TECHNICAL REPORT

Evaluating the Benefits and Costs of Increased Water-Use Efficiency in Commercial Buildings

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Preface

Improving water-use efficiency is increasingly seen as an important water management strategy for water agencies and rate payers in regions where supplies are limited. Water consumed in commercial buildings represents a significant amount of total public water supply deliveries—in 1995, around 18 percent of the water supplied in the southwest United States (1.5 billion gallons per day) or 17 percent in the country as a whole (Solley, Pierce, and Perlman, 1998). Investments in water-use efficiency can reduce water and energy use in commercial buildings and provide favorable returns to business owners. Estimating the value of efficiency investment can be difficult as the benefits accrue over time and in response to uncertain factors such as future water and energy prices. This uncertainty may contribute to under- or overinvestment in water-use efficiency.

The Jane and Marc Nathanson Family Foundation asked the RAND Corporation to develop a quantitative methodology and computer tool to help building managers, consultants, and efficiency-service representatives evaluate the net benefits of water-efficiency investments for commercial buildings. Note that a codirector of the Jane and Marc Nathanson Family Foundation, Marc Nathanson, also serves as the chair of Falcon Waterfree Technologies, a manufacturer of non–water-using urinals. This report describes such a methodology and its implementation in an easy-to-use, spreadsheet-based tool, the Building Water Efficiency Analysis Model (BEAM). The model utilizes a novel scenario-analysis approach and is demonstrated in a case study. Together, this report and tool provide a valuable new method for business owners and managers to identify sensible water-use efficiency investments. A copy of the model is available on this report's product page (see Groves, Fischbach, and Hickey, 2007). This work complements other RAND project work evaluating the benefits of water-use efficiency to water agencies and identifying robust water-management strategies for addressing uncertain climate-change impacts.

The RAND Environment, Energy, and Economic Development Program

This research was conducted under the auspices of the Environment, Energy, and Economic Development Program (EEED) within RAND Infrastructure, Safety, and Environment (ISE). The mission of RAND Infrastructure, Safety, and Environment is to improve the development, operation, use, and protection of society's essential physical assets and natural resources and to enhance the related social assets of safety and security of individuals in transit and in their workplaces and communities. The EEED research portfolio addresses environmental quality and regulation, energy resources and systems, water resources and systems, climate, natural hazards and disasters, and economic development—both domestically and internationally. EEED research is conducted for government, foundations, and the private sector. Questions or comments about this report should be sent to the project leader, David Groves (David_Groves@rand.org). Information about the Environment, Energy, and Economic Development Program is available online (www.rand.org/ise/environ). Inquiries about EEED projects should be sent to the following address:

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Summary

Water is a critical input to commercial buildings, yet the amount of water required to meet the uses in a typical commercial building is highly variable. Water use depends on the technology employed in water-using devices, system maintenance, and intensity of building use. The cost of water used in commercial buildings can be substantial, and commercial building owners and managers face increasing operation costs in regions where water is scarce and the costs of energy used to heat water are on the rise.

Commercial building owners have many options for improving the water-use efficiency of their buildings. They can increase efficiency by replacing or retrofitting water-using devices before scheduled remodels. They can also purchase more efficient models when updating restrooms and other water-using systems. Not all efficiency investments will make financial sense to a building owner. A key decision facing owners is whether and how much to invest in new technologies, retrofits, or repairs to improve water efficiency.

This report presents an analytical framework and describes a spreadsheet-based tool to help commercial building owners make reasoned judgments about various water-efficiency investment options. The framework considers the costs that are typically incurred when improving efficiency and seeks to include all tangible financial benefits. Specifically, it considers the avoided water, wastewater, and energy costs realized through increased water efficiency, and it allows the user to specify tiered utility rates that can have a significant impact on investment decisions. As future water savings from efficiency investments cannot always be forecast with certainty, the model includes an innovative scenario-analysis capability to consider variable increases in utility prices (a key uncertainty affecting the financial performance of water efficiency). Although the costs and water savings of efficiency devices may also be uncertain, the framework described here assumes that these characteristics are known with certainty.

The report begins by reviewing the basic financial framework that can be used to value water-use efficiency investments (Chapter Two). The standard financial framework for evaluating investment decisions weighs the present value (PV) of all costs against the PV of all benefits associated with an investment. The report describes the major costs and benefits associated with implementing a generic water efficiency improvement package for a commercial building. It describes the financial metrics that can be used to value water-efficiency investments and proposes a scenario method for considering uncertainty. In Chapter Three, the report describes many efficiency options in commercial restrooms and cooling systems.

Chapter Four describes a spreadsheet-based model called the Building Water Efficiency Analysis Model (BEAM). This model was developed to help building owners evaluate water-use efficiency options for commercial buildings. BEAM considers water use and efficiency improvements in restrooms (including toilets, urinals, sinks, and showers) and building-

cooling systems and is designed to be easily used by building managers, consultants, and efficiency service representatives. Although these efficiency options represent many of the major efficiency opportunities available to commercial business owners, there are others, such as replacing landscaping with low water–using designs, that the software tool does not model.

BEAM analyzes the financial performance of water-use efficiency packages in the following steps. First, the tool prompts the user for information about the building to be analyzed, the specific efficiency packages to be evaluated, and characterizations of resource price scenarios to be considered. Next, the tool uses this information, along with specific assumptions about water use by device type and standard building occupants, to estimate the water and energy use for the base case condition and under each of the different efficiency packages. After calculating water and energy use, BEAM begins the financial analysis. The tool uses a scenario analysis to illustrate the financial performance of the various efficiency packages under the different scenarios of water price, presenting scenario results as tables and graphs. For each scenario, BEAM performs a simple Monte Carlo simulation to evaluate the expected performance of each efficiency option under ranges of water and energy price trends specified for the specific scenario. Note, however, that, because BEAM does not consider uncertainty about device-specific water use or costs, the tool does not fully capture the inherent uncertainty in the benefit and cost calculations. Lastly, BEAM provides results for single combinations of efficiency packages and resource price scenarios and for the entire ensemble of packages and scenarios. A detailed user's guide is provided in Appendix A.

To demonstrate the capabilities of BEAM, Chapter Five presents a case study of restroom efficiency improvement potential based on the building headquarters of the RAND Corporation. The analysis considers two baseline efficiency conditions—one hypothetical, typical of an older building constructed prior to 1992, and the other consistent with the current building constructed in 2004. The analysis evaluates a wide range of efficiency investments from a simple retrofit of sinks and showers to the installation of the most efficient devices on the market, including non–water-using urinals and high-efficiency toilets. BEAM analyzes the financial performance of these investments under a broad range of scenarios reflecting different trends in water, wastewater, and energy utility prices.

The results for the first baseline efficiency conditions (pre-1992 fixtures) suggest highly favorable investment returns for all efficiency packages. A package that upgrades all devices to the 1992 standard and replacing urinals with non–water-using designs performs particularly well. A $41,000 investment pays for itself in about 3.6 years and provides a net present value (NPV) ranging from $91,000 to $122,000, depending on the scenario of future utility prices. A similar efficiency package that includes replacing existing toilets with the latest (and most expensive) high-efficiency toilets (1.28 gallons per flush) performs less well—it pays for itself in 6.5 years. For the second baseline efficiency case (post-1992 fixtures), only efficiency packages that upgrade urinals to non–water-using models perform well. Specifically, a $22,000 investment replacing all urinals with non–water-using models yields about $37,000 in NPV. The analysis shows that the benefit from the non–water-using urinals derives largely from reductions in operation and maintenance costs.

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Abbreviations

BEAM	Building Water Efficiency Analysis Model
CII	commercial, industrial, institutional
CR	concentration ratio
EANB	equivalent annual net benefit
gpf	gallons per flush
gpm	gallons per minute
gpv	gallons per visit
HCF	hundred cubic feet
HET	high-efficiency toilet
HEU	high-efficiency urinal
IRR	internal rate of return
kgal	kilogallon
LEED	Leadership in Energy and Environmental Design
O&M	operation and maintenance
NPV	net present value
PV	present value
RDM	robust decisionmaking
TDS	total dissolved solids
ULFT	ultralow-flush toilet
ULFU	ultralow-flow urinal

CHAPTER ONE

Introduction

Water is a critical input to commercial buildings. Water is used in restrooms and kitchens, for cooling, and for outdoor landscape irrigation. Estimates of water use by employee for commercial buildings range from 30 to 1,000 gallons of water per employee per day, depending on the type of business (Dziegielewski et al., 2000; Gleick et al., 2003). Heating of water for some of this use also contributes to a building's energy use. In the past, the cost of resources such as electricity and natural gas has overshadowed the cost of this water use to businesses. However, recent droughts and ongoing requirements for expanding available supply in water-scarce regions such as the southwest United States have led to a 27 percent average nationwide increase in urban water prices over the past five years (Clark, 2007). Commercial building owners and managers thus face rising operation costs in many parts of the country.

The amount of water required to meet commercial uses is highly variable. Water use depends on the technology employed in water-using devices, system maintenance, and intensity of building use. Improving any of these factors can increase water-use efficiency and lead to reduced building-operation costs. Water efficiency typically increases as building owners remodel or update their buildings. Improvements in operational processes can often lead to lower water use.

Commercial building owners can also invest in water-use efficiency, and investment options are vast. Building owners can increase water-use efficiency by replacing or retrofitting water-using devices before scheduled remodels for the water-saving benefits alone. For example, business owners can replace existing toilets with low-flow models and replace urinals with low-flow or non–water-using models. They can retrofit or replace faucets and showerheads with low-flow models. Water-using cooling systems can be retrofitted to recirculate water or to use less water within a recirculating system. Landscaping and irrigation practices can be modified to minimize water use. Owners may also choose to install more efficient devices than required when remodeling to realize the benefits from additional water savings.

Although many options exist for improving water-use efficiency, not all make financial sense to a building owner. Owners thus face the key decision of whether to invest in new technologies, retrofits, or repairs to improve water efficiency. This decision can be analyzed by weighing the up-front costs of improving efficiency with the financial benefits that accrue over time in the form of reduced water, wastewater, and energy bills, and identify investments that yield a positive rate of return.[1] To make an informed investment decision, such analysis should consider as many benefits and costs as possible. Costs include those for equipment and instal-

[1] Other benefits, such as favorable publicity for operating an efficient building, are also important to consider.

lation. In some cases, increasing efficiency also leads to increased operation or maintenance costs.

Projections of future costs and benefits of an efficiency investment are usually uncertain. Future water savings from efficiency investments cannot always be forecast with certainty. Changes in maintenance costs may be unknown for newer technologies or water-use methods, and care must be used when evaluating new technologies without a proven track record of performance. In many cases, however, the most uncertain factors affecting efficiency investment performance, however, are the costs of water, wastewater services, and energy.

Well-established methods exist to propagate uncertainty through a quantitative analysis (Morgan, Henrion, and Small, 1990). To apply such methods, a model composed of a single set of analytic relationships among all factors (including those specifying the investment decision or decisions) and outcomes is selected. Then the variability of all uncertain parameters within the model is characterized, typically using probability distributions. As any single outcome will depend on the uncertain parameters, a typical analysis computes probabilistically weighted results. The "expected" (or average) result is often reported along with the computed variability of the results.

Applying standard quantitative decision analysis can be problematic when factors affecting the outcome are not well understood or easily characterized by probability distributions. Future utility rates, for example, affect avoided costs from efficiency, yet are difficult to predict, as numerous, complex forces influence them (*Annual Energy Outlook 2007*, 2007). Future water and energy rates depend not only on the balance of future water and energy supply and demand, but also on regulatory conditions and political decisions by local and regional providers.

In cases in which important factors affecting an analysis are not well understood or easily characterized, analysts often turn to scenario analysis. Scenarios aim to describe future conditions that differ in ways important to those making decisions. They help decisionmakers understand how specific outcomes will affect their choices and thus suggest ways to reduce the vulnerability of their choices to uncertainties about the future. Scenario analysis can range from simple narrative scenarios,[2] as pioneered by Schwartz while working for Shell Oil (Schwartz, 1998), to advanced, quantitative, multiscenario methods such as robust decisionmaking (RDM) (Groves and Lempert, 2007; Lempert et al., 2006).[3]

This report presents an analytical framework and describes a spreadsheet-based tool to help commercial building owners and managers make reasoned judgments about various investment options, including doing nothing at all. The framework considers the costs that are typically incurred when improving efficiency and seeks to include all tangible financial benefits. Specifically, it considers the avoided water, wastewater, and energy costs associated with efficiency, and it allows the user to specify tiered utility rates that can have a significant impact on investment decisions. As future water, wastewater, and energy costs are critical

[2] A standard scenario analysis develops a small set of stories or quantified projections of future conditions that helps decisionmakers consider how select policies (or investments) would perform under a wide array of disparate future conditions. The results may then help identify alternative policies or investments that perform better across each scenario.

[3] RDM builds on standard scenario analysis by generating large ensembles of quantitative scenarios to reflect a wide range of possible future conditions. RDM then provides an analytic method for evaluating the performance of policy or investment across the large set of scenarios, identifying key vulnerabilities, and developing hedges that improve the robustness of the policies or investments.

to the financial performance of water-efficiency investments yet very difficult to predict, the model includes an innovative scenario-analysis capability to consider variable increases in utility prices. Building owners are likely to have different expectations about future utility prices, and thus the model enables the customization of these scenarios.

The report begins by reviewing the basic financial framework that can be used to value water-use efficiency investments (Chapter Two). In Chapter Three, we highlight many options for improving efficiency in typical commercial buildings. In Chapter Four, we propose a framework and describe a spreadsheet tool designed to evaluate the net benefits of water-use efficiency investments. In Chapter Five, we present a demonstration case study of efficiency improvement potential based on the building headquarters of the RAND Corporation. In Chapter Six, we offer some concluding remarks. Appendix A provides detailed instructions on using the spreadsheet tool developed for this study. Appendix B presents a case study of water use and cost assumptions.

CHAPTER TWO

Assessing Water Efficiency's Value to a Building Owner

The standard financial framework for evaluating investment decisions weighs the present value (PV) of all costs against the PV of all benefits associated with an investment. To evaluate water-use efficiency investments, one can use this same framework but must use care to identify and properly account for all the costs and benefits. Below, we describe the major costs and benefits associated with implementing a generic water-efficiency improvement package for a commercial building. We then describe the financial metrics that can be used to value investments in water-use efficiency. Next, we discuss methods for considering uncertainty and choosing an efficiency investment under uncertainty.

Costs and Benefits

The costs of an investment in water-use efficiency can be divided into up-front material and labor costs and ongoing operation and maintenance (O&M) costs. Material and labor typically account for most of the costs for equipment retrofits (the replacement of older, less efficient devices, with newer, more efficient devices). Some efficiency investments, however, lead to considerably increased O&M costs—particularly those that require process changes or more monitoring of water-using equipment. Chapter Three describes in detail these costs for a variety of efficiency improvements.

Improving efficiency provides direct financial benefits to building owners by reducing their costs for water, sewage, and energy. In some cases, implementing efficiency improvements can also lead to lower O&M costs.[1]

Business owners realize direct monetary benefits from efficiency in the form of avoided future resource costs. These avoided costs fall into three major categories:

- *Water costs:* the amount spent on water that all end uses at the facility consume
- *Wastewater costs:* the amount charged by the utility that disposes of any waste water leaving the facility; these costs are often tied to water costs (or billed as a single combined amount).

[1] Another potential nonmonetary benefit of efficiency to the business owner is positive publicity from adopting environmentally friendly activities, which can generate new customers and lead to an improved public image for the company. This publicity can be realized through channels including internal products (company newsletter, Web site), as part of the business' regular public relations activities, and through government or private programs that promote these efforts and provide certification for businesses adopting certain levels of efficiency. Examples of such programs include the Leadership in Energy and Environmental Design (LEED) certification levels and the ENERGY STAR® program. Although methods exist to quantify this benefit, such estimates are difficult to make and are typically considered along with other nontangible, financial investment considerations.

- *Energy costs:* costs associated with heating water (typically by electricity, natural gas, or both).

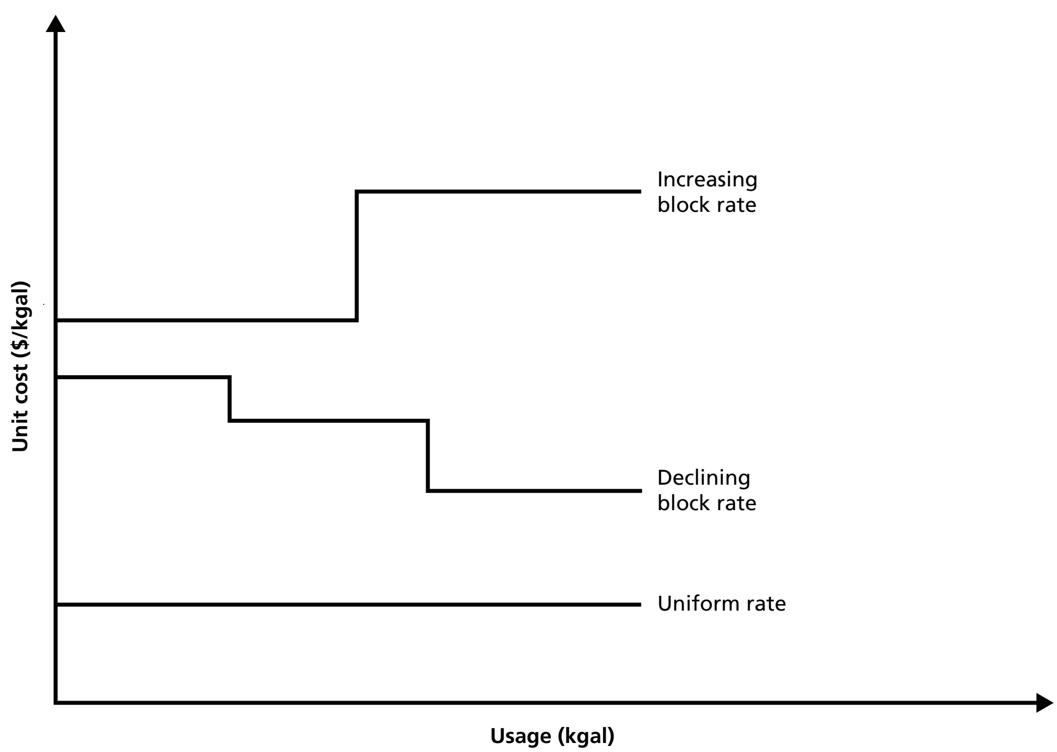
Reducing Water Costs

The water rate structure charged to the customer can affect the amount of water cost savings due to efficiency. Some providers charge a single, fixed monthly fee, although this practice is decreasing as awareness of water scarcity increases. This is often the practice for small or very small water systems or for residential areas with separate water supplies (e.g., those with homeowners' associations). If users face a fixed fee for water service, efficiency leads to no cost reduction.

