THE ROLE OF CHOICE ARCHITECTURE IN TOILET DESIGN:

A BEHAVIORAL ECONOMICS APPROACH TO WATER CONSERVATION

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by
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The undersigned, appointed by the Dean of the Graduate School, have examined the thesis entitled:

THE ROLE OF CHOICE ARCHITECTURE IN TOILET DESIGN:
A BEHAVIORAL ECONOMICS APPROACH TO WATER CONSERVATION

Presented by Jade Arocha

A candidate for the degree of Master of Science

And hereby certify that in their opinion it is worthy of acceptance.

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To my family, whose love and support have helped me through
every step of this long and incredible journey.

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ABSTRACT

Fresh water is a renewable, but finite, and increasingly scarce resource. In many regions, fresh water supplies are already exploited to the fullest extent possible. Thus, strategies to reduce water consumption are becoming ever more important in order to minimize future water shortages. One such approach is to focus upon the publicly supplied sector of water use, which includes households and also large-scale commercial and industrial enterprises such as schools, hospitals, airports, and private firms. If such enterprises were to implement water-saving appliances and fixtures on a large scale, substantial water savings could be realized.

One such water-saving appliance is the dual-flush toilet, which uses a high-volume flush for solid waste and a lower-volume flush for liquid waste. However, due to the high level of variation between different dual flush models, some are far more comprehensible to the user than others. This thesis uses the principles of behavioral economics, which studies human behavior and decision-making, in order to determine whether the design of the dual flush mechanism can lead the user to make the incorrect ‗choice‘ and thus waste water. A field experiment performed in the public restrooms of a municipal building in Columbia, Missouri definitively showed that in the case of one particular model of dual flush toilet, the Sloan Uppercut®, water usage was considerably higher than the manufacturer‘s projections. This was due to the fact that the default option, pushing the flush handle down, resulted in a large flush. While Sloan predicted a 2:1 urination-to-defecation (U/D) flush ratio, the observed ratio during the control period was roughly 1:4. The treatment period consisted of adding multiple signs to each stall that instructed users on how to use the toilets correctly; however, even with signs added, the U/D ratio only increased to 2:5. The implications of this research are that if water savings are to be fully maximized, the ‗real-world‘ actions of users must be taken into account. These results are of particular relevance in areas where water is especially scarce and/or costly.

CHAPTER 1: INTRODUCTION

Water is essential to all life on earth. According to a 2010 World Bank report on global climate change, while more than two-thirds of the earth‘s surface is covered by water, 99% of that water is either unsuitable or unavailable for human use. Over 97% of the global water supply is contained in oceans and is therefore saline; only the remaining 2.5% is fresh water. Roughly 70% of this is trapped in glaciers and ice caps, and only 0.4% of fresh water is found on the earth‘s surface or in the atmosphere. The remaining 30% of freshwater is located underground in aquifers (World Bank 2010). Therefore, while water may appear to be an abundant, renewable natural resource, its supply is finite. In the United States, the vast majority of water consumed by an individual is limited to domestic uses such as drinking, showering, bathing, laundry, and using the toilet (DOE 2001). Clean water is obviously critical for human health and sanitation, but it is also used in a wide variety of large-scale applications, including agricultural irrigation, industrial manufacturing, and hydroelectric power generation. As the global population grows, so does the demand for fresh water. Considering its finite supply, new and improved methods of conservation will be needed on an increasing scale to minimize water consumption if there is to be enough to go around in the future.

The increasing scarcity of freshwater is obviously a problem, but exacerbating that scarcity is the fact that there is also a general lack of incentives to conserve water. As such, it makes sense that parties interested in reducing the general population‘s aggregate water use have focused on two main areas: one, educating the public on the importance of water conservation and on methods of doing so; and two, developing fixtures that consume less water. This thesis focuses upon the latter approach, and how the design of water fixtures, and dual flush toilets in particular, can affect the overall amount of water used and/or saved.

1.1 Justification for research

Technological innovation is paramount to improving the eco-efficiency of water-consumptive domestic appliances and fixtures. It is important to note that the majority of the energy and water consumption of these appliances occurs in the use and/or operation stage (Morelli 2001). With this in mind, water-efficient fixtures such as dual flush toilets can be a valuable asset in water-scarce regions both in the United States and abroad. When the projected effects of climate change and population growth are also accounted for, the need for increased water conservation by households and firms becomes quite evident. It therefore makes sense to not only encourage the installation and use of these water-saving toilets, but to ensure that the design of such toilets is as water-efficient as possible. It is not sufficient that the toilet be designed to reduce water consumption; it is also imperative that its dual flush mechanism is clearly marked and easy for the user to operate correctly. In other words, in order for the water savings to be fully realized, it is imperative that the behavior of the user is taken into account. With these factors in mind, this research project will: a) test the hypothesis that the design of the flush mechanism on a dual flush toilet has a significant effect on human behavior and thus water usage; b) examine the effect of instructional signage on the use of the toilet; and c) provide quantifiable data on exactly how much water can be saved by improving this design to account for the user‘s default behavior. Finally, an analysis of the relative cost advantages of dual flush toilets will be performed in order to determine what economic benefit, if any, results from using a dual flush toilet versus a traditional one when user behavior is taken into account. This is necessary because while conserving water is a laudable goal in and of itself, most decision makers will not choose to do so unless it produces a neutral or positive financial result for them.

The focus of this project: ‘Intelligent Design’

Reducing the need for water is an essential component of demand-side strategies to address water scarcity (in contrast to supply-side strategies, which attempt to locate and utilize new water sources). The particular emphasis that this project places upon user choice and behavior provides a new and needed perspective to the existing body of literature. Additionally, it is hoped that if this project demonstrates the capacity to save water with a simple change in toilet design, then this study will provide an incentive for decision-makers in commercial and industrial firms to either retrofit existing toilets or install toilets that are designed to be more water-efficient. Finally, because decision-makers may choose to do so not only because of environmental concerns but also to reduce costs, the study results are likely to have the most impact in regions where water is relatively expensive and/or scarce.

1.2 Organization of thesis

This thesis is organized to initially provide the reader with a clear understanding of the background issues related to the research question. Thus, Chapter 2 is a literature review of water scarcity issues, opportunities for water conservation, water laws and policies in the United States, different types of toilets, and a survey of behavioral economics. Chapter 3 describes the conceptual framework of the research project and the characteristics of natural field experiments, while Chapter 4 provides a step-by-step explanation of each stage of the research trial. Chapter 5 presents and analyzes the results of the trial. Finally, Chapter 6 concludes this thesis and offers suggestions for further research.

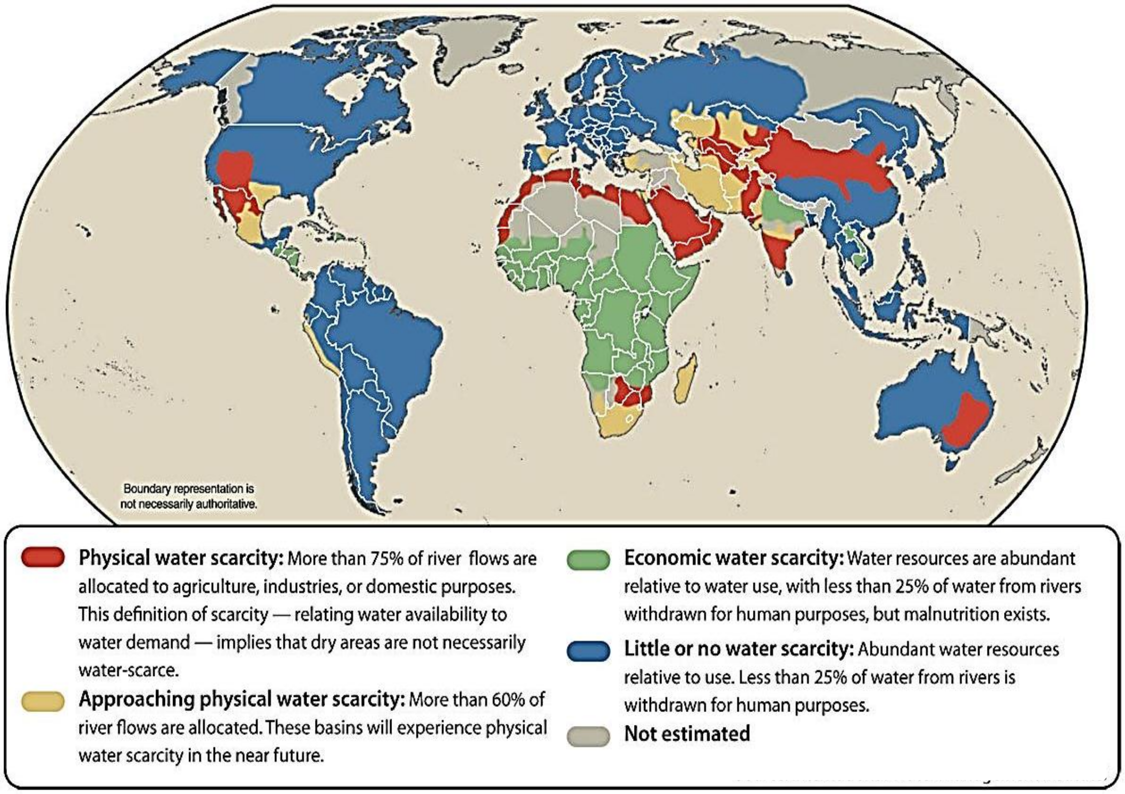
CHAPTER TWO: BACKGROUND AND REVIEW OF LITERATURE

2.1 Water scarcity issues in the U.S. and abroad

Water may appear to be a plentiful resource, and indeed, it is a renewable one. However, its supply is finite, and water is becoming increasingly scarce for a variety of reasons. The problems associated with water use and allocation vary widely depending on the characteristics of the region in question. In some water-abundant areas of the world, water issues tend to involve the maintenance of water *quality* (as opposed to water *quantity*), water storage, and problems with runoff and erosion (Tietenberg 2006). In water-scarce areas, the simple act of acquiring enough water to go around can be a major challenge.

In any case, it is important to understand that whether rich or poor, whether water-abundant or water-scarce, every region and country in the world faces water problems in one form or another. These problems will only become more pronounced as the global population increases—and with it, the need for fresh, clean water. Figure 1 below illustrates the predicted future divergence between supply and demand. A 1999 study by the International Water Management Institute predicted that 1/4 of the entire world population and 1/3 of the population in developing countries, or 1.4 billion people, would face severe water scarcity by the year 2025 (Seckler, Molden, and Amarasinghe 1999).

Figure 1: Projected global water scarcity, 2025



🟥 **Physical water scarcity:** More than 75% of river flows are allocated to agriculture, industries, or domestic purposes. This definition of scarcity — relating water availability to water demand — implies that dry areas are not necessarily water-scarce.

🟨 **Approaching physical water scarcity:** More than 60% of river flows are allocated. These basins will experience physical water scarcity in the near future.

🟩 **Economic water scarcity:** Water resources are abundant relative to water use, with less than 25% of water from rivers withdrawn for human purposes, but malnutrition exists.

🟦 **Little or no water scarcity:** Abundant water resources relative to use. Less than 25% of water from rivers is withdrawn for human purposes.

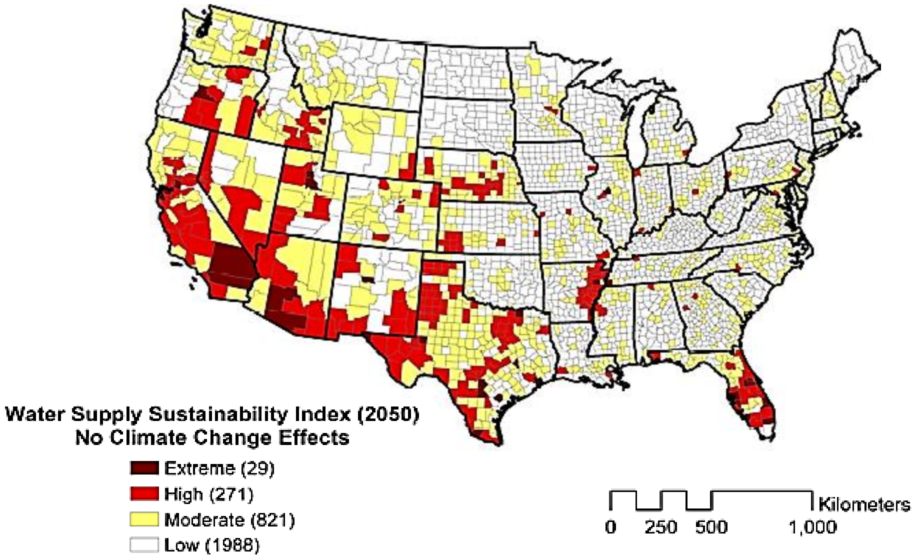
⬜ **Not estimated**

Source: National Intelligence Council 2008. Adapted from International Water Resources Council 2007

Although water scarcity is of particular concern in developing countries, even industrialized nations such as the United States face water shortages due to increasing demand from a growing population and a fixed (or in some cases, decreasing) supply. Note in figure 1 above that predicted future scarcity will affect not only developing regions such as northern Africa, southern India, and northern China, but also developed regions such as eastern Australia and the American southwest. These shortages are only predicted to worsen with time, although actual projections vary depending upon the extent to which climate change is accounted for. Roy et al. (2010) used historical USGS water census data for freshwater withdrawals, hydroelectric power withdrawals, population increases, and changes in precipitation and temperature to create the Projected

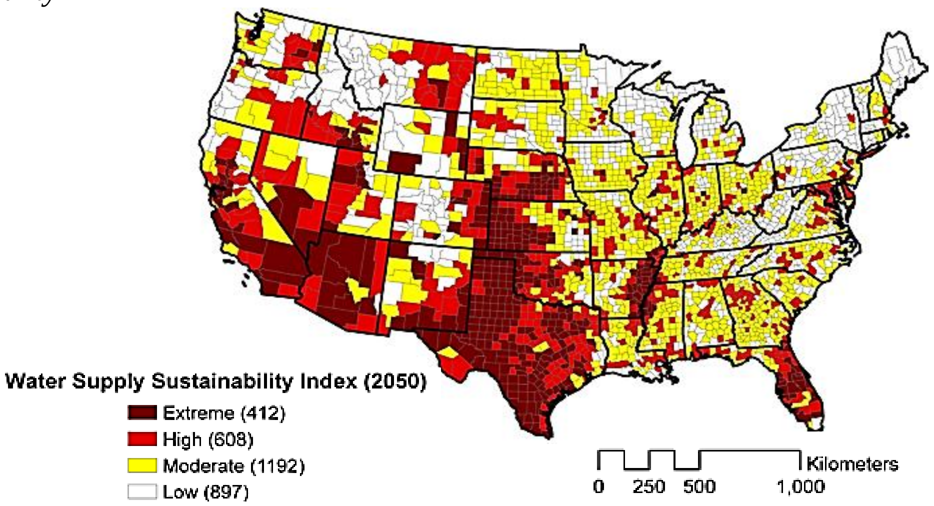
Water Sustainability Supply Index, which is illustrated in figures 2 and 3 below. Figure 2 ignores climate change projections, while figure 3 demonstrates water supply risk under the assumption of climate change. The numbers in parentheses in the legends are the total number of counties in each risk category.

Figure 2: Risks to water sustainability in 2050 with no climate change, by U.S. county



Source: Roy et al. 2010

Figure 3: Risks to water sustainability in 2050 using projected climate change, by U.S county



Source: Roy et al. 2010

It is important to note that the risk of water scarcity is significant under *both* assumptions, especially in the southwestern and western United States. Also, even areas which have, on average, a sufficient supply of water over the course of a year often find that water demand varies dramatically depending on the season, temperature, and drought conditions. Finally, regions which are generally considered to be water-abundant may still lack sufficient quantities of clean or potable water. While climate change remains a fiercely debated topic in the realm of public discussion, the U.S. government considers it enough of a threat to have appointed an ―Interagency Climate Change Adaptation Task Force" to draft action plans addressing the various effects of climate change. One such plan, *Priorities For Managing Freshwater Resources in a Changing Climate*, enumerates the primary challenges associated with water availability and offers recommendations to address them (ICCATF 2011). Thus, the need for a reduction in water use is clear; what is less clear is the extent to which water use will need to be curtailed. In any case, the design of water fixtures in the future, including toilets, must necessarily become increasingly water-efficient in order to conserve the dwindling supply.

2.2 Water quality issues

Minimizing the water usage of fixtures and appliances (such as in dual flush toilets) can help address issues of water quantity. However, this can also affect issues of water quality. The former is fairly self-explanatory: the less water a toilet utilizes per flush, the less water is removed from the public water supply and therefore remains in the local ecosystem. This may be of little interest to the inhabitants of water-rich regions, but the impacts on water quality affect all water users no matter their level of concern for water conservation. In societies with modern plumbing and water treatment facilities, raw sewage is treated and the effluent released back into a local water body, which may be a river, reservoir, aquifer, or the like. The quality of the effluent depends on the degree to which the waste has been treated, as shown in Table 1 below.

