Water Supply Planning for Landscape Irrigation in Virginia

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ABSTRACT

A water supply plan approach was used to investigate irrigation application on landscaped areas in Virginia with a focus on turfgrass. The economically-important turfgrass industry in Virginia should be proactive in conserving drinking water supplies to meet human consumption needs, especially in drought times. This thesis investigates current irrigation water supplies, water supply sustainability, and alternative water sources to meet irrigation demands and offers an insight on how potable water is unnecessarily consumed for non-potable irrigation needs.

A Virginia evapotranspiration website was developed to offer a scientifically based source for efficient irrigation scheduling. The website was developed using a collaborative and user-centered design method, which included potential users in the process. The final website is hosted on the Virginia Tech website at http://www.turf.cses.vt.edu/Ervin/et_display.html and utilizes data from weatherstations throughout the state.

Evapotranspiration-based irrigation was tested at three case study sites in Blacksburg, Williamsburg and Norfolk, Virginia to assess potential water conservation. In Williamsburg, a 55% water savings was reported with evapotranspiration-based irrigation. In Blacksburg, slightly more water was applied on research greens irrigated based on evapotranspiration demand. Significantly less water was applied in Norfolk, compared to the evapotranspiration-based irrigated plots. The study also uncovered increased confidence to alter irrigation systems and the need to conduct irrigation audits when irrigating based on evapotranspiration.

Evapotranspiration-based irrigation, reclaimed water and harvested rainwater were investigated to determine feasibility for meeting irrigation demands, while reducing potable

water consumption at four case study sites in Blacksburg, Fairfax, Williamsburg and Norfolk, Virginia. Due to the limited collection potential at the Blacksburg site, reclaimed water and harvested rainwater was not feasible. However, the on-site weatherstation could offer a unique opportunity to calculate evapotranspiration. In Fairfax, all three alternative water sources could be integrated to supply enough water to irrigate a soccer field and adjacent athletic fields and save an estimated $7,000 per season in potable water costs. Harvested rainwater at the Williamsburg site could supplement the irrigation pond and reduce reliance on groundwater. In Norfolk, reclaimed water use is economically feasible, but rainwater harvesting could meet the irrigation needs, while evapotranspiration-based irrigation is too labor intensive for homeowners.

DEDICATION

This dissertation is dedicated to the person who first put the crazy notion in my head that graduate school and a Ph.D. were in my future, Dr. T. L. Senn. Thank you for your advising, ongoing support and reminders that hard work is worthless if not accompanied by happiness.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1: INTRODUCTION & OBJECTIVES

Water supply issues are paramount in today's environmental and social landscape. What is typically considered a western US problem is now plaguing the East Coast. During 2007, southwest and Northern Virginia received 36 and 35 inches of rain, respectively compared to the normal 45 inches (National Weather Service 2007; National Weather Service 2008). The 2007 dry year sparked Governor Kaine to request a statewide drought disaster declaration due to significant crop losses (Commonwealth of Virginia 2007a). On October 30, 2007, the Governor issued another notice urging Virginia localities "to update water conservation and drought contingency ordinances and plans and begin preparations to implement those plans" (Commonwealth of Virginia 2007b). The Governor stressed the need to plan for future drought occurrences and reducing non-essential water use. In 2007, all of the Southeast including, Virginia, Tennessee, North Carolina, South Carolina, Georgia, Florida, Mississippi, Alabama, and Louisiana were identified as receiving "much below normal" precipitation (National Climatic Data Center 2008)

Virginia and national populations increased 8.9% and 7.2% from 2000 and 2007, respectively. These increasing populations are straining fresh water supplies due to the increasing demands. Water authorities have the priority to supply the population drinking water and if water levels are threatened, secondary water usage like irrigation will be restricted or banned. Fresno, California farmers are even selling their irrigation water rather than producing a crop because water is worth more as drinking water than irrigation water (U.S. Water News Online 2008a).

Virginia agriculture relies on supplemental irrigation to enhance plant growth and ensure revenues. Turfgrass is one of the state's top agricultural products and has proven to offer more revenue than other irrigated crops per acre. Golf courses use 4,170 gallons of water per acre per day, while corn and grape production consumes 2,521 and 3,879 gallons of water per acre per day, respectively. However, golf courses receive $18,480 per acre in revenue compared to

$2,453 and $189 per acre for grapes and corn, respectively (SRI International 2006). In 2004, the turfgrass industry supplied $1.2 billion in labor, which was a 43% increase from 1998, the last time an economic report was conducted (NASS 2006). Another study, which focused primarily on the Virginia golf course industry, found the 2005 Virginia golf industry supplied $3.1 billion of direct, indirect and induced economic output (SRI International 2006). Turfgrass and landscape irrigation uses approximately 65% of the country's potable water supply, with 75% of this amount being consumed in the western US (Barrett 2004; Hutson et al. 2004). The Virginia golf industry, however, accounts for only 0.4% of the state's water use, whereas Virginia agriculture accounts for 1.4% (DEQ 2005). Such a large and economically influential industry should be proactive in water conservation endeavors to ensure its continued success.

To address Virginia's impending water supply issues, water planners must look to alternative water sources. Alternative water sources encompass ground water and surface water sources as well as desalinization, reclaimed water, rainwater harvesting and conservation (AWWA 2001). When considering future water supplies, planners and scientists often have to evaluate all the available water source options, especially if calculated demand exceeds projected water supplies.

Reclaimed water, rainwater harvesting and conservation will be investigated as alternative water sources for irrigation needs. Virginia recently passed a regulation that encourages the use of reclaimed water (2008b). Reclaimed water is water from wastewater treatment plants that has been treated to adequate levels for land application, but not drinking water (Haering et al. 2008; HRSD 2006). Rainwater harvesting is rising in popularity as it is a moderately inexpensive system to install and provides water on-site for non-potable needs like irrigation (LaBranche et al. 2007). Irrigation water conservation can be addressed through evapotranspiration-based scheduling, which calculates water requirements based on plant transpiration and soil evaporation potential. Calculated real-time evapotranspiration is not currently available in Virginia unlike other US states (Arizona Board of Regents 2007; Colorado State University 2007; State of California 2005; Texas A&M University 2004; University of Idaho 2007; University of Oklahoma 2007).

This research will assist in developing a Virginia irrigation water supply plan, specifically for irrigated turfgrass areas. Turfgrass irrigation practices will be highlighted throughout due to the economic impact the turfgrass industry has on Virginia and available cooperation. The theories utilized in and developed from this research can be applied to both turfgrass and mixed ornamental horticultural areas.

The collaborative process, a planning discipline based theory, will be incorporated with user-centered website development and an information technology discipline based theory, to assist in an evapotranspiration website creation process as means to develop a user-friendly and easy to use website. Three turfgrass case studies will be employed throughout Virginia to test evapotranspiration-based irrigation scheduling and to implement the proposed website in a research study. Finally, the three case study sites will serve to delineate the practicality of utilizing alternative water sources to meet turfgrass irrigation demands. All three portions of the research will assist Virginia water planners in understanding water consumption practices of different turfgrass irrigation water consumers.

Objectives:

1. To create a collaborative process to determine information that should be included in a website containing climate and ET data to be used for landscape irrigation scheduling.
    a. To collaboratively create an ET website through the use of surveys and website prototypes.
2. To employ irrigated turfgrass case studies to assess conservation and alternative water source effectiveness.
    a. To determine if water use could be reduced when employing ET-based irrigation scheduling compared to normal irrigation practices.
    b. To investigate ET-based irrigation conservation, reclaimed water, and rainwater harvesting as alternative irrigation water sources.

Chapter 2: Literature Review

Virginia Water Issues

Although Virginia is considered a wet state as it receives around 45 inches of rainfall a year, Virginia has dealt with and will continue to deal with its own water supply issues. Many of the water supply issues are the result of periodic drought occurrences compounded by increasing population demands.

Drought and Legislation

According to the National Oceanic and Atmospheric Association's Palmer Drought Severity Index, Virginia experienced a range of drought conditions from 1999 to 2002 (NOAA 2005). This four-year drought spurred government officials and water consumers alike to adopt water consumption conservation practices. Governor Mark Warner issued Executive Order #39 to address the drought and ensure Virginia has an adequate water supply to meet future demands (Warner 2002).

Through Executive Order #39, the Drought Management Task Force was developed. The Task Force consisted of groups and agencies involved in water management such as: Mid-Atlantic Car Wash Association, Virginia Agribusiness Association, Virginia Turfgrass Council, Virginia Golf Course Superintendent's Association, Virginia Municipal League, and Virginia Water Well Association (DRTAC 2003). Individuals on the Task Force assessed drought severity stages ranging from "drought watch" to "drought emergency" and the associated conservation activities that will occur at the various stages. In reference to landscape irrigation, home lawn, golf courses, and athletic fields will be subjected to mandatory water conservation only under a "drought emergency" (DRTAC 2003). A "drought emergency" level indicates that stream flows and groundwater have fallen below the 5th percentile, reservoirs contain 60 days or less supply, and/or precipitation has fallen below the 60% normal level (DRTAC 2003).

Deficit snow fall from the 2006 and 2007 winter months led to equally dry spring and summer months. Virginia statewide drought intensity ranged from moderate to severe, becoming more severe as the summer and fall months passed (NOAA 2007). Rainfall from October 2006 to September 2007 was 19% below normal, with increasing drought occurrences as rainfall from October 2006 to April 2008 was 22% below normal (USGS 2008a). Areas like the New River Valley, Northern Piedmont, and the Upper James were 38% to 35% below normal rainfall from April 2007 to 2008 (USGS 2008a).

On October 18, 2007, Virginia Governor Tim Kaine requested statewide drought disaster declaration due to significant crop losses (Commonwealth of Virginia 2007a). York and Arlington counties along with Alexandria, Bristol, Falls Church, Poquoson, and Norton cities were among the noted contiguous disaster areas (USGS 2008a). Then on October 30, 2007, the Governor issued another notice urging Virginia localities "to update water conservation and drought contingency ordinances and plans and begin preparations to implement those plans" (Commonwealth of Virginia 2007b; Sluss 2007). The Governor stressed the need to plan for future drought occurrences and reducing non-essential water use.

In January 2008, 13 water supply localities were under mandatory water restrictions and 31 public water supply localities were under voluntary restrictions (USGS 2008b). Rainfall increased in 2008, which resulted in less water restrictions. Throughout the year, around four localities were under mandatory water restrictions, while 20 were under voluntary restrictions. At the end of 2008, Virginia statewide rainfall was considered slightly below normal (USGS 2008c). The York-James region, which encompasses Williamsburg, was the lowest below normal (69%) from January 2008 through November 2008, while the Northern Virginia area was at the highest (104%) (USGS 2008d).

Population Effects on Water Supply

Virginia's water issues are confounded by the continuous population increases. Virginia was recently identified as the best state in which to do business (Hickey 2007; Pollina Corporate Real Estate Inc. 2007). The rating is based on the combined assessment of six key points: business costs, labor issues, regulatory environment, economic climate, growth prospects, and overall quality of life (Hickey 2007). Population statistics reinforce that Virginia is a desirable place to live and do business. However, this climbing population is placing a strain on our natural resources, like fresh water.

Virginia's population increased by 12.5% from 1990 to 2000 and 7.4% from 2000 to 2005 (U.S. Census Bureau 1990; U.S. Census Bureau 2000; U.S. Census Bureau 2006). Between 1997 and 2001, public water supply withdrawals from groundwater and surface water have increased by 12.7% and 1%, respectively. Comparatively, crop irrigation water usage between 1997 and 2006 has decreased by 2.6% for groundwater and 1.5% for surface water (DEQ 2003; DEQ 2007). Between 2002 and 2006, public water supplies consumed 58% of the combined groundwater and surface water resources in Virginia, while crop irrigation consumed 1% (DEQ 2007). Crop irrigation water consumption has decreased 3% between the 2002-2006 timeframe, while public water supply consumption increased 0.4% (DEQ 2007).

As the data indicate, increasing population is slowly and steadily increasing the demand on potable water. Crop irrigation water consumption could be decreasing for a variety of reasons including greater water restrictions, decreasing farm land, irrigation technology improvement and water conservation strategies. Although crop irrigation as a whole is decreasing, increasing population will result in greater demand for the state's water resources. It could be argued that crop irrigation water could be diverted to serve public drinking water needs. Therefore, the irrigation industry must utilize scientific practices to utilize the available water as effectively and efficiently as possible.

Population increases have also impacted Virginia's water quality due to increased runoff from new homes. Nonpoint source pollution is degrading much of Virginia's natural water bodies, particularly the Chesapeake Bay. Between 2000 and 2006, 475,535 new homes were built in the Commonwealth of Virginia (U.S. Census Bureau 2007), which resulted in an estimated 713 million square feet of impervious surfaces, assuming 1,500 square feet of roof area. Residential roof lines are impervious surfaces, which contribute significantly to nonpoint source pollution.

The increased populations coupled with new residential properties places an increasing strain on safe potable water supplies. Many water treatment plants are at maximum capacity; supplying the increasing demands can be burdensome. Likewise, increasing nonpoint source pollution makes water treatment endeavors harder and more expensive.

Landscape Irrigation

The term "landscape" refers to both ornamental and turfgrass planting areas. Water needs do vary within landscape irrigation. Some studies have found that turfgrass has a lower evapotranspiration rate than ornamental plantings (Devitt et al. 1995; Saha 2004), while others have reported higher evapotranspiration rates (Erickson et al. 1999). Turfgrass roots are morphologically different from ornamental plant root systems as they consist of fibrous roots that aid in shallow water uptake, while ornamentals have fibrous roots for shallow uptake and woody roots that mine water from deeper soil profiles. As a result, ornamental plantings require less frequent irrigation applications. More frequent turfgrass irrigation events can lead to the public perception that turfgrass irrigation is wasteful and excessive (Barrett 2004; Ratcliff 1999). Based on this perception, the focus of this research will be on turfgrass. However, all findings can be applied to ornamental areas as both turfgrass and ornamental landscapes rely on supplemental irrigation.

Eliminating irrigation practices for landscaped areas would be detrimental both economically and environmentally. The landscape industry is oftentimes reliant on supplemental irrigation to maintain plant health and quality. When Denver restricted irrigation only to tees and fairways due to drought, four municipal golf courses closed (Barrett 2004). This not only affects municipality economic viability, but also recreational use. Through evaporative cooling, landscapes also can reduce energy consumption. A report by the Irrigation Association (2000) stated that "eight average front lawns have the cooling effect of 70 tons of air conditioning."

Irrigation Water Consumption

Estimating Virginia landscape water use proves difficult as the Status of Virginia's Water Resources (DEQ 2007) report groups all irrigation practices under the "irrigation" heading. Therefore, crop production is grouped with landscape and turfgrass irrigation. Likewise, Virginia USGS (USGS 2004) reports group all irrigation practices under "agricultural," which also encompasses all on-farm needs like livestock watering and dairy operations. One DEQ report (2005) stated the Virginia golf industry accounts for 0.4% of the state's water use, but no information is available for ornamental landscape water use.

The Irrigation Association reported that nationwide landscape irrigation, which encompasses all turf surfaces other than golf courses, utilizes 2.9% of the country's potable water supplies, while golf courses utilize 1.5% of the country's water supply (Irrigation Association 2000; Ratcliff 1999). Unlike crop production irrigation, turfgrass and landscape irrigation is very visible and the public often judge such irrigation practices as being wasteful (Barrett 2004). To curb irrigation water use, turfgrass and landscape irrigators have turned to water conserving technologies and practices.

Irrigation Technology

The turfgrass industry has investigated technologically advanced equipment to ensure water use efficiency. Zoldoske (2004) found that the simple act of changing irrigation nozzles can conserve water and money. New soil moisture sensors are programmed to offer real-time data for irrigation guidance, but require upfront cost and maintenance (Carrow 2006). Plant-based measurements like relative water content, stomatal conductance, and light reflectance offer more direct measurements of plant water need, but automation is not possible in the field setting (Carrow 2006; Jones 2004). In select US locations, irrigation (based on evapotranspiration demand) data can be transmitted to “smart irrigation controllers” to adjust daily irrigation timing to conserve water and promote plant growth (U.S. EPA 2007; U.S. EPA 2008).

The EPA released a draft “Water-Efficient Single-Family New Home Specification” (2008) for public comment. This specification details water saving approaches under the WaterSense label for new single family homes of three stories or less. Landscape irrigation design and application was discussed, which included no turfgrass area over 40% of the landscaped area, a cool season turfgrass crop coefficient of 0.6, limited irrigation run times and pop-up irrigation height guidelines (EPA WaterSense 2008). While this specification is under review, the guidelines pave the way for promoting water efficient homes, which include all landscaped areas.

Evapotranspiration

One tactic covered in the EPA draft specification (2008) is basing irrigation on evapotranspiration (ET). Evapotranspiration-based irrigation scheduling is an effective way to ensure that only water lost from a turfgrass system, via plant transpiration and soil evaporation, is replaced via supplemental irrigation. Many researchers, in Virginia and throughout the US, have studied ET-based irrigation scheduling as a scientific approach to assessing appropriate irrigation quantities (Allen et al. 1989; Aronson et al. 1987; ASCE 1990; Bastug and Buyuktas 2003; Devitt et al. 1992; Ervin and Koski 1998; Feldhake et al. 1984; Huang and Fry 1999; LaBranche 2005; Pereira et al. 1999; Richie et al. 1997).

A study conducted by the Irvine Ranch Water District found that prior to ET-based scheduling, irrigation was applied at up to three times more than ET estimates (Slack 2000). An independent researcher in Colorado conducted a study on home lawns to test the WeatherTRAK™ system, which sends daily ET data to irrigation controllers. This study found an average of 26,000 gallons of water saved per site each season compared to historical usage. On these sites water savings averaged $197 yearly, with no significant decrease in turfgrass appearance (Aquacraft 2003).

There are several ET equations available to estimate atmospheric demand within the plant science field. The Penman-Monteith (PM) equation is the most widely used and most consistent ET equation (Allen et al. 1989). Also, the PM equation is suitable for use in various climatic regions and for various crops (Itenfisu et al. 2003; Ortega-Farias et al. 2004; Stockle et al. 2004).

Many states have developed websites that utilize a version of the PM equation to calculate local ET rates with the goal to guide irrigation practices and reduce water consumption. Texas A&M (2004) developed a website, the Texas Evapotranspiration Network, which contains regional ET calculations, reported in inches, based on the day's climatic conditions. Arizona, California, Colorado, Idaho and Oklahoma are all western US states that also have websites detailing ET rate for irrigation purposes (Colorado State University 2007; State of California 2005; University of Idaho 2007; University of Oklahoma 2007). Evapotranspiration-based irrigation is gaining popularity in the humid southeast due to increasing water demands and drought occurrences. North Carolina recently developed a website that guides irrigators through the process of determining water demand and irrigation run time (North Carolina State University 2008).

Unlike the above states Virginia does not have an ET website detailing real-time irrigation demands. The University of Virginia Climatology Office (2000) has developed an online table (http://climate.virginia.edu/va_pet_prec_diff.htm) that details average ET demand for various Virginia locations throughout the year. This is the sole online public source of information that Virginia irrigators can use to determine irrigation needs based on ET demand. Since all the data are averages, it may not be useful in years when weather patterns stray from the normal.

Recently installed weatherstations throughout Virginia by the Virginia Agricultural Experiment Station collect climate data like temperature, humidity, solar radiation, wind speed rainfall, etc. (AHNR-IT 2005). This information is displayed online as raw numerical data. Ideally, the climate data would be utilized to determine ET, but this requires users to enter the data themselves into a separate computer program. This process is quite laborsome, especially for a time-strapped landscape professional who is also responsible for managing a labor force. Managers' current scheduling procedures, which are not necessarily based on climatic conditions, may be adequate when water is plentiful, but may not be suitable for long-term water supply planning.

Information Dissemination

Computer technology is imbedded in today's lifestyle. Internet and email allow users to share information at an expedited rate and when most convenient, which in turn increases user efficiency and productivity (Dumlao and Duke 2003). The Internet can serve as a platform through which information can be relayed between many sources. The ET websites discussed in the previous section create an information platform in which irrigation demands are shared. This platform can be accessed by academics, professionals and homeowners. However, the way in which the data is viewed and utilized will vary.

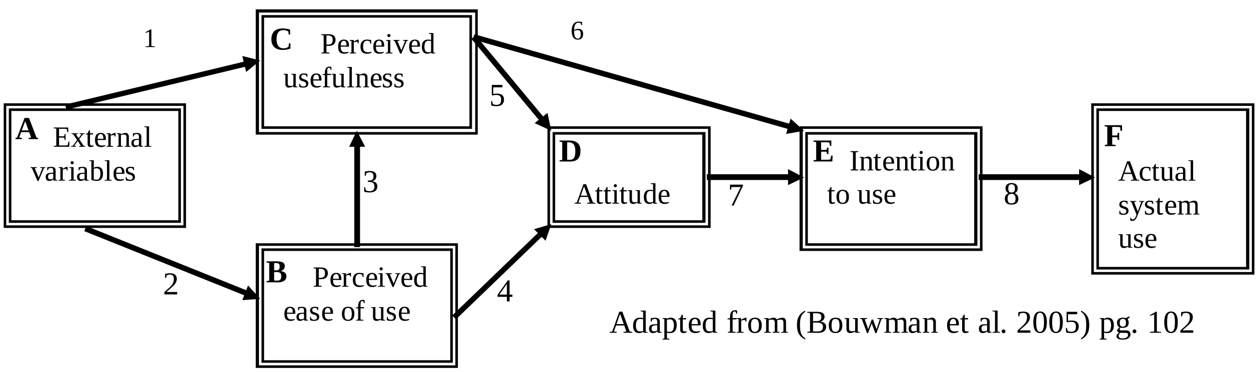
Technology Adoption Model

According to Rogers (2003), technology diffusion is "the process in which an innovation is communicated through certain channels over time among the members of a social system". These four variables, innovation, certain channels, time, and social system, all impact how a given population perceives certain technologies and can be linked to the willingness to adopt that technology. Likewise, the individuals analyze certain aspects before deciding the technology's fate. These aspects are: relative advantage, compatibility, complexity, trialability, and observability (Rogers 2003). All of these aspects are dependent on the present social system. If a technology is perceived to have a relative advantage, is compatible with current systems, is not complex, can be used on a trial basis and is seen utilized in the society, then the likelihood that it would be adopted increases (Bouwman et al. 2005). Furthermore, a technology's relative advantage is linked to its complexity and compatibility as a piece of technology is perceived to have an advantage when it is user friendly and works with current infrastructure (Bouwman et al.

2005).

When organizations and individuals are processing information to determine whether a certain technology should be adopted, they are engaged in a several step process. During this process they are exploring, researching, deliberating and ultimately making a decision concerning its adoption plausibility (Bouwman et al. 2005). When a technological innovation is adopted, it is determined to offer the "best course of action" for the desired use (Rogers 2003).

Due to landscape managers' risk aversion, proper incentives must be employed to enhance their willingness to conserve water. The technology adoption model, first postulated by Davis (1985) in his doctoral dissertation in management at Massachusetts Institute of Technology, states that willingness to accept a new information communication technology is based on perceived usefulness and ease of use. Figure 2.1 gives a graphical representation of the technology adoption model.



Adapted from (Bouwman et al. 2005) pg. 102

Figure 2.1. Technology Adoption Model

Vishwanath and Goldhaber (2003) and Karahanna and Straub (1999) claimed that perceived usefulness (C) is dependent on the perceived ease of use (3,B), meaning that ease of use is figured into the human calculation, or external variables (2,A), of whether a certain technology is useful. Individuals are less apt to adopt a new technology if it is not useful or if the technology is not considered to be user-friendly. Legris et al. (2003) summarized the main points of the technology acceptance model when they stated that the model provides “a basis for tracing the impact of external variables [A] on internal beliefs [1,C,2,B], attitudes [4,5,D], and intentions [7,E].” The ultimate goal of this model is to allow researchers to analyze the variables and manipulate them to subsequently alter human information communication technology adoption preferences (Vishwanath and Goldhaber 2003).

Individual beliefs and attitudes affect a media’s perceived usefulness and ease of use (A,1,2). Beliefs actually indirectly impact intentions (6) to adopt a communication information technology by directly influencing a person’s attitudes (5) (Vishwanath and Goldhaber 2003). Karahanna and Straub (1999) discovered that a person’s perceived ease of use was not dependent on the availability of technological training and support. Therefore, companies need not invest considerable amounts of money in training and support for perceived complex technologies, as it will not affect the individuals’ ultimate opinion of the technology. Rather, only technologies with initial perceived usefulness and ease of use will be adopted. Perceived complexity, relative disadvantage, incompatibility with current infrastructure, and lack of observability within social surroundings can all also affect an individual’s attitudes and subsequent perceived ease of use and usefulness (Vishwanath and Goldhaber 2003). Other researchers have tested the validity of the technology acceptance model and found that the belief antecedent of technology compatibility affected adoption and usage the most (Al-Gahtani and King 1999).

As Venkatesh and Davis (1996) found, the type of information communication technology adopted is dependent on the users and how these users would perceive usefulness and ease of use. Age, gender, experience, ownership, and observable results are all variables of a particular target that technology companies seek to target with their varying technologies (Venkatesh et al. 2003; Vishwanath and Goldhaber 2003). Therefore, technologies are created for targeted audiences and only these targeted audiences would attain the most use from the developed technologies. It is not beneficial to attempt to mold a technology to the individual. In a study analyzing answering machines, voicemail, pagers, caller-ID, call waiting, fax machines, second phone line and internet service, Vishwanath and Goldhaber (2003) found that ownership of the media had the strongest impact on an individual’s attitudes and intentions, which can be linked to experience. Ko et al. (2005) researched Internet usage and gratifications and found that people most often utilized the Internet for information, convenience, entertainment and social interaction. This research can be extrapolated to determine how to alter individual's perceived usefulness and ease of use through marketing techniques of targeting particular audiences and their main objectives for utilizing information communication technologies.

User-Centered Web Development

User-centered web development is a process that involves the users in the design and development process (Lazar 2001). Web developers should take additional steps in their design process to understand their target population to encourage success (Calongne 2001). As discussed with the technology adoption model, a technology that is easy to use is more likely to be adopted. Utilizing the target audience in the design process is one sure way to ensure the website is easy to use and built for the targeted population, thus increasing likelihood of adoption.

The first step in the process is to indentify to users (Lazar 2001). Few websites are designed for an extremely broad population. Most websites are designed for a target population and this target population will have its own nuances that range from available computer equipment to website color scheme preferences. Understanding the user demographics is critical for the whole process as the website design approach relies on their cooperation and input.

The second step of the process is to determine the user needs and the ultimate goal of the website (Lazar 2001). Different approaches will be taken for a new website made from scratch than for updating a website. The users' needs must be identified to warrant the need to create the website and include the users in the design process. If the users do not find the website within their interests, then the website will fail, even if the users assist in the design process.

If the second step is successful and the website design process is deemed feasible, the third step is to develop the proposed website with the users' input (Lazar 2001). The final step is to test the website to ensure the product does meet the criteria of being useful and easy to use. The website can be continued to be tested and any updates can be made to ensure the website remains important and designed properly for the target audience (Lazar 2001).

Indiana University used the user-created design process to update its website in 1995, just as the Internet was becoming ingrained in daily lives. Identified users were polled to determine their needs from the website, which led to a new website layout. Usability tests were made for both the old website design and the newly designed website (Corry et al. 1997). The tests took four months to complete, which may be more time, which translates into money, than some are willing to spend on a website. However, Indiana University's website was ultimately changed due to the research results and was found to be one of the top 50 most frequently visited websites thereafter (Corry et al. 1997).

User-centered design research studies typically report success and increased user satisfaction. However, this approach does add an additional layer of expense for developing a website. Vredenburg et al. (2002) were unable to determine if utilizing user-centered design reduced the website development time or cost. They also reported that user-created development consumed 20% of the budget, compared to 10% for traditional website development (Vredenburg et al. 2002).

Collaborative Planning

The collaborative planning theory has been utilized to address environmental conflicts, mostly in forest planning. In 1999, the Committee of Scientists recommended forming more partnerships with outside groups and the government when deciding how to manage the national forests and grasslands (USDA 1999). Ontario also adopted the collaborative approach to address its forest management plan to ensure the tourist industry is not negatively impacted (Harvey 2003). In both these examples, governmental bodies, private organizations and local citizens were involved in the consensus building process. Harvey (2003) noted that the collaborative process can fail if the public interest is not acknowledged or included. The collaborative planning theory can be successful if all the stakeholders' opinions are integrated, which allows for consensus formation. Stakeholders are defined as all individuals or organizations that express an interest in, concern of, or impact from the subsequent plan (Selin and Chavez 1995).

Collaborative planning can be characterized as both a descriptive and prescriptive theory. The theory details how the planning process should be employed in an attempt to foster social learning and the involvement of various stakeholders in the decision making process (Huxham and Vangen 2005; Margerum 2002). Ultimately, the planning process will lead to an end product, the plan. This plan details the issue components and addresses the steps that should be taken in an attempt to solve the problem. The theory's prescriptive component also unearths the problems that may arise during the planning process (Huxham and Vangen 2005). These problems can then be addressed during the next collaboration session to ensure the process has improved.

While the end product of the collaborative process is the plan, more social results can ensue from this process. Organizations can develop organically due to the interaction amongst the stakeholders (Randolph 2004). Chrislip et al. (1994) refers to this occurrence as creating a civic community. These community organizations may play an important role in future planning occurrences. Collaborative planning seeks to encourage social learning by allowing stakeholders to share their knowledge as means to educate others and to engage them in a critical thought process concerning their own beliefs (Margerum 2002). Stakeholders not only share their knowledge, they learn from others, which may cause them to question their original beliefs.

Collaboration is often adopted because it is the only solution to solving the particular issue at hand. Chrislip et al. (1994) and Huxham and Vangen (2005) indicated that the collaborative process allows stakeholders to reach a decision, that neither party could have reached alone. Collaboration also brings together groups and individuals whom would otherwise not have communicated with one another (Innes and Booher 1999), especially not on an even playing field. If the objective is to create an innovative plan, the collaborative theory should be employed as it includes the various stakeholders who are linked together directly and indirectly (Innes and Booher 1999). Chrislip et al. (1994) noted that collaboration is not a process limited to the planning profession. Collaboration is common in business, education, health care, and the family and children services professions. Huxham and Vangen (2005) illustrate the possibilities in collaboration in business terms. One organization may provide product engineering expertise, while another may provide marketing and advertising. Each organization is a stakeholder and offers differing points of view, but each want to reach the common goal. Through collaborative decision making, a community decision is reached that includes all the varying stakeholders' view points and is a balance of all the ideals.

Water Planning

Recently, bill 9 VAC 25-780 (2005) was passed to develop local and regional water supply plans. Virginia cities, towns and counties are required to develop either individual water supply plans or collaborate with neighboring areas to develop regional water supply plans. Likewise, municipalities must include the developed water supply plans within the municipal comprehensive plans to ensure that future water demands are met, even in drought conditions. The goals of the bill are to:

> (i) ensure that adequate and safe drinking water is available to all citizens of the Commonwealth; (ii) encourage, promote, and protect all other beneficial uses of the Commonwealth's water resources; and (iii) encourage, promote, and develop incentives for alternative water sources, including but not limited to desalinization (2005).

Plans were submitted to the Virginia Department of Environmental Quality starting in November of 2008 for local governments with populations above 35,000 and will continue until November 2010 for regional water supply plans (DEQ 2008).

Water supply plans are intended to assist in the decision making process regarding water supplies for all intended uses. The planning process is intended to be comprehensive, which includes evaluating the current situation, projecting for the future and researching alternative means of supplying water to meet the future demands (Daniels and Daniels 2003; Dzurik 2003). Projecting future water demands is complex, but modern forecasting methods have assisted in this process (Dzurik 2003).

Water supply plans should be dynamic and able to be updated often based on changing legislation and water technology (Daniels and Daniels 2003; Dzurik 2003).

A water supply plan should address the following:

- Current water supply
- Present and projected water supply demand
- Safe Drinking Water Act compliance
- Source water protection plan
- Drought management plan
- Possible alternative water sources, including conservation
- Recommendation for future measures to meet water supply (AWWA 2001; Daniels and Daniels 2003).

The states work with the federal government to follow the Safe Drinking Water Act through the planning process. However, states are now adopting their own water supply plans. Starting in 1995 California required cities and counties to include water supply assessments within their comprehensive plans (Daniels and Daniels 2003). Texas enacted a legislation that required regional water supply plans to be submitted by 2001 (TWDB 2008a). Some of the goals of the regional plans are to determine water demands, determine how to handle water demands during drought times, and coordinate plans with neighboring regions (TWDB 2008a).