About 50 percent of public water supply districts, small and large, charge a uniform price for water (EPA, 2002). In these districts, the average cost of water used and the marginal cost of water to the user (cost of using the next 1,000 gallons) is the same (Figure 2.1). Under a uniform rate, the average cost per unit of water remains the same, but the reduction in use will lead to a direct reduction in water costs. A 10 percent reduction in water use will reduce water bills by 10 percent.

Other districts (19 percent of all systems) charge a declining block rate to consumers, meaning that the price of water decreases at higher levels of usage (EPA, 2002). By reducing the marginal cost of water as usage increases, these systems provide an incentive to businesses

Figure 2.1
Examples of Different Water Pricing Structures



NOTE: kgal = kilogallon
RAND *TR461-2.1*

to use more water. These structures are more common in areas where fresh water is plentiful. Under a declining block-rate structure, the average cost per unit of water may actually increase as water use decreases (Figure 2.1). If the operation consumes more water than the base allocation, then efficiency will reduce the consumption of the cheaper, upper-tier water. The operation will then consume proportionally more of the expensive, lower-tier water and less of the less expensive, upper-tier water. The result will be greater average costs of water and water cost savings that are less than the water savings. For example, a 10 percent reduction in water use could reduce water costs by only 6 percent.

To encourage efficiency at the district level, however, rising block-rate structures (or conservation-rate structures) are often used. About 12 percent of water districts in the United States employ these pricing structures (EPA, 2002). In such a scheme, the price for the first block of water is lower than the prices for each successive block of water (Figure 2.1). For example, the first 1,000 kgal would cost $1 per kgal, the next 2,000 kgal would cost $2 per kgal, and so on. With increasing block-rate structures, however, water users can reduce costs at a greater rate than they save water through efficiency. If operations consume more water than the base tier allocation, then any savings will reduce their average cost, as they will use less high-cost water and thus use proportionally more of the low-cost water. If efficiency saves enough water to eliminate consumption in a higher tier, then the marginal cost of consumption decreases as well. As a result, conservation can reduce the per-unit water costs for all other water uses.

A few districts (about 1 percent) also employ a seasonal rate for which the price of water increases during the months in which usage is expected to be highest—typically during the summer, due to irrigation and outdoor use (EPA, 2002). A seasonal rate can be combined with an increasing block rate so that the seasonal rate applies only to higher-tiered water use.

Reducing Wastewater Costs

The amount of wastewater cost savings due to efficiency also depends on the rate structure. Waste water is billed either separately or together with water (i.e., as a percentage of metered water at a uniform rate), and it is generally billed either using a uniform rate or as a fixed fee. Under a uniform rate structure, efficiency leads to avoided wastewater costs similarly to the way in which it leads to avoided water costs under a uniform water rate structure. If waste water is billed as a flat fee, efficiency does not reduce the user's wastewater costs.

Reducing Energy Costs

Improving water-use efficiency can lead to lower energy bills, as heated water is used in commercial buildings for faucets, showers, dishwashing, and laundry. These savings can be significant for facilities that use substantial amounts of heated water, such as laundry facilities, hotels, and restaurants.

Business owners who obtain their energy from utilities typically face increasing rate structures (similar to those used for water). In some cases, they may be charged a higher rate for peak power than for off-peak power. The reductions in energy costs due to efficiency under the different rate structures are similar to the reductions in water costs. In regions with relatively high rates, energy savings due to efficiency can be significant to a building owner.

Investment Performance Metrics

Business planners and investors generally use several complementary metrics to evaluate an investment or choose among a set of investment options. These metrics can be used to evaluate investments in water efficiency as well. Each of the measures presented below provides a different view on the investment and will be useful to business owners depending on their ultimate concerns and objectives. In the following section, we discuss ways to consider uncertainty in investment evaluation analyses.

Net Present Value

The most direct measure of the potential value of a capital investment is the financial return provided over the lifetime of the investment. Measuring the benefits of an investment in currency (e.g., dollars) allows a decisionmaker to readily compare these benefits with the up-front and long-term costs of the investment.

When investors or business owners consider new investments, they frequently discount the monetary benefits received in future years using present-value (PV) discounting. PV discounting explicitly accounts for the time value of money—investing a dollar in a project today prevents a planner from using that dollar (plus the interest that it would accrue) for another purpose tomorrow. To compare all costs and benefits in terms of current dollars, expected future payments or costs are discounted back to their PV using the following formula:

$$PV = \frac{Y_t}{\left(1+r\right)^t},$$

where Y_t is the expected cost or benefit, r is the assumed discount rate, and t is the number of periods into the future in which the benefit is received.[2] The discount rate used for such calculations depends on the context. For a business with cash reserves, it may be the rate that a default alternative investment would yield (e.g., a high-yield money market account). For a business that must borrow to make the particular investment, the discount rate should be the interest rate charged by its lender. For a detailed discussion of discounting, see Frederick, Loewenstein, and O'Donoghue (2002).

Using this procedure, the PV of quantified, expected future benefits (and costs) can be compared to the initial investment cost. This calculation accounts for the opportunity cost of the investment—the lost value from spending now versus waiting and spending later—and allows the business owner to better understand the trade-offs involved with the current investment decision.

Net present value (NPV) is the sum of the discounted benefits minus the sum of the discounted costs over the lifetime of the project:

$$NPV = \sum_{t=0}^{N} \frac{Benefit_t - Cost_t}{\left(1+r\right)^t},$$

[2] Discount rates are typically set by the planner. They can range from 3 percent to 20 percent, but U.S. government agencies typically use 3 percent to 7 percent when evaluating potential new regulations (OMB, 1992).

where t is the time period, r is the assumed discount rate, and the number of periods, N, corresponds to the expected lifetime of the new installation. Typically, the capital cost accrues in the base period (period 0), and benefits begin to accrue once the project is complete. Normally, the benefits that business owners use to calculate NPV are simply the additional revenue that the project generates. As discussed, however, the benefits of a water-efficiency project are not typically positive revenues, but instead, the avoided water, wastewater, and energy costs from using less water. Thus, the owners would use the avoided costs—the difference between what they would have spent without efficiency and the amount spent with efficiency—as benefits for the NPV calculation.

If the calculated NPV is positive, then the expected benefits over the lifetime of the project exceed the investment cost and the overall return on the investment is positive. If comparing multiple options, business owners could use a simple decision rule and select the option with the largest NPV (assuming that each project has the same service life).

Equivalent Annual Net Benefits

NPV, however, depends heavily on the assumed discount rate and anticipated service life of the project. If the service life is uncertain, the assumed NPV could change dramatically with different horizon values. In addition, business owners cannot simply compare the NPV of several project options with notably different services lives to select the project with the highest rate of return. For example, consider two potential efficiency projects: one with a service life of 10 years and another with a service life of five years. Even if the first project has a larger NPV than the second project, the larger NPV does *not* necessarily indicate that the first project is the preferred option. This is because the first, longer-lived project has had five more years to accumulate benefits than the second option has had. If one were to renew or roll over the five-year investment at year 5, the total combined NPV could be larger than the 10-year investment.

To correctly compare these projects, each project must be given the same period to accrue benefits. In this example, the owner could compare the NPV of both projects using the same time frame by assuming a rollover or reinvestment in the shorter project at the five-year mark, thus giving each project 10 years to accrue benefits. Rolling over the shorter project one or more times is one method through which NPV can be modified to compare two or more projects with different service lives. However, this approach may not be appropriate when analyzing building-water efficiency: The business owner might prefer to switch to a newer, more efficient technology at the end of the shorter service life, and this method precludes such a switch.

Another method, which we apply in the BEAM tool, involves using the equivalent annual net benefit (EANB) metric. EANB represents the equivalent amount of income required annually to achieve the overall NPV of the project throughout its service life. As the metric is annualized, EANB can be compared across projects without concern for differing horizon values (Boardman et al., 2006).

To calculate EANB, one first calculates the annuity factor (A) for a given discount rate and time horizon.[3] The annuity factor is equivalent to an annuity of $1 per year discounted over the period considered:

[3] An annuity is commonly defined as a stream of payments provided at regular intervals over a certain period. In this context, the annuity is also assumed to provide the same amount in each payment.

$$A = \frac{1-\left(1+r\right)^{-N}}{r},$$

where r is the discount rate utilized and N is the overall service life of the project. Then, the *NPV* of the project is divided by the appropriate annuity factor to yield the EANB:

$$EANB = \frac{NPV}{A}.$$

Note that EANB essentially scales NPV so that it becomes a fixed, annual income figure that can be readily compared across projects with different service lives (Boardman et al., 2006).

Internal Rate of Return

Another important metric is the internal rate of return (IRR), defined as the discount rate at which the NPV of an investment equals zero. IRR is generally interpreted as the overall expected return on an investment as a percentage of the initial capital cost. The IRR thus provides a rate of return for the project that can be directly compared to the assumed interest (discount) rate. If the IRR exceeds the business owner's assumed discount rate, then the rate of return from the project exceeds the rate of return from investing that money elsewhere, and the owner should move forward with the project.

However, because IRR is measured as a percentage rather than as a dollar value, scale can prevent meaningful comparisons of different projects. For example, a small project with a large IRR might nevertheless have smaller NPV than would another larger project with a smaller IRR. Though the former project offers the highest rate of return, a larger project with a lower IRR but with greater overall returns may be preferable to a business owner. Thus, IRR should generally not be used by itself when comparing various options with very different initial capital costs (Boardman et al., 2006).

Payback Period

The payback period is the length of time it takes for an initial investment to be recouped. Payback period can be computed using discounted or undiscounted cash flows, but, when discounted cash flows are used, the payback period is equivalent to the period during which the NPV of the investment equals zero at a given discount rate. Other things equal, the business owner or investor prefers a project with a short payback period, especially when the owner is uncertain about the lifetime or time horizon of the project. With an uncertain lifetime, a short payback time can indicate that a project is worthwhile, particularly if the payback period is much smaller than the theoretical lifetime (e.g., a payback time of three years versus a 25-year assumed lifetime for a given technology). If the payback period is much longer than the expected lifetime, alternately, the overall cost of the project will likely exceed the benefits and the planner should not choose this option. Once again, however, this measure suffers from a problem of scale, and it gives no information about the net profits received from an investment. Therefore, by itself, payback period is not useful for comparing the ultimate net benefits received from different investment options.

Ultimately, these measures (NPV, EANB, IRR, and payback period) are most helpful to a business owner when used together to evaluate a potential efficiency investment. NPV provides a projection of the net discounted monetary returns on a project under consideration and is the best way to determine the expected profits from the investment. EANB scales NPV for comparisons of projects with different lifetimes. IRR provides both the return on investment as a percentage of the initial investment and a measure of return readily comparable to other noncapital investments. The projected payback period, finally, gives the business owner a clear view of when investment costs will be recouped. In combination, these are valuable tools for an individual business owner considering a capital water-efficiency project.

Operation and Maintenance Costs

Business owners may also be concerned with conditions that affect their future cash flow. In this case of efficiency investments, changes in O&M costs, such as reductions in utility expenditures or increases in device maintenance, may be important metrics to consider when weighing investment options.

Uncertainty

Projecting the costs and benefits of water-efficiency investments is complicated by uncertainty about the cost- and water-saving characteristics of efficiency devices and uncertainty about future conditions, such as the future costs of water, wastewater services, and energy. Examples of important factors that may be uncertain due to poor data include facility water use, performance of individual technologies, and the installation or maintenance costs of technologies.

For example, the actual water usage of both new and currently installed technologies may differ from its rated value due to variation in performance, individual usage, maintenance, and other factors.[4] Some studies offer guidance: Chesnutt, Bamezai, and McSpadden (1992a, 1992b), for example, have explored these effects empirically using aggregate data to better estimate actual per-unit water use, while Mayer et al. (1999) have evaluated these effects at the residential household level. Care must be taken when using rated saving values, as there are little available data in the existing literature on installed technology performance in the commercial sector (Dziegielewski et al., 2000). The investment costs and O&M costs of water-saving technologies may also be uncertain, as they will differ by vendor, location, and facility, and O&M costs will depend upon the type of facility, amount of fixture use, and facility labor costs.

In this report, we do not attempt to characterize uncertainty that emerges from a lack of available data. Instead, we focus on uncertainty that is largely irresolvable with improved data, namely the future cost of water, wastewater services, and energy. If a business owner anticipates large increases in utility costs, larger efficiency investments that lead to larger water savings may appear favorable. Similarly, if utility costs are not expected to rise, less aggressive efficiency improvements may be warranted.

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[4] For example, a toilet's actual usage per visit would differ from the rated value if users flush multiple times or the flush mechanism has an unnoticed leak. Likewise, there is likely to be significant variation in wager usage—and thus potential water savings—due to common differences in personal use, such as shorter or longer showers or varying time spent using the faucet.

Uncertainty Propagation and Expectation Value

A variety of methods exists to address uncertainty in a decision problem or analysis (see Morgan, Henrion, and Small, 1990, for an overview of issues and methods). A standard approach, often used for analyses of simple to moderate complexity, is to propagate the uncertainty through a model of the decision problem and estimate the expected value of the result. Uncertainty is propagated by evaluating the model numerous times for discrete values of any uncertain parameters. The results are then weighted according to the estimated probability of each combination of parameters for each model run. For the discrete case, the analysts could evaluate S different combinations of input parameters and weight them according to their relative probability of occurring, Pr_s. The expected NPV and variance of NPV can then be calculated using the following formulas:

$$E(NPV) = \sum_s^S \Pr_s \times NPV_s$$

$$\sigma_{NPV}^2 = \sum_s^S \Pr_s \times \left(NPV_s - E[NPV]\right)^2.$$

Alternatively, one can treat the uncertain parameters as continuous, random variables from an assumed underlying probability distribution (e.g., normal, exponential). Monte Carlo sampling techniques can then be used to choose a finite set of possible scenarios, selected according to their probabilities of occurring. The expected value and variance of NPV using the results of these simulations runs can then be evaluated using the same formulas above. The expected value of other financial performance metrics can be estimated as well.

The expected value and variance of NPV and other financial metrics thus become themselves metrics worthy of consideration. Managers concerned about limiting their risk to outcomes in which the investment performance is low may weight investments with lower expected returns but also lower variance over those with higher expected returns but higher variance. Similarly, they may prefer investments that limit the variability of their O&M costs.

Note that an important requirement for uncertainty propagation is the appropriate characterization of uncertainty. When analysts do not have confidence in a single parameter characterization or there is a dispute among interested parties, there are no unequivocal results. In the case of efficiency investment evaluations, different investment packages could be preferred, depending on which of the competing uncertainty characterization on which the decisionmaker relied.

Scenario Analysis

Scenario analysis offers an approach for situations in which analysts cannot uniquely characterize all the important uncertain parameters with probability distributions. In such cases, the analyst may only be confident in specifying a range of possible values for these parameters. Without probabilities assigned to all the model parameters, no single answer emerges. In scenario analysis, the analyst develops a set of scenarios, each corresponding to a single value for the poorly characterized uncertain parameters. These scenarios, when viewed together, provide guidance to the analysts about the impact of the poorly understood uncertainty on the decision under analysis.

In the case of evaluating business investments, scenario analysis can enable the business owner to explore how investment performance varies according to different assumptions about poorly understood factors, such as future resource prices. For example, a business owner might want to consider a small set of scenarios corresponding to the performance of several investment options under different assumptions of resource price trends. Each scenario could correspond to a single trend in water price, for example, or to a particular distribution of possible water price trends.

For each scenario, the business owner would consider the standard financial results described above, such as NPV, IRR, and payback period. Note that, if the analyst considers other uncertain factors probabilistically, then each scenario result would also be probabilistic and could be reported as the variance and expected value of each financial metric.

Decisions based on a set of independent scenarios, rather than a single probabilistic result, require subjective reasoning on the part of the decisionmaker. The decisionmaker may choose to concern himself or herself with the results for some scenarios (deemed likelier, perhaps) than others. In some cases, results suggesting very poor performance under particular scenarios could lead the decisionmaker to consider alternatives that perform more acceptably across all scenarios, particularly if he or she is risk averse. Alternatively, the evaluation of different scenarios could help generate new strategies for hedging an investment against poor performance under specific conditions.

CHAPTER THREE

Selected Water-Efficiency Opportunities in Commercial Buildings

Introduction

The commercial, industrial, and institutional (CII) water-use sector, in the broadest sense, encompasses all nonresidential municipal water deliveries. Recent estimates show that between 15 percent and 34 percent of domestic U.S. water deliveries are made to CII customers, with the remainder provided primarily to residential customers (Dziegielewski et al., 2000).[1] This report focuses on opportunities within the commercial sector, which includes retail and wholesale businesses, office buildings, hotels and motels, laundry facilities, restaurants, car washes, and many other good- or service-providing organizations. Note that many of the end uses in the commercial sector are also present in the industrial or institutional sectors, and there is significant overlap in terms of water-efficiency potential.

