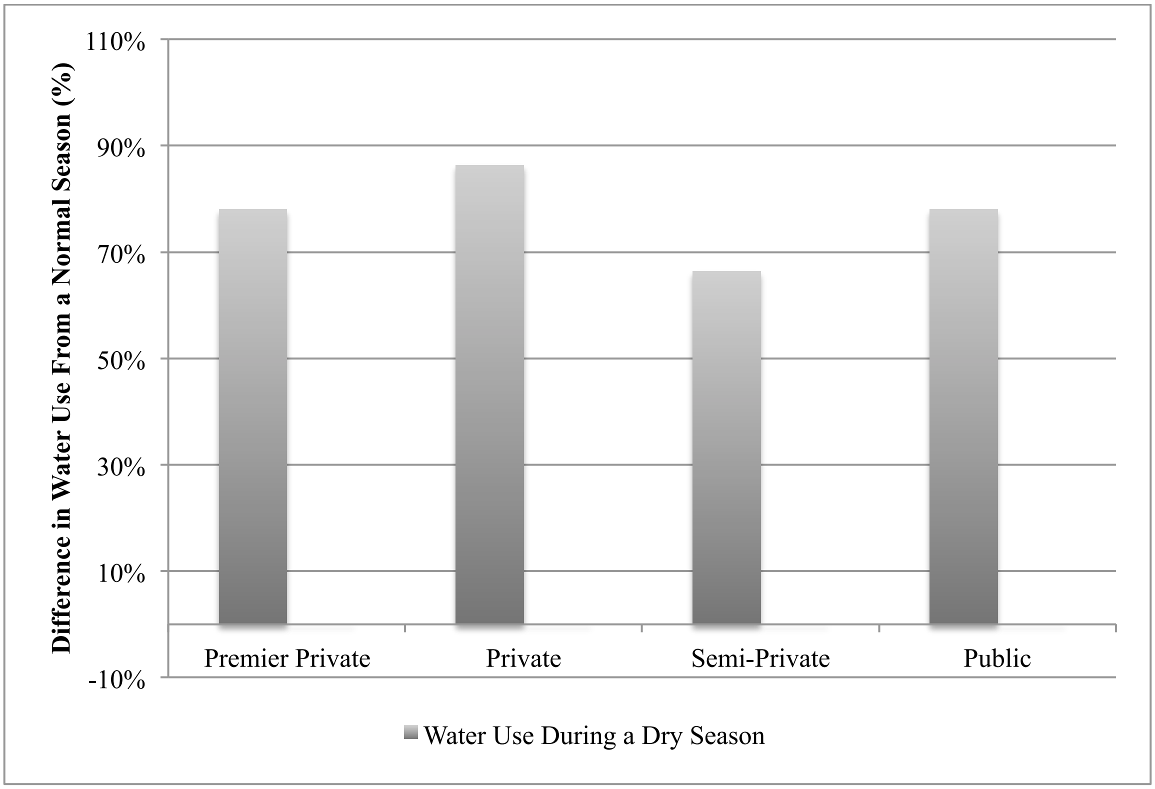

Figure 5: The Difference in Water Use From a Normal Season (0%) to a Dry Season For Different Golf Course Types Once Outliers Were Removed

4.2.1.3 Golf Course Age and Its Influence on Water Use

The sample was divided into twelve age categories to investigate whether golf course age influences water use. The age of 26 golf courses was not identifiable from online resources thereby reducing the sample size for this analysis to 103. The age categories for this analysis included golf courses of: 0-9, 10-14, 15-19, 20-29, 30-39, 40-49, 50-59, 60-69, 70-79, 80-89, 90-99 and 100+ years since original development. In order to explain the differences in water use due to golf course age, soil type and golf course type were first identified for all the golf courses in the sample (Table 3.4).

Table 3.4: Soil Type, Golf Course Type, Total Average Water Use During a Climatically Normal Season (Million L/Ha), The Average Difference In Water Use and The Standard Deviation for All Golf Courses of Different Ages

Age Category	Number of Golf Courses in the MOE Database	Soil Types						Golf Course Types								Average Golf Course Area (Ha)	Total Average Water Use (Million L/Ha) During a Climatically Normal Season	Average Difference In Water Use From a Normal Season To a Dry Season	Standard Deviation
		Sand		Silt		Clay		Daily Fee		Semi-Private		Private		All Premier					
0-9	2	1	50%	1	50%	0	0%	1	50%	0	0%	1	50%	0	0%	26	1.1	26%	0.91
10-14	10	5	50%	4	40%	1	10%	4	40%	2	20%	0	0%	4	40%	56	1.8	79%	0.41
15-19	3	0	0%	2	67%	1	33%	2	67%	1	33%	0	0%	0	0%	47	1.3	117%	1.15
20-29	12	5	42%	4	33%	3	25%	4	33%	4	33%	1	8%	3	25%	47	1.1	91%	1.09
30-39	6	1	17%	1	17%	4	67%	4	67%	1	17%	1	17%	0	0%	58	1.8	151%	1.85
40-49	15	8	53%	3	20%	4	27%	13	87%	2	13%	0	0%	0	0%	48	1.2	85%	1.01
50-59 *	19	8	44%	5	28%	5	28%	7	37%	3	16%	5	26%	4	21%	58	1.1	100%	1.06
60-69	1	1	100%	0	0%	0	0%	1	100%	0	0%	0	0%	0	0%	30	1.8	177%	0
70-79	4	3	75%	1	25%	0	0%	2	50%	0	0%	0	0%	2	50%	63	1.1	76%	0.48
80-89	9	6	67%	2	22%	1	11%	4	44%	2	22%	1	11%	2	22%	50	1.1	140%	1.84
90-99 *	9	5	63%	0	0%	3	38%	1	11%	0	0%	4	44%	4	44%	55	1.8	44%	0.57
100+	13	6	46%	7	54%	0	0%	1	8%	1	8%	3	23%	8	62%	64	1.3	92%	1.12
TOTAL	103	*note: age categories 50-59 and 90-99 each have 1 golf course with an unidentified soil type																	

Table 3.4 shows great variability regarding the different soil types, golf course types and water use for golf courses in each age category. The data showed that during the dry season, every age category increased their average water use. However, water use increase is quite variable among age categories, ranging from an increase of only 26% to an increase of up to 177% (Table 3.4). An in depth analysis of the age categories that increased their water use by more than 100% during the dry season (i.e. the age categories 15-19, 30-39, 50-59, 60-69 and 80-89) revealed 14 outliers in the data that likely skewed the results. Although the obtained data provided no evidence as to why the outlying golf courses in the dry season had high increases in water use, it was speculated that the high water use could be a result of a) golf course type, b) soil type, c) an inefficient irrigation system, d) a lack of water conservation strategies, e) management practices and/or f) incorrect self-reported data.