Table 1: Stages of wastewater treatment in the United States

Level of Treatment	Preliminary	Primary	Secondary	Industrial Pretreatment	Tertiary
Substances removed	Large objects such as rocks, cans, bottles	Course solids such as grit and sand, or anything larger	Biodegradable organic matter (including feces)	Heavy metals, VOCs, chemicals	Varies; includes nitrogen, phosphorus, carbon
Method	Heavy grates and screens	Screens and sedimentation	Biological agents such as bacteria, algae, and other microorganisms	Varies; includes reverse osmosis, deionization	Varies; includes biological agents, minerals, sedimentation
Is treatment required by law?	No; facilities may voluntarily include this stage	Yes	Yes	No; firms must comply with regional requirements	No

Source: Adapted from EPA 2004

Stages higher than secondary

The key idea here is that even treated wastewater may contain traces of chemicals, pathogens, and a number of other toxic substances. Although the EPA states that –secondary treatment processes can remove up to 90 percent of the organic matter in wastewater”, it is unclear what happens to the remaining 10 or more percent that is left behind (2004, p.11). Furthermore, only about 30 percent of all wastewater facilities in the U.S. utilize any higher level of treatment beyond secondary (the gray-shaded area in Table 1)[1]. Because each level of treatment can be quite costly, municipalities can save money on water treatment, and even delay the need for construction of additional

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[1] It should be noted here that disinfection, which is the process of killing or deactivating microorganisms and pathogens through the use of chlorine, ozone, or ultraviolet radiation (EPA 2004), occurs after wastewater is treated and before it is returned to the public supply; therefore, it is not considered to be a stage in the wastewater treatment process described above.

treatment facilities, by minimizing water use. This is especially important as population growth places additional strain on aging and overtaxed sewer systems (EPA 2004). Thus, even consumers who are unconcerned with issues of water quantity are likely to want to reduce water usage in areas where the costs of treating water are high.

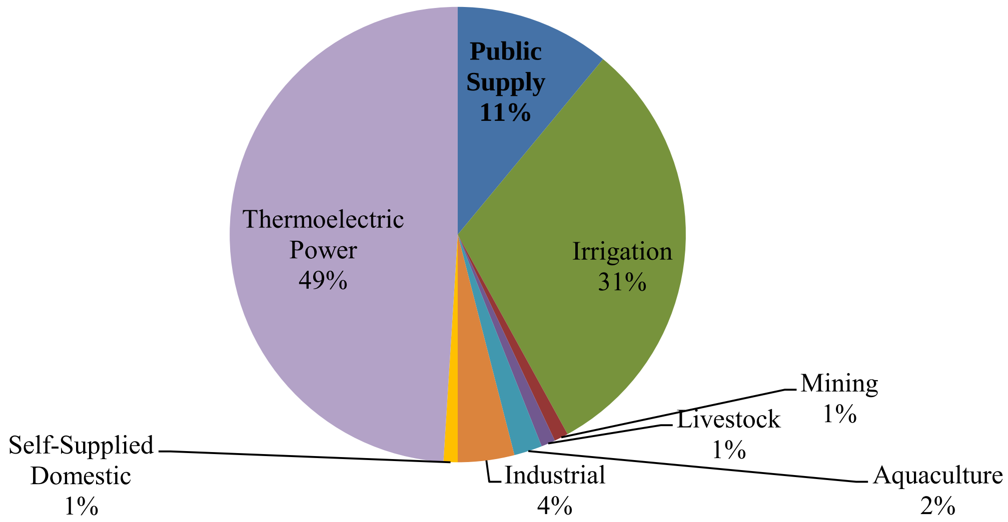
Finally, while this point may be self-evident, it is vital to understand that wastewater treatment affects not only the quality of water used for human consumption, but also the health of local freshwater ecosystems. According to a special report by the *Economist*, nearly 40% of sewer systems in the United States illegally contaminated freshwater systems with untreated sewage in the period 2007-2009, and 40% of the entire U.S. supply of fresh water is estimated to be heavily polluted (Grimond 2010). The goods and services provided by these ecosystems include, but are not limited to, ―biodiversity, flood control, climate regulation, water filtration, recreational opportunities, and cultural benefits”, and their collective importance cannot be overstated (Conca 2008, p. 218).

2.3 Allocation and uses of publicly supplied water

One of the primary challenges in evaluating strategies to address water scarcity issues is that consistent, up-to-date data on water usage can be difficult to obtain. In this country, the United States Geological Survey (USGS) is responsible for aggregating and analyzing information on water, but many researchers acknowledge that data collection with regard to the end uses of water is far from adequate. According to Peter Gleick, a well-respected researcher in the field, ―far fewer data are collected on water use than on water supply and availability. Domestic water use is often not measured directly, and details on how that water is used are rarely collected" (2003, p. 281). Comprehensive data are even rarer for the commercial sector. The Water Resources Council, a Denver-based research organization, acknowledges the information-gathering efforts of the USGS but maintains that ―despite the substantive proportion of total urban water use for [commercial and institutional] customers, comparatively little attention has been focused on the water usage of this sector" (AWWRA 2000, xix). Even though data may not be precise, it is nonetheless important to provide a brief overview of the end uses of publicly-supplied water in order to estimate the relevance of this research project to real-world conditions.

A breakdown of total water withdrawals in the United States is shown in figure 4 below. Water classified by the USGS as ―public supply", which aggregates domestic (household), commercial, and industrial water usage that is not used in manufacturing and/or production processes, accounts for, on average, about 11% of total water withdrawals in the United States (USGS 2005). Another 1% of total water withdrawals are referred to as ―self-supplied domestic" and usually refer to homeowners that utilize wells or surface water. Note that the percentages shown below are average *national* withdrawals; these numbers may vary widely in specific states and/or regions.

Figure 4: Total water withdrawals in the U.S. by sector[2]



Source: Adapted from USGS 2005

It should be observed here that according to USGS terminology, ―water withdrawal" refers to the total amount of water withdrawn from the source without regard to whether its end use is consumptive or non-consumptive. Domestic water use specifically refers to ―indoor and outdoor uses at residences" and accounts for less than 10% of public supply. Figure 5 shows the estimates of domestic water use by the EPA's WaterSense program, which attempts to reduce domestic water consumption through public outreach, education, and incentives.

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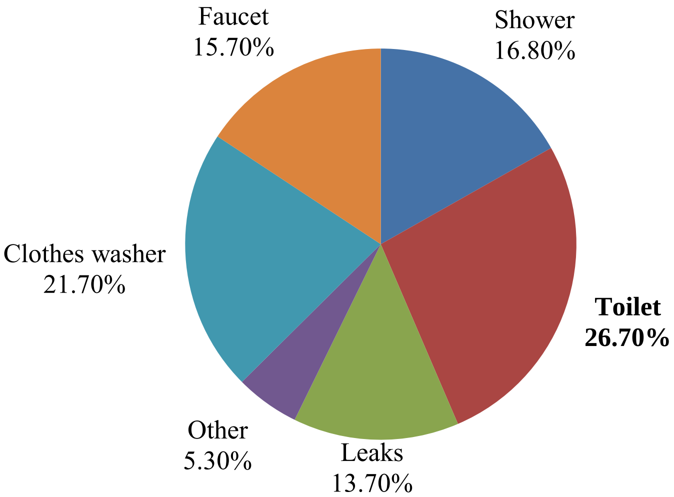
[2] According to the USGS (2005), ―Water for thermoelectric power is used in generating electricity with steam-driven turbine generators." Most commonly, thermoelectric power generation involves coal, natural gas, and nuclear power plants that use water for cooling purposes (Brown 2000). This water use is consumptive to varying degrees depending on the specific cooling processes it is used for; some processes are far more consumptive than others. Thermoelectric power should be distinguished from hydroelectric power in that the USGS considers hydroelectric power to be a non-consumptive ―in-stream use" (2005). Thus, the agency does not include hydroelectricity generation in their calculations of water use.

Figure 5: Residential end uses of water

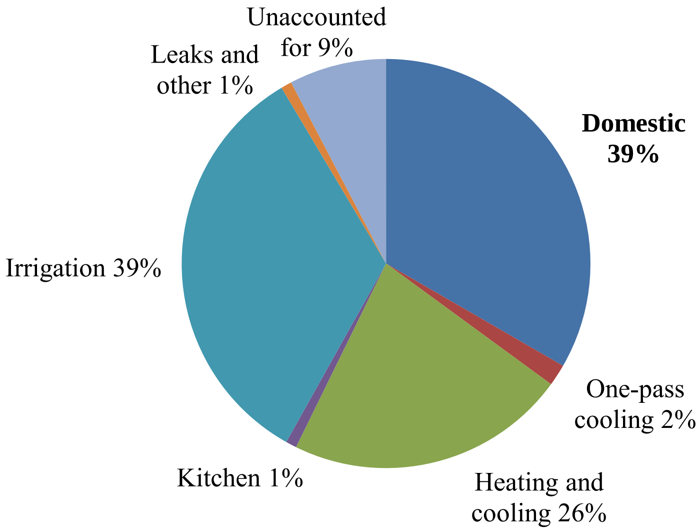


Source: EPA WaterSense 2008. Adapted from AWWRA 1999

On average, most Americans use about 80-100 gallons of water per day, and about 70 percent of that water is used inside the home (USGS 2010; EPA WaterSense 2008). Toilets are the most consumptive water fixture in the home and consume approximately 27% of all water used indoors; thus, improved water efficiency in toilets represents a significant opportunity for residential water savings, as figure 5 demonstrates.

As previously noted, there is considerably more data available for domestic water consumption than for commercial or industrial, which comprises the remainder of public supply. If roughly 10% of the amount of water used in public supply is attributed to domestic use, one may surmise that the remaining 90% is consumed by commercial and industrial firms (USGS 2005). This category also includes water withdrawals by large institutional establishments such as hospitals, universities, government offices, and airports. Due to the methods by which water data are collected and the enormous range of water needs among these types of firms, the actual amount of water consumed exclusively by toilets in commercial and industrial firms is difficult to estimate accurately, though estimates do exist. One such approximation, illustrated in figure 6 below, depicts the average end uses of water in commercial buildings in the United States. The ―domestic” category euphemistically refers to water consumed in restrooms, i.e. toilets, faucets, and showers.

Figure 6: Water use in commercial buildings



Source: U.S. Department of Energy 2001

One of the most comprehensive studies to date on the commercial/institutional (CI) subsector of public supply was performed by the American Water Works Research Foundation in 1999 and paid special attention to the complexity of amassing and analyzing data in this sector. The authors repeatedly characterize the firms that comprise this sector as ―heterogeneous customers with highly variable use” (AWWRF 2000, xix). Importantly, the study also notes that CI water use varies widely not only among firms but also across regions. Although the USGS data displayed earlier in figure 4 shows *total*

U.S. public supply withdrawals at 11% of the total, the AWWRF study claims that roughly 25% of withdrawals in *urban* areas are attributed to public supply. It follows that if maximizing total water savings is the primary goal, further research would be most effectively directed toward the commercial and institutional (CI) sector rather than the domestic portion of publicly supplied water. Special emphasis on urban water projects should be considered due to their relatively higher proportion of public water withdrawals.

In general, water conservation and allocation efforts are far easier to consider in theory rather than to implement in practice. In the United States, due to water laws and policies that are highly variable at the state, county, and/or municipal level, specific recommendations to increase water conservation efforts can be difficult. The next section of this literature review provides an overview of the issues associated with formal and informal water institutions, both in this country and in others.

2.4 Water legislation and institutions

A comprehensive and in-depth survey of water laws and institutions in the United States would be an enormous undertaking in and of itself. However, a brief explanation of the structure of water laws in this country—and in others—provides an understanding of the *supply*-side issues of water allocation (as opposed to *demand*-side issues, one approach to which is to improve the water efficiency of fixtures). This section will illustrate that due to the complexity and frequent ineffectiveness of laws and policies designed to allocate existing water supplies, strategies to reduce water consumption (such as the research performed in this thesis) may be more effective at solving water-related issues, especially in the short term.

Water scarcity and the price mechanism

Before providing a detailed explanation of water laws, it is important to understand why government intervention is necessary to allocate water. If the price of a private good increases, traditional economic theory holds that quantity demanded of that good will decrease, *ceteris paribus*. In contrast to private goods, which are allocated by the market and Adam Smith‘s ‗invisible hand‘, water is typically classified as a common-pool or open access resource (Hanley, Shogren, and White 2007; Ostrom 1990). Common-pool resources are defined as ―natural or man-made resources where exclusion is difficult, and yield is subtractable" (Ostrom and Gardner 1993, p. 93, citing Gardner, Ostrom, and Walker 1990). The market for water represents a market failure, which occurs when the market allocates resources inefficiently and therefore fails to optimize social welfare (Hanley, Shogren, and White 2007). Baxtresser (2010, pp. 774-775) stresses the fact that ―as a commodity, water has the potential to be sold as a natural resource for a price much higher than most Americans pay today."

Government intervention is thus necessary because water has the characteristics of a common-pool resource and is usually priced far below its actual value. These and other factors lead to the eventual overuse of water supplies. Other economic goods have markets that determine an equilibrium price and quantity. However, due to the classification of water as a common-pool resource rather than a private good, the determination of a ‗correct,‘ welfare-maximizing market price for water can be difficult, if not impossible. In the case of water, institutions (rather than markets) have been developed in order to determine an acceptable level of water withdrawal and also to ensure that all users ―follow the rules” in order to keep withdrawals at that level. A brief explanation of institutions is provided in the next section.

Formal vs. informal water institutions in the United States

As defined by Easter and McCann (2010), institutions ―set the rules for using water […] but exclude the organizations which manage it. […] Institutions include the laws and regulations that guide the water organizations in their operations” (p. 501). Due to the fact that groundwater, surface water, and watersheds all interact in ways that may be difficult to observe or quantify, institutions that treat them as wholly separate resources may be ineffective. Additionally, the more scarce water is, the more complex water institutions must be to address that scarcity (Easter and McCann 2010). This is one reason why institutions governing water need to evolve as supply, demand, technology, and other factors do.

Because legal and political systems affect the feasibility of institutions, states with different legal frameworks regarding water rights would naturally be expected to have different institutional structures. While there are many potential causes for institutional failure, an institution that is at odds with local laws, or even local value systems, is especially likely to fail. Easter and McCann give ―poor water distribution and system maintenance at the local level” as primary examples of the effects of failing institutions (p. 507). A specific example is the Tennessee Valley Authority (TVA), a government initiative created to plan and manage water resources. While the TVA project itself has been successful, similar attempts at water resources management in the U.S. have failed due to ―political opposition by existing government agencies and utility companies" (Easter and McCann, 2010, p. 502). In sum, it is very important for institutions to recognize and support the incentives of water users in order to be successful. As the following subsections will demonstrate, formal water institutions at the state and local levels usually fail to take these incentives into account.

Surface water laws by state: riparian rights vs. prior appropriation

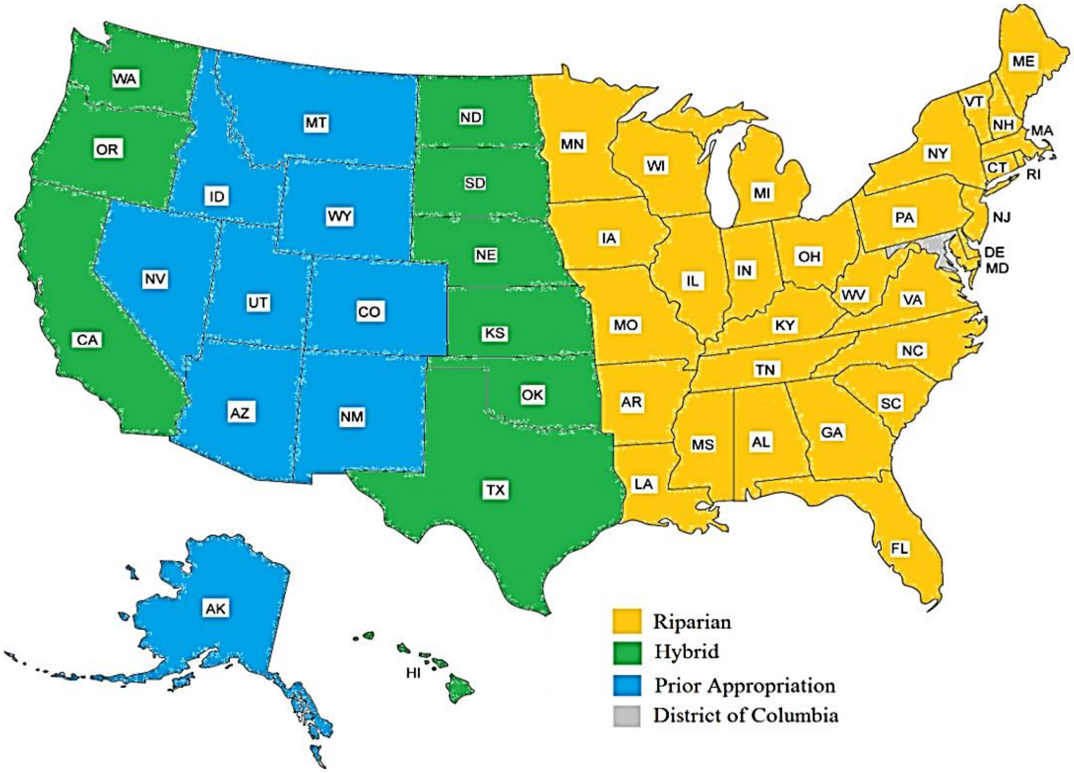
According to Tietenberg (2006), ―An efficient allocation of surface water: (1) must strike a balance among a host of competing users and (2) must supply an acceptable means of handling the year-to-year variability in surface water flow". Unfortunately, the water policies of most U.S. states do not fulfill either of these two essential provisions. In essence, there are two main types of water rights ownership structures in the United States. The older of these is called ‗riparian'. It is related to English water law and assigns the rights of surface water touching a particular property to the owner of that property. While simple in theory, this legal structure is complicated by various restrictions on what the property owner may or may not do with the water he or she has rights to. For example, according to riparian law, ―[water] cannot be unreasonably detained or diverted, and it must be returned to the stream from which it was obtained" (Hecox 2005, para. 2). Additionally, while the water may be used consumptively, it must comply with the edict of ‗reasonable use'. The exact meaning of this term varies widely from state to state and, for obvious reasons, has been a frequent cause of dispute.