Within the commercial sector, businesses use water to serve the daily needs of their employees, provide services to clients, and maintain building comfort, landscaping, and other general upkeep. In general, commercial organizations consume about 25 percent to 50 percent of their water for restroom use (Dziegielewski et al., 2000). Other major end-use categories include building- and device-specific cooling, kitchens and restaurants, laundry, and outdoor irrigation. In the next section, we detail strategies for increasing efficiency for two important indoor end uses: restrooms and building cooling. These end uses can make up a significant share of indoor building water use and are the focus of the remainder of this analysis.

Water-Efficiency Potential

Commercial water-use efficiency can be improved in several ways. First, a business can retrofit existing fixtures or technologies to use less water. For example, a business can install inexpensive new aerators into existing faucets to reduce the flow rate of the devices. Such retrofits require low up-front capital or labor expenses but have relatively short lifetimes and may require additional upkeep or maintenance after installation. Second, a business can replace older technologies with new, water-efficient devices. Replacement requires additional capital and labor costs but will generally last longer than retrofits and may have smaller O&M costs over their lifetimes. Third, an organization can implement process or O&M changes to encourage efficiency. An important example of this kind of change is the implementation of a formal leak-detection program. O&M changes often require little to no capital investment but are generally more labor intensive and may have less certain water-saving outcomes than retro-

[1] The EPA estimate of 34 percent excludes wholesale deliveries to other water providers.

fits or replacements have. Finally, a business can educate its employees to change behaviors and adopt water-efficient practices, such as promptly reporting any observed leaks.

The federal government, state, or city may also mandate certain types of water efficiency for CII water customers. For example, the Energy Policy Act of 1992 (P.L. 102-486) mandated that certain types of water-using devices newly installed after January 1, 1994—including toilets, urinals, faucets, and showerheads—must not exceed a maximum level of water use (EPA, 1998). The Energy Policy Act of 2005 (P.L. 109-58) placed further standards on other devices, including dishwashing equipment, certain clothes washers, and automatic icemakers (Osann, 2005).

Restrooms

Toilets. Domestic use for toilets is often the primary target of residential water-efficiency programs and is also a significant end use across the commercial sector. Most currently installed toilets are rated at 5.0, 3.5, or 1.6 gallons per flush (gpf). The Energy Policy Act of 1992 (P.L. 102-486) mandated that all new gravity (tank-type) or flushometer (valve-type) toilets installed in the United States after January 1, 1994, must use 1.6 gpf or less, but many less efficient toilets installed prior to this date are still in use. The 1.6 gpf toilets, commonly known as ultralow-flush toilets (ULFT), are considered efficient, but emerging technologies use even less water.

Companies considering efficiency have many options for improving toilet efficiency, depending on the type of toilets currently installed. The most commonly used types of toilets in commercial buildings are tank- and valve-type toilets. Tank-type toilets, also found in most residential units, hold a certain amount of water in the tank and rely on the siphon action created when the water in the tank is released to remove waste. Valve-type toilets have a flush valve connected to a pressurized water supply and release a set amount of pressurized water when the valve is released. Both types of toilets can be either retrofitted or replaced to improve efficiency.

Older tank-type toilets can be retrofitted to use less water either through displacement devices or mechanical upgrades, though these retrofits are most effective on much older models that use more than 3.5 gpf. Displacement devices function by replacing or displacing the water in the tank and can save up to 0.75 gpf. These devices include bags or bottles designed to fit in a gravity tank or toilet dams, which are flexible metal or plastic sheets that prevent 0.5–1.0 gallons from leaving the tank in each cycle. Possible mechanical retrofits include replacing the flush valve with an early closure device, which uses less water but maintains the same water pressure, or installing a dual-flush adapter, which allows for two different flushes for liquid and solid waste. The early closure device can save 1–2 gpf, while the dual-flush adapter generally saves 0.6–1.2 gpf (New Mexico Office of the State Engineer, 1999).

There are also several retrofitting options for valve-type toilets. The least expensive option is to install a plastic valve insert into the existing valve, which can reduce water flow by 0.5 to 1.0 gpf. Next, the business could replace all of the existing valve mechanisms without changing the bowl, which is a more expensive option than the valve insert but could yield a longer service life. Finally, dual-flush adapters are also available for valve-type toilets (New Mexico Office of the State Engineer, 1999).

A business owner or manager can also replace older tank- and valve-type toilets with more efficient models. ULFTs remain the industry standard and are available in both types, but a new standard, called high-efficiency toilets (HETs), has recently emerged. A HET is defined as a toilet that uses, on average, at least 20 percent less water per flush than a ULFT, or less than 1.3 gpf. Dual-flush (1.6 gpf/1.1 gpf), single-flush (1.28 gpf), and pressure-assisted, single-flush toilets (1.1 gpf or less) are currently available to replace tank- and valve-type toilets. At present, ULFTs are typically less expensive than the newer HET models (Koeller, Riesenberger, and Bamezai, 2006).

Urinals. Urinals have generally received less attention than toilets have in terms of government or utility incentive programs because they are used almost exclusively in the CII sector and not in the residential sector. Nevertheless, there are several retrofit and replacement options available for urinals currently installed in commercial buildings and facilities that could result in substantial water savings. Older urinals use between 2 gpf and 3 gpf, but the Energy Policy Act of 1992 (P.L. 102-486) established a standard for all new urinal installations of no more than 1.0 gpf.

There are two types of urinals commonly installed in commercial buildings: siphonic jet urinals and washout or washdown urinals. Siphonic jet urinals are generally used in high-traffic areas and use an elevated tank to flush regularly throughout the day regardless of use. Washout or washdown urinals, alternately, generally use flushometer valves and are flushed by the user or automatic sensor on a per-use basis. Though siphonic jet urinals are a more sanitary option and require less frequent cleaning, they may use significantly more water than washout or washdown urinals, depending on the volume of users (New Mexico Office of the State Engineer, 1999).

Commercial building managers can retrofit siphonic jet urinals by installing timers that stop the water flow when the building is not occupied or in use. For washout or washdown urinals, managers can retrofit or replace the flushometer valve (similar to the toilet retrofits described above) for partial savings.

There are also several replacement options available for all types of urinals. First, a business can install ultralow-flush urinals (ULFUs), which meet the current 1.0 gpf requirements and are the current standard. As with toilets, however, there is also a collection of new technologies available collectively labeled high-efficiency urinals (HEUs), which use 0.5 gpf or less. One type of HEU is a valve-based urinal that uses about 0.5 gpf (Koeller, Riesenberger, and Bamezai, 2006). However, another important new option is the 0 gpf non–water-using urinal, which does not use any water for operation. These non–water-using urinals rely instead on a liquid sealant–based trap with a biodegradable liquid sealant to allow waste to flow into the drain while preventing odors and sewer gases from escaping from the pipes below (Koeller, Riesenberger, and Bamezai, 2006). Because the non–water-using urinals require no incoming water for flushing and do not rely on a flush valve, they may provide significant savings from lower annual maintenance costs in addition to the benefits incurred from reduced water use. The urinals require regular replacement of the liquid sealant–based trap but otherwise allow the manager to avoid maintenance costs from repairing or replacing the valve mechanism. When designing new buildings with non–water-using urinals, costs savings can also be realized from simpler installations for each urinal.[2]

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2 The sealant-based traps in non–water-using urinals comply with U.S. plumbing and building codes for trap seals. Model U.S. plumbing codes prohibit the use of moving parts to provide a trap seal (International Plumbing Code §§1002.3–1002.4, Uniform Plumbing Code §§1004.0–1005.0, National Standards Plumbing Code §§ 5.3.2, 5.3.5).

Faucets. Restroom faucet flow rates tend to range from 3 to 5 gallons per minute (gpm) (New Mexico Office of the State Engineer, 1999), although the federal standard established in 1994 is a maximum flow rate of 2.5 gpm at a pressure of 80 PSI. Restroom faucets can be readily retrofitted through the use of aerators or flow restrictors. Efficient aerators are very inexpensive and easy to install on most existing faucet heads and can reduce flow rates to 0.5–1.0 gpm. Flow valves or flow restrictors can be installed on hot and cold water feed lines when aerators are not an option and similarly restrict flow rates to a maximum of 0.5–1.5 gpm.

Further efficiency can be achieved, however, by replacing older faucets with models designed to curb excessive use. There are several types of faucets available that turn on and off automatically, thus preventing overuse through abuse or carelessness. Metered-valve faucets deliver a certain amount of water (measured by a certain amount of time) and then turn themselves off, while self-closing and infrared and ultrasonic faucets deliver water only when the user pushes the handle or has his or her hands directly below the faucet. Infrared and ultrasonic faucets are generally more expensive than metered-valve and self-closing faucets but are also more sanitary and may be easier for disabled persons to use. The current federal standard for these types of faucets is no more than 0.25 gallons per visit (gpv) (New Mexico Office of the State Engineer, 1999).

Showers. Although showers are less common in commercial settings than in residential ones, many companies offer shower facilities to their employees or guests. Older showers use between 5 and 7 gpm at maximum flow, while the federal standard for newly installed showerheads is no more than 2.5 gpm at 80 PSI. Showers can be made more efficient simply by retrofitting or replacing the showerhead. Retrofit options include aerators or flow restrictors (disks installed inside the showerhead to limit water flow), while replacement involves simply replacing the showerhead with a new version that uses 2.5 gpm or less. Note that both options involve little up-front capital costs and minimal installation effort (North Carolina Division of Pollution Prevention and Environmental Assistance, North Carolina Division of Water Resources, and Land-of-Sky Regional Council, 1998).

HVAC and Cooling

Another important end use for water in many commercial facilities is cooling, either through comfort cooling for employees and customers or devices that rely on water-cooling (e.g., icemakers). Depending on the type of cooling system installed, location of the business, and devices used, cooling can make up close to 50 percent of total water use at the high end (with significant variation) (Dziegielewski et al., 2000). The water consumed by such cooling systems could often be significantly reduced by installing new technology or by optimizing current systems.

Single-Pass Cooling Devices. Single-pass cooling uses water for cooling for one cycle only and then sends 100 percent of the water to the sewer system as waste. Single-pass cooling is often used to cool small devices, such as icemakers, and is highly inefficient from a water-use perspective. These devices may use a significant amount of water, particularly in facilities such as hotels and restaurants (New Mexico Office of the State Engineer, 1999).

To improve the efficiency of these devices, several options are possible. First, a business could convert the single-pass device to a closed-loop system or connect the devices to an existing cooled water loop (which works in the same manner as the cooling towers described below). A closed-loop system could use as little as 2–3 percent of the water used in a single-pass system (Gleick et al., 2003). Second, the business could replace single-pass cooling devices with air-cooled devices. Note, however, that air-cooled devices use electricity, and switching to these devices will likely increase energy costs. Finally, the water from the device could be reused for another purpose in the facility.

Recirculating Cooling Towers. Many businesses, particularly in arid climates, use water-cooling as part of their HVAC system. These systems use cooling towers—structures designed with a large surface area of fill material to expose circulated water to outside airflow—to facilitate evaporation. The process of evaporation removes heat from the circulated water, and the remaining water flows through a heat exchanger to facilitate building cooling before returning to the cooling tower.[3]

Cooling towers generally recirculate water, but water is lost to three processes: evaporation, drift, and blowdown. *Evaporation* is an inevitable by-product of this system, though the amount of evaporation depends on the cooling load on the tower and the climate in which the building is located. Drift is comprised of the water droplets that *airflow* carries away from the cooling tower and usually makes up a very small portion of the overall water used. Blowdown is the water that must be *removed* from the system to maintain a certain concentration of solids.

As water passes through the cooling tower and is evaporated in each cycle, the remaining water in the system builds up suspended and dissolved solids left behind by the evaporated water. These solids can damage the system through corrosion, scale, or biological growth, and must be removed to maintain system operation. Blowdown, as well as the water lost through evaporation and drift, must be replaced as the system operates, and this replacement is known as *makeup water*. Blowdown can vary significantly with the operation of the system and is the primary focus of cooling-efficiency efforts. The ratio of the maximum total dissolved solids (TDS) in the system compared with the TDS in the makeup water is known as the *concentration ratio* (CR, or cycles of concentration). For example, if a system's CR is 2, the TDS in the system can be only twice that of the makeup water before requiring blowdown and replacement. The lower the CR, the greater the blowdown and makeup water needed to maintain that concentration. At low CRs, cooling systems use a large amount of water each day.

Most cooling-efficiency efforts are designed to increase the CR at which the system can operate. Most well-run cooling-tower systems already use some form of chemical treatment to maintain a CR and prevent corrosion, scale, and microbial growth, but several options in addition to (or in place of) chemical treatment could yield significant water savings. Commonly considered alternatives include submeters, conductivity controllers, pH control, ozonation, sidestream filtration, and blowdown reuse.

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[3] For details on the functions and operation of cooling systems, see Loretitsch (2002).

CHAPTER FOUR

A New Tool for Evaluating Efficiency Investments

Introduction

To help building owners evaluate water-use efficiency options for commercial buildings, the project team developed a spreadsheet-based model: BEAM. BEAM provides an analytic framework for evaluating the net benefits of improving water efficiency in commercial buildings. BEAM considers water use and efficiency improvements in restrooms (including toilets, urinals, sinks, and showers) and building-cooling systems. BEAM is first customized to reflect the water uses of a specific building, using commonly available water-use data, water-use equipment inventories (e.g., counts of toilets and urinals), and utility rate structures. The tool then allows the user to define up to seven efficiency investment options and six scenarios of future utility prices. BEAM uses these data to estimate the net benefits, IRRs, and payback periods of the various water-efficiency packages. BEAM allows the user to take into account possible uncertainties about future water and energy prices.

This tool is designed to be easily used by building managers, consultants, and efficiency service representatives. To help demonstrate its use and highlight its capabilities, Chapter Five presents a detailed case study using the model. Appendix A provides a detailed user's guide.

Building Water Efficiency Analysis Model Overview

BEAM analyzes the financial performance of water-use efficiency packages in the following steps. First, the tool prompts the user for information about the building to be analyzed, the specific efficiency packages to be evaluated, and characterizations of resource price scenarios to be considered. Next, the tool uses this information, along with specific assumptions about water use by device type and standard building occupants, to estimate the water and energy use for the base case condition and under each of the efficiency packages. After calculating water and energy use, BEAM begins the financial analysis. The tool uses a scenario analysis to illustrate the financial performance of the various efficiency packages under the different scenarios of water price, presenting scenario results as tables and graphs. For each scenario, BEAM performs a simple Monte Carlo simulation (over the range of price trends) to evaluate the expected performance of each efficiency option. Lastly, BEAM provides results for single combinations of efficiency packages and resource price scenarios and for the entire ensemble of packages and scenarios.

Limitations

BEAM was developed to more fully explore the potential net benefits of commercial water-efficiency investments while incorporating uncertainty that building operators face about future water and energy prices. BEAM does not address uncertainties that would arise if poor-quality data were used to characterize building-specific water use, technological performance, installation costs, or O&M costs. The tool therefore does not provide probabilistic estimates for costs, water savings, or energy savings. The user, however, may change the actual water used by specific devices to evaluate alternative assumptions about device performance.

Instead, the tool relies on deterministic point estimates of water use, potential water and energy savings, and technology costs to generate financial performance results. The tool includes many default point estimates, which may vary significantly from the true values for a given facility. However, these assumptions are clearly presented to the user within the model, and the user is encouraged to change these values as appropriate to improve the quality and accuracy of the predictions. Nevertheless, due to these limitations, BEAM should be thought of as a screening tool to help identify promising efficiency options (which would require further, detailed study) rather than as a comprehensive water-efficiency benefit-prediction model.

Efficiency Packages

BEAM considers up to seven unique efficiency packages, comprised of actions designed to increase the efficiency of restroom and cooling-system water use. These packages are fully user customizable and can be quickly altered to compare a wide variety of options. The tool includes as options many of the efficient technologies described in Chapter Three, and the user can define packages that replace all or a subset of a given type of current technology using the package interface. Chapter Five describes the efficiency packages used for the case study.

Resource Price Scenarios

BEAM allows the user to explicitly incorporate uncertainty about future water and energy prices. BEAM provides for the analysis of up to six discrete scenarios of water and energy price increases over a 25-year time horizon. The user can customize these scenarios to match his or her current beliefs about the likelihood of future price increases.

BEAM evaluates a set of price scenarios, derived from five built-in price trends (or price paths), each representing an annual percent increase (above inflation) in resource (water, wastewater, and energy) price and a distributional assumption.[1] The predefined trends were included to represent the range of possible price outcomes over the next several decades and range from a best-case assumption that prices will stay constant over time to a worst-case assumption that prices will grow 4 percent (water/wastewater) or 6 percent (energy) annually, yielding a compounded price increase that exceeds 250 percent of the baseline over 25 years (Table 4.1).

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1 BEAM assumes that the price trend used for a specific simulation is drawn from a normal distribution characterized by a specified mean and standard deviation. As such, about 68 percent of the simulations will be based on trends that are within one standard deviation of the mean trend. The user also has the option of disregarding the distributions when performing the analysis. See Table 4.1 for the parameters of each distribution.

Table 4.1
Building Water Efficiency Analysis Model Predefined Price Trends

		Mean Annual Price Increase (%)			
		Water and Waste Water		Energy	
Trend	Description	Mean	Standard Deviation	Mean	Standard Deviation
1	No price increase (best case)	0	0.50	0	0.50
2	Small increase	1	0.50	1	0.50
3	Moderate increase	2	0.75	2	0.75
4	Large increase	3	1.00	4	1.00
5	Very large increase (worst case)	4	1.00	6	1.00

Resource price scenarios can be specified using different possible weightings of the predefined price trends described above. A scenario weighting may involve putting all of the weight on one trend, in which case that trend alone (and its distribution) would determine the price path used in the corresponding simulation. Alternately, the user can put different amounts of weight on different trends to construct new price-path distributions for the simulation. These customizable weightings allow a building manager or owner to incorporate his or her prior subjective beliefs about the likelihood of price outcomes into the simulation and analysis. For example, if a building owner believes that prices will increase a small amount in the future but also thinks that there is a small possibility of a larger price increase, he or she could put a large weight on the 1 percent increase and a small weight on the 2 percent increase. These scenarios can be readily altered to explore the range of possible weightings, although the price trends are not presently designed to be altered.

