INNOVATIVE
CONSERVATION
PROGRAM
Metropolitan Water District
of Southern California

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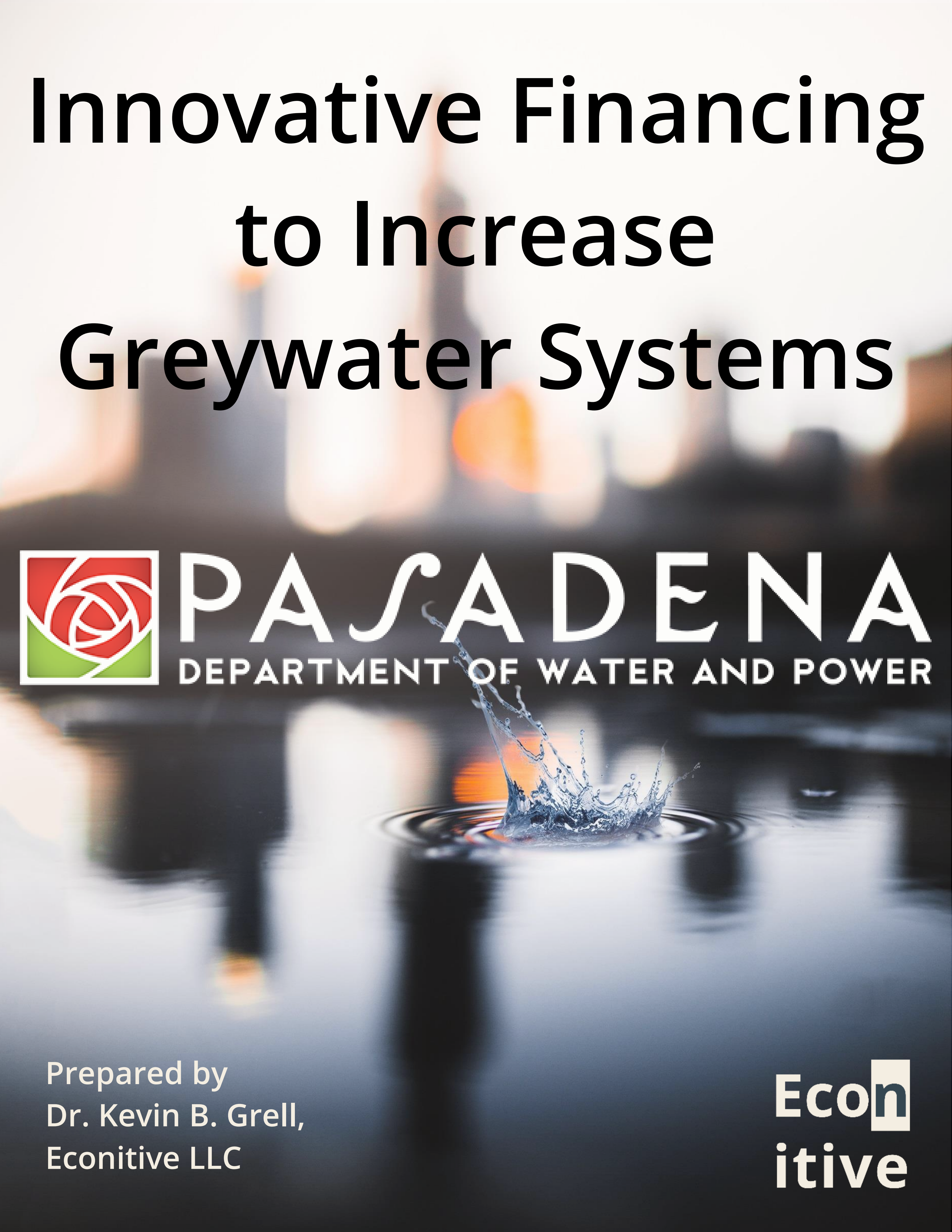
Innovative Financing to Increase Greywater Systems



PASADENA
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TITLE PAGE

Title: Innovative Financing to Increase Greywater Systems

ICP Recipient Name: Pasadena Water and Power

Agreement No. 181247

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Front matter photo credit: Misael Garcia.

Contents

Executive Summary

Background

This research project explores to what extent leasing can help accelerate adaptation of residential and commercial greywater applications. The results are applicable for utilities, water agencies, and water reuse companies and water customers.

The project analyzes optimal leasing, as a tool to accelerate investments in residential and commercial greywater systems, leading to greater potable water savings.

The research context is an augmented microeconomic model of common agency with three groups of active players: the Public (the Principal), PWP (the Agency), and "Stakeholders" (vendors, installers, technology providers, financiers, leasing companies, etc.).

We rely on valuation techniques from corporate/managerial finance to assess the total value of greywater systems. That is, we identify all relevant cash flows from greywater system leasing and purchase, and use this setup to analyze which decision is optimal for the full range of possible water savings and lease payments.

The report consists of six chapters where we present

- Survey results from Pasadena Water and Power's service area
- A general presentation of relevant capital budgeting practices
- A detailed analysis of PWP's Laundry-to-Landscape program
- An overview of relevant financing models and a detailed presentation of the viability of leasing of greywater systems
- A risk and sensitivity analysis
- A roadmap for how PWP's greywater initiative can leverage the leasing model

Highlights

1) Greywater leasing potentials are determined by a combination of:

The Savings Threshold for Leasing, S_0

Whenever a greywater system provides periodical savings above this level, leasing will be viable and can be offered to the mutual benefits of both lessor and lessee.

The Savings Threshold for Purchase, S_1

Whenever a greywater system provides periodical savings above this level, it will be viable for the end-user to purchase the system.

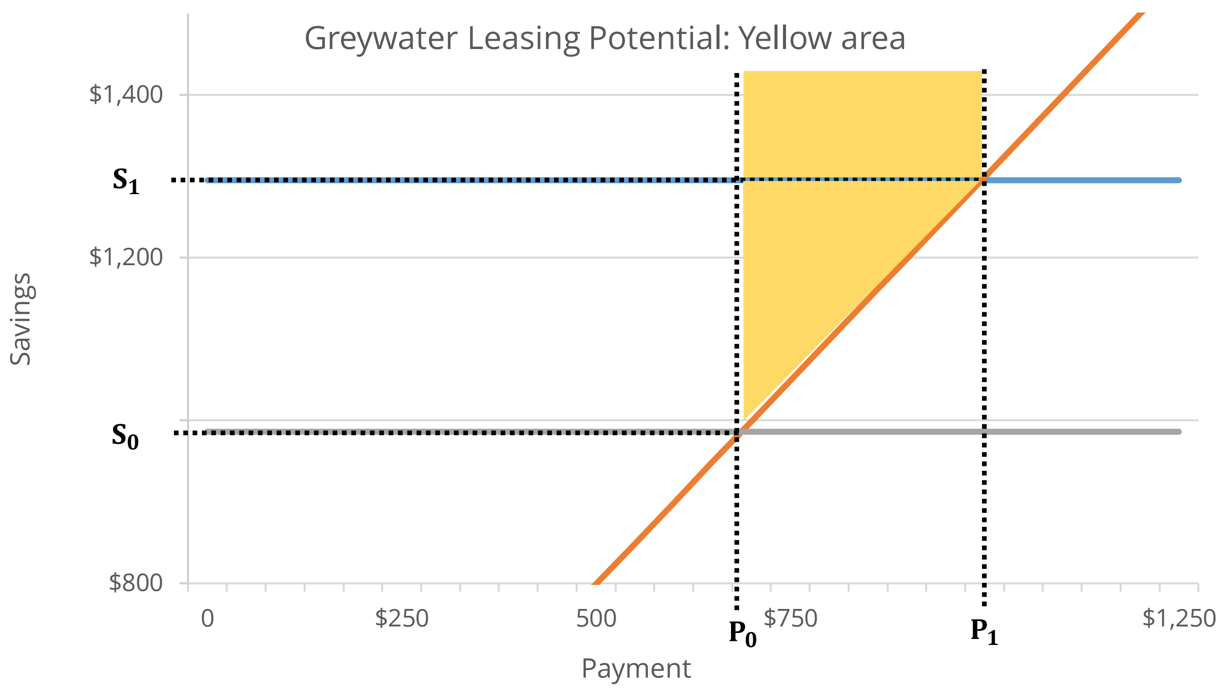
The Minimum Lease Payment, P_0

When the periodical lease payments exceed this level, the leasing contract is viable from the lessor's point of view.

The Payment Threshold for Purchase Preference, P_1

This is the maximum possible periodical lease payment. If a greywater system provides savings at S_1, leasing will be viable as long as the periodical payments are lower than P_1.

The figure below illustrates how the leasing potential depends on these savings and lease payment levels. Within the report, we show how these savings and payment levels can be determined.



2) Risk and Sensitivity

The model is robust in the sense that all statistics respond monotonically to parameter changes. All statistics can be evaluated based on the financial conditions (e.g. discounting rates) of the water customers; the market conditions for leasing companies; and the equipment and installation costs of various greywater systems.

The Savings Threshold for Leasing, S_0, can be lowered by a reduction in any of the underlying parameters (except the economic life of the greywater system). The Savings Threshold for Purchase, S_1, can be lowered by a reduction in the lessee's discounting rate or the greywater equipment/installation costs. The Minimum Lease Payment, P_0, can be lowered by reductions in the lessor's discounting rate (e.g. by lowering lessor's cost of capital), by a reduced marginal tax rate, or by a reduction in the greywater system costs. The Payment Threshold for Purchase Preference, P_1, can be lowered by reductions in the lessee's discounting rate and/or the greywater system costs.

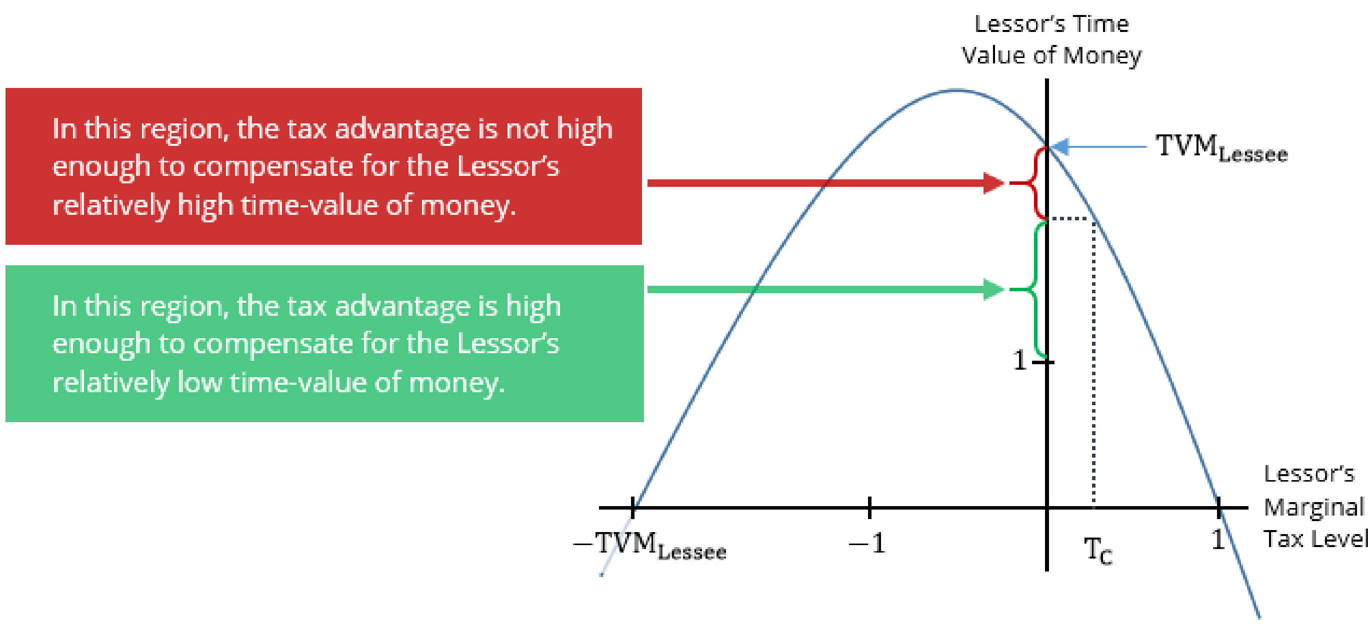
Parameters \ Coordinates	S_0	S_1	P_0	P_1
r_{Lessee}	Increasing ↗	Increasing ↗	No impact	Increasing ↗
r_{Lessor}	Increasing ↗	No impact	Increasing ↗	No impact
T_C	Increasing ↗	No impact	Increasing ↗	No impact
T	Decreasing ↘	Decreasing ↘	Decreasing ↘	Decreasing ↘
GWS	Increasing ↗	Increasing ↗	Increasing ↗	Increasing ↗
$Install$	Increasing ↗	Increasing ↗	No impact	No impact