A newer form of water rights ownership, called ‗prior appropriation‘, is usually described by the adage ―first in time, first in right"—that is, whomever first appropriates the water has rights to it. For the most part unnecessary in the more water-rich eastern half of the United States, the doctrine of prior appropriation evolved as American settlers moved further and further into the arid western frontier. These water rights are not tied to the land and may be sold or transferred to parties other than the landowner (Hecox 2005).

Some more controversial aspects of prior appropriation include its requirement of ‗beneficial use‘ (which, like the ‗reasonable use‘ condition of riparian rights, can be widely interpreted), and the fact that water rights owners may lose their rights due to ‗non-use‘, which encourages the owners to use their full allotment of water whether they actually need to or not. Prior appropriation also differentiates between ‗junior‘ and ‗senior‘ appropriators in that the former cannot divert water for their own use if there isn‘t enough water available for the latter to fulfill their needs (Easter and McCann 2010; Tietenberg 2006; McClain 2006). It should be noted, then, that the doctrine of prior appropriation, which is currently in use in the most water-scarce states, actually provides a *disincentive* to conserve water due to this ―use it or lose it" stipulation (Easter and McCann 2010). It is thus a concern that water users in states that have the greatest need for innovative water-conserving fixtures may not be inclined to seek them out.

Finally, in an attempt to combine the benefits of both types of water ownership laws, some states began to adopt a ―hybrid" legal structure. California was the first state to do so; the ―California Doctrine" essentially allowed policy makers to enact riparian laws in water-rich portions of the state while assigning prior appropriation doctrine in more arid regions (McClain 2006). Figure 7 summarizes the different types of surface water ownership laws in the United States, and clearly demonstrates that legal allocation is highly correlated with the regional availability of water (or lack thereof). Riparian, prior appropriation, and hybrid systems almost always apply exclusively to surface water; groundwater is allocated differently and will now be discussed.

Figure 7: United States map of surface water allocation laws



Source: Adapted from McClain 2006

Groundwater allocation in the United States

Groundwater is often associated with agricultural irrigation, but that is not its only application. Groundwater withdrawals account for about 20% of total water withdrawals in the United States and about one-third of public supply withdrawals (USGS 2005). Much like surface water laws, groundwater is allocated at the state level. Other similarities to surface water laws are that groundwater laws are typically quite old, do not take water shortages or conservation incentives into consideration, and often lead to overuse (Baxtresser 2010). Baxtresser notes that groundwater allocation doctrines vary widely from state to state and groups them into five broad categories. He also establishes three factors that these doctrines should incorporate: efficiency, utility maximization, and clarity so that ―judicial interpretations" are unnecessary (2010, p. 776). According to him, none of the five categories of groundwater allocation laws meet all three of these criteria, and some fail to meet any (Baxtresser 2010).

As discussed at length by such scholars as Mancur Olson (1965), Garrett Hardin (1968), and Elinor Ostrom (1990), groundwater‘s status as a common-pool resource causes it to be especially difficult to allocate. As stated previously, this is because excluding users is not feasible and because one user‘s consumption decreases the total amount of groundwater available to other users (Ostrom 2003). This also creates an incentive for the overuse of the resource, because each user will behave in a way that maximizes his or her own benefit. In other words, although *individual* outcomes may be maximized, the *joint* outcome for all users is less than optimal. This type of gross overuse will eventually lead to the depletion of the resource when there is no disincentive for the users to withdraw as much water as they desire. Thus, an institution becomes necessary to ensure that the common-pool resource is managed in such a way that an optimal *joint* outcome is achieved.

It should be noted that state-by-state water laws have evolved dramatically over the years and will likely continue to do so. State laws, particularly the doctrine of prior appropriation as described above, may have an effect on the likelihood of water users‘ adoption of water-saving fixtures. This is due to the fact that water utilities can potentially lower rates to consumers in order to encourage consumption, thus keeping their current allotment. Baxtresser (2010, pp. 774-775) also emphasizes the role of government subsidies: ―Water in the United States is heavily subsidized […] This subsidization incentivizes the use of large quantities of water, resulting in wasteful practices and economically inefficient uses." The lower the cost of water to homeowners and other users, the less incentive they have to conserve water (or to purchase water-conserving fixtures). As outlined in the following section, federal water guidelines have had an even more pronounced effect on the innovation and adoption of such fixtures, and toilets in particular.

Federal water laws in the United States

While states have historically been responsible for water allocation due in part to regional variability in climate, federal legislation seeks to maximize both water quality and efficiency in the aggregate. Of course, there is certain amount of discord that can occur between the state and federal levels, and lawmakers sometimes disagree on proper courses of action. At a policy conference among governors of 19 western states in 2010, ―federal experts urged state leaders to weigh water needs over water wants, while state leaders pleaded for less federal oversight and more flexible water agreements" (Silva 2010). Both federal and state legislators agreed that the low price of water in some areas has been a major contributor to its overuse, but specific action plans can be difficult for both parties to agree on. As one governor stated to a federal official, ―I look forward to your assistance, but not too much of it" (Silva 2010). Friction between state and federal water laws, and even among states themselves, comprises a major barrier to efficient and conservative water allocation. It is important to note, however, that while state water laws focus primarily upon ownership and use rights, federal legislation usually applies to limiting water pollution and mandating the water efficiency of fixtures.

The first major U.S. legislation that addressed water concerns was the Federal Water Pollution Control Act of 1948, which limited the amount of pollutants that could legally be discharged into the water supply. This legislation has since been expanded and amended numerous times and is known today as the Clean Water Act (EPA 2011a). With regard to water conservation, the first major federal legislation to be implemented that addressed the water efficiency of household and commercial appliances was the Energy Policy Act of 1992 (102nd Congress 1992). This enormous piece of legislation covered a wide array of topics, including alternative fuel sources, health coverage for coal miners, energy efficient mortgages, electric vehicles, uranium disposal, and public education funding for math and science programs, among many others. One small subsection of this bill had big ramifications for the plumbing industry and its consumers, however.

The impact of the 1992 Energy Policy Act on water fixtures

Toilets remain the most consumptive fixture in terms of domestic water use, but it was not long ago that they consumed a great deal more. In the first half of the 20th century, a standard toilet consumed between 5 and 7 gallons per flush (GPF). While not federally mandated, the standard GPF for most models had fallen to 3.5 GPF by the

1960s (Fernandez 2001; Reyes 2004). This initial reduction in water usage was voluntarily initiated from within the industry itself, beginning with the first 3.5 GPF model in the U.S., the American Standard Cadet™ (Anon. 1998). Toilet flush volume was not regulated by law until 1992; Section 123 of the Energy Policy Act, titled ―Energy conservation requirements for certain lamps and plumbing products", referred mainly to updated requirements for fluorescent lighting fixtures but also included a section that would drastically change the water efficiency requirements of most indoor plumbing appliances, including showerheads, faucets, urinals, and toilets (102nd Congress 1992, Section 123):

> Not later than one year after the date of the enactment of the Energy Policy Act of 1992, the Commission shall prescribe labeling rules […] Such rules shall provide that the labeling of any water closet or urinal manufactured after the 12-month period beginning [January 1, 1994] […] shall bear a permanent legible marking indicating the water use, expressed in gallons per flush (GPF), and the water use value shall be the actual water use or the maximum water use specified by the standards established in subsection (k) of section 325.

The new law, which was intended to reduce household water consumption, water treatment costs, and pumping costs, required that all toilets manufactured and installed after January 1, 1994 consume 1.6 GPF or less and that all urinals consume 1.0 GPF or less (102nd Congress 1992). However, the manner in which the legislation was implemented had several unforeseen consequences. First, the new 1.6 GPF volume requirement chosen by Congress had not been adequately researched in order to determine whether this specific flush volume was, in fact, efficient or effective (George 2001). Second, toilet manufacturers had little more than a year to redesign, manufacture, and ship the new low-flow toilets; the result was that the new toilets were not physically redesigned to perform the same tasks with less than half the amount of water and performed very poorly (Fernandez 2001). Finally, the existing plumbing infrastructure was, in some cases, incompatible with the lower flush volume. A 2004 study at Texas A&M University compared the performance of low-flow, 1.6 gallons-per-flush toilets to the 3.5 gallons-per-flush toilets that had been the pre-1992 standard. The study, which sought to determine the cause for consumer performance complaints such as —plumbing backups” and complete bowl clearance problems,” found that the reduced flush volume caused solid waste to travel a much shorter distance through connecting pipes than did the higher flush volume, in some cases less than half the distance (Reyes 2004). These and other performance issues caused users to flush the toilet more than once, which not only negated the water-saving functions of the low-flow toilets, but often used even more water than one flush from the older 3.5 GPF models (Conley 1998).

Unsurprisingly, consumers were very displeased with the first low-flow models, citing that the very small amount of water in the bowl caused frequent clogs and necessitated constant cleaning. This caused a consumer backlash such that a black market for the older, illegal models existed for some time even after the passage of the 1994 legislation (U.S. Water News 1996). Over the next few years, manufacturers invested in research for improved design and performance for the new low-flow toilets in order to address consumer concerns. Today, now that technological innovation has had time to –catch up” to the hastily implemented 1992 laws, other formal institutions have evolved that encourage—but do not mandate—the use of low-flow water fixtures.

Other water-related programs in the U.S.

The EPA WaterSense program, which uses a third-party certification process to market and label high-efficiency water fixtures, assures consumers that the products it endorses are tested for both water efficiency *and* performance. WaterSense-labeled toilets must consume 1.28 GPF or less, which is 20% less water than required by law (EPA 2010). The WaterSense label, similar to that of the well-known Energy Star program also implemented by the EPA, attempts to give consumers a clear visual cue of products‘ water efficiency in hopes of increasing their appeal. Both labels are shown in Figures 8 and 9 below.

Figure 8: EPA WaterSense label

Source: EPA 2010

Figure 9: EPA Energy Star label

Source: Energy Star 2011

Another institution that is particularly relevant to commercial and industrial applications is the LEED® (Leadership in Energy and Environmental Design) certification program, which uses a third-party certification process similar to that of the WaterSense program to recognize building and construction practices that are environmentally sustainable. LEED® certification was originally limited to commercial construction applications, but newer standards for residential construction are now included under the LEED-H® program specifications. The degree to which a LEED®-certified commercial building is considered to be sustainable is indicated by its rating, which is designated as either platinum, gold, silver, or simply ‗certified‘ (platinum being the highest certification level possible). The specific criteria that LEED® certifiers use to evaluate buildings are site sustainability, energy efficiency, use of sustainable materials, indoor air quality, building location, promotion of environmental awareness, focus upon regional concerns, and water efficiency (U.S. Green Building Council 2010). This last criterion is naturally the most relevant to this thesis topic. Examples of LEED®-approved water-efficient technologies include high-efficiency showerheads, dishwashers, and washing machines, as well as several types of water-conserving toilets. These include high-efficiency single-flush gravity toilets, pressure-assisted toilets, and dual flush toilets, as well as high-efficiency flushometer toilets.

2.5 Adoption of green technologies

While specific literature on the adoption of dual flush toilets does not exist, research has been conducted on the psychosocial barriers to adoption of green building in general. Given that water-saving fixtures and technologies are an important component of green building (as shown in the description of LEED certification standards earlier in this thesis), it is reasonable to assume that adoption barriers to green building might serve as a proxy for barriers to the adoption of dual flush toilets.

Researchers at the University of Michigan found that barriers to green building were not related to technological or economic issues, but rather to social and psychological factors (Hoffman and Henn 2008). A common myth surrounding green building is that this type of construction costs far more than its conventional counterpart, but this myth was shown to be largely false when costs were computed in the long term—that is, reduced energy bills over time tended to offset up-front construction costs.

Additionally, many green technologies and materials that were initially prohibitively expensive at the time of their development have decreased in price, largely due to an increase of those products‘ market share over time and higher market returns (Hoffman and Henn 2008).

With regard to psychological and social barriers to adoption, Hoffman and Henn found that these existed on individual, organizational, and institutional levels. Examples of individual-level biases included overdiscounting of the future, egocentrism (i.e., the desire to purchase a large single-family home rather than a smaller, more energy-efficient one), positive illusions about the future, presumed associations (i.e., that proponents of green building are politically progressive and/or liberal), and lack of environmental literacy. Organizational perspectives were specific to the ―culture" of an individual firm or business and included business structure, terminology, rewards/incentives to employees, and resource limitations. Finally, institutional perspectives such as legal requirements, government regulatory agencies, and economic indicators can also influence adoption (Hoffman and Henn 2008). Examples of institutional perspectives include tax codes that incentivize the purchase of green technologies or alternatively, lending agencies that are reluctant to pay for energy-efficient upgrades to a home. It is important to note that this wide variety of possible barriers to adoption (and there are others as well), when viewed as a whole, present a substantial obstacle to the adoption of green building practices.

It seems that the more information available to the consumer with regard to the myriad financial and economic benefits of adoption, the more likely that adoption will actually occur. When one extrapolates this concept specifically to dual flush toilets, it would seem the more precise information that can be provided on water savings, the more likely the chances of adoption. An in-depth discussion of the relative cost advantages and disadvantages of dual flush toilets is included later in this thesis, but more general background information on toilets is provided first.

2.6 Overview of toilets

History of flush toilets

Methods of human sanitation and waste disposal have varied greatly throughout history and across cultures, with wide-ranging effects upon human health. Given that the ‗modern‘ conveniences of indoor plumbing and flush toilets are still not available in many areas of the world today, one may be surprised to learn that these innovations have existed for thousands of years. The inhabitants of Mesopotamia and the Indus Valley were already utilizing privies, or outdoor toilets, in the 2nd millennium B.C.E. (Avvannavar and Mani 2008). The Indus Harappans even invented an underground sewer system that channeled wastewater from homes to underground cesspits via a series of connecting pipes (Lofrano and Brown 2010; Horan 1997). What is believed to be the world‘s first flush toilet exists at the Palace of Knossos, which was constructed in the middle of the 2nd millennium B.C.E. on the island of Crete

Figure 10: Roman-era latrines at Ostia Antica

Source: Obfusco 2004

(Angelakis, Koutsoyiannis, and Tchobanoglous 2005). Rainwater collected from the roof was used to flush the contents of the toilet into an integrated sewer system (Horan 1997).

Over the following centuries, waste disposal techniques included large open sewer canals that emptied into rivers or seas, communal dung heaps, cesspools, and even upending chamber pots directly into the street from an open window (Horan 1997). Poor sanitation practices were not only a nuisance, but created serious human health issues. One of the worst of these was the ‗Black Death‘ epidemic in mid-14th-century Europe, which killed approximately one-third of the entire population of Europe with a combination of insect and water-borne diseases such as plague and cholera. Due to both a lack of technology and rigid social norms, human waste continued to contribute to the filth and squalor of European cities until the beginning of the 19th century. Although the first (post-Knossos) flush toilet was invented in 1596 by Sir John Harrington, the use of an indoor toilet was considered unseemly by most of the general populace at the time. Chamber pots and privies (small outbuildings consisting of a seat centered over a hole in the ground) remained the standard in Britain until 1775, when Alexander Cummings received the first patent for a water closet (Kravetz 2009). Various innovations to Cummings‘ basic toilet followed over the course of the next century: George Jennings added a pressure-assist mechanism that more effectively flushed waste from the bowl, Thomas Crapper added a pull-chain valve that conserved water, and Thomas Twyford first utilized porcelain to cover the toilet‘s inner workings and provide an easier-to-clean surface (Horan 1997).

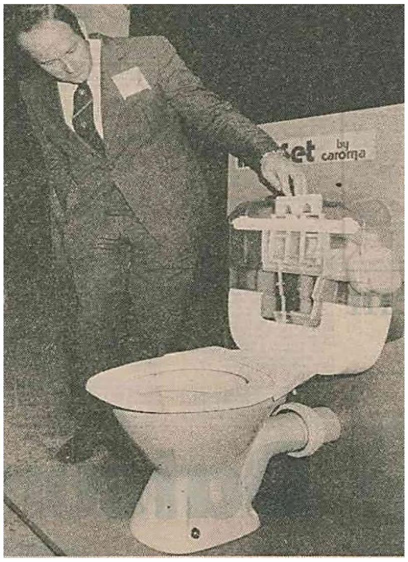
In America, most people continued to utilize outdoor privies and cesspools until the late 19th century, when indoor toilets started to become fashionable and sewers for waste and storm water began to be constructed in urban areas (EPA 2004). English toilets were initially imported from across the Atlantic, but as most consumers found these prohibitively expensive, a domestic market soon evolved when New Yorker Thomas Maddock began production of the first porcelain toilets in 1874 in Trenton, New Jersey (Simpson 2007; Horan 1997). Though the United States endured its share of epidemics from waterborne illnesses such as cholera, disease rates plummeted beginning in the early 20th century due to heavy investment and expansion in wastewater treatment plants and sewer systems. Today, more than 75% of U.S. households are connected to mainline sewer and waste treatment systems, while most of the rest utilize septic or some other form of on-site treatment (EPA 2004).