Particular attention should be brought towards golf courses aged 10-14 in Table 3.4. The total average water use during a climatically normal season for these golf courses is one of the highest for all the golf courses in this analysis. It is believed that the high total average water use for this this age group is due to turfgrass development. It is speculated that due to the need to ensure turfgrass maturity, additional irrigation is applied to the turf to encourage root and shoot depth. Although very few studies look at irrigation requirements for newly planted turfgrass, and how long it actually takes for the turfgrass to mature, previous literature identifies sufficient irrigation as an essential method in developing the extensive root system and shoot depth of turfgrass (Beard and Green, 1993; Foy, 2006; Barton, Wan and Colmer, 2006; Cheng, Salminen and Grewal, 2010). An extensive root system increases the resilience of the turfgrass, enhancing its ability to withstand damage during drought periods and allowing for long term reductions in daily irrigation (Barton et al., 2006; Beard and Green, 1993; Foy, 2006; Cheng, Salminen and Grewal, 2010). Due to these findings, it is believed that 10-14 years after development is likely the stage at which the turfgrass is maturing and therefore has higher water use requirements.

The second highest total average water use during a climatically normal season occurs for golf courses aged 100+. Courses aged 100+ are believed to be high water users due to the higher number of both private and premier golf courses in this age category (Table 3.4). Golf courses aged 100+ have eight premier private golf courses and two non-premier private golf courses. Based on the analysis in section 4.2.1.2, premier golf courses tend to have a higher average water use than all other golf courses in the study (Figure 5). Since the golf courses in this age category are also built on sand and silt dominated soils, which are soils requiring the greatest amount of irrigation during the dry representative season (Figure 4), it is believed that the high water use is due to golf course type and soil type and not necessarily due to the age of the golf courses and related infrastructure.

Based on the individual analyses of the change in average seasonal water use during a dry season for golf courses of different age categories, it is believed that there is no connection between water use and the age of the golf course. The analysis of golf course water use and age during a dry season supports the findings of previous analyses, suggesting that golf course type, soil type, temperature, precipitation and perhaps management practices and irrigation systems influence golf course water use.

4.3 Provincial Estimate of Water Use on Ontario Golf Courses

The purpose of calculating a provincial estimate was to provide insight into how much water is used annually on golf courses in Ontario. Due to the difference in water use for the climatically representative seasons, the provincial estimate provides a range of water use during both a dry and normal season. Since this study sample represents only 15% of all Ontario golf courses, it is important to reiterate the assumption that the proportional distribution of golf course characteristics (i.e. soil type, golf course type, number of holes and age) are similar for the entire province. The assumptions, which are thoroughly discussed in section 3.5, have been made due to a lack of information for all 848 golf courses in Ontario. As was seen in the sample for this study, online resources did not fully provide the information needed to categorize all the golf courses in Ontario. In particular, the soil type, golf course type, number of holes and golf course age could not be collected for the entire population of Ontario's 848 golf courses. Due to these assumptions, the provincial estimate in this thesis must be considered to be the 'best estimate' based on the current available data.

In order to extrapolate water use from the sample to the province-wide golf sector, which is reported as 848 golf courses, the sample needed to be converted to a consistent unit of 18-hole equivalent courses. Since the area of the golf courses in the sample varies depending on the number of holes, the average seasonal water use on 9, 27 and 36-hole golf courses was manipulated so that the irrigated area and its water use was representative of both the area and water use of a standard 18-hole equivalent golf course (Table 3.5). This allowed for an equal comparison of water use among the golf courses in the sample. The provincial estimate also accounted for the average seasonal water use in the two climatically representative seasons (dry and normal seasons). Creating a provincial estimate for both the representative seasons allowed for a range of water use to be estimated to further understand how weather could directly influence total water use by the Ontario golf industry.

Table 3.5: Golf Course Area and Total Seasonal Water Use for 18-Hole Equivalent Courses During a Climatically Normal Season

Golf Course Size	Average Hectares	Hectares/ Hole	18-Hole Equivalent Area	Total Average Water Use (L/Ha) During a Climatically Normal Season	Total Seasonal Water Use (Million L/Season) Per Course as an 18-Hole Equivalent
9-hole	32	3.55	64	960,000	61.8
18-hole	57	3.19	57	1,000,000	63
27-hole	81	2.98	54	680,000	36.4
36-hole	98	2.72	49	1,100,000	54.4

*Note: there are no golf courses in this sample greater than 36-holes

Due to missing information for one golf course in the sample regarding its golf course size, the sample size for this analysis is 128 instead of 129. To calculate total seasonal water use for 18-hole equivalent golf courses, the number of golf courses (or the percent of the sample) for each golf course size was accounted for. This was done by multiplying the number of golf courses in the sample (or the percent of the sample) by the total seasonal water use per course as an 18-hole equivalent, which is identified in Table 3.5. As discussed in section 3.5, the sum of the total seasonal water use for all the 18-hole equivalents was divided by the sample size of 128. The results of this analysis showed that during a normal season, an 18-hole equivalent golf course is expected to use 59.6 million L of water (Table 3.6), and during a dry season, an 18-hole equivalent golf course is expected to use 94.2 million L of water (Table 3.7).