3) Viability of Residential Greywater Systems Leasing

The viability of **residential greywater systems** leasing is heavily influenced by the leasing company's tax advantage: The lessor can write off the initial costs of the system as depreciation throughout the economic life of the system.

In this report we show how the viability of greywater leasing can be determined by a combination of the leasing company's tax rate, T_C, and the relationship between lessor's and lessee's Time Value of Money for the economic life of the greywater system.

Furthermore, utility companies can play a crucial role, not only by providing financial incentives, but also by producing and distributing vital information to spur both a demand for greywater systems and a supply of leasing options.



4) Capital Budgeting Practices

The greywater leasing potential for **commercial water customers** may be distorted by the water customers' capital budgeting practices.

- If investment decisions are based on **payback periods**, greywater systems will generally be rejected since their fiscal benefits spread out over very long periods.
- If investment decisions are based on the **Internal Rate of Return** or the **Net Present Value** of the greywater system, the appropriate required rate of return should reflect the water customers' risk-free post-tax opportunity costs and not their Weighted Average Cost of Capital (WACC).

5) Section 179 Election

The greywater leasing potential for **small commercial water customers** is limited due to tax options that favor greywater purchases.

- Section 179 of the United States Internal Revenue Code (26 U.S.C. § 179) allows businesses to deduct the cost of certain property as a business expense. This means that the initial investment in the greywater system effectively is reduced by the product of the company's tax-rate and the total cost of the system.[1]
- For tax years beginning after 2017, the maximum expense deduction is $1 million and the total amount used for equipment is $2.5 million (both caps in 2019-$).[2]
- The deduction phases out on after $2.5 million is spent by a given business. This means that the entire deduction disappears once the business has more than $3.5 million in purchases in a given year. This is why the Section 179 election mainly applies to small and medium-sized businesses.[3]

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[1] See "IRS issues guidance on Section 179 expenses and Section 168(g) depreciation under Tax Cuts and Jobs Act". Available via https://www.irs.gov/newsroom/irs-issues-guidance-on-section-179-expenses-and-section-168g-depreciation-under-tax-cuts-and-jobs-act. Accessed 11/29/19.
[2] Expense deduction and phase-out limits are indexed for inflation for tax years beginning after 2018.
[3] See https://www.section179.org for additional details. Accessed 11/29/19.

Introduction:
Greywater in the Demand Management Portfolio

Motivation: California Droughts

California has experienced several periods of (sometimes-extreme) droughts. In *Managing California's Water,* researchers from the Public Policy Institute of California emphasize how droughts in 1924, 1928-1934, 1976-1977, 1988-1992, and 2007-2009 had severe environmental consequences, but also spurred innovations in infrastructure, conservation measures, management and conjunctive use, and heavy water supply investments.[4] The present research, *Innovative Financing to Increase Greywater Systems*, is perfectly aligned with this development insofar as the most recent California drought from 2012 to 2016 illustrated a statewide need for accelerated water demand management; in particular water conservation.

The 1924 drought led to great losses for farmers and herders, primarily in the Sacramento Valley. Declining outflows and growing upstream diversions introduced sea salt into the Sacramento-San Joaquin Delta. This led to a broad understanding of California's emerging needs for infrastructure investments in large reservoirs, conveyance and irrigation systems, in order to support agricultural and population growth in the future.[5] The 1928-1934 drought exacerbated the situation, and accelerated design and construction of the Central Valley Project.

Following the accelerated supply-side investments inspired by the Central Valley Project, the 1976-1977 drought gave rise to a focus on water demand management. The 1976-1977 drought was at the time the driest in recorded history and it had severe environmental

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[4] See "Managing California's Water – From Conflict to Reconciliation", Hanak et al. 2011, published by the Public Policy Institute of California.
[5] See "From the Family Farm to Agribusiness: The Irrigation Crusade in California, 1850-1931", Donald J. Pisani 1984, published by University of California Press.

impacts. In response, cities and utilities shifted their focus to permanent water conservation and how long-term conservation plans could be established for urban areas.[6]

The 1988-1992 drought raised the importance of conjunctive water use. Managing surface water and groundwater in conjunction was uncommon before this period. The drought also motivated the development of economic engineering in water management. Specifically, the development of water markets helped reduce the economic effects of drought. This mechanism basically allows owners of higher-valued water to buy water from willing owners of lower-valued water.[7]

The drought of 2007-2009 was relatively mild with limited environmental impacts. However, it had a disproportional harsh economic impact; primarily due to a reduction in water supply from rivers and the Sacramento-San Joaquin Delta. In their report *Measuring the Employment Impact of Water Reductions*, researchers from Dept. of Agricultural and Resource Economics and Center for Watershed Sciences at UC Davis found that around 21,000 agricultural jobs were lost in California; 16,000 were lost due to the drought while the remaining 5,000 were lost due to export restrictions from the Delta.

The drought of 2012–2016 showed unusually high temperatures, which rapidly depleted soil moisture and diminished snowpack at a much higher rate than usual. According to Lund et al. in *Lessons from California's 2012–2016 Drought,* warmer temperatures accounted for as much as 25% of the drought's cumulative moisture deficit and reductions in both soil moisture and snowpack; a reduction of cold water in reservoirs; and increases in river temperatures.[8]

The drought had grave supply-side impacts for various areas throughout the state. "Table 1" in the figure below is obtained from "Lessons from California's 2012–2016 Drought" and summarizes the supply levels relative to demand from the Central Valley Project and State Water Project in each year in the period 2011 to 2017.

[6] See "Reducing Water Demand During Drought Years", Gilbert et al. 1990, Journal (American Water Works Association), Vol. 82, No. 5, CONSERVATION (MAY 1990), pp. 34-39, published by Wiley.
[7] See "Lessons Learned From the California Drought (1987-1992)", Brumbaugh et al. 1994, US Army Corps of Engineers, Institute for Water Resources, Alexandria, VA. and "Optimization of Transfers in Urban Water Supply Planning" 1995, Journal of Water Resources Planning and Management, Volume 121 Issue 1 - January 1995.
[8] See "Lessons from California's 2012–2016 Drought", Lund et al., Journal of Water Resources Planning and Management, Volume 144 Issue 10 - October 2018.

Table 1. Major water project deliveries 2011–2017

Year	State water project (SWP)[a]	Central Valley project (CVP)[b]
2011	80%	100%, except south of Delta junior agricultural contractors (e.g., Westlands) 80%
2012	65%	100%—North of Delta, wildlife refuges, San Joaquin Exchange, and Eastside (New Melones) contractors
		75%—South of Delta urban
		50%—Friant; 40%—south of Delta junior agricultural contractors
2013	35%	100%—Wildlife, San Joaquin Exchange, and Eastside contractors
		75%—North of Delta agriculture and settlement
		70%–75%—Urban; 62%—Friant; 20%—south of Delta agricultural
2014	5%	75%—Sacramento Valley settlement and wildlife refuges
		65%—San Joaquin Exchange contracts and wildlife refuges
		55%—Eastside (New Melones) contractors; 50%—urban
		0%—Other agricultural contracts (including Friant, Westlands)
2015	20%, except north of Delta urban 22–28%	75%—Sacramento Valley settlement, wildlife, San Joaquin Exchange contracts; 25%—urban
		0%—Eastside (New Melones) and other agricultural contracts
2016	60%, except north of Delta urban 60–100%	100%—North of Delta, wildlife, San Joaquin Exchange contracts
		75%—Friant; 55%—urban; 5%—south of Delta agriculture
		0%—Eastside (New Melones) contractors
2017	85%, except north of Delta urban 100%	100%, all

[a] Data from California Department of Water Resources (2018a).

[b] Data from US Bureau of Reclamation (2018).

Figure 1: Table obtained from "Lessons from California's 2012–2016 Drought" in Journal of Water Resources Planning and Management

As the table shows, supply-side shocks do not distribute evenly among the two projects' customers. This reflects different legal priorities due to legislation and/or pre-project water rights, such as the Sacramento Valley "Settlement" and San Joaquin River "Exchange" contracts.

High temperatures and reduced precipitation, combined with supply-side shocks had various impacts throughout California. The agricultural sector faced a 30% reduction in available surface water; the difference was largely replaced with additional groundwater pumping. According to UC Davis research the additional cost of groundwater pumping in the drought period was $600 million.[9] The same research estimates that the total economic losses to agriculture from 2014 to 2016 were 3.8 billion.

As several areas throughout California became more dependent on local groundwater, it became clear that many small water systems and rural domestic wells are lacking in the necessary emergency or permanent connections to other water systems that can help during droughts. Researchers Fencl and Klasic report in, *Small, self-sufficient water systems continue to battle a hidden drought,* that many small water systems were unprepared for

[9] See "Economic Analysis of the 2015 Drought For California Agriculture" Accessed 11/22. https://wedocs.unep.org/bitstream/handle/20.500.11822/17784/Economic_Analysis_of_the_2015_Drought_For_Cali.pdf?sequence=1

the drought, and that areas such as Tulare County, which primarily relied on local groundwater eventually had to rely on delivered bottled water instead. It has been estimated that the additional pumping and rehabilitation for wells in Tulare County from groundwater declines were between $10 million and $18 million.

Another troubled area is California's many forests that simply cannot sustain themselves in deep droughts like the one in 2012-2016. In November 2016, the U.S. Dept. of Agriculture announced the U.S. Forest Service had identified an additional 36 million dead trees over a period of just six months. At the time, the amount of dead trees statewide was 102 million,[10] with grave implications for wildfires, erosion, and public safety. The economic costs of these dying forests and in particular wildfires are very difficult to assess and estimate. They have long-lasting public health impacts and could potentially become a substantial economic burden many years after the drought.