Landscape Water Planning

Landscape irrigation is typically the first water source to be restricted during drought. Drought management plans make up a larger portion of water supply plans. Virginia has developed a state-wide drought management plan independent of the local water supply plans. The Virginia Drought Monitoring Task Force consisted of various entities throughout the state that represent the vast water industries. The Task Force developed drought stages and the voluntary and mandatory water restrictions that occur at each level for landscape irrigation and other water uses. For example, under drought emergencies, golf course tees, greens and fairways can only be irrigated between 9:00 pm and 10:00 am; restored and newly constructed fairways, tees and greens cannot exceed one inch of irrigation per week; no puddling or runoff can result from irrigation applications (DRTAC 2003).

The GAWCC, or Green Associations Water Conservation Council, is made up of four green industries: American Nursery and Landscape Association, Associated Landscape and Contractors of America, The Irrigation Association, and Turfgrass Producers International. This Council developed the Water Action Guide (GAWCC 2007), which details the importance of the Green Industry, how to deal with a water crisis, and how to develop a coalition to promote the Green Industry, even in drought times. The GAWCC represents the growing concern amongst the Green Industry. With drinking water demands continuing to increase, it is the Green Industry that is suffering from, and blamed for, the lack of available water. The Green Industry must continue to be proactive in water conservation endeavors to ensure the allocated water for supporting plant life is used as efficiently as possible. Likewise, the GAWCC serves as a collaborative stakeholder to offer information from the landscape standpoint in the water supply planning process for a state or region.

Alternative Water Sources

Alternative water sources are water sources that curb the consumption of fresh water (AWWA 2001; Baumann 1990). Since landscape irrigation practices are often viewed as non-essential, there is a strong movement to reduce the consumption of fresh water and allocate this fresh water for drinking water purposes. Water conservation through evapotranspiration-based scheduling, reclaimed or recycled water, rainwater, and desalinized water are all feasible alternative water sources for landscape irrigation purposes.

Water Conservation: Evapotranspiration-Based Scheduling

The American Water Works Association (2006) states water conservation “is doing more with less, not doing without.” Landscape water conservation efforts do just that: do more with less water. Eliminating a critical element like water, will result in negative impacts and the benefits the landscaped areas offered will be diminished. However, water applications can be reduced without unsustainably impacting plant health and vitality.

As stated previously, ET-based scheduling allows irrigation managers to replace only the amount of water lost from the landscape through the combined forces of evaporation and plant transpiration. Therefore, irrigation practices are more exact and excessive amounts of water are not used and wasted.

However, irrigation water can be curbed even more through deficit irrigation, more commonly known as irrigating based on crop coefficients. Numerous universities have studied water conservation and deficit irrigation on plant health. The consensus is that landscape plantings, including turfgrass, can be irrigated at deficit levels (Carrow 2006; DeCosta and Huang 2004; LaBranche 2005; MSU 2005), which is the act of irrigating below the optimum plant health threshold. The level of deficit irrigation that maintains plant health is called a crop coefficient (McCarty 2001). Crop coefficients vary depending on plant species and management level. The Irrigation Association uses a crop coefficient of 0.8 for cool season turfgrass, 0.6 for warm season turfgrass, and 0.5 for trees, shrubs and mixed plantings (Water Management Committee 2005).

Several states have developed ET websites to assist with irrigation scheduling and some have included an adjustment for crop coefficients. Texas A&M is one university with this feature as seen below in Figure 2.2. Other states like California (State of California 2005), include crop coefficient information in the written literature, but do not integrate the calculation into their website design.

Scheduling based on ET requires certain technological equipment. For the few states with websites detailing ET rates, only a computer with internet access is required. In states without such websites, access to a local weatherstation and ET calculation software is necessary. This self-calculation process can be complicated and may deter many from adopting the ET-based irrigation scheduling technique. Adoption of ET-based irrigation scheduling regimes may be encouraged by offering an easy to use website database to access the necessary ET information.

Figure 2.2. Texas A&M ET adjusted with crop coefficient Used with permission (*http://texaset.tamu.edu/date.php?stn=28&spread=14)*

Reclaimed Water

Another alternative irrigation water source is reclaimed water, which is water that has undergone water treatment, but is not treated to drinking water standards (AWWA 2001; U.S. EPA 2004). Reclaimed water is also referred to as recycled water. The American Water Works Association (2007) explains the terminology, "water is *reclaimed* from wastewater in order to be *recycled* for *reuse*."

Reclaimed water is produced through a series of processes to ensure the water is safe for reuse. Sewage can undergo various forms of treatment to reach the stage where it is safe for reuse. Some treatment processes include sedimentation, aerobic biological treatment, anaerobic biological treatment, coagulation-flocculation, and disinfection (Lazarova and Bahri 2005). Typically, when treatment plants receive sewage, it is screened to remove large debris, then dense materials like sand and stones are separated from the sewage. Next, suspended solids are removed and the remaining liquid is called primary effluent. This effluent then undergoes secondary treatment, where biological decomposition and disinfection via chlorination, ozonation or UV radiation is done to kill bacteria and remove odor (Haering et al. 2008; Lazarova and Bahri 2005). After secondary treatment the effluent is suitable for use as a nonpotable water source or released into the environment, or it can be treated further to remove more organic matter, depending on the state regulations (Harivandi 1982; Lazarova and Bahri 2005). A further treatment is termed tertiary treatment, which is a biological process to break down organic matter and metabolize it into simple organisms (Harivandi 1982; Lazarova and Bahri 2005).

Virginia reclaimed water laws classify water reuse dependant on treatment process level. A "Level 2" treatment includes secondary treatment and standard disinfection, while a "Level 1" treatment includes secondary treatment, filtration and a higher-level disinfection (Haering et al. 2008). The Level 2 reclaimed water is suitable for non-food crop application and sod farms, while the Level 1 water is suitable for food crops and landscape irrigation, which includes golf courses and athletic fields (Haering et al. 2008).

The Hampton Roads Sanitation District in Virginia Beach operates a water reclamation plant and produces 165 million gallons of reclaimed water each day (HRSD 2006). A recent study with the Virginia Initiatives Plant in Norfolk, Virginia found that reclaimed water applied on turfgrass had no negative effect. However, long-term application could impact turfgrass health with increasing salt buildup (Evanylo et al. 2007).

Utilizing reclaimed water as irrigation water may entail an altering of maintenance practices due to the nutrients and contaminants present in the water. Common nutrients and contaminants that can pose a problem with reclaimed water are sodium, chloride, boron, microbes, phosphorus, and nitrogen (Lazarova and Bahri 2005). Therefore, landscape managers must adjust their fertility and irrigation regimes to manage for these issues.

Also, separate plumbing is required for both reclaimed water and backup potable water (Lazarova and Bahri 2005). This adds expense and additional management issues. The public may also have an aversion towards using this nonpotable water source due to health concerns (Lazarova and Bahri 2005). To combat all these issues, education plans must be developed and extended.

Reusing reclaimed water as irrigation can have positive environmental and social impacts. The reclaimed water is piped to the irrigation areas, rather than being discharged into local waterways (Lazarova and Bahri 2005) to potentially affect quality of future drinking water. Likewise, fresh water sources can be allocated for drinking water, rather than irrigation water.

Rainwater Harvesting

Another alternative water source, rainwater harvesting, is growing in popularity in the United States due to increasingly sophisticated technologies that increase efficiency and efficacy. The practice of harvesting rainwater follows very simple ideas of collecting rainwater for reuse in and around a building, but the technology developed for the practice is continually increasing in complexity.

Rainwater harvesting dates back thousands of years when rainwater was collected as a main drinking water source. Early collection cisterns determined survival through drought times and were found through Europe, India, Asia and Mexico (Kinkade-Levario 2007). Kinkade-

Levario, a leading rainwater harvesting researcher, reports that even the early systems employed first-flush systems to collect organic contaminants to protect water quality (2007). Today's systems still follow the same principles developed long ago.

Most developed areas of the United States rely on centralized water distribution systems, which consist of one water treatment center, and water is distributed from this site to water consumers within a designated area. This system has worked effectively for the last 100 years, but many water main pipes are reaching their lifespan and replacement is cost prohibitive. Likewise, water treatment facilities are reaching maximum capacity and cannot handle more demand without building onto existing facilities. Yet, more and more United States citizens are looking towards rainwater harvesting as an alternative water source for irrigation purposes as well as a decentralized potable and nonpotable water source.

Those whom adopt rainwater harvesting practices do so for many different reasons. Large developments look to rainwater harvesting as an alternative to stormwater detention areas. The collected water is then used as irrigation or within buildings for toilets or cooling towers. Industrial and commercial sites may collect rainwater for washing clothes, manufacturing processes, cleaning, irrigation and various other nonpotable water demands (LaBranche et al. 2007). Residents may turn to rainwater harvesting to reduce site stormwater runoff and also to irrigate gardens and lawns even during drought time water bans. Some rural homeowners use treated harvested rainwater when their wells no longer produce enough water to meet their potable water demands.

In Germany, all new developments must implement rainwater systems to handle runoff water quality and quantity from densely populated areas (Nodle 2007). The United States is slowly adopting these techniques with the first installations in rural communities, where municipal water is not available and well water is limited, especially during drought times (Younos et al. 1998). Most picture rain barrels when rainwater harvesting is mentioned. Now more residential, commercial and industrial buildings are installing complex rainwater harvesting systems that consist of sophisticated below ground tank systems that serve non-potable demands inside and outside the home (Fig. 2.3).

Texas, a leading rainwater harvesting state, developed Rain Catcher Awards (TWDB 2008b). A medical office building in Webster, Texas received the fall 2007 Texas Rain Catcher Award from the Texas Water Development Board. The building consists of 14,500 square foot roof area, 175,000 gallons of below ground water storage and the collected water is used for toilet flushing and irrigation (TWDB 2008b).

Many states, especially the Southeastern states, have experienced landscape irrigation bans due to drought occurrences (U.S. Water News Online 2008b). Now some homeowners and even developers are turning to rainwater harvesting to supply water for irrigation and even total household water needs. One Roanoke, Virginia resident turned to rainwater harvesting when his well water supply was failing and drilling a deeper well did not supply enough water for his family's needs (Membreno 2007).

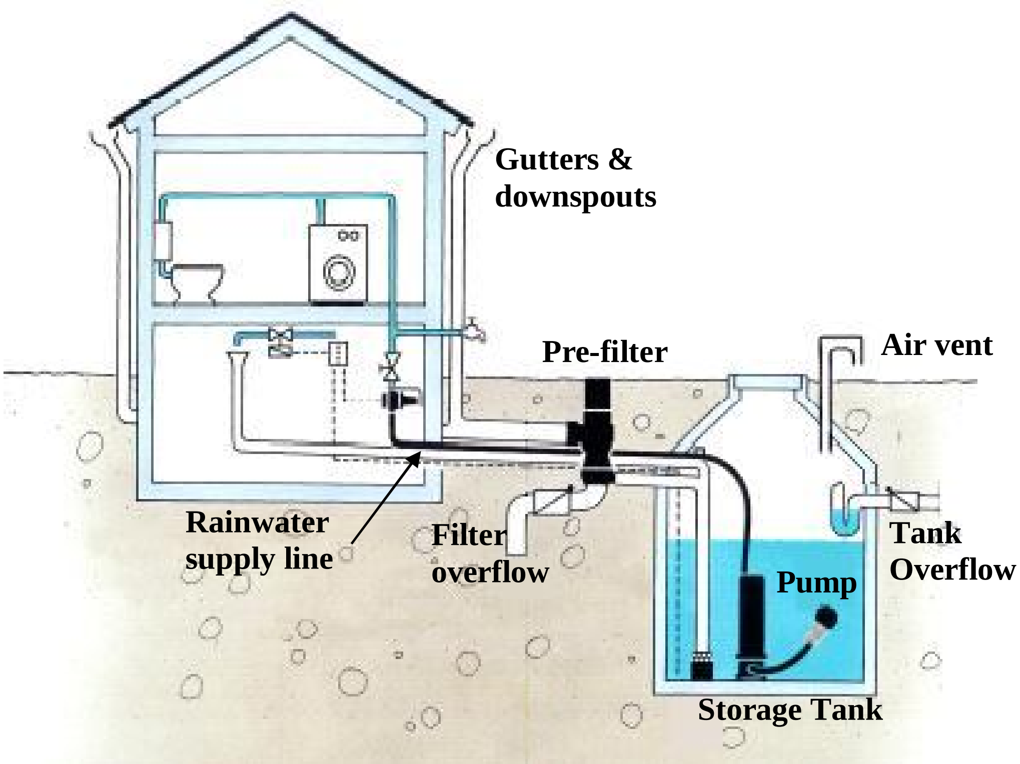


Figure 2.3. Residential Rainwater Harvesting System Example
Used with permission *Rainwater Management Solutions, Salem, Virginia*

Some states and cities have developed rainwater harvesting guidelines for small do-it-yourself projects to large sophisticated projects. Texas and Virginia both have rainwater harvesting manuals that offer insight as to social and environmental impacts, application, design, and installation (LaBranche et al. 2007; TWDB 2005). Ohio (2000) developed guidelines detailing cistern construction and filtering requirements. Likewise, Montana's regulations (Montana DEQ 2002) detail cistern location, construction, maintenance and cleaning. Kentucky's code, developed in 1990, provides an overview of information which includes roof washers, cistern materials and how to deal with contamination (Taraba et al. 1990)

Some of the more recent city and state codes include Portland, Oregon, Santa Fe, New Mexico, Texas and Virginia. Portland, Oregon (2001) developed codes that detailed appropriate system components from the roof surface to gutters, filters and cisterns. Santa Fe requires rainwater harvesting on all new residential buildings. Residences less than 2,500 sq. ft. must utilize rain barrels, while larger residences must implement belowground cisterns (2003). Also, Santa Fe requires collection from at least 85% of the roof area and collected rainwater can only be used for irrigation purposes (2003). King County, Washington (2007) provides in-depth guidelines for cisterns, pumps, filtration and/or disinfection for residential and commercial applications. Hawaii (Macomber 2004) offers an extensive publication, which details water collection, storage, treatment, testing and rainwater harvesting system maintenance. The Texas Commission on Environmental Quality (2007) has even developed guidelines for public water systems that will use rainwater systems to serve as potable water. Virginia (2008a) recently developed standards to be incorporated into the state's Construction and Professional Services Manual, which covers all state run buildings. The American Rainwater Catchment Systems Association (ARCSA) is also working to develop US standards for rainwater harvesting systems. These standards are currently under review, but they include recommendations for conveyance systems, filters, tanks, maintenance and assessing water quality.

There is concern that collecting rainwater could reduce groundwater and stream water levels, which can impede water rights. In Colorado, rainwater harvesting is illegal for non-rural residents connected to municipal water, as water is considered public property and cannot be used for private uses (Ashby 2009; Rodebaugh 2008). Research is ongoing to determine the rainwater harvesting impact on watersheds and to determine if collecting rooftop runoff does impede stream and groundwater levels.

While all United States locations receive rainfall, not all sites receive rainfall during the peak consumption times. As a result, tank systems must be sized to allocate extra storage for the high demand times, which results in very large tanks. Most difficulties with rainwater harvesting systems are related to tank size and location and selecting high-quality products, which prevent system maintenance. Installing rainwater systems may also be cost-prohibitive for many homeowners due to upfront costs. The payback for rainwater harvesting systems depend on water demand, cost of water, and system size. However, installing rainwater harvesting systems could offset the cost of installing large detention ponds in neighborhoods and large sites as stormwater runoff could be significantly reduced. Likewise, the harvested rainwater can be recycled onsite as irrigation to maintain the grounds without relying on potable water sources.

Developing an Irrigation Water Supply Plan

Water supply plans take an integrated approach of assessing current supplies, how these supplies can meet current and future demands and assessing feasible alternative water sources. Many disciplines are necessary to ensure the planning and dissemination processes are a success. The water planning discipline itself is inherently inter-disciplinary as hydrology, environmental water requirements, social water needs, data collection, and information transfer are among a few requirements needed to develop a water supply plan.

When developing an irrigation water supply plan, all the same information for a water supply plan is needed, but the application scope is limited to landscaped area that receives irrigation. More specifically, this research is focused on turfgrass irrigated surfaces in Virginia like residential grounds, golf courses, and sports fields, but the theories can be applied to all landscaped areas.

Adapting the requirements set forth in Virginia Water Supply Plan bill 9 VAC 25-780 (2005) and the AWWA water supply planning guidelines (AWWA 2001), the following steps can be followed to develop an irrigation water supply plan:

1. Assess current water supplies
    a. What is the current water source?
    b. What is the price for the water source?
2. Assess water demands
    a. What is the current demand?
        i. How is the current demand calculated?
    b. Is the demand expected to increase?
3. Compare supply and demand balance
    a. Is the population increasing?
    b. Will competition for water resources increase?
    c. Are drought occurrences increasing?
        i. Are there mandatory or voluntary water restrictions?
4. Assess alternative water sources
    a. What is the technology involved?
    b. How intrusive is implementation?
    c. What is public opinion of adoption?
    d. What is the payoff?
        i. Economic
        ii. Environment

This list of questions can assist in developing a well-rounded irrigation water supply plan. It analyzes the current water source, which may be municipal water, groundwater or surface water withdrawal. Due to more people withdrawing groundwater, there is less water available per person or plant. Likewise, increasing impervious parking lots or housing developments around a golf course can impact the quantity and quality of water collected in an on-site pond.

Assessing how demand is determined for a landscaped area is important. Determining how landscape managers assess plant demands can impact water application during drought times. Having a scientific basis for calculating demand will hold more weight when allocating water restrictions. Water restrictions may also be based on such scientific calculations, rather than arbitrary levels.

A supply and demand imbalance will have negative environmental effects for many reasons. Eliminating irrigation on sports fields will reduce economic input and put players in danger due to poorly maintained fields. Likewise, irrigating in excess will produce water runoff and drain the water source of valuable water others could have used efficiently. Idealistically, the water supply and balance should be even, meaning demand should not exceed supply and water should be applied as efficiently as possible to promote plant health and prohibit water wasting.

It is also critical to understand the local social landscape to determine how it will impact current and future irrigation supplies. Increasing local populations can increase demand on municipal and groundwater supplies, which means less water per person or irrigated acreage is available. Likewise, if drought is occurring, more of the population may be critical of the potable water supplies that are used for irrigation purposes. This dynamic must be evaluated to assess the need for utilizing alternative water sources.

Typical alternative water sources range from conservation, water reuse, desalinization, groundwater withdrawals, water transfers, and surface water purchasing (Standish-Lee et al. 2005). One other alternative water source that is not included in many sources, but is growing in popularity is rainwater harvesting. Analyses must be conducted to determine what type of technology (i.e. separate plumbing, storage tanks, treatment plants) is needed for each alternative water source and the feasibility of implementing each. Public opinion concerning safety and willingness to adopt the new technology are important to consider as without public cooperation, the new technology may not be successful in meeting increasing water demands. Each source must also be analyzed to determine the economic and environmental feasibility of implementation. Some technologies may cause too much land disruption, like building a new treatment plant, while payoff to implement another technology may not be short enough.

Planning is critical to ensure adequate water sources are available not only for the human life, but also plant life as plant life is what produces oxygen for humans to survive. Plant life, specifically turfgrass areas, benefits humans beyond providing a surface for golf or playing soccer. Beard and Green (1994) noted the environmental benefits to include improving groundwater recharge, filtering poor quality water, flood control, reducing noise and air pollution through buffering and absorbing capabilities, and cooling urban areas through plant transpiration. Likewise, urban and community forests can assist in energy conservation through evaporative cooling, improving air quality, controlling stormwater runoff quantity and quality, and protecting wildlife (Dwyer et al. 1992). Social benefits include offering an aesthetic area for recreation and relaxation, encouraging exercise, offering therapy through the use of turfgrass mixed with landscape plants, and an improved quality of life (Beard and Green 1994; Dwyer et al. 1992). Based on this long list of environmental and social benefits plant life offers, steps must be taken to ensure there will be available water supplies to promote healthy growth and that these supplies are utilized efficiently and effectively.

References

(2000). "Construction and surface design of cisterns, hauled water storage tanks, and roof washers." 3701-28-13, Columbus, OH.

(2001). "Rainwater Harvesting." One & two family dwelling specialty code:2000 edition; plumbing specialty code: 2000 edition, Portland, Oregon.

(2003). "Amendment to Santa Fe County Land Development Code Article III, Section 4.4.1 and Section 2.4.1." Ordinance No. 2003-6, Santa Fe, NM.

(2005). "Chapter 780 - Local and Regional Water Supply Planning." 9 VAC 25-780, Richmond, VA.

(2007). "Rainwater harvesting and connection to plumbing fixtures." 07-001, King County, WA.

(2008a). "Rainwater Harvesting Systems." 915.15, Richmond, VA.

(2008b). "Water Reclamation and Reuse Regulation." 9 VAC 25-740-10 et seq.

AHNR-IT. (2005). "VAES Weather Mesonet." College of Agriculture and Life Sciences.

Al-Gahtani, S. S., and King, M. (1999). "Attitudes, satisfaction and usage: factors contributing to each in the acceptance of information technology." *Behaviour & Information Technology*, 18(4), 277-297.

Allen, R. G., Jensen, M. E., Wright, J. L., and Burman, R. D. (1989). "Operational estimates of reference evapotranspiration." *Agron. J.*, 81(4), 650-662.

Aquacraft, I. (2003). "Performance evaluation of WeatherTRAK™ irrigation controllers in Colorado." Boulder, CO.

Arizona Board of Regents. (2007). "AZMET: The Arizona meteorological network." The University of Arizona, Tucson, AZ.

Aronson, L. J., Gold, A. J., Hull, R. J., and Cisar, J. L. (1987). "Evapotranspiration of cool-season turfgrasses in the humid Northeast." *Agron. J.*, 79, 901-905.

ASCE. (1990). *Evapotranspiration and Irrigation Water Requirements: A Manual Prepared by* *the Committee on Irrigation Water Requirements.*, American Society of Civil Engineers, New York.

Ashby, C. (2009) “Rainwater collection bill clears house: qualifying rural residents would be allowed to collect water from up to 3,000 square feet of roof.” The Pueblo Chieftain, Pueblo, Colorado.

AWWA. (2001). *Water Resources Planning: Manual of Water Supply Practices*, American Water Works Association, Denver, CO.

AWWA. (2006). *Water Conservation Programs - A Planning Manual*, American Water Works Association, Denver, CO.

AWWA. (2007). *Water Resources Planning: Manual of Water Supply Practices*, American Water Works Association, Denver, CO.

Barrett, J. (2004). "Mandated water restrictions: the future." *Golf Course Management*, 103-106.

Bastug, R., and Buyuktas, D. (2003). "The effects of different irrigation levels applied in golf courses on some quality characteristics of turfgrass." *Irrig Sci*, 22, 87-93.

Baumann, D. D. (1990). "Water conservation issues: introduction to water supply and conservation planning." *Journal of Contemporary Water Research and Education* (83).

Beard, J. B., and Green, R. L. (1994). "The role of turfgrasses in environmental protection and their benefits to humans." *Journal of Environmental Quality*, 23(3), 452-460.

Bouwman, H., Hooff, B. v. d., Wijngaert, L. v. d., and Dijk, J. v. (2005). *Information & communication technology in organizations*, SAGE Publications, Thousand Oaks, CA.

Calongne, C. M. (2001). "Designing for web site usability." *JCSC*, 16(3).

Carrow, R. N. (2006). "Can we maintain turf to customers' satisfaction with less water?" *Agricultural Water Management*, 80, 117-131.

Chrislip, D. D., Larson, C. E., and Parr, J. (1994). *Collaborative Leadership: How citizens and civic leaders can make a difference*, Jossey-Bass, San Francisco, CA.

Colorado State University. (2007). "CoAgMet." Colorado Climate Center, Fort Collins, CO.

Commonwealth of Virginia. (2007a). "Governor Kaine announces federal disaster designations for 78 Virginia counties, 34 cities." Office of the Governor, Richmond, VA.

Commonwealth of Virginia. (2007b). "Governor Kaine encourages voluntary water conservation and calls on localities to update drought contingency plans." Office of the Governor, Richmond, VA.

Corry, M. D., Frick, T. W., and Hansen, L. (1997). "User-centered design and usability testing of a web site: an illustrative case study." *ETD&D*, 45(4).

Daniels, T., and Daniels, K. (2003). *The Environmental Planning Handbook: for sustainable communities and regions*, Planners Press, Washington, DC.

Davis, F. D. (1985). "A technology acceptance model for empirically testing new end-user information systems: Theory and results," Dissertation, Massachusetts Institute of Technology, Cambridge, MA.

DeCosta, M., and Huang, B. "Evaluation of irrigation requirements and water use characteristics among three bentgrss species." *2004 Rutgers Turfgrass Proceedings*, Atlantic City, NJ.

DEQ. (2003). "Status of Virginia's Water Resources: A report on Virginia's water supply planning activities." Department of Environmental Quality, Richmond, VA.

DEQ. (2005). "Status of Virginia's Water Resources: A report on Virginia's water supply planning activities." Department of Environmental Quality, Richmond, VA.

DEQ. (2007). "Status of Virginia's Water Resources: A report on Virginia's water supply planning activities." Department of Environmental Quality, Richmond, VA.

DEQ. (2008). "Water Supply Planning Program." Department of Environmental Quality, Richmond, VA.

Devitt, D. A., Morris, R. L., and Bowman, D. C. (1992). "Evapotranspiration, crop coefficients, and leaching fractions of irrigated desert turfgrass systems." *Agron. J.*, 84, 717-723.

Devitt, D. A., Neuman, D. S., Bowman, D. C., and Morris, R. L. (1995). "Comparative water use of turfgrass and ornamental trees in an arid environment." *Journal of Turfgrass Management*, 1(2), 47-63.

DRTAC. (2003). "Virginia Drought Assessment and Response Plan." Drought Response Technical Advisory Committee.

Dumlao, R., and Duke, S. (2003). "The web and e-mail in science communication." *Science Communication*, 24(3), 283-308.

Dwyer, J. F., McPherson, G., Schroeder, H. W., and Rountree, R. A. (1992). "Assessing the benefits and costs of the urban forest." *Journal of Arboriculture*, 18(5), 227-234.

Dzurik, A. A. (2003). *Water Resources Planning*, Rowman & Littlefield Publishers, Inc., New York, NY.

EPA WaterSense. (2008). "Water-efficient single-family new home specification supporting statement." EPA, Washington, DC.

Erickson, J. E., Volin, J. C., Cisar, J. L., and Snyder, G. H. "A facility for documenting the effect of urban landscape type on fertilizer nitrogen runoff." *Proceedings of the 112th Annual Meeting of the Florida State Horticultural Society*, Stuart, FL.

Ervin, E. H., and Koski, A. J. (1998). "Drought avoidance aspects and crop coefficients of Kentucky bluegrass and tall fescue turfs in the semiarid west." *Crop Sci.*, 38(3), 788-795.

Evanylo, G. K., Ervin, E. H., Zhang, X., and Sukkariyah, B. F. (2007). "Water Reuse for Turfgrass Irrigation." Virginia Tech, Blacksburg, VA.

Feldhake, C. M., Danielson, R. E., and Butler, J. D. (1984). "Turfgrass evapotranspiration. II. Responses to deficit irrigation." *Agron. J.*, 76, 85-89.

Foster, L. M., and Smith, R. H. (2004). "JCSA - Letter of transmittal." James City Service Authority, Williamsburg, VA.

GAWCC. (2007). "Water Action Guide." Green Associations Water Conservation Council, Herndon, VA.

Haering, K. C., Evanylo, G. K., Benham, B., and Goatley, M. (2008). "Water Reuse: Using Reclaimed Water for Irrigation." Virginia Tech, Blacksburg, VA.

Harivandi, M. A. (1982). "The use of effluent water for turfgrass irrigation." University of California Cooperative Extension.

Harvey, S. "Resource stewardship agreements: Addressing the needs of Ontario's resource-based tourist industry in forest management through collaborative planning." *Meeting emerging ecological, economic, and social challenges in the Great Lakes region*, Sault Ste. Marie, ON., 41-42.

Hickey, G. (2007). "Governor Kaine announces Virginia's top business ranking for second year." Office of the Governor Timothy M. Kaine: Commonwealth of Virginia, Richmond, VA.

HRSD. (2006). "Water reuse: planning for the future." Hampton Roads Sanitation District, Virginia Beach, VA.

Huang, B., and Fry, J. (1999). "Turfgrass evapotranspiration." *J. Crop Production*, 2, 317-333.

Hutson, S. S., Barber, N. L., Kenny, J. F., Linsey, K. S., Lumia, S. S., and Maupin, M. A. (2004). "Estimated use of water in the United States in 2000." U.S. Geological Survey, Reston, VA.

Huxham, C., and Vangen, S. (2005). *Managing to Collaborate: The theory and practice of collaborative advantage*, Routledge, New York, NY.

Innes, J. E., and Booher, D. E. (1999). "Consensus building and complex adaptive systems: a framework for evaluating collaborative planning." *APA Journal*, 65(4), 412-423.

Irrigation Association. (2000). "Legislative data sheet: turf/landscape." Irrigation Association, Falls Church, VA.

Itenfisu, D., Elliott, R. L., Allen, R. G., and Walter, I. A. (2003). "Comparison of reference evapotranspiration calculations as part of the ASCE standardization effort." *Journal of Irrigation and Drainage Engineering-ASCE*, 129(6), 440-448.

Jones, H. G. (2004). "Irrigation scheduling: advantages and pitfalls of plant-based methods." *Journal of Experimental Botany*, 55(407), 2427-2436.

Kinkade-Levario, H. (2007). *Design for Water: Rainwater Harvesting, Stormwater Catchment, and Alternate Water Reuse*, New Society Publishers, Gabriola Island, BC Canada.

Ko, H., Cho, C.-H., and Roberts, M. S. (2005). "Internet uses and gratifications: A structural equation model of interactive advertising." *Journal of Advertising*, 34(2), 57-76.

LaBranche, A., Wack, H.-O., Crawford, D., Crawford, E., Soyka, N. J., and Brand, C. (2007). *Virginia Rainwater Harvesting Manual*, The Cabell Brand Center, Salem, VA.

LaBranche, A. J. (2005). "Creeping bentgrass and tall fescue responses to plant growth stimulants under deficit irrigation," Masters thesis, Virginia Tech, Blacksburg, VA.

Lazar, J. (2001). *User-Centered Web Development*, Jones and Bartlett Publishers, Sudbury, MA.

Lazarova, V., and Bahri, A. (2005). *Water Reuse for Irrigation: Agriculture, Landscapes, and Turf Grass,* CRC press, Washington, DC.

Lu, S., Guo, Z., and Peng, X. (2003). "Effects of ABA and S-3307 on drought resistance and antioxidative enzyme activity of turfgrass." *J. of Hort. Sci. & Biotech.*, 78(5), 663-666.

Macomber, P. S. H. (2004). "Guidelines on Rainwater Catchment Systems for Hawai'i." College of Tropical Agriculture and Human Resources, University of Hawai‘i, Mänoa, Hawaii.

Margerum, R. D. (2002). "Collaborative planning: building consensus and building a distinct model for practice." *J. of Planning Education and Research*, 21, 237-253.

McCarty, L. B. (2001). *Best golf course management practices,* Prentice-Hall, Inc., Upper Saddle River, New Jersey.

Membreno, D. (2007). "Couple happy with alternative water systems." The Roanoke Times Online, Roanoke, VA.

Montana DEQ. (2002). "Circular DEQ 17: Montana standards for cisterns (water storage tanks) for individual non-public systems." M. D. o. E. Quality, ed.

MSU. (2005). "Best Management Practices for Non-Agricultural Irrigation." Michigan State University, East Lansing, MI.

NASS. (2006). "Virginia's Turfgrass Industry." National Agricultural Statistics Service/USDA, Richmond, VA.

National Climatic Data Center. (2008). "2007 Annual Climate Review: U.S. Summary." National Oceanic and Atmospheric Administration.

National Weather Service. (2007). "2007 Climate Summary: Blacksburg." National Oceanic and Atmospheric Administration.

National Weather Service. (2008). "Baltimore Average Monthly Precipitation (since 1871)." National Oceanic and Atmospheric Administration.

NOAA. (2005). "Palmer Drought Severity Index.", National Oceanic and Atmospheric

Association. Internet. Available: http//www.cpc.ncep.noaa.gov/products/monitoring_and_data/drought.shtml. Accessed April 2, 2005. Modified January 17, 2005.

NOAA. (2007). "2007 Drought severity index by division (long-term Palmer) archive." N. W. S. C. P. Center, ed., NOAA, Camp Springs, MD.

Nodle, E. (2007). "Possibilities of rainwater utilisation in densely populated areas including precipitation runoffs from traffic surfaces." *Desalination*, 215.

North Carolina State University. (2008). " TIMS: Turf irrigation water management model registration." North Carolina State University, Raleigh, NC.