Table 3.6: Total Seasonal Water Use (Million L/Season) For All 18-Hole Equivalents During a Normal Season

Golf Course Size	Number of Courses	Percent of the Sample	Total Seasonal Water Use (Million L/Season) Per Course as an 18-Hole Equivalent	Total Seasonal Water Use (Million L/Season) For All 18-Hole Equivalents
9-hole	16	12%	61.8	990
18-hole	95	74%	63	5,980
27-hole	15	12%	36.4	550
36-hole	2	2%	54.4	110
			Sum	7,600
			18-Hole Equivalent	59.6

Table 3.7: Total Seasonal Water Use (Million L/Season) For All 18-Hole Equivalents During a Dry Season

Golf Course Size	Number of Courses	Percent of the Sample	Total Average Water Use (Million L/Ha) During a Climatically Dry Season	Total Seasonal Water Use (Million L/Season) Per Course as an 18-Hole Equivalent	Total Seasonal Water Use (Million L/Season) For All 18-Hole Equivalents
9-hole	16	12%	1.6	103	1,647
18-hole	95	74%	1.6	94	8,982
27-hole	15	12%	1.5	81	1,225
36-hole	2	2%	2.1	105	210
				Sum	12,000
				18-Hole Equivalent	94.2

From these calculations, and from the information provided by SNG (2009) regarding the number of golf courses in Ontario, the provincial estimate was made. The analysis showed, assuming that the proportion of all golf courses in Ontario are similar to the 128 golf courses in the sample size with respect to soil type, golf course type, number of holes and golf course age that:

- During a normal season 50.5 billion L of water a year will be applied to Ontario golf courses; and

- During a dry season 79.9 billion L of water a year will be applied to Ontario golf courses.

4.4 Summary of Results

The obtained water use data from the MOE's PTTW database over the 2007 to 2012 period showed four trends:

- The warmest seasons (2007 and 2012) had the highest average water use;
- The coolest seasons (2009 and 2008) had the lowest average water use;
- The driest season (2007) had the highest average water use; and
- The wettest seasons (2011 and 2008) had very different water uses suggesting that in addition to variable rainfall, golf course characteristics influence water use.

This information suggested that factors other than temperature and/or precipitation impact the water use of Ontario golf courses for irrigation purposes. Analyzing the difference in water use from the climatically normal season to the climatically dry season revealed how water use is influenced by weather. The soil type analysis showed that golf courses comprised of sand and silt soils require more water during the dry season than golf courses comprised of clay soil. On average, water use increased by 95% for golf courses comprised of both sand and silt soil from a climatically normal season to a climatically dry season.

The golf course type analysis found that private golf courses (both premier and non-premier) were the least efficient at irrigating the golf course during the dry season. During the dry season, private golf courses increased their water use by the greatest amount (86%) while semi-private golf courses increased their water use by the least amount (66%). Golf course age was not found to be an influencing factor of water use, instead, the age analysis supported the previous findings, suggesting that soil type and golf course type influence water use.

Chapter Five: Discussion

5.1 Water Use Comparisons

The results of this research have provided new information regarding water use on Ontario golf courses and biophysical characteristics that influence water use. Since studies calculating average water use on golf courses in North America are quite rare, the ability to compare water use among studies is limited. Throssell and colleagues (2009) created a similar study to the one in this thesis, however, they analyzed water use by agronomic regions, due to the vast differences in climate, across the United States. In the Northeast agronomic region, which has 391 golf courses and a climate similar to southern Ontario, Throssell and colleagues (2009) found the average annual water use, from 2003 to 2005, for standard 18-hole golf courses to be 52 million L. Although Throssell and colleagues (2009) did not account for the difference in water use due to soil type, golf course type and weather conditions as was completed in this thesis, their data can be compared to the results of this thesis to show how water use varies for golf courses in similar climate regimes.

The estimated average annual water consumption for an 18-hole equivalent golf course during a normal season in Ontario is 59.6 million L/yr, which is 12% greater than Throssell and colleagues' (2009) estimation. However, the estimation by Throssell and colleagues (2009) does not include any information regarding soil type, golf course type and weather conditions during their 2003 to 2005 study period. These discrepancies make it impossible to explain the reported difference of 12% in water use. The findings of Throssell and colleagues' (2009) research also stated that climate and other external characteristics such as soil type, growing season, management practices and best management practices can influence golf course water use, which supports the findings of this research.

Now that average annual water use has been estimated for Ontario golf courses, comparisons can be made with other water users at the regional or provincial scale. In 2005 and 2011, the Grand River Conservation Authority (GRCA) analyzed the water use in the Grand River Watershed. In 2005, golf courses were considered to be the sixth greatest water consumer, after municipal supply, dewatering, aggregate washing, aquaculture and remediation, respectively (Bellamy and Boyd, 2005). By 2011, golf courses were considered to be the eleventh greatest water consumer, suggesting that water use on golf courses has reduced since 2005 after the integration of the PTTW program (Figure 6) (Wong, 2011).

In comparison to golf course irrigation, agricultural irrigation consumes greater quantities of water in the Grand River watershed. In 2005, water use for agriculture was considered to be the seventh greatest water consumer, and in 2011, it was considered to be the third greatest water consumer (Bellamy and Boyd, 2005). Bellamy and Boyd (2005) further analyzed the seasonal water use for agricultural irrigation (Figure 6). They found that although agricultural irrigation was ranked as the eighth largest water user over the course of the year in 2005, during July it became the second largest water user. This analysis was not completed for golf courses during the summer months, however, the results are likely similar due to warmer temperatures, increased evapotranspiration and heightened crop water demands.