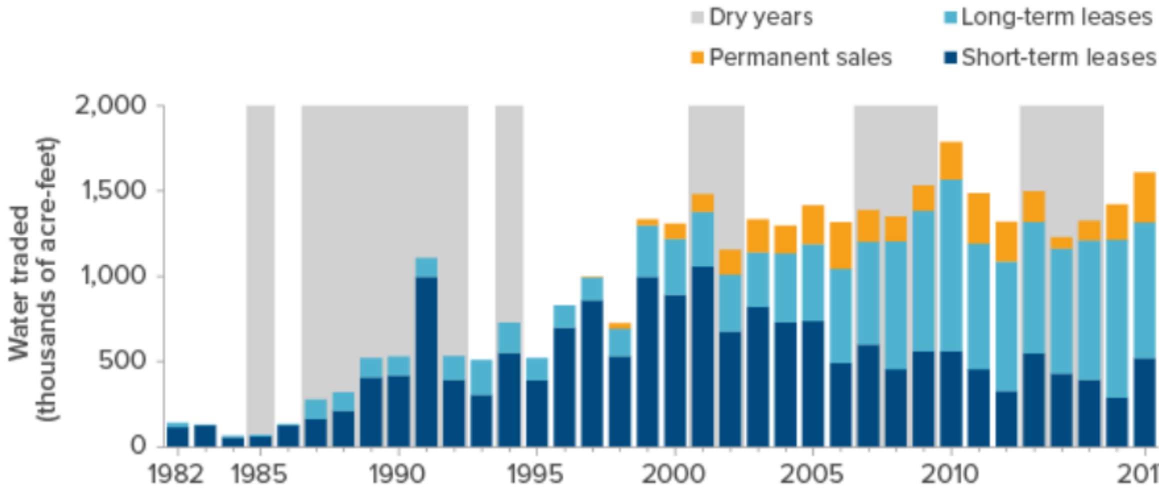
Innovation

In *California droughts precipitate innovation*, UC Davis professor Jay Lund argues that in the aftermath of the 2012-2016 drought, we are likely to see innovations within the following areas:[11]

- **Market-based Water Transfers**. Continuing the focus on demand-side management opportunities, the streamlining of water market transfers is a likely outcome. As the figure here below illustrates, the 2012-2016 drought was indeed followed by an increase in water market transfers. However, the increase was mainly due to very large relative increases in permanent sales, and not due to an uptake in market activity.
- **Groundwater Management**. Advances in groundwater quantification, rights and management are central to securing the future resilience of both rural and urban areas throughout the State. California has a long history of managing groundwater resources through locally controlled programs developed and refined over the past century. Groundwater was widespread and abundant at the beginning of the 20th

[10] See "New Aerial Survey Identifies More Than 100 Million Dead Trees in California" Accessed 11/22. https://www.fs.fed.us/news/releases/new-aerial-survey-identifies-more-100-million-dead-trees-california

[11] See "California droughts precipitate innovation" on California Water Blog. Accessed 11/20. https://californiawaterblog.com/2014/01/21/california-droughts-precipitate-innovation/



SOURCE: Updated from E. Hanak and E. Stryjewski. *California's Water Market, By the Numbers: Update 2012* (PPIC 2012)..

NOTES: The figure shows surface water traded between entities that are not members of the same water district or wholesale agency. It excludes volumes committed under long-term lease and permanent-sale contracts that were not physically transferred because of hydrologic conditions or other factors (in 2017, roughly 500,000 acre-feet). Dry years are those classified as critical or dry for the Sacramento Valley. Volumes are in thousands of acre-feet (taf).

century. This contributed to both agricultural and urban growth, which in turn increased demand for water.

In drought periods, California relies mostly on groundwater. This means that without proper groundwater management, decreasing groundwater levels exposes the end-user to water shortages exactly when need is greatest. The Sustainable Groundwater Management Act (SGMA), which was adopted in 2014, seeks to address these issues and secure a reliable access to groundwater for generations to come.

- **Access to capital**. Building up a drought resilient infrastructure while mitigating immediate environmental and societal impacts of an extended drought are very capital intensive projects that require reliable long-term access to capital.

  In 2014 Proposition 1 enacted the Water Quality, Supply, and Infrastructure Improvement Act of 2014, which authorized $7.12 billion in general obligation bonds for state water supply infrastructure projects. Of this funding $520 million would be allocated to improve water quality; $1.495 billion would be directed towards competitive grants for multi-benefit ecosystem and watershed protection and restoration projects; $810 million targeted expenditures for integrated regional water management plan projects; $2.7 billion for water storage projects, dams, and reservoirs; $725 million for water recycling and advanced water treatment technology projects; $900 million for competitive grants and loans for projects to prevent or clean up the contamination of groundwater that serves as a source of drinking water; and finally $395 million for statewide flood management projects and activities.

The research in this report highlights an additional source of capital that is yet to see its full potential. We focus on the potential for leasing models applied to onsite (i.e. non-infrastructure investments) greywater systems. These investments differ from typical water conservation measures in three ways:

- **Many relatively small investments outlays.**
  Greywater system costs range from around $100 for simple residential laundry-to-landscape (L2L) systems, to hundreds of thousands for larger industrial scale systems. Compared to infrastructure investments each of these is relatively small, although at the aggregate level they could yield similar environmental and demand side impacts.

- **Many disjoined decision makers.**
  One of the benefits of infrastructure investments from a capital budgeting point of view is the centralized decision process. Costs and benefits can be estimated with some accuracy, and the financial merits of the investment can be analyzed in this context.

  For residential and commercial greywater systems, the situation is very different. The viability of each greywater system is assessed at the end-user level, which means taking into account only the specific water customer's cost savings, investment needs, and cost of capital. This means that in order to stimulate acceleration in greywater adaptation, the financial merits of the necessary systems must be assessed for the whole distribution of water customers.

  We show that the utility company can leverage knowledge about the distribution of end-user discounting rates to stimulate greywater leasing adaptation, and in turn use this mechanism to meet specific demand reduction targets. Whether these demand reductions are motivated by state mandates; diversification of the utility's supply portfolio; or something else, they represent a direct monetary value which offset the necessary subsidy as explained in the *Risk and Sensitivity* chapter.

- **Lack of transparency and expertise.**

  In order to access private leasing capital, it is paramount that the financial merits of greywater leasing are fully understood by water customers, leasing firms, and utilities.

  Greywater systems require a relatively large capital investment up front (for equipment and installation), but little to no maintenance afterwards. The benefits in the form of cost savings then spread out over several years (typically 10 years). For most residential and commercial water customers, this is problematic when simple (and mistaken) capital budgeting techniques such as Payback Periods are applied. Even when a greywater system is financially viable, it can be rejected as an investment opportunity simply because it does not recover its initial cost until several years after installation.

  The problem can be solved with a leasing agreement that distributes all cash flows evenly throughout the economic life of the greywater system. If the system is financially viable to begin with, it means that the water customer will see a financial benefit from beginning to end, and will not have to take on the relatively large capital investment themselves; the Payback Period effectively goes to zero.

  However, an active leasing market to address residential and commercial greywater systems needs is hindered by a lack of transparency into which systems are needed and where.

  Water utilities, districts and municipalities can play an active role in this regard:

    - By producing insights about their service area such as the segmentation of their water customers;
    - By producing insights for their water customers about water savings opportunities; and
    - By stimulating interest from leasing companies by showing the market potential and in turn by providing an overview of leasing options to greywater systems manufacturers and water customers.

Price vs. Non-price Water Demand Management

As explained above, the 1976-1977 drought increased the focus on demand-side initiatives. Demand management and in particular water conservation measures were considered necessary to safeguard against future droughts.

The Demand Curve

Following the basic insight of the demand curve, the first measure to decrease water demand was to increase water rates. This measure will not shift the demand curve itself, but rather move aggregate demand up and to the left along the demand curve. The actual water savings as a function of the rate increase can then be determined by the demand elasticity, which measures the local slope of the demand curve. A relatively flat demand curve yields high water savings, while a steep demand curve yields modest water savings.

As an alternative or supplement to increasing water rates, utilities, districts, municipalities, etc. can try to shift the entire demand curve to the left. This would have the effect that the

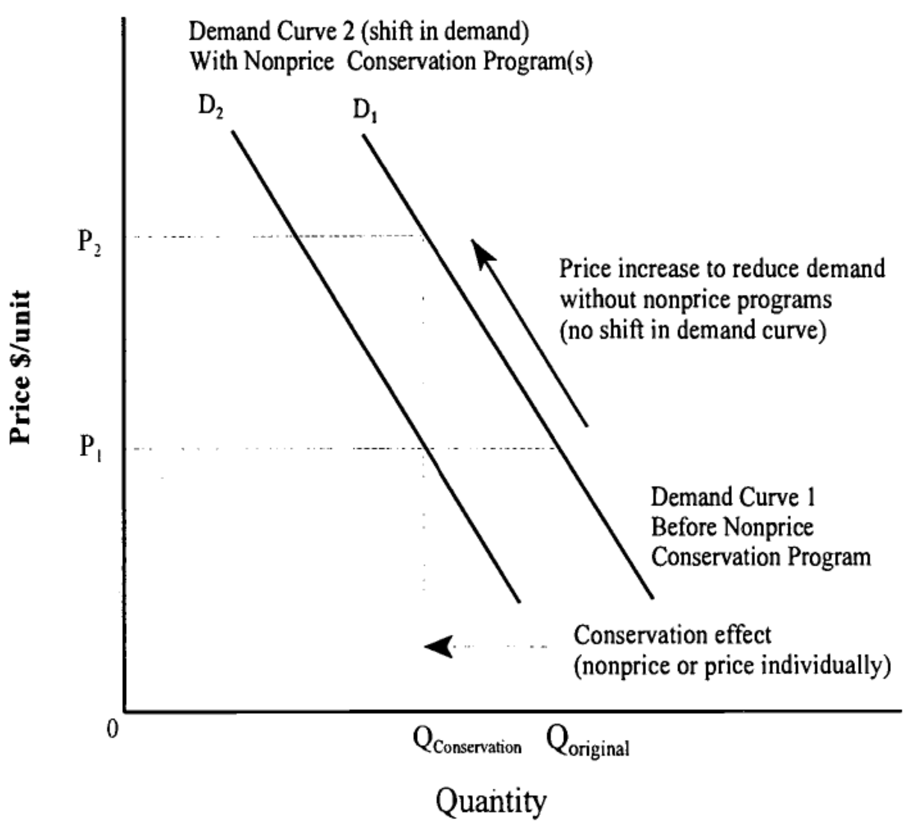


Figure 2: Water demand curve. From "Nonprice Water Conservation Programs as a Demand Management Tool" (1999), Michelsen et al. in Journal of the American Water Resources Association, Vol. 35, No 3.

demand for water is reduced at every potential price point (i.e. water rate) relative to the original demand curve. The effectiveness of water conservation programs should therefore be seen in light of which water savings that are possible with increasing water rates, i.e. how steep is the demand curve; and which saving are possible from non-price conservation programs, i.e. to what extend can the entire demand curve be shifted to the left.

The figure above illustrates the impacts of two distinct water conservation programs where the water demand is reduced from $Q_{Original}$ to $Q_{Conservation}$, either via a rate increase from P_1 to P_2, or via a non-price conservation program that shifts the entire demand curve D_1 to D_2.