Ortega-Farias, S., Olioso, A., Antonioletti, R., and Brisson, N. (2004). "Evaluation of the Penman-Monteith model for estimating soybean evapotranspiration." *Irrig Sci.*, 23, 1-9.

Pereira, L. S., Perrier, A., Allen, R. G., and Alves, I. (1999). "Evapotranspiration: concepts and future trends." *J. Irrigation and Drainage Eng.*, 125, 45-51.

PFMC. (1999). "Description of adverse effects on Pacific salmon essential fish habitat and actions to encourage the conservation and enhancement of essential fish habitat." Pacific Fisher Management Council, Portland, Oregon.

Pollina Corporate Real Estate Inc. (2007). "Top 10 pro-business states." Pollina Corporate Real Estate, Inc., Park Ridge, IL.

Randolph, J. (2004). *Environmental Land Use Planning and Management*, Island Press, Washington, DC.

Ratcliff, C. (1999). "Water supply and demand." *Grounds Maintenance*, 34(6), 10.

Richie, W. E., Green, R. L., and Gibeault, V. A. (1997). "Using ET_o (Reference Evapotranspiration) for turfgrass irrigation efficiency." University of California Cooperative Extension, University of California, Riverside.

Rodebaugh, D. (2008). "Collecting public rainwater is tricky: legislature considers ways to make it legal." The Durango Herald, Durango, Colorado.

Rogers, E. M. (2003). *Diffusion of Innovations*, Free Press, New York, NY.

Saha, S. K. (2004). "Effect of fertilizer source on nitrate leaching, plant water consuption, and turf and ornamental quality," University of Florida, Gainesville, FL.

Selin, S., and Chavez, D. (1995). "Developing a collaborative model for environmental planning and management." *Environmental Management,* 19(2), 189-195.

Slack, E. V. (2000). "Maintaining superior landscapes on a water budget." Water Right: Conserving our water preserving our environment, International Turf Producers Foundation, Rolling Meadows, IL, 55-56.

Sluss, M. (2007). "Kaine asks Virginians to restrict water use." The Roanoke Times, Roanoke, VA.

SRI International. (2006). "Virginia's Golf Economy, 2005." SRI International, Arlington, VA.

Standish-Lee, P., Loboschefsky, E., and Beuhler, M. "The future of water: Identifying and developing effective methods for managing water in are and semi-arid regions." *Proceedings of the Water Environment Federation, WEFTEC 2005,* Washington, DC, 8598-8606(

State of California. (2005). "California irrigation management information system." California Department of Water Resources, Office of Water Use Efficiency, Sacramento CA

Stockle, C. O., Kjelgaard, J., and Bellocchi, G. (2004). "Evaluation of estimated weather data for calculating Penman-Monteith reference crop evapotranspiration." *Irrig Sci.*, 23(39-46).

Taraba, J. L., Holmes, E., Ilvento, T. W., and Heaton, L. M. (1990). "Water Quality in Kentucky: Cisterns for Kentucky." University of Kentucky, Lexington, KY.

TCEQ. (2007). "Rainwater Harvesting: guidance for public water systems." Texas Commission on Environmental Quality Austin, TX.

Texas A&M University. (2004). "Texas Evapotranspiration Network." Texas A&M University System.

TWDB. (2005). "The Texas Manual on Rainwater Harvesting, Third Edition." Texas Water Development Board, Austin, TX.

TWDB. (2008a). "Regional Water Planning." Texas Water Development Board, Austin, TX.

TWDB. (2008b). "Texas Rain Catcher Award - Fall 2007." Texas Water Development Board, Austin, TX.

U.S. Census Bureau. (1990). "1990 Census of Population and Housing." U.S. Census Bureau, Population Division, Washington, DC.

U.S. Census Bureau. (2000). "Profile of General Demographic Characteristics: 2000." U.S. Census Bureau, Population Division, Washington, DC.

U.S. Census Bureau. (2006). "ACS Demographic and Housing Estimates: 2006 ", U.S. Census Bureau, Population Division, Washington, DC.

U.S. Census Bureau. (2007). "Virginia QuickFacts." U.S. Census Bureau, Washington, DC.

U.S. EPA. (2004). "Guidelines for Water Reuse." U.S. Environmental Protection Agency
U.S. Agency for International Development, Washington, DC.

U.S. EPA. (2007). "Weather- or sensor-based irrigation control technologies." WaterSense: Efficiency made easy, EPA, Washington, DC.

U.S. EPA. (2008). "Expert advice on watering wisely." WaterSense, EPA, Washington, DC.

U.S. Water News Online. (2008a). "As supplies dry up, growers pass on farming and sell water." U.S. Water News Online.

U.S. Water News Online. (2008b). "Georgia's Gov. Perdue announces reductions to state's outdoor watering ban."

University of Idaho. (2007). "ETIdaho: Evapotranspiration and consumptive irrigation water requirements for Idaho ", University of Idaho Research and Extension Center, Kimberly, Idaho.

University of Oklahoma. (2007). "Oklahoma agweather." Board of Regents of the University of Oklahoma, Norman, OK.

University of Virginia. (2000). "Virginia potential evapotranspiration, annual precipitation, and annual precipitation minus potential evapotranspiration." University of Virginia Climatology Office, Charlottesville, VA.

USDA. (1999). "Sustaining the people's lands: Recommendations for stewardship of the national forests and grasslands into the next century." U.S. Department of Agriculture, Washington, DC.

USGS. (2004). "Total water withdrawals for Virginia, 1995." United States Geological Science, Water Resources.

USGS. (2008a). "Drought Status Report: April 22, 2008." United States Geological Services, Richmond, VA.

USGS. (2008b). "Drought Status Report: January 22, 2008." United States Geological Survey, Richmond, VA.

USGS. (2008c). "Drought Status Report: November 25, 2008." United States Geological Services, Richmond, VA.

USGS. (2008d). "Precipitation Departures by Drought Evaluation Region." United States Geological Services, Richmond, VA.

Vallee, D., Margat, J., Eliasson, A., Hoogeveen, J., and Faures, J.-M. (2003). *Review of the world water resources by country*, Food and Agriculture Organization of the United Nations, Rome, Italy.

Venkatesh, V., and Davis, F. D. (1996). "A model of the antecedents of perceived ease of use: Development and test." *Decision Sciences*, 27(3), 451-480.

Venkatesh, V., Morris, M. G., Davis, G. B., and Davis, F. D. (2003). "User acceptance of information technology: Toward a unified view." *MIS Quarterly*, 27(3), 425-478.

Vishwanath, A., and Goldhaber, G. M. (2003). "An examination of the factors contributing to adoption decisions among late-diffused technology products." *New Media & Society*, 5(4), 547-572.

Vredenburg, K., Mao, J.-Y., Smith, P. W., and Carey, T. (2002). "A survey of user-centered design practice." CHI 2002, Minneapolis, Minnesota.

Warner, G. M. (2002). "Executive Order 39: Virginia water supply initiative."

Water Management Committee. (2005). "Landscape Irrigation Scheduling and Water Management." Irrigation Association, Falls Church, VA.

Younos, T. (2004). "The Feasibility of Using Desalination to Supplement Drinking Water Supplies in Eastern Virginia." Virginia Water Resources Research Center, Virginia

Polytechnic and State University, Blacksburg, VA.

Younos, T., Bohdan, R., Anderson, E., Ramsey, K., Cook, N., Ross, B. B., and Dillaha., T. (1998). "Evaluation of rooftop rainfall collection-cistern storage systems in southwest Virginia. VWRRC Special Publication SP3-1998.", Virginia Water Resources Research Center. Virginia Tech, Blacksburg, VA.

Zoldoske, D. F. (2004). "A simple step toward savings: California study examines effect of new nozzles of golf course irrigation systems." *Golf Course Management*, 72(1), 209-213.

CHAPTER 3: DEVELOPING THE VIRGINIA EVAPOTRANSPIRATION WEBSITE

Abstract

Although Virginia is considered a water rich state, water conservation is important for turfgrass irrigation to ensure adequate supplies are available for future needs. Evapotranspiration based irrigation is one proven way to reduce irrigation water consumption without affecting plant health.

The user-center and collaborative website design process was initiated in January 2006 and finalized in August 2008. Feasibility surveys were distributed during the Virginia Turfgrass Council (VTC) annual meeting in January 2006. Since the results reflected that many turfgrass professionals utilize the Internet often and are well versed on Virginia water conservation needs, the study was implemented. During the VTC 2007 annual meeting, an updated survey was distributed to gather more data to determine how much supplemental information would be needed in the website design and to determine likelihood of adoption. Website prototypes were developed for the 2008 annual conference, but due to low focus group attendance, an online survey was emailed through Virginia turfgrass professional listservs. The final website was developed based on collaborative input through the survey responses with the goal to produce an easy to use and useful website. Survey results showed a preference for more user input to select the appropriate weatherstation, turfgrass species and data range. The website is fully functioning and is available at http://www.turf.cses.vt.edu/Ervin/et_display.html.

Introduction

When discussing landscape water conservation practices, one typically pictures installing desert landscapes consisting of cacti and stone front lawns. Although Virginia is considered a water rich state as it receives an average of 45 inches yearly (National Climatic Data Center 2008), water conservation endeavors are in full force due to recent drought occurrences and continuing population increases.

In late October of 2007, Governor Mark Warner issued a notice that urged Virginia localities to update their water conservation plans and reduce non-essential water use due to drought (Commonwealth of Virginia 2007; Sluss 2007). Likewise, Virginia populations continue to rise as the Commonwealth was identified as the best state in which to do business (Hickey 2007; Pollina Corporate Real Estate Inc. 2007). Virginia's population increased by 12.5% from 1990 to 2000 and 7.4% from 2000 to 2005 (U.S. Census Bureau 1990; U.S. Census Bureau 2000; U.S. Census Bureau 2006). Although Virginia is considered a water-rich state, the commonwealth's increasing water withdrawals from growing populations (U.S. Census Bureau 2007) coupled with the ongoing drought events (DEQ 2007) stress the need to conserve water resources.

Virginia's landscaped areas rely on supplemental irrigation to promote and enhance growth during the summer months. Turfgrass is one of the state's top agricultural products and produces more money per irrigated acre compared to any other crop in the state. Golf courses use 4,170 gallons of water per acre per day, while corn and grape production consumes 2,521 and 3,879 gallons of water per acre per day, respectively. However, golf courses receive $18,480 per acre in revenue compared to $2,453 and $189 per acre for grapes and corn, respectively (SRI International 2006). In 2004, the turfgrass industry supplied $1.2 billion in labor, which was a 43% increase from 1998, the last time an economic report was conducted (NASS 2006). Another study, which focused primarily on the Virginia golf course industry, found the 2005 Virginia golf industry grossed $3.1 billion (SRI International 2006). The Virginia golf industry, accounts for 0.4% of the state's water use, whereas Virginia agriculture accounts for 1.4% (DEQ 2005). Such a large and economically influential industry should be proactive in water conservation endeavors to ensure its continued success.

The EPA recently released a draft "Water-Efficient Single-Family New Home Specification" (2008) for public comment. One tactic covered in the EPA draft specification is basing irrigation on evapotranspiration (ET). Evapotranspiration-based irrigation scheduling is an effective way to ensure that only water lost from a turfgrass system, via plant transpiration and soil evaporation, is replaced via supplemental irrigation. Many researchers, in Virginia and throughout the United States, determined that ET-based irrigation scheduling is a scientific approach to assessing appropriate irrigation quantities (Allen et al. 1989; Aronson et al. 1987; ASCE 1990; Bastug and Buyuktas 2003; Devitt et al. 1992; Ervin and Koski 1998; Feldhake et al. 1984; Huang and Fry 1999; LaBranche 2005; Pereira et al. 1999; Richie et al. 1997).

A study conducted by the Irvine Ranch Water District found that prior to ET-based scheduling, irrigation was applied at up to three times more than ET estimates (Slack 2000). An independent researcher in Colorado conducted a study on home lawns to test the WeatherTRAK™ system, which sends daily ET data to irrigation controllers. This study found an average of 98,420 liters (26,000 gallons) of water saved per site each season compared to historical usage with water savings averaged $197 yearly and no significant decrease in turfgrass appearance (Aquacraft 2003).

There are several ET equations available to estimate atmospheric demand within the plant science field. The Penman-Monteith (PM) equation is the most widely used and most consistent ET equation that is suitable for use in various climatic regions and for various crops (Allen et al. 1989; Itenfisu et al. 2003; Ortega-Farias et al. 2004; Stockle et al. 2004). Many states have developed websites that utilize a version of the PM equation to calculate ET throughout the state. Among the states are Arizona (Fig.3.1, 3.2), California (Fig. 3.3, 3.4), Idaho (Fig. 3.5, 3.6), North Carolina, Oklahoma (Fig. 3.7, 3.8), and Texas (Fig. 3.9, 3.10) (Arizona Board of Regents 2007; North Carolina State University 2008; State of California 2005; TAMU 2004; University of Idaho 2007; University of Oklahoma 2007).

Most of the developed websites are for western states where rainfall is limited and water conservation is prevalent. Evapotranspiration-based irrigation is gaining popularity in the humid southeast due to increasing water demands and drought occurrences. For example, North Carolina recently developed a website that guides irrigators through the process of determining water demand and irrigation run time (North Carolina State University 2008).

AZMET Stations : Current Data Files

Most Current Daily, Weekly, Monthly and Year-To-Date Files

All Stations : Yesterday's Summary, Heat Units, ETo Reports

Aguila	Status Daily Weekly Monthly Annual Heat Units Ref ETo
Bonita	Status Daily Weekly Monthly Annual Heat Units Ref ETo
Bowie	Status Daily Weekly Monthly Annual Heat Units Ref ETo
Buckeye	Status Daily Weekly Monthly Annual Heat Units Ref ETo
Ciudad Obregon	Status
Coolidge	Status Daily Weekly Monthly Annual Heat Units Ref ETo
Dateland	Status
Desert Ridge	Status Daily Weekly Monthly Annual Heat Units Ref ETo
Eloy	Status Daily Weekly Monthly Annual Heat Units Ref ETo
Flagstaff	Status Daily Weekly Monthly Annual Heat Units Ref ETo
Harquahala	Status Daily Weekly Monthly Annual Heat Units Ref ETo
Kansas Settlement	Status Daily Weekly Monthly Annual Heat Units Ref ETo
Laveen	Status
Litchfield	Status
Mesa	Status Daily Weekly Monthly Annual Heat Units Ref ETo
Marana	Status Daily Weekly Monthly Annual Heat Units Ref ETo
Maricopa	Status Daily Weekly Monthly Annual Heat Units Ref ETo

Figure 3.1 Arizona ET website input
Used with permission (*http://ag.arizona.edu/AZMET/current.htm*)

Bonita : 2005

Reference Evapotranspiration (ETo)

Units = Inches
DOY = Day Of Year (1 to 365)
CUM = Accumulated Total Since Jan 1, 2005
* = Missing data. ETo estimated; based on previous day.

		Original AZMET		Penman Monteith		Precipitation	
DOY	Date	DAY	CUM	DAY	CUM	DAY	CUM
1	Jan 1	0.07	0.07	0.05	0.05	0.00	0.00
2	Jan 2	0.00	0.07	0.03	0.09	0.34	0.34
3	Jan 3	0.00	0.08	0.03	0.12	0.62	0.96
4	Jan 4	0.07	0.15	0.06	0.18	0.13	1.09
5	Jan 5	0.04	0.19	0.04	0.22	0.01	1.10
6	Jan 6	0.06	0.26	0.05	0.27	0.00	1.10
7	Jan 7	0.07	0.33	0.06	0.32	0.00	1.10
8	Jan 8	0.08	0.41	0.07	0.39	0.00	1.10
9	Jan 9	0.05	0.46	0.06	0.45	0.00	1.10
10	Jan 10	0.09	0.56	0.08	0.53	0.00	1.10
11	Jan 11	0.08	0.63	0.12	0.65	0.00	1.10
12	Jan 12	0.09	0.72	0.06	0.71	0.00	1.10
13	Jan 13	0.07	0.80	0.05	0.76	0.00	1.10
14	Jan 14	0.06	0.86	0.06	0.82	0.00	1.10
15	Jan 15	0.10	0.96	0.08	0.91	0.00	1.10
16	Jan 16	0.14	1.10	0.11	1.01	0.00	1.10
17	Jan 17	0.13	1.23	0.10	1.12	0.00	1.10
18	Jan 18	0.14	1.37	0.11	1.23	0.00	1.10
19	Jan 19	0.12	1.49	0.10	1.33	0.00	1.10
20	Jan 20	0.07	1.56	0.08	1.41	0.00	1.10
21	Jan 21	0.00	1.56	0.03	1.44	0.22	1.32

Figure 3.2 Arizona ET website output
Used with permission

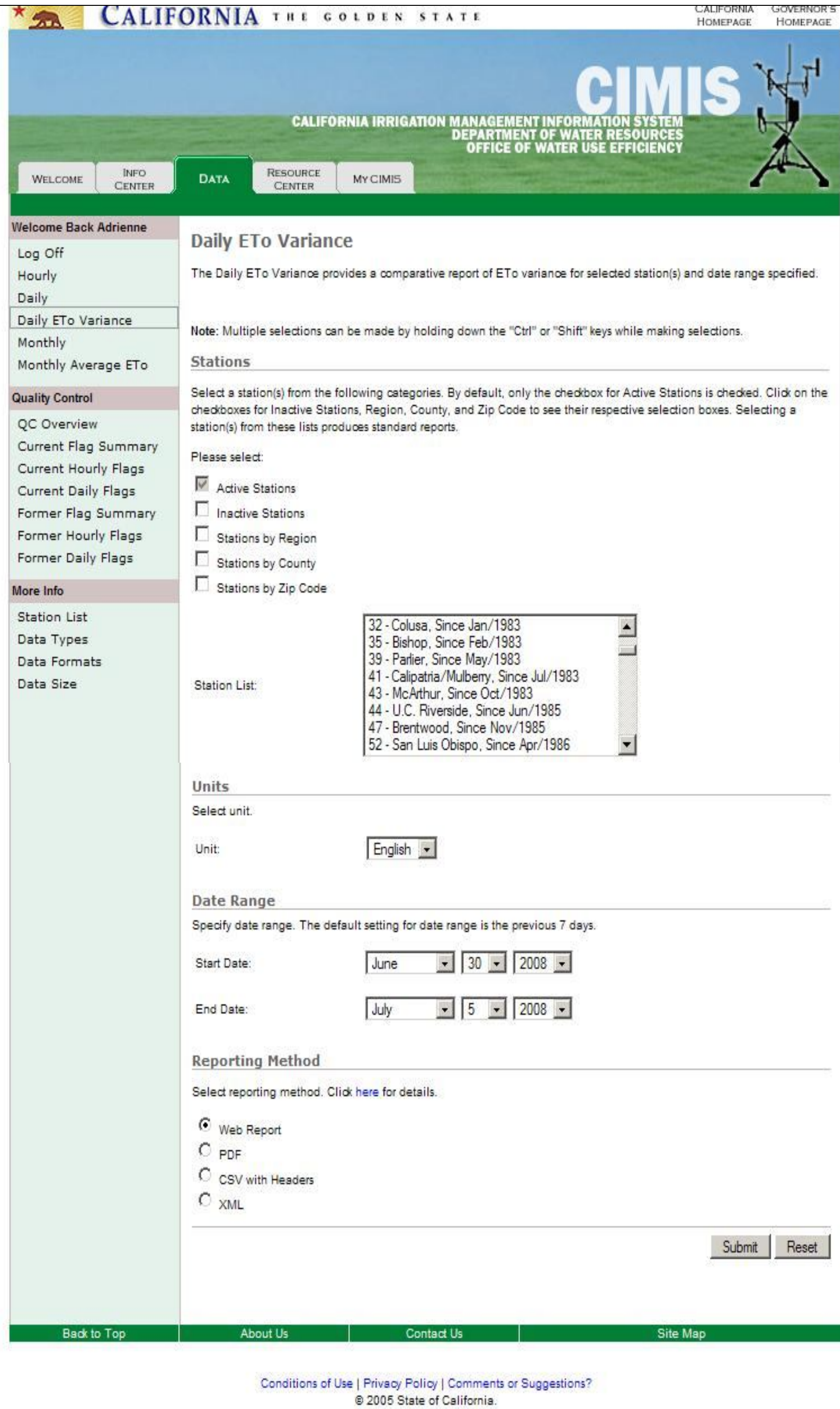


Figure 3.3 California ET website input

Used with permission *(http://wwwcimis.water.ca.gov/cimis/logon.do?forwardURL=frontMonthlyEToReport&selTab=data)*

CIMIS (California Irrigation Management Information System)

Daily ETo Variance Report

Rendered in ENGLISH Units.
June 30, 2008 - July 5, 2008
Printed on November 6, 2008

San Joaquin Valley - FivePoints - #2

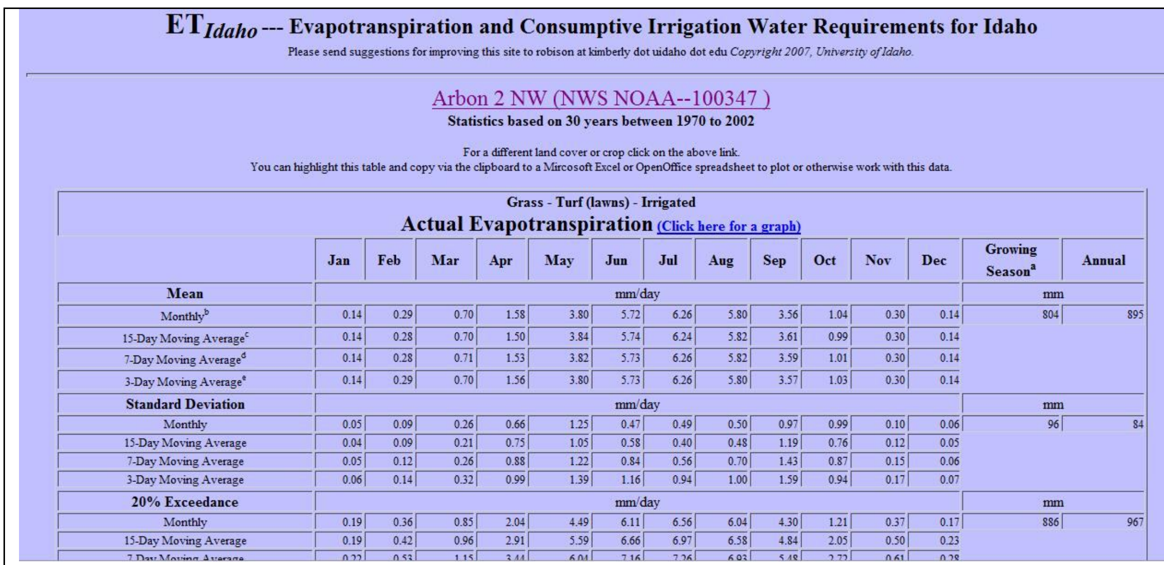
Date	Target Year (in)	Previous Year (in)	Historic Average (in)	*Difference (%)
30-JUN-2008 Monday	0.27	0.31	0.28	-4
01-JUL-2008 Tuesday	0.27	0.32	0.28	-4
02-JUL-2008 Wednesday	0.29	0.34	0.28	4
03-JUL-2008 Thursday	0.27	0.32	0.28	-4
04-JUL-2008 Friday	0.27	0.31	0.28	-4
05-JUL-2008 Saturday	0.28	0.29	0.28	0
Totals/Avgs	1.65	1.89	1.68	-2

Normal Year Projection for Next Seven Days = 1.96

* Diffference (%) = (target - historic) / historic * 100

Figure 3.4 California ET website output
Used with permission

Figure 3.5 Idaho ET website input
Used with permission *(http://www.kimberly.uidaho.edu/ETIdaho/)*


ET*Idaho* --- Evapotranspiration and Consumptive Irrigation Water Requirements for Idaho

Please send suggestions for improving this site to robison at kimberly dot uidaho dot edu *Copyright 2007, University of Idaho.*

Arbon 2 NW (NWS NOAA--100347)

Statistics based on 30 years between 1970 to 2002

For a different land cover or crop click on the above link.
You can highlight this table and copy via the clipboard to a Mircosoft Excel or OpenOffice spreadsheet to plot or otherwise work with this data.

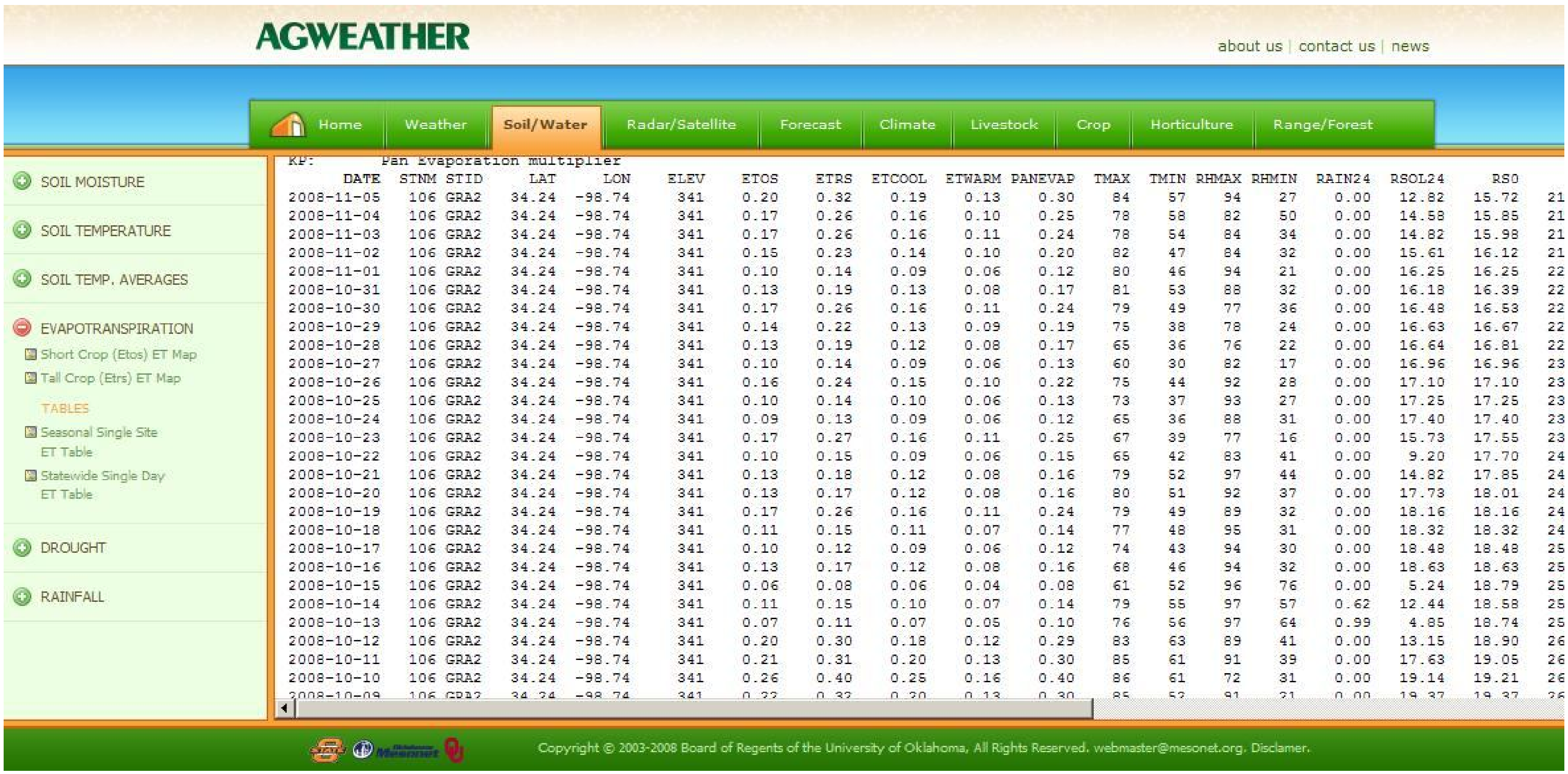
Grass - Turf (lawns) - Irrigated

Actual Evapotranspiration (Click here for a graph)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Growing Season[a]	Annual
Mean	mm/day												mm	
Monthly[b]	0.14	0.29	0.70	1.58	3.80	5.72	6.26	5.80	3.56	1.04	0.30	0.14	804	895
15-Day Moving Average[c]	0.14	0.28	0.70	1.50	3.84	5.74	6.24	5.82	3.61	0.99	0.30	0.14		
7-Day Moving Average[d]	0.14	0.28	0.71	1.53	3.82	5.73	6.26	5.82	3.59	1.01	0.30	0.14		
3-Day Moving Average[e]	0.14	0.29	0.70	1.56	3.80	5.73	6.26	5.80	3.57	1.03	0.30	0.14		
Standard Deviation	mm/day												mm	
Monthly	0.05	0.09	0.26	0.66	1.25	0.47	0.49	0.50	0.97	0.99	0.10	0.06	96	84
15-Day Moving Average	0.04	0.09	0.21	0.75	1.05	0.58	0.40	0.48	1.19	0.76	0.12	0.05		
7-Day Moving Average	0.05	0.12	0.26	0.88	1.22	0.84	0.56	0.70	1.43	0.87	0.15	0.06		
3-Day Moving Average	0.06	0.14	0.32	0.99	1.39	1.16	0.94	1.00	1.59	0.94	0.17	0.07		
20% Exceedance	mm/day												mm	
Monthly	0.19	0.36	0.85	2.04	4.49	6.11	6.56	6.04	4.30	1.21	0.37	0.17	886	967
15-Day Moving Average	0.19	0.42	0.96	2.91	5.59	6.66	6.97	6.58	4.84	2.05	0.50	0.23		

Figure 3.6 Idaho ET website output
Used with permission

Figure 3.7 Oklahoma ET website input
Used with permission *(http://agweather.mesonet.org/index.php/data/section/soil_water)*



DATE	STNM	STID	LAT	LON	ELEV	ETOS	ETRS	ETCOOL	ETWARM	PANEVAP	TMAX	TMIN	RHMAX	RHMIN	RAIN24	RSOL24	RSO	
2008-11-05	106	GRA2	34.24	-98.74	341	0.20	0.32	0.19	0.13	0.30	84	57	94	27	0.00	12.82	15.72	21
2008-11-04	106	GRA2	34.24	-98.74	341	0.17	0.26	0.16	0.10	0.25	78	58	82	50	0.00	14.58	15.85	21
2008-11-03	106	GRA2	34.24	-98.74	341	0.17	0.26	0.16	0.11	0.24	78	54	84	34	0.00	14.82	15.98	21
2008-11-02	106	GRA2	34.24	-98.74	341	0.15	0.23	0.14	0.10	0.20	82	47	84	32	0.00	15.61	16.12	21
2008-11-01	106	GRA2	34.24	-98.74	341	0.10	0.14	0.09	0.06	0.12	80	46	94	21	0.00	16.25	16.25	22
2008-10-31	106	GRA2	34.24	-98.74	341	0.13	0.19	0.13	0.08	0.17	81	53	88	32	0.00	16.18	16.39	22
2008-10-30	106	GRA2	34.24	-98.74	341	0.17	0.26	0.16	0.11	0.24	79	49	77	36	0.00	16.48	16.53	22
2008-10-29	106	GRA2	34.24	-98.74	341	0.14	0.22	0.13	0.09	0.19	75	38	78	24	0.00	16.63	16.67	22
2008-10-28	106	GRA2	34.24	-98.74	341	0.13	0.19	0.12	0.08	0.17	65	36	76	22	0.00	16.64	16.81	22
2008-10-27	106	GRA2	34.24	-98.74	341	0.10	0.14	0.09	0.06	0.13	60	30	82	17	0.00	16.96	16.96	23
2008-10-26	106	GRA2	34.24	-98.74	341	0.16	0.24	0.15	0.10	0.22	75	44	92	28	0.00	17.10	17.10	23
2008-10-25	106	GRA2	34.24	-98.74	341	0.10	0.14	0.10	0.06	0.13	73	37	93	27	0.00	17.25	17.25	23
2008-10-24	106	GRA2	34.24	-98.74	341	0.09	0.13	0.09	0.06	0.12	65	36	88	31	0.00	17.40	17.40	23
2008-10-23	106	GRA2	34.24	-98.74	341	0.17	0.27	0.16	0.11	0.25	67	39	77	16	0.00	15.73	17.55	23
2008-10-22	106	GRA2	34.24	-98.74	341	0.10	0.15	0.09	0.06	0.15	65	42	83	41	0.00	9.20	17.70	24
2008-10-21	106	GRA2	34.24	-98.74	341	0.13	0.18	0.12	0.08	0.16	79	52	97	44	0.00	14.82	17.85	24
2008-10-20	106	GRA2	34.24	-98.74	341	0.13	0.17	0.12	0.08	0.16	80	51	92	37	0.00	17.73	18.01	24
2008-10-19	106	GRA2	34.24	-98.74	341	0.17	0.26	0.16	0.11	0.24	79	49	89	32	0.00	18.16	18.16	24
2008-10-18	106	GRA2	34.24	-98.74	341	0.11	0.15	0.11	0.07	0.14	77	48	95	31	0.00	18.32	18.32	24
2008-10-17	106	GRA2	34.24	-98.74	341	0.10	0.12	0.09	0.06	0.12	74	43	94	30	0.00	18.48	18.48	25
2008-10-16	106	GRA2	34.24	-98.74	341	0.13	0.17	0.12	0.08	0.16	68	46	94	32	0.00	18.63	18.63	25
2008-10-15	106	GRA2	34.24	-98.74	341	0.06	0.08	0.06	0.04	0.08	61	52	96	76	0.00	5.24	18.79	25
2008-10-14	106	GRA2	34.24	-98.74	341	0.11	0.15	0.10	0.07	0.14	79	55	97	57	0.62	12.44	18.58	25
2008-10-13	106	GRA2	34.24	-98.74	341	0.07	0.11	0.07	0.05	0.10	76	56	97	64	0.99	4.85	18.74	25
2008-10-12	106	GRA2	34.24	-98.74	341	0.20	0.30	0.18	0.12	0.29	83	63	89	41	0.00	13.15	18.90	26
2008-10-11	106	GRA2	34.24	-98.74	341	0.21	0.31	0.20	0.13	0.30	85	61	91	39	0.00	17.63	19.05	26
2008-10-10	106	GRA2	34.24	-98.74	341	0.26	0.40	0.25	0.16	0.40	86	61	72	31	0.00	19.14	19.21	26
2008-10-09	106	GRA2	34.24	-98.74	341	0.22	0.32	0.20	0.13	0.30	85	52	91	21	0.00	19.37	19.37	26