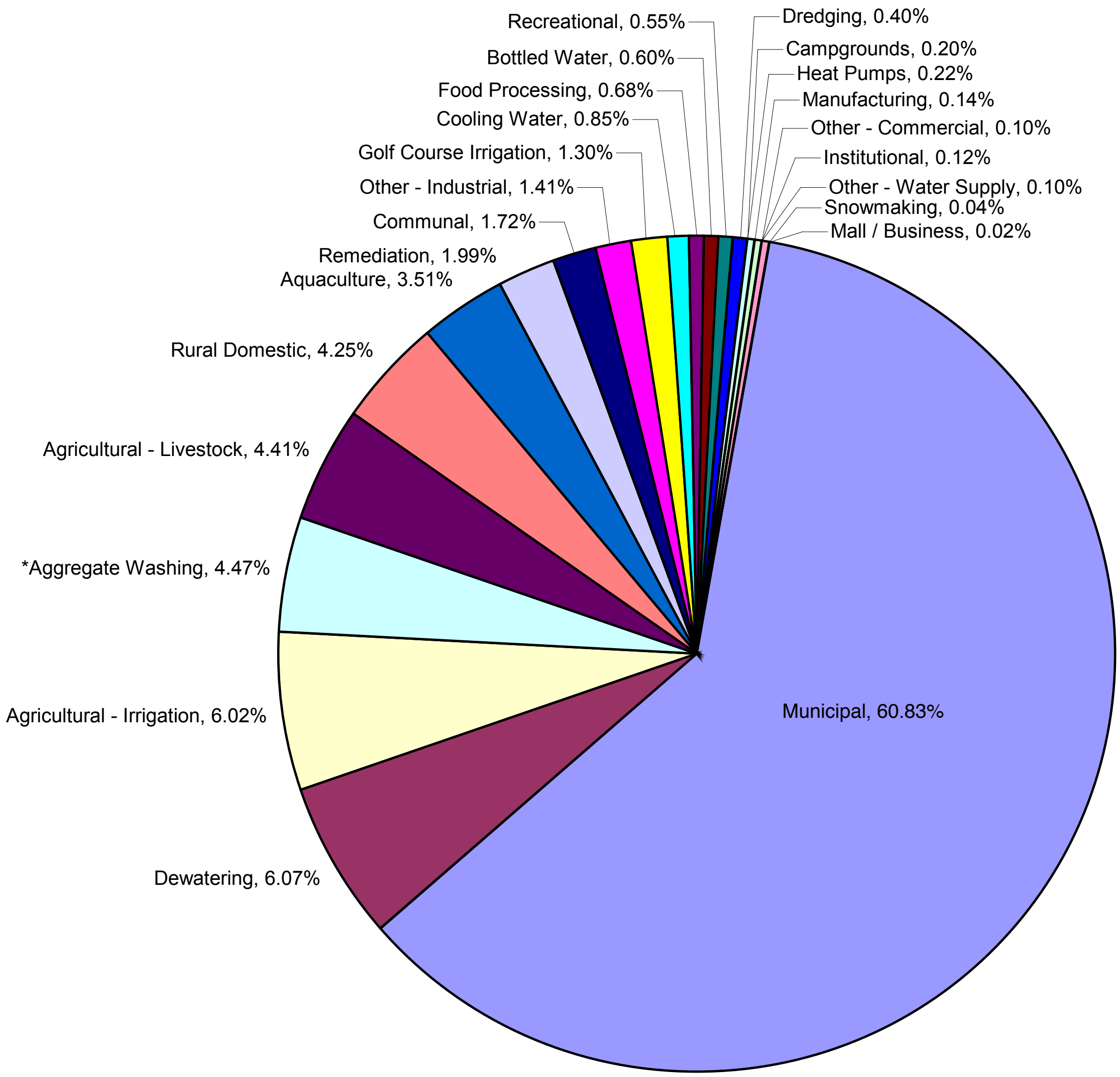

Figure 6: Major Water Uses for the Grand River Watershed (Wong, 2011).

The GRCA considers golf course irrigation and agriculture irrigation to be climate sensitive, meaning that the amount of water applied to both golf courses and agricultural fields varies each year due to changes in climate (Bellamy and Boyd, 2005). Although these comparisons do not apply to the provincial scale, it is clear that golf courses in the Grand River watershed compete with other high water using sectors, particularly during the summer months.

The latest data provided by the Great Lakes Regional Water Use Database (GLRWUD) allows for provincial comparisons. In 2011, 74% of Ontario's water use was withdrawn for nuclear power, 14% was withdrawn for fossil fuel power and 5% was withdrawn for public supply (Figure 7) (Great Lakes Commission, 2013). According to Figure 7, irrigation represents a very small proportion of Ontario's water taking. Irrigation includes any water that is applied to the land to "assist in the growing of crops and pastures or in the maintenance of recreational lands, such as parks and golf courses" (Great Lakes Commission, 2013). The data provided in Figure 7 suggests that roughly 280 million L of water are taken a day, and 101 billion L of water are taken each year, for irrigation purposes in Ontario. The provincial estimate for golf course water use calculated in this thesis suggests that 50.5 billion L of water is used each year to irrigate Ontario golf courses, during a normal season. Based on this information, it can be estimated that Ontario golf courses use, on average, 50% of the water withdrawn for irrigation purposes and the remaining 50% of water withdrawn for irrigation purposes is applied to agriculture fields and other recreational lands. Since this estimation has been generated from two different databases, it is likely that the water use recording requirements and measurements, as well as the way in which water use is analyzed, is inconsistent. Therefore, the water use comparison may not be an accurate estimation and further investigation is required.