The typical modern incarnation of a flush toilet, then, has only been in use for a little over 200 years, and further improvements to the original design during that time were minimal and infrequent. As we shall see in the next section, there have been a multitude of innovations in toilet technology in recent years. In the United States, these were driven primarily by preemptive legislation as previously discussed; in other areas such as Australia, efficiency improvements in toilets came about due to the dire need for reduced water consumption.

Modern-day toilet innovations

The dual flush toilet was invented in 1980 in South Australia by the toilet manufacturer Caroma, which received a Commonwealth Government grant in order to conduct the necessary research and development (South Australia State Library 2006). Australia, as the driest continent on earth, has a particular need for water-saving technologies. This need is even greater during times of drought, which occur frequently in certain parts of Australia; therefore, the Australian government had significant reason to invest in water-conserving toilet technology. This first line of dual flush toilets by Caroma, pictured at right, operated with two separate buttons, one for a small flush (1.45 GPF) for liquid wastes and the other for a large flush (2.9 GPF) for solid wastes. The toilet bowl also had to be redesigned to ensure that the bowl remained clear even with less water flow (as American toilet manufacturers would learn the hard way over a decade later). This invention represents an example of the concept of induced innovation, where new technologies are invented and adopted due to relative scarcity of resources and thus differences in relative prices (Hayami and Ruttan 1971). In this example, the increasingly scarce resource in Australia is water. In 1993, Caroma introduced an even more efficient version of the dual flush toilet that used 1.6 GPF for a large flush and 0.8 GPF for a small flush (South Australia State Library 2006). This remains the industry standard today, although more efficient technology

Figure 11: Caroma Duoset dual flush toilet



Source: Gill 1981

exists. Further detail on dual-flush toilets is included in Chapter 3 of this thesis, but a brief overview of other types of toilet innovations will be presented next.

Low-flush toilets

As previously stated, current U.S. federal regulations require that all toilets use 1.6 GPF or less. These toilets are alternatively referred to as either low-flush (LF) or ultra-low-flush (ULF) toilets. One might imagine that this could cause confusion on the part of consumers because the use of the word ‗ultra‘ seems to imply extra water savings. However, both LF and ULF toilets use the federally mandated amount of water (Marin Municipal Water District 2011).

High-efficiency toilets

High-efficiency toilets (HETs) use about 1.3 GPF on average, depending on the particular type of toilet (Marin Municipal Water District 2011). HETs are the only toilets that can be certified by the WaterSense program discussed earlier. However, this does not mean that all HETs meet WaterSense standards; WaterSense labeled toilets must also demonstrate high performance. There are three types of HETs: dual flush, which typically use 0.8 GPF for a small flush and 1.28 GPF for a large flush; single flush, which uses 1.28 GPF or less for each flush; and pressure-assist, which also uses 1.28 GPF per flush but also uses electricity to power an air compressor that aids in the flushing process (Marin Municipal Water District 2011; Kohler 2009).

Composting toilets

Composting toilets are far less common than LF or HET toilets, but are still deserving of mention due to their unique eco-friendly design. Various models and designs of composting toilets exist, but they all use the same ―process of aerobic decomposition" to break down human waste into compost that can be used as a safe, natural fertilizer (Envirolet 2010, p.1). There are various advantages and disadvantages to composting toilets when compared to conventional toilets, but one point of particular interest is that they do not require water, or a sewage system, to function (OWDP 2011). This clearly not only reduces water consumption, but also reduces the volume of outgoing wastewater that must subsequently be treated. At the present time, however, the perceived drawbacks of composting toilets sharply curtails consumers‘ willingness to adopt this water-saving technology. A feasibility study in Australia found that these drawbacks included ―perceived operating problems (odour, difficult operation, health risk), residue disposal opportunities and restrictions, significant additional cost to the household compared to installation of a standard toilet, difficulty of retrofitting in existing buildings, cultural acceptability and institutional discouragement" (Crockett et. al 2004). As such, it is unlikely that this technology will be adopted on a large scale anywhere in the near future.

Dual flush toilets

Dual flush toilets operate in much the same way as LF or HET toilets, but they are capable of two different flush volumes. These volumes vary between models. Many have a 1.6 GPF high-volume flush and a 0.8 GPF low-volume flush, although 1.6/1.1 and 1.6/1.0 are also quite common. Some dual flush toilets are also HETs, which typically have a 1.28/0.8 low-to high flush volume, respectively. While many types of water-efficient toilets exist, dual flush toilets are the only type that present the user with a choice. This choice requires a specific decision or action on the part of the user, and some models of dual flush toilets may make a ‗correct‘ decision more difficult than others. For example, a 2002 study on dual flush toilets sponsored by the Canada Mortgage and Housing Corporation and carried out by Veritec Consulting Inc., a firm specializing in water-related studies, evaluated four different models of dual flush toilets in order to determine customer satisfaction, water savings, and cost efficiency. The authors emphasize the difference between the theoretical versus actual water savings of dual-flush toilets as follows (Veritec Consulting Inc. 2002, p.1):

> *Theoretically*, a toilet using 3 litres for liquid waste and 6 litres for solid waste would flush with an average of about 3.8 litres (based on a ratio of approximately three ‗short‘ flushes for every ‗long‘ flush) – a savings of almost 37% more than the design flush volume of a standard 6-litre toilet. Data collected as part of this project was analyzed to determine *actual* savings [emphasis in original].

The study found the actual ratio to be 1.7:1 short to long flushes overall, although this ratio was greater in women‘s restrooms (2.7:1) than in men‘s (1.1:1). Veritec assumes that this disparity is due to the fact that urinals are typically available in men‘s restrooms. That assumption regarding urinals has also been made in this thesis; thus, flush counter devices were installed only in women‘s restrooms. Interestingly, both ratios fall short of the ‗theoretical‘ use of 3:1. The authors of the Veritec study attribute this discrepancy to ‗double flushing‘ in order to fully clear the toilet bowl and, less commonly, the curiosity of the user leading to multiple flushes (Veritec Consulting Inc. 2002). While these factors may certainly contribute to a smaller-than-expected ratio, it is hypothesized in this thesis that the design of the flush mechanism, and thus user behavior, also plays an important role. This is one aspect of toilet use that the Veritec study did not address. The concept of user behavior and decision-making will discussed in greater detail in Chapter 3.

The role of the user in toilet water conservation

This subsection has provided an overview of the history of the toilet, innovations that have occurred over time (some induced, some not), and efforts to produce toilets that conserve water by various means. What has not been discussed thus far, however, is the fundamental role of the user during operation of the toilet. That is, if the user uses the toilet incorrectly or does not understand its design, the toilet may not be saving as much water as it was designed to. The next section of this thesis focuses on the user behaviors and decision-making processes that affect virtually all areas of everyday life (including flushing the toilet). Human decision-making is highly related to the field of behavioral economics, which is an integral part of this thesis research.

2.7 Behavioral economics

A historical perspective: behavioral vs. neoclassical

The field of behavioral economics integrates both economics and psychology in an attempt to better understand human behavior and how people make decisions. While behavioral economics does not reject the concepts of market equilibrium, utility maximization, and efficiency that are critically important to neoclassical economics, studies in behavioral economics do often involve discarding certain simplifying assumptions, such as that of the perfectly rational economic actor, that are common to neoclassical approaches (Camerer and Loewenstein 2004). It follows that a certain amount of debate exists between, and even within, the two schools of thought.

This intradisciplinary feud extends many decades into the past. Milton Friedman, the enormously influential 20th century neoclassical economist at the University of Chicago, defended the broad, simplifying assumptions of neoclassical economics in his seminal 1953 paper ―The Methodology of Positive Economics" by saying that they are necessary in the creation of a hypothesis in order to be able to apply a theory to a broad spectrum of circumstances. Friedman even went so far as to claim that this ‗principle of unreality‘ becomes increasingly important as the hypothesis becomes more accurate. ―Truly important and significant hypotheses," he stated, ―will be found to have ‗assumptions‘ that are wildly inaccurate descriptive representations of reality, and in general, the more significant the theory, the more unrealistic the assumptions" (1953). Herbert Simon, winner of the Nobel Prize in Economics in 1978 and an early pioneer in the behavioral field at Carnegie Mellon University, emphatically disagreed with Friedman. He claimed that there are only two conditions under which neoclassical economic analysis may be considered useful: one, that the ―ever-present deviations" of neoclassical assumptions from reality cannot be too great, and two, that ―real-world people" must be able to carry out the calculations required in order to make the relevant decisions (Simon 1982; Pingle 2010). Friedman countered this by saying that it is irrelevant whether decision-makers are actually capable of performing these calculations; so long as they behave *as if* they are, their actions serve an adequate approximation of rational behavior (i.e., utility maximization) (Friedman 1953; Pingle 2010). Simon, on the other hand, argued that economics should replace Friedman‘s model of the perfectly rational ‗economic man‘ with one that explains rational behavior in the context of both the limited cognitive abilities of humans (known alternatively as either ‗cognitive scarcity‘ or ‗bounded rationality‘) and the actual environments in which they make decisions (Simon 1955).

Decision making and bounded rationality

This early debate spawned an extensive inquiry into the factors that are relevant in determining the accuracy of rational choice models in economic theory. Colin Camerer and George Loewenstein, modern-day leading scholars in the field of behavioral economics, state that theories in economics, and in the behavioral field more specifically, should be ―judged by [George Stigler‘s] three criteria: congruence with reality, generality, and tractability" (Camerer and Loewenstein 2004; Stigler 1950). As such, bounded rationality—that is, the effects of limited cognitive ability on an individual‘s decision-making process—is a vital assumption in behavioral economics. Simply put, it is entirely unrealistic to assume that the decision-maker has the desire, time, and/or ability to carefully weigh the advantages and disadvantages of each decision he or she makes. Indeed, many day-to-day decisions are made without any conscious thought at all. Richard Thaler and Cass Sunstein, two leading experts in the field of behavioral economics, draw from theories in the field of psychology and distinguish between two cognitive systems, the Automatic and the Reflective (2008). The differing attributes of each system are shown below in table 2.

Table 2: Characteristics of two cognitive systems

Automatic	**Reflective**
Uncontrolled	Controlled
Effortless	Effortful
Associative	Deductive
Fast	Slow
Unconscious	Self-aware
Skilled	Rule-following

Source: Thaler and Sunstein 2008, p.20

Examples of Automatic responses include braking quickly to avoid an auto collision, holding one's breath before diving underwater, or smiling at a young child; Reflective responses, conversely, include solving math problems, choosing a restaurant for dinner, or purchasing a birthday gift for a friend or relative. Neuroscience research has helped us to understand that these two basic types of cognitive responses originate in parts of the human brain that evolved at different times. Automatic responses are linked to instinct and self-preservation, whereas Reflective responses, which evolved far later, enable the individual to think logically and rationally in order to reach a utility-maximizing decision (Cory 2006). Each of these responses, whether deliberate or not, are actually discrete *decisions,* and individuals make hundreds, if not thousands, of these decisions each day. Under the neoclassical assumption of the perfectly rational decision-maker, each and every one of these decisions are made with the complete and undivided attention of the decision-maker, who carefully weighs all the costs and benefits of each possible course of action before making a final decision. Both behavioral economics research and common sense tells us that this is not the case (e.g., Simon 1955; Thaler and Sunstein 2003; Camerer and Loewenstein 2004). Even decisions which are made using the Reflective system and thus carefully thought through by the decision maker are affected by various outside influences and biases, some of which will be discussed in the following subsection.

Cognitive bias and heuristics in decision-making

There are those who argue that the assumption of utility maximization is not so different between the two school of thought, and that even decisions made within the constraints of bounded rationality are still utility-maximizing. Following this argument, an individual who smokes or drinks excessively makes the decision to do so in order to maximize his or her own ―hedonistic satisfaction"—that is, his or her utility (Rizzo and Whitman 2009). This example works well if the decision-maker has no desire to stop the behavior, but what of the smoker, the drinker, or the gambler who repeatedly tries to quit but cannot? According to Thaler and Sunstein, ―in some cases individuals make inferior choices […] that they would change if they had complete information, unlimited cognitive abilities, and no lack of willpower" (2003, p. 175). There are in fact a wide range of cognitive biases that influence the decisions we make, some of which are described in Table 3 (though there are many others).

Table 3: Types of cognitive bias in decision-making

Type of bias	Description	Real-world example
Anchoring	Basing one‗s decision upon a reference point or ‗anchor‘, which results in over- or under-estimation.	Guessing a city‗s population based upon that of a nearby city, even when the nearby city is far larger or smaller.
Availability	The effect of how familiar or easily imagined a particular event is on a decision.	Assuming that one‗s chance of death via plane crash is higher than via car crash.
Representa-tiveness	Using stereotypes or perceived likelihoods to make a decision.	Basing an opinion of a person on a stereotype of one‗s gender, race, or ethnicity.
Framing effects	The context in which a decision is presented affects the outcome of the decision.	Being told that a surgical procedure has a ‗90% success rate‘ will increase the likelihood of choosing surgery as opposed to a ‗10% failure rate‘.

Type of bias	Description	Real-world example
Loss/risk aversion	Decision-makers are typically far more interested in minimizing losses than in increasing gains.	Reluctance to invest in the stock market, even when the potential for gains is great, due to fear of losing one‘s principal investment.
Time discounting	Placing more value on payoffs that happen now as opposed to those that happen in the future.	Spending money now versus saving for later; enjoying unhealthy behaviors now without considering long-term health effects.
―Status quo”	Also known as the ‗default option‘ bias. What occurs when a decision maker takes no action or an automatic result occurs.	‗Opt-in‘ versus ‗opt-out‘ retirement savings plans (the latter of which causes much higher rates of savings); not changing the television channel even when one is uninterested in the program. Can be thought of the ‗path of least resistance‘.
Deliberation or transaction costs	The inconvenience of having to put forth effort (whether physical or mental) during the decision-making process.	Having to travel and/or ‗go out of one‘s way‘ in order to make a decision; the time and mental stress involved with planning big decisions (such as buying a house).
Bounded rationality/ cognitive scarcity	The cognitive inability of human actors to accurately evaluate all the possible outcomes of a given decision.	The inability of most people to evaluate every possible outcome of a single play of a chess game (much less multiple plays).
Imperfect information	Circumstances under which necessary information is not known to the decision-maker.	Purchasing a car without knowing it has mechanical problems; unwittingly consuming contaminated food; going for a hike without knowledge of an incoming storm.
Unrealistic optimism and/or pessimism	Believing that one‘s chances of success or failure are higher or lower than average.	50% of a college class believing they are in the top 10%; newlyweds believing they will never divorce; fear that one cannot learn a new, yet simple, task, such as basic computing.

Adapted from Thaler and Sunstein 2006; Rizzo and Whitman 2009; includes examples by the author

The idea of ―libertarian paternalism”, a term coined by Thaler and Sunstein (2003) that implies encouragement without coercion toward a particular decision or unconscious behavior, is possibly the most important link between the field of behavioral economics and this thesis project. Three field studies will be presented in order to illustrate this concept. In the first study (Wansink, van Ittersum, and Painter 2006), 85 nutrition experts were served ice cream in either a 17-ounce or 34-ounce bowl and given either a 2-ounce or a 3-ounce scoop. The results showed that even though the research subjects were nutrition experts themselves, the ones who were given a larger bowl consumed 31% more ice cream than the sample with the smaller bowls, and those given larger scoops consumed an additional 14.5%. The authors concluded that the larger bowls and spoons caused the participants to unknowingly over-serve themselves, and that such knowledge might be useful to those interested in either weight loss or weight gain (Wansink, van Ittersum, and Painter 2006). In a second study (van Kleef, Shimizu, and Wansink 2011), study participants watched a series of either exercise-related television commercials or ‗neutral‘ ones before being served lunch. The group that watched the exercise commercials ate 21.7% fewer calories than the group who watched neutral commercials, implying that the ads reminded participants of the relationship between caloric intake and physical activity (van Kleef, Shimizu, and Wansink 2011). Finally, the third study (Just and Wansink 2008) was conducted at an all-you-can-eat pizza restaurant. One group of participants paid full price while a second randomly selected group received a 50% discount. Those who received the discount consumed 27.9% less pizza than those who had paid more; Just and Wansink (2008) theorize that the participants were driven by the desire to get the most ‗bang for their buck‘; thus, those who paid less consumed less.

All of these studies are excellent examples of libertarian paternalism: study participants unknowingly consumed more or less food depending upon contextual cues and other influencing factors in each study. It has been theorized that libertarian paternalism may serve well as an alternative to laws which ban or limit the consumption of certain goods—for example, high-fructose corn syrup or unsaturated fatty acids (‗trans‘ fats). Under the influence of the subtle ‗nudges‘ of libertarian paternalism (a term popularized by Thaler and Sunstein in their 2008 book), ‗choice architects‘—that is, those who frame the decision and therefore attempt to influence the outcome of the decision—individuals can be driven toward, but not forced into, choices that are considered to be _better‘ in some way. Libertarian paternalism can not only encourage people to eat more healthfully or to exercise, it can also be applied in a wide variety of other situations and for different purposes.