Figure 3.8 Oklahoma ET website output
Used with permission

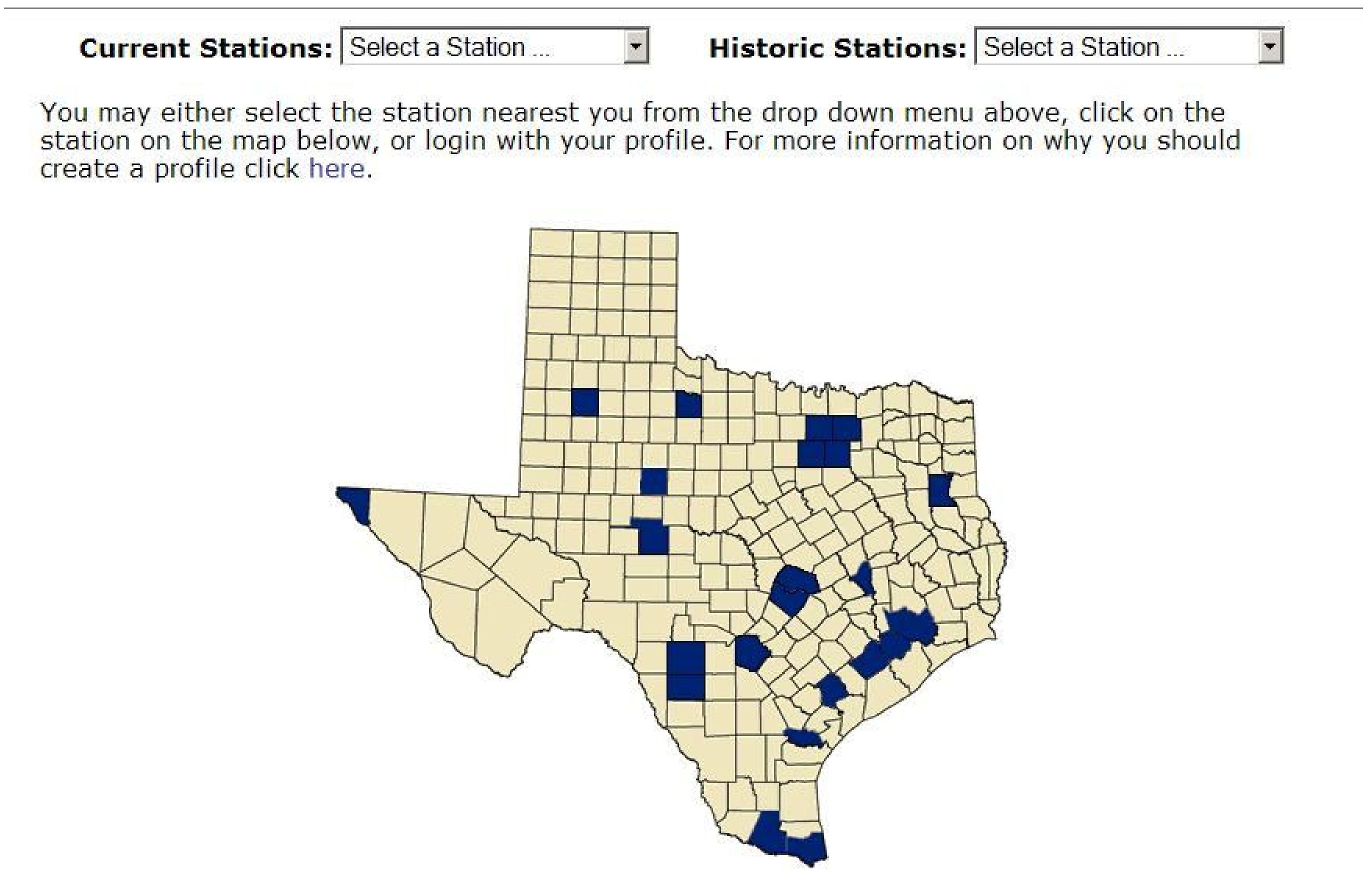


Figure 3.9 Texas ET input
Used with permission *(http://texaset.tamu.edu/)*

Kingwood Weather Station
***Station Sponsored by :* Texas AgriLife Extension**

Date	ETo PET (in)	Tmax (F)	Tmin (F)	RHmin (%)	Solar (MJm2)	Rain (in)	Wind 4am (mph)	Wind 4pm (mph)
2008-10-23	0.08	70	50	45	13.56	0.00	1.57	1.71
2008-10-24	0.08	77	43	34	15.61	0.00	0.00	1.59
2008-10-25	0.07	81	46	39	14.93	0.00	0.00	0.44
2008-10-26	0.08	84	49	46	14.60	0.00	0.00	0.25
2008-10-27	0.09	66	45	27	15.01	0.00	0.38	2.74
2008-10-28	0.07	67	37	30	14.54	0.00	0.03	1.83
2008-10-29	0.06	73	40	37	14.17	0.00	0.00	0.92
2008-10-30	0.07	78	46	50	13.63	0.00	0.00	0.74
2008-10-31	0.07	78	54	59	12.36	0.00	0.00	0.60
2008-11-01	0.06	80	54	60	10.43	0.00	0.00	0.58
2008-11-02	0.07	79	53	54	12.98	0.00	0.00	0.94
2008-11-03	0.07	78	50	51	12.38	0.00	0.00	0.63
2008-11-04	0.06	77	49	66	10.52	0.00	0.00	0.41
2008-11-05	0.06	83	59	62	9.49	0.00	0.00	1.02
14 Day Summary	**0.99**	**76**	**48**	**47**	**13.16**	**0.00**	**0.14**	**1.03**

Note: Reported are the average hourly values, not the absolute highs and lows.

3 day summary | 5 day summary | 7 day summary | other day range

Figure 3.10 Texas ET output
Used with permission

Unlike the above states, Virginia does not have an ET website detailing real-time irrigation demands. The University of Virginia Climatology Office (2000) has developed a table that details average ET demand for various Virginia locations throughout the year. This is the sole source of information that Virginia irrigators can use to determine irrigation needs based on ET demand. Since all the data are averages, it may not be useful in years when weather patterns diverge from normal.

The Virginia Tech Agriculture, Human and Natural Resources Information Technology (AHNR-IT) department installed weatherstations at Virginia Agricultural Experiment Stations to collect climate data like temperature, humidity, solar radiation, wind speed rainfall, etc. (AHNR-IT 2005). The weatherstations collect all the weather data needed to calculate ET, which can be done with a software calculator like REF-ET (Allen 2000). However, this process is time consuming as data must be organized properly and the calculator must be programmed properly to ensure the calculator works. This tedious self-calculation process may deter many from adopting the ET-based irrigation scheduling technique.

Technology diffusion is “the process in which an innovation is communicated through certain channels over time among the members of a social system” (Rogers 2003). The four variables, innovation, channels, time, and social system, all impact how a given population perceives certain technologies and can be linked to adoption willingness. The technology adoption model, first postulated by Davis (1985), states that willingness to accept a new information communication technology is based on perceived usefulness and ease of use. Vishwanath and Goldhaber (2003) and Karahanna and Straub (1999) claimed that perceived usefulness is dependent on the perceived ease of use. Therefore, individuals are less apt to adopt a new technology if it is not useful or if the technology is not considered to be user-friendly. As Venkatesh and Davis (1996) found, new information communication technology adoption is dependent on the targeted population. The population’s census makeup, previous technological interactions, and influence in developing the new technology will all impact adoption (Venkatesh et al. 2003; Vishwanath and Goldhaber 2003).

To ensure the target population is represented as means to positively impact technology adoption, user-centered design methodology can be implanted to develop a new technology. User-centered web development is a collaborative process that includes the users in the design and development process (Lazar 2001). The additional steps taken to understand the target population can encourage adoption and success (Calongne 2001). As discussed with the technology adoption model, a technology that is easy to use is more likely to be adopted. Utilizing website users in the design process is one sure way to ensure the website is easy to use and built for the targeted population, thus increasing likelihood of adoption.

In the planning sector, user-centered design is called collaboration, which is the integration of stakeholders, individuals or organizations that express an interest in, concern of, or impact from the subsequent plan, to develop a plan (Selin and Chavez 1995). Through the collaborative user-centered design process, social learning could occur due to the involvement of various stakeholders in the decision making process (Huxham and Vangen 2005; Margerum 2002). This involvement in the plan or design making process not only leads to learning from one another, but also gives the participants ownership of the final product, which in turn could also encourage adoption.

The objective of this study is to develop an ET website by incorporating the technology adoption theory through a user-center design and collaborative process. By these theories and processes, it is postulated that an easy to use and useful website will be developed, which will encourage website adoption. Furthermore, the developed website will allow users to create irrigation schedules that will promote water conservation as the schedules will be based on real-time climate data.

Materials and Methods

To determine project feasibility, preliminary data were collected at the 2006 annual Virginia Turfgrass Council (VTC) meeting in Fredericksburg, Virginia. The VTC holds an annual conference that includes research talks, certification opportunities, continuing education learning credits and a tradeshow. This conference hosts the largest gathering of Virginia turfgrass professionals and serves as an optimum platform to interact with many irrigators, which were identified as the stakeholders. The conference typically attracts around 600 turfgrass professionals from around Virginia and nearby states. The conference attendees were approached and informed about the proposed website and then were asked to take a survey concerning their water use, current water conservation practices, and likelihood of utilizing an ET website for scheduling irrigation (Appendix 1). The data collected was used to determine research feasibility. All survey questions were developed on a Likert-type scale and responses were scaled with numerical values to determine response frequency (de Vaus 1986).

During the 2007 VTC annual meeting, surveys edited from the 2006 version were distributed again to attendees touring the tradeshow, attending lectures and conversing in the hallways (Appendix 2). The 2007 collected data were used to determine the website design approach. Technology availability and familiarity with ET data were used to determine website sophistication. The awareness of ET-based irrigation scheduling and current water conservation practices data were used to determine the supplemental information that should be included in the website. Likelihood of adoption assisted in determining future trends and possible adoption.

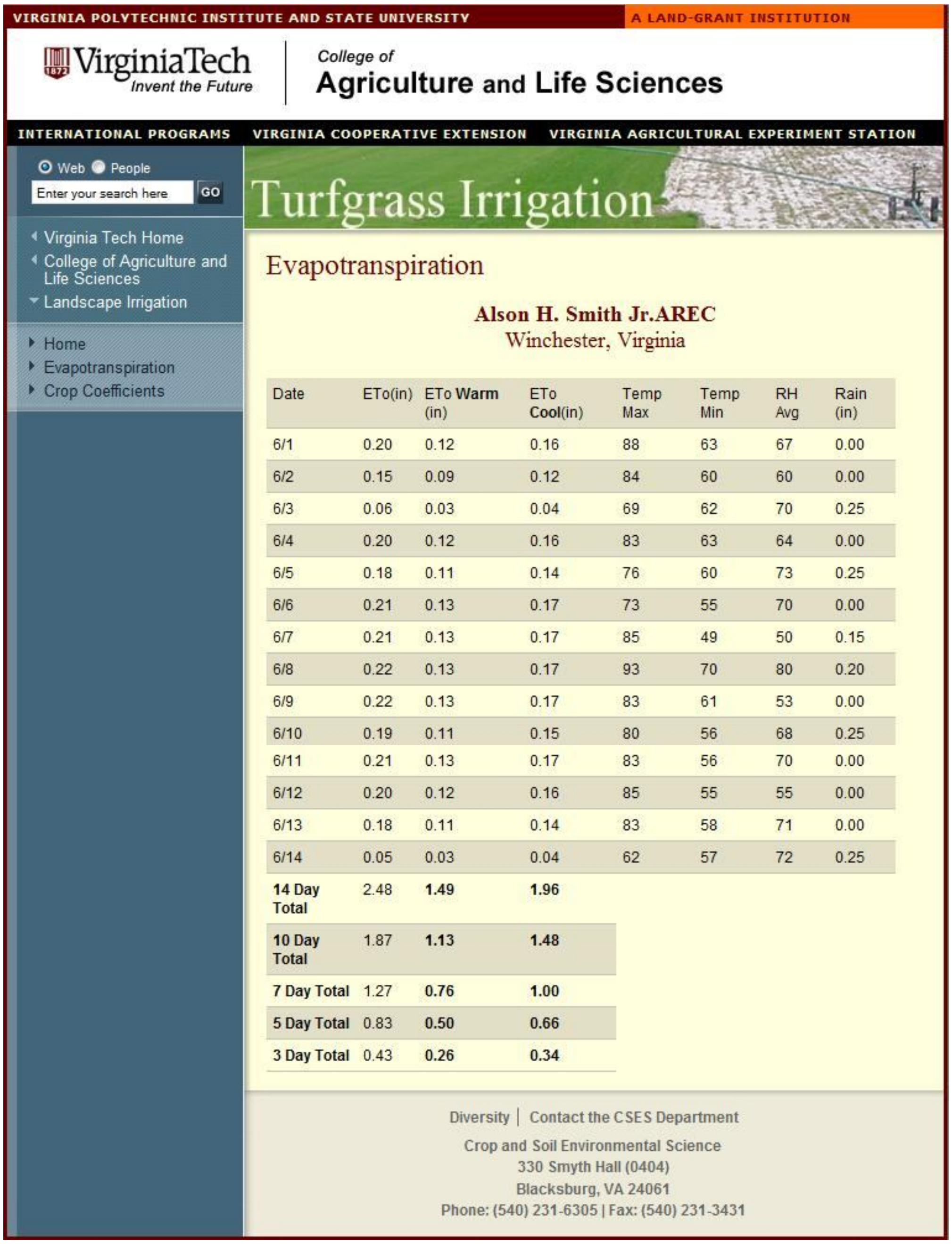
Two prototype websites were developed based on the 2006 and 2007 survey data. The designs were also modeled after current ET websites from other states. Websites like California's (State of California 2005) that require registration before utilizing the website were deemed as not user-friendly. The researcher made the decision to make the data access a two screen process like Idaho's (University of Idaho 2007) and Texas's (TAMU 2004), which require the user to select the appropriate weatherstation (Fig. 3.5, 3.9), which then links the user to a second screen that shows ET (Fig. 3.6, 3.10). However, neither Idaho nor Texas' website allows the user to alter the data timeline. Oklahoma's original website required users to select the appropriate weatherstation on the map, crop species and data time line. The website has since been redesigned and the output is as seen in Figure 3.7. This output requires the user to sum the necessary ET data to determine actual irrigation time, whereas the Texas website creates a 14 day summary to assist in scheduling. However, not every manager uses a 14 day irrigation schedule. Arizona and Idaho both show yearly ET data (Fig. 3.2, 3.6) and require the user to identify the applicable data in a large table. North Carolina (North Carolina State University

2008) has a very sophisticated system that requires equally sophisticated skills to navigate. Like California, users have to register with the North Carolina website to access data. Users then must enter detailed information concerning the area to be landscaped, which is a time consuming and elaborate process.

The developed website prototypes were not real-time working websites; they served to show the users how data could be accessed and the possible output design. The two website prototypes combined all the notably positive attributes from the current states' websites and were designed with ease of use in mind. The first website prototype simply prompted users to click on the closest weatherstation on the map (Fig. 3.11), which then led the user to a second screen (Fig. 3.12). The page detailed ET adjusted for warm and cool season turfgrass and summed data for three, five, seven and fourteen day increments. The second website prototype (Fig. 3.13) had a drop-down menu, crop species selection drop-down menu, and data length menu. When the individual inputted the desired information, the second page (Fig. 3.14) showed the ET for the desired crop species and summed the data based on the timeline input.

At the 2008 VTC meeting, a focus group was initiated to gain feedback on the website prototypes. Attendance was low so emails were sent to various turfgrass related Virginia organizations' listservs including the VTC, the Virginia Master Gardener's Association, the Virginia Golf Course Superintendent's Association and Virginia Extension Agents. Individuals were asked to assist with the research by interacting with the two website prototypes and then answer survey questions. The survey asked the users' preference for one website over the other, content usefulness, navigation ability, preference for selecting weatherstations, crop species and data length, and what additional information should be incorporated on the website (Appendix 3). The website prototype survey data were analyzed and the final real-time Virginia ET website was based on the responses.

Figure 3.11 ET prototype website 1 input
Adrienne J.L. Tucker



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Turfgrass Irrigation

Evapotranspiration

Alson H. Smith Jr.AREC
Winchester, Virginia

Date	ETo(in)	ETo **Warm** (in)	ETo **Cool**(in)	Temp Max	Temp Min	RH Avg	Rain (in)
6/1	0.20	0.12	0.16	88	63	67	0.00
6/2	0.15	0.09	0.12	84	60	60	0.00
6/3	0.06	0.03	0.04	69	62	70	0.25
6/4	0.20	0.12	0.16	83	63	64	0.00
6/5	0.18	0.11	0.14	76	60	73	0.25
6/6	0.21	0.13	0.17	73	55	70	0.00
6/7	0.21	0.13	0.17	85	49	50	0.15
6/8	0.22	0.13	0.17	93	70	80	0.20
6/9	0.22	0.13	0.17	83	61	53	0.00
6/10	0.19	0.11	0.15	80	56	68	0.25
6/11	0.21	0.13	0.17	83	56	70	0.00
6/12	0.20	0.12	0.16	85	55	55	0.00
6/13	0.18	0.11	0.14	83	58	71	0.00
6/14	0.05	0.03	0.04	62	57	72	0.25
14 Day Total	2.48	**1.49**	**1.96**				
10 Day Total	1.87	**1.13**	**1.48**				
7 Day Total	1.27	**0.76**	**1.00**				
5 Day Total	0.83	**0.50**	**0.66**				
3 Day Total	0.43	**0.26**	**0.34**				

Diversity | Contact the CSES Department

Crop and Soil Environmental Science
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Figure 3.12 ET prototype website 1 output
Adrienne J.L. Tucker

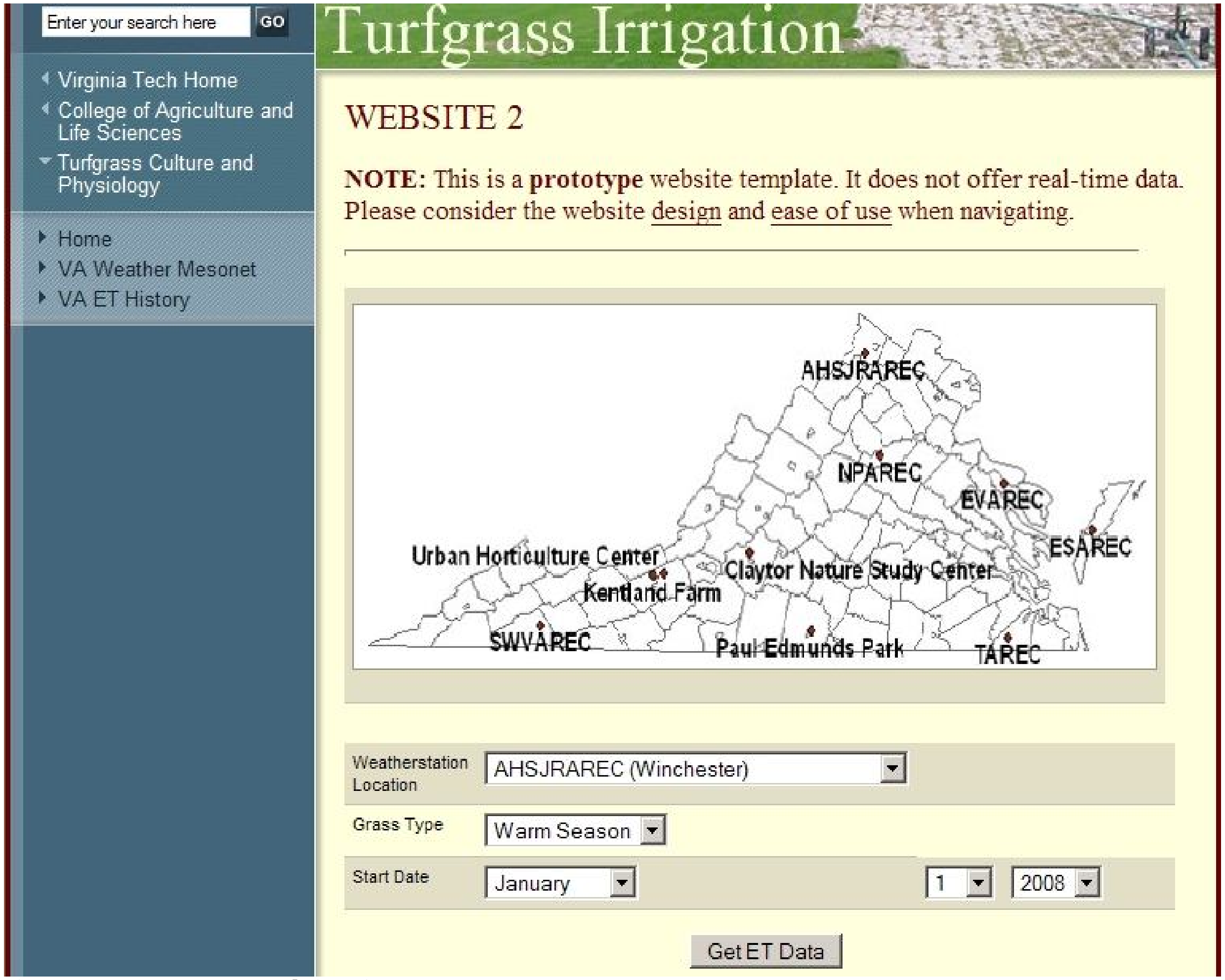

Figure 3.13 ET prototype website 2 input

Adrienne J.L. Tucker

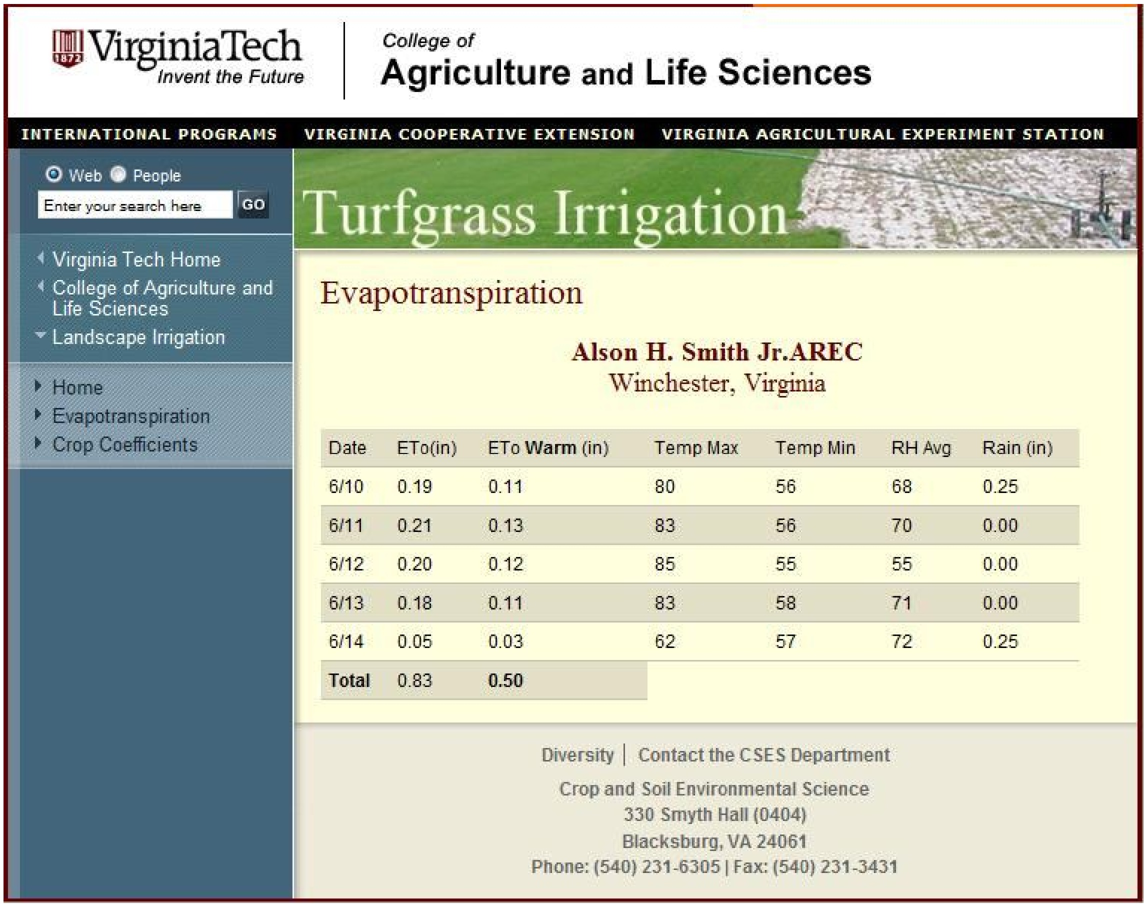

Figure 3.14 ET prototype website 2 output

considerable effort to conserve water as 59% believed water conservation in Virginia is very important. However, 72% were not aware of the weather data that was available through AHNRIT. Under normal weather conditions, 38% were very likely to use the proposed website, while under drought conditions, 45% were very likely to use the website. Also of note, 40% reported they were very likely to utilize the website if it was developed by and for turfgrass managers.

The 2007 survey results were very similar to the 2006 data, which is interesting as Virginia underwent drought during the summer following the 2006 survey. Ninety-two percent utilized email and/or the Internet at work and half relied heavily for research and communication. Ninety-six percent controlled all or some of the irrigation. Sixty-four percent made a considerable effort to conserve water and 62% believed water conservation in Virginia is very important, but 77% were not aware of the ANHRIT website. Under normal weather conditions, 29% were very likely to use the proposed website and 38% were likely to use the website under drought conditions. Finally, 27% were very likely to use the website if it was created by and for turfgrass managers.

Distinct trends were recorded with the website prototype survey (Table 3.2). Thirty-three percent felt the website content was useful and 55% felt the website content was very useful. Fifty-four percent preferred the second website prototype to the first prototype even though 71% reported that the first website was very easy to navigate, while 62% felt the second website was very easy to navigate. Sixty-five percent preferred selecting the turfgrass species (website 2), compared to the 24% who preferred both species included in the final table (website 1). Likewise, 59% preferred the drop down menu with map option for selecting a weatherstation (website 2), compared to 34% who preferred just the map option (website 1).

Finally, 62% preferred selecting the data length (website 2), compared to the 30% who preferred the fixed data length (website 1). Potential users were also polled about what additional components they would like to see on the final website. They were given options that ranged from a discussion board to email messages with ET data (Figure 3.16). The most commonly chosen component was water conservation tips (52%), followed by instructions on how to conduct an irrigation audit (43%) and research data (33%). Surprisingly, only 7% wished to receive text messages with ET data

Discussion

Due to the similar survey responses after a normal and drought growing season, it could be argued that within the turfgrass industry maintenance practices and opinions remain stable despite varying weather conditions. The industry has survived many years of drought and years of excessive rainfall, thus industry professionals have learned to cope with the ups and downs in weather without extreme reactions. This finding could be applied to the likelihood of adopting and continually using a technology like the ET website, which relies on continuous use, independent of weather extremes.

The preliminary data shaped the prototype website designs. It is understood that efficiency in disseminating information is of utmost importance for a discipline where little time is spent behind a computer screen. However, a significant percent of the population does have access to a computer and utilizes it often. Likewise, turfgrass professionals are well versed in conservation practices and employ such practices, independent of drought or wet seasons. Although Virginia is considered a wet state, the preliminary data showed that turfgrass professionals understand the importance of conserving water and may be willing to adopt another technology to manage their irrigation applications.

Research like the one conducted has never been performed for any state ET website design. However, user-created web development research has been done to develop other websites outside of the turfgrass and agricultural discipline. Corry et al. (1997) asked users to find information on the current and prototype Indiana University websites in attempt to create a more user friendly website. The research resulted in a new home page for the University, which was then ranked in the top 50 more frequently visited websites in the world from home computers. .

Table 3.1 Survey results 2006 & 2007

Do you have Internet or email?			
	2006 n=98	**2007** n=26	**Combined years** n=114
Web browsing	1%	4%	2%
Email	7%	0%	6%
Both	85%	88%	85%
Neither	7%	8%	7%
Which description explains your Internet use:			
	2006 n=98	**2007** n=26	**Combined years** n=114
I rely on it heavily to access information	55%	50%	54%
I use it occasionally	32%	31%	31%
I use it as a backup source of information	3%	8%	4%
I never use it	10%	12%	10%
Which description explains your email use:			
	2006 n=98	**2007** n=26	**Combined years** n=114
I rely on it heavily to access information	51%	50%	51%
I use it occasionally	33%	12%	28%
I use it as a backup source of information	7%	23%	10%
I never use it	9%	15%	10%

To what extent do you control the irrigation at your site(s)?			
	2006 n=98	**2007** n=26	**Combined years** n=114
All	58	65	60
Some	34	31	34
None	6	4	6

To what extent does your business/field./course attempt to conserve water?			
	2006 n=98	**2007** n=26	**Combined years** n=114
Little attempt	9%	4%	8%
Slight attempt	39%	32%	38%
Considerable attempt	52%	64%	54%

On the following scale, how important do you think water conservation is in Virginia?			
	2006 n=98	**2007** n=26	**Combined years** n=114
Unimportant	0%	0%	0%
Between unimportant and moderately important	1%	0%	1%
Moderately important	14%	8%	13%
Between moderately and very important	22%	31%	24%
Very important	62%	61%	62%

How likely would you be to access a website like the one described to determine your irrigation scheduling under <u>Normal Climatic</u> conditions?			
	2006 n=98	**2007** n=26	**Combined years** n=114
Very unlikely	7%	17%	9%
Between very unlikely and somewhat likely	6%	8%	6%
Somewhat likely	24%	25%	24%
Between somewhat and very likely	18%	13%	17%
Very likely	40%	29%	38%

How likely would you be to access a website like the one described to determine your irrigation scheduling is the state was under <u>Severe Drought</u> conditions?			
	2006 n=98	**2007** n=26	**Combined years** n=114
Very unlikely	8%	8%	8%
Between very unlikely and somewhat likely	6%	13%	7%
Somewhat likely	16%	21%	17%
Between somewhat and very likely	11%	13%	12%
Very likely	54%	38%	50%

How likely would you be to access a website to determine your irrigation scheduling if it was designed for and by fellow turfgrass managers?			
	2006 n=98	**2007** n=26	**Combined years** n=114
Very unlikely	3%	0%	3%
Between very unlikely and somewhat likely	3%	9%	5%
Somewhat likely	23%	36%	26%
Between somewhat and very likely	21%	18%	20%
Very likely	43%	27%	40%
Percentages may not add up 100%. Less than 100% reflects unanswered questions.			