Water- and Energy-Use Calculations

Restroom Fixtures

BEAM uses basic, user-supplied information about the population and the number and type of fixtures in the building, together with a set of assumptions about water use per fixture and fixture use per person, to project how much water is consumed for each end use in a given day. For simplicity of use, these calculations are deterministic—there are no probability distributions associated with any of the user-supplied inputs—and thus provide a single value for water use for a given population and combination of technology types. For example, one of the analyses presented below specifies that the building uses 3.5 gpf toilets. Assuming that average employee toilet use is 2.6 visits per day (Gleick et al., 2003) and that there are 871 FTEs, the daily employee water consumption for toilets is calculated as

$$\text{Toilet use/day (kgal/day)} = \frac{871 \text{ persons} \times 2.6 \text{ visits/person/day} \times 3.5 \text{ gal/visit}}{1{,}000 \text{ gal/kgal}}$$
$$= 7.93 \text{ kgal/day.}$$

For a 260-day work year, this is equivalent to about 2,060 kgal/year. BEAM performs similar calculations for urinals, faucets, and showers, utilizing assumptions about usage frequency at these end uses. To estimate the potential water savings from efficiency, BEAM calculates a weighted average of the gallons per visit for a given end use. For example, to calculate the water savings from replacing 75 percent of the building toilets with ULFTs, the average gallons per visit would become

$$\begin{aligned}\text{Average gal/visit} &= (0.75)\times 1.6 \text{ gal/flush} + (0.25)\times 3.5 \text{ gal/flush} \\ &= 2.08 \text{ gal/visit.}\end{aligned}$$

Replacing the gallons per visit in the toilet use–per-day equation with this weighted value results in a new value of 4.71 kgal per day or 1,225 kgal per year. Thus, the water savings from this upgrade would be the difference between usage before and after ULFTs were installed:

$$\text{Water savings} = 7.93 \text{ kgal/day} - 4.71 \text{ kgal/day} = 3.22 \text{ kgal/day.}$$

According to these simple calculations, replacing 75 percent of the older toilets in the building with ULFTs would yield a water savings of 3.22 kgal per day or 837 kgal annually. Similar calculations are made for urinals, faucets, and showers.

Cooling Devices

To calculate the water usage of cooling devices, BEAM relies on commonly used, simplified calculations to provide a rough estimate of average daily use. These calculations are deliberately simple—they trade off a significant amount of building- and region-specific detail in favor of simplicity and ease of use and are designed to give a quick, first-order approximation of cooling-water use for this analysis.

For single-pass cooling devices, because there is no closed-loop system, the water used is simply the average daily flow through the device (converted from gpm to GPD). For recirculating devices, alternately, BEAM uses user-supplied information about the existing system solids *CR* and average daily cooling load on the cooling unit (in tons) to calculate average evaporation loss, blowdown, and makeup water needed for the system. Evaporation loss (E) is calculated using the rule that a system loses about 3 gpm per 100 tons of cooling load (North Carolina Division of Pollution Prevention and Environmental Assistance, North Carolina Division of Water Resources, and Land-of-Sky Regional Council, 1998). Blowdown (B), the amount of water released from the system to maintain a certain *CR*, is calculated as

$$B = \frac{E}{CR - 1}.$$

This calculation assumes that the *CR* is greater than 1 (a *CR* of 1 indicates a single-pass device) (Loretitsch, 2002). Using these values, the makeup water (M) needed in gpm becomes $M = B + E$.[2]

[2] This calculation omits drift—the water carried out of the device as vapor during operation—because it is typically a very small percentage of overall use (0.05–0.2%) (North Carolina Department of Environment and Natural Resources, 1998).

BEAM converts this calculation from gpm to GPD to obtain the average daily makeup water used by the system.

Because the cooling calculations are deliberately simplified and the gains from efficiency can vary greatly depending on building and usage conditions, the potential gains from cooling efficiency are also simplified for the BEAM analysis. Efficiency gains are treated as a percentage of total cooling-water use, with default assumptions included that the user can readily modify. For example, installing automatic conductivity controllers is assumed to save about 20 percent of a device's original water use (Gleick et al., 2003). Thus, if a package with conductivity controllers is implemented, BEAM will simply subtract 20 percent of the total water use of the cooling device to calculate the efficient value.

Financial Calculations

Capital Costs

The capital costs associated with each efficiency package are based solely on user-changeable assumptions about per-fixture equipment and installation labor costs associated with each efficiency action. These costs are incurred in the first year of the analysis period.

Operation Costs

Operation costs include the cost of maintaining water-using devices and the costs of water, waste water, and energy associated with the building's water use. Operation costs accrue in each year of the analysis period. Fixture maintenance costs are based on user-entered annual per-fixture material and labor costs.

Resource costs are calculated based on utility pricing structures entered by the user for water, wastewater, and energy use. BEAM allows the user to enter a variety of per-unit pricing structures, such as the uniform, increasing, or declining block-rate structures described in Chapter Two. If the user enters a uniform price, BEAM treats this as the average unit price and subsequently increases, decreases, or keeps this price level over time, depending on the price scenario chosen. If the user enters a block-rate structure, BEAM uses the block-rate structure, together with user-supplied information about total water use in the building, to convert the tiered (marginal) rate structure to an average per-unit price. To convert from a tiered to an average rate, BEAM uses a weighted average calculation (see Chapter Five or Appendix A of this report for examples).

Because average price is a function of both the tiered prices and actual resource usage (see Chapter Two), BEAM calculates an average price both under the initial resource usage and with the efficiency package applied. With tiered rates, the "efficient" average price will change relative to the initial average price, and BEAM includes any additional avoided costs that accrue from this change in the financial return calculations. By separately tracking the average price under both the original and "efficient" conditions, the weighted average calculations described above provide equivalent results to those provided by calculations using separate marginal prices.[3]

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[3] This approach makes two key assumptions: (a) water use will remain stable over time except for the changes yielded by new efficiency devices, and (b) tiered pricing structures will have fixed, unchanging thresholds, with each of the marginal prices growing at the same proportional rate.

Efficiency Benefits

Efficiency benefits are calculated as the difference between what the building owner would have spent on operation costs with no new efficiency installed (baseline) and what the business owner would spend if a given package were implemented, over the lifetime of the project considered. These avoided costs may include reduced maintenance, water, sewer, or energy costs.

Investment Results

BEAM allows the user to calculate investment results in two ways: detailed investment results for a specific efficiency package under a given price scenario and a summary analysis of the ensemble of all packages evaluated against all price scenarios.

Single Package and Scenario

For a selected efficiency package and single price scenario, BEAM calculates the net present benefits, NPV, EANB, IRR, and payback time for the package. BEAM calculates net present benefits, NPV, and EANB using (1) the capital costs of efficiency actions comprising the efficiency packages, (2) avoided maintenance costs, and (3) avoided resource costs. These numbers are used together in a 100-sample Monte Carlo simulation, with each metric calculated separately for each sample run. For each Monte Carlo simulation, BEAM selects water, wastewater, and energy price trends reflecting the distributions defined by the specific scenario.[4] The simulation runs are then averaged for each metric to determine the expectation result. BEAM also calculates standard error for these simulated results.

To calculate IRR and payback time, BEAM also simulates a discounted cash-flow stream for each Monte Carlo sample run. The average cash flow across the sample runs is used to estimate IRR using standard methods. Likewise, payback year is defined as the year in which this average discounted cash flow exceeds zero. See Appendix A for a detailed discussion of and examples from BEAM's single package and scenario result worksheet.

Ensemble of Efficiency Packages and Price Scenarios

To facilitate a comparison of the performance of multiple efficiency packages under multiple possible price scenarios, BEAM provides selected summary results for the entire ensemble of cases. For each combination of efficiency packages and price scenarios, this summary sheet reports capital costs and water usage (graph; results do not vary by scenario), average NPV (table and graph), payback time (table), EANB (table), and average operation costs (table and graph). See Appendix A for a detailed discussion of and examples from BEAM's ensemble result worksheet.

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[4] Note that the Monte Carlo simulation samples only from distributions of resource price trends.

CHAPTER FIVE

Case Study Using the Building Water Efficiency Analysis Model

In this chapter, we present a case study evaluating water-efficiency investments in a commercial building using BEAM. This analysis demonstrates how a building manager could apply the tools of cost-benefit and uncertainty analysis described above to a water-efficiency investment decision. Although BEAM evaluates water efficiency for both restroom and building-cooling end uses, this example focuses only on restroom end uses. Building characteristics and water usage can vary dramatically among buildings of different sizes, ages, industries, or geographic areas, and thus these results are not necessary representative or typical for all office buildings.

We begin by describing the building characteristics, resource price scenarios, and efficiency packages considered. We then use these inputs to analyze the efficiency packages under two baseline conditions described below.

Analysis Setup

Building Characteristics

We base this case study on the RAND headquarters building, located in Santa Monica, California. The RAND building was opened in late 2004 and includes many water-efficient devices. All restrooms, for example, include ULFTs and ULFUs, and landscaping irrigation uses reclaimed water piped from the city of Santa Monica.[1] According to the facility manager, the RAND headquarters currently supports 753 full-time and 236 part-time employees and has an average of 44 visitors daily.[2] The restrooms in the facility include 77 toilets, 68 urinals, 85 faucets, and eight showers.

We use BEAM to analyze two levels of baseline efficiency. For the first and counterfactual baseline, we assume that the water-using fixtures are similar to a Santa Monica building constructed before 1992. We assume that this benchmark, older building uses 3.5 gpf valve-tank toilets, 3.0 gpf urinals, faucets with a 3.0 gpm average flow rate, and showers with a 4.0 gpm

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1 Some of the restrooms in the building also used reclaimed water for toilets and urinals.

2 We assume that full-time employees are present in the building eight hours per day, 260 days per year (which we define as one FTE), and that part-time employees work 50 percent of full-time hours (0.5 FTE). Without detailed information on staff gender, we assume that employees are divided 50 percent male and female, although the building manager indicates that the daily visitors are predominantly male (75 percent). Combining these assumptions, BEAM calculates 435.5 male FTEs and 435.5 female FTEs for use in the calculations and 33 male and 11 female visitors daily (Vasquez, 2006).

average flow rate.[3] These fixtures do not meet the efficiency requirements of the Energy Policy Act of 1992 (P.L. 102-486).

For the second baseline, we consider the existing fixtures in the RAND building. These fixtures include ULFTs (1.6 gpf), ULFUs (1.0 gpf), faucets with 1–2 gpm average flow rates (most using 1.5 gpm), and showers with 2.0 gpm average flow rates. These fixtures all meet or exceed the standards of the Energy Policy Act of 1992 (P.L. 102-486).

We included many planning assumptions commonly used by RAND facility managers and maintenance staff. Through conversations with the facility operations manager and director of Facilities Services, we established a service lifetime (the amount of time a fixture will be functional before it needs complete replacement) of 25 years for toilets and urinals and 10 years for faucets and showers (Vazquez, 2006). We also used a discount rate of 8 percent, the same rate used by RAND for capital planning (Williams, 2007). See Appendix B for further detail on the parameter assumptions used in this demonstration analysis.

Utility Prices

RAND is charged an increasing block-rate structure for potable water and a uniform rate for wastewater outflow. The building uses natural gas for water heating (considered by BEAM for restroom end uses) and is charged a declining block rate for this energy (Table 5.1). The RAND building used a total of 4,105 kgal of water for indoor purposes from November 2005 to November 2006. During the same period, the building used approximately 39,870 therms of natural gas.[4] Using these values along with the utility rate structures in Table 5.1, BEAM calculates an initial average price of $1.45 per kgal for potable water, $1.65 per kgal for waste water, and $0.80 per therm for natural gas.

Table 5.1
Utility Rate Structures Used in Case Study

Resource	Tier	Block Cutoff	Unit Cost
Water	1	292 kgal/month	$1.20/kgal
	2	1,953 kgal/month	$2.93/kgal
	3	> 1,953 kgal/month	$6.74/kgal
Waste water	NA	NA	$1.65
Natural gas	1	100 therms/month	$1.01/therm
	2	4,167 therms/month	$0.79/therm
	3	> 4,167 therms/month	$0.61/therm

NOTE: Original wastewater rate is $1.39/100 hundred cubic feet (HCF) ($1.85/kgal), but a discharge factor of 89 percent is applied to all water use to derive this rate.

[3] Note that the average flow rates listed for the faucets and showers are smaller than the maximum-rated flow rates for these devices, because individuals rarely use these devices at maximum flow (Gleick et al., 2003).

[4] The water- and energy-use figures were derived from data provided by RAND Facilities Services personnel.

Future Price Scenarios

For this analysis, we customize the six future price scenarios in BEAM to allow for the exploration of the full range of price trends discussed in Chapter Four. Table 5.2 describes the weighting of price trends (defined in Table 4.1 in Chapter Four) for each scenario. For example, scenario E specifies that half the price trends are drawn from the price trend distribution 1 (0 percent increase, 0.5 percent standard deviation) and the other half draw from the price trend distribution 5 (4 percent increase, 1 percent standard deviation). The weightings chosen may be more widely distributed than a specific analyst would choose.

Efficiency Packages

This case study evaluates seven water-efficiency investment packages ranging from replacing only faucets and showerheads to replacing most restroom water-using devices with the most efficient available (Table 5.3). These packages are only one possible suite of packages that could be analyzed using BEAM. BEAM also has several classes of efficiency measures (e.g., fixture retrofits, self-closing faucets, cooling improvements) not considered here.

Results for Baseline 1: Pre-1992 Fixtures

We begin the case study by analyzing the performance of all seven efficiency packages for the RAND building using pre-1992 fixtures. Figure 5.1 shows the investment costs (bars, left axis) and total water usage for the end uses considered (line, right axis) for baseline 1 for each of the seven efficiency packages (x axis).[5] Note that these results are constant across the price scenarios, as they derive directly from the specified capital costs and are independent of the utility price scenarios considered in Table 5.2.

As expected, Figure 5.1 shows that capital costs (bars) and water use (line) are negatively correlated. For this baseline, the building uses around 4,000 kgal of water annually without any additional efficiency (package 1). Under the various efficiency packages, water use decreases to about 3,200 kgal per year for efficiency package 3 (only 0 gpf urinals) and

Table 5.2
Weightings of Price Trends for Each Scenario

		Price Trend Weighting (%)[a]				
Scenario	Description	1	2	3	4	5
A	Best case: no price growth	100	0	0	0	0
B	Low price growth	0	100	0	0	0
C	Moderate price growth	0	0	100	0	0
D	Moderate price growth: balanced weighting	10	20	30	20	10
E	Moderate price growth: extreme weighting	50	0	0	0	50
F	Worst case: high price growth	0	0	0	0	100

[a] For details on the price trends, see Table 4.1 in Chapter Four.

[5] The efficiency packages are ordered roughly from lowest to highest investment costs to facilitate interpretation.

Table 5.3
Efficiency Packages Considered in Analysis

No.	Name	Description
1	No new efficiency	Existing devices remain in place, and no new devices are installed. This is the baseline against which other packages can be compared.
2	Replace faucets and showers	Replace aerator or flow regulator in faucets to achieve 1.0 gpm (actual, not rated) flows and replace showerheads with 1.7 gpm (actual, not rated) models. Note that this project has a 10-year investment horizon—according to building management assumptions, all faucet and shower fixtures would need to be replaced again after 10 years.
3	Install non–water-using urinals	Replace all building urinals with models that use 0 gpf.
4	Install HETs	Replace all building toilets with models that achieve an average flush volume of 1.28 gpf.
5	Raise to standards of Energy Policy Act of 1992 (P.L. 102-486)	Bring all technologies up to at least the minimum federal standards for devices manufactured after 1992 (though faucets and showers here perform marginally better than the act's minimum standard). Includes ULFTs, ULFUs, 1.0 gpm faucets, and 1.7 gpm showers.
6	Install non–water-using urinals, otherwise raise to standards of Energy Policy Act of 1992 (P.L. 102-486)	Same as 5, except installs non–water-using urinals instead of 1.0 gpf models.
7	Maximum efficiency	Invest in the most efficient current technologies: install HETs, non–water-using urinals, 1.0 gpm faucets, and 1.7 gpm showers.

to below 1,500 kgal for efficiency package 7 (install 0 gpf urinals + maximum efficiency). Investment costs also vary widely. Installing faucet aerators and replacing showerheads only (package 2) costs only $700, whereas the maximum efficiency package (package 7) costs about $70,000.