Non-price Conservation Programs

Non-price conservation programs span from informational/educational programs, over retrofit programs, to ordinances and regulation.

Public Information Programs are intended to create awareness of the environmental impacts of water consumption, the means water customers have to curb water demand, and to some extent signal, how the water utility is planning for future scarcity in water supply. The overarching goal is to shift the water demand curve to reflect sustainable usage on a voluntary basis.

Education Programs are very similar, but while public information programs create awareness via public service announcements, billboards, pamphlets, ebooks, etc., educational programs target schools and similar institutions with targeted educational content to be used in the curriculum.

Retrofit Programs leverage direct subsidies such as distribution, rebates, and installation of water saving devices. Free distribution and/or installation of water saving equipment such as L2L systems, low-flow showerheads, faucet restrictors, low-flow toilets, etc. are common for many retrofit programs.

Finally, **Permanent Ordinances and Regulations** such as building ordinances that require specific water saving measures for new construction and remodeling, shift the demand curve to the left simply by force. Similarly, **Temporary Ordinances and Regulations** shift the water demand curve by restricting certain type of water demand. A typical example is the restriction on residential irrigation in certain periods where water supply is scarce.

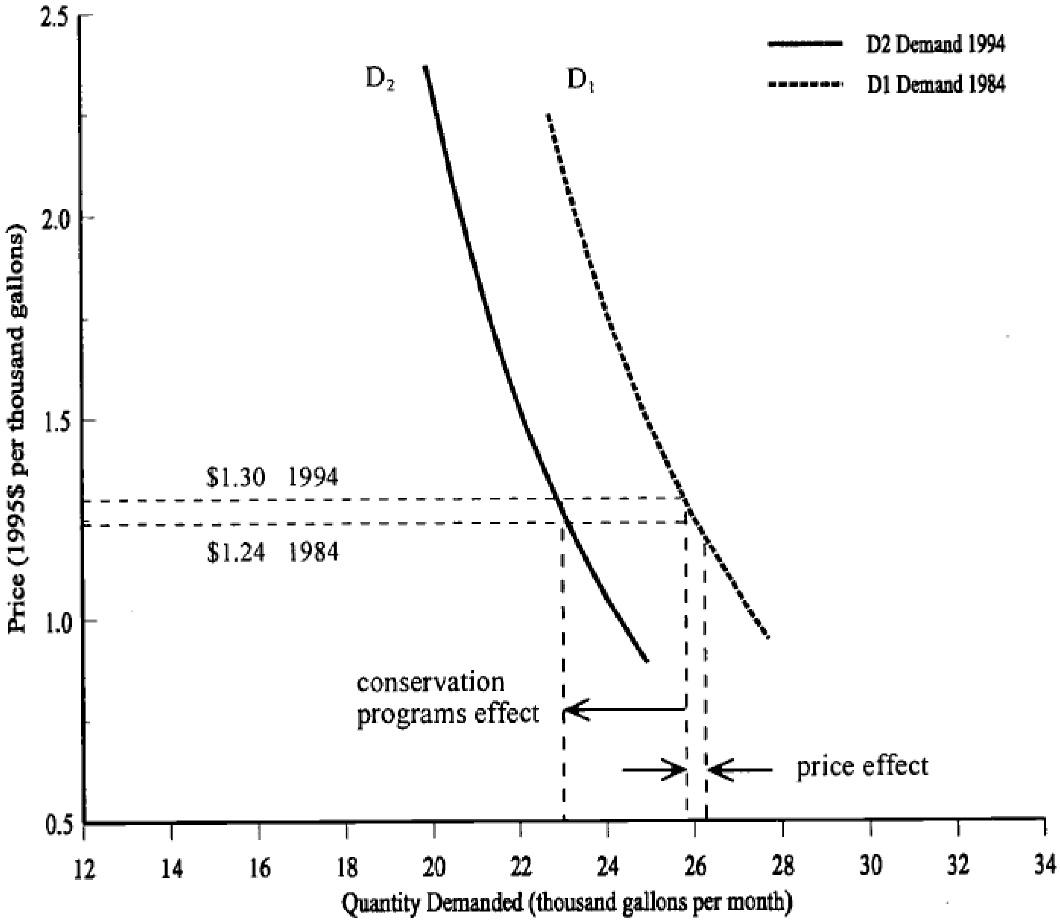


Figure 3: Demand side impacts of non-price conservation programs (Denver). From "Nonprice Water Conservation Programs as a Demand Management Tool" (1999), Michelsen et al. in Journal of the American Water Resources Association, Vol. 35, No 3.

Historical Experiences

A natural question to ask concerning water conservation is what the optimal mix of water rate increases and non-price conservation programs is. In order to address this question, we need a better understanding of the shape demand curve (i.e. the demand elasticity) and the magnitude of horizontal shifts in demand.

One of the first large-scale research projects to uncover the impacts of price- and non-price conservation measures was presented in 1999 in Journal of the American Water Resources Association by professors Michelsen, McGuckin, and then post-graduate student Stumpf[12]. The research looked at price- and non-price conservation programs in seven cities: Los

[12] See "Nonprice Water Conservation Programs as a Demand Management Tool" (1999), Michelsen et al. in Journal of the American Water Resources Association, Vol. 35, No 3.

Angeles, San Diego, Denver, Broomfield, Albuquerque, Santa Fe, and Las Cruces, over the period 1984-1995.

Due to a lack of access to data, the research could not address cost efficiency, but it could identify the effectiveness of non-price programs and relate these to the effectiveness of rate increases. Specifically, they found that the region-wide price elasticity for water demand was -0.23, which indicate that, say, a 10% increase in water rates would lead to a 2.3% drop in demand. This inelastic demand is illustrated by a very steep demand curve (see figure above).

A natural consequence of such a steep demand curve is that utilities need to look for additional mechanisms to manage water demand—rate hikes will rarely be sufficient to meet demand reduction targets. Non-price demand management has therefore resonated, and the research has shown them to be comparatively effective. In the research by Michelsen et al. (1999), one city, Denver, in particular showed a 14.4% water reduction from 1984 to 1995, where 2.3% is due to rate hikes, while 12.1% is due to the city's non-price conservation programs over the period. The figure above illustrates the demand curve shift from D_1 (1984) to D_2 (1995), along with the 4.8% rate increase from $1.24 (1984) to $1.30 (1995).

The relative low impact rate hikes have on aggregate water demand has been verified several times since the research by Michelsen, McGuckin, and Stumpf described above.[13] In context of Californian water utilities, the result is potentially even more extreme. A recent study by Dr. Elena Maggioni does not find a significant correlation between water rates and residential demand reductions at all.[14] Further, her research does not find significant correlation between the level of rebates and residential water demand reductions. She

[13] See "Estimation of residential water demand: a state-of-the-art review", Arbués et al., 2003, The Journal of Socio-Economics, Volume 32, Issue 1, March 2003, Pages 81-102; "Price and income elasticities of water demand: A meta-analysis", 2003, Dalhuisen et al. Land Economics, May 2003, 79(2), 292-308; "The Distributional Effects of Water Quantity Management Strategies: A Spatial Analysis", 2002, Duke et al. Review of Regional Studies 32 (1), 19-35; "A discrete/continuous choice approach to residential water demand under block rate pricing", 1995, Land Economics, 71(2), 173–192; "Urban water demand with fixed volumetric charging in a large municipality: The case of Brisbane, Australia", 2006, The Australian Journal of Agricultural and Resource Economics, 50, 347–359; "Water demand under alternative price structures", 2007, Journal of Environmental Economics and Management, Volume 54, Issue 2, September 2007, Pages 181-198; "An empirical survey of residential water demand modeling", 2008, Journal of Economic Surveys, 22(5), 842–871.

[14] See "Water demand management in times of drought: What matters for water conservation", 2015, Water Resources Research, 51, 125–139.

does, however find a strong impact of local ordinances limiting outdoor watering and waste water.

Most of Dr. Maggioni findings are comparable to the existing literature in this field, but the fact that she does not find significant correlation between rate hikes and demand reductions may be specific to her sample in that, throughout California utilities tend to increase water rates in response to demand reduction to cover the utility's fixed costs.

Another finding that may be specific to her sample is that, when we look at a sampling period between 2006 and 2010, we are encapsulating a mild drought period (2007-2009) where some utilities needed local ordinances while others could manage demand via other non-price programs and rate hikes. Ordinances will generally have a much higher and abrupt impact on water demand while the effect of other measures may have lagged effects that are not captured by the analysis.

Dr. Maggioni concludes her paper with several policy recommendations. Among these, she suggests that utilities should invest resources only where substantial water savings are expected. That point should guide any greywater leasing initiative as well.

Greywater Leasing in Context

The leasing initiative that we analyze in this report is a first of its kind, and to that end, its implementation requires a substantial informational campaign. Greywater systems investments include both equipment and installation costs, and it is assumed in the later analysis that the water customer covers that installation cost whether leasing or purchasing the greywater system. For this reason, the relative systems cost (i.e. as a portion of the total up front cost) drives a substantial portion of the leasing decision.

In order to leverage greywater leasing in a water utility's demand management portfolio, we consider direct subsidies of installation costs. This means that we only consider greywater systems that are financially viable in terms of water savings. As will be shown in later chapters, *Financing Models* and *Risk and Sensitivity*, the utility can predict aggregate water savings as a function of subsidy levels if it knows the required rate of return throughout the specific customer group.

This finding highlights the importance of internal knowledge production. Specifically, utilities need to generate information about:

- **Customer-level greywater output**
  Derive the greywater cost function based on onsite wastewater output and the cost of producing greywater from this output. The various technologies and needs are then ranked by cost per gallon of greywater and finally combined into a full cost function.
- **Onsite greywater needs**
  The main uses of greywater are subsurface irrigation and toilet flushing, and it cannot be stored for long periods because the nutrients in the water will start to break down and create bad odors. Different water customers have different ongoing needs for recaptured greywater and these needs set an upper bound on how much greywater capture is viable at the customer-level.

This information about the cost of greywater output potentials and onsite reuse needs will differ throughout the utility's customer base. It is therefore recommended in this report that utilities create segmentations of their users in order to understand where a given greywater leasing program would have the greatest effect—and be most cost-efficient (see *Recommendations* here below).

Without proper segmentation, it is impossible to give a satisfying estimate of the potential water savings from greywater leasing. The water customer base is simply too diverse and the greywater needs and output potentials to varied. We can, however get an idea of the potential water savings by comparing distributional indoor water needs for normal households from EPA's website (the figure to the right), with the finding that, if a residential water customer uses potable water for irrigation, then their irrigation needs approximately match their indoor water needs.

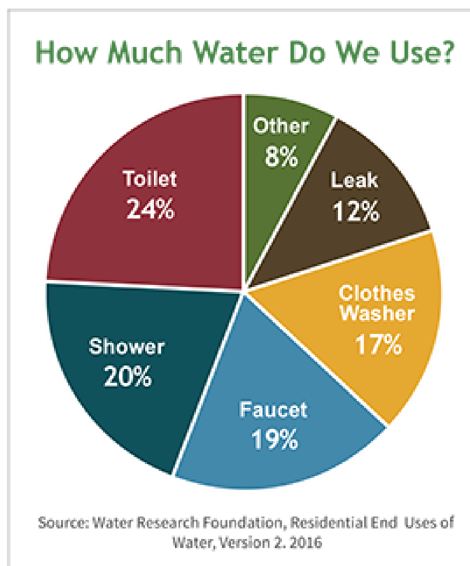


Figure 4: See United States Environmental Protection Agency (EPA) website: https://www.epa.gov/watersense/how-we-use-water. Accessed 11/27/19.