In the previous examples of the buffet line, TV commercial, and ice cream experiments, the decision-maker‘s actions *directly affected his or her own welfare*. Consuming too much at the buffet in order to _get the most bang for the buck‘, or serving oneself too much ice cream due to a misconception of portion size, results in an increased risk that the individual will consume more than they intended or realized, which will in turn affect his or her own health. In these situations and in many others, the decision-maker has an incentive (e.g., his or her own personal health and well-being) to overcome the cognitive biases listed above in Table 3.

But what about a situation in which an individual‘s decision has *no effect* on him or her personally—for example, the decision whether to flush a dual-flush toilet correctly in a commercial or public setting? While some incentive may still exist (for example, the sense of ethical or altruistic satisfaction one receives from saving water), the user does not have to pay for the water he or she uses; also, because restroom stalls are private, there is no risk of others observing the user‘s decision and thus exhibiting a negative response. Furthermore, as the habit of flushing a toilet handle down is virtually ingrained, a user may very well flush down reflexively even if he or she meant to do otherwise (that is, an Automatic versus a Reflective response).

As this section has demonstrated, libertarian paternalism has both proponents and critics, but it is arguably most useful in situations where the decision-maker has little or no personal incentive to ‗do the right thing‘ *and* where the design of the default option strongly influences user choice. Accordingly, the dual flush toilet which was chosen for this study, and its use in commercial and institutional environments, fits this description very well. Chapter 3 provides a conceptual framework in which the specific designs of several dual flush toilets are explained at length. A thorough explanation of the hypotheses of this thesis is also provided.

CHAPTER 3: CONCEPTUAL FRAMEWORK

3.1 Overview

As noted in previous chapters, the purpose of this thesis project is to determine the extent to which the design of the flush handle on a dual-flush toilet impacts the actual amount of water saved. The Sloan Uppercut® flushometer has been selected as the research focus due to the fact that it presents the user with a choice: pull the handle up for a small flush, or push it down for a large flush. As most Americans (along with toilet users in many other countries) have been ―conditioned” to push the handle down, it is hypothesized that most users will automatically push the handle down out of habit even when they do not need a large flush, thus wasting water. Therefore, the primary research question is as follows: do toilet users inadvertently push the handle down due to the default design of the handle? If so, how much water is wasted as a result of this design? Does adding instructional signage to the stalls help to reduce water consumption? Finally, is there any financial benefit to the consumer in choosing the Uppercut® over a standard flushometer? In order to address these questions, some basic assumptions about water use in toilets must be identified and analyzed.

3.2 Assumptions regarding water use in dual flush toilets

Manufacturers of dual flush toilets advertise that their products conserve water and often provide numerical estimates of the potential amount saved. For example, Sloan Valve Company, the maker of the Sloan Uppercut® flushometer, estimates a 21% water savings when compared to a standard 1.6 GPF model, though they do not elaborate on the methods by which they arrived at this figure (Sloan Valve Company 2010a). Sloan also offers an online water savings calculator tool, which assumes that men use urinals twice daily and toilets once daily and that women use the toilet three times daily in commercial buildings (Sloan Valve Company 2010b). It should be noted that Sloan does not attempt to estimate the ratio of small to large flushes in women's restrooms, but it is reasonable to infer that the 2:1 ratio is the same for women. The 2002 Veritec study mentioned in Chapter 2 assumes a 3:1 urination-to-defecation (U/D) ratio. However, this may be due to the fact that that study was performed not only in businesses, schools, and other public places, but also in private homes, where people tend to use toilets more frequently (Veritec Consulting Inc. 2002). Other estimates can be as high as 4:1 or 5:1; accurate data that could be used in such an estimate are difficult to obtain. Few estimates of U/D ratios in humans exist, and there is significant variation between those that do. This may be due to the fact that there is a wide range in the daily bodily needs of individuals. Also, it is important to note that some individuals demonstrate avoidance behavior with regard to public defecation (Avvannavar and Mani 2008; Watkins 2000), which could have a significant effect on estimations of U/D ratios. Although it is unknown what percentage of the population may exhibit this particular avoidance behavior, one may infer that U/D ratios may be higher in commercial buildings (i.e., the workplace) and lower in the home. As such, the provision of a low-volume flush option, as exists in dual flush toilets, may be especially suitable for commercial buildings.

3.3 Discussion and analysis of dual flush toilets

It should be noted that an in-depth analysis of all, or even a majority, of the different dual flush models and manufacturers was not feasible for the purposes of this thesis. As of July 21st, 2011, there were 313 different models of WaterSense-approved dual flush toilets listed on their website, and 801 toilets in total (EPA 2011b). However, a description of common types of dual flush toilets and flushometers is necessary before evaluating the soundness of the design of the Sloan Uppercut®. Emphasis in the section is placed not on the design of the toilet itself, but on the user interface—that is, the flush mechanism.

Figure 12: Caroma flush mechanism

Source: Blaha 2008

Figure 13: Kohler flush mechanism

Source: Zaleski 2011

Figure 12 shows a brand that is especially popular in households, dual flush inventor Caroma. The flush mechanism shown above is available on a variety of models of Caroma toilets. It is designed such that there is no default option; the user chooses between two equally accessible buttons, which are large and clearly visible on the top of the toilet tank. Most importantly, it is obvious to the user which button produces a low- versus a high-volume flush. In terms of user interface, this flush mechanism is designed quite well from a behavioral economics standpoint in that it is easy for the user to make the ‗correct' choice, even if he or she is unfamiliar with the design.

Figure 13 shows a flush mechanism by Kohler, some variation of which is used on most of their dual flush models. Like the Caroma model, this flush mechanism is also located on the top of the toilet tank, but the similarities end there. Neither button is clearly marked, and a new user must think about which button to push. For example, assume that the user desires a small flush. She may reason that the smaller button results in a smaller flush (in which case she would be correct). Alternatively, she may reason that because a small flush is needed much more frequently, the toilet‘s manufacturers designed the mechanism so that the small flush button is larger and therefore slightly easier to push. Finally, she may be confused and/or hurried enough that she pushes both (or neither). This could happen either intentionally or accidentally given that the entire mechanism is rather small. In light of these observations, this design is much less clear than the Caroma model and makes it more likely that the user will make an ‗incorrect‘ decision, thus wasting water. Of course, this would be less of a problem for repeat users, such as in one‘s home, as one would expect that the user would eventually ‗learn‘ the correct behavior.

Figure 14: Grohe flush mechanism

Source: Home Decorations 2011

Figure 15: Geberit flush mechanism

Source: Geberit 2009

Figure 14 shows a design that is especially common in Europe. In this design by manufacturer Grohe, there is a small button embedded within a much larger one. According to a plumbing distributor that sells many models with this flush mechanism,

―Button designs vary from toilet to toilet, but most often the smaller button is used for the liquid-waste flush" (Signature Hardware 2011, p. 1). As is the case in figure 13, it is unclear to a new user which button produces a small versus a large flush (if they even realize that it is a dual flush toilet at all). Even if the user is aware of the correct use of the flush mechanism, the chrome finish may cause one‘s finger to slip (thus accidentally pushing the larger button). In figure 15, the wall-mounted Gerberit brand flush mechanism has larger buttons and therefore is easier to manipulate, but the problem remains the same as in figures 13 and 14. Without any graphics or other indication of which button produces which type of flush, a new user may inadvertently make the ‗incorrect‘ decision. The preceding quote from Signature Hardware (2011, p.1) is also indicative of another potential problem: the fact that ―button designs vary from toilet to toilet" means that a button that produces a small flush in one flush mechanism may produce a large flush in another. This clearly allows even more opportunity for user error. In sum, while figures 13, 14, and 15 may be more aesthetically pleasing to some users, they are all poorly designed when using the methodology of behavioral economics.

Figure 16: Sloan ECOS® flush mechanism

Source: Plumbing Supply 2011

Figure 17: Sloan Uppercut® flush mechanism

Source: Sloan Valve Company 2011

Figures 16 and 17 show two different models of dual flush flushometers that are specifically designed for commercial buildings. Figure 16, the Sloan ECOS®, has two easily distinguishable buttons. With the use of water droplet graphics, the buttons clearly show which produces a large versus a small flush. The ECOS® flushometer is unique in that it also features an electronic sensor that flushes automatically if the user declines to press a button. It produces a small flush if the user is within range of the flushometer for less than one minute and a large flush if more than one minute (Sloan 2010c.) One obvious advantage of this design is that the toilet will flush even if the user takes no action, thus reducing or even eliminating the potential for an incorrect choice. Conversely, one disadvantage is that the automatic sensor will not always ‗choose' the appropriate flush volume. Many users may remain in the sensor's range for more than one minute even if they only need a low-volume flush. Without further investigation, it is not possible to estimate the frequency with which this occurs; it may be statistically insignificant. In any case, the ECOS®, if it functions as designed, offers the unique advantage of being both an automatic and a dual flush system. Theoretically, it could drastically reduce the occurrence of user error, reduce the spread of bacteria (due to the automatic no-touch mechanism), and conserve water all at once.

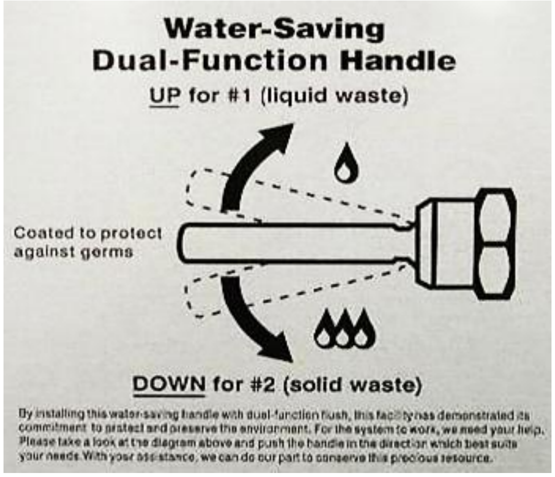
Finally, figure 17 shows the subject of this study, the Sloan Uppercut® flushometer. This is a specific type of dual-flush mechanism in which the user must choose between pulling the handle up or pushing it down, depending on whether he or she desires a small or large flush. The Uppercut®, which is designed for use in commercial and/or public buildings, is a flushometer rather than a toilet. This means that the Uppercut® can be installed on most types of commercial toilets. Many older toilet models can be retrofitted with new flushometers, such as the Uppercut®, and therefore provide a less expensive alternative to purchasing entirely new toilets if a building owner seeks to renovate existing construction. The major point of interest in the Sloan Uppercut® for the purpose of this thesis is that, unlike any of the other dual flush mechanisms discussed in this chapter, it presents the user with a ‗default‘ option. More specifically, the handle is pulled up for a low-volume flush (1.1 GPF) and pushed down for a large-volume flush (1.6 GPF). The primary design flaw, as far as water savings, in the Uppercut® is that the default option—pushing the handle down—produces the larger flush. As virtually all toilet users have been taught to push toilet handles down from childhood, it is hypothesized that much water is wasted due to people inadvertently choosing the ‗incorrect‘ flush for their needs. This is an example of the Automatic response discussed in Chapter 2 (Thaler and Sunstein 2008). Lifelong habits, such as flushing a toilet handle downwards, are powerful and difficult to change. Logically speaking, based upon a 2:1 or 3:1 U/D ratio, individuals need a low-volume flush most of the time. The Sloan Uppercut®, by virtue of its design, requires users to ‗retrain‘ themselves to use the toilet in the intended manner. If saving water is the desired outcome, it is hypothesized that reversing the flush mechanism, so that pushing the handle downwards produces a small flush, would produce far superior results.

Figure 18: Instructional signage for the Sloan Uppercut®, flush handle mount

Source: Sloan Valve Company 2011

Figures 18 and 19 show the two types of instructional signage that are intended for use with the Uppercut®. Figure 18 depicts instructional stickers that are attached to the base of the handle itself. Note the conspicuously green handle, which draws attention to the stickers and thus may help signal to users that the Uppercut® is not a standard flushometer. However, various individuals associated with this project (including MU faculty/students and employees at the research site) commented that the stickers were not very noticeable and that the instructions provided were unclear. These stickers come pre-applied to the flush handle and no additional purchase is necessary.

Figure 19: Instructional signage for the Sloan Uppercut®, door/wall mount



Water-Saving
Dual-Function Handle

UP for #1 (liquid waste)

Coated to protect against germs

DOWN for #2 (solid waste)

By installing this water-saving handle with dual-function flush, this facility has demonstrated its commitment to protect and preserve the environment. For the system to work, we need your help. Please take a look at the diagram above and push the handle in the direction which best suits your needs. With your assistance, we can do our part to conserve this precious resource.

Source: Sloan Valve Company 2011

Figure 19 is an engraved stainless steel plate with an adhesive backing that can be mounted to a variety of different surfaces. Most commonly, these wall plates are mounted on the wall above the flushometers, on the back of the stall doors, or both. It should be noted that the current specification sheet for the Sloan Uppercut® (see Appendix 2) claims that the wall plates are included with the purchase of the flushometer; however, they are in fact *not* included and must be ordered separately at an additional cost. It is unknown what effect, if any, these instructional graphics have on user behavior or whether they help to reduce water consumption.

3.4 Explanation of hypotheses

The general hypotheses of this study are as follows:

1. The default option of a Sloan Uppercut® flushometer often causes the user to inadvertently choose the _incorrect‘ flush type for their needs, thus wasting water.
2. Due to the flushometer‘s design, projected water savings are overestimated and actual water usage is higher than expected.
3. Adding the instructional wall plates shown in figure 18 will reduce water consumption, but still not reach the level of projected water savings.
4. Cost savings are also less than expected due to the underestimation of water usage.

In order to test these hypotheses, the research project will record the number of up and down flushes of Sloan Uppercut® flushometers in women‘s restrooms during a control period and compare that to the projected usage. The 2:1 U/D ratio used by Sloan will be used as a benchmark. Therefore, it is projected that roughly 66% of total flushes should be up flushes, while 33% should be down flushes. After the initial control period, two wall plates will be added to each stall. One will be placed on the wall directly above the flushometer and the other will be placed on the rear of each stall door, at eye level when the user is seated. The number of up and down flushes will continue to be counted to determine the effects of adding the instructional signs.

Expressed numerically, the hypotheses of this thesis are as follows:

1. During the *control* period, the actual ratio of up-to-down flushes are less than the company-projected ratio of 2:1 or 66.667%, or:

   $\%\ \text{up flushes}^{\text{control}} < \%\ \text{up flushes}^{\text{projected}} \rightarrow$

   H_{A1}: % up flushes$^{\text{control}}$ < 66.667%

2. During the *treatment* period, the actual ratio of up-to-down flushes are greater than during the control period, but still less than the projected ratio of 66.667%, or:

   $\%\ \text{up flushes}^{\text{control}} < \%\ \text{up flushes}^{\text{treatment}} < \%\ \text{up flushes}^{\text{projected}} \rightarrow$

   H_{A2}: % up flushes$^{\text{control}}$ < % up flushes$^{\text{treatment}}$ < 66.667%

The null hypotheses for both of the preceding alternative hypotheses is as follows:

H_{O1}: % up flushes$^{\text{control}}$ $\geq$ 66.667%

H_{O2}: % up flushes$^{\text{treatment}}$ $\geq$ 66.667%

The methods and procedures by which these hypotheses were tested are discussed at length in the following chapter.

CHAPTER 4: METHODS AND PROCEDURES

4.1 Introduction and overview of data collection

As stated throughout this thesis, this research project focuses upon the Sloan Uppercut® flushometer, model number WES-111. The toilets were monitored for a total of seven weeks to count the number of up versus down flushes. During the first four weeks, the control period, there were no instructional signs in the stalls other than the small stickers attached to the flush handles (figure 18). The ‗treatment' for this experiment consisted of adding instructional signs (figure 19) to each stall, which took place during the final three weeks of the seven-week trial. This was done in order to test the hypotheses outlined in the previous chapter.

Data were collected from a total of eight separate women's toilet stalls (two separate restrooms on different floors of the same building with a total of four stalls each). The restrooms are located in the new Columbia City Hall building at 701 E. Broadway in Columbia, Missouri. The City Hall building has been awarded gold-level LEED® certification from the Department of Energy. There are Sloan Uppercut® flushometers installed in each of its restrooms as part of the requirements for LEED® water efficiency. As stated previously, the exclusive use of women's restrooms was deemed necessary due to the fact that men typically utilize urinals rather than toilets if they desire a low-volume flush. The dual-flush toilets in City Hall are installed in the intended fashion, such that pulling upward on the handle produces a small flush and pushing down produces a large flush. Additionally, no signs had ever been posted to alert the user as to the handle‘s specialized functions other than the instructional stickers attached to the flush handles themselves (pictured in figure 18 in the previous chapter). The toilets were fitted with sensors that count the number of up and down flushes. Approval to install sensors and collect data was obtained from the City of Columbia‘s Office of Sustainability. Other than the Sustainability Manager, building employees and other users were not given any information about the study or the flush counting sensors unless they requested it. As detailed below, these sensors were designed, fabricated, and fitted by the MU Engineering Lab. An additional flushometer was purchased in order to allow the lab to design the flush counters off-site.