Return on Investment

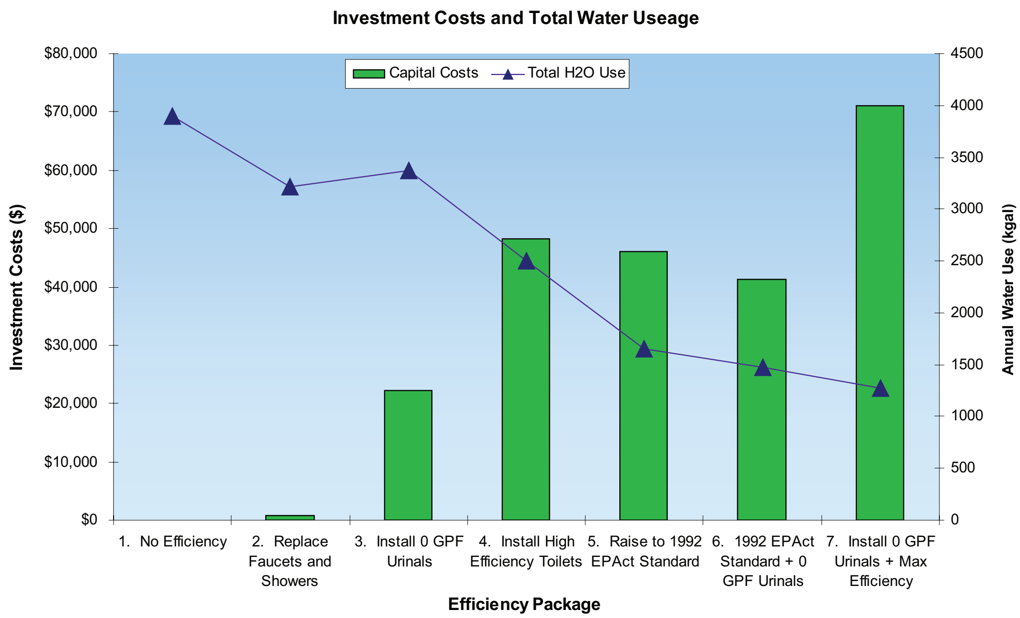
Next, we examine the financial performance of the investments across the price scenarios, as measured by NPV, payback time,[6] and IRR. The top portion of Table 5.4 shows the expected NPV for each efficiency package under all six price scenarios. Each expected NPV value is generated using an independent 100-case Monte Carlo simulation. Figure 5.2 shows the expected NPV results graphically; each symbol in the columns represents the expected NPV result for a given package under a given scenario, and the stacked columns of symbols provide a simple visual representation of the variability associated with that efficiency package.[7] The middle and

[6] Payback time is calculated by projecting annual cash flows for each simulation, taking the expectation of these cash flows for each year, and then calculating the break-even year from the expected value.

[7] To account for potential differences in assumed service life and investment lifetime, BEAM also calculates investment return as an EANB for all projects. The EANB results for this case (not shown) show that package 2 performs better than the NPV results indicate when each package is considered as equivalent annuities. This is because package 2 has a shorter service life (10 years) than the other packages considered (25 years).

bottom portions of Table 5.4 show the maximum, minimum, and average payback time and maximum, minimum, and average IRR for each scenario, respectively.

Figure 5.1
Investment Costs and Total Water Usage for Each Efficiency Package, Pre-1992 Fixtures

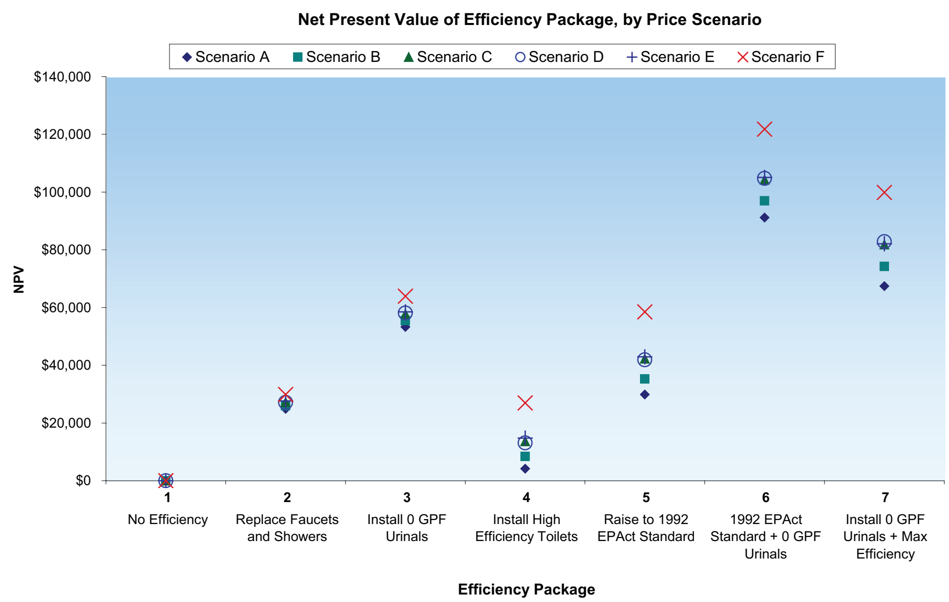


RAND *TR461-5.1*

Table 5.4
Expected Net Present Value, Payback, and Internal Rate of Return Results for Each Efficiency Package Under Each Price Scenario for Baseline 1 (Pre-1992 Fixtures)

		Package						
Measure	**Scenario**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
NPV	A ($)	0	24,919	53,264	4,158	29,898	91,171	67,429
	B ($)	0	25,972	55,440	8,425	35,252	96,959	74,245
	C ($)	0	27,182	57,732	13,630	42,221	104,254	81,765
	D ($)	0	27,142	58,094	13,122	41,881	104,749	82,793
	E ($)	0	27,658	58,467	14,747	42,917	105,093	82,054
	F ($)	0	29,871	63,956	26,936	58,502	121,776	99,855
Payback	Maximum (years)	NA	0.2	3.7	19.9	7.7	3.6	6.7
	Average (years)	NA	0.2	3.7	16.2	7.2	3.6	6.5
	Minimum (years)	NA	0.2	3.6	13	6.6	3.5	6.2
IRR	Maximum (%)	NA	543.6	33.7	12.9	20.2	35.0	21.5
	Average (%)	NA	541.2	32.9	10.8	18.0	33.5	20.1
	Minimum (%)	NA	539.2	32.2	9.0	16.2	32.3	18.9

Figure 5.2
Expected Net Present Value of Efficiency Package, by Scenario for Baseline 1



RAND *TR461-5.2*

Table 5.4 and Figure 5.2 provide a straightforward comparison of the investment return for each package and how this return varies with assumptions about future price increases. Scenario A, for example, assumes no price increases above inflation over the next 25 years. Under this scenario, the expected NPV for the maximum efficiency package (7) is $67,429. However, for scenario F, which assumes large annual price increases for both potable water and energy, the expected NPV increases to $99,855. Recall that the scenarios are ordered such that the probability of high future prices rises from scenario A through F.

Table 5.4 and Figure 5.2 also show that all of the efficiency packages provide positive returns under all six price scenarios relative to the old-building fixture baseline and greater efficiency benefits for all efficiency packages under the scenarios with greater utility price increases. This is expected, given the large water savings achieved when replacing decade-old fixtures with efficient models. These results also show a wide range of investment outcomes across the price scenarios.[8] Those investments that save more water are subject to a wider spread in investment performance, because the benefits derive from net water savings and resource price (which varies across the scenarios).

The expected NPV, payback, and IRR results combined with the capital investment amount from Figure 5.1 show different investment profiles for each of the packages considered. The faucets and showers package (2), for example, provides an expected NPV ranging from $25,000 to $30,000 across the scenarios, a consistently short payback time of several months, and an IRR of greater than 500 percent, all with little to no variation across scenarios. These results suggest a moderate return on investment with very low up-front capital costs and an IRR that is orders of magnitude greater than the assumed discount rate, supporting a strategy for installing faucet aerators and replacing building showerheads as a low-intensity, low-to-

[8] Because the means also vary, a larger spread does not necessarily imply a larger statistical variance.

moderate return capital investment opportunity. Efficiency package 4 (install only HETs) leads to about half the water savings as the most saving package (7), but the high investment costs lead to the lowest NPV, longest payback period, and lowest IRR of all the efficiency packages.[9] The non–water-using urinal replacement package (3) provides a midrange option: moderate capital cost (when compared to the other packages), moderate return and IRR, and reasonably short payback time. Package 6 (replacing all devices to the Energy Policy Act of 1992 standard plus non–water-using urinals) leads to the second greatest water savings and the highest NPV. Finally, efficiency package 7 (replacing all fixtures with technologies that provide the best possible current efficiency) provides yet larger investment returns but at a much larger capital cost—thus yielding a lower NPV, longer payback time, and lower IRR than package 6.

Operation and Maintenance and Resource Costs

BEAM also reports the Monte Carlo simulation average of average annual costs (the sum of O&M and resource costs averaged over each year of the simulation) for each price scenario (Figure 5.3—as before, each point in the column represents one realization of average annual costs using a 100-case Monte Carlo simulation). These results reveal another benefit to efficiency investments: as water savings increase, average annual operating costs decrease and the spread of operating costs across the different scenarios decreases. Installing no efficiency (package 1), for example, yields average annual costs anywhere between approximately $20,000 and $30,000, a range of about $10,000, whereas installing maximum feasible efficiency (package 7) both reduces average costs for all scenarios to between about $5,000 to $8,000 and reduces the range of these costs to $3,000. These results indicate that efficiency investments leading to greater water savings both lower operating costs and reduce the variation in these costs across the resource price scenarios. This result suggests that efficiency can reduce volatility of future operating costs. If business owners value reduced volatility of building-operation costs, then those packages leading to greater water savings would be even more attractive than the average financial returns indicate.

Choosing an Efficiency Package

We next consider how a business owner might use the results above to choose an efficiency investment package under baseline 1 (pre-1992 fixtures). Looking first at the water savings from the efficiency investment, package 7 saves the most—67 percent of the original restroom water use—and package 6 saves the second most—62 percent. If the business owner were interested only in maximizing water savings, then package 7 would clearly be the best choice.

The investment results, however, show that package 6 provides the greatest return under all price scenarios, followed by package 7 (Figure 5.2). If the manager or decisionmaker is uncertain about the usable service life of the project, however, he or she might consider the payback time and favor package 2, which provides the smallest payback time by a considerable margin (several months) (Table 5.4). Likewise, if the manager is unsure of the appropriate discount rate, package 2 also yields a large IRR very likely to exceed the discount rate under all scenarios. This investment would thus be nearly certain to at least break even. Packages 3 and 6 are the next best options according to the payback and IRR metrics. However, if overall return is most critical to the decisionmaker, he or she might instead use payback and IRR as

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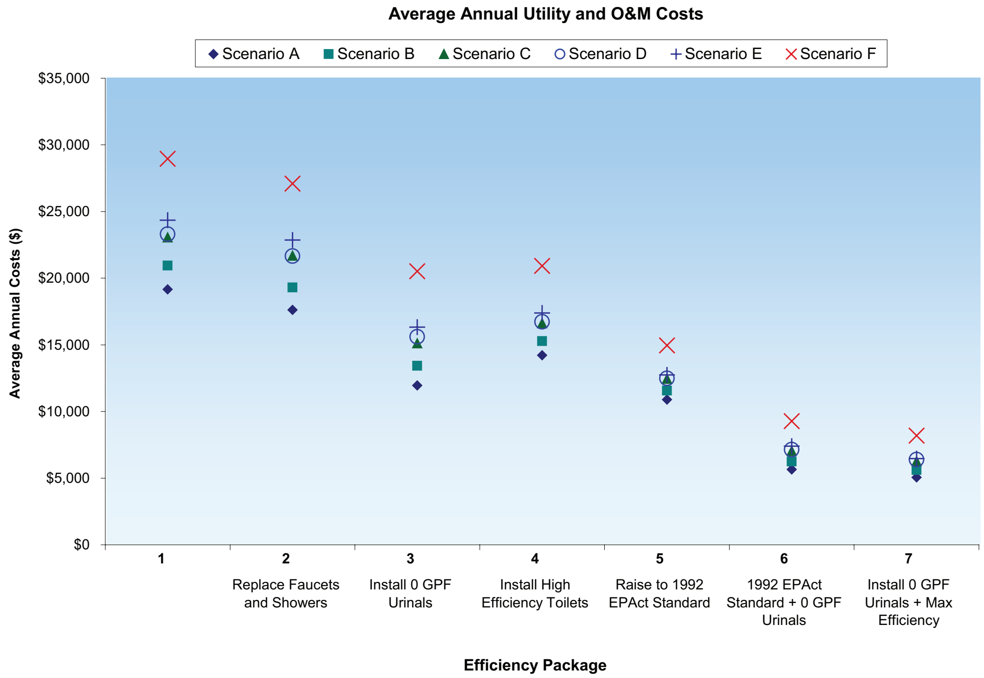
9 The analysis is based on a per-unit cost for HETs (1.28 gpf) of $626 compared to $275 for 1.6 gpf toilets.

Figure 5.3
Average Annual Utility and Operation and Maintenance Costs for Each Efficiency Package, by Scenario, for the Old-Fixture Case



RAND *TR461-5.3*

secondary metrics to ensure that a project with high NPV will nevertheless break even in an acceptable time frame or provide a sufficient return given the size of the capital investment.

The final package comparison BEAM provides is annual operating costs. Figure 5.3 shows that packages 6 and 7 yield the lowest annual operating costs, and, once again, this is true across all price scenarios considered. Package 7 provides the lowest annual costs, although the marginal advantage over package 6 is very small except in price scenario F (worst case). The spread of average costs is also very similar between these two packages. Package 7 has the best performance both in the location and spread of average annual costs, though 6 is a close second and provides very similar performance.

Considering all these results together, package 6 is a clear winner and dominates package 7 in several dimensions. The package has the largest expected NPV in each scenario considered and performs best even under the worst-case scenario (in which we might expect the package with maximum efficiency to do better). Package 6 also provides the second-largest IRR (32–35 percent), and this IRR exceeds that of package 7 (19–22 percent) by more than 10 percent. Although the initial capital cost exceeds $40,000, the payback time (3.6–3.7 years) is reasonably short and indicates that the initial investment is likely to be quickly recouped even if service life is shorter than expected. Package 7, alternately, provides payback times of 6.2–6.7 years, nearly double that of package 6, and these longer times may cause concern for the facility manager or business owner. The ability of a building owner to implement this package, however, may be constrained by availability of affordable capital. An owner looking to achieve cost savings through efficiency with little up-front investment would likely favor package 2. Table 5.5 summarizes these results for efficiency packages 2–7.

Table 5.5
Summary of Key Results for Efficiency Packages 2–7

	Package					
Performance Metric	**2**	**3**	**4**	**5**	**6**	**7**
Investment cost ($)	709	22,169	48,225	46,049	41,358	71,103
Water savings (%)	17.6	13.7	36.0	57.6	62.1	67.3
NPV ($)[a]	27,142	58,094	13,122	41,881	104,749	82,793
IRR (%)[a]	541	33	11	18	34	20
Payback time (years)[a]	0.2	3.7	15.7	7.1	3.6	6.4
Average operating costs ($)[a]	21,664	15,604	16,733	12,492	7,136	6,397

[a] Results for scenario D.

The principal reason for this dominance is the capital cost of the emerging toilet technology included in package 7. HETs are considerably more expensive per unit than are ULFTs. Although HETs use less water (1.28 gpf versus 1.6 gpf), the efficiency gains are insufficient to overcome the capital cost difference even in scenarios with large water price increases. The high capital cost of HETs significantly reduces the financial performance of package 7. As a result, building owners may prefer installing cheaper, more established toilet technology until the price of the new devices falls to similar price levels.

Examining Package 6 in Detail

We next explore in more detail the water use and financial performance associated with efficiency package 6 (an attractive option according to the previous results) under a single price scenario, D. Recall that this scenario specifies a roughly normal weighting across the price trends with the most weight on the 2 percent water and energy price trend.

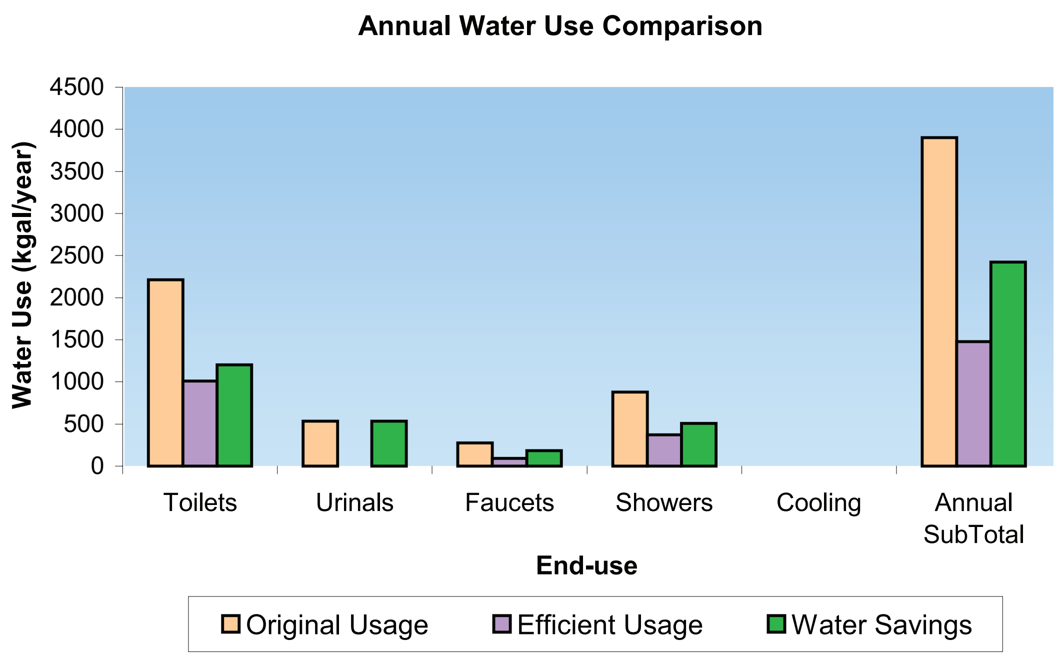
Table 5.6 and Figure 5.4 show modeled water consumption by end use before and after efficiency package 6 is implemented. Package 6 saves approximately two-thirds of the total water consumed through these end uses. Toilet usage accounts for the majority (56 percent) of the total saved—replacing the older 3.5 gpf toilets with 1.6 gpf toilets saves approximately 1,200 kgal annually (about 30 percent of the original water usage). Urinal water usage drops to zero, because the efficiency package replaces 3.0 gpf valve urinals with non–water-using models. Urinals, however, account for only 14 percent of the original water usage. Note that these water-usage results are calculated deterministically for each package and do not vary with the scenario chosen. BEAM also provides similar comparison for energy use (not shown).