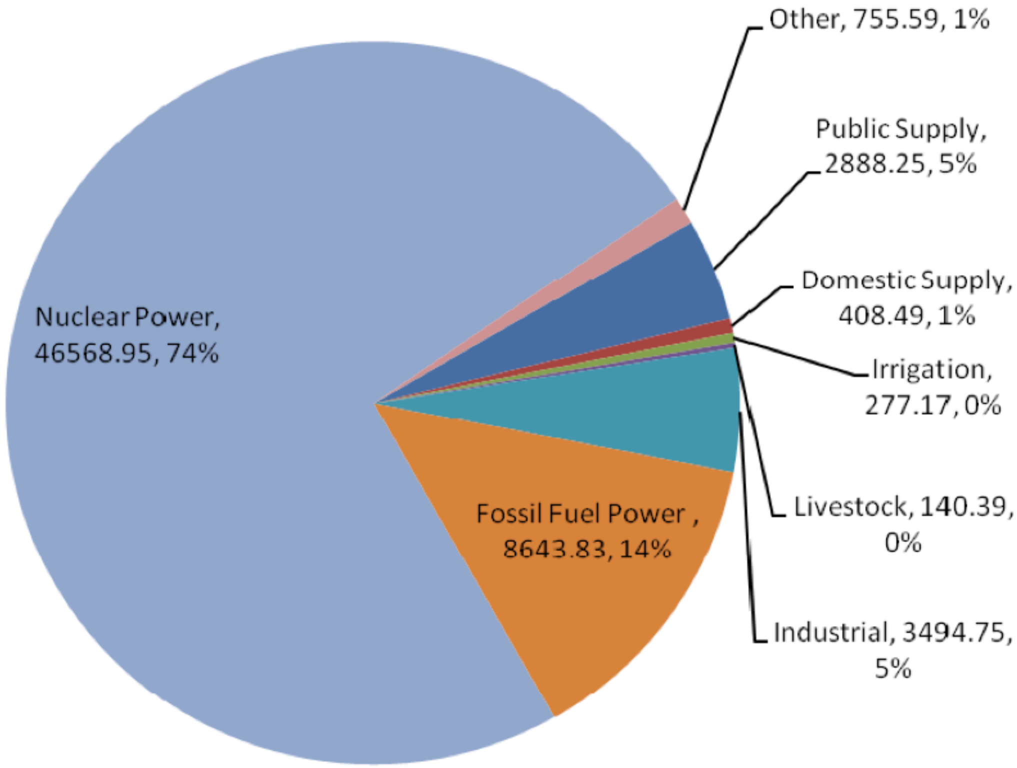

Figure 7: 2011 Ontario Water Use (Millions of Litres/Day)
(Great Lakes Commission, 2013).

Although irrigation withdrawals represents a small proportion of Ontario's total water withdrawals, it remains important to increase irrigation efficiency and reduce irrigation water consumption to ensure future sustainability of Ontario's water resources. Now that comparisons between water-intensive industries can be made and water taking data is publicly available for Ontario golf courses, the public can be better informed about golf course water consumption and more water conservation strategies can be developed within the province.

5.2 How May Predicted Climate Change Influence Golf Course Water Use in Ontario?

The fourth and final research question of this thesis was to identify how examined climate change may influence golf course water use in Ontario. To reiterate the details presented in section 2.4.1, climate change is expected to extend the season length of golf in Ontario by up to seven weeks by 2020 and by up to 12 weeks by 2050 (Scott and Jones, 2006). In order to maintain aesthetically pleasing golf courses during an extended season length due to warmer temperatures, it is expected that the need to irrigate and fertilize will intensify in response to not only the warmer temperatures, but also due to increased turf stress and damage, shallow root zones, increased weed infestation and increased play due to a lengthened golf season.

A climate change analogue has been used to identify how increased temperatures caused by climate change may influence golf course water use in the future. A climate change analogue allows for water use comparisons among golf courses in the same regions that experienced differences in average seasonal temperature and precipitation during the climatically normal season and the climatically dry season. In order to estimate how future golf course water use may change due to increased temperatures, the average seasonal temperature and precipitation during the climatically dry season for each climate station was first compared to the 1981-2010 climate normals. The dry season was identified for each climate station (Table 2.8): 13 climate stations identified the year 2007 as the dry season, three climate stations identified 2011 as the dry season and three climate stations identified 2012 as the dry season. When compared to the 1981-2010 climate normals, the climate data showed that during the dry representative season:

- 2007 was 1.3°C warmer and received 35% less precipitation;
- 2011 was 0.9°C warmer and received 16% less precipitation; and
- 2012 was 0.9°C warmer and received 19% less precipitation.

Once the average seasonal temperature and precipitation during the dry season was identified for each climate station, the change in temperature and precipitation was compared to future climate change projections. Although future climate change projections are variable, A2 projections suggest that by mid-century (2050), three regions in Ontario will experience an increase in temperature, particularly during the summer months:

- Eastern Ontario is expected to warm by 1°C or 2°C;
- Northern Ontario is expected to warm by 2°C or 3°C; and
- Southern Ontario, where golf course density is greatest, is expected to warm by 2°C or 3°C.

(Colombo et al., 2007).

Furthermore, southern, northern and eastern Ontario are expected to receive 10% less rainfall during the summer months by 2050, receiving between 360mm to 540mm, under the A2 climate change scenario (Colombo et al., 2007). Since golf course density is greatest in southern Ontario, the climate change analogue was used to estimate how water use will increase in the southern Ontario region. As is shown in Table 2.9 in Chapter Three, the normal season identified in this thesis is only 0.2°C warmer and received 1% more precipitation than the 1981-2010 climate data. If the identified normal golf season is to reach the mid-century A2 climate change projection for southern

Ontario, average temperatures will need to increase by up to 2.8°C and precipitation will need to decrease by 11%.

The research conducted for this thesis found that the dry representative season occurred during three different years (2007, 2011 and 2012) for golf courses in Ontario due to their location. In general, the dry season experienced an increase in average seasonal temperature by 1.2°C and a reduction in average precipitation by 30% from the 1981-2010 climate normal. This change in temperature and precipitation resulted in an average increase in water use by 93%. Since 2011 experienced similar temperature (+0.9°C) and precipitation (-16%) changes to what is expected to occur mid-century under the A2 climate change scenario, golf course water use during the 2011 dry season was analyzed in order to estimate future water use under climate change. The data showed that in the 2011 dry season, golf course water use increased by an average of 151%. Although the 2011 dry season was only 0.9°C warmer, rather than the projected 2°C increase, it is believed that by 2050 the water use during a normal golf season will be similar to the water use during the 2011 dry season in southern Ontario. This means that average seasonal water use will likely increase by 151%, which equates to two and a half times our normal water use today. With the prediction that future water use will likely increase by 151% by 2050, it becomes very important that golf courses adapt best management practices, and particularly water conservation strategies to mitigate negative impacts on Ontario's freshwater resources.

5.3 Potential Water Savings

The analyses for this thesis indicated that water use varies substantially among golf courses, even among golf courses with similar characteristics of soil type or golf course type. In order to estimate potentially achievable water savings, the median seasonal water use, rather than the average seasonal water use, was identified for golf courses in the sample of key characteristics in order to eliminate the influence of large outliers in the data (Table 4.1). For some key course characteristics, the difference between the minimum water use and the maximum water use was as high as 9,719%. Eliminating the outliers in the data allowed for a more accurate representation of the average water use for golf courses in the sample.