4.2 Description of natural field experiments

According to frameworks developed by Jayson Lusk and Jason Shogren (2007) in the field of experimental economics, the research carried out in this thesis can be classified as a natural field experiment. Lusk (2010) defines an experiment as ―a controlled investigation to determine causal relationships between variables.” His framework of the classifications of field experiments is shown below in table 4. Natural field experiments are generally considered to be the most desirable type of experiment because they mimic ‗real-world‘ situations as closely as possible. This is ideal due to the context-rich experimental environment and the high degree of control that the experimenter has over conditions. The research conducted in this thesis qualifies as a natural field experiment because a) the subjects were self-selected, b) data collection took place in actual restrooms in a public building, and c) a majority of the subjects were not aware of the experiment.

Table 4: Types of field experiments

Type of experiment	Subject pool	Context, information, commodity traded	Subjects know?
Conventional lab experiment	recruited students	abstract	yes
Artefactual lab experiment	recruited non-students	abstract	yes
Framed field experiment	recruited or self-selected non-students	field	yes
Natural field experiment	**self-selected non-students**	**field**	**no**

Source: Lusk 2010

Due to these characteristics, Columbia City Hall therefore provided a fairly desirable location to conduct research.

4.3 Design, fabrication, and installation of flush counters

A device able to accurately count the number of up and down flushes for this type of toilet, and to differentiate between the two, did not exist before the start of this project. As such, the collaboration of the MU Engineering Lab was needed to design and manufacture a total of eight flush counters. The costs associated with design, fabrication, and labor were acquired via an MU Research Council grant.

Initial design of flush counters

Figures 20 and 21 below illustrate model number WES-111 of the Sloan Uppercut® flushometer, as installed in Columbia City Hall before the start of the experiment.

Figure 20: Sloan Uppercut®, as installed in Columbia City Hall 1

Figure 21: Sloan Uppercut®, as installed in Columbia City Hall 2

In order to accurately count the number of up and down flushes, a series of sensor magnets were attached to plastic rings that were then fitted onto the flushometer and handle. The fact that the handle can rotate 360 degrees within the mounting caused some initial problems in design; magnets and sensors had to be placed all the way around both the handle and the flushometer to ensure accurate counts. The plastic components and magnets were attached firmly to the flushometer and handle to assure that they could not be removed, misaligned, or easily tampered with. Electrical wiring (coated with plastic for safety) connected the magnetic rings to a wall-mounted plastic case, which housed a small digital flush count tracker and a battery pack. Each flush counter required four AA batteries which did not need to be replaced for the entire duration of the trial. Finally, a reproduction of the instructional sticker on the handle was attached to the larger sensor ring. This was necessary in order to replicate ordinary conditions as closely as possible, as the flush counters covered the original stickers. Photos of the flush counter, magnetic rings, and housing are provided below.

Figure 22: Magnetic sensor rings 1

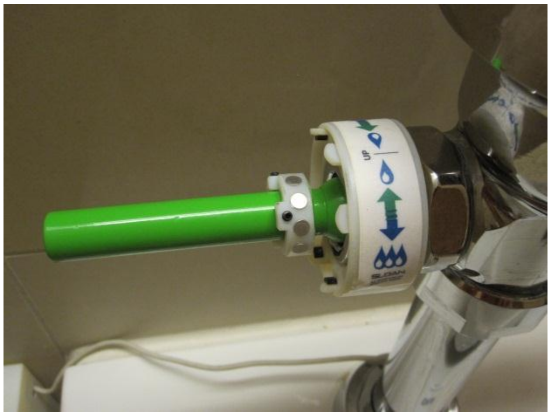


Figure 23: Magnetic sensor rings 2

Figure 24: Flush counter ring and digital readout housing

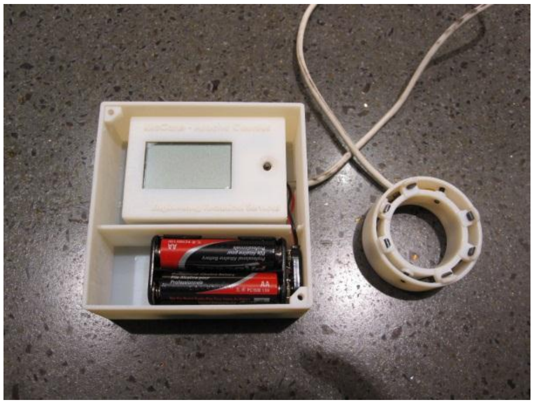


Figure 25: Flush counter rings and housing, installed

4.4 Data collection procedures

Data were usually collected each morning between 8:30 and 9:30 a.m. On several occasions, data were not collected until later in the morning due to scheduling conflicts. The data collected were recorded as data for the previous day; for example, data collected on Tuesday morning were counted as Monday‘s data. In addition to recording flush counts daily, the digital counters were reset and each flush counter apparatus was carefully inspected to ensure proper function and fit. Due to the sensitive nature of the magnetic counters, the magnetic rings occasionally moved out of place and yielded several highly unusual observations (i.e., extremely high counts or none at all). These observations are considered as missing and therefore are not included in the data set.

4.5 Phases of research

The research trial occurred over a seven-week period from Monday, June 20—Friday, August 6, 2011. Prior to the trial, a prototype flush counter was installed for several weeks in one stall in order to determine whether the design needed to be modified. After this initial period, during which the prototype functioned accurately and reliably, the seven remaining flush counters were fabricated and installed. Data were collected only on business days as City Hall is closed on the weekends. Data were also not collected on Monday July 4, which occurred during the third week of the control period, as the building was closed for the holiday.

The control period consisted of four consecutive weeks (Monday June 20—Friday July 15), during which the signage in the restrooms was the same as before the trial (small stickers but no wall plates). The treatment period occurred over the three consecutive weeks immediately following the control period (Monday July 18—Friday August 6). The treatment, as discussed in Chapter 3, was to install two instructional wall plates in each stall, one on the wall directly above the flushometer and the other on the rear of each stall door. At the end of the trial, all equipment associated with data collection were removed from the stalls with the exception of the wall plates. Photos of the wall plates in situ are provided below in figures 26 and 27.

Figure 26: Instructional wall plate as installed in City Hall 1

Figure 27: Instructional wall plate as installed in City Hall 2

4.6 Variables

The dependent variable for this experiment was the proportion of up to down flushes. This is expressed as a percentage (percentage of up flushes). Important independent variables included floor of building (2 or 3), week of the trial (1 through 7), and treatment period (yes or no). Each of these variables will be discussed in further detail in the following chapter, and the results of this study will be presented and discussed.

CHAPTER 5: DISCUSSION AND ANALYSIS OF RESULTS

5.1 Results and discussion

Control period

Numerical data for the control period is summarized in table 5 below. The table includes the dependent variable ―percentage of up flushes”, which was 26.6% for the control period. The projected percentage of up flushes, 66.67%, is not included in these tables for simplifying purposes but should be considered for comparison. The independent variables ―floor of building” and ―stall number” are also represented; day of week and week of trial are not shown for simplicity. Complete data tables for each week of the trial are included in Appendix 1.

As the table clearly shows, average flush counts were well below the expected 2:1 up-to-down ratio during the control period; only 26.6% of total flushes were up flushes, which is much less than the expected percentage of 66.67%. The failure to reach the projected percentage of up flushes holds true even when the two different floors of the building are analyzed independently of each other. Floor 2 had an average up flush rate of 35.3%, while floor 3 had a rate of only 17.6%. The difference between projected and actual percentages of up flushes is stark; thus H_{A1}: % up flushes$^{\text{control}} < 66.667\%$. The first alternative hypothesis is therefore accepted and the null hypothesis of H_{O}: % up flushes$^{\text{control}} \geq 66.667\%$ is rejected.

Table 5: Control period results summary

Floor and stall	Number of flushes			Relative % of up and down flushes	
2nd floor	# of up flushes	# of down flushes	# of total flushes	% of up flushes	% of down flushes
Stall 1 totals	126	100	226	55.8%	44.2%
Stall 2 totals	122	214	336	36.3%	63.7%
Stall 3 totals	56	185	241	23.2%	76.8%
Stall 4 totals	30	112	142	21.1%	78.9%
2nd floor totals	334	611	945	35.3%	64.7%
3rd floor					
Stall 1 totals	33	252	285	11.6%	88.4%
Stall 2 totals	84	92	176	47.7%	52.3%
Stall 3 totals	26	213	239	10.9%	89.1%
Stall 4 totals	20	205	225	8.9%	91.1%
3rd floor totals	163	762	925	17.6%	82.4%
Totals for both floors	**497**	**1373**	**1870**	**26.6%**	**73.4%**

Treatment period

The treatment period, during which wall plates were displayed in each stall, is summarized in table 6 below. During treatment, an increase in the percentage of up flushes was observed but still did not reach the projected level of 66.67%. The average percentage of up flushes for the treatment period was 38.8%. Again, even when floors 2 and 3 are examined independently of each other, neither meets the projected percentage; the percentage of up flushes were 49.5% and 27.6%, respectively. Therefore, the second alternative hypothesis, H_{A2}: % up flushes$^{\text{control}}$ < % up flushes$^{\text{treatment}}$ < 66.667% is accepted and the null, H_{O2}: % up flushes$^{\text{treatment}}$ $\geq$ 66.667%, is rejected.

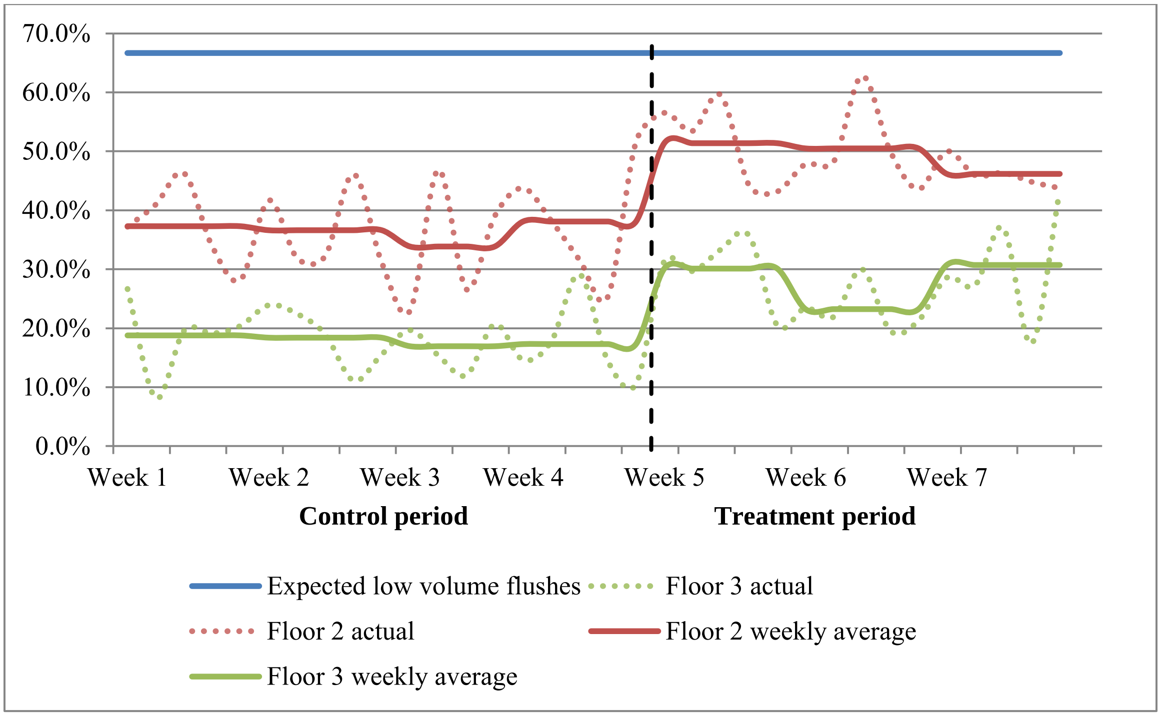
Table 6: Treatment period results summary

Floor and stall	Number of flushes			Relative % of up and down flushes	
2nd floor	# of up flushes	# of down flushes	# of total flushes	% of up flushes	% of down flushes
Stall 1 totals	85	75	160	53.1%	46.9%
Stall 2 totals	86	111	197	43.7%	56.3%
Stall 3 totals	91	60	151	60.3%	39.7%
Stall 4 totals	47	69	116	40.5%	59.5%
2nd floor totals	309	315	624	49.5%	50.5%
3rd floor					
Stall 1 totals	32	148	180	17.8%	82.2%
Stall 2 totals	69	85	154	44.8%	55.2%
Stall 3 totals	47	74	121	38.8%	61.2%
Stall 4 totals	17	125	142	12.0%	88.0%
3rd floor totals	165	432	597	27.6%	72.4%
Totals for both floors	**474**	**747**	**1221**	**38.8%**	**61.2%**

Significance of treatment and other effects

Figure 28 below depicts the weekly averages graphically. The blue line represents a constant value of 66.67%, the expected percentage of up flushes. The dotted lines indicate data plots by day for floors 2 and 3, while the solid lines are weekly averages. The vertical black dotted line at week 5 indicates the beginning of the treatment period.

Figure 28: Observed vs. projected percentage of up flushes by week



Several inferences can be made by examining the chart above. First, as indicated in tables 5 and 6, there is an obvious divergence between the observed and projected percentages of up flushes. Second, one can easily see the increase in percentage of up flushes at the beginning of the treatment period, although as previously indicated, even with instructional signage, the actual percentage of up flushes is far below the company projection. Third, there is a clear difference between the up flush rates between the second and third floors. While the averaged trend lines illustrate a similar pattern between the two floors (i.e., the lines closely mirror each other), the second floor maintains a significantly higher percentage of up flushes during the entire course of the seven-week trial. The potential reasons for this will be explained in further detail later in this chapter.

Table 7 below depicts an analysis of variance for the dependent variable ‗percentage of up flushes‘ and the predictor variable ‗treatment‘. The significance value, 0.000, confirms that the treatment has a statistically significant effect on the percentage of up flushes. However, while the treatment had *some* effect, it was not nearly enough to bring the percentage of up flushes close to the projected level.

Table 7: Analysis of variance for the independent variable 'treatment'

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	0.949	1	0.949	20.962	0.000^a
	Residual	10.505	232	0.045		
	Total	11.454	233			

a. Predictors: (Constant), Treatment
b. Dependent Variable: % Up flushes

Table 8 below shows an analysis of variance for the dependent variable ‗percentage of up flushes‘ and the predictor variable ‗floor 2‘. The significance value, .000, confirms that the floor number also has a statistically significant effect on the percentage of up flushes. Potential reasons for this will be discussed in detail later in this chapter.

Table 8: Analysis of variance for the independent variable 'floor 2'

ANOVA^b

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	3.504	1	3.504	21.347	.000^a
	Residual	35.619	217	.164		
	Total	39.123	218			

a. Predictors: (Constant), Floor 2
b. Dependent Variable: % Up

5.2 Analysis and interpretation of results

As the previous discussion has shown, the data collected for this research trial strongly support both alternative hypotheses presented in Chapters 3 and 4. In other words, even with instructional signage, the Sloan Uppercut® does not result in the expected 2:1 U/D ratio. It is worth repeating that Sloan uses this ratio in their own water savings calculation tool, and as demonstrated in Chapter 3, this ratio is a conservative estimate of actual U/D ratios. In fact, the ratios are essentially the opposite of what would be expected, indicating the importance of the choice of a default. Additionally, the data show that Sloan‘s own claim of the Uppercut‘s® ability to save 21% more water than a conventional 1.6 GPF model is, at least in some cases, inaccurate. Even during the treatment period, only a 12.1% decrease in water use would have been realized relative to1.6 GPF flushometers. As such, where water efficiency is the goal, the Uppercut® does not perform nearly as well as it is advertised to do in a real-world setting. It is especially important to note that in a public restroom, users have no cost-saving incentive to conserve water. If an individual does not have intrinsic motivation to be environmentally conscious, then they may not take note of, or care about, the correct use of the toilet. However, if the default option was the water-saving option (a low-volume flush), then the user would most often choose the correct action despite their lack of incentive to do so.

Water usage as a function of flush counts

User behavior is clearly impacted by the Uppercut‘s® design, but it is also important to note how much water is wasted as a result of that behavior. When multiplying up and down flushes by their respective 1.1 and 1.6 flush volumes, the following data in table 9 are obtained.

Table 9: Projected vs. actual water consumption of toilets during experiment[a]

	Control period	Treatment period
Projected water usage (in gallons):	2369[b]	1547[c]
Actual water usage (in gallons):	2745	1717
Water waste (in gallons):	376	170
Water waste (percent of projected):	15.87%	11.00%

[a] These calculations were derived as follows:

- Projected water use: ((Total number of flushes during period x 66.67%) x 1.1 GPF) + ((Total number of flushes during period x 33.33%) x 1.6 GPF)
- Actual water use: ((Total number of flushes during period x actual percentage of up flushes) x 1.1 GPF) + ((Total number of flushes during period x actual percentage of down flushes) x 1.6 GPF)
- Water waste (in gallons): Actual water use – projected water use
- Water waste (percent of projected): Water waste (in gallons) / projected water usage (in gallons)

[b] 1870 total flushes over a four-week period

[c] 1221 total flushes over a three-week period

The amount of water wasted may seem insignificant to some; many enterprises use hundreds or even thousands of gallons of water per *day* in their operations. However, it should be noted that traffic into City Hall is relatively low. Over the entire course of the seven week-trial, there were 3091 total flushes counted. Water waste should therefore be evaluated as a percentage of the total rather than in absolute terms; the more water consumed by a business or other enterprise, the greater the volume of water that is wasted. Table 10 below shows estimated water use and waste if the results of the experiment were extended over the course of a year, and also what standard 1.6 GPF and high-efficiency 1.28 flushometers would consume during the same period.