Table 5.7 shows the financial results for efficiency package 6 under scenario D. Package 6 requires a $41,000 initial investment and, under price scenario D, it yields $146,000 in net present benefits. This translates into an IRR of about 34 percent and a short payback of 3.6 years. The standard error for NPV and net present benefits are also shown. Note, however, that this value is a small fraction of the total because only price uncertainty is accounted for in the 100-case Monte Carlo simulation. BEAM does not currently account for uncertainty in water consumption or performance of efficient technologies. If included, this uncertainty would likely substantially increase the standard errors.

Table 5.6
Annual Water Use and Savings for Efficiency Package 6

Purpose	Original Usage (kgal)	Efficient Usage (kgal)	Water Savings (kgal)	Savings (%)
Toilets	2,214	1,012	1,202	54
Urinals	535	0	535	100
Faucets	273	91	182	67
Showers	879	374	506	58
Cooking	0	0	0	0
End-use subtotal	3,902	1,477	2,425	62

Figure 5.4
Annual Water Use and Savings for Efficiency Package 6



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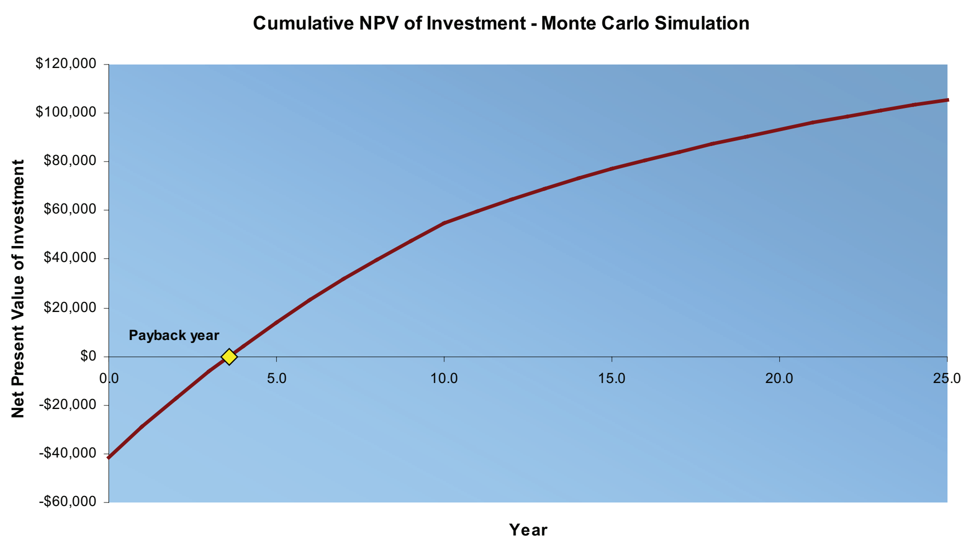
Finally, Figure 5.5 shows how costs and benefits accrue over 25 years, in the form of cumulative NPV. In year 0, the investment yields a negative result equal to the capital cost of the project. As avoided costs (benefits) accrue over time, the return increases, until it crosses the x axis. At this point—the payback year—the investment breaks even. Note that benefits from efficiency slowly subside over time (and the curve is concave-down) because they are discounted back to the present and lose value in future years. There is also a slight kink point at the 10-year mark. At this point, the faucets and showers installed (which have an assumed life of 10 years) cease to provide efficiency benefits, and NPV in future years increases at a reduced rate.

Table 5.7
Financial Results for Package 6 Under Scenario D

	Return on Investment	
Measure	**Mean**	**Standard Error**
Capital investment ($)	41,358	NA
Net present benefits (avoided costs) ($)	146,827	820
NPV ($)	105,469	820
EANBs ($)	11,108	81
Payback time (years)[a]	3.6	NA
IRR (%)[b]	33.6	NA

[a] Mean payback time is based on mean cash flow over time.
[b] Mean IRR is based on mean NPV over time.

Figure 5.5
Cumulative Net Present Value of Efficiency Package 6 Under Price Scenario D



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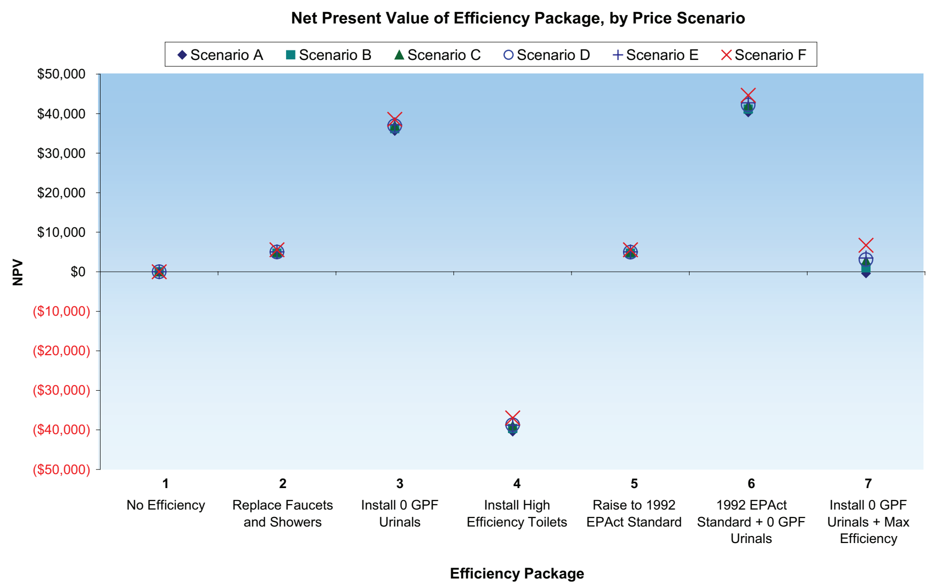
Results for Baseline 2: Current (Post-1992) Fixtures

We next examine the potential water savings and financial benefits from replacing the current RAND building's fixtures with the most efficient technologies available. We first explore the seven efficiency packages described above across the six price scenarios and then focus on a single efficiency package of interest.

Return on Investment

The NPV results by package and scenario for the current fixtures (baseline 2) are significantly different from those for the pre-1992 fixtures (baseline 1) (Figure 5.6). In particular, because

Figure 5.6
Net Present Value of Efficiency Package by Scenario for the Current-Fixture Case



RAND *TR461-5.6*

the current fixtures are already relatively efficient, most of the efficiency packages provide small or negative returns. Package 2 reflects a small potential gain due to installing slightly lower-flow showerheads and faucets. Package 5 shows the same result because no other fixture changes are needed to meet the Energy Policy Act of 1992 standard (P.L. 102-486). Replacing the ULFTs with HETs in package 4 provides a strongly negative investment return across all scenarios, and package 7 breaks even only because the capital costs of the HETs mitigate the potential returns from installing 0 gpf urinals. Under the intermediate price scenario (D) and planning discount rate used, HETs would need to be priced within $125 of the ULFT alternative to be worthwhile from a purely investment-return perspective.

Packages 3 and 6, however, have large positive investment returns. Both packages include non–water-using urinals, which appear to lead to the positive returns. We now focus on package 3 in detail to better understand the favorable performance due to the installation of non–water-using urinals.

Examining Package 3 in Detail

Replacing all urinals in the RAND building (package 3) would require a capital investment of about $22,000, and, under price scenario D, it leads to $59,000 of avoided costs for a total NPV of $36,800 (Table 5.8). This translates to an IRR of 24.6 percent and a five-year payback period.

For baseline 2 (current RAND fixtures), BEAM projects that urinals use about 178 kgal of water annually—10 percent of the restroom total. Installing non–water-using urinals eliminates all water use for urinals (not shown). At an average water price of $1.45/kgal in the first year of the projection, however, the water cost savings are only about $258 annually.

Table 5.9 shows a comparison of the average annual restroom operation costs under scenario D for the current fixtures and for efficiency package 3. These costs are separated out for water and waste water, energy, and O&M. This comparison reveals negligible energy

Table 5.8
Financial Results for Package 3 Under Scenario D

	Return on Investment	
Measure	**Mean**	**Standard Error**
Capital investment ($)	22,169	NA
Net present benefits (avoided costs) ($)	59,006	77
NPV ($)	36,838	77
EANBs ($)	3,468	7
IRR (%)	24.6	NA
Payback time (years)	5.1	NA

Table 5.9
Comparison of Average Annual Costs Under Cost Scenario D with No Additional Efficiency and with Package 3

	No Additional Efficiency ($)		With Package 3 ($)	
Cost	**Mean**	**Standard Error**	**Mean**	**Standard Error**
Water and wastewater	7,454	110	6,477	83
Energy	1,070	27	1,094	30
O&M	5,559	NA	797	NA
Total	14,084	115	8,368	91

cost saving,[10] small water and wastewater cost savings ($977), and large O&M cost savings ($4,762). Note that the differences in energy costs for the two efficiency packages are due only to differences in Monte Carlo sampling for each evaluation. Both packages include the same efficiency improvements to hot water–using devices (e.g., faucets).

Due to the current level of building efficiency and comparatively small share of restroom water consumption due to urinal use, the high returns from efficiency package 3 are largely attributable not to water savings, but to the O&M cost savings realized by moving away from urinals with valves. Valve urinals are assumed to cost $81.75 per unit annually for servicing and repairs, whereas non–water-using urinals have a variable annual cost that depends instead on the number of cartridge replacements required.[11] Using a conservative assumption of 1.25 flushes per full-time male employee per day (Gleick et al., 2003), non–water-using urinal use in the RAND building leads to an estimated O&M cost of only $12 per unit annually. Increasing the assumed daily usage of the non–water-using urinals would increase the water savings from urinal replacement. However, increased usage would simultaneously decrease the O&M savings because non–water-using urinal O&M costs increase as a function of the number of uses (while valve urinals are assumed to have a constant annual O&M cost).

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[10] The difference between the two reported mean energy costs is due to variation between the two independent Monte Carlo simulations used; in reality, the mean energy costs would not change under efficiency package 3.

[11] The cartridges for Falcon Waterfree urinals, for example, are recommended to be replaced after 7,000 uses (Falcon Waterfree Technologies, 2006).

These results suggest that the RAND headquarters building manager ought to consider replacing current ULFUs with non–water-using urinals, but due only to savings in O&M. The analysis does not support replacing the current ULFUs with non–water-using models for water-saving purposes alone.

CHAPTER SIX

Conclusion

This report has presented a simple analytic framework to consider the net benefits of commercial building water-use efficiency investments. It accounts for the costs of implementation and balances these against the benefits: avoided water, energy, and wastewater costs and net changes in O&M. It explicitly addresses uncertainty in future utility prices through the use of scenarios.

Using this framework, as implemented in BEAM, we analyzed the current RAND headquarters building in Santa Monica, California. The results for the first baseline efficiency conditions (pre-1992 fixtures) suggest highly favorable investment returns for all efficiency packages. Upgrading all devices to the 1992 standard and replacing urinals with non–water-using designs performs particularly well. A $41,000 investment pays for itself in about 3.6 years and provides an NPV ranging from $91,000 to $122,000, depending on the scenario of future utility prices. A similar efficiency package that includes replacing existing toilets with the latest HETs (1.28 gpf) performs less well: It pays for itself in 6.5 years. This result is due to the high cost of HETs ($626 versus $240 for a standard 1.6 gpf model). Currently, the costs of new HETs are too high to warrant their purchase instead of ULFTs. Under the intermediate price scenario (D) and planning discount rate used in Chapter Five, HETs would need to be priced within $125 of the ULFT alternative to be worthwhile from a purely investment-return perspective.

The performance of the efficiency packages also depends on the projected trends in water, energy, and wastewater utility prices. The greater the water savings due to efficiency, the larger the range in investment returns due to the uncertainty about utility prices (e.g., Figure 5.2 in Chapter Five). In regions where utility prices are not expected to drop over the time horizon of the water using devices analyzed in this study, business owners can be confident that efficiency packages will perform as well as or better than the results for the no-price-growth scenario.

The upside of the water-efficiency investments can be seen in the results of average cost of building operational costs for each price scenario (e.g., Figure 5.2 in Chapter Five). Efficiency investments that save the most water lead to the lowest range in operation costs across the various price scenarios. In this way, efficiency investments reduce the uncertainty of future operation costs. Although this volatility reduction is not quantified formally with BEAM, it nonetheless represents a real benefit to efficiency that may be of considerable value to a business owner. For the first baseline efficiency case, for example, the efficiency packages that include HETs do not lead to the highest return (as measured by NPV) but do lead to lower future uncertainty about operating costs.

For the second baseline efficiency case (post-1992 fixtures), only efficiency packages that include replacing existing urinals with non–water-using models perform well. Specifically, a

$22,000 investment replacing all urinals with non–water-using models yields about $37,000 in NPV. The analysis shows that the benefit from the non–water-using urinals derives largely from reductions in O&M costs and are thus sensitive to assumptions about maintenance expenditures for the existing valve-type and non–water-using urinals. Replacing currently functional ULFTs with HETs cannot be justified on financial grounds under any price scenario considered. Newer buildings may need to look beyond restroom water use for beneficial efficiency investments.

It is important to note that the framework and tool described here were designed to provide the user a convenient way to consider the potential value of efficiency under price uncertainty without collecting extensive data or hiring a consultant. If one or more of the packages looks promising to the building manager, it might be prudent to conduct a more detailed planning-level analysis of the capital cost, annual water savings, and expected financial return for the package or packages. Of course, the ability of a building owner to implement any package may be constrained by availability of affordable capital. Also, although the costs and savings of efficiency devices may also be uncertain, the framework described here assumes that these characteristics are known with certainty. Nevertheless, we believe that this framework and model provide a valuable new tool for building owners to identify sensible efficiency improvement investments that will save water and energy while making financial sense.

APPENDIX A

Building Water Efficiency Analysis Model User's Guide

What Does the Building Water Efficiency Analysis Model Do?

BEAM is a software tool developed by RAND to help office building managers estimate potential water, energy, and cost savings from investment in water-efficient technologies.[1] BEAM provides building managers with an easy-to-use financial framework to help analyze the costs, benefits, and returns on investments in water-efficiency technologies and improved operations. Notably, BEAM calculates efficiency benefits from water, energy, and wastewater savings, and it explicitly considers the impact of different trends in future resource prices on efficiency investments. The conceptual foundation of BEAM is described in the body of this report.

BEAM calculates the financial costs and benefits of replacing (or retrofitting) existing water-using devices with new, more efficient devices for a specific building or collection of buildings. To begin an analysis, users enter information about a building's basic characteristics and existing water-using devices. BEAM then prompts users to specify up to six scenarios of future water, sewer, and energy prices. Each scenario is defined by providing likelihoods for six predefined price trends, ranging from no change in price to a significant annual price increase. The user then may define up to seven efficiency packages to analyze. Each efficiency package is defined by the percentage of devices that are retrofitted or replaced with more efficient models. BEAM then calculates the net benefits of implementing each efficiency package against each of these possible price scenarios. For each price scenario, BEAM uses a Monte Carlo simulation method to calculate results weighted according to defined variability for each price trend and user-specified weighting for each trend.

BEAM presents the analytic results numerically and graphically to help facilitate choice among these efficiency packages. These results can help building managers identify whether efficiency investment strategies are beneficial, determine which strategies yield the most favorable returns, and help users better understand how such investments could help them hedge against future water, energy, and wastewater price increases.

The Building Water Efficiency Analysis Model's Limitations

BEAM is designed for use by commercial office building managers. The tool analyzes water usage in restrooms and by cooling systems. These two areas encompass a significant portion of total water use for many commercial buildings. As water is used in other areas of commercial

[1] Jordan Fischbach, David Groves, and Scot Hickey of the RAND Corporation developed BEAM. A copy of the model is available from RAND (see Groves, Fischbach, and Hickey, 2007).

buildings (e.g., for irrigation, drinking fountains, kitchenettes, cafeterias, and ice-making), more efficiency improvement is likely to be possible than is evaluated in BEAM.

BEAM is not specifically designed to evaluate efficiency opportunities in industrial buildings, as water-use patterns differ dramatically between the commercial and industrial sectors and industrial processes that use water are not captured in this model. BEAM, however, may still be used to evaluate restroom and cooling-water efficiency opportunities for many industrial buildings.

BEAM was developed to more fully explore the potential net benefits of commercial water-efficiency investments while incorporating uncertainty about future water and energy prices faced by the building operator. BEAM does not address uncertainties that would arise if poor-quality data were used to characterize building-specific water use, technological performance, installation costs, or O&M costs. The tool therefore does not provide probabilistic estimates for costs, water savings, or energy savings, and likewise does not fully characterize the uncertainties inherent to this decision problem.

The current version of BEAM is not compatible with the Macintosh operating system.

Entering Data into the Building Water Efficiency Analysis Model

To use BEAM to evaluate the water efficiency opportunities for a specific building or set of buildings, you must enter basic information about the building occupants and overall water usage, details on the restroom and cooling technologies currently installed, and the resource prices charged by local utilities. The tool uses this information, together with a set of water-use, capital, and O&M cost assumptions, to estimate annual water usage and water costs in the building, by end use. You will be able to review and modify these assumptions in later steps, as described below. The data entry and analysis process is shown below (Figure A.1).

Step 1: Choose Method of Data Entry

When you first open BEAM, you have the option of entering data via a set of interactive forms or directly onto the spreadsheets. To use the interactive forms, click **Begin Data Entry** button on the **Intro** worksheet. You may switch back to spreadsheet entry at any time by simply clicking the x (close button) in the upper-right corner of the entry form.