If we look at the residential distribution in the pie chart to the right, and assume that the indoor distribution is unaffected by whether the water customer has irrigation needs or not, we can easily augment the statistics to include outdoor usage.

If we look at a household that uses 250 GPD where 60% (150 GPD) is for irrigation and outdoor usage and 40% (100 GPD) covers indoor usage, the greywater sources are

- Showers (20 GPD), which could reduce toilet flushing with the same amount, and
- Clothes washing (17 GPD) and Faucets (19 GPD), which combined could reduce the water demand for irrigation by (36 GPD)

This simple example shows a 22.4% (56/250) reduction in the households water demand. As mentioned earlier, different water customers would show different potentials. Some differences will be driven by onsite greywater needs; others will be driven by the onsite costs of producing greywater.

Recommendations

The key insight from this report is that water utilities can in fact accelerate greywater investments if they are able to play an active role between water customers, systems manufacturers, leasing companies, and potentially systems installers. In order to do so, the utility needs to build an actionable knowledge base that makes it easy to strategize and select water conservation initiatives based on projected efficiency.

Segmentation

To this end, it is recommended that PWP conduct a thorough segmentation of all its water customers as explained in chapter *Goal Setting and Mechanisms.* The goal is to divide all water customers into groups such that the **Customer-level greywater output** and **Onsite greywater needs** are comparable within each group.

The outcome of this segmentation is a **bottom-up** framework that allows the utility to manage and predict specific non-price conservation initiatives. Each initiative should be targeted to the water customer's greywater needs and potentials, which will differ throughout the service area, but should be comparable within each group.

The challenge is to leverage the utility's current information about the customer's water usage, and combine this information with the type of business. Chapter *Goal Setting and Mechanisms* provides a detailed rundown of which pieces of information to segmentation could contain, but the overall structure looks like this.

- Sector – Industry – Business Type
  - Size – Ownership – Entity
    - Water Usage
      - Greywater Cost Function
      - Onsite Greywater Needs

Dynamic Performance Measurement

Next, the utility should set greywater targets for each group based on the financial viability from the water customer's point of view, and track how close specific customers are to those targets on an ongoing basis.

The relevant metrics in this context are:

- The marginal cost of water savings (i.e. what hinders additional onsite greywater output?), and
- Updated greywater needs (i.e. has the onsite needs for greywater changed since the original assessment and if so, why has it changed?)

Pilot Project – Focus on Commercial Accounts

In order to leverage the results of this research, it is recommended that PWP initiate a pilot program for a specific segment, say hotels or laundries. The workflow looks like this:

1. Choose Segment

PWP could go about choosing a target segment for a pilot program in several ways. The most thorough approach entails an initial discovery phase where all segments are identified by: i) Sectors, industries, and business types; ii) Size, ownership, and entity type; and iii) Historical water usage. Hereafter, PWP can choose a target segment based on a high-level estimate of the aggregate effectiveness, equitability, or similar criteria. The simpler approach entails picking a segment, not based on effectiveness, but on in-house experiences or ambitions towards a specific target.

2. Identify companies within segment

After the target segment has been identified, PWP needs detailed information about the water customers within the target segment. At this point, it is informative to get an understanding of who the early adopters may be to start producing surveys and outreach materials.

PWP should at this point collect information about the size, ownership, and entity type, if this information was not already collected before the target segment was chosen. Furthermore, PWP should compile the historical water usage for each customer at this point. This information may already have been collected before the target segment was chosen, but if it was not, it is important before moving on with any customer outreach.

The historical water usage may reveal an unacceptable in-group variation, which means that the segment has been poorly defined. A typical example of unacceptable in-group variation are clusters in the sampling, i.e. cases where historical water usage shows that the group clearly consists of customers with different water needs.

There are several ways of detecting this problem. For instance, we can look for variations in sample variances. Common test for this (heteroscedasticity) problem are the Bartlett Test, the Breusch-Pagan Test, the Score Test, and the F-Test.

3. Outreach to water customers within segment

It is important that the water customers get informed about the goals of the pilot project early on, and that they get an opportunity to weigh in and share their views on which opportunities they see for onsite greywater capture, production, and reuse on their premises. A phone campaign (or in-person visit depending on the size of the target segment) at this point is recommended, because it gives PWP an opportunity to lead the pilot project forward; confirm/update customer level information; and collect preliminary information about the customer's water usage.

4. Informational materials and circulation

Once PWP has collected high-level information about the customers in the target segment, informational materials such as fact sheets, pamphlets, infographics and posters about the pilot project should be prepared for greywater systems manufacturers, installers, and leasing companies. If needed, this material can be circulated for reviews by the water customers in the target segment.

Once PWP determines that, the materials are ready and reflect the scope and ambitions of the pilot project, they should be distributed to the relevant stakeholders (greywater systems manufacturers, installers, and leasing companies).

5. Determine subsidy forms and sizes based on customer interest, needs, and demand reduction targets

Based on the interest from customers in the target segment, greywater systems manufacturers, installers, and leasing companies, PWP can then determine the needed subsidy level to reach a desired demand reduction target. Chapters *Risk and Sensitivity* and *Goals and Mechanisms* explain how the subsidy level can be determined as a function of conservation targets.

6. Track early adopters

It is paramount that PWP tracks conservation performance for the customers who adopt the pilot program. Not only does this provide proof-of-concept relevant to other segments in the service area, it also provides much needed inputs when PWP calculates the conservation cost efficiency of the pilot. The latter helps setting conservation goals for other target segments and ultimately informs which segments PWP should focus on in subsequent greywater leasing programs.

Greywater survey

Summary

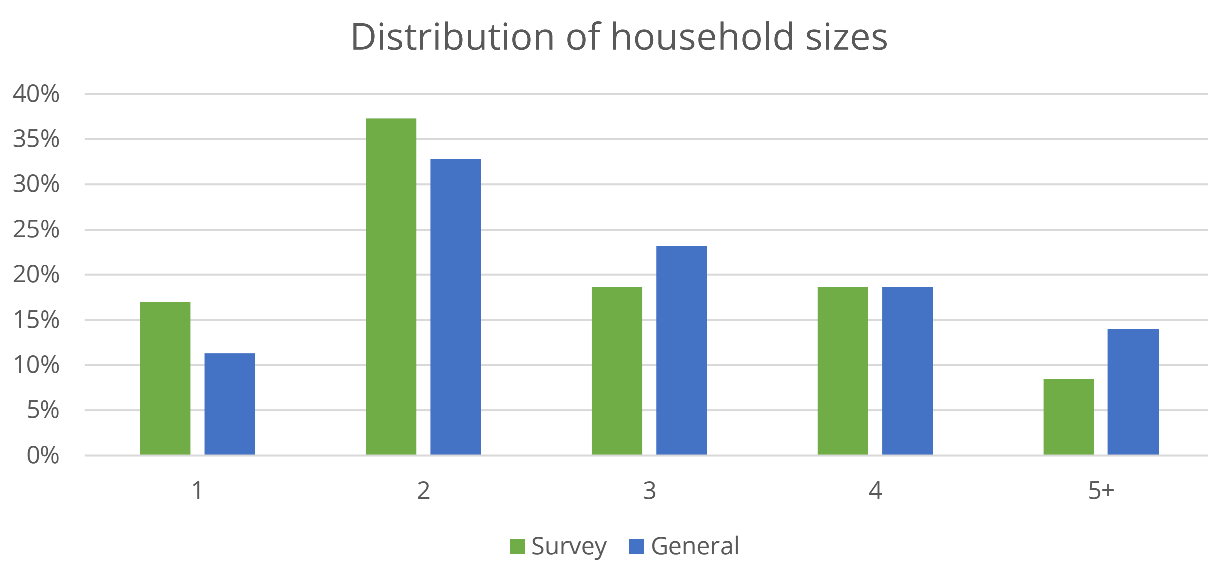
As a part of our research, we surveyed PWP customers to learn more about their interests in and ability to take part in greywater and other water conservation programs. The survey was open throughout the research, and we compiled survey responses on an ongoing basis.

Responses

To date, 59 customers have responded, and in more than 95% of the cases, provided complete or nearly complete feedback. The survey is distributed via the WaterSmart platform, which allows us to integrate additional sources of data such as public records of homeownership, number of occupants, lot sizes etc.

The responses we have received so far do not indicate any critical demographical misrepresentation even though opt in surveys like these are exposed to some bias; opt in surveys can sometimes be skewed toward the extremes of the sampling group, but we do not have any indication of that at the moment.

Since we are pairing this research with PWP's Laundry-to-Landscape Program where the output of greywater strongly depends on household sizes, it is very important in this context that our responders actually represent the distribution of household sizes in the

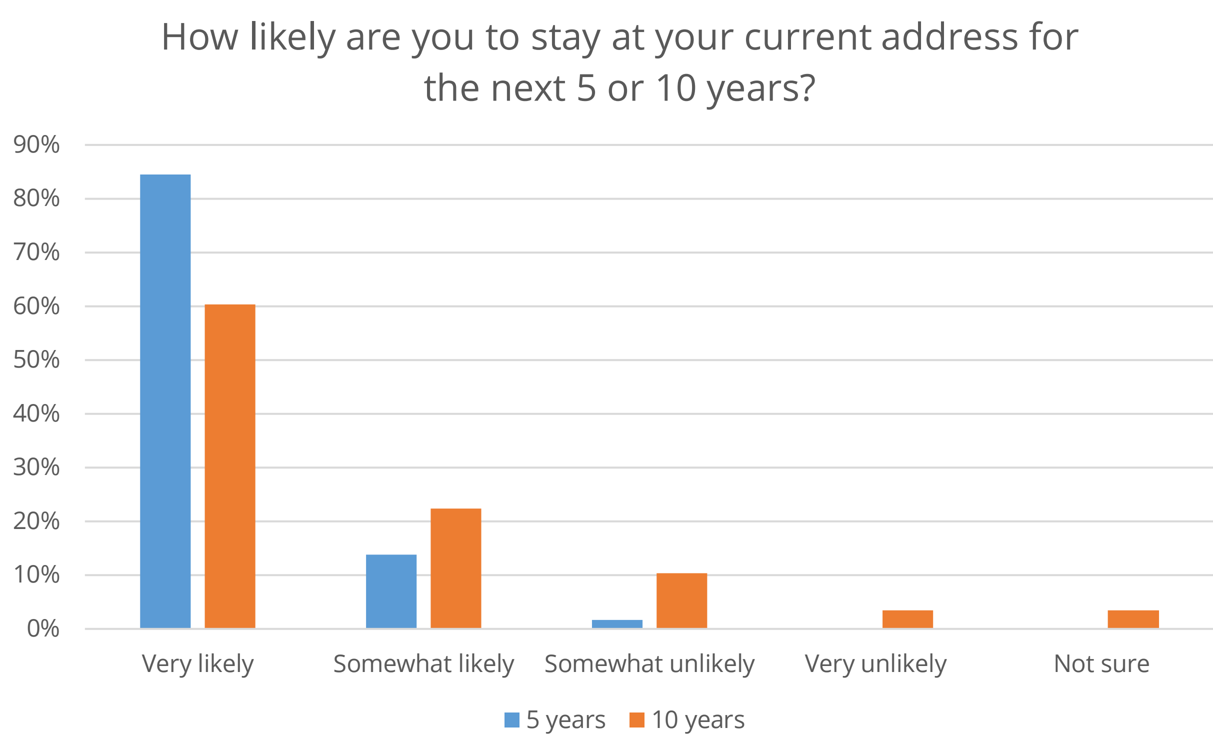


entire service are. The figure below compares the distribution of household sizes from the 59 survey responders with the distribution of household sizes from all PWP SFR households. The latter is identified based on WaterSmart's data obtained from public record paired with PWP's billing data.