Table 3.2 Survey Results 2008

Is there one website and all its components you preferred over the other?	
	2008 n=92
Website 1	26%
Website 2	54%
Neither	17%
How useful do you feel the content contained in the websites is?	
Not useful	5%
Slightly useful	33%
Very useful	55%
How easy was WEBSITE 1 to navigate?	
Not easy	2%
Slightly easy	24%
Very easy	71%
How easy was WEBSITE 2 to navigate?	
Not easy	7%
Slightly easy	30%
Very easy	62%

Which website design did you prefer when assessing irrigation needs for a warm vs. cool season turf?	
Website 1 (table)	24%
Website 2 (drop down menu)	65%
Neither	10%
Which weatherstation selection design did you prefer?	
Website 1 (map only)	34%
Website 2 (map and drop down menu)	59%
Neither	5%
Which data length of time selection did you prefer?	
Website 1 (14 – 3 day summary)	30%
Website 2 (select start date)	62%
Neither	3%
Percentages may not add up 100%. Less than 100% reflects unanswered questions.	

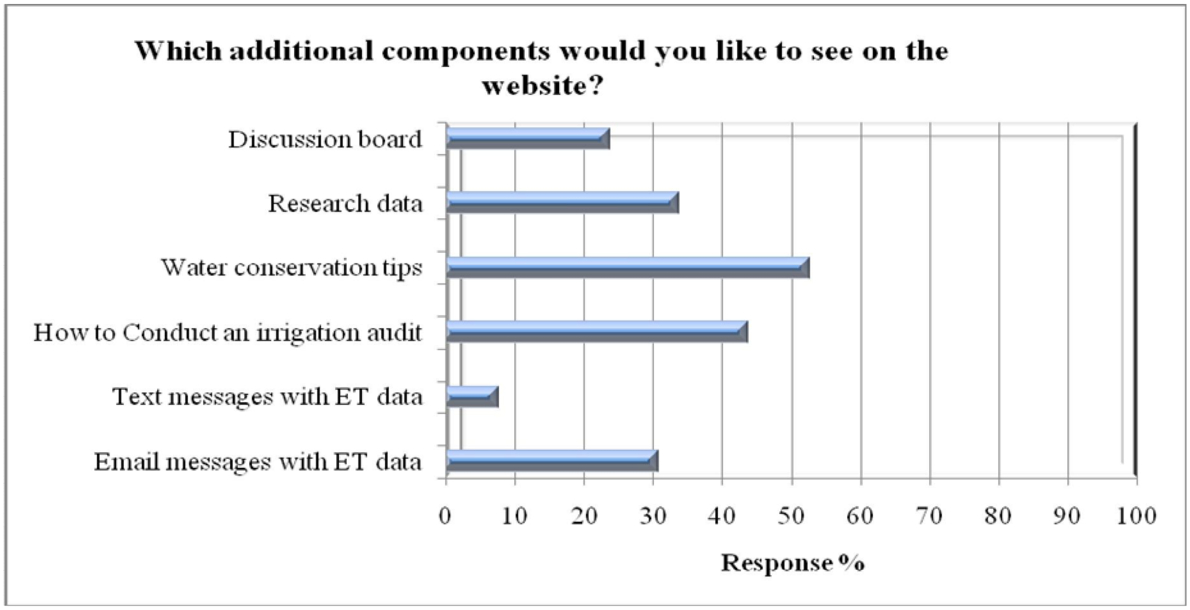

Figure 3.15 Survey results 2008: website components

Another study at the U.S. Census Bureau worked with employees to improve the intranet the employees use on a daily basis (Murphy et al. 2005). Card sorting to determine website layout, surveys to determine user requirements, and logs to determine actual usage level all assisted in developing a new user friendly intranet (Murphy et al. 2005).

Using the collaborative process and user-centered design approach to determine the layout of the final ET website seemed obvious when implementing a technology with little assistance from other university entities and minimal money to advertise such a website. Collaborative planning incorporating the public, local and state government officials, and local experts is often used in the natural resource industry to develop environmental plans (Randolph 2004). Likewise, British Columbia successfully uses collaborative planning to develop land and resource management plans throughout the province (Frame et al. 2004). Collaboration is often adopted because it is the only solution to solving the particular issue at hand (Chrislip et al. 1994).

The operating website design and content was solely based on the cooperative user feedback from the prototype survey responses in attempt to follow the technology adoption model goals: to develop a user-friendly and useful website. A majority of the users preferred the second website prototype, which required more user input, to the first website prototype. The resulting website requires user input to select the specific weatherstation, turfgrass species and data length.

The website was completed in August of 2008 and can be accessed at http://www.turf.cses.vt.edu/Ervin/et_display.html. Since the website is hosted on the university's server, certain material and color scheme must follow the Virginia Tech set website design standards. However, the turfgrass irrigation heading picture, side navigation and main website content were edited to meet the user specifications.

Utilizing ET based irrigation has been proven to be an effective means of reducing water consumption. A study in Central Florida found that landscapes irrigated based on ET demand used 30% less water than human regulated irrigation scheduling without affecting turfgrass health (Haley et al. 2007). Likewise, another study on agricultural crops found that irrigating based on an adjusted ET rate did increase water productivity, or net income per unit of water used, which also resulted in an increase of net income (Fereres and Soriano 2007).

Conclusion

When developing a new technology for a specific target audience, including the potential users in the development process can aid in future adoption and ensure the product is easy to use. Two website prototypes developed contained the same data, but were organized differently. The surveyed potential users preferred more user input to attain ET data. Survey results showed that more users (54%) preferred the second website prototype, which included selecting turfgrass species preference (65%), selecting the weatherstation with both a dropdown menu and map selection (59%), and selecting a preferred data length (62%). A finalized website was developed based on the user preferences and is now freely available at http://www.turf.cses.vt.edu/Ervin/et_display.html for the public to access and determine turfgrass irrigation demands throughout Virginia.

References

AHNR-IT. (2005). "VAES Weather Mesonet." College of Agriculture and Life Sciences.

Allen, R. G. (2000). "Reference Evapotranspiration Calculator." University of Idaho Research and Extension Center Kimberly, Idaho.

Allen, R. G., Jensen, M. E., Wright, J. L., and Burman, R. D. (1989). "Operational estimates of reference evapotranspiration." *Agron. J.*, 81(4), 650-662.

Aquacraft, I. (2003). "Performance evaluation of WeatherTRAK™ irrigation controllers in Colorado." Boulder, CO.

Arizona Board of Regents. (2007). "AZMET: The Arizona meteorological network." The University of Arizona, Tucson, AZ.

Aronson, L. J., Gold, A. J., Hull, R. J., and Cisar, J. L. (1987). "Evapotranspiration of cool-season turfgrasses in the humid Northeast." *Agron. J.*, 79, 901-905.

ASCE. (1990). *Evapotranspiration and Irrigation Water Requirements: A Manual Prepared by the Committee on Irrigation Water Requirements.*, American Society of Civil Engineers, New York.

Bastug, R., and Buyuktas, D. (2003). "The effects of different irrigation levels applied in golf courses on some quality characteristics of turfgrass." *Irrig Sci*, 22, 87-93.

Calongne, C. M. (2001). "Designing for web site usability." *JCSC*, 16(3).

Chrislip, D. D., Larson, C. E., and Parr, J. (1994). *Collaborative Leadership: How citizens and civic leaders can make a difference*, Jossey-Bass, San Francisco, CA.

Commonwealth of Virginia. (2007). "Governor Kaine encourages voluntary water conservation and calls on localities to update drought contingency plans." Office of the Governor, Richmond, VA.

Corry, M. D., Frick, T. W., and Hansen, L. (1997). "User-centered design and usability testing of a web site: an illustrative case study." *ETD&D*, 45(4).

Davis, F. D. (1985). "A technology acceptance model for empirically testing new end-user information systems: Theory and results," Dissertation, Massachusetts Institute of Technology, Cambridge, MA.

de Vaus, D. A. (1986). *Surveys in Social Research*, George Allen & Unwin, Boston, MA.

DEQ. (2005). "Status of Virginia's Water Resources: A report on Virginia's water supply planning activities." Department of Environmental Quality, Richmond, VA.

DEQ. (2007). "Status of Virginia's Water Resources: A report on Virginia's water supply planning activities." Department of Environmental Quality, Richmond, VA.

Devitt, D. A., Morris, R. L., and Bowman, D. C. (1992). "Evapotranspiration, crop coefficients, and leaching fractions of irrigated desert turfgrass systems." *Agron. J.*, 84, 717-723.

EPA WaterSense. (2008). "Water-efficient single-family new home specification supporting statement." EPA, Washington, DC.

Ervin, E. H., and Koski, A. J. (1998). "Drought avoidance aspects and crop coefficients of Kentucky bluegrass and tall fescue turfs in the semiarid west." *Crop Sci.*, 38(3), 788-795.

Feldhake, C. M., Danielson, R. E., and Butler, J. D. (1984). "Turfgrass evapotranspiration. II. Responses to deficit irrigation." *Agron. J.*, 76, 85-89.

Fereres, E., and Soriano, M. A. (2007). "Deficit irrigation for reducing agricultural water use." *Journal of Experimental Botany*, 58(2), 147-158.

Frame, T. M., Gunton, T., and Day, J. C. (2004). "The role of collaboration in environmental management: an evaluation of land and resource planning in British Columbia." *Journal of Environmental Planning and Management*, 47(1), 59-82.

Haley, M. B., Dukes, M. D., and Miller, G. L. (2007). "Residential irrigation water use in Central Florida." *J. of Irrigation and Drainage Engineering*, 133(5).

Hickey, G. (2007). "Governor Kaine announces Virginia's top business ranking for second year." Office of the Governor Timothy M. Kaine: Commonwealth of Virginia, Richmond, VA.

Huang, B., and Fry, J. (1999). "Turfgrass evapotranspiration." *J. Crop Production*, 2, 317-333.

Huxham, C., and Vangen, S. (2005). *Managing to Collaborate: The theory and practice of collaborative advantage*, Routledge, New York, NY.

Itenfisu, D., Elliott, R. L., Allen, R. G., and Walter, I. A. (2003). "Comparison of reference evapotranspiration calculations as part of the ASCE standardization effort." *Journal of Irrigation and Drainage Engineering-ASCE*, 129(6), 440-448.

LaBranche, A. J. (2005). "Creeping bentgrass and tall fescue responses to plant growth stimulants under deficit irrigation," Masters thesis, Virginia Tech, Blacksburg, VA.

Lazar, J. (2001). *User-Centered Web Development*, Jones and Bartlett Publishers, Sudbury, MA.

Margerum, R. D. (2002). "Collaborative planning: building consensus and building a distinct model for practice." *J. of Planning Education and Research*, 21, 237-253.

Murphy, E. D., Ciochetto, S., and Bateman, C. I. (2005). "Redesigning and Evaluating the Census Bureau's Intranet Site for Usability: Methods and Lessons Learned." U.S. Census Bureau, Washington, DC.

NASS. (2006). "Virginia's Turfgrass Industry." National Agricultural Statistics Service/USDA, Richmond, VA.

National Climatic Data Center. (2008). "2007 Annual Climate Review: U.S. Summary." National Oceanic and Atmospheric Administration.

North Carolina State University. (2008). " TIMS: Turf irrigation water management model registration." North Carolina State University, Raleigh, NC.

Ortega-Farias, S., Olioso, A., Antonioletti, R., and Brisson, N. (2004). "Evaluation of the Penman-Monteith model for estimating soybean evapotranspiration." *Irrig Sci.*, 23, 1-9.

Pereira, L. S., Perrier, A., Allen, R. G., and Alves, I. (1999). "Evapotranspiration: concepts and future trends." *J. Irrigation and Drainage Eng.*, 125, 45-51.

PFMC. (1999). "Description of adverse effects on Pacific salmon essential fish habitat and actions to encourage the conservation and enhancement of essential fish habitat." Pacific Fisher Management Council, Portland, Oregon.

Pollina Corporate Real Estate Inc. (2007). "Top 10 pro-business states." Pollina Corporate Real Estate, Inc., Park Ridge, IL.

Randolph, J. (2004). *Environmental Land Use Planning and Management*, Island Press, Washington, DC.

Richie, W. E., Green, R. L., and Gibeault, V. A. (1997). "Using ET_o (Reference Evapotranspiration) for turfgrass irrigation efficiency." University of California Cooperative Extension, University of California, Riverside.

Rogers, E. M. (2003). *Diffusion of Innovations*, Free Press, New York, NY.

Selin, S., and Chavez, D. (1995). "Developing a collaborative model for environmental planning and management." *Environmental Management*, 19(2), 189-195.

Slack, E. V. (2000). "Maintaining superior landscapes on a water budget." Water Right: Conserving our water preserving our environment, International Turf Producers Foundation, Rolling Meadows, IL, 55-56.

Sluss, M. (2007). "Kaine asks Virginians to restrict water use." The Roanoke Times, Roanoke, VA.

SRI International. (2006). "Virginia's Golf Economy, 2005." SRI International, Arlington, VA.

State of California. (2005). "California irrigation management information system." California Department of Water Resources, Office of Water Use Efficiency, Sacramento CA

Stockle, C. O., Kjelgaard, J., and Bellocchi, G. (2004). "Evaluation of estimated weather data for calculating Penman-Monteith reference crop evapotranspiration." *Irrig Sci.*, 23(39-46).

TAMU. (2004). "Texas Evapotranspiration Network." Texas A&M University System.

U.S. Census Bureau. (1990). "1990 Census of Population and Housing." U.S. Census Bureau, Population Division, Washington, DC.

U.S. Census Bureau. (2000). "Profile of General Demographic Characteristics: 2000." U.S. Census Bureau, Population Division, Washington, DC.

U.S. Census Bureau. (2006). "ACS Demographic and Housing Estimates: 2006 ", U.S. Census Bureau, Population Division, Washington, DC.

U.S. Census Bureau. (2007). "Cumulative estimate of population change for the United States, regions, states, and Puerto Rico and region and state rankings." U.S. Census Bureau, Population Division.

University of Idaho. (2007). "ETIdaho: Evapotranspiration and consumptive irrigation water requirements for Idaho ", University of Idaho Research and Extension Center, Kimberly, Idaho.

University of Oklahoma. (2007). "Oklahoma agweather." Board of Regents of the University of Oklahoma, Norman, OK.

University of Virginia. (2000). "Virginia potential evapotranspiration, annual precipitation, and annual precipitation minus potential evapotranspiration." University of Virginia Climatology Office, Charlottesville, VA.

Vallee, D., Margat, J., Eliasson, A., Hoogeveen, J., and Faures, J.-M. (2003). *Review of the world water resources by country*, Food and Agriculture Organization of the United Nations, Rome, Italy.

Venkatesh, V., and Davis, F. D. (1996). "A model of the antecedents of perceived ease of use: Development and test." *Decision Sciences*, 27(3), 451-480.

Venkatesh, V., Morris, M. G., Davis, G. B., and Davis, F. D. (2003). "User acceptance of information technology: Toward a unified view." *MIS Quarterly*, 27(3), 425-478.

Vishwanath, A., and Goldhaber, G. M. (2003). "An examination of the factors contributing to adoption decisions among late-diffused technology products." *New Media & Society*, 5(4), 547-572.

CHAPTER 4: CASE STUDY: IRRIGATING BASED ON EVAPOTRANSPIRATION RATE

Abstract

Due to recent droughts, which have spurred the need to develop water conservation plans, and the strong economic impact the turfgrass industry has on the state, proven techniques are needed to promote water conservation on irrigated turfgrass surfaces. Evapotranspiration (ET)-based irrigation scheduling has proven to be effective at reducing water consumption without affecting turfgrass health and vitality. Two preliminary case studies were implemented during the 2007 summer to assess water conservation when irrigated based on ET. A Fairfax, Virginia university soccer field could have conserved 35% of water if irrigation was based on ET. During the 2008 summer, three case study sites were implemented to compare normal (manager-based irrigation) irrigation schedules with ET-based irrigation schedules. Each site consisted of one control plot, which received the manager-based irrigation, and one experimental plot, which received the ET-based irrigation. A golf course in Williamsburg, Virginia reported a 55% water savings when irrigated based on ET demand. Blacksburg, Virginia research greens received slightly more water on the experimental ET plot than the manager-based irrigation plot. Whereas, significantly less water was applied to the manager-based residential plots in Norfolk, Virginia, compared to the experimental ET plots. No differences in quality between the manager-based and ET plots were noted at any sites. The study also uncovered additional impacts when irrigating based on ET including increased confidence to alter irrigation systems and the need to conduct irrigation audits, which could lead to additional water savings when irrigation is applied per the precipitation rate and when heads are adjusted or replaced.

Introduction

Virginia's recent drought occurrences have sparked water conservation action and legislation. Deficit snow fall from the 2007 winter months was followed by equally dry spring and summer months. Virginia statewide drought intensity ranged from moderate to severe, becoming more severe as the summer and fall months passed (NOAA 2007). Rainfall from

October 2006 to September 2007 was 19% below normal, with increasing drought occurrences as rainfall from October 2006 to April 2008 was 22% below normal (USGS 2008a). Areas like the New River Valley, Northern Piedmont, and the Upper James areas were 38% to 35% below normal rainfall from April 2007 to 2008 (USGS 2008a).

On October 18, 2007, Virginia Governor Tim Kaine requested a statewide drought disaster to be declared due to significant crop losses (Commonwealth of Virginia 2007a). York and Arlington counties along with Alexandria, Bristol, Falls Church, Poquoson, and Norton cities were among the noted contiguous disaster areas (USGS 2008a). On October 30, 2007, the Governor issued another notice urging Virginia localities "to update water conservation and drought contingency ordinances and plans and begin preparations to implement those plans" (Commonwealth of Virginia 2007b; Sluss 2007). The Governor stressed the need to plan for future drought occurrences and reducing non-essential water use.

In January 2008, 13 and 31 public water supply localities were under mandatory and voluntary water restrictions, respectively (USGS 2008b). Rainfall increased in 2008 to near normal levels, which resulted in less water restrictions. Throughout the year, around four localities were under mandatory water restrictions, while 20 were under voluntary restrictions At the end of 2008, the Virginia statewide rainfall was considered slightly below normal (USGS 2008c). The York-James region, which encompasses Williamsburg, was the most below the normal (69%) from January 2008 through November 2008, while the Northern Virginia area was at the highest (104%) (USGS 2008d).

The turfgrass industry is reliant on supplemental irrigation, especially in times of prolonged drought. However, the public views turfgrass irrigation as non-essential (Barrett 2004; Ratcliff 1999). The general public often does not understand the environmental and economic impact of the turfgrass industry. When Denver restricted irrigation only to tees and fairways due to drought, four municipal golf courses closed (Barrett 2004). This not only affects recreational use, but also local economic and environmental conditions. A report by the Irrigation Association (2000) stated that, "eight average front lawns have the cooling effect of 70 tons of air conditioning." In times where climate change talks are prevalent, the energy savings benefits of turfgrass surfaces should be weighed into water conservation policies.

Virginia has a large turfgrass industry; supplying $3.1 billion to the state's economy annually (SRI International 2006). Turfgrass and landscape irrigation uses approximately 65% of the country's potable water supply, with 75% of this amount being consumed in the western US (Barrett 2004; Hutson et al. 2004). The Virginia golf industry, however, accounts for only 0.4% of the state's water use, whereas Virginia agriculture accounts for 1.4% (DEQ 2005). Despite the relatively low water usage levels, a large and economically influential industry like turfgrass should be proactive in water conservation endeavors to ensure its continued success.

The Irrigation Association reported that nationwide landscape irrigation, which encompasses all turf surfaces other than golf courses, utilizes 2.9% of the country's potable water supplies, while golf courses utilize 1.5% of the country's water supply (Irrigation Association 2000; Ratcliff 1999). Unlike crop production irrigation, turfgrass and landscape irrigation is very visible. To curb irrigation water use, turfgrass and landscape irrigators have turned to water conserving technologies and practices.

Zoldoske (2004) found that the simple act of changing irrigation nozzles can conserve water and money. New soil moisture sensors are programmed to offer real-time data for irrigation guidance, but require significant upfront cost and ongoing maintenance (Carrow 2006). Plant-based measurements like relative water content, stomatal conductance, and light reflectance offer more direct measurements of plant water need, but automation is not possible in the field setting (Carrow 2006; Jones 2004). Arguably, the least expensive water conservation technology is to irrigate based on climatic demand, or evapotranspiration (ET).

Evapotranspiration-based irrigation scheduling is an effective way to ensure that only water lost from a turfgrass system, via plant transpiration and soil evaporation, is replaced with supplemental irrigation. Many researchers, in Virginia and throughout the United States, determined that ET-based irrigation scheduling is a valid scientific approach to estimate appropriate irrigation quantities (Allen et al. 1989; Aronson et al. 1987; ASCE 1990; Bastug and Buyuktas 2003; Devitt et al. 1992; Ervin and Koski 1998; Feldhake et al. 1984; Huang and Fry

1999; LaBranche 2005; Pereira et al. 1999; Richie et al. 1997).

In select US locations, ET data can be transmitted to "smart irrigation controllers" as a means of adjusting daily irrigation timing to meet demand (U.S. EPA 2007; U.S. EPA 2008). The EPA also included ET-based irrigation techniques in its draft "Water-Efficient Single-Family New Home Specification" (2008) report. While this specification is under review, the guidelines may pave the way for promoting water efficient homes, which includes water conserving irrigation practices and technologies.

A study conducted by the Irvine Ranch Water District in California found that prior to ET-based scheduling, irrigation was applied at up to three times more than ET estimates (Slack 2000). An independent researcher in Colorado conducted a study on home lawns to test the WeatherTRAK™ system, which sends daily ET data to irrigation controllers. This study found an average of 26,000 gallons of water was saved per site compared to historical usage and resulted in an average of $197 savings with no significant decrease in turfgrass appearance (Aquacraft 2003).

The objective of this study is to investigate how water usage and turfgrass quality is impacted when irrigation is applied based on ET. Case studies were implemented throughout the state to compare ET-based irrigation scheduling to manager-based irrigation scheduling for research greens, golf course tees and residential lawns.

Materials and Methods

Preliminary case studies were conducted during the 2007 summer at George Mason University in Fairfax, Virginia (FF) and Williamsburg Country Club in Williamsburg, Virginia (WG) to determine feasibility of expanding the research during the 2008 summer. The George Mason University grounds manager and Williamsburg Country Club superintendent recorded all irrigation events on the bermudagrass (*Cynodon dactylon*) soccer field and golf course nursery, respectively, from June through the end of August 2007. Irrigation data was compared to calculated irrigation if applied based on ET data to determine if ET-based irrigation would have afforded any water savings.

During the following 2008 summer season, three case study sites in Blacksburg, Norfolk, and Williamsburg were employed to further expand the research to test ET-based irrigation scheduling. .The Virginia Tech Turfgrass Research Center in Blacksburg (BB) case study site utilized two creeping bentgrass (*Agrostis palustris)* sand-based greens located 61 meters (200 ft.) apart. The second case study site (NF) was in Norfolk, Virginia and employed two native soil tall fescue (*Festuca arundinacea*) residential lawns located 4.8 km (3 miles) apart. The third case study site (WB) was at the Williamsburg Country Club in Williamsburg, Virginia and included two native soil bermudagrass (*Cynodon dactylon*) tees, located approximately 46 meters (150 ft.) apart. Evapotranspiration data were adjusted with a crop coefficient (K_c) of 0.8 for cool season turfgrass (BB and NF) and 0.6 for warm season turfgrass (WB) based on the Irrigation Association Best Management Practices (Irrigation Association 2005). George Mason University did not participate during the 2008 summer due to staffing problems however, Williamsburg Country Club was included during the 2008 summer but research was focused on higher maintenance tee boxes as opposed to the low-maintenance nursery

Irrigation audits were conducted on all turfgrass plots in May 2008 to determine precipitation rate; the research study ran from June 1, 2008 to August 31, 2008. All case study sites included two study plots. One plot was the control and was irrigated per normal schedules determined by the manager. The second plot was the experimental plot and was irrigated based on calculated ET determined by the researcher and transferred to the manager. Irrigation run time based on ET demand, calculated with the REF-ET (Allen 2000) program from June to mid-July and with the Virginia ET Website (Virginia Tech 2008) from mid-July through August, was sent to case study site irrigators via email and/or text messaging. Weatherstations accessed to calculate ET were selected based on the proximity to the case study site. The Alison H. Smith Jr. AREC weatherstation was utilized for FF; the Eastern Virginia AREC weatherstation was accessed for WG and WB; the Urban Horticulture Center weatherstation provided data for BB calculations and the Tidewater AREC weatherstation was utilized for NF.

Case study sites were chosen based on potential water supply issues, available research space and cooperation with data collection. The comprehensive plans for all the case study cities/towns indicate a need to protect current drinking water resources, promote water conservation and minimize wasteful water practices (City of Williamsburg 2006; Norfolk City Planning Commission 1992; Town of Blacksburg 2006). Research was feasible at the BB site due to cooperation with the Virginia Tech Turfgrass Program. The NF and WB sites are located in the eastern portion of the state, where population continues to rise, thus straining available water resources (City of Williamsburg 2006; Younos 2004). The city of Norfolk ranked fourth in the state for water withdrawal amounts for public water supplies in 2006, whereas Williamsburg's nearby Richmond City ranked third (DEQ 2007). The NF turfgrass manager and WB superintendent also expressed interest in assisting with the research and agreed to subject one area to ET-based irrigation, record all irrigation events and make turfgrass quality notes.

Results

During the preliminary study at FF, a total of 368 mm of irrigation water was applied from June through August (Table 4.1). Evapotranspiration calculations, adjusted with a 0.6 crop coefficient (K_c), determined 239 mm of irrigation water would be required during the 2007 season. This translates into a 35% water savings or 644,370 liters of water.

The WG preliminary case study site did not show similar data. The nursery area only received one irrigation application on June 24, 2007 of 45 minutes. This totaled to 5.1 mm of irrigation, based on the precipitation rate of 6.4 mm hr^{-1} (Table 4.1). If the area was irrigated based on ET demand, 277 mm would have been applied.

At the 2008 BB case study site, irrigation occurred every Monday, Wednesday and Saturday on both the manager-based and ET greens. The manager-based irrigation green received a total of 568 minutes of irrigation from June through August. This translated into 211 mm for a precipitation rate of 22.4 mm hr^{-1} (Table 4.2). The ET green had a precipitation rate of 29.5 mm hr^{-1} and received 606 minutes, or 297 mm, of total irrigation. Irrigation events ranged from a high of 17.4 mm for the manager-based irrigation green (July 27) and 13.7 mm (June 27) for the experimental green to a low of 2.5 mm (July 15) for the manager-based irrigation green and 3.6 mm (July 11, 15) for the experimental green (Fig. 4.1). Quality was monitored on a bi-weekly basis by the researcher. No obvious differences in quality were detected throughout the study period.

At the NF site, irrigation occurred weekly with total irrigation run times separated into six irrigation events; three events were on Mondays and three events were on Tuesdays. The manager-based irrigation lawn received three 10 minute irrigation events twice a week from the start of the study in June until mid-July. After the mid-July mark, the manager-based irrigation lawn received three 12 minute events twice a week. Irrigation differed greatly for the experimental plot. Irrigation events ranged from 16 minute events to 29 minute events throughout the study period (Fig. 4.2). The manager-based irrigation lawn had a precipitation rate of 15.7 mm hr^{-1} and received a total of 828 minutes of irrigation, which translated into 218 mm of water. Whereas, the ET lawn had a precipitation rate of 14.2 mm hr^{-1} and received a total of 1,197 minutes of irrigation, or 284 mm (Table 4.2).

The NF manager indicated consistent quality throughout the study on both case study lawns. However, he did notice active brown patch disease on the ET lawn for 21 days in July. Brown patch (*Rhizoctonia solani*) occurs during hot, humid conditions (Couch 2000). There were also three days when the Norfolk manager turned off irrigation at the ET lawn due to rain forecasted later in the day, but irrigation still ran for the manager-based irrigation lawn (Fig. 4.2).

The WB site was irrigated every two days except those days when rainfall occurred. The manager-based irrigation tee received a consistent 60 minute irrigation application throughout the summer (Fig. 4.3). The ET tee reached a maximum irrigation timing of 68 minutes in July, but due to the difference in precipitation rate, the ET tee received considerably less irrigation throughout the summer (Table 4.2). The maximum ET irrigation amount was 5.2 mm on July 18 and 20, while the minimum ET irrigation amount was 2.1 mm on August 30 (Fig. 4.3). The manager-based irrigation tee received a consistent 9.1 mm application rate throughout the experimental period. The manager-based irrigation tee was irrigated a total of 1,380 minutes and received a total of 210 mm, while the ET tee was irrigated a total of 1,252 minutes and received a total of 95 mm (3.7 in.) (Table 4.2).

The WB superintendent reported the ET tee "had a more consistent moisture profile than the one with the 'standard' program." He also noted that overall turfgrass quality did not vary between the two tees throughout the summer.