Table 4.1: Median Seasonal Water Use (L/Ha) For Golf Courses of Different Soil Type and Golf Course Type During a Climatically Normal Season

Soil Type	Golf Course Type					
	Public	Semi-Private	Private	Premier Public	Premier Semi-Private	Premier Private
Sand	790,000	880,000	740,000	-	970,000	1,400,000
Silt	430,000	370,000	800,000	1,200,000	-	980,000
Clay	570,000	870,000	1,300,000	-	-	860,000

As discussed in section 3.6, in each key characteristic group, the water use of the golf course in the 80th percentile was identified and compared to the median water use. Using the 80th percentile, instead of using the golf course with the lowest average water use, not only eliminated outliers that could be caused by reporting problems, but it also eliminated the low end golf courses in Ontario that are very poorly managed and rarely irrigate for aesthetics or playability. Eliminating these golf courses was important for estimating potential water savings since the average golf course in Ontario irrigates not only to maintain healthy turf but also to maintain an aesthetically pleasing appearance.

Since there was only one golf course in the premier semi-private category and two golf courses in the premier public category, water use comparisons were not made due to low confidence with the small sample size; therefore they were excluded from the water savings prediction (Table 4.2).

Table 4.2: Potential Water Savings For Ontario Golf Courses of Key Characteristics: Based on the Median Water Use and the Average Water Use of Golf Courses in the 80th Percentile During a Climatically Normal Season

Soil Type	Golf Course Type			
	Public	Semi-Private	Private	Premier Private
Sand	-46%	-57%	-30%	-42%
Silt	-76%	-14%	-36%	-12%
Clay	-27%	-38%	-29%	-14%
Total Average	-35%			

The results showed that the greatest potential water savings could be made for public golf courses that are comprised of silt dominated soil. The data suggests that these golf courses could potentially reduce their water use by 76% if they adopt similar irrigation and management practices similar to the golf course in the 80th percentile of that category (i.e. another public golf course on silt soil). On average, these results also show that if every golf course in each key characteristic group reduced their water use to an amount similar to the golf course in their 80th percentile category, provincial water use could be reduced by 35% for Ontario golf courses. In order for these water savings to occur, it is likely that golf courses will need to upgrade their irrigation equipment and alter their management practices to be less intensive, which in turn will also require golfers to accept imperfections on the golf course, such as inconsistent turf colour, coupled with a change in mowing heights and green speeds. Although this research did not involve gathering primary data from each individual golf course, further research by means of interviews and surveys is recommended to understand what the golf courses in the 80th percentile are doing, in terms of their irrigation systems and management practices, to conserve water. Based on Chapter Two of this thesis, it is believed that the golf courses in the 80th percentile are reducing their irrigation requirements by integrating certain tools and instruments, such as soil moisture meters and weather stations that assist in making irrigation practices more of a science than a guessing game. Understanding the golf course processes involved with conserving water will be even more valuable in the future since climate change is expected to increase the average seasonal water use for golf courses in Ontario (see section 5.2).

Chapter Six: Recommendations and Conclusions

6.1 Introduction

Due to the potential for average seasonal water use to increase by 151% by 2050 due to warming temperatures and changes in precipitation, it is necessary that Ontario golf courses invest in water conservation strategies prior to intensive climate change to ensure future prosperity within the industry. Ontario golf courses should voluntarily work with Ontario's municipalities and their advocacy bodies, and invest in water conservation strategies available to them today, which include incorporating soil moisture meters into their management techniques, naturalizing the golf course to include native turfgrass species and vegetation, and by using several water sources for irrigation purposes. Incorporating these water conservation strategies can lead to reduced irrigation water consumption, increased drought resistance and improved golf course aesthetics. Investing in water conservation strategies will prove to be critical in the decades ahead since water challenges and competition among water users will likely increase because of a reduced supply (Bellamy and Boyd, 2005; Colombo et al., 2007; de Loë and Berg, 2006). Now that characteristics have been identified that directly influence golf course water use, the development, management and irrigation practices of golf courses can be adjusted in order to reduce irrigation water consumption.

6.2 Recommendations for Golf Courses

Based on the reviewed literature discussed in section 2.2, there are several development strategies available to golf courses that encourage sustainable and environmentally friendly golf courses. In order to ensure golf course development is conducted in a sustainable manner, with minimizing irrigation water consumption as a main focus, it will be necessary for the government to collaborate with the golf industry and incentivize golf courses to implement best management practices and perhaps even subsidize some of the water conservation technology. Incentivizing golf courses to reduce their water use could lead to the estimated 35% reduction in water use for Ontario golf courses.

Golf course development can safeguard the environment if sustainable practices are integrated during the establishment, or reconstruction, of the golf course. To enforce such sustainable practices, the municipal and provincial governments should administer obligatory studies, such as EIAs of noise, waste, hydrogeology, management plans, construction mitigation plans, etc., (see section 2.2.2) in any area that a golf course is to be developed or reconstructed, not only when a zone change is requested. Ensuring that these types of EIAs are conducted will improve the sustainability and environmental protection of future golf courses.

However, it is the golf courses that are currently in operation that have the largest potential to save water by altering their management techniques. Based on the data analysis in section 5.3, it is believed that if every golf course in Ontario reduced their current water use to a quantity more similar to that of the golf courses in the 80th percentile of the sample, water savings of 35% are possible. Although this research did not examine the differences in management techniques among the golf courses in the sample, Chapter Two of this thesis identified several water conservation strategies that can be easily integrated into everyday techniques on the golf course. A brief summary of these practices is provided in Table 5.1. It is strongly believed that if further research were carried out to identify management practices of the golf courses in the sample, several of the water conservation strategies and BMPs identified in Table 5.1 would likely already be integrated into the management techniques of the golf courses in the 80th percentile. If the Ontario government incentivizes golf courses to incorporate these BMPs, it is likely that the estimated water savings could be achieved.