We do see a small skew towards smaller household sizes. 17% of survey responders represents household with only one occupant, while such household in general account for 11% of PWP's service area. The percentages for households with two occupants is 37% versus 33%. We expect these differences to mitigate as the sample of survey responses grows.

Planning horizons

In order to get a better understanding of the viability of greywater systems for SFR households we ask the responders to assess the likelihood of them staying at their current address for the near future. The figure below summarize responses for 5- and 10-year planning horizons.



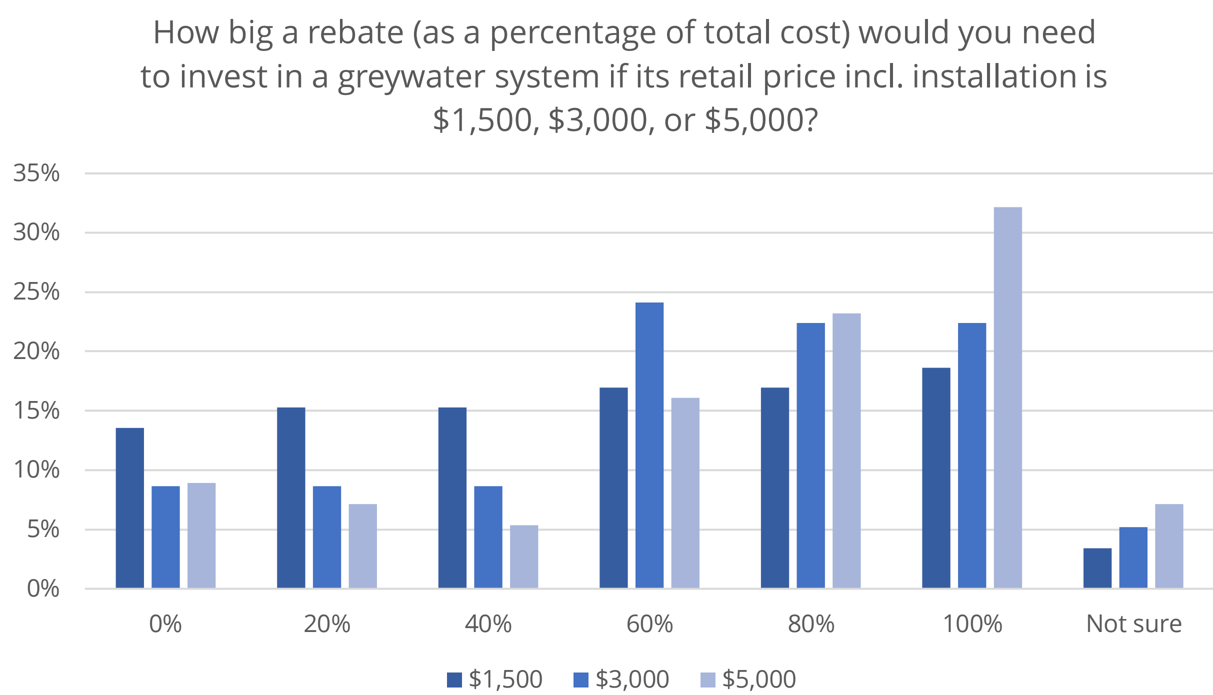
These finding are probably biased towards long-term homeownership; a bias that could stem from the fact that the survey responders generally are engaged with PWP's water conservation efforts, rebate programs, and communication in general. This bias is likely to mitigate to some extent as the sample grows, but in order to prevent it entirely we would need to do a random sampling with incentive to respond.

Planning horizons of 10 years means that a prospective greywater investment with the same economic life (such as an L2L installation) does not rely on an assumption that property values will appreciate with the investment. For the homeowner, this is crucial since we do not have any indication (yet) that the market does put a premium on greywater systems.

Financing needs

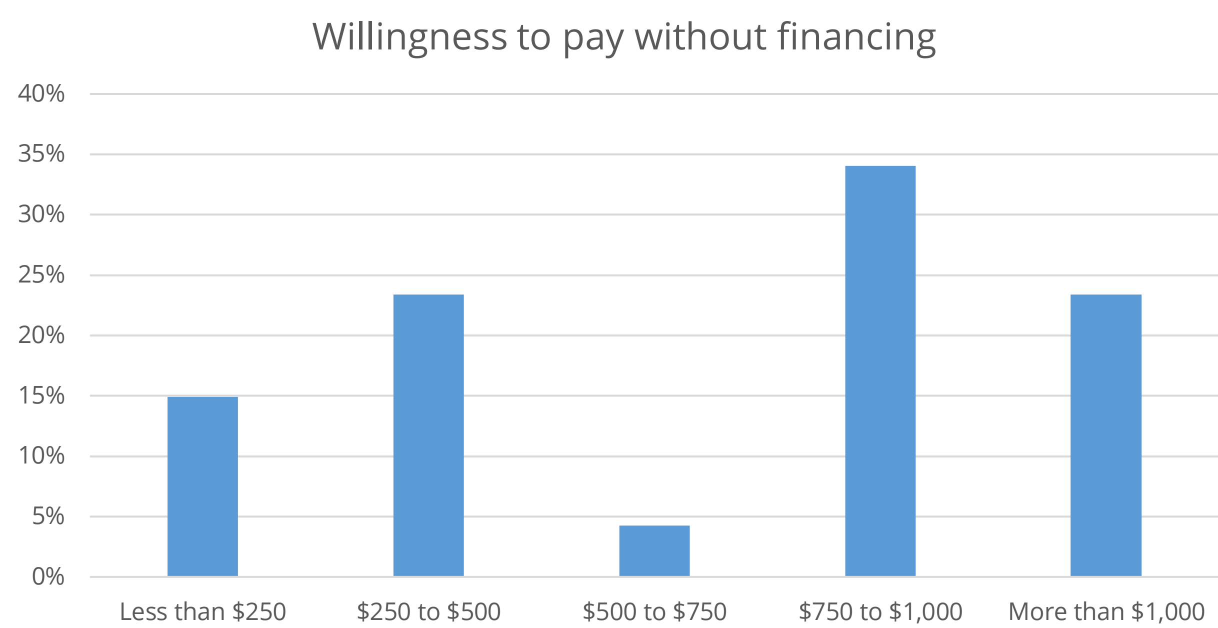
The costs of greywater systems can be substantial and require external financing and subsidizing.

We ask responders to indicate how big a subsidy should be before they would consider installing a greywater system. The figure below summarizes what we have found so far.



Interestingly, a relative few responders indicate that they would need a full rebate; 19%, 22%, and 32% for system costs of $1,500, $3,000, and $5,000 respectively. At the same time even fewer indicate that they would not need any rebate at all; 14%, 9%, and 9% for systems costs of $1,500, $3,000, and $5,000 respectively. Further note that the relative rebate distributions tilt such that there is a higher percentage requirement for the lower cost greywater systems, and a reverse tilt for higher cost systems. This suggests that there is a fixed willingness-to-pay, above which PWP is expected to play an active role subsidizing the cost.

Willingness-to-pay levels are notoriously difficult to estimate, and direct self-assessed levels rarely reliable. We can, however get an idea of what this level is, by looking at the co-investment willingness; i.e. the cutoff where the customer would need external financing. We have asked responders for this level, and our findings are summarized in the figure below.

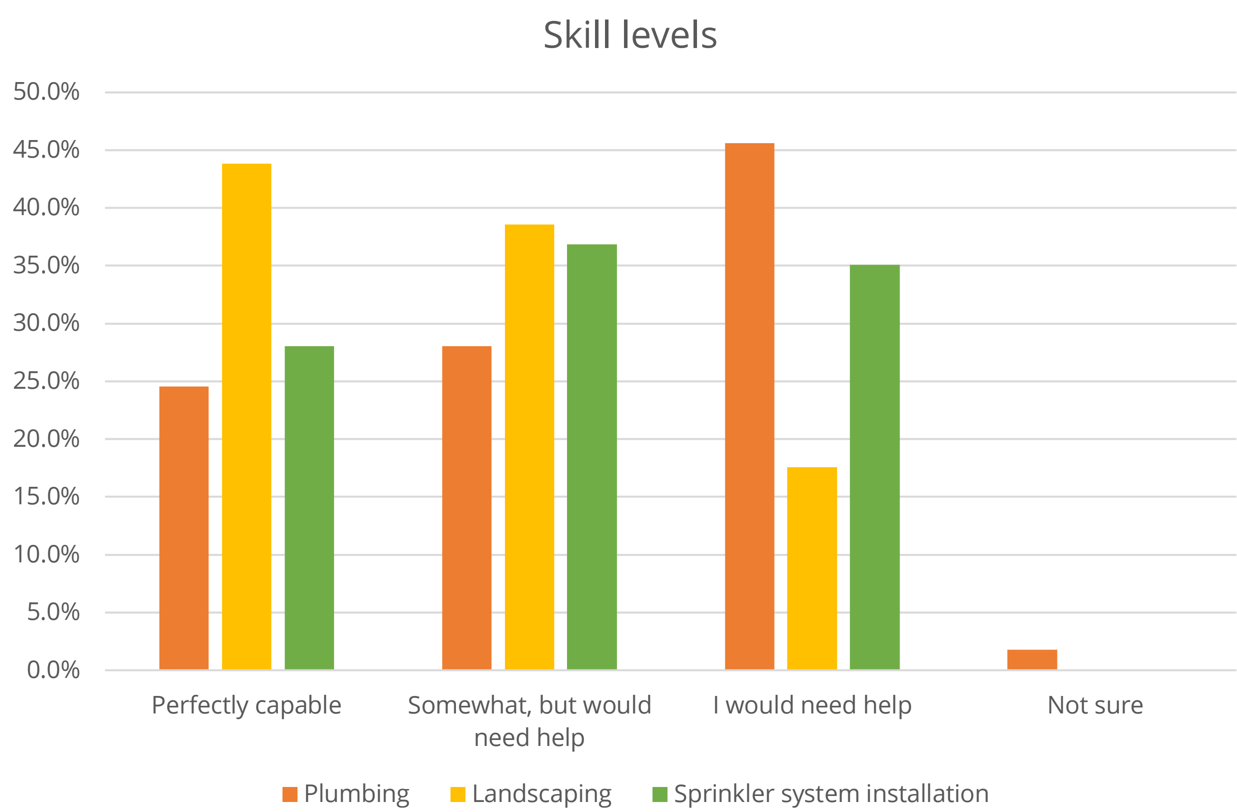


This question was only answered by 80% (47 out of 59) of the responses. As the sample grows, we expect the distribution to even out with greater weight on the "$500 to $750" range. The relevant question was asked as a free text option. This can be beneficial especially in regards to consumer preferences, which is why we decided on this format when designing the questionnaire.