Table 10: Estimated water consumption of toilets in one year[a] based on experiment results[b]

	Without treatment	With treatment
Projected water usage (in gallons):	29250	29250[c]
Actual water usage (in gallons):	33894	32468
Water waste (in gallons):	4644	3218
Water use of a 1.6 GPF flushometer (hypothetical):	36947	N/A
Water use of a 1.28 GPF flushometer (hypothetical):	29558	N/A

[a] These calculations were derived as follows:

- Total number of flushes per year (not shown): (3091 total flushes / 34 days of research trial) x 254 working days per year = 23092
- Projected water usage: ((Total number of flushes per year x 66.67%) x 1.1 GPF) + ((Total number of flushes per year x 33.33%) x 1.6 GPF)
- Actual water use: ((Total number of flushes per year x actual percentage of up flushes during each period) x 1.1 GPF) + ((Total number of flushes per year x actual percentage of down flushes during each period) x 1.6 GPF)
- Water waste (in gallons): Actual water use – projected water use
- Water use of a 1.6 GPF flushometer (hypothetical): total number of flushes per year x 1.6

Water use of a 1.28 GPF flushometer (hypothetical): total number of flushes per year x 1.28

[b] Weekends and holidays excluded (estimated 254 working days per year)

[c] Assuming same water usage with and without treatment

The effects of this flush design appear more substantial when extrapolated over a year‘s time. Even with additional instructional signage added, over 3200 gallons of water are wasted each year due to the flushometer‘s design.

Factors affecting the experimental data

As mentioned previously, certain independent variables appeared to have more of an effect on the percentage of up flushes than others. Averages for day of week and week of trial remained fairly constant over the course of the study (with the exception of the change between weeks 4 and 5, when the treatment was put into place). Patterns in stall numbers can also be seen in the raw data. Certain stalls were used far more frequently than others (usually the two nearest the door), while other stalls had a higher proportion of up flushes than others. This makes sense if one takes City Hall employees into account; it is likely that some ‗prefer‘ certain stalls and/or would be more interested in making use of the water-conserving feature of the toilet.

The two variables that had the most effect on the number of up flushes, however, were the floor and the treatment period. Recall from tables 7 and 8 earlier in this chapter that both of these variables were found to be statistically significant. The treatment effects are easily explained, as one would expect the percentage of up flushes to increase due to signage. Indeed, this effect was predicted in the second alternative hypothesis presented in this thesis. The effect of the different floors of the building, however, require further explanation: as a LEED$^{®}$ gold-level-certified building, City Hall has an Office of Sustainability to ensure that the LEED$^{®}$ requirements are continually met. This office is located on the second floor, just down the hall from one of the experimental restrooms. One may surmise that sustainability-oriented employees would be more likely to both have knowledge of the dual-flush nature of the flushometers and also to be motivated to use them correctly. Conversely, the third floor of City Hall contains the Columbia Office of Public Works. Not only are the Public Works employees less likely to know about or correctly use the dual flush mechanism, there is also a greater amount of foot traffic from people who do not work in the building and thus are even less likely to use the flushometer correctly. Thus, the factors enumerated above help to explain the noticeable differences in percentage of up flushes between the two floors, although further research would be necessary in order to explain this relationship more fully.

Limitations and weaknesses of experiment

While the implications of this study are clear—that is, that the design of the default mechanism on a dual-flush toilet has a pronounced effect on whether it is used correctly—the conditions for the experiment were not ideal. First, as already described, the presence of the Office of Sustainability on the second floor seems to have had an effect on user behavior. It would have been helpful to have prior knowledge of the subjects' familiarity with the Uppercut's® mechanism. Second, data more representative of the population as a whole may have been obtained from a larger facility with a greater amount of foot traffic due to the larger sample size. Third, while the MU Engineering Lab made their best efforts to minimize the size of the flush counters, they were still quite visible on the flush handles. While most subjects had no knowledge of the experiment, the mere presence of the counters may have changed the behavior of some users. For example, some may have wondered if the toilet was under maintenance, while others may have had concerns about what the mechanism was for and whether it could be violating their privacy. Finally, while City Hall employees in general were not given any information about the study, it was necessary to inform certain individuals. This project did, after all, require the permission and cooperation of City Hall administration.

Therefore, it is highly likely that some word-of-mouth information was spread to building employees, especially those who asked questions. The effects of these factors are not known, but they were minimized as much as possible; those who did ask about the flush counters were told only that the mechanisms counted the number of flushes and were part of a project to measure water use in the building.

Implications of results

If maximizing water efficiency is the intended function of a dual flush toilet, then it is clear that the Sloan Uppercut® falls far short of this expectation. The question, then, is not *whether* the Uppercut® wastes water, but *why* it does so. Returning to the previous discussion of behavioral economics, remember that flushing the toilet is what Sunstein and Thaler (2008) refer to as an Automatic response—a decision that is made quickly and unconsciously. For most people, pushing a toilet handle down in order to flush it is second nature. The experiment carried out in this thesis indicates that even with abundant instructional signage in each stall, and even with a population sample that is biased *toward* choosing the appropriate action, the ‗decision' to push down isn't really a decision at all. Instead, it is a reflexive, ingrained response that, for most users, requires a deliberate mental effort on the part of the user to override. Again, this is referred to as the ‗default' option, and as previously discussed, behavioral economics research indicates that defaults can be a powerful tool in guiding people toward making better decisions.

As such, the results of this study indicate that the design of the Uppercut® prevents the mechanism from maximizing water savings. Given that individuals need a low-volume flush a majority of the time, a more intuitive design would be to reverse the mechanism such that pushing the handle down results in a low flush. Alternatively, those seeking to conserve water could also choose one of the many other designs of dual flush mechanisms described in Chapter 3. Those that have two separate buttons (for example, the Caroma model shown in figure 12) eliminate a default option altogether; the user must choose between one button or the other, rather than using the same mechanism to perform two distinct functions. Alternatively, a non-dual flush, high-efficiency 1.28 flushometer would also save a considerable amount of water over the Uppercut®.

It is important to take into account, however, that firms and individuals often have very different incentives—that is, not every stakeholder prioritizes water savings above all else. There are a number of incentives for both individuals and firms to adopt water-saving technologies such as dual flush toilets. Some customers may seek only to save money on utility bills, while other parties may purchase the Uppercut® in order to conform to LEED® building requirements, as Columbia City Hall did. Still others may choose to purchase the Uppercut® in order to promote themselves as a sustainability-oriented enterprise, or simply because of their personal value systems. Indeed, many commercial and industrial firms have embraced the growing trends of sustainability and _green‘ practices, not only to improve their public image, but also because water and energy savings improve their bottom line.

Additionally, because the *buyer* and the *user* of a dual flush toilet are usually not the same person in commercial applications, it should be noted that the user of a dual flush toilet may not have any incentive at all to choose the correct flush mechanism. The user is not responsible for paying for the water consumed by the commercial establishment. Unless the user values water savings intrinsically, he or she will realize no personal gain from the Uppercut®. This lack of incentives makes the design of the default option even more important. In short, the Uppercut® needs to be redesigned if it is to meet the needs of all of these and any other similarly motivated potential buyers.

There is variation among the incentives of dual flush toilet *buyers*, to be sure, but there are entirely different motivations where the *manufacturers* are concerned. Manufacturers, as firms, are interested primarily in profitability. Decreasing the amount of water consumed in a toilet helps the manufacturer to target a specific, eco-conscious market for toilets. However, in contrast to the users, who often seek to maximize water savings, manufacturers seek to maximize profit—and a part of this process is maintaining brand reputation. Manufacturers will not likely sacrifice aesthetics or performance—that is, reliable operation without clogs or the need for repair—for water savings. While a reputation for reliable and strong performance at a reasonable price benefits both the manufacturer‘s status *and* its bottom line, minimizing the water use of toilets does not appear to directly benefit the manufacturer in the same way it would the buyer. Thus, for the purposes of saving water, the incentives of manufacturers, users, and buyers are all quite misaligned.

5.3 Relative cost advantages/disadvantages of dual flush toilets

While it is true that the Sloan Uppercut® is competitively priced with other *dual flush* flushometers, it is considerably more expensive than its single-flush counterparts. Table 11 below compares the pricing of the Uppercut® to a selection of other flushometers. Except where noted, prices were all obtained from the same source, Mr. Supply, an online discount plumbing retailer, and include shipping fees. These are prices available to the general public.

Table 11: Price comparison of select flushometers, lowest to highest

Manufacturer	**Model**	**Single or dual flush**	**Type of mechanism**	**GPF**	**Price**
Sloan	Regal®	single	manual	1.6	$72.00
American Standard	FloWise	single	manual	1.28	$90.72
Delany	Flush Boy	single	manual	1.6	$101.96
Sloan	Royal®	single	manual	1.6	$109.43
Sloan	Uppercut®	dual	manual	1.1/1.6	$134.45[a]
American Standard	Selectronic® FloWise	single	hands-free	1.28	$245.38
Sloan	ECOS®	dual	hands-free	1.1/1.6	$351.98
American Standard	Selectronic® FloWise	dual	hands-free	1.1/1/6	$501-$599[b]

[a] *Includes two wall-mounted signs as shown in figure 19*

[b] *Source:http://www.americanstandard-us.com; all others, mrsupply.com*

One can see from the table that in general, the price of the flushometer increases as more desirable features (i.e., lower flush volume or hands-free operation) are added. It should also be noted that the Uppercut® is currently the only manually-operated dual flush flushometer readily available for commercial applications; therefore, prices should be compared accordingly. Even so, the $62 price difference between the Uppercut® and Sloan‘s base model flushometer, the Regal®, is substantial and may deter some of the more profit-driven consumers described previously. A financially savvy consumer would weigh the additional cost of the Uppercut® against the water savings realized.

Costs of water utilities

While up-front costs are important to consider, consumers‘ desire to conserve water will also be affected by local water utility rates. These vary widely from city to city and region to region, as shown in table 12 below.

Table 12: Water utility rates of selected cities

City	Marginal commercial summer rate (per 1,000 gallons)	Marginal commercial non-summer rate (per 1,000 gallons)
Denver, CO	$3.38	$1.69
Phoenix, AZ	$3.77	$2.44
Portland, OR	$3.86	$3.86
Columbia, MO	$4.20	$2.78
Atlanta, GA	$6.16	$6.16

Sources: Denver Water 2011; City of Phoenix 2011; Portland Water Bureau 2011; Columbia Water and Light 2010; City of Atlanta 2008

As the cost of water increases, toilet buyers have more of an incentive to purchase water-saving appliances such as the Uppercut®. Table 13 below uses the data obtained from Columbia City Hall to estimate how much money the Uppercut® could save a firm versus the Sloan Regal®, a base-model single-flush flushometer, depending on how many times the toilet is flushed over a period of time. For some perspective, a toilet in Columbia City Hall is flushed an average of 28860 times over a period of ten years and uses 40577 gallons of water during that time. It should be noted that City Hall has a relatively low volume of user traffic, especially when compared to a larger commercial building such as a hospital, school, or airport. The table assumes that instructional signs are used in conjunction with the Uppercut® so the average water savings under ―treatment” scenario are used.

Table 13: Dollar value of water savings of the Sloan Uppercut®[a]

		Cost per 1000 gallons						
Total number of flushes per toilet		$2.00	$2.50	$3.00	$3.50	$4.00	$4.50	$5.00
	25000	-52.75	-50.32	-47.89	-45.47	-43.04	-40.62	-38.19
	50000	-43.04	-38.19	-33.34	-28.49	-23.63	-18.78	-13.93
	75000	-33.34	-26.06	-18.78	-11.50	-4.23	3.05	10.33
	100000	-23.63	-13.93	-4.23	5.48	15.18	24.89	34.59
	125000	-13.93	-1.80	10.33	22.46	34.59	46.72	58.85
	150000	-4.23	10.33	24.89	39.44	54.00	68.55	83.11
	175000	5.48	22.46	39.44	56.42	73.41	90.39	107.37
	200000	15.18	34.59	54.00	73.41	92.81	112.22	131.63
	225000	24.89	46.72	68.55	90.39	112.22	134.06	155.89
	250000	34.59	58.85	83.11	107.37	131.63	155.89	180.15
	275000	44.29	70.98	97.67	124.35	151.04	177.72	204.41

[a] These calculations were derived as follows: (Total number of flushes per toilet x water savings of the Uppercut® vs. a standard 1.6 GPF flushometer x (water cost per 1000 gallons/1000)) – price difference between Sloan Uppercut® and Sloan Regal®

One can see from the table that the water savings realized from an Uppercut® increases as both local water costs and the total number of flushes increase. The more use an Uppercut® flushometer receives, the more quickly its price premium is offset by the value of the water it saves. While the Uppercut® appears to make financial sense for high-traffic establishments, this is less true for smaller firms. For example, even in summer when water is most costly, water rates in Columbia would need to reach more than triple their current levels in order for the Uppercut® to pay off at City Hall. Therefore, for purposes of saving money, the Uppercut® is best reserved for larger establishments.

CHAPTER 6: CONCLUSION

6.1 Summary of thesis

The overall goal of this thesis project has been to determine the relationship between the design of a fixture intended to save water, and the impact on user behavior and thus water consumption. In order to achieve this, the history and current design of dual flush toilets were reviewed in order to present a context for the specific toilet examined in the thesis. Behavioral economics provided the theoretical foundation for the examination of the default flush mechanism. Finally, a natural field experiment that evaluated actual behavior in a ‗real world' environment was performed. The results showed a large discrepancy between the water savings projected by the manufacturer and the actual water savings observed. The actual percentages of up flushes were virtually the opposite of what was projected, providing support for the fundamental importance of the default option. The treatment, instructional signage, did not overcome the poor choice of a default. The main conclusion drawn was that for the purposes of saving water, the Sloan Uppercut® should be redesigned in order to be more intuitive to the user. Finally, this experiment has provided original and quantifiable data that can aid in our understanding of human behavior within the context of default options, behavioral economics, and human decision-making in general.

6.2 Opportunities for further research

The research performed during the course of this thesis has provided answers to a number of questions; however, given the limitations of this study, additional inquiries are needed to expand on these findings. One example of this would be a study that reversed the flush mechanism of the Sloan Uppercut® such that pushing the handle down produces a small flush. This could be especially helpful in determining the influence of Automatic responses versus that of instructional signage and whether any performance issues arose. Another possible experiment could involve a longer treatment period to determine whether the initial effects of adding signage decrease over time. Given greater resources, a larger and more randomized sample group would likely provide results more representative of the population as a whole. Further research could also target the handicapped, elderly, and other sample groups with physical impairments in order to determine which flush mechanisms are best suited to their specific needs —that is, easiest to use correctly. Small buttons may be especially difficult for this group to use. Finally, a study of other types of dual flush toilets in public settings could help to determine which designs are the most conducive to water savings.

The scope of future research could be broadened further by incorporating several more general concepts. For example, research could address the incentives of stakeholders seeking to save water versus those of stakeholders seeking to increase profitability and attempt to align those incentives to maximize overall welfare. Similarly, a survey could be designed to determine consumers‘ willingness to pay for water-saving technologies. From a financial perspective, an in-depth financial cost-benefit analysis could be performed in order to determine the net present value of the flushometer over a specified period of time. Finally, a survey of water laws and regulations in other countries would be of use in order to determine their impact on the innovation of water-saving technologies.

In summary, it is hoped that this thesis has provided insight into an appliance that many individuals pay little attention to—which, in reality, is the reason why the default option is so important in its operation. Unless actual, real world human behavior is taken into account by the parties that design and market water fixtures and/or other appliances, the maximization of water savings (or that of any other scarce resource) will not be achieved.