Table 5.1: Summary of Best Water Management Practices That Can Reduce Water Use on Golf Courses

Best Water Management Practices That Can Reduce Water Use on Golf Courses	
Incorporate natural features of the landscape into the golf course architecture	Incorporate drought-tolerant turfgrass
Frequently use wetting agents to increase the soil moisture	Frequently cultivate the soil to increase infiltration
Retrofit or install appropriate irrigation systems for individual golf courses (i.e. single or double row system, full circle or half circle irrigation heads, etc.)	Irrigate the turfgrass during appropriate timeframes (i.e. early in the morning or late at night)
Irrigate with collected stormwater or effluent water	Design new golf courses with environmentally friendly designs (i.e. maintain natural land contours, water features and flora and fauna)
Incorporate soil moisture sensors to make irrigation a science rather than a guessing game	Minimize chemical applications on the turfgrass
Recapture irrigated water via the drainage system to redirect surplus water back into the irrigation reservoirs	Perform irrigation audits to identify irrigation inefficiencies
Maintain a vegetated buffer system of natural vegetation around all water features	Reduce the irrigation area by practicing "maintenance up the middle"

Characteristics other than seasonal temperature and precipitation that were found to influence golf course water use were soil type and golf course type. It was found that, on average, golf courses comprised of sand and silt dominated soils required 95% more water during a climatically dry season than during a climatically normal season. Furthermore, golf courses comprised of clay dominated soils required 13% less water than golf courses on sand and silt dominated soils during a dry season. In order to reduce irrigation requirements for golf courses comprised of sand and silt dominated soils it is recommended to regularly apply wetting agents and practice soil cultivation techniques to improve the soil moisture content. These practices will reduce irrigation requirements and maintain golf course aesthetics. In addition, if any section of a golf course comprised of sand or silt dominated soil is reconstructed, it is suggested that a small amount of clay soil be added into the soil mix to increase the soil moisture content in hopes of reducing irrigation requirements.

This study also found that private golf courses increased their water use by the greatest amount during the dry season (+86%). It is hypothesized that the reason for such a high water use increase is due to the “Augusta National Syndrome” and member perception, despite efficient irrigation systems. Observations from personal experiences with the golf industry indicate that it is usually the private golf courses and premier golf courses that heavily invest in water conservation strategies by integrating weather stations and soil moisture meters. Soil moisture meters and weather stations have been available to the golf industry for quite some time, however, it has not been until recently that they have become more affordable and the science behind the tools more accurate. Private and premier golf courses were the first golf courses to integrate these water conservation tools into their management practices because of their large maintenance budgets. This has created an advantage over other golf courses that are just now integrating these tools into their management practices. The superintendents of the private and premier golf courses are highly experienced and educated with these tools regarding the irrigation requirements of their course, while the superintendents of other golf course types are now only just experimenting with the tools and learning the science behind their course's irrigation requirements. Despite their experience with these tools, water use is greater among private and premier golf courses than public golf courses. This suggests that superintendents at these golf course types need to be more aware of the irrigation requirements of their golf course.

Although literature suggests that incorporating these water conservation tools into everyday management techniques on the golf course can reduce irrigation requirements (Augustin and Snyder, 1984; Bremer and Ham, 2003), the potential water savings are dependent on the education of the operator or superintendent, as is demonstrated with the high water use of private and premier golf courses. It is important that the golf industry increases their role in educating superintendents with regards to water conservation strategies and the proper use of tools, while also providing them with information regarding typical water use on golf courses of different golf course types and soil types. It would be very beneficial for Ontario and Canadian golf courses to receive frequent golf reports regarding current water use and water conservation practices, and attend frequent workshops and seminars hosted by the Canadian Golf Superintendents Association and the respective provincial associations, as is done by the United States Golf Association. It is hypothesized that as water conservation technology becomes more accurate and less expensive, especially if the government subsidizes this technology, more golf courses in Ontario will be able to reduce their irrigation consumption and become more efficient with their water resources.

In addition to soil type and golf course type, golf course management, particularly regarding irrigation practices, can greatly influence water use. Throssell and colleagues (2009) found that 80% of the turfgrass located on a standard 18-hole golf course in the United States was irrigated and maintained. The turfgrass receiving the greatest amount of irrigation was the rough and fairways, representing 50% and 38%, respectively, of the total irrigated area. In contrast, the turfgrass receiving the least amount of irrigation is the tees and greens, representing 4.2% and 4.6%, respectively, of the total irrigated area. Since a large proportion of irrigation occurs in the rough, an area golfers typically try to avoid, it is recommended that golf courses reduce the frequency and quantity of irrigation in the rough and accept drier playing conditions; add clay soil to the soil mix to enhance moisture content on fairways and in the rough; and/or integrate drought-tolerant turfgrass that requires less irrigation into the rough and fairways. Integrating any or all of these recommendations will likely result in further irrigation savings. Although this information is unavailable for Ontario golf courses, if the values are similar there is a large possibility to reduce water use. It is therefore recommended that research regarding the irrigated area of Ontario golf courses be completed to further identify where additional potential water savings are possible on the golf course.

With regards to water use, the Ontario PTTW program is the only enforceable program that deals with water withdrawals. Each permit, which can be issued for a maximum of up to 10 years, is allowed to withdraw a total quantity of water for the duration of the permit (Ministry of Environment, 2005). As discussed in section 2.2.3, the purpose of the PTTW program is to conserve and protect Ontario's freshwater resources by ensuring fair sharing while minimizing competition among water users; increasing public awareness regarding water taking activities; and by ensuring water conservation initiatives are implemented by those withdrawing water (Ministry of Environment, 2005). Since climate change is expected to alter the availability of our freshwater resources, frequent changes to water conservation and sustainability initiatives is likely to occur.

By allowing a permit to be active for 10 years, the MOE reduces the opportunity to update water taking rules and enforce new innovative conservation and sustainability initiatives to these long-term permits. Therefore, it is recommended that the duration of the permits be reduced to five years so that water taking rules can be frequently updated to meet the latest water use requirements. If, however, golf courses would prefer to have a permit for a ten-year period because of convenience, it is highly recommended that the MOE enforce the golf course to a) fully report their water use each year to ensure there is no missing data, and b) perform an irrigation audit after five years of the permit being active. Enforcing an irrigation audit will likely encourage golf course management to act sustainably when applying irrigation to the golf course and to maintain efficient equipment throughout the life cycle of the golf course. If the irrigation audit reveals distribution inefficiencies, the MOE should require the golf course to repair or perhaps even upgrade the irrigation system in a timely manner without penalization. If the golf course is non-compliant with data reporting, the MOE should pursue a more aggressive approach (i.e. fines, permit cancellations, etc.). Shortening the duration of the permit and enforcing an irrigation audit may incentivize golf courses to consistently invest in current water conservation strategies and voluntarily reduce golf course irrigation since failure to meet the permit requirements can result in fines or loss of permit. It is recommended that if golf courses are compliant with the terms of their permit and voluntarily reduce their irrigation water consumption, the government should compensate the golf courses that take meaningful action with tax breaks for capital investment or subsidized water conservation technology in order for them to maintain aesthetics and maintain revenue.