The survey furthermore asks about which financing sources the responder would consider, but the response rate was very low on this question. Only 54% (32 out of 59) of responders provided answers to this question, and we might need to revise either the question or make it mandatory if the response rate does not improve.

Installation needs

As will be clear from reading the Financing Models chapter, upfront installation costs can in many cases deter greywater investments, even when the system in itself is viable. For this reason, we are very interested to learn whether there are educational needs among PWP's customers, to overcome the costs and hurdles associated with installing greywater systems. This is particular relevant for the smaller L2L greywater systems that can be installed without a permit.



This image is consistent with our initial expectations and the idea behind PWP's L2L workshops where participants learn about the system installation inside the laundry room. As we see in the Laundry-to-Landscape Greywater Systems chapter, the plumbing requirements are minimal, but when this task cannot be managed by the homeowner, the greywater system's viability is jeopardized.

Capital budgeting

Summary

In this section we introduce capital budgeting and outline which metrics we will apply in the financial viability analysis of greywater systems (GWS). It is important to remember that we are interested in analyzing the role of the utility company as well as the end-user, and we will therefore need to augment the capital budgeting techniques applied to the end-user's investment decision with the value created for the utility company. This addition is non-standard and necessary when we evaluate the utility's decision to subsidize.

Since its inception in the early sixties, the field of corporate finance has contributed greatly to our understanding of corporate behavior as well as investor decision making. Chief among all contributions is the theory of capital budgeting, i.e. the principles that govern investment decisions.

The core insight is that capital investments are financially viable if (and only if) the *present value* of all current and future benefits outweigh the *present value* of all current and future costs. A present value is an aggregation of current and discounted future cash flows—we explain and motivate this concept in detail below.

Another important result is that we can use the present values of benefits and cost and simply consider the difference between them; this difference is the *Net Present Value* (commonly denoted the NPV) of the capital investment. Consistent with the benefit-cost approach, a capital investment will be financially viable whenever the NPV is positive.

Furthermore, the NPV can function as a ranking mechanism. This means that, given a series of mutually exclusive opportunities, we can calculate the NPV for each of them; the project with the highest (positive) NPV will be financially superior in absolute terms, and thus, should be preferred to all other alternatives.

Payback time

How do we know if an investment project is worthwhile? Without knowledge of capital budgeting, many individuals (and some companies!) rely on what is referred to as the *payback time method.* The idea is to determine whether the costs of a project are expected to be recovered within a certain timeframe.

Although the simplicity of this approach is appealing, it comes at a cost: It fails to recognize the timing of cash flows; the risk of the investment; and the total cash flow implications. For these reasons, calculating and comparing payback times for competing investment projects can also lead to very poor investment decisions. Furthermore, the timeframe requirement is rather arbitrary and could reflect anything from corporate culture and risk aversion, to "gut-feeling" and intuition. For these reasons, it is highly problematic to rely on the payback time method for capital budgeting and when it is included in an analysis, there should be a really good reason for it.

Example 1: Payback Time

To illustrate, consider a residential, maintenance-free greywater system that requires an initial investment of $1,000, and has an expected life-span of ten years. A homeowner is willing to invest in this system, if it can recover the initial cost within half the life-span, i.e. if the $1,000 can be recovered in 5 years.

The system is expected to provide rate savings of $150 per year for ten years after which it will be discarded free of cost. If we apply the payback time method in this case, we see that by the end of year 6, the system has recovered $900, and by the end of year 7, the system has recovered a total of $1,050, which is $50 more than the cost of the system.

Assuming that the annual cost savings of $150 are evenly distributed throughout the seventh year, the remaining $100 should be recovered after $^2/_3$ of that year. The payback time in this case is therefore 6 years and 8 months, i.e. $6\,^2/_3$ years. The homeowner would therefore reject the greywater system because the annual cost savings have not recovered the initial investment within 5 years.

As this example illustrates, the payback time method has a couple of very unfortunate flaws. Firstly, it ignores all cash flows after the cut-off (5 years in this case). This means that it would not matter if the cost savings continued for 20 years, 50 years, or even longer. When sticking to this method, we thus ignore obviously relevant information.

Secondly, as a decision rule it fails to recognize that cost savings that materialize 10 years from the initial investment should be less important to the decision maker than savings that occur sooner. Cash flows that occur sooner than others carry a greater weight in our decision making, and thus, we have to account for this *time value of money* in the capital budgeting mechanism.

Time value of money

Why should cash flows that occur in the distant future carry less weight than the ones that occur immediately or in the near future?

Consider the following simple case: We wish the sell a piece of equipment, say a car, and we have received two offers. The first offer would give us $10,000 in hand today, while the other promises $11,000 to be received one year from today. Both prospective buyers are risk-free, and in either case, the car will be delivered today. We can deposit any proceeds from the sale into a savings bank account that pays 5% interest p.a.

So, which option is more financially viable? If we go with the first offer, we can earn $500 in interest, which means that the value of this option is $10,500 in one year. If we go with the second offer, the value in one year will be $11,000. For this reason, we should accept the second offer.

This type of assessment compares *future values* of mutually exclusive opportunities. It is a simple way of ensuring that we have taken the time value of money into account when we evaluate investment opportunities. The approach can, however, be challenging to use in practice when projects of different maturities are evaluated. For this reason, we often focus on the *present values* of these opportunities instead.

The present value is the value (cash in hand today) that would allow us to replicate a specific cash flow stream by investing in the financial markets. In the example above, where $11,000 is offered with a one-year delay, and the interest rate is 5%, we must ask: What is the cash value needed today to generate a $11,000 payment in one year. The answer is

$$\mathrm{PV} = \frac{\$11{,}000}{1.05} = \$10{,}476.19$$

This means that we would be indifferent between an immediate payment of $10,476.19 and a one-year delayed payment of $11,000. By comparing this present value to the first offer of $10,000, it is clear, once more, that the second offer is preferable, since an immediate payment would have to be at least as high as the present value of the second offer before we would consider it. In fact, the present value and the future value assessments will always be consistent in terms of the decisions they generate.

We focus on present values rather than future values for a couple of reasons. Firstly, the PV makes it easy to compare the financial viability of opportunities with different maturities. Secondly, it is more intuitively clear which values we are actually comparing; the future value assessment forces the analyst to base the comparison on the longest maturity, which can challenge the perception of how valuable an opportunity actually is. Finally, the present value gives us a point of comparison, when we try to determine the market value of asset purchases.

Net Present Value (NPV)

NPV Decision Rule

The difference between the present value of a specific asset or strategy and its initial cost is called the *Net Present Value* or NPV for short.

Whenever the NPV is positive, the investment opportunity is deemed financially viable. Equivalently, whenever an opportunity yields both benefits and costs that are distributed over time, we can calculate the NPV as the difference between the present value of all benefits and the present value of all costs.

Formally, the NPV can be written as:

$$\mathrm{NPV} = \frac{\mathrm{CF}_1}{1+\mathrm{r}} + \frac{\mathrm{CF}_2}{(1+\mathrm{r})^2} + \cdots + \frac{\mathrm{CF}_\mathrm{T}}{(1+\mathrm{r})^\mathrm{T}} - \mathrm{I}_0 = \sum_{\mathrm{i}=1}^{\mathrm{T}} \frac{\mathrm{CF}_\mathrm{i}}{(1+\mathrm{r})^\mathrm{i}} - \mathrm{I}_0$$

Here,

- **CF_i** is the estimated cash flow in the i^{th} period;
- **r** is the rate of return that the decision maker could receive from the financial markets if the investment were not made (this parameter is commonly referred to as the *opportunity cost of capital* or the *required rate of return*);
- **T** is the number of periods where cash flow is generated; and
- **I_0** is the initial investment.

Example 2: Net Present Value

In order to find a better alternative than the payback time method, we will need to know the required rate of return, *r*, of the decision maker. In this example, we assume that *r* = 5%.

We can thus calculate the NPV of the greywater system with the following parameters: **CF_i** is equal to the annual $150 cost saving, which means that $CF_1 = CF_2 = ... = CF_{10}$ = $150; r = 0.05; T = 10; and I_0 = $1,000. With these parameters we get **NPV = $158.26**.

Since the NPV is positive, the greywater system provides a better investment return than the 5% alternative, and the investment should therefore be made. In fact, the decision maker should be willing to pay up to **$1,158.26** ($1,000 + $158.26) for the system.

Since the NPV decision rule ties the decision makers opportunity cost of capital to the investment at hand, we sometimes refer to the present value of all incremental benefit as the market value of the opportunity. This is not to say to that there is an actual market where the project trades at its present value, but rather that, if there were a market, where all participants shared the decision maker's information, then the fair price of the project would be its present value.

For this reason, it becomes clear how the NPV decision rule extends to a *ranking criteria*; if we calculated the NPV of several mutually exclusive projects, the one with the highest NPV, would also be the most valuable opportunity.

Greywater Example 3: NPV Ranking

Consider the residential, maintenance-free greywater system Examples 1 and 2. What would happen if there were a competing greywater system offered at the same price, $1,000, which offered annual savings of $300 for 5 years, instead of $150 annually for 10 years?

In order to assess the viability of the competing system, we can calculate its NPV using the same formula as before. In this case we have: **CF_i** is equal to the annual $300 cost saving, which means that $CF_1 = CF_2 = ... = CF_5$ = $300; r = 0.05; T = 5; and I_0 = $1,000. With these parameters we get **NPV = $298.84**.

Since the NPV is higher than the NPV of the original system (which was **$158.26**), it provides a much better opportunity for the decision maker.

It is important to note where the difference in NPVs is coming from in the Examples 2 and 3. Both systems have an initial cost of $1,000; they both generate $1,500 worth of aggregated cost savings; and these savings are all discounted at 5%. The only difference is in the timing of these savings. Hence, the additional (market) value of the second system is solely due to the time value of money.

Present Value Interest Factor for Annuities, PVIFA(r,T)

There are a couple of special cases where we can obtain simple formulas and avoid the summation when we calculate the NPV. The examples are:

- Annuities, where the cash flow is fixed for a specific timeframe
- Perpetuities, where the cash flow is fixed forever
- Growing annuities, where the cash flow grows at a fixed rate, *g*, for a specific timeframe
- Growing perpetuities, where the cash flow grows at a fixed rate, *g*, forever

In these cases, the present value component (the summation) in the NPV formula simplifies to:

- Annuity: $\mathrm{CF} \times {}^{1-(1+\mathrm{r})^{-\mathrm{T}}}/_{\mathrm{r}}$, the factor on the cash flow is called the *Present Value Interest Factor for Annuities*, *PVIFA(r,T)*
- Perpetuity: ${}^{\mathrm{CF}}/_{\mathrm{r}}$
- Growing Annuity: $\mathrm{CF} \times {}^{1-((1+\mathrm{g})/(1+\mathrm{r}))^{\mathrm{T}}}/_{\mathrm{r}-\mathrm{g}}$
- Growing perpetuity: ${}^{\mathrm{CF}}/_{\mathrm{r}-\mathrm{g}}$

We can measure a decision maker's time value of money is by $\frac{\mathrm{T}}{\mathrm{PVIFA(r,T)}}$. Although this measure will vary with the time horizon, it can sometimes simplify matters when we work with several decision makers, who have different time values of money. We will sometimes refer to $\mathrm{TVM(r,T)} = \frac{\mathrm{T}}{\mathrm{PVIFA(r,T)}}$ as the *time value of money*, or simply *TVM* directly.