APPENDIX 1: DAILY FLUSH COUNT DATA COLLECTION TABLES

Week 1: Monday, June 20 - Friday, June 24, 2011

	20-Jun		21-Jun		22-Jun		23-Jun		24-Jun							
2nd floor	up	down	up	down	up	down	up	down	up	down	2nd floor	up	down	total	% up	% down
Stall 1	10	8	12	5	7	8	8	7	6	4	Stall 1 totals	43	32	75	57.3%	42.7%
Stall 2	5	15	7	13	10	10	5	21	1	10	Stall 2 totals	28	69	97	28.9%	71.1%
Stall 3	1	4	3	12	5	5	6	8	1	6	Stall 3 totals	16	35	51	31.4%	68.6%
Stall 4 (large)	no data		3	6	3	6	3	7	3	8	Stall 4 totals	12	27	39	30.8%	69.2%
2nd floor totals	16	27	25	36	25	29	22	43	11	28	2nd floor totals	99	163	262	37.8%	62.2%
3rd floor											3rd floor					
Stall 1	3	11	0	15	2	11	6	20	5	14	Stall 1 totals	16	71	87	18.4%	81.6%
Stall 2	6	5	2	9	5	8	4	5	2	3	Stall 2 totals	19	30	49	38.8%	61.2%
Stall 3	3	9	2	15	0	9	2	20	1	15	Stall 3 totals	8	68	76	10.5%	89.5%
Stall 4 (large)	0	8	0	6	2	9	1	10	2	7	Stall 4 totals	5	40	45	11.1%	88.9%
3rd floor totals	12	33	4	45	9	37	13	55	10	39	3rd floor totals	48	209	257	18.7%	81.3%
Daily totals	**28**	**60**	**29**	**81**	**34**	**66**	**35**	**98**	**21**	**67**	**Totals for week**	**147**	**372**	**519**	**28.3%**	**71.7%**

Week 2: Monday, June 27 - Friday, July 1, 2011

	27-Jun		28-Jun		29-Jun		30-Jun		1-Jul	
2nd floor	up	down	up	down	up	down	up	down	up	down
Stall 1	5	6	5	9	8	6	4	4	7	6
Stall 2	10	9	5	6	8	11	12	10	5	4
Stall 3	4	7	4	10	3	15	2	7	1	12
Stall 4 (large)	1	6	1	7	1	10	no data		1	9
2nd floor totals	20	28	15	32	20	42	18	21	14	31
3rd floor										
Stall 1	4	13	1	9	1	19	2	9	0	13
Stall 2	5	4	6	4	8	3	no data		5	4
Stall 3	1	10	2	9	1	8	2	10	1	8
Stall 4 (large)	1	8	2	16	1	17	0	13	1	13
3rd floor totals	11	35	11	38	11	47	4	32	7	38
Daily totals	**31**	**63**	**26**	**70**	**31**	**89**	**22**	**53**	**21**	**69**

2nd floor	up	down	total	% up	% down
Stall 1 totals	29	31	60	48.3%	51.7%
Stall 2 totals	40	40	80	50.0%	50.0%
Stall 3 totals	14	51	65	21.5%	78.5%
Stall 4 totals	4	32	36	11.1%	88.9%
2nd floor totals	87	154	241	36.1%	63.9%
3rd floor					
Stall 1 totals	8	63	71	11.3%	88.7%
Stall 2 totals	24	15	39	61.5%	38.5%
Stall 3 totals	7	45	52	13.5%	86.5%
Stall 4 totals	5	67	72	6.9%	93.1%
3rd floor totals	44	190	234	18.8%	81.2%
Totals for week	**131.0**	**344**	**475**	**27.6%**	**72.4%**

Week 3: Monday, July 4 - Friday, July 8, 2011

	4-Jul		5-Jul		6-Jul		7-Jul		8-Jul	
2nd floor	holiday		up	down	up	down	up	down	up	down
Stall 1			8	4	5	1	8	7	6	5
Stall 2			2	11	6	6	6	21	10	10
Stall 3			4	21	3	6	4	15	0	10
Stall 4 (large)			0	11	1	4	3	15	no data	
2nd floor totals	0	0	14	47	15	17	21	58	16	25
3rd floor	holiday									
Stall 1			1	18	0	11	4	21	1	5
Stall 2			9	7	5	4	4	9	4	3
Stall 3			1	9	1	8	2	27	1	10
Stall 4 (large)			1	15	0	10	0	16	0	5
3rd floor totals	0	0	12	49	6	33	10	73	6	23
Daily totals	**0**	**0**	**26**	**96**	**21**	**50**	**31**	**131**	**22**	**48**

2nd floor	up	down	total	% up	% down
Stall 1 totals	27	17	44	61.4%	38.6%
Stall 2 totals	24	48	72	33.3%	66.7%
Stall 3 totals	11	52	63	17.5%	82.5%
Stall 4 totals	4	30	34	11.8%	88.2%
2nd floor totals	66	147	213	31.0%	69.0%
3rd floor					
Stall 1 totals	6	55	61	9.8%	90.2%
Stall 2 totals	22	23	45	48.9%	51.1%
Stall 3 totals	5	54	59	8.5%	91.5%
Stall 4 totals	1	46	47	2.1%	97.9%
3rd floor totals	34	178	212	16.0%	84.0%
Totals for week	**100**	**325**	**425**	**23.5%**	**76.5%**

Week 4: Monday, July 11 - Friday, July 15, 2011

	11-Jul		12-Jul		13-Jul		14-Jul		15-Jul							
2nd floor	up	down	up	down	up	down	up	down	up	down	2nd floor	up	down	total	% up	% down
Stall 1	6	3	9	4	2	1	4	10	6	2	Stall 1 totals	27	20	47	57.4%	42.6%
Stall 2	7	7	9	16	2	6	9	23	3	5	Stall 2 totals	30	57	87	34.5%	65.5%
Stall 3	1	8	6	12	2	4	4	17	2	6	Stall 3 totals	15	47	62	24.2%	75.8%
Stall 4 (large)	no data		2	10	0	2	3	9	5	2	Stall 4 totals	10	23	33	30.3%	69.7%
2nd floor totals	14	18	26	42	6	13	20	59	16	15	2nd floor totals	82	147	229	35.8%	64.2%
3rd floor											3rd floor					
Stall 1	0	12	0	16	1	5	1	25	1	5	Stall 1 totals	3	63	66	4.5%	95.5%
Stall 2	4	3	4	6	5	4	6	8	0	3	Stall 2 totals	19	24	43	44.2%	55.8%
Stall 3	2	10	2	14	0	4	1	16	1	2	Stall 3 totals	6	46	52	11.5%	88.5%
Stall 4 (large)	0	10	5	15	1	4	3	16	0	7	Stall 4 totals	9	52	61	14.8%	85.2%
3rd floor totals	6	35	11	51	7	17	11	65	2	17	3rd floor totals	37	185	222	16.7%	83.3%
Daily totals	**20**	**53**	**37**	**93**	**13**	**30**	**31**	**124**	**18**	**32**	**Totals for week**	**119**	**332**	**451**	**26.4%**	**73.6%**

Week 5: Monday, July 18 - Friday, July 22, 2011

	18-Jul		19-Jul		20-Jul		21-Jul		22-Jul							
2nd floor	up	down	up	down	up	down	up	down	up	down	2nd floor	up	down	total	% up	% down
Stall 1	7	8	7	9	6	5	5	8	4	8	Stall 1 totals	29	38	67	43.3%	56.7%
Stall 2	9	6	10	8	9	3	5	15	5	11	Stall 2 totals	38	43	81	46.9%	53.1%
Stall 3	5	3	11	3	6	3	8	4	8	4	Stall 3 totals	38	17	55	69.1%	30.9%
Stall 4 (large)	5	3	3	7	4	6	5	2	2	2	Stall 4 totals	19	20	39	48.7%	51.3%
2nd floor totals	26	20	31	27	25	17	23	29	19	25	2nd floor totals	124	118	242	51.2%	48.8%
3rd floor											3rd floor					
Stall 1	4	8	3	16	0	6	1	8	2	11	Stall 1 totals	10	49	59	16.9%	83.1%
Stall 2	6	6	9	7	6	6	7	9	3	7	Stall 2 totals	31	35	66	47.0%	53.0%
Stall 3	2	8	6	6	1	2	5	5	3	5	Stall 3 totals	17	26	43	39.5%	60.5%
Stall 4 (large)	4	13	1	16	2	4	2	5	1	12	Stall 4 totals	10	50	60	16.7%	83.3%
3rd floor totals	16	35	19	45	9	18	15	27	9	35	3rd floor totals	68	160	228	29.8%	70.2%
Daily totals	**42**	**55**	**50**	**72**	**34**	**35**	**38**	**56**	**28**	**60**	**Totals for week**	**192**	**278**	**470**	**40.9%**	**59.1%**

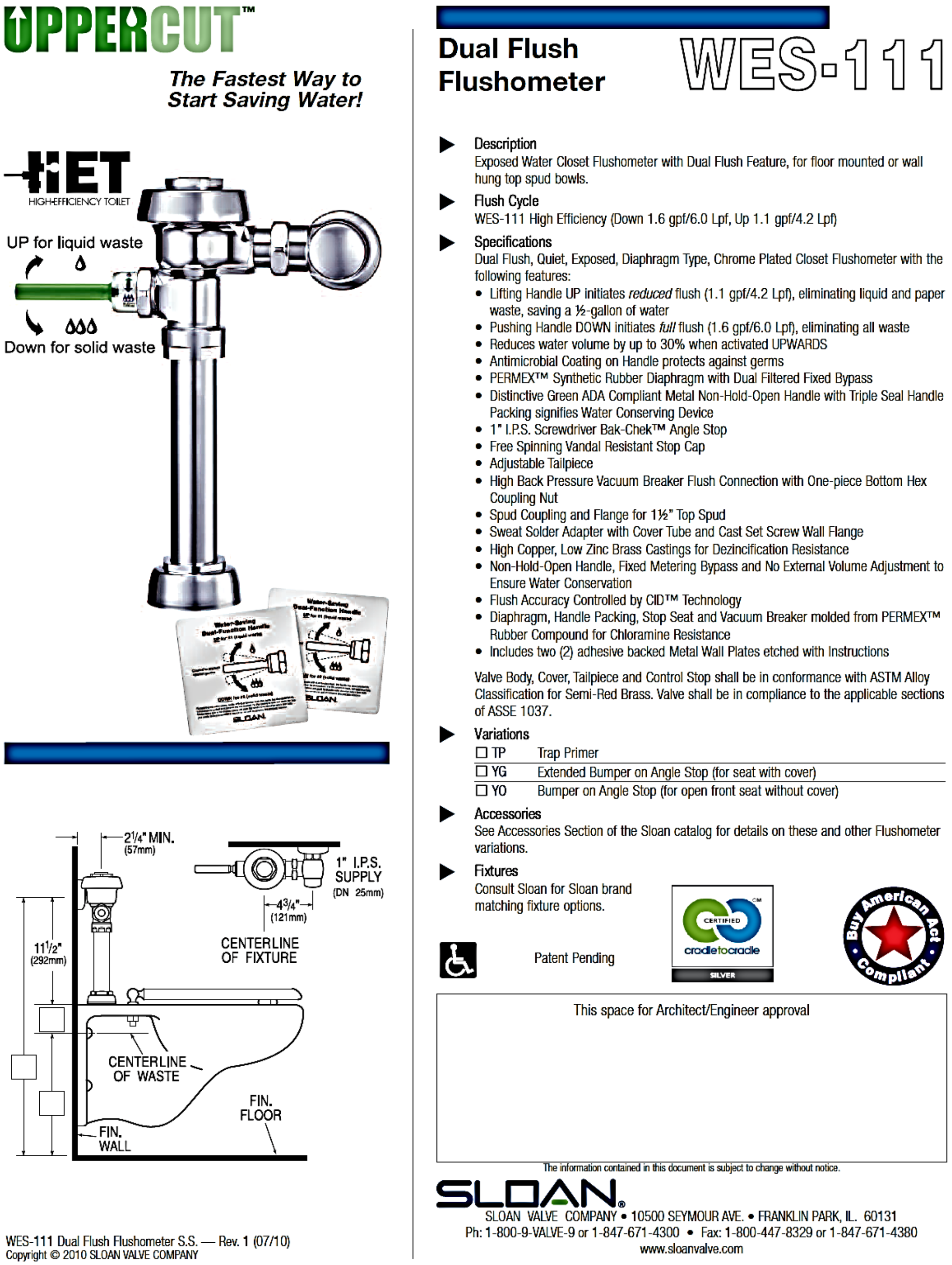
Week 6: Monday, July 25 - Friday, July 29, 2011

	25-Jul		26-Jul		27-Jul		28-Jul		29-Jul							
2nd floor	up	down	up	down	up	down	up	down	up	down	2nd floor	up	down	total	% up	% down
Stall 1	5	9	6	2	7	2	6	3	6	6	Stall 1 totals	30	22	52	57.7%	42.3%
Stall 2	6	11	3	7	6	9	4	8	4	5	Stall 2 totals	23	40	63	36.5%	63.5%
Stall 3	8	4	5	2	9	2	9	3	5	4	Stall 3 totals	36	15	51	70.6%	29.4%
Stall 4 (large)	3	2	0	4	5	3	3	8	2	7	Stall 4 totals	13	24	37	35.1%	64.9%
2nd floor totals	22	26	14	15	27	16	22	22	17	22	2nd floor totals	102	101	203	50.2%	49.8%
3rd floor											3rd floor					
Stall 1	2	11	1	9	2	4	1	17	4	15	Stall 1 totals	10	56	66	15.2%	84.8%
Stall 2	4	7	2	6	5	7	6	5	3	6	Stall 2 totals	20	31	51	39.2%	60.8%
Stall 3	4	6	2	3	4	4	2	5	3	3	Stall 3 totals	15	21	36	41.7%	58.3%
Stall 4 (large)	1	12	4	14	1	13	0	10	0	13	Stall 4 totals	6	62	68	8.8%	91.2%
3rd floor totals	11	36	9	32	12	28	9	37	10	37	3rd floor totals	51	170	221	23.1%	76.9%
Daily totals	**33**	**62**	**23**	**47**	**39**	**44**	**31**	**59**	**27**	**59**	**Totals for week**	**153**	**271**	**424**	**36.1%**	**63.9%**

Week 7: Monday, August 1 - Friday, August 5, 2011

	1-Aug		2-Aug		3-Aug		4-Aug		5-Aug							
2nd floor	up	down	up	down	up	down	up	down	up	down	2nd floor	up	down	total	% up	% down
Stall 1	6	2	5	3	8	3	3	3	4	4	Stall 1 totals	26	15	41	63.4%	36.6%
Stall 2	4	5	4	5	6	10	5	4	6	4	Stall 2 totals	25	28	53	47.2%	52.8%
Stall 3	4	6	3	6	4	6	4	4	2	6	Stall 3 totals	17	28	45	37.8%	62.2%
Stall 4 (large)	6	7	5	6	1	3	1	5	2	4	Stall 4 totals	15	25	40	37.5%	62.5%
2nd floor totals	20	20	17	20	19	22	13	16	14	18	2nd floor totals	83	96	179	46.4%	53.6%
3rd floor											3rd floor					
Stall 1	3	11	2	10	3	10	1	4	3	8	Stall 1 totals	12	43	55	21.8%	78.2%
Stall 2	4	4	4	3	3	3	2	7	5	2	Stall 2 totals	18	19	37	48.6%	51.4%
Stall 3	3	6	2	7	4	4	1	4	5	6	Stall 3 totals	15	27	42	35.7%	64.3%
Stall 4 (large)	0	4	1	4	no data		0	4	0	1	Stall 4 totals	1	13	14	7.1%	92.9%
3rd floor totals	10	25	9	24	10	17	4	19	13	17	3rd floor totals	46	102	148	31.1%	68.9%
Daily totals	**30**	**45**	**26**	**44**	**29**	**39**	**17**	**35**	**27**	**35**	**Totals for week**	**129**	**198**	**327**	**39.4%**	**60.6%**

APPENDIX 2: SPECIFICATIONS FOR SLOAN UPPERCUT® FLUSHOMETER, MODEL WES-111



The Fastest Way to Start Saving Water!

WES-111 Dual Flush Flushometer S.S. — Rev. 1 (07/10)

Dual Flush Flushometer

WES-111

Description

Exposed Water Closet Flushometer with Dual Flush Feature, for floor mounted or wall hung top spud bowls.

Flush Cycle

WES-111 High Efficiency (Down 1.6 gpf/6.0 Lpf, Up 1.1 gpf/4.2 Lpf)

Specifications

Dual Flush, Quiet, Exposed, Diaphragm Type, Chrome Plated Closet Flushometer with the following features:

- Lifting Handle UP initiates *reduced* flush (1.1 gpf/4.2 Lpf), eliminating liquid and paper waste, saving a ½-gallon of water
- Pushing Handle DOWN initiates *full* flush (1.6 gpf/6.0 Lpf), eliminating all waste
- Reduces water volume by up to 30% when activated UPWARDS
- Antimicrobial Coating on Handle protects against germs
- PERMEX™ Synthetic Rubber Diaphragm with Dual Filtered Fixed Bypass
- Distinctive Green ADA Compliant Metal Non-Hold-Open Handle with Triple Seal Handle Packing signifies Water Conserving Device
- 1" I.P.S. Screwdriver Bak-Chek™ Angle Stop
- Free Spinning Vandal Resistant Stop Cap
- Adjustable Tailpiece
- High Back Pressure Vacuum Breaker Flush Connection with One-piece Bottom Hex Coupling Nut
- Spud Coupling and Flange for 1½" Top Spud
- Sweat Solder Adapter with Cover Tube and Cast Set Screw Wall Flange
- High Copper, Low Zinc Brass Castings for Dezincification Resistance
- Non-Hold-Open Handle, Fixed Metering Bypass and No External Volume Adjustment to Ensure Water Conservation
- Flush Accuracy Controlled by CID™ Technology
- Diaphragm, Handle Packing, Stop Seat and Vacuum Breaker molded from PERMEX™ Rubber Compound for Chloramine Resistance
- Includes two (2) adhesive backed Metal Wall Plates etched with Instructions

Valve Body, Cover, Tailpiece and Control Stop shall be in conformance with ASTM Alloy Classification for Semi-Red Brass. Valve shall be in compliance to the applicable sections of ASSE 1037.

Variations

☐ TP	Trap Primer
☐ YG	Extended Bumper on Angle Stop (for seat with cover)
☐ YO	Bumper on Angle Stop (for open front seat without cover)

Accessories

See Accessories Section of the Sloan catalog for details on these and other Flushometer variations.

Fixtures

Consult Sloan for Sloan brand matching fixture options.

Patent Pending

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www.sloanvalve.com

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