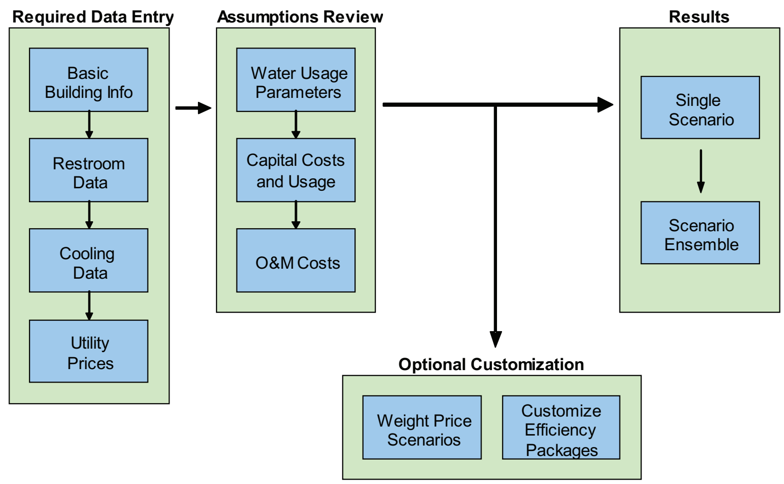
To use the forms, enter all requested information in the appropriate spaces, and then click **Next** to move to the next sheet. Note that the actual spreadsheet updates only when you move away from the entry sheet, and the tool will alert you if you try to close the entry forms without first updating the cells.

Alternately, you may enter data directly into the spreadsheets. You can navigate to the desired sheet by clicking directly on the analysis flow diagram on the **Intro** worksheet, or you can select the appropriate worksheet tab at the bottom of the spreadsheet window. On the spreadsheets, the blue cells are those that you can modify. You can switch to the interactive, form-based entry by clicking **Open Data Entry Form**, which appears on each worksheet.

Step 2: Enter Basic Building Information

Basic building information is entered on the **Building - INPUT** worksheet. The first form asks for basic information about your building, including number of full-time and part-time

Figure A.1
Analysis Flow Diagram



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employees and number of visitors. If you do not know the breakout of gender for any of these categories, assume 50 percent male and 50 percent female.

The cell **% time PT** refers to the approximate percentage of full-time hours you consider part time. The default is set to 50 percent, so that, if you consider full-time employment to be 260 days annually, using the default, BEAM would consider part-time employment to be 130 days of work annually.

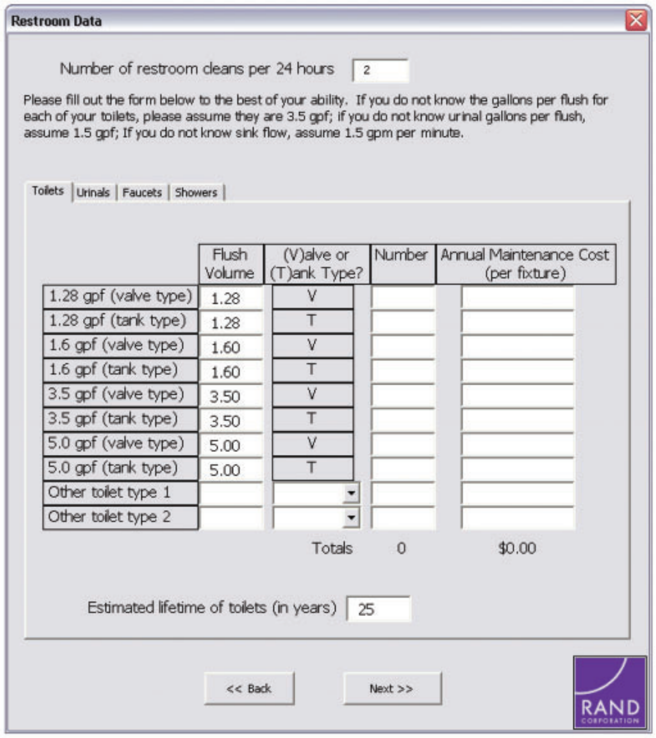
Step 3: Enter Existing Restroom Information

The next step is to enter information about the fixtures currently installed in your building's restrooms (**Restroom - INPUT** worksheet). First, enter the number of times per workday that the restrooms are cleaned. The remaining entry is divided into four parts—one for each basic type of restroom fixture. Navigate to each part using the four tabs provided on the restroom data form.

Each tab contains cells to enter detailed information about the building's toilets, urinals, faucets, and showers, respectively. For each type of device, you must enter an *estimated lifetime* of the device, in years. BEAM will use this lifetime as the number of years a newly installed device or fixture will function before it must be *entirely replaced*. In the case of a valve toilet, for example, you would enter the estimated number of years before the entire valve required replacement. Do not enter the amount of time before the device requires any rehabilitation or repair in the cell; the tool treats ongoing maintenance, repair, or rehabilitation separately, the costs associated with these repairs can be entered (optional) as the *annual maintenance cost per fixture* for that type of fixture.

Toilets. The **Toilets** tab (Figure A.2) shows commonly observed toilet types in commercial buildings. For each type presented, enter the number of that type of toilet currently in use in your building. If the building does not have a given type, leave that row blank. By default, BEAM assumes that the actual flush volume of the toilets listed equals the rated volume. If you believe that the actual flush volume is greater or less than the rated volume, you can change the flush volume for the device in the first column.

Figure A.2
Restroom Data Dialog Box, Toilet Tab



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For each type of toilet, the tool also allows you to consider the approximate annual maintenance (or O&M) cost for that type of toilet. Note that entering O&M costs is *optional*—if you do not know the average O&M cost or do not expect this cost to change when installing a new device, you may leave these cells blank and the tool will disregard these costs.

If you want to consider O&M costs, enter the cost on a per-unit basis. If you know the total cost of maintaining those types of toilets for a year, you can simply divide the cost by the number of toilets to arrive at the per-unit cost. The annual maintenance cost should include all of the parts, labor, and other costs associated with repairing that type of toilet throughout a given year and, as noted above, would includes ongoing rehabilitation or repair (short of total replacement).

If you use a type of toilet (in terms of rated gpf) not present in the list, enter, using the **Other toilet type 1** or **Other toilet type 2** fields, the appropriate (actual) flush volume, whether those toilets use a flush valve or a gravity tank, the number of such toilets you use, and (optional) the associated annual per-unit maintenance cost.

If you do not know the rated gpf of the toilets in your building, assume 3.5 gpf.

Urinals. The **Urinals** tab provides a similar table to that on the **Toilets** tab, though only the number of each type of urinal is required (annual per-unit maintenance costs are optional). As on the **Toilets** tab, if you use a urinal type not listed, enter the appropriate information in **Other Urinal Type 1** or **Other Urinal Type 2**.

If you do not know the rated gpf of the urinals in your building, assume 1.5 gpf.

Faucets. You may enter two categories of restroom faucets on the **Faucets** tab: standard faucets, which are rated in gpm, or metering faucets, which control the amount of time the faucet is turned on (via a spring valve or infrared sensor) and are thus generally measured in terms of gpv.

Enter the number and annual cost of each type of standard faucet in the specified rows, and separately enter metering faucets. The default for metering faucets is 0.25 gpv. The tool considers metering faucets to be efficient technologies, so the tool will not consider replacing these devices if entered.

If you use a standard faucet with an unlisted flow rate, enter the necessary information under **Other Faucet Type 1** or **Other Faucet Type 2**.

If you do not know the rated gpm of the faucets in your building, assume 1.5 gpm.

Showers. The **Showers** tab provides a table for entering information about existing showers in your building. Enter the number of showers with each average flow rate (in gpm) in the spaces provided, any changes to the actual flow rates (optional), and the associated annual O&M costs (optional).

If the building has showers with unlisted flow rates, enter the necessary information under **Other Shower Type 1** or **Other Shower Type 2**.

Step 4: Enter Building-Cooling Information

BEAM allows you to examine current water usage for building cooling and to evaluate several basic options to improve cooling-water efficiency. If your building currently utilizes evaporative cooling towers or other evaporative cooling devices and you want to consider these devices in your efficiency analysis, fill out the appropriate sections of either the cooling data entry form or the **Cooling - INPUT** worksheet. If your building does not use these devices for cooling or you do not wish to consider cooling efficiency, move to the next section.

To enter cooling data, first enter the *estimated lifetime* of your cooling devices (in years). Once again, note that this is the expected life of the device before complete replacement will be required.

Beyond the service lifetime, cooling data entry is divided into two sections: single-pass and recirculating cooling devices. See below for details on each of these sections.

Single-Pass Devices. The first tab or section is for single-pass evaporative cooling devices. Single-pass refrigeration or cooling devices use water for cooling for one cycle only and then send 100 percent of the water to the sewer system as waste. Single-pass cooling is often used to cool small devices, such as icemakers.

Up to six single-pass devices can be entered using the provided data sheet. For each device, fill out the average flow rate of the device (in gpm). The tool will then calculate the average water usage per day based on 24-hour usage at this flow rate.

BEAM allows you to consider improving single-pass cooling efficiency by closing the chilled water loop and creating a recirculating system. However, because the costs of this investment will vary greatly between buildings and devices, the tool does not include a capital cost assumption for this modification. Thus, if you want to consider converting a single-pass device to a recirculating system, you must enter a cost estimate for both the installation costs and annual O&M cost for each device in the spaces provided. If you do not provide a cost estimate, the tool will not allow you to examine the potential efficiency benefits of the device.

Recirculating Devices (Cooling Towers). The second tab allows you to enter information about recirculating cooling towers in your building. Cooling towers or other recirculating cooling devices are used in many areas to provide comfort cooling for office buildings. In these devices, the process of evaporation removes heat from the circulated water, and the remaining water flows through a heat exchanger to facilitate building cooling before returning to the cooling tower.

If your building uses cooling towers and you want to consider improving the efficiency of these devices, you can enter information for up to 10 cooling towers in the space provided in this form. For each tower, enter the average cooling load, in tons, for 24-hour operation of the device. Ensure that this represents an average of the actual usage, rather than the rated capacity of the device.

Next, enter the current estimated CR for the device. The CR is the ratio of TDS in the system compared with the TDS in the makeup water. It is used to calculate how much water is needed to maintain the cooling system each day.[2]

Once you have entered the appropriate values, BEAM will estimate the water lost to evaporation, the water required (in gpm) for blowdown, and the system's average daily water use.

BEAM considers several basic options for improving cooling-tower efficiency, including the installation of automated conductivity controllers and the use of treatment or filtration on the water circulating in the system. If you currently implement one or more of these measures in this building, check off the appropriate box(es) in the next two columns on the form. If you currently use treatment or filtration in this building and want to compare these O&M costs to the potential costs of a new method, also enter the annual cost of this treatment for comparison purposes. Note that this will also require you to enter estimated O&M costs for any new treatment method you are considering.

If you already use conductivity controllers, the tool will not consider these devices as part of the analysis. However, note that, even if you currently use some form of treatment, BEAM will allow you to consider replacing this treatment with another form of treatment that may allow for greater efficiency or lower O&M costs.

Step 5: Enter Resource Price Information

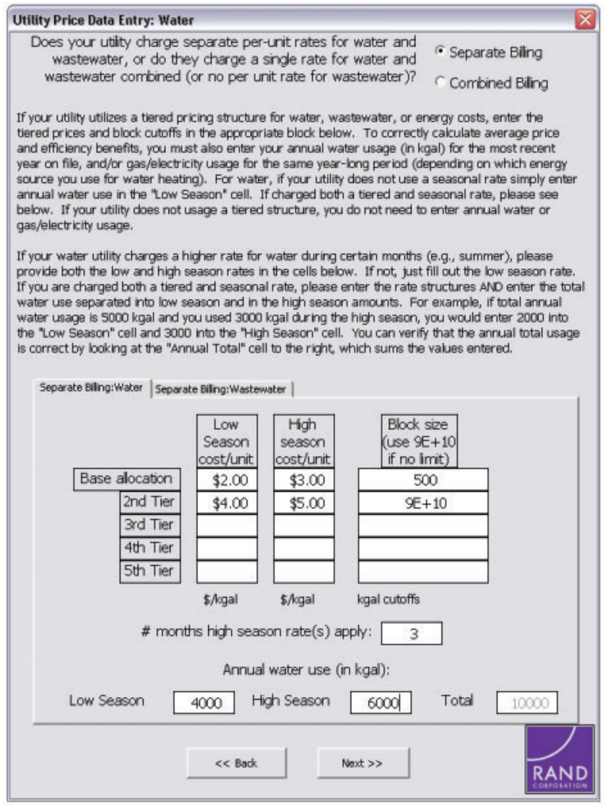
To calculate the potential efficiency benefits from reduced resource costs, BEAM requires information about the current unit prices of water, waste water, and energy to your building and the pricing structure used by your utility (**Utility Prices - INPUT** worksheet). If your utility uses tiered pricing structures, then you must enter the estimated annual use. This ensures that efficiency savings reduce use in the appropriate price tier. If no tiered pricing structures are used, then these fields should be left blank.

The most critical costs to enter in this section are water and wastewater costs. Energy savings are a secondary benefit from water efficiency, and, if you choose not to enter energy prices, you can still evaluate the primary benefits that accrue from reduced water and wastewater costs.

Water. In the **Utility Price Data Entry: Water** dialog box (Figure A.3), first use the option buttons at the top to choose whether your utility charges via **Separate billing** or **Combined billing** for water and waste water. **Separate billing** means that water inflow and wastewater outflow are metered and billed separately, whereas **Combined billing** means that only

[2] For more information on cooling-tower operation, see Chapter Four.

Figure A.3
Utility Price Data Entry: Water Dialog Box



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the water received is metered and you receive one bill for both water and waste water. The tabs in the data entry area change depending on your selection of billing type.

Each tab contains fields for you to fill out. The tool allows for tiered pricing structures, which specify different unit costs for different levels of consumption. For example, an increasing block-rate structure will lead to a larger unit cost as consumption increases beyond certain cutoff points, whereas a uniform rate structure will lead to a constant unit cost not affected by consumption.

If your utility uses a tiered pricing structure, BEAM allows you to enter up to five rates for each resource type. Each row of the table represents one of these tiers. Starting from the top row, in each row, enter the unit cost and the block-rate cutoff up to which this rate applies. You must also enter the total annual water use (in kgal). Note that BEAM assumes that usage is calculated and billed monthly, and thus these cutoffs are applied to monthly usage. The unit cost should be in dollars per thousand gallons ($/kgal), while the cutoff should be entered in thousands of gallons (kgal). Once the top rate is reached, enter a cutoff of 9E+10, or another large number much greater than your monthly usage. If your utility has only a single, uniform rate, enter the rate on the top line and set the block cutoff to 9E+10.

For water prices, BEAM can also consider rates that vary by season. If your water utility charges a higher rate for water during certain months (e.g., summer) but does not otherwise use a tiered water billing structure, enter the low season rate and high season rate in the first row of the table, as well as the number of months in which the high season rate applies in each year. If you are not charged rates that vary by season, fill out the low season rate column and leave the high season column blank.

If you are charged both tiered *and* seasonal rates, enter the tiered rate structures and enter the total annual water use separated into low season and high season amounts.

For example, suppose that a building's water provider charges a two-tiered pricing structure together with a seasonal rate: $2.00/kgal for the first 500 kgal used in a month and $4.00 for all usage above 500 kgal for the nine nonsummer months and $3.00/kgal for the first 500 kgal and $5.00 for all usage above 500 kgal for the three summer months. Further, the building uses 4,000 kgal combined during the nine nonsummer months and 6,000 kgal during the three summer months, for a total of 10,000 kgal annually.

Separate Water and Wastewater Billing. If you select separate billing, you will see two tabs to be completed for water pricing: one for water and one for wastewater. Fill out the water price and wastewater price tabs separately, using the same basic structure as described above. Note that no seasonal price option is provided for wastewater billing.

Combined Water and Wastewater Billing. If you select combined billing, you will see only a single tab to complete. Fill out the appropriate section of the table as described above.

Energy. BEAM also considers the cost of heating water in your building for a subset of end uses (faucets and showers). If you would like to consider the cost of heating water for these uses, fill out the **Resource Price Data Entry: Energy** form. If you do not want to consider potential energy-reduction benefits, you may leave this form blank.

The first step is to select the type of energy used to heat water in your building—electricity or natural gas—using the radio button at the top. The entry table will change units depending on your selection.

Next, fill out the table provided on the form. Once again, the energy form allows you to enter a tiered, block-rate energy pricing structure and annual use, if applicable. This table is similar to the table described in the water price section above and should be filled out in the same manner, except that energy uses different units and no seasonal pricing structure. If you enter a tiered pricing structure, however, you must also enter total annual usage.

If you select electricity, enter the price(s) into the table in dollars per kwh ($/kwh) and the block-rate cutoffs in kw. Once again, BEAM assumes that usage is tabulated monthly, and these cutoffs should be entered as monthly usage cutoffs.

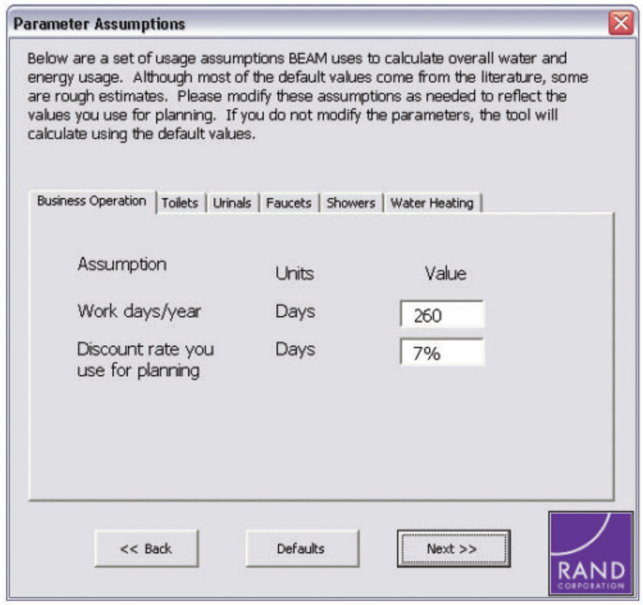
If you select natural gas, enter the price(s) into the table in dollars per therm ($/therm) and the block-rate cutoffs in therms. Note that 1 therm is equal to 100,000 BTUs or about 100 HCF of natural gas.

Step 6: Review Model Parameter Assumptions

BEAM uses a set of water-usage assumptions to calculate overall water and energy usage in your building (Figure A.4). Although most of the default values were derived from other studies, some are rough estimates made by the authors.