Table 4.1 Preliminary study summary of irrigation data (2007 summer)

		Treatment	
		Applied	**ET Demand**
FF	Precipitation rate	10.7 mm hr^{-1}	---
	Total irrigation	368 mm	239 mm
	Average irrigation event	6.2 mm	4.1 mm
WG	Precipitation rate	6.4 mm hr^{-1}	---
	Total irrigation	5.1 mm	277 mm
	Average irrigation event	5.1 mm	---

FF = Fairfax, George Mason University bermudagrass (*Cynodon dactylon*) soccer field
WG = Williamsburg, Williamsburg Country Club bermudagrass (*Cynodon dactylon*) nursery

Table 4.2 Summary of irrigation data (2008 summer)

		Treatment	
		Manager-based irrigation	**ET**
BB	Precipitation rate	22.4 mm hr^{-1}	29.5 mm hr^{-1}
	Total irrigation	211 mm	297 mm
	Average irrigation event	7.1 mm	7.6 mm
NF	Precipitation rate	15.7 mm hr^{-1}	14.2 mm hr^{-1}
	Total irrigation	218 mm	284 mm
	Average irrigation event	9.1 mm	40.4 mm
WB	Precipitation rate	9.1 mm hr^{-1}	4.6 mm hr^{-1}
	Total irrigation	210 mm	95 mm
	Average irrigation event	9.1 mm	4.1 mm

BB = Blacksburg, Virginia Tech Turfgrass Research Center bentgrass (*Agrostis palustris*) greens

NF = Norfolk, Residential tall fescue (*Festuca arundinacea)* lawns

WB = Williamsburg, Williamsburg Country Club bermudagrass (*Cynodon dactylon)* tees

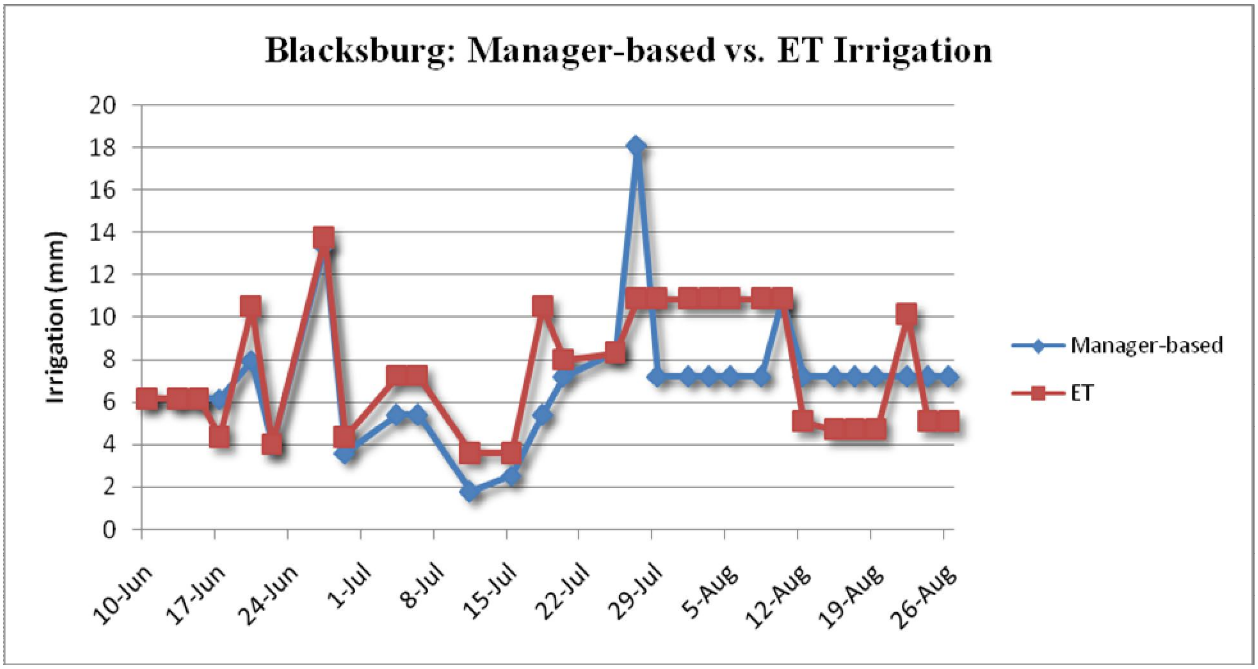

Figure 4.1 Blacksburg irrigation log for 2008 summer

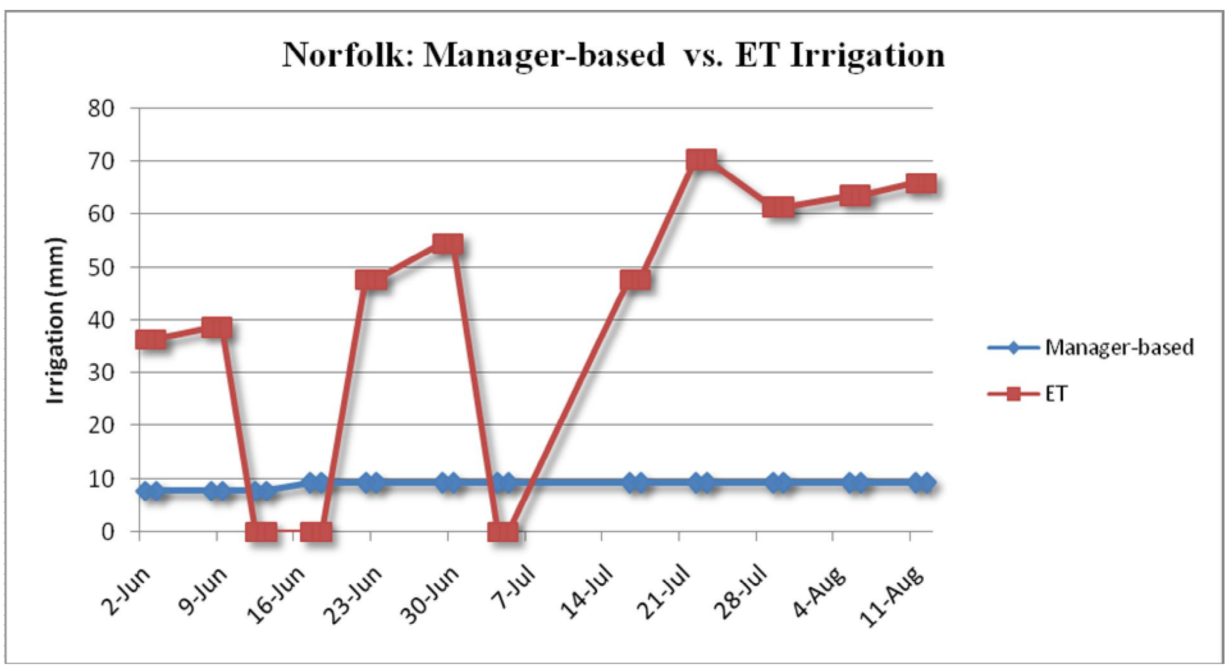

Figure 4.2 Norfolk irrigation log for 2008 summer

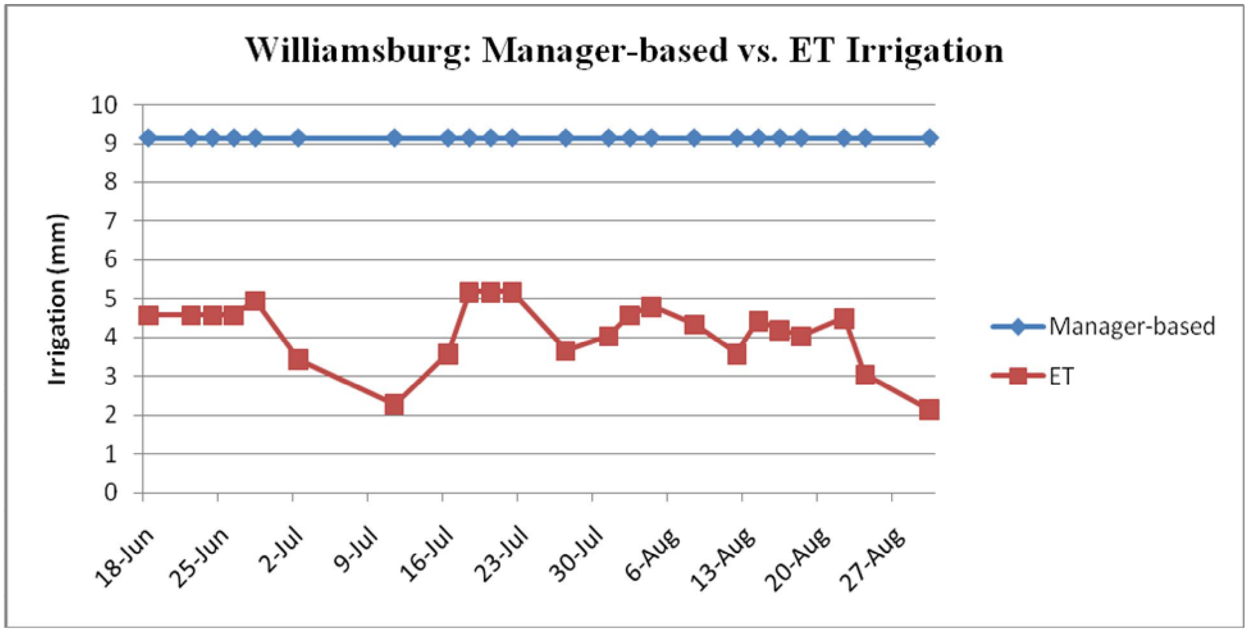

Figure 4.3 Williamsburg irrigation log for 2008 summer

Discussion

Based on the preliminary data, ET-based irrigation is most suited for high quality turfgrass areas. As seen with the WG case study, a golf course nursery is not a high quality expectation area, and thus receives very little irrigation. However, for high quality turfgrass areas like the FF soccer field, considerable water savings could occur if irrigated based on ET demand and adjusted with the appropriate K_c.

Water Consumption

When the WG second year study (WB) was relocated to a high maintenance tee box area, differences were observed between the manager-based irrigation events and ET-based irrigation. The ET irrigation schedule resulted in 55% less water applied from June to August. This translates into almost 9,464 liters (2,500 gallons) of water saved for one tee. When applied to all irrigated areas on the golf course, an estimated 8,244,601 liters (2,138,000 gallons) could be saved during the peak summer months.

The WB and NF ET-based scheduling differed greatly from the manager-based irrigation scheduling, which remained consistent throughout the summer. The "set it and forget it" approach is common for many irrigation managers and often results in over watering. A group of University of Florida researchers found just that: home lawn irrigation systems programmed once in the season consumed more water than those programmed monthly based on ET demand (Haley et al. 2008).

Unlike the Florida study, the NF residential case study actually showed the manager-based irrigation "set it and forget it" schedule resulted in less irrigation than the monthly ET-based irrigation schedule. It should be noted that the residential areas were not controlled by the homeowner, but by a hired turfgrass manager. The manager explained at the onset of the study that he irrigates minimally and this was proven as irrigation was very minimal for the manager-based irrigation lawn. The manager-based irrigation irrigation was applied at a rate that was consistent to a K_c of 0.2, which is not recommended for cool season grasses. The smallest K_c recommendation for cool season turfgrass is 0.4, which is in the EPA Residential WaterSense handbook currently under review (2008). Research studies recommend a tall fescue K_c from 0.6

to 0.8 to maintain turfgrass health and metabolic processes (Devitt et al. 1992; Ervin and Koski 1998; Feldhake et al. 1984; LaBranche 2005). It is unsure why the tall fescue manager-based irrigation lawn was able to maintain quality under the low irrigation regime. The manager highly promotes frequent core aerification to allow for air flow, root growth, and water absorption.

When irrigation is plotted against the average temperature (Fig 4.4, 4.5, 4.6), the ET irrigation events closely coincided with temperature drops and peaks as temperature readings are incorporated into the ET calculation process. The manager-based irrigation and ET BB irrigation events followed temperature fluctuations until late July (Fig. 4.4). At this point, the manager-based irrigation spiked and then declined while the ET irrigation remained constant and then declined with temperature readings. Likewise, the NF ET irrigation events followed the temperature ranges closer than the manager-based irrigation, which remained constant throughout the summer months (Fig. 4.5). The same is true for the WB tees; the manager-based irrigation tee received the same irrigation amount independent of temperature changes, but the ET irrigation events followed the change in temperature throughout the summer (Fig. 4.6).

Social Implication

One side effect of scheduling based on ET demand is awareness of irrigation events as observed at the NF ET lawn. The manager was more aware of the upcoming rains and thus, turned the irrigation off for the ET lawn, while the manager-based irrigation lawn remained on the same schedule. Again, using the “set it and forget it” schedule separates the owner from the irrigation controller, which can result in water wasting (Haley et al. 2007). Following an ET-based irrigation schedule requires homeowners and managers to alter the irrigation setting frequently. The more comfortable the homeowners and managers are with the irrigation system may influence their likelihood of turning off the irrigation if rainfall is forecasted after the irrigation event.

Also noted at the WB case study site is the need to know precipitation rates of all irrigated areas. Precipitation rates, calculated from irrigation audits, are necessary to determine irrigation run time for ET-based irrigation scheduling. Conducting an irrigation audit not only allows for the irrigation manager to assess actual precipitation rate, it also allows him/her to assess if heads need replacing or adjusting, water pressure requires altering, or if leaks are present. Up to 50% water savings could occur from conducting an irrigation audit through the various adjustments and/or head replacement (Evans et al. 1998).

Two WB tee boxes located close to each other had significantly different precipitation rates. The sixteenth tee, which served as the manager-based irrigation tee, had a precipitation rate of 9.1 mm hr^{-1} (0.36 in. hr^{-1}), while the thirteenth tee, which served as the ET tee, had a precipitation rate of 4.6 mm hr^{-1} (0.18 in. hr^{-1}) (Table 4.2). Obviously following the same irrigation protocol for both the tees would not be appropriate based on the large difference in precipitation rate. When superintendents take the step to actively conserve water, irrigation audits should be conducted and this study showed that they are critical to the ET-based irrigation scheduling practices.

One drawback of ET-based irrigation is the need to continually alter the irrigation controller. Haley et al. (2007) found that irrigating based on historical ET data resulted in over irrigating, whereas scheduling based on real-time ET data proved to conserve the most residential water. However, few homeowners are willing to alter their irrigation systems weekly. Conserving irrigation applications on residential lawns could have a significant water savings as residential lawns compromise 62% of all turfgrass surfaces in the Commonwealth (NASS and VDACS 2006).

Conclusions

Evapotranspiration-based irrigation has proven to conserve water resources in many high maintenance turfgrass applications. Supporting data were recorded at a Williamsburg golf course and Fairfax university soccer field, where water could be reduced by 55% and 35%, respectively. At the WB site, no difference in turfgrass quality was noted and the superintendent reported even water distribution in the experimental tee.

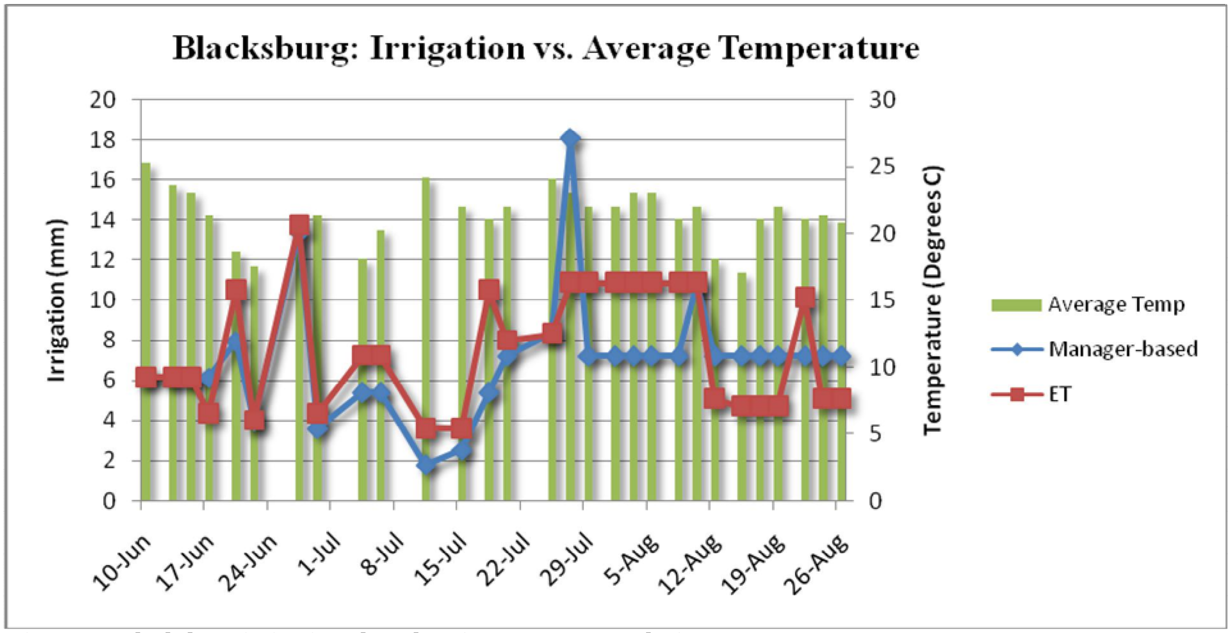

Figure 4.4 Blacksburg irrigation plotted against temperature during 2008 summer

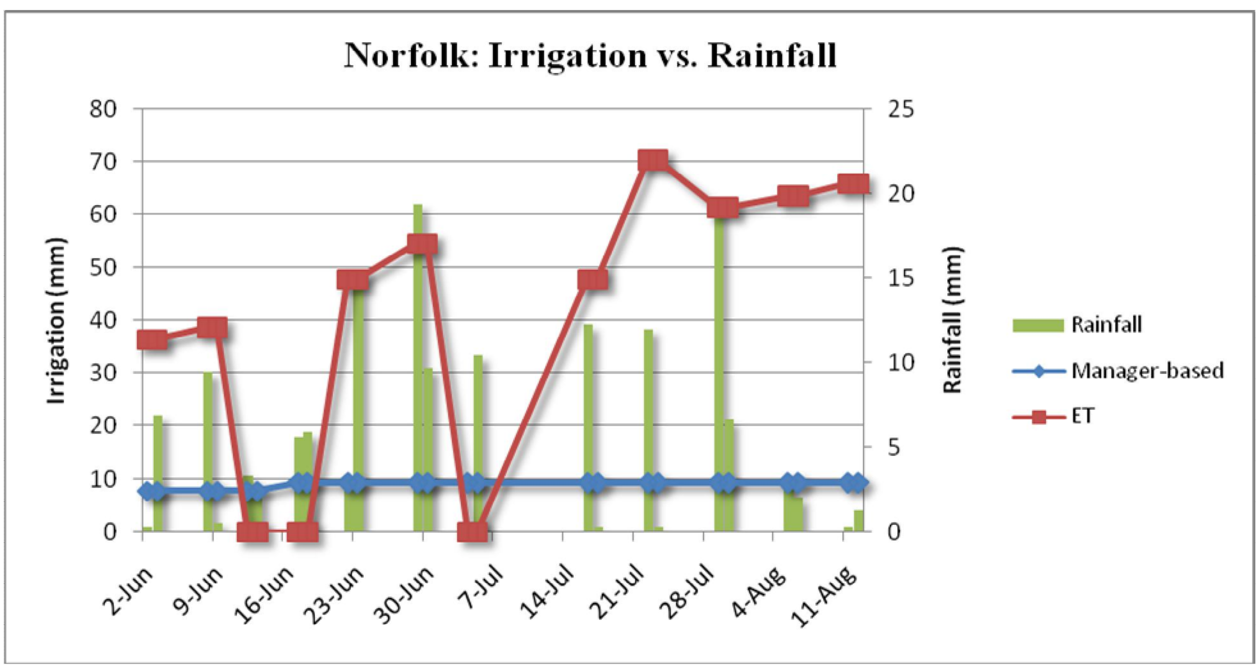

Figure 4.5 Norfolk irrigation plotted against temperature during 2008 summer

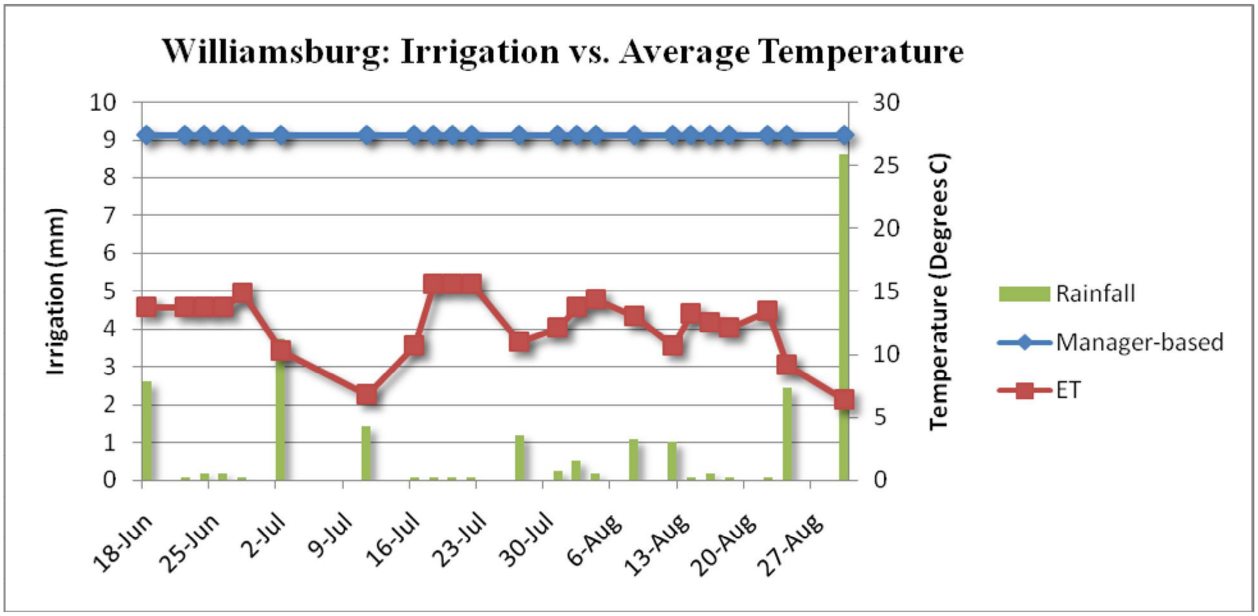

Figure 4.6 Williamsburg irrigation plotted against temperature during 2008 summer

Evapotranspiration-based irrigation scheduling has been proven by many researchers throughout the US and within Virginia to reduce water consumption, but none appear to acknowledge the social learning aspect. Including turfgrass professionals in the study not only attains real-world data, but also may teach the professionals to question their irrigation timing and reasoning behind their scheduling. This was evident in the NF case study where the manager felt more comfortable adapting the ET irrigation because he was actively altering the controls throughout the summer season. Likewise, ET-based irrigation requires managers to conduct irrigation audits to determine the precipitation rate. The act of conducting irrigation audits could lead to additional water savings through identifying potential water wasting problems like broken heads.

Future Research

Due to the limited budget for this project and available irrigated areas, research replication was not possible. This research could be expanded to include replications for each turfgrass species and/or maintenance level to provide sound statistical data to further investigate real-world ET-based irrigation application.

Real-time ET scheduling could save the most water, compared to historical monthly ET rates, but requires frequent input to alter irrigation timing. Research is needed to determine if irrigation can be altered less often and still conserve water. Additional research to test onsite ET irrigation sensors and ET signal-based irrigation systems as discussed by Davis et al. (2007) should be tested in Virginia to assess effectiveness and ease of use compared to systems requiring user input.

References

Allen, R. G. (2000). "Reference Evapotranspiration Calculator." University of Idaho Research and Extension Center Kimberly, Idaho.

Allen, R. G., Jensen, M. E., Wright, J. L., and Burman, R. D. (1989). "Operational estimates of reference evapotranspiration." *Agron. J.*, 81(4), 650-662.

Aquacraft, I. (2003). "Performance evaluation of WeatherTRAK™ irrigation controllers in Colorado." Boulder, CO.

Aronson, L. J., Gold, A. J., Hull, R. J., and Cisar, J. L. (1987). "Evapotranspiration of cool-season turfgrasses in the humid Northeast." *Agron. J.*, 79, 901-905.

ASCE. (1990). *Evapotranspiration and Irrigation Water Requirements: A Manual Prepared by the Committee on Irrigation Water Requirements.*, American Society of Civil Engineers, New York.

Barrett, J. (2004). "Mandated water restrictions: the future." *Golf Course Management*, 103-106.

Bastug, R., and Buyuktas, D. (2003). "The effects of different irrigation levels applied in golf courses on some quality characteristics of turfgrass." *Irrig Sci*, 22, 87-93.

Carrow, R. N. (2006). "Can we maintain turf to customers' satisfaction with less water?" *Agricultural Water Management*, 80, 117-131.

City of Williamsburg. (2006). "Chapter 11: Infrastructure." City of Williamsburg Planning Commission, Williamsburg, VA.

Commonwealth of Virginia. (2007a). "Governor Kaine announces federal disaster designations for 78 Virginia counties, 34 cities." Office of the Governor, Richmond, VA.

Commonwealth of Virginia. (2007b). "Governor Kaine encourages voluntary water conservation and calls on localities to update drought contingency plans." Office of the Governor, Richmond, VA.

Couch, H. B. (2000). *The Turfgrass Disease Handbook*, krieger Publishing Company, Malabar, FL.

Davis, S., Dukes, M. D., Vyapari, S., and Miller, G. L. "Evaluation and demonstration of evapotranspiration-based irrigation controllers." *ASCE EWRI World Environmental & Water Resources Congress*, Tampa, FL.

DEQ. (2005). "Status of Virginia's Water Resources: A report on Virginia's water supply planning activities." Department of Environmental Quality, Richmond, VA.

DEQ. (2007). "Status of Virginia's Water Resources: A report on Virginia's water supply planning activities." Department of Environmental Quality, Richmond, VA.

Devitt, D. A., Morris, R. L., and Bowman, D. C. (1992). "Evapotranspiration, crop coefficients, and leaching fractions of irrigated desert turfgrass systems." *Agron. J.*, 84, 717-723.

EPA WaterSense. (2008). "Water-efficient single-family new home specification supporting statement." EPA, Washington, DC.

Ervin, E. H., and Koski, A. J. (1998). "Drought avoidance aspects and crop coefficients of Kentucky bluegrass and tall fescue turfs in the semiarid west." *Crop Sci.*, 38(3), 788-795.

Evans, R. O., Harrison, K. A., Hook, J. E., Privette, C. V., Segars, W. I., Smith, W. B., Thomas, D. L., and Tyson, A. W. (1998). "Irrigation Conservation Practices Appropriate for the Southeastern United States." Georgia Department of Natural Resources, Environmental Protection Division, Georgia Geologic Survey, Atlanta, GA.

Feldhake, C. M., Danielson, R. E., and Butler, J. D. (1984). "Turfgrass evapotranspiration. II. Responses to deficit irrigation." *Agron. J.*, 76, 85-89.

Haley, M. B., Dukes, M. D., and Miller, G. L. (2007). "Residential irrigation water use in Central Florida." *J. of Irrigation and Drainage Engineering*, 133(5).

Haley, M. B., Dukes, M. D., Miller, G. L., and Haman, D. Z. (2008). "Home Irrigation and Landscape Combinations for Water Conservation in Florida." University of Florida, Gainesville, FL.

Huang, B., and Fry, J. (1999). "Turfgrass evapotranspiration." *J. Crop Production*, 2, 317-333.

Hutson, S. S., Barber, N. L., Kenny, J. F., Linsey, K. S., Lumia, S. S., and Maupin, M. A. (2004). "Estimated use of water in the United States in 2000." U.S. Geological Survey, Reston, VA.

Irrigation Association. (2000). "Legislative data sheet: turf/landscape." Irrigation Association, Falls Church, VA.

Irrigation Association. (2005). "Turf and Landscape Irrigation Best Management Practices." Irrigation Association, Falls Church, VA.

Jones, H. G. (2004). "Irrigation scheduling: advantages and pitfalls of plant-based methods." *Journal of Experimental Botany*, 55(407), 2427-2436.

LaBranche, A. J. (2005). "Creeping bentgrass and tall fescue responses to plant growth stimulants under deficit irrigation," Masters thesis, Virginia Tech, Blacksburg, VA.

NASS, and VDACS. (2006). "Virginia's 2004 Turfgrass Industry." Virginia Turfgrass Council, Virginia Beach, Virginia.

NOAA. (2007). "2007 Drought severity index by division (long-term Palmer) archive." N. W. S. C. P. Center, ed., NOAA, Camp Springs, MD.

Norfolk City Planning Commission. (1992). "General Plan of Norfolk." Norfolk, VA.

Pereira, L. S., Perrier, A., Allen, R. G., and Alves, I. (1999). "Evapotranspiration: concepts and future trends." *J. Irrigation and Drainage Eng.*, 125, 45-51.

Ratcliff, C. (1999). "Water supply and demand." *Grounds Maintenance*, 34(6), 10.

Richie, W. E., Green, R. L., and Gibeault, V. A. (1997). "Using ET_o (Reference Evapotranspiration) for turfgrass irrigation efficiency." University of California Cooperative Extension, University of California, Riverside.

Slack, E. V. (2000). "Maintaining superior landscapes on a water budget." Water Right: Conserving our water preserving our environment, International Turf Producers Foundation, Rolling Meadows, IL, 55-56.

Sluss, M. (2007). "Kaine asks Virginians to restrict water use." The Roanoke Times, Roanoke, VA.

SRI International. (2006). "Virginia's Golf Economy, 2005." SRI International, Arlington, VA.

Town of Blacksburg. (2006). "Environment: Preserving Blacksburg's Abundant Natural Resources." Blacksburg Planning Commission, Blacksburg, Virginia.

U.S. EPA. (2007). "Weather- or sensor-based irrigation control technologies." WaterSense: Efficiency made easy, EPA, Washington, DC.

U.S. EPA. (2008). "Expert advice on watering wisely." WaterSense, EPA, Washington, DC.

USGS. (2008a). "Drought Status Report: April 22, 2008." United States Geological Survey, Richmond, VA.

USGS. (2008b). "Drought Status Report: January 22, 2008." United States Geological Survey, Richmond, VA.

USGS. (2008c). "Drought Status Report: November 25, 2008." United States Geological Survey, Richmond, VA.

USGS. (2008d). "Precipitation Departures by Drought Evaluation Region." United States Geological Survey, Richmond, VA.

Virginia Tech. (2008). "Turfgrass Irrigation Scheduling." Virginia Polytechnic Institute and State University, Blacksburg, VA.

Younos, T. (2004). "The Feasibility of Using Desalination to Supplement Drinking Water

Supplies in Eastern Virginia." Virginia Water Resources Research Center, Virginia Polytechnic and State University, Blacksburg, VA.

Zoldoske, D. F. (2004). "A simple step toward savings: California study examines effect of new nozzles of golf course irrigation systems." *Golf Course Management*, 72(1), 209-213.

CHAPTER 5: CASE STUDY: INVESTIGATING ALTERNATIVE WATER SOURCES FOR TURFGRASS IRRIGATION

Abstract

Turfgrass irrigation is a non-essential, non-potable water demand that does not require energy intensive drinking water treatment. The Virginia turfgrass industry is reliant on supplemental irrigation and contributes substantially to the state's economy. Ideally, the industry would curb its reliance on potable water and utilize alternative water sources to adequately meet the irrigation demand and conserve potable water. Four case study sites were analyzed to determine the feasibility of utilizing evapotranspiration (ET)-based irrigation scheduling, reclaimed water and harvested rainwater as turfgrass irrigation alternative water sources. The case study sites included diverse turfgrass species and management practices: George Mason University bermudagrass soccer field in Fairfax, Virginia; Williamsburg Country Club bentgrass greens with bermudagrass tees and fairways in Williamsburg, VA; tall fescue home lawns in Norfolk, VA; and Virginia Tech Turfgrass Research Center bentgrass research greens in Blacksburg.

All three alternative water sources could supply enough water to irrigate George Mason University's soccer field and adjacent fields. The combined processes could save the University an estimated $7,000 a season. Evapotranspiration-based irrigation could curb Williamsburg Country Club's irrigation by 55%. Harvested rainwater could supplement the course's irrigation pond and reduce reliance on groundwater. Likewise, rainwater could be used for foundation plantings and/or washing mowers and golf carts. The two residential lawns in Norfolk, Virginia do not require enough water to make reclaimed water or harvested rainwater economically feasible and ET-based irrigation requires frequent irrigation timing adjustments, which may not be feasible at the homeowner level. Residential rainwater harvesting systems are typically installed in Virginia when homeowners are concerned about the environmental and social impact of using drinking water for irrigation needs. Finally, the Virginia Tech Turfgrass Research

Center does not have enough collection potential to make reclaimed water or harvested rainwater feasible. The on-site weatherstation could offer the Research Center a unique opportunity to attain accurate weather readings from which to calculate ET demand. The three highlighted alternative water sources are feasible sources for maintaining sustainable water supplies to meet the irrigation demands in Virginia and throughout the United States. Reclaimed water and harvested rainwater may be more economically feasible where municipal water costs are more expensive than found in Virginia.

Introduction

Water supply issues are paramount in today's environmental and social landscape. As example, Bill H.R. 631 titled "Water Use Efficiency and Conservation Research Act" passed the United States House of Representatives without amendment on February 11, 2009. The bill

> "requires the Environmental Protection Agency Assistant Administrator for Research and Development to establish a research and development program to promote water use efficiency and conservation, including: (1) technologies and processes that enable the collection, storage, treatment, and reuse of rainwater, stormwater, and greywater; (2) water storage and distribution systems; and (3) behavioral, social, and economic barriers to achieving greater water use efficiency" (2009).

Water supply plans investigate current water sources, current and projected water supply demands, the ability of the current water supplies to meet the demands, and potentially feasible alternative water sources (Daniels and Daniels 2003; Dzurik 2003). Conservation plans are a portion of the water supply plan and they investigate potential conservation methods to reduce dependence, especially in times of drought. Landscape water supply plans are inherently water conservation plans, especially when the current water source is potable.

Locally, Virginia has been plagued with water issues typically associated with the western United States. During 2007, southwest and northern Virginia received 36 and 35 inches of rain, respectively compared to the normal 45 inches (National Weather Service 2007; National Weather Service 2008). A push for water conservation plans resulted from the droughts, which have affected crop yields and supplemental irrigation applications (Commonwealth of Virginia 2007a). In October, 2007, Virginia's Governor, Tim Kaine, stressed the need for localities to update water conservation plans for future implementation and eliminate non-essential water use (Commonwealth of Virginia 2007b).

Water conservation plans are a portion of water supply plans. Conservation plans are needed for drought occurrences, but also to deal with increasing drinking water demand, which is a result of rising populations. Virginia and national populations increased 8.9% and 7.2% respectively from 2000 and 2007. The increasing demand from the increasing population is straining the nation's fresh water supplies. The water authorities' main priority is to supply the population safe drinking water despite population increases and droughts. Drinking water is often used for non-essential, non-potable water needs like irrigation, car washing and pool filling. In one instance in Fresno, California, farmers are making more money selling their irrigation water rights to municipalities to use for drinking water than growing an actual crop (U.S. Water News Online 2008).

To address irrigation water demand, water planners should look to alternative water sources and save drinking water for essential water needs. Alternative water sources encompass ground water and surface water sources as well as desalination, reclaimed water, rainwater harvesting and conservation (AWWA 2001). The need to "encourage, promote, and develop incentives for alternative water sources, including but not limited to desalinization" was identified in a portion of the 9 VAC 25-870 regulation (2005), which requires Virginia localities to develop local or regional water supply plans. Water conservation through evapotranspiration (ET)-based scheduling, reclaimed or recycled water, and harvested rainwater are all possible alternative water sources for landscape irrigation purposes, dependent on the site requirements.

Evapotranspiration-based scheduling allows irrigation managers to replace only the amount of water lost from the landscape through the combined forces of evaporation and plant transpiration. Therefore, irrigation practices are more exact and water is not wasted through over irrigation. Crop coefficients further adjust the ET level to a deficit level specific to the landscaped crop and management level. The Irrigation Association uses a crop coefficient of 0.8 for cool season turfgrass, 0.6 for warm season turfgrass, and 0.5 for trees, shrubs and mixed plantings (Water Management Committee 2005). Evapotranspiration-based irrigation scheduling is an inexpensive approach to curb water use and could provide significant water savings. One study conducted by the Irvine Ranch Water District reported that turfgrass irrigation was applied at three times the estimated ET demand (Slack 2000).

Reclaimed water is treated wastewater that undergoes a series of processes to ensure the water is safe for reuse, but is not suitable as drinking water (Lazarova and Bahri 2005). The treatment process can be achieved at municipal treatment plants and transferred through piping separate from drinking water or can be treated with decentralized on-site treatment systems (Asano et al. 2007). The treatment level depends on the original water source. Centralized treatment systems treat all municipal wastewater, including water from showers, sinks, washing machines, dishwashers and toilets, while decentralized treatment systems treat only greywater from showers, sinks and washing machines (AWWA 2007). Dishwashing water and blackwater from toilets could carry harmful pathogens and living organisms that must undergo additional treatment at a centralized water treatment plant.