Educating the people involved with making management decisions on the golf course regarding characteristics that influence golf course irrigation could result in more sustainable management practices. If education is paired with government incentives, voluntary BMPs such as soil moisture meters and weather stations will likely be integrated on all golf course types. Increasing superintendents' awareness of irrigation water consumption, soil moisture content, evapotranspiration rates, environmental impacts and innovative conservation strategies would likely aid in sustainable management and reduce irrigation water consumption.

6.3 Recommendations for the MOE's PTTW Database

This research revealed new information regarding water takings of golf courses in Ontario. Although the PTTW program has a high compliance rate, as is discussed in Table 4.1 in section 3.2, there are many problems with the self-reported data that limits analysis that can be done with it. As is discussed in section 3.7, the human error aspect of self-reporting data, the exclusion of some golf courses in the PTTW program, the ambiguity of some golf courses and the inconsistent naming of some golf courses and their locations significantly limit research opportunities that could result in advances in water use efficiency. These data limitations, as well as the quality of the data, are entirely consistent with the ECO's criticisms regarding the inconsistencies and deficiencies of the PTTW data.

To create a more reliable database it is recommended that the MOE develop a more accurate reporting system for golf courses in Ontario. It is suggested that the reporting system not be self-reporting but rather a system that automatically records and reports the amount of water that is pumped through the irrigation system on a daily basis. This will reduce the human error aspect in the database and reduce the unexplainable outliers, creating a more reliable database. In addition, it is recommended that the MOE require better identification of the golf courses in the database and maintain a consistent organization name and location. Since the permit number can change from year to year depending on its expiry date, it is recommended that a more concrete identifier be included, such as the address of each individual golf course or the municipal tax roll number for the golf course property.

Lastly, it is recommended that the MOE develop a generic water use questionnaire that will allow the database to expand its information on golf course water use. The questionnaire should be administered when each permit is renewed, and should include generic questions such as:

a) How many holes is your golf course comprised of?
b) What is the irrigated area of your golf course?
c) Has the irrigated area of your golf course changed recently? If so, how?
d) Has your golf course administered any irrigation upgrades recently? If so, what were the upgrades? And,
e) How is water use measured at your golf course (i.e. self-reported, measured electronically, etc.)?

If the MOE has this type of information for each golf course with a PTTW, agencies in the future will have more evidence to make more accurate claims regarding water use. Incorporating any of these suggestions will advance the database, increase its reliability, allow for future water use comparisons and provide more valuable data for future research and water efficiency program development.

6.4 Conclusions

The Ontario golf industry is an important economic player in both the Ontario and Canadian recreation and tourism economy (Ontario Ministry of Tourism, 2006; SNG, 2009). As the pressure on water use increases in Ontario due to estimated population growth (Ontario Ministry of Finance, 2006) and climate change impacts (Colombo et al., 2007, IPCC, 2013), it will become essential for the golf industry to more closely monitor water use by reducing when and wherever possible, in order to remain profitable and operate as a socially responsible industry. In order for the golf industry to reduce their irrigation water consumption and become more sustainable at managing Ontario's freshwater resources, a baseline dataset of current irrigation water consumption was completed by this thesis.

In the past, the golf industry has faced criticisms from anti-golf organizations regarding excessive and inappropriate water use. However, the golf industry in Ontario has never responded to these criticisms with actual water taking data to support their claims of environmental sustainability. This research has provided the first approximation of water use by the Ontario golf industry for irrigation purposes. Now that sustainability initiatives and biophysical characteristics that influence golf course water use have been explored and the average annual water use for Ontario golf courses has been estimated, the Ontario golf industry can increase their environmental stewardship. Because of this research, the Ontario golf industry is better informed regarding their water taking patterns and therefore can adjust their maintenance practices to become even more environmentally friendly, to assist in the protection of Ontario's freshwater resources, to development more comprehensible water conservation plans and to develop standardized irrigation practices. Additionally, since climate change is expected to increase golf course water use in Ontario, golf courses can begin launching mitigation and adaption plans to prepare for future climate change. In order to maintain current golf course aesthetics and playability, it is likely that golf courses will have to adapt their current management techniques to revolve around reduced irrigation, especially since water availability is expected to reduce due to climate change. Adapting to warmer temperatures and reduced precipitation while maintaining current golf course aesthetics and playability may involve integrating drought-tolerant turfgrasses, reducing the irrigated area of the golf course, integrating native vegetation and turfgrass, incorporating soil moisture meters, frequently applying wetting agents and regularly cultivating the soil.

This research has calculated the average seasonal water use for an 18-hole equivalent golf course in Ontario, during a climatically normal season, to be 59.6 million L/Ha. In addition, it has calculated a provincial estimate of seasonal water use to be 50.5 billion L of water a season. Identifying the water use of Ontario golf courses can lead to irrigation improvements within the golf industry and allow future irrigation improvements to be recorded and verified. Further research is needed to correct the data inaccuracies and discrepancies within the PTTW program, to identify cost savings associated with reduced irrigation water consumption and to identify how specific BMPs in Ontario can reduce irrigation water consumption, particularly regarding soil moisture meters, drought-tolerant turfgrass and practicing “maintenance up the middle” (Augustin and Snyder, 1984; Bremer and Ham, 2003; Carrow and Duncan, 2007; Hartwiger, 2012; Mccarthy, 2006; Mitra et al., 2006).

The results of this research have reduced knowledge gaps regarding biophysical characteristics that influence golf course water use in Ontario. In addition, it has identified potential water savings that would likely be achieved through best management practices and water conservation strategies. To achieve the potential water savings of 35%, it is necessary that the government and the golf industry collaborate and educate those who make management decisions on the golf course. Increasing the education of superintendents and managers will encourage the proper integration and use of conservation programs and tools. The collaboration of the government and the Ontario golf industry, along with incentives and subsidizations, will not only protect Ontario’s freshwater resources but it will advance the sustainability of the golf industry in Ontario.

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