The **Parameter Assumptions** dialog box (Figure A.4) allows you to modify these assumptions as needed to reflect the values you use for planning. Review the usage assumptions listed on this form, and modify the assumptions as needed. If you do not modify the parameters, the tool will calculate using the default values. If, at any point, you want to cancel out the changes you have made and instead return to the initial default values, click **Defaults** in this dialog box or on the **Model Parameters - ASSUMPTIONS** worksheet.

Figure A.4
Parameter Assumptions Dialog Box



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Step 7: Review Efficient-Technology Water-Use and Installation-Cost Assumptions

BEAM also contains assumptions used to calculate the water-use and installation costs for potential new efficiency technologies. The **Efficient Technology Water Use and Installation Cost Assumptions** form allows you to review and modify these assumptions.

The default water-use assumptions provided are either (a) the rated water use of the device, or (b) an estimated usage or saving value provided in the literature. You may change these values to fit your planning assumptions.

The installation costs include material and installation labor costs. Some of the cost assumptions listed on this form come from recent estimates in the literature. However, note that many others are simply placeholder values and should be reviewed carefully before moving forward. To the extent possible, you should replace these costs with your own estimates. The better your cost estimates, the more accurate and helpful BEAM will be in calculating your potential return on efficiency investment.

Also, note that there is currently no cost estimate available for installation costs for new treatment or filtration for recirculating cooling devices. You must enter a cost value in the appropriate cell or field if you wish to evaluate the installation of new treatment or filtration for recirculating cooling devices.

If you do not modify the costs, the tool will calculate using the default values. If you want to return to default water use or cost values after making modifications, click **Defaults** at the bottom of the form.

Step 8: (Optional) Enter New O&M Costs

Finally, BEAM provides a form to enter O&M costs for potential new efficiency technologies. The model treats these as annual, per-unit O&M costs, which would include any repairs or rehabilitations (both materials and labor) for each type of device. Because these costs will vary widely from building to building and area to area, the modeling team chose not to include default values for the vast majority of cases.

Thus, if you want to compare the O&M costs of your existing devices to the O&M costs of potential new devices, you must enter values in the appropriate sections of these tables. Again, the cost should be an estimate of the annual cost of repairing each unit of a given type of device, including both parts and labor.

If you do not want to evaluate O&M costs, you may leave this form blank, and BEAM will not take the costs into consideration. However, *if you leave these cells blank you must also leave the maintenance or service costs for existing devices blank in the restroom and cooling data-entry sections*. If the restroom and cooling O&M costs are not left blank, the return on investment will be overstated, because no O&M costs will be associated with the new devices.

If you are unsure, simply leave the maintenance and service costs blank through the entire data-entry section, and leave this form blank as well.

Once you have completed this form, click **Finish** to be redirected to the **Single Scenario - RESULTS** worksheet. More information on interpreting these results can be found in the "Interpreting Individual Results" section of this chapter.

Step 9: (Optional) Customize Price Scenarios

BEAM performs a simple scenario analysis reflecting the implications of different expectations about future resource prices. To customize this analysis, click **Customize Price Scenarios** on the **Single Scenario - RESULTS** worksheet, or simply select the **Define Price Scenarios - OPTION** worksheet.

For this analysis, BEAM includes five predefined price trends, which represent different annual price increases for water, wastewater, and energy prices up to 25 years into the future (Table A.1). Each trend is defined by a mean increase and standard deviation, and BEAM uses Monte Carlo sampling according to these distributions. You may change the values defining these trends. If you would rather that each trend be deterministic (no variability about the mean annual price increase), deselect **Stochastic Scenarios?** in the upper-right corner of the worksheet.

A scenario is a particular weighting of these five trends, and there are six predefined scenarios in BEAM. On this worksheet, you can examine the price trends graphically and

Table A.1
Predefined Resource Price Trends

Predefined Price Trends		Water and Wastewater		Energy	
Trend	Description	Mean Annual Price Increase (%)	Standard Deviation (%)	Mean Annual Price Increase (%)	Standard Deviation (%)
1	No price increase (best case)	0	0.50	0	0.50
2	Small increase	1	0.50	1	0.50
3	Moderate increase	2	0.75	2	0.75
4	Large increase	3	1.00	4	1.00
5	Very large increase (worst case)	4	1.00	6	1.00

define up to six different scenarios by weighting these predefined trends using the matrix at the bottom of the page. Each scenario represents a different weighting of these trends, corresponding to your belief about the likelihood of that trend. For example, if you believe that a modest price increase is likeliest but you would like the analysis to reflect a smaller possibility of more considerable increases over time, you could weight the five price trends as shown in Table A.2.

Initially, scenarios 1–5 are set so that each one has 100 percent weight on a different trend (e.g., scenario 1 has 100 percent weight on trend 1), while scenario 6 has mixed weights, but these can be altered as you see fit.

For each scenario, you can enter numbers on any scale, and the tool will normalize them to a 0–100–percent scale.

Step 10: (Optional) Review and Customize Efficiency Packages

To consider the potential benefits from investing in different types of water efficiency, BEAM includes a set of predefined water-efficiency packages for comparison purposes. You can customize these efficiency packages. To review and customize the efficiency packages, click **Customize Efficiency Package** on the **Single Scenario - RESULTS** worksheet, or simply select the **Efficiency Packages - OPTION** worksheet. You may also specify any utility rebates that would be received were the efficiency package to be implemented.

This worksheet shows the packages of efficiency devices BEAM can consider. Each package corresponds to a column on the table. The packages provide for the replacement, rehabilitation, or retrofit of devices in each major end use previously described in the data-entry section. The percentages on the table correspond to the percentage of that type of device that will be replaced or retrofitted in a given package. Thus, **100%** in the **3.5 gpf-valve toilet** row indicates that 100 percent of the 3.5 gpf toilets in your building will be replaced or retrofitted in this package. At the bottom of each end-use table, you will also see a toggle (**0/1** or **0/1/2**). These toggles determine whether the devices for this end use will be retrofitted if they are not replaced (by entering **1** for **Retrofit remaining?**), as well as set the type of device that will be used to replace the existing device (**1 = x**, **2 = y**, **3 = z**).

BEAM contains seven predefined packages (see Table A.3). You can customize any of the options for any of the packages to reflect a range of efficiency alternatives you are considering. When in BEAM, you can also change the names of the packages using the first cell in each column.

Table A.2
Possible Weighting of Price Trends

Trend	Description	Weight
1	No price increase	10
2	Small increase (1%/year)	50
3	Moderate increase (2%/year)	25
4	Large increase (3%/year)	10
5	Very large increase (4%/year)	5

Table A.3 shows the settings for toilets for each efficiency package and the optional rebates. Note that four other similar blocks of input cells correspond to urinals, faucets, showerheads, and the cooling system.

Results

BEAM provides you with a variety of results to understand how different water efficiency packages will affect water use, energy use, and resource costs and to evaluate the financial performance of the considered efficiency packages.

Single Scenario and Efficiency Package Results

After entering all required input data into BEAM, the Data Entry Guide will lead you to the **Single Scenario - RESULTS** worksheet. This sheet allows you to compare results for any single combination of efficiency package and price trend scenario. Use the selections in the upper-left portion of the sheet to specify the efficiency package and price trend scenario. To the right of these selections is a graph that shows the price-trend weighting corresponding to the selected price trend scenario. Note that the price trends listed to the right of the graph are the default values and will not reflect any changes made to the trends on the **Define**

Table A.3
Capital Rebates and Efficiency Package Specification for Toilets

	Package						
Specification	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Government or utility capital rebate ($)							
Enter any overall monetary incentive you would receive in the base year by implementing this package (excluding per-unit rebates).	0	0	0	0	0	0	0
Toilets to replace (%)							
1.6 gpf (valve)	0	0	0	100	0	0	100
1.6 gpf (tank)	0	0	0	100	0	0	100
3.5 gpf (valve)	0	100	0	100	0	0	100
3.5 gpf (tank)	0	100	0	100	0	0	100
5.0 gpf (valve)	0	100	0	100	0	0	100
5.0 gpf (tank)	0	100	0	100	0	0	100
Other toilet type 1	0	100	0	100	0	0	100
Other toilet type 2	0	100	0	100	0	0	100
Replacement toilet gpf	1.6	1.6	1.6	1.28	1.6	1.6	1.28
Retrofit remaining	No	No	No	No	No	No	No
Retrofit mechanism[a]	0	0	0	0	0	0	0

[a] 0 = mechanical.

Price Scenarios - OPTION worksheet. Buttons take you to the worksheets, on which you can customize the efficiency packages and price scenarios.

The results provided on the **Single Scenario - RESULTS** worksheet are organized into two sections: (1) water and energy use and savings and (2) investment results.

Water and Energy Usage and Savings. The water and energy usage and saving results are presented in tabular and graphical form. For each type of device and total of all devices, BEAM provides the following results:

- original water and energy usage
- efficient water and energy usage (usage after efficiency investment)
- water and energy savings (absolute amount of savings)
- percent water and energy savings.

The graphics to the right indicate the annual original usage, efficient usage, and savings by device type for water and energy.

Investment Results for Monte Carlo Simulation. The **Single Scenario - RESULTS** worksheet provides investment financial results for a single efficiency package under the selected price scenario, based on a 100-case Monte Carlo simulation. The Monte Carlo simulation samples across different water, wastewater, and energy price trends as characterized by the resource price scenarios. *To review up-to-date results, each time you change the combination of efficiency package and price trend scenario, you must click **Update Simulation Result**.*

The left block shows investment results for the specified efficiency package. The following results are provided.

- *Capital Investment:* The capital investment is the total up-front costs in present dollars for the efficiency package. This value is deterministic and does not vary by simulation.
- *Net Present Benefits (Avoided Costs):* Net present benefits are the water, energy, and wastewater costs that the building owner does *not* have to pay due to the implemented efficiency over the lifetime of the investment. These results are discounted back to the present using the discount rate specified on the **Model Parameters - ASSUMPTIONS** worksheet.
- *NPV:* The NPV of the investment considers the avoided costs as a benefit and the up-front and ongoing O&M costs of the efficiency investment. A positive value indicates that the selected efficiency package return a positive return on average across the 100 simulations.
- *EANB:* The EANBs are a scaled investment metric closely related to NPV. EANB represents the equivalent amount of income required annually to achieve the overall NPV of the project throughout its service life. As the metric is annualized, EANB can be compared across projects without concern for differing project horizon values.
- *IRR:* The IRR is the yield of the efficiency investment. The IRR is calculated based on the average cash flow (based on the 100 simulations) and thus has no standard error. If no value is displayed, then either no investment is being evaluated or the investment has a negative return.
- *Payback Time:* The payback time indicates in how many years the discounted benefits will exceed the discounted costs. The payback time is calculated based on the mean benefits and thus has no standard error.

The right block of results shows mean and standard error values for water and wastewater, energy, O&M, and total costs. No standard error is calculated for O&M costs, as these results are deterministic.

At the bottom of the **Single Scenario - RESULTS** worksheet is a graph of NPV of the investment over time for the entire efficiency package. The time in which the line crosses the zero NPV point is equal to the payback time.

Efficiency Package Comparison: Multiple Price Scenarios

At the top of the **Single Scenario - RESULTS** worksheet is a button that will take you to the **Scenario Comparison - RESULTS** worksheet. Begin by updating these results by clicking **Update Ensemble** button at the top of the worksheet. Be patient, as the calculations will take a minute or two.

On this page, BEAM provides tabular and graphical results for all of the water-efficiency packages and price scenarios. This information can help you to compare the performance of different efficiency packages as well as consider how performance varies across scenarios of resource price. One typical result is that investments that lead to greater water savings are less sensitive to water price and can provide a hedge against future price increases.

The top graph shows investment costs (bars) and total water use (lines) for each of the seven efficiency packages. These results do not depend on resource prices and thus do not vary across price scenarios. This graph, in many cases, will show a trade-off between investment cost and water use—the greater the investment in efficiency, the lower the water use.

BEAM next displays the mean NPV for each efficiency package under each resource cost scenario and the minimum, average, and maximum payback times for each efficiency package. Note that investments with negative NPV will have no payback time. It next shows the NPV results graphically by scenario, with each symbol pertaining to a different resource price scenario. The tool also provides a table detailing the mean EANB for each package under each scenario.

The last two results show the average annual utility and O&M costs by efficiency package. The top table shows the average annual costs for each individual resource price scenario by efficiency package, and the chart below shows these results graphically.

APPENDIX B

Case Study: Water Usage and Cost Assumptions

This appendix provides key usage parameters and cost assumptions that support the example case study presented in Chapter Five. Most assumptions presented below are also defaults provided in BEAM. Due to potentially significant variance among different facilities in water-usage profiles and costs, we anticipate that most users will alter these assumptions to more accurately reflect their buildings' characteristics (Tables B.1, B.2, and B.3).

Table B.1
Water Use Parameter Assumptions

Parameter	Value	Unit
Business Operation		
Work days per year	260	Days
Toilets		
Toilet use per day: male	2.6[a]	Average flushes/capita/day
Toilet use per day: female	2.6[a]	Average flushes/capita/day
Toilet use per day: visitor male	0.33[a]	Average flushes/capita/day
Toilet use per day: visitor female	0.33[a]	Average flushes/capita/day
Toilet cleaning	1	Average flushes/clean
Urinals		
Urinal use per day: male	1.25[a]	Average flushes/capita/day
Urinal use per day: visitor male	0.17[a]	Average flushes/capita/day
Urinal cleaning	1	Average flushes/clean
Faucets		
Bathroom visitors using faucet	70[a]	Percent of visitors
Faucet use per flush	0.167[a]	Minutes/visit
Housekeeping wash use	0.5	Minutes/clean
Showers		
Average shower length	8.2[b]	Minutes
Employees using showers	10	Percent/day
Shower cleaning	1	Minutes

Table B.1—Continued

Parameter	Value	Unit
Water heating		
Incoming water temperature	58	Degrees F
Average hand-washing temperature	70	Degrees F
Average shower temperature	75	Degrees F
Gas heater efficiency	82[c]	Percent reaching end use
Electric heater efficiency	100[c]	Percent reaching end use

[a] Gleick et al. (2003).
[b] Mayer et al. (1999).
[c] EnergyIdeas Clearinghouse (undated).

Table B.2
Efficient-Technology Water-Usage and Installation-Cost Assumptions

Technology (rated capacity)	Water Use	Units	Installation Cost ($)[a]
1.6 gpf toilet: tank-type replacement	1.6	gpf	275[b]
1.6 gpf toilet: valve-type replacement	1.6	gpf	240[c]
1.28 gpf toilet: tank-type replacement	1.28	gpf	626[d]
1.28 gpf toilet: valve-type replacement	1.28	gpf	626[d]
Tank toilet retrofit: displacement device	0.75[e]	gpf saved	3[f]
Tank toilet retrofit: mechanical device	0.75[e]	gpf saved	11[f]
Valve toilet retrofit: water-saver valve	1.0[e]	gpf saved	23[f]
1.0 gpf urinal	1.0	gpf	395[f]
0.5 gpf urinal	0.5	gpf	1,002[g]
0 gpf urinal	0.0	gpf	326[h]
Urinal valve-kit retrofit	0.5[i]	gpf saved	23[f]
Faucet aerators retrofit	1.0	gpm	6[f]
Faucet-flow regulators	1.0	gpm	13[f]
Metering faucets: infrared	0.25[j]	gpv	200[k]
Metering faucets: spring valve	0.25[j]	gpv	50[k]
Low-flow showerhead replacement (2.5 gpm rated)	1.67[l]	gpm	27[f]
Showerhead retrofit	1.67	gpm	6[m]
Conductivity controllers	20[n]	Percent savings	2,000[f]
New treatment or filtration	15[n]	Percent savings	NA
Closing single-pass loop	90[n]	Percent savings	NA

Table B.2—Continued

[a] Installation costs include unit cost and labor for each fixture.

[b] Average of eight unit prices provided for various models. Assumes $55 installation cost. EPA (undated).

[c] Average of three unit prices. Assumes $60 installation cost. EPA (undated).

[d] Average price based on industry snapshot, January 23, 2007. Snapshot includes 21 HET models from eight manufacturers, assuming default characteristics. Assumes $100 installation cost.

[e] North Carolina Division of Pollution Prevention and Environmental Assistance, North Carolina Division of Water Resources, and Land-of-Sky Regional Council (1998); New Mexico Office of the State Engineer (1999); EPA (undated).

[f] EPA (undated).

[g] Average price based on industry snapshot, January 23, 2007. Snapshot includes three models from two manufacturers. Assumes $100 installation cost.

[h] Falcon Waterfree Technologies (2006). Assumes $100 installation cost.

[i] EPA (undated). Software presents a range of values, and we selected the lower end of the range as a conservative estimate.

[j] Assumes that usage conforms to the Energy Policy Act of 1992 standard of no more than 0.25 gallons per cycle (P.L. 102-486; EPA, 1998).

[k] Pekelney and Chesnutt (1996), cited in CUWCC and A&N Technical Services (2003, pp. 2–69).

[l] Without specific information, we assume that actual flow rates of faucets and showers are about 67 percent of the rated maximum, as individuals rarely run these devices at maximum flow rates (Vickers, 2001, cited in Gleick et al., 2003, p. 494).

[m] North Carolina Division of Pollution Prevention and Environmental Assistance, North Carolina Division of Water Resources, and Land-of-Sky Regional Council (1998).

[n] Gleick et al. (2003).

Table B.3
Urinal Operation and Maintenance Cost Assumptions

Technology	Annual O&M Cost Assumption ($)
Valve urinal	81.75[a]
Non–water-using urinal	12.00[b]

SOURCE: Falcon Waterfree Technologies (2006).

[a] Average per-unit annual maintenance cost, including all parts and labor, for water-flushed urinals.

[b] Annual per-unit cost based on existing usage assumptions, a $39.00 unit cost per replacement cartridge, and a service life of 7,000 flushes for each cartridge. BEAM will vary annual O&M cost as usage assumptions change.

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