A state regulation (9 VAC 25-740-10) enacted in Virginia allows unrestricted use of reclaimed water that has undergone secondary treatment with filtration and higher-level disinfection for landscape irrigation (2008b). Despite the regulations, there are many environmental and public health concerns with the use of reclaimed water. The water nutrient and salinity levels may pose long-term environmental problems if not properly addressed (Carrow and Duncan 2000). California and Florida are the largest users of reclaimed water for irrigation purposes. In California, 50% of the reclaimed water is used on golf courses, whereas 36% of the reclaimed water is used for golf course irrigation in Florida (Asano et al. 2007). The effectiveness of reclaimed water use as irrigation water is dependent on the plant tolerance to sodium, chloride, boron and sodium that are found in reclaimed water (Asano et al. 2007). A study by Evanylo et al. (2007) found that reclaimed water applied on turfgrass had no immediate negative effect, but long-term application could impact turfgrass health with increasing salt buildup.

Rainwater harvesting applications are on the rise to not only supply an alternative water supply for non-potable water demands like irrigation, but also to reduce stormwater runoff. Rainwater harvesting is the process of collecting impervious rooftop rainfall runoff, storing it on-site and reusing it for non-potable water needs (Kinkade-Levario 2007; LaBranche et al. 2007). Research on rainwater harvesting to supply landscape irrigation demands is limited in the US due to the unfamiliarity with appropriate harvesting approaches outside rain barrel collection. At the 2006 International Irrigation Show, a presenter described a system that was comprised of 11,000 liters of storage and supplied irrigation through gravity fed soaker hoses (Peterson 2006). More sophisticated systems can include pre-filtering, submersible pumps, and make-up water source for when the rainwater supply is exhausted. The Lady Bird Johnson Wildflower Center in Austin, Texas is a large scale application of rainwater harvesting to supply irrigation water. The Center has the potential to harvest 1,135,620 liters yearly from the 1,580 sq. m. of roof area (Lady Bird Johnson Wildflower Center 2001).

The objectives of this study are to investigate the feasibility of using alternative water sources for turfgrass irrigation demands at four case study sites in Virginia. Conservation through ET-based irrigation, reclaimed water, and harvested rainwater will be investigated as viable water sources. The case study sites include a soccer field at George Mason University in Fairfax, a golf course in Williamsburg, two residential lawns in Norfolk, and research plots at the Virginia Tech Turfgrass Research Center in Blacksburg.

Methods and Materials

The identified alternative water source (ET-based irrigation scheduling for conservation, reclaimed water, and harvested rainwater) will be considered as an irrigation water supply at each case study site to determine feasibility. Feasibility will be governed by the ease of implementation, environmental impact, water conservation impact and cost. Ease of implementation will be based on the materials required for adoption including the installation intensity. Environmental impact will be based on both direct and indirect impacts from implementing the alternative water source. These impacts include, but are not limited to, any soil disruption required for installation and nutrient loading resulting from application. Water conservation impact will be assessed based on the potential water savings and/or reduction on drinking water supply. Cost will be estimated based on available information. Generalizations will be made when more specific cost information is not available.

Case Study Sites

George Mason University Soccer Field

George Mason University is located in Fairfax, Virginia, which is in northern Virginia, outside Washington DC. The university's soccer field is approximately 0.7 hectares and comprised of bermudagrass (*Cynodon dactylon*). The field is situated next to the 10,580 sq. m. university field house, which houses basketball, tennis, volleyball, and racquetball courts, indoor track, weight room, locker rooms and saunas. Baseball, softball and intramural fields are also located nearby. All potable and irrigation water for the university is supplied by the Fairfax City Water.

Figure 5.1 George Mason University field house
Used with permission
(http://recsports.gmu.edu/files/u1/fieldhouse-exterior-1.jpg)

Figure 5.2 George Mason University soccer field
Used with permission
(http://recsports.gmu.edu/files/u1/Stadium-Endzone-15_web-header.jpg)

Williamsburg Country Club

Williamsburg Country Club is located in a light commercial district in Williamsburg, Virginia. The fairways and tees consist of bermudagrass (*Cynodon dactylon*), while the greens consist of bentgrass (*Agrostis palustris*). The golf course covers 62 hectares with 36 managed hectares and 16 irrigated hectares. The clubhouse is approximately 280 sq. m., which includes locker rooms, pro shop, restaurant, and golf cart storage (Fig. 5.3). A 5 hectare on-site pond collects the natural runoff from the course and is supplemented with groundwater from several wells (Fig. 5.4).

Figure 5.3 Williamsburg Country Club clubhouse
Adrienne J.L. Tucker

Figure 5.4 Williamsburg Country Club pond
Adrienne J.L. Tucker

Norfolk Residences

Both sites are located in residential neighborhoods of Norfolk, Virginia and are planted with tall fescue (*Festuca arundinacea*) lawns with additional ornamental beds. Residence A has approximately 205 sq. m. of irrigated lawn area and 195 sq. m. of roof line (Fig. 5.5, 5.6). Residence B has approximately 250 sq. m. of irrigated lawn area with 345 sq. m. of roof line (Fig. 5.7, 5.8). Both residences utilize city water to supply drinking and irrigation water.

Figure 5.5 Norfolk Residence A
Adrienne J.L. Tucker

Figure 5.6 Norfolk Residence A irrigated lawn
Adrienne J.L. Tucker

Figure 5.7 Norfolk Residence B
Adrienne J.L. Tucker

Figure 5.8 Norfolk Residence B irrigated lawn
Adrienne J.L. Tucker

Virginia Tech Turfgrass Research Center

The Turfgrass Research Center is situated just outside the Virginia Tech campus in Blacksburg, Virginia. The center encompasses 12 hectares consisting of both warm and cool season turfgrasses (Fig. 5.9). Automatic irrigation is installed on four sand-based greens, which total 0.4 hectares of land. The entire research center can be irrigated with hose and sprinkler irrigation. One 240 sq. m. maintenance building, housing offices and equipment storage, is located on the property (Fig. 5.10). Irrigation water is supplied by the Blacksburg-Christiansburg-VPI Water Authority.

Figure 5. 9 Virginia Tech Turfgrass Research Center research plot
Adrienne J.L. Tucker

Figure 5.10 Virginia Tech Turfgrass Research Center maintenance building
Adrienne J.L. Tucker

Water Conservation with ET-based Irrigation

A newly developed website calculates ET demand for 10 regions throughout Virginia (Virginia Tech 2008b). The regions represent the locations of individual weatherstations, which collect climate data like temperature, humidity, and wind speed to calculate ET. The website was developed specifically for turfgrass application and was modeled after other existing easy to use state ET websites. Users select the weatherstation closest to their site, type of turfgrass (warm or cool season), and data range. The daily ET, daily adjusted ET for type of turfgrass, high and low temperature, and high and low humidity output data are organized in a table format. Daily calculated and adjusted ET data are summed to indicate the amount of irrigation (in inches) that is required to meet the turfgrass plant demands. Irrigators must then adjust irrigation controls to apply the appropriate amount, based on the irrigation system precipitation rate.

The feasibility of utilizing ET-based irrigation scheduling at each case study site will depend on water conservation potential upon implementation and adoption likelihood. Environmental impact and cost are independent of site location as no additional technology or implementation is required, other than an existing personal computer and internet connection. However, managers at each case study site would be required to alter irrigation settings to reflect the changing ET demand.

Willingness to alter the irrigation controller as often as ET-based irrigation scheduling requires is dependent on the site manager/homeowner and his familiarity with the irrigation control panel. A Scotts® 2005 study of 1,235 U.S. households found that 73% of homeowners believed their actions can affect the environment, but only 25% reporting taking steps to protect the environment (Martinez 2006). Few homeowners would be willing to alter their irrigation settings and even less would be willing to alter the irrigation settings on a weekly basis. Professionals that are more familiar with their irrigation controllers might be more willing to change the irrigation settings based on ET demand.

George Mason University

A study during the 2007 summer months tracked the irrigation scheduling on the George Mason University soccer field. A total of 370 mm of irrigation water was applied during the study period. Climate data from the Alson H. Smith Jr. AREC weatherstation was used to calculate the ET demand during the July through August 2007 months. The calculated ET, adjusted with a 0.6 crop coefficient, was 240 mm. If the soccer field was irrigated based on the ET demand, 35% of the water could have been saved (Tucker 2009). The water savings translates directly in saved money for the university. Based on the City of Fairfax's water rates (2008), the university could have saved an estimated $2,000 during the summer months on the one soccer field. Further cost savings would occur if the ET-based irrigation scheduling is adopted for all on-campus irrigated playing fields, depending on the willingness to alter the irrigation schedule as often as once a day.

Williamsburg Country Club

A study conducted on two Williamsburg Country Club tee boxes during the June through

August 2008 summer months found that irrigation could be reduced by 55% when irrigating based on ET, calculated from the Eastern Virginia weatherstation, compared to the golf course's normal irrigation regime (Tucker 2009). Since the golf course relies on a pond and wells for irrigation water, water savings would translate into energy savings to utilize the pumps to disperse the irrigation water. Likewise, groundwater would be conserved for other nearby potential users.

Norfolk Residences

The same 2008 summer study recorded that both the Norfolk residential lawns used 23% less water when irrigation was not scheduled in accordance to ET demand calculated with data from the Tidewater AREC weatherstation (Tucker 2009). A lawn maintenance company manages the lawn areas and controls the irrigation applied. The manager's irrigation approach is very conservative. It is believed that differing data would be gathered if the homeowners managed the irrigation application.

Virginia Tech Turfgrass Research Center

Similar to the Norfolk summer 2008 results, the Turfgrass Research Center used 29% more water when a research green was irrigated based on the ET rate, calculated with climate data from the Urban Horticulture Farm weatherstation in Blacksburg (Tucker 2009). There is a weatherstation located on the Turfgrass Research Center grounds that is not included in the Turfgrass Irrigation Scheduling website. A more accurate ET rate could be calculated by using the weatherstation at the Center, which may result in water savings, but additional steps would be required to download the data and calculate ET. The required time input may not be worth the water savings for the Center.

Reclaimed Water

When using reclaimed water for irrigation purposes, potable water is saved for drinking water demands, which allows municipalities to meet the consumers' needs. Treating water to drinking water standards requires considerable energy. Four percent of the total energy consumed in the US is used to treat and deliver drinking water. Municipal water treatment plants spend 80% of their total budget on energy costs to treat and deliver drinking water to the end users (EPRI 2002). Many municipal water treatment centers are reaching or are at capacity and require billions of dollars to expand or build new treatment plants (University of Michigan 2008).

Reclaimed water can be treated in a centralized treatment plant or in a decentralized on-site system. Centralized treatment systems require plumbing to be laid from the plant to each consumer. One study found that pipe diameter could be reduced for duel piping system delivering potable and reclaimed water, but the dual system also increased pipe costs from 50 to 100% (Digiano et al. 2009). Decentralized systems can be installed in areas where centralized systems are not available. Greywater from sinks, showers, and washing machines can be diverted to a septic tank or solid separating unit on-site. The water passes through filters to remove coarse solids and the resulting water is utilized for irrigation; additional treatment is required if the water is brought back into a building for toilet flushing (Asano et al. 2007). While decentralized systems require less capital cost to implement, the users are responsible for ensuring a decentralized system is maintained properly (Asano et al. 2007; U.S. EPA 2005a; U.S. EPA 2005b).

Using reclaimed water for landscape irrigation purposes alleviates demand on potable water resources. However, there are concerns about the sustainability of the practice in regards to soil and plant health. Due to the high salt and mineral content in reclaimed water, sodic soils can result, which affects soil permeability and water holding ability (Bouwer 2005; Kennedy and Tsuchihashi 2005; Sheikh 2005). Likewise, groundwater samplings at Florida golf courses irrigated with reclaimed water reported lower pH and higher chloride measurements, compared to golf courses not irrigated with reclaimed water (Swancar 1996). However, Skeikh (2005) postulates that reclaimed water is best used on golf courses, where management is vigilant and adaptations can be made to balance the effects of the reclaimed water.

While developing centralized reclaimed water infrastructure is an expensive undertaking, governmental funding may be available to complete such projects and the municipality can recoup expenses through consumption fees. Decentralized systems treat greywater from hand washing, showers, and washing machines from a building or group of buildings onsite. These systems are less expensive to install than centralized treatment systems, but water quality is not regulated and if not maintained properly, they could pose health and environmental risks (U.S. EPA 2005a). Deciding on a decentralized greywater treatment system is dependent on the likelihood of a centralized system being implemented, population it could serve, available land for the system, and system payback.

The largest hurdle to overcome when considering using reclaimed water as an alternative irrigation water source from a centralized or decentralized system is public perception. Without appropriate education, the public can overreact to technologies outside the norm, especially when it pertains to environmental and personal health and safety (Erickson 2004). Integrating the public, irrigation and grounds managers, and experts into the planning process is needed to spread information and make an informed decision to determine if reclaimed water is a viable option (Sheikh 2005).

Facility water usage is estimated for LEED (Leadership in Energy and Environmental Design) certified buildings to assess water conservation potential. The calculations incorporate bathroom, lavatory sink, kitchen sink, and shower usage frequency. The average person uses the bathroom three times a day at work and five times a day at home. Also, residents shower once a day and 0.1 of the population showers in a public facility like a gym (Haselbach 2008). The average person uses about two liters of water washing his/her hands and 50 liters taking a shower and the typical washing machine uses 150 liters per cycle (Henken 2000).

George Mason University

Fairfax does not currently have a centralized treatment system to supply reclaimed water to the university. The Fairfax City Comprehensive Plan public facilities section indicated that the municipal water treatment plant can survive a four month drought with enough water to supply drinking water demands and there is adequate capacity to treat wastewater until 2010 (Fairfax City 2004b). The City is also proactively working to replace water main pipes as the system is showing signs of deterioration (Fairfax City 2004b). Reducing the reliance on the potable water supply through reclaimed water adoption would assist in maintaining the lifespan of the existing infrastructure and delay the need to expand or build a new infrastructure, even though the comprehensive plan does not indicate the need to expand in the near future.

Since reclaimed water is not available in the area and the comprehensive plan does not indicate any plans to supply reclaimed water in the near future, decentralized treatment systems could be installed on the university's grounds to supply irrigation water, rather than pulling from the potable water supply. There is a 10,580 sq. m. recreation field house located adjacent to the case study soccer site. The field house is used daily by students, faculty and staff for fitness activities like basketball, racquetball, running, and lifting weights. Approximately 400 students, faculty and staff use the building on any given day; approximately 355 of the daily patrons visit the facility for recreational activities and 45 faculty members have offices in the field house (Houston 2009). Of the 355 daily patrons, 0.1 take a shower, which adds up to 9,000 liters a work week. The 45 faculty members use water during bathroom visits and subsequent hand washing three times a day, which totals 270 liters a day, or 1,350 liters a week. There are also two washing machines in the building that are run daily to wash uniforms (Houston 2009). Each washing machine runs two cycles each day, which results in 600 liters of water used daily, or 3,000 liters are used weekly. A total of 13,350 liters could result each week from all the greywater uses, which translates to 53,400 liters each month.

Williamsburg Country Club

In the City of Williamsburg's Comprehensive Plan, future water sources are addressed to meet the growing water demands. The Comprehensive Plan indicates that future water resources will be attained by developing an additional pumping station and an earthen dam to create a lake that will serve as a reservoir (City of Williamsburg 2006). The City adopted a Water Conservation Plan in 1993 that included metering, increasing water usage and connection fees, and offering conservation kits to reduce indoor water usage. A recommendation under the "Conservation" section denotes the need to look at tactics like regulating irrigation to reduce outdoor water usage (City of Williamsburg 2006).

The Hampton Roads Sanitation District (HRSD) is working with localities to determine where reclaimed water can be utilized to replace potable water supplied for nonpotable needs. In one project with Giant, a large oil refinery, reclaimed water was used in the boiler and some operating processes. In one year, the refinery was able to conserve 635 million liters of potable water by using the reclaimed water (Newport News Waterworks 2006). However, HRSD has not extended reclaimed water service for public use.

The Williamsburg Country Club draws irrigation water from an on-site pond that is fed by groundwater and natural site runoff. There is not a strong likelihood that the pond will go dry in the near future, but if the country club was interested in using reclaimed water for irrigation, a decentralized system may be feasible for the site since municipal supplies are not yet available. The clubhouse, supplied with city water, has large locker rooms for members to shower after a round of golf. In 2008, there were 25,000 rounds played at the Country Club along with many weddings and private parties in the clubhouse (Whitmire 2009). If the monthly traffic is around 2,100 people, 210 will use the shower facilities and lavatory sinks. A total of 10,920 liters will be contributed to the greywater supplies a month.

If reclaimed water is used the Williamsburg Country Club or any golf course, the salinity problems associated with its use can be managed by irrigating deep and infrequently, altering fertilizer application based on the nutrient level in the water, irrigating subsurfacely, and applying gypsum or lime to counterbalance the low water pH (Sheikh 2005). The use of reclaimed water for irrigation is best suited for a golf course setting, where budgets and manpower allow for close monitoring. Fertilizer applications can be altered to balance out the nutrients in the water, which could also result in fertilizer savings.

Norfolk Residences

Norfolk also falls in the HRSD area, which may eventually supply reclaimed water for nonpotable needs. However, the Norfolk Comprehensive Plan does not indicate any interest in utilizing reclaimed water. Rather, emphasis is placed on protecting the Chesapeake Bay through reduced nonpoint source pollution (Norfolk City Planning Commission 1992). If reclaimed water is applied in excess to result in surface runoff, the water could actually contribute to nonpoint source pollution through the surface runoff and the nutrients naturally present in the reclaimed water.

A family of four averages four loads of laundry a week, one shower per person and five hand washings after bathroom visits each day. This calculates out to 600 liters of machine water discharge a week, or 2,400 liters a month. Showers and hand washing result in 1,400 liters and 280 liters a week, respectively, or 5,600 liters and 1,120 liters a month. The total resulting greywater to be used as irrigation at Residence A or B would be 9,120 liters a month. Due to initial costs and small lot size, a decentralized reclaimed water treatment system for Residence A or B may not be best suited. Decentralized systems may be more feasible for large planned residential areas. Both residential homes in the case study are situated in densely populated neighborhood communities lacking green space to place a decentralized neighborhood treatment system.

Virginia Tech Turfgrass Research Center

The Blacksburg Comprehensive Plan does not address the use of reclaimed water to reduce reliance on potable water. The Plan stresses the need to protect current water supplies and natural areas (Town of Blacksburg 2006a). The University, including the Turfgrass Research Center, receives its water from the Blacksburg-Christiansburg-VPI Water Authority. The Authority treats an average of six million gallons of water per day, but the maximum treatment level is 12 million gallons per day, which is enough to supply the projected water demands for an additional 40 years (Town of Blacksburg 2006b). Utilizing a decentralized reclaimed water system would not be feasible for the Turfgrass Research Center as there is one building on the property that houses one bathroom for hand washing. An average of 10 people have access to the building during the day, which translates to around 1,200 liters of water supplied per month through three daily hand washings.

Rainwater Harvesting

Rainwater harvesting systems allow for the collection and use of rainfall runoff from impervious surfaces like rooftops. This rainfall is typically diverted to rooftop gutters and then to downspouts, where the water is then released to the environment. The environment can consist of impervious surfaces like driveways, sidewalks, parking lots and pervious surfaces like bioswales, rain gardens or lawns. Harvesting rainwater from rooftops can offer a nonpotable water source for irrigation while reducing stormwater runoff, which contributes to nonpoint source pollution (LaBranche et al. 2007; Seymour 2005). Likewise, rainwater harvesting systems can prevent rooftop originated heavy metals from entering the environment. The metals settle to the bottom of the storage tank and are trapped in a biofilm layer where they remain as long as the tank water is not agitated, which can be avoided through the use of calming inlets or turning the inlet piping upwards (Coombes et al. 2006; LaBranche et al. 2007).

Rainwater harvesting systems are decentralized water supply systems that supply nonpotable water with little filtration or potable water with advanced treatment. Rainwater can be collected from single downspouts or from all the downspouts on the building. A system consists of conveying gutters and downspouts, filtration, storage tank(s) and pump(s) (Fig 5.11). If filtered properly to limit organic debris from entering the tank, rainwater quality will not degrade during long-term storage (i.e. collection during winter wet seasons for use during dry summer seasons). If organic debris enters the tank, anaerobic conditions will occur, resulting in foul odor and maintenance concerns.

There are no environmental concerns when utilizing rainwater as irrigation water as rainwater does not contain any salts and the pH is typically neutral. To install belowground systems, there is some land disruption involved. Aboveground storage is less invasive, but large tanks are not always aesthetically pleasing and harvesting capabilities may be limited to the tank location due to the need for gravity flow from downspouts. Belowground systems are best suited for situations where most of the roof area is harvested as plumbing can be manipulated to ensure gravity flow occurs to the tank.

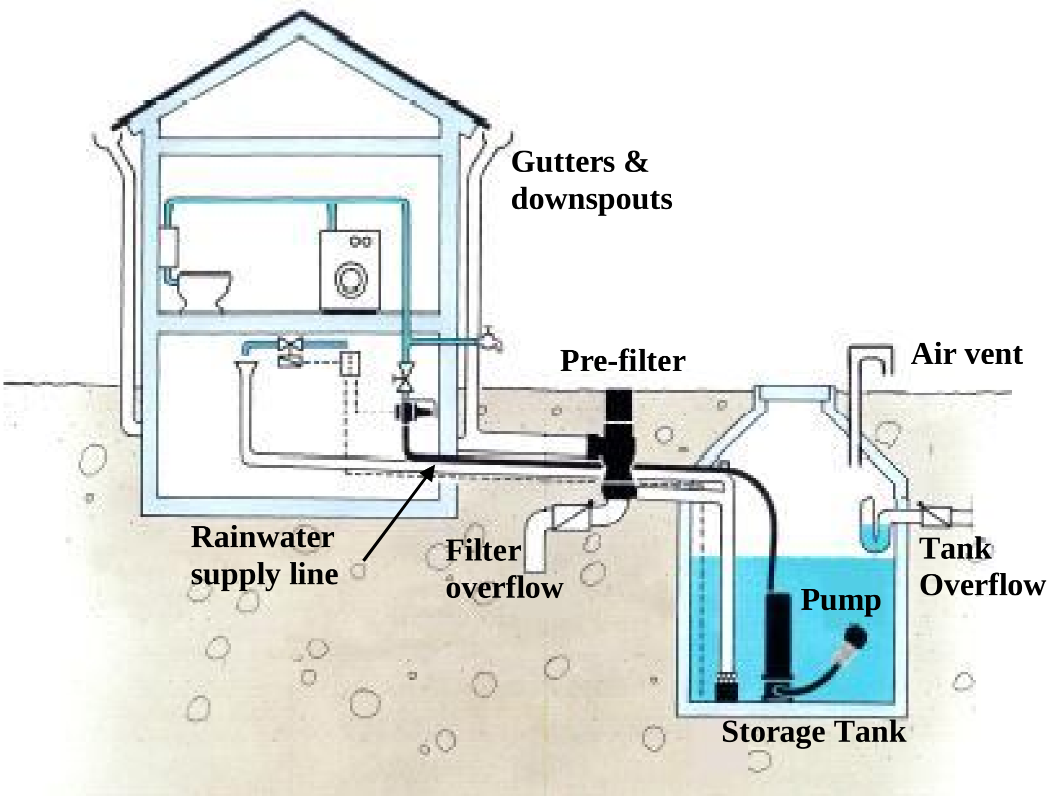

Figure 5.11. Rainwater harvesting system
Used with permission *Rainwater Management Solutions, Salem, Virginia*

In Germany, all new developments must implement rainwater systems to handle runoff water quality and quantity from densely populated areas (Nodle 2007). The collected water is used solely for nonpotable water needs like irrigation. While rainwater harvesting is more common in countries like Germany and Australia, systems are becoming more commonplace in the United States. Using harvested rainwater for irrigation qualifies for points toward LEED certification, which certifies "green" buildings through the United States Green Building Council (Pushard 2008). In Virginia, the use of rainwater has been approved in state buildings for nonpotable uses like flushing toilets, landscape irrigation, and fire protection; the capturing, filtering, and storing of rainwater must be done in accordance with the *Virginia Rainwater*

Harvesting Manual (2008a).

When determining the feasibility for installing a rainwater harvesting system for irrigation and/or other nonpotable needs, the collection potential (supply) and water use (demand) must be analyzed. For each 25 cm. of rainfall that falls on a 93 sq. m. roof, 2,345 liters of runoff results (LaBranche et al. 2007). Supply is calculated on a monthly basis to assist in determining tank size. Rainfall in Virginia is on average 7.6 cm a month without any designated wet and dry seasons.

George Mason University

The Fairfax City Comprehensive Plan indicates that urban runoff has impaired many streams and lakes in the surrounding area (Fairfax City 2004a). To combat the problem with stormwater runoff, the city adopted the Chesapeake Bay Preservation Act in 1990 and has since been continuously implemented (Fairfax City 2004a). George Mason University's Master Plan indicates the need for expansion for both academic buildings and also recreational areas (Sasaki Associates and MMM Design Group 2002). The addition of both buildings and recreational areas will increase impervious rooftop areas and irrigation demands, which is ideal for rainwater harvesting application.

The 10,580 sq. m. university field house located adjacent to the soccer field could serve as the impervious rooftop collection area. Monthly collection during normal rainfall would be 800,000 liters. There is available land located next to the field house to install below or aboveground tank(s). Total storage volume required would be around 400,000 liters to store half a month's supply. The natural slope of the land from the field house to the soccer field could reduce pumping requirement from the storage tanks(s). The largest cost of the system would be for the tank(s) and excavation to install belowground tanks. A 400,000 liter storage capacity could cost upwards of $300,000 to $400,000.

Williamsburg Country Club

The Williamsburg Country Club currently indirectly harvests rainwater, as the course is developed to naturally drain into the irrigation pond. The clubhouse on the grounds can also serve as an impervious collection area. Currently, there are downspouts that release runoff directly onto cart paths around the building (Fig. 5.12). The rooftop harvested rainwater could be linked together and diverted through underground plumbing to the pond, rather than washing across impervious areas. In this case study, the existing pond would serve as the rainwater storage vessel as opposed to tanks. However, an aboveground tank can also be located underneath a downspout to allow for irrigating ornamental plants around the clubhouse, and for washing mowing equipment and golf carts rather than using the potable water from existing hose bibs (Womack 2009).

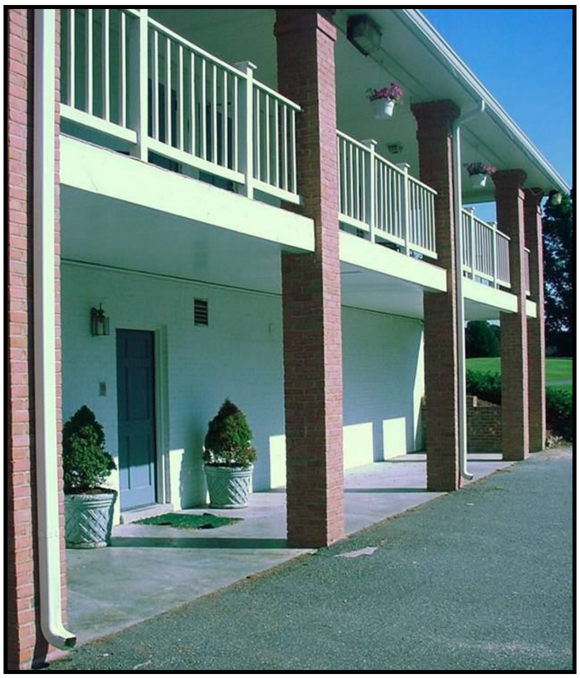

Figure 5.12 Williamsburg Country Club downspouts draining onto the golf path
Adrienne J.L. Tucker

The clubhouse roof collection area of 280 sq. m. would supply 21,100 liters during a normal rainfall month. The golf course irrigation demand exceeds the available supply through rainwater harvesting. However, the harvested rainwater could supplement the pond water and perhaps curb groundwater pumping to supply the irrigation pond. The collected rainwater could also supply approximately nine hours of hose irrigation for seasonal foundation plantings.

Norfolk Residences

The Norfolk residences are located in the highly protected Chesapeake Bay watershed. Nonpoint source pollution from stormwater runoff degrades the Chesapeake Bay; state and federal regulations have been enacted to protect the Bay's integrity by reducing runoff potential. Norfolk's Comprehensive Plan indicates nonpoint source pollution strategies that range from using stormwater Best Management Practices to improving drainage and addressing improper discharges in the city's stormwater discharge (Norfolk City Planning Commission 1992). Collecting rainwater from the residential homes would decrease the stormwater runoff resulting from rooftops, while providing irrigation water.

The downspouts from the 160 sq. m. roof of Residence A are directed into the ground (Figs. 5.13) and the separate 35 sq. m. garage/in-law apartment downspouts are directed to the driveway (Fig. 5.14). The gutters from the main building are diverted into the street to drain the water from the home (Fig. 5.15). This practice contributes significantly to stormwater runoff from individual residential lots and from whole residential neighborhoods, which can potentially impair local streams and rivers with nonpoint source pollution.

Figure 5.13 Residence A front downspout directed belowground
Adrienne J.L. Tucker

Figure 5.14 Residence A garage/in-law apartment downspout directed onto the driveway
Adrienne J.L. Tucker

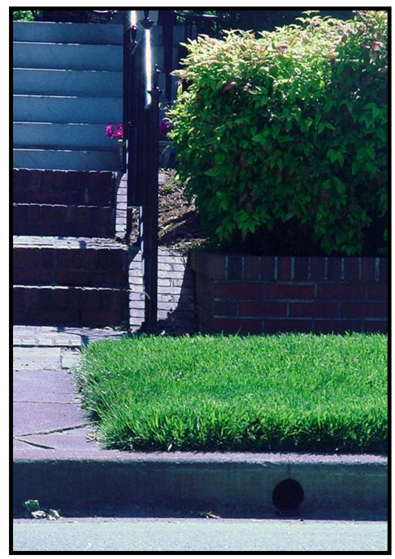

Figure 5.15 Residence A drain into the street
Adrienne J.L. Tucker

Residence A can harvest an estimated combined 14,760 liters of rainwater from the main building and garage. Installing a rainwater collection system to collect all the rooftop runoff at Residence A would require an initial investment to link the downspouts, install filtration, pump, plumbing and above or belowground storage tanks. Land is limited at the Residence A to install an above ground tank; a belowground system with linked downspouts that drain into a belowground storage tank in the existing lawn area would be best suited, but installation would disrupt the established landscape plantings. Rain barrels could be implemented for ornamental irrigation needs, but would not be suitable to irrigate the turfgrass areas.

Residence B has 345 sq. m. roof collection area to supply the 250 sq. m. of irrigated lawn area. The residence, not currently equipped with a gutter conveyance system, appears to allow rooftop runoff to drain on underlying landscape beds (Fig. 5.16). Gutters and downspouts ensure that water drains away from the building to protect the integrity of the building's foundation and would require installation to harvest rainwater. The rainwater collection potential for Residence B is 26,000 liters per month. The turf area located behind the home would be a convenient area to house above or belowground tanks (Fig. 5.17). Like Residence A, rain barrels can also be implemented to irrigate small areas, but cannot harvest enough water to irrigate the turfgrass areas.

Virginia Tech Turfgrass Research Center

Located in Blacksburg, Virginia, the Virginia Tech Turfgrass Research Center is surrounded by the well admired landscape of the New River Valley. As indicated in the Blacksburg Comprehensive Plan, the town's environmental objectives are to maintain open spaces and protect streams and groundwater (Town of Blacksburg 2006a). The university's

Figure 5.16 Residence B roofline without gutters and downspouts
Adrienne J.L. Tucker

Figure 5.17 Residence B land available to install rainwater harvesting tank(s)
Adrienne J.L. Tucker

comprehensive plan is currently being updated, but current summarized findings are highlighted online. The university's stormwater problems and impaired Stroubles Creek are indentified on the website as topics that must be addressed (Virginia Tech 2008a). The Turfgrass Research Center is located outside the main campus and is not near the Stroubles Creek. Nonetheless, rainwater harvesting at the Turfgrass Research Center may provide a stormwater management solution for the rest of the university and neighboring community.

The sole building on the Turfgrass Research Center grounds has a 240 sq. m. roofline. During an average summer, approximately 18,170 liters could be harvested from the roof area. Unlike the residential lots, there are many acres around the building that are available to place an above or below ground tank for water storage.

Discussion

Evapotranspiration-based irrigation conservation practices can be employed at all four case study sites inexpensively. Success of the ET-based irrigation scheduling is dependent on the preexisting irrigation practices. A preliminary study like the one conducted for George Mason University in 2007, where irrigation was tracked during the summer and compared to ET demand during the same period, should be conducted before ET-based irrigation is implemented. Such a preliminary study will offer insight to determine if ET-based irrigation could indeed conserve water. As seen with the Norfolk residence, ET-based irrigation does not always conserve water, compared to the original irrigation regime (Tucker 2009). Unlike the Norfolk, residence, Williamsburg Country Club exemplified that water could be saved significantly when ET-based irrigation is employed. The water savings can transfer to cost savings for golf courses supplied by municipal water, not just in Virginia, but around the country.

A recent study surveyed golf course superintendents throughout the country to attain a better understanding of golf course maintenance, resource conservation and cost, and property features. Throssell et al. (2009) were able to collect water cost data throughout the country, which is applied in Table 5.1 to compare water cost savings if golf courses use ET-based irrigation, based on the 55% savings recorded at Williamsburg Country Club.

The varying water cost throughout the United States impacts the interest of using alternative water sources and conservation efforts. The Southwest has the highest water cost per hectare, which is why conservation is strongest in that area. Virginia is in the transition zone, where water is among the least expensive. The calculated $2,000 water savings at George Mason University when ET-based irrigation is used, could translate into a savings of $31,000, if the soccer field was located in the Southwest. Water costs are not expected to remain stagnant; across the US, prices are continuing to increase as much as 25% over a five year period (Clark 2007).

Table 5.1 Golf course turfgrass irrigation cost savings throughout the country when using ET-based irrigation

	Average Cost of Water per Irrigated Hectare ($)[1]	Cost of Water per Hectare with ET-based Irrigation Savings
Northeast	2,552	1,148
North Central	1,904	857
Transition	2,795	1,258
Southeast	6,075	2,734
Southwest	43,659	19,647
Upper West/Mountains	8,424	3,791
Pacific	17,172	7,727

[1] (Throssell et al. 2009)

Collection potential (supply) must be balanced with demand when researching the feasibility of using reclaimed water and rainwater harvesting. Table 5.2 shows the supply and demand balance for reclaimed water and rainwater harvesting at the case study sites. Demand is based on irrigation area,previous research where irrigation was tracked or average monthly ET demand derived from the University of Virginia potential ET website (2000).

Table 5.2 Case study site monthly reclaimed water and rainwater harvesting supply compared to irrigation demand

		SUPPLY (liters)		
	Irrigated Area	**Reclaimed Water**	**Rainwater Harvesting**	**DEMAND (liters)**
George Mason University	0.7 hectare soccer field	53,400	800,000	844,580[1]
Williamsburg Country Club	16 hectares irrigated surfaces	10,920	21,100	3,905,970[2]
Norfolk Residence A	205 sq. m. home lawn	9,120	14,760	6,180[3]
Norfolk Residence B	250 sq. m. home lawn	9,120	26,000	7,580[3]
Virginia Tech Turfgrass Research Center	4 hectares research greens	1,200	18,170	186,050[4]

[1] (Tucker 2009)
[2] Average Williamsburg summer ET demand of 2.4 cm (University of Virginia 2000)
[3] Average Norfolk summer ET demand of 3.0 cm. (University of Virginia 2000)
[4] Average Roanoke summer ET demand of 4.6 cm. (University of Virginia 2000)

Williamsburg Country Club cannot meet its demands through just reclaimed water or rainwater harvesting. Irrigation on one 185 sq. m. green with a 9.1 mm hr^{-1} precipitation rate could run for 6.5 hours with the reclaimed water and 13 hours with the harvested rainwater. A rainwater harvesting system could be installed to supplement the existing pond, if deemed necessary. In the advent of increased competition for groundwater, which supplies the pond, through development around the golf course, the supplied rainwater from the rooftop runoff could assist in maintaining the pond water level to meet the irrigation demand. Also, implementing ET-based irrigation would assist in curbing the water consumption on the golf course by as much as 55%.

Williamsburg Country Club is not located in a residential area nor are there homes located on the golf course grounds. In the situations where homes surround a golf course or are located on the golf course grounds, greywater from the residential dwellings could be diverted to a decentralized reclaimed water treatment system or pond to supply the golf course irrigation needs (Asano et al. 2007).

Reclaimed water is most often available for golf course irrigation through a 'purple pipe' distribution system from a centralized treatment plant. The Heritage at Westmoor Golf Course in Colorado is supplied reclaimed water through the City of Westminster's 29 kilometers of distribution lines; the treatment plant was built in response to the city's ongoing drought and the populations' increasing potable water demand (Johnson 2007). Similarly, the Sand Creek Station Golf Course in Sand Creek Station, Kansas, is supplied with reclaimed water from the city's wastewater treatment plant to protect the groundwater levels and conserve potable water for the future demands (Houchen 2008).

Rainwater harvesting could supply 95% of the irrigation demands for the George Mason University soccer field. A system could be installed to collect the field house rooftop runoff with city water as backup when the rainwater supply is diminished. The rainwater collection could save the university an estimated $2,700 a month, or $10,800 a season (City of Fairfax Virginia 2008). Combined with the $2,000 savings through ET-based irrigation, the university could curb irrigation water expenditures at least $13,000 a season. However, payback for a rainwater system would be long based on the relatively low water cost in Fairfax.

Residential use of reclaimed water occurs on a limited scale, compared to golf course utilization. Orange County, Florida supplies reclaimed water for residential irrigation, which allows residents to irrigate their lawn without any time constraints (Orange County Florida 2008). Another city in Florida, St. Petersburg, also offers residential reclaimed water supplies for irrigation purposes. The city has four treatment plants that supply over 140 million liters of water a day to the over 10,000 users (City of St. Petersburg 2009).

Both Residence A and B are supplied by the City of Norfolk water utility. The water charge per hundred cubic feet (ccf) is $3.61, while the sewer charge per ccf is $2.89 (The City of Norfolk 2009). If rainwater was harvested at both Residence A and B, the cost savings would be estimated at $20 a month, which adds up to $80 during the four summer irrigation months for each residence. Due to the inexpensive water rates in Norfolk, the owner may never recoup the cost for installing a large belowground system, but smaller systems to supplement irrigation are feasible. Large belowground residential rainwater harvesting systems in Virginia are usually not installed to save money on water, but rather to promote environmentally responsible practices like reducing the reliance on drinking water and curbing stormwater runoff. Virginian residential rainwater harvesting systems are most economical when groundwater is no longer a reliable water source and municipal water supply is not available, but under these circumstances rainwater systems are primarily installed to supply the whole home with water. The cost of installing and operating a rainwater system is comparable to drilling a well (Grady and Younos 2008). However, if the Norfolk lawns were in the Southwest, the $80 savings would be close to a $1,200 savings and rainwater harvesting for irrigation purposes would be more economical (Throssell et al. 2009).

Using reclaimed water and/or harvested rainwater would not be feasible at the Virginia Tech Turfgrass Research Center. The 1,200 liters of reclaimed water resulting from hand washing in the maintenance building, could run the irrigation for13 minutes on one 185 q. m. research green with a 29.5 mm hr^{-1} precipitation rate. Likewise, the 18,170 liters available from rainwater harvesting could irrigate a 185 sq. m. research green for 3 hrs 24 minutes, assuming a 29.5 mm hr^{-1} precipitation rate. The most beneficial alternative water source that can be implemented at the Turfgrass Research Center is ET-based irrigation, once a preliminary study is conducted for the areas intended to be irrigated.

The George Mason University case study site offers a unique situation where the three alterative water sources discussed can be implemented (Fig. 5.18). The harvested rainwater (800,000 liters) can supply the washing machine (12,000 liters) and toilet flushing (145,000 liters) monthly demands with 157,000 liters of the total supply. The remaining 788,000 liters of rainwater can be applied as irrigation. In the field house, the 12,000 liters of rainwater supplied for the washing machines can then be recycled as greywater along with the 53,400 liters of water from showers and hand washing, which are supplied by the municipal potable water. The 53,400 liters of reclaimed water along with the remaining 643,000 liters of rainwater can be applied as irrigation. The original irrigation demand from Table 5.2 of 844,580 liters, adjusted by 35% per the ET irrigation research (Tucker 2009), results in a total of 549,000 liters of required irrigation. The remaining 143,400 liters of harvested rainwater could also be used to irrigate adjacent recreation fields. The use of the combined processes to supply the irrigation water could save the university an estimated $7,000 a season, based on the city's water usage charge (City of Fairfax Virginia 2008).

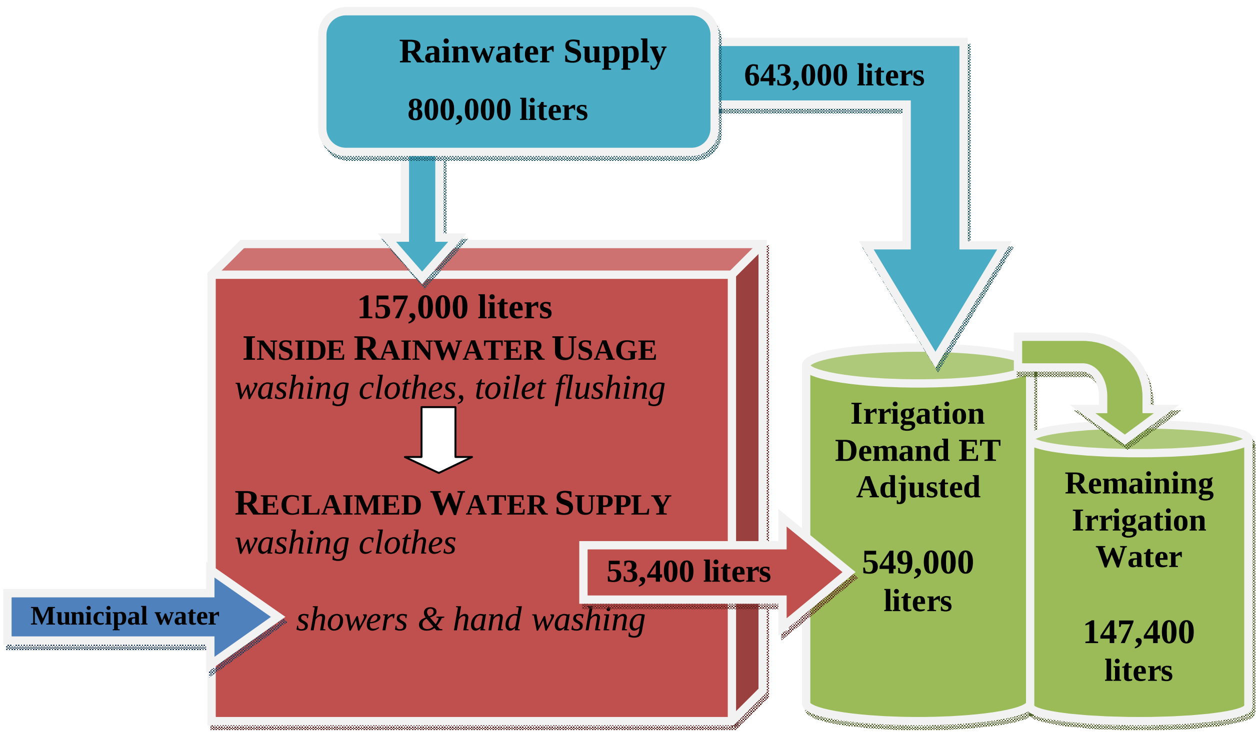

Fig. 5.18 Monthly water supply through harvested rainwater from the George Mason University field house and resulting reclaimed water to exceed the soccer field irrigation demand. Remaining rainwater and reclaimed water could supply additional recreational field irrigation needs.

Desalination in the eastern Virginia area has been previously investigated to provide an alternative drinking water supply (Foster and Smith 2004; Younos 2004). Desalination is a costly process, but the increasing populations in eastern Virginia make the alternative more appealing. Desalination is viewed as an alternative water source as it allows for the usage of seawater and/or brackish water to meet drinking water needs. However, using desalinated water for irrigation would not differ from using municipally supplied drinking water for irrigation and should not be considered as an alternative water source for irrigation purposes.

The four case study sites are very different in turfgrass maintenance practices, water usage and water collection and reuse potential. Alternative water sources like ET-based irrigation scheduling, reclaimed water and harvested rainwater have unique properties that may make them beneficial in certain applications. No one alternative water source will be suitable for all irrigation needs. When determining the most suitable alternative water source, the site could also be approached from a larger town, city or even watershed scale to determine the impact the alternative water source may have on surrounding water supplies.

A collaborative process could assist in determining which alternative water source is most feasible for the state or regional water supply plan based on the hydrology, environmental issues, comprehensive plan guidelines, and public opinion. The collaborative planning theory can be successful if all the stakeholders' opinions are integrated, which allows for consensus formation. Stakeholders are defined as all individuals or organizations that express an interest in, concern of, or impact from the subsequent plan (Selin and Chavez 1995). The collaborative process can be initiated by the local planning bodies to further investigate if efforts should be enacted to promote a particular alternative water use in the area, based on the collaborative consensus from the stakeholders, including water planners, engineers, land owners, land managers, local and neighboring governing bodies, and residents.

Landscape water supply plans can be integrated into state or regional water supply plans to assess current supplies and how reliance can be reduced, especially when the current water supply is potable water. Alternative water sources likes the ones discussed reduce potable water consumption, while maintaining landscape plant health, which is the ultimate goal of a landscape water supply plan. Reclaimed water and harvested rainwater require initial investment in equipment, while ET-based irrigation scheduling does not. Reclaimed water can potentially be the least laborsome practice, especially if supplied centrally, but the use of reclaimed water does have environmental and management impacts. When considering an alternative water source, the locale must be analyzed closely to determine which source is most feasible in terms on current water supplies, required resources, cost and maintenance needed to implement an alternative water source, and public opinion and willingness to adopt a new technology.

Conclusions

George Mason University could benefit from all three alternative water sources either independently or in conjunction. The nearby field house could supply collected rooftop runoff and greywater from showers, hand washing and washing machines and ET-based irrigation could curb irrigation water demand. The University could be an archetype for sustainable irrigation practices by installing dual rainwater and reclaimed water system to supply the needed recreation irrigation, while saving an estimated $7,000 a season on municipal water usage.

Residential lawns individually do not require enough water for large capacity rainwater harvesting or decentralized greywater treatment systems to be economically feasible in Norfolk, Virginia, where municipal water is inexpensive. However, a small capacity (190 - 4,000 liters) above ground rainwater system to meet some of the irrigation demand may be more economical. In areas where water is more expensive, the economics may make the large scale option that meets all irrigation needs more feasible. Most homeowners in Virginia install rainwater harvesting systems to have the option to irrigate during droughts and promote a sustainable lifestyle.

Williamsburg Country Club could curb its water use through ET-based irrigation practices. While the water conservation may not provide more water for potable means since the golf course uses an on-site pond for irrigation, it could save groundwater resources and offer nearby well withdrawers more water. Likewise, if the rooftop rainwater from the clubhouse is diverted to the pond, even more water could be conserved. Reclaimed water would be best supplied from a central treatment facility, of which none are planned in the area.

The Virginia Tech Turfgrass Research Center would not benefit from either rainwater harvesting or reclaimed water use due to the limited collection potential with the one small maintenance building on site. However, the Research Center is unlike any other case study site as it houses a weatherstation on the grounds that could provide precise ET demand data from which irrigation could be based.

All alternative water sources should be investigated on an individual site or town/city basis to ensure the source falls within the town or city's ideals for water conservation and environmental protection. Drinking water prices will continue to increase, which may be enough initiative for water users to consider alternative water sources to supply their nonpotable needs and conserve potable water resources.

References

(2005). "Chapter 780 - Local and Regional Water Supply Planning." 9 VAC 25-780, Richmond, VA.

(2008a). "Rainwater Harvesting Systems." 915.15, Richmond, VA.

(2008b). "Water Reclamation and Reuse Regulation." 9 VAC 25-740-10 et seq.

(2009). "Water Use Efficiency and Conservation Research Act." H.R. 631.

Asano, T., Leverenz, H. L., Leverenz, R., and Tchobanoglous, G. (2007). *Water Reuse: Issues, Technologies, and Applications*, McGraw-Hill, New York.

AWWA. (2001). *Water Resources Planning: Manual of Water Supply Practices*, American Water Works Association, Denver, CO.

AWWA. (2007). *Water Resources Planning: Manual of Water Supply Practices*, American Water Works Association, Denver, CO.

Bouwer, H. (2005). "Adverse Effects of Sewage Irrigation on Plants, Crops, Soil, and Groundwater." Water Reuse for Irrigation: Agriculture, Landscapes, and Turf Grasses, V. Lazarova and A. Bahri, eds., CRC Press, Washington, D.C., 235-263.

Carrow, R. N., and Duncan, R. R. (2000). "Wastewater and Seawater Use for Turfgrasses: Potential Problems and Solutions." Irrigation Association of Australia 2000, Melbourne, Australia.

City of Fairfax Virginia. (2008). "Water and sewer service rates." City of Fairfax, Fairfax, VA.

City of St. Petersburg. (2009). "Reclaimed Water." W. R. D. R. W. Division, ed., City of St. Petersburg, Florida, St. Petersburg, FL.

City of Williamsburg. (2006). "Chapter 11: Infrastructure." City of Williamsburg Planning Commission, Williamsburg, VA.

Clark, E. H. (2007). "Water Prices Rising Worldwide." Earth Policy Institute, Washington, D.C.

Commonwealth of Virginia. (2007a). "Governor Kaine announces federal disaster designations for 78 Virginia counties, 34 cities." Office of the Governor, Richmond, VA.

Commonwealth of Virginia. (2007b). "Governor Kaine encourages voluntary water conservation and calls on localities to update drought contingency plans." Office of the Governor, Richmond, VA.

Coombes, P. J., Dunstan, H., Spinks, A., Evans, C., and Harrison, T. (2006). "Key Messages from a Decase of Water Quality Research into Roof Collected Rainwater Supplies." 1st

National HYDROPOLIS Conference, Perth, Western Australia.

Daniels, T., and Daniels, K. (2003). *The Environmental Planning Handbook: for sustainable communities and regions*, Planners Press, Washington, DC.

Digiano, F. A., Weaver, C. C., and Okun, D. A. (2009). "Benefits of shifting fire protection to recalimed water." *Journal AWWA*, 101(2), 65-74.

Dzurik, A. A. (2003). *Water Resources Planning*, Rowman & Littlefield Publishers, Inc., New York, NY.

EPRI. (2002). "U.S. Electricity Consumption for Water Supply & Treatment - The Next Half Century." Electrical Power Research Institute, Palo Alto, California.

Erickson, M. C. (2004). "Reclaimed Water: Merits and Constraints as an Alternative Water Source." University of Georgia, Griffin, GA.

Evanylo, G. K., Ervin, E. H., Zhang, X., and Sukkariyah, B. F. (2007). "Water Reuse for Turfgrass Irrigation." Virginia Tech, Blacksburg, VA.

Fairfax City. (2004a). "Environment." Fairfax City Comprehensive Plan, Fairfax, Virginia.

Fairfax City. (2004b). "Public Facilities." Fairfax City Comprehensive Plan, Fairfax, VA.

Foster, L. M., and Smith, R. H. (2004). "JCSA - Letter of transmittal." James City Service Authority, Williamsburg, VA.

Grady, C., and Younos, T. (2008). "Analysis of Water and Energy Conservation of Rainwater Capture System on a Single Family Home." Virgina Water Resources and Research Center, Virginia Tech, Blacksburg, Virginia.

Haselbach, L. (2008). *The Engineering Guide to LEED - New Construction: Sustainable Construction for Engineers*, The McGraw Hill Companies, New York, NY.

Henken, K. (2000). "Ways to Limit Water Use to Forty Gallons per Day." *ENRI-126*, University of Kentucky, College of Agriculture, Cooperative Extension Service, Lexington, KY.

Houchen, J. H. (2008). "Developing the Infrastructure for Reclaimed Water at Sand Creek Station." Golf Course Superintendent Association of America, Lawrence, KS.

Houston, L. A. (2009). "Personal Communication: George Mason University Field House Traffic." Fairfax, VA.

Johnson, L. J. (2007). "Reclaimed Water Use at The Heritage at Westmoor Golf Course." Golf Course Superintendent's Association of America, Lawrence, KS.

Kennedy, L. A., and Tsuchihashi, R. (2005). "Is water reuse sustainable? Factors affecting its sustainability." *The Arabian Journal for Science and Engineering*, 30(2C).

Kinkade-Levario, H. (2007). *Design for Water: Rainwater Harvesting, Stormwater Catchment, and Alternate Water Reuse*, New Society Publishers, Gabriola Island, BC Canada.

Lady Bird Johnson Wildfower Center. (2001). .*Rainwater Harvesting*, The Lady Bird Johnson Wildflower Center, Austin, TX.

LaBranche, A., Wack, H.-O., Crawford, D., Crawford, E., Soyka, N. J., and Brand, C. (2007). *Virginia Rainwater Harvesting Manual*, The Cabell Brand Center, Salem, VA.

Lazarova, V., and Bahri, A. (2005). *Water Reuse for Irrigation: Agriculture, Landscapes, and Turf Grass*, CRC press, Washington, DC.

Martinez, R. "ScottsMiracle-Gro Survey of 1,235 U.S. Households " *Lawns, Gardens and the Environment Media Web Conference*.

National Weather Service. (2007). "2007 Climate Summary: Blacksburg." National Oceanic and Atmospheric Administration.

National Weather Service. (2008). "Baltimore Average Monthly Precipitation (since 1871)." National Oceanic and Atmospheric Administration.

Newport News Waterworks. (2006). "Water Conservation and Management Plan: 2006 Update." Newport News Waterworks, Newport News, VA.

Nodle, E. (2007). "Possibilities of rainwater utilisation in densely populated areas including precipitation runoffs from traffic surfaces." *Desalination*, 215.

Norfolk City Planning Commission. (1992). "General Plan of Norfolk." Norfolk, VA.

Orange County Florida. (2008). "Reclaimed Water." Orange County Government, Florida County of Orange, Florida.

Peterson, D. "Urban Rainwater Harvesting for Landscape Irrigation." *International Irrigation Show*, San Antonio, Texas.

Pushard, D. (2008). "Going Green is Building." Harvest H2O.com.

Sasaki Associates, and MMM Design Group. (2002). "George Mason University Master Plan." George Mason University, Fairfax, Virginia.

Selin, S., and Chavez, D. (1995). "Developing a collaborative model for environmental planning and management." *Environmental Management*, 19(2), 189-195.

Seymour, R. M. "Capturing rainwater to replace irrigation water for landscapes: rain harvesting and rain gardens." *Proceedings of the 2005 Georgia Water Rresources Conference*, Athens, GA.

Sheikh, B. (2005). "Codes of Practices for Landscape and Golf Course Irrigation." Water Reuse for Irrigation: Agriculture, Landscapes, and Turf Grasses, V. Lazarova and A. Bahri, eds., CRC Press, Washington D.C., 151-161.

Slack, E. V. (2000). "Maintaining superior landscapes on a water budget." Water Right: Conserving our water preserving our environment, International Turf Producers Foundation, Rolling Meadows, IL, 55-56.

Swancar, A. (1996). "Water Quality, Pesticide Occurrence, and Effects of Irrigation with Reclaimed Water at Golf Courses in Florida." United States Geological Survey, Tallahassee.

The City of Norfolk. (2009). "Water and Sewer Rate Information." Norfolk, VA.

Throssell, C. S., Lyman, G. T., Johnson, M. E., and Stacey, G. A. (2009). "Golf course environmental profile measures water use, sources, cost, quality, and management and conservation strategies." *Applied Turfgrass Science*, Online.

Town of Blacksburg. (2006a). "Environment: Preserving Blacksburg's Abundant Natural Resources." Blacksburg Planning Commission, Blacksburg, Virginia.

Town of Blacksburg. (2006b). "Utility Services: providing Safe, Reliable Services to Your Front Door." Blacksburg Planning Commission, Blacksburg, Virginia.

Tucker, A. J. L. (2009). "Case study: Irrigating based on evapotranspiration rate." Water Supply Planning for Landscape Irrigation in Virginia, Ph.D. Dissertation, Virginia Tech, Blacksburg, Virginia.

U.S. EPA. (2005a). "Decentralized Wastewater Treatment Systems: A Program Strategy." US Environmental Protection Agency, Washington, D.C.

U.S. EPA. (2005b). "Handbook for Managing of Onsite and Clustered (Decentralized) Wastewater Treatment Systems: An Introduction to Management Tools and Information for Implementing EPA's Management Guidelines.", U.S. Environmental Protection Agency, Washington, D.C.

U.S. Water News Online. (2008). "As supplies dry up, growers pass on farming and sell water." U.S. Water News Online.

University of Michigan. (2008). "U.S. Water Supply and Distribution Factsheets." University of Michigan, Center for Sustainable Systems, Ann Arbor, Michigan.

University of Virginia. (2000). "Virginia potential evapotranspiration, annual precipitation, and annual precipitation minus potential evapotranspiration." University of Virginia

Climatology Office, Charlottesville, VA.

Virginia Tech. (2008a). "Insights from Discovery Phase." Master Plan Update, Virginia Tech, Blacksburg, VA.

Virginia Tech. (2008b). "Turfgrass Irrigation Scheduling." Virginia Polytechnic Institute and State University, Blacksburg, VA.

Water Management Committee. (2005). "Landscape Irrigation Scheduling and Water Management." Irrigation Association, Falls Church, VA.

Whitmire, J. (2009). "Personal Communication: Williamsburg Country Club Traffic." Williamsburg, VA.

Womack, R. (2009). "Rainwater irrigation." *Superintendent*(March).

Younos, T. (2004). "The Feasibility of Using Desalination to Supplement Drinking Water Supplies in Eastern Virginia." Virginia Water Resources Research Center, Virginia Polytechnic and State University, Blacksburg, VA.

APPENDIX

Appendix 1: 2006 Survey Questions

Virginia Turfgrass Water Planning

This survey is designed to determine the turfgrass clientele that would use a proposed website, which would utilize climate data from weatherstations throughout the state to determine irrigation requirements.

ABOUT YOU

1. What part of the turfgrass industry do you work in? (check all that apply)

○ Golf course ○ Athletics ○ Residential ○ Sod production

2. What is your job title?

____

3. Do you have Internet or email?

○ Web browsing ○ Email ○ Both ○ Neither

4. Which description explains your Internet and email use?

Web browsing	*Email*
○ I rely on it heavily to access information	○ I rely on it heavily to communicate
○ I use it only occasionally	○ I use it when I can not reach someone directly
○ I use it as a backup source of information	○ I use it only when absolutely necessary
○ I never use it	○ I never use it

ABOUT YOUR IRRIGATION PRACTICES

5. To what extent do you control the irrigation at your site(s)?

○ All ○ Some ○ None

5b. *If applicable*, how do you determine your irrigation schedule?

____

6. How often do you irrigate?

Golf course: Indicate any scheduling differences in greens, tees, fairways and roughs.

____

____

7. What is your water source?

○ Surface water ○ Groundwater ○ Unknown

WATER CONSERVATION IN VIRGINIA

8. Are you aware of weatherstation weather data available online from Virginia Tech's Agriculture, Human and Natural Resources Information Technology (AHNRIT)?

○ Yes ○ No

8b. If *Yes:* To what extent have you used the information?

○ Very little ○ Slightly ○ A lot

Why? Why not?

____

9. To what extent does your business/field/course attempt to conserve water?

○ Little attempt ○ Slight attempt ○ Considerable attempt

9b. Explain your conservation efforts:

____

10. On the following scale, how important do you think water conservation is in Virginia?

○	○	○	○	○
unimportant		moderately important		very important

WEBSITE

11. How likely would you be to access a website like the one described above to determine your irrigation scheduling under **normal climatic** conditions?

○	○	○	○	○	○
very unlikely		somewhat likely		very likely	Not applicable to me

Why? Why not?

____

12. How likely would you be to access a website like the one described above to determine your irrigation scheduling if the state was under **severe drought** conditions?

○	○	○	○	○	○
very unlikely		somewhat likely		very likely	Not applicable to me

Why? Why not?

____

13. On the following scale, how likely would you be to access a website to determine your irrigation scheduling if it was designed for and by turfgrass managers?

○	○	○	○	○	○
very unlikely		somewhat likely		very likely	Not applicable to me

CONTACT INFORMATION

14. Would you be willing to be contacted for further input in the website creation process?

If *Yes*, please enter information below

____
Name

____
Address City, State, Zip

____
Phone Email

Which method do you prefer to be contacted by?

○ Phone
○ Email
○ Postal mail

Thank you for your help!

Appendix 2: 2007 Survey Questions

Virginia Turfgrass Water Planning

This survey is designed to determine the turfgrass clientele that would use a proposed website, which would utilize climate data from weatherstations throughout the state to determine irrigation requirements.

About You

1. What part of the turfgrass industry do you work in? (check all that apply)
   ○ Golf course ○ Athletics ○ Residential ○ Sod production

2. What is your job title?

   ____

3. Do you have Internet or email?
   ○ Web browsing ○ Email ○ Both ○ Neither

4. Which description explains your Internet and email use?

Web browsing	*Email*
○ I rely on it heavily to access information	○ I rely on it heavily to communicate
○ I use it only occasionally	○ I use it when I can not reach someone directly
○ I use it as a backup source of information	○ I use it only when absolutely necessary
○ I never use it	○ I never use it

About Your Irrigation Practices

5. To what extent do *you* control the irrigation at your site(s)?
   ○ All ○ Some ○ None

6. How often do you irrigate?
   Golf course: Indicate any scheduling differences in greens, tees, fairways and roughs.

   ____
   ____

7. What is your water source?
○ Surface water ○ Groundwater ○ Unknown

Water Conservation in Virginia

8. Are you aware of weatherstation weather data available online from Virginia Tech's Agriculture, Human and Natural Resources Information Technology (AHNRIT)?
   ○ Yes ○ No

8b. If *Yes:* To what extent have you used the information?
   ○ Very little ○ Slightly ○ A lot

9. To what extent does your business/field/course attempt to conserve water?
   ○ Little attempt ○ Slight attempt ○ Considerable attempt

9b. Which of the following conservation practices do you utilize? *(Check all that apply)*

O Schedule based on weather	O Have updated and efficient irrigation heads
O Schedule based on evapotranspiration data	O Do irrigation audits
O Monitor soil moisture	O Using wetting agents
O Irrigate when turf is wilted	O Educational efforts
O Other ______________________	

10. On the following scale, how important do you think water conservation is in Virginia?

O O O O O

unimportant — moderately important — very important

Website

11. How likely would you be to access a website like the one described above to determine your irrigation scheduling under normal climatic conditions?

O O O O O O

very unlikely — somewhat likely — very likely — Not applicable to me

Why? Why not?

____

12. How likely would you be to access a website like the one described above to determine your irrigation scheduling if the state was under severe drought conditions?

O O O O O O

very unlikely — somewhat likely — very likely — Not applicable to me

Why? Why not?

____

13. On the following scale, how likely would you be to access a website to determine your irrigation scheduling if it was designed for and by fellow turfgrass managers?

O O O O O O

very unlikely — somewhat likely — very likely — Not applicable to me

CONTACT INFORMATION

14. Would you be willing to be contacted for further input in the website creation process?

If *Yes*, please enter information below

____
Name

____
Address — City, State, Zip

____
Phone — Email

Which method do you prefer to be contacted by?

O Phone
O Email
O Postal mail

Thank you for your help!

Appendix 3: 2008 Website Survey Questions

Irrigation Website

Virginia ET Irrigation Website Focus Group This survey is to gain your opinion of the ease of use and usefulness of two prototype websites. Please navigate the two websites first. They are available at http://filebox.vt.edu/users/alabranc/index.html
Is there one website and all its components you preferred over the other?

☐ Website 1

☐ Website 2

☐ Did not prefer one over the other

How useful do you feel the content contained in the websites is?

☐ Not useful ☐ Slightly useful ☐ Very useful

How easy was WEBSITE 1 to navigate?

☐ Not easy ☐ Slightly easy ☐ Very easy

How easy was WEBSITE 2 to navigate?

☐ Not easy ☐ Slightly easy ☐ Very easy

Which website design did you prefer when assessing irrigation needs for a warm vs. cool season turf?

☐ Website 1 (table)

☐ Website 2 (drop down menu)

☐ Neither

Which weatherstation selection design did you prefer?

☐ Website 1 (map only)

☐ Website 2 (map and drop down menu)

☐ Neither

Which data length of time selection did you prefer?

☐ Website 1 (14 - 3 day summary)

☐ Website 2 (select start date)

☐ Neither

Which additional components would you like to see on the website?

- [ ] Email messages with ET data
- [ ] Text messages with ET data
- [ ] How to Conduct an irrigation audit
- [ ] Water conservation tips
- [ ] Research data
- [ ] Discussion board

Other: ______

Do you have any other feedback that was not included in the survey questions?