NPV Profiles

For large corporations—especially publicly traded companies—it is straight forward to find the appropriate discounting rate. If we evaluate a project that is equal in risk to the overall company, we can use the *weighted average cost of capital* (WACC) as the discounting rate.

If the project is riskier than the overall company is, we add a premium to the discounting rate for the additional risk, and if the project is less risky, we lower the discounting rate.

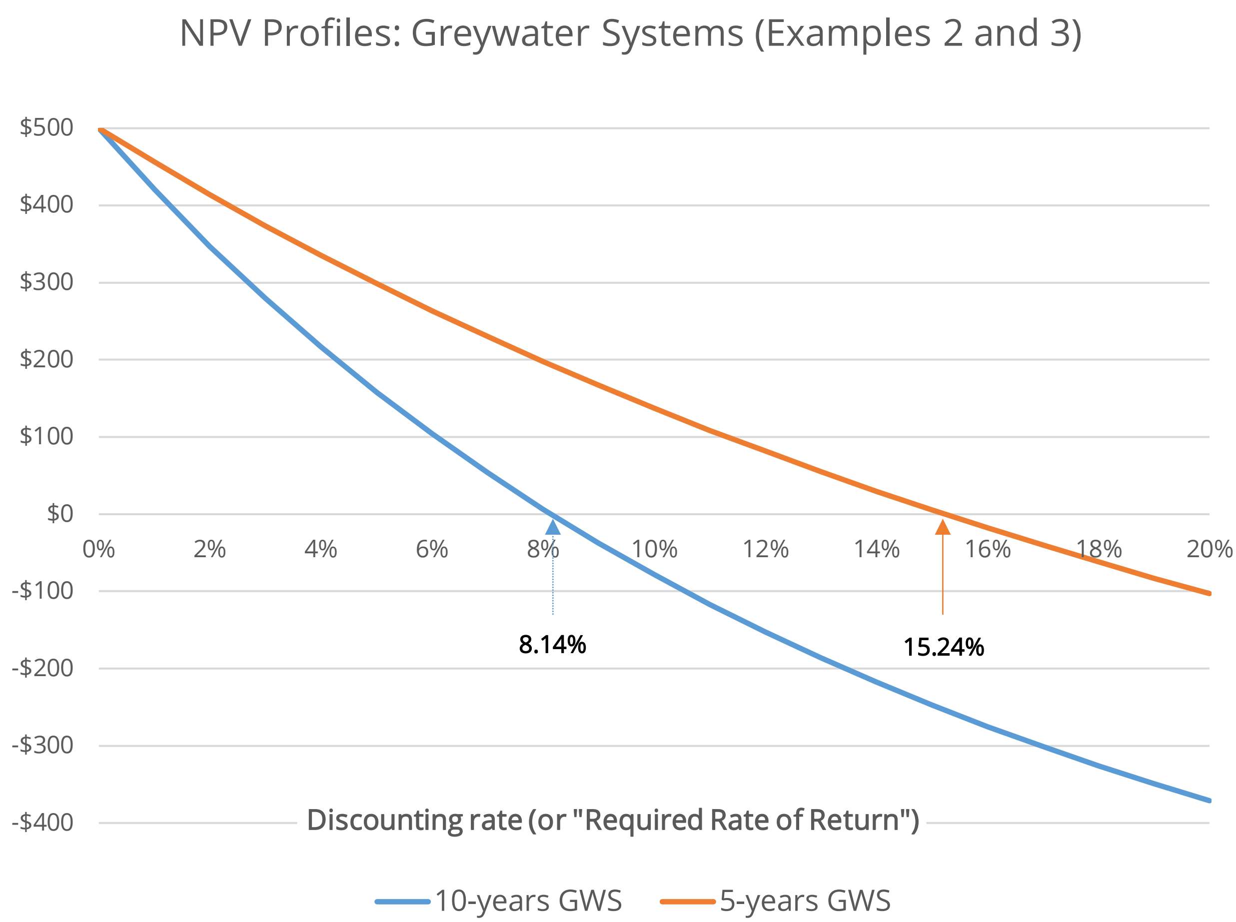
For private companies and individual homeowners it can be difficult to quantify which discounting rate to apply. As a guiding principle, we can pair the risk of the future cash flow to the cost of capital to finance the project.

To illuminate the potential viability of an investment, we can plot the NPV of an investment as a function of varying discounting rates; this is called an *NPV Profile*, and is helpful in any case, but in particular, when there is uncertainty about the true cost of capital.

The NPV profiles for the two residential, maintenance–free greywater systems from Examples 2 and 3 are shown in the figure below. The 10-year GWS provides a positive NPV for discounting rates lower than 8.14%, while the 5-year GWS is viable for discounting rates up to 15.24%. Not surprisingly, the system that provides cost-savings quicker, appeals to a larger customer base than the system where the savings are distributed over 10 years.

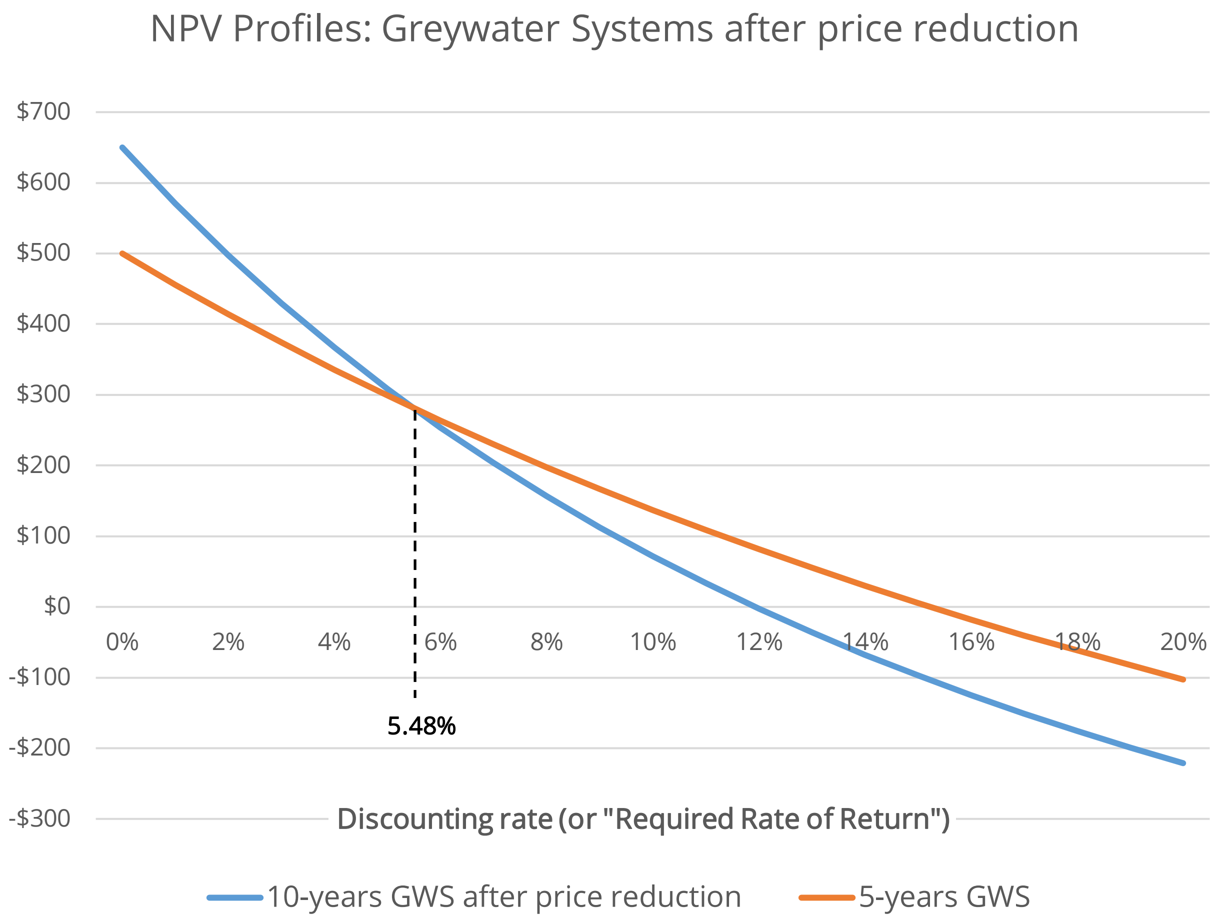
The figure reveals a couple of other interesting features of NPV profiles. First, note that the NPV decreases as the discounting rate increases. This will be the case for all *conventional* investments, that is, where the “sign” of the cash flow stream only switches once; in the case of the greywater systems in Examples 2 and 3, we begin with a cash flow of *negative* $1,000 to purchase the system, followed by a stream of *positive* cash flow from the cost-savings.

For larger projects where follow-up investments, replacements, maintenance, or similar events impose shifts in the sign of the cash flow stream, the NPV profile can potentially change direction and intersect the NPV=0 baseline for every shift. This feature makes an NPV profile extremely helpful, as it reveals how sensitive the viability of the system is to the discounting rate, and thus to the financing options made available.



Second, both NPV profiles start out in $500 (when the discounting rate is equal to 0%), and they will converge towards -$1,000 (as the discounting rate grows large). This is no coincidence. A discounting rate of 0% resembles a case where the decision maker is infinitely patient, and thus ignores the time value of money. In such a case, the value of the greywater system is the sum of all cash flow; for both systems, this turns out to be $500. Further, the case where the discounting rate grows arbitrarily large, future cash flow, will not matter at all; the “value” in these extremes is simply equal to the initial investment. In both cases, the initial investment was (negative) $1,000. Third, the second greywater system, the 5-year GWS, strictly dominates, when we apply NPV Ranking. This means that in practice, everything else being equal, the 10-year GWS would not have a customer base, and the price of the system would eventually have to decrease.

To illustrate, assume that the price of the 10-year GWS drops to $850. We can then redraw the NPV profiles of the two systems (figure below).



While the profile for the 5-year GWS is unchanged, the profile for the 10-year GWS has shifted upwards, revealing that for relatively low discounting rates, this system will be preferable to the 5-year GWS. The cut-off can be found numerically to 5.48%.

Using NPV Ranking, we can then conclude that the 10-year GWS after price reduction is preferable to the 5-year GWS if the discounting rate is lower than 5.48%; the 5-year GWS will be preferred if the discounting rate is higher than 5.48%. Hence, only when the decision maker is very patient, can the initial purchase price reduction justify the postponed cost-savings of the 10-year GWS.

Internal Rate of Return (IRR)

Definition

Closely related to the NPV analysis is the Internal Rate of Return (or "IRR" for short). This averaging annual return rate captures the entire cash flow stream of a project, and provides us with a simple indicator of its value.

In many practical applications, such as the greywater systems from Examples 2 and 3, the return materialize over a long period of time, and it can therefore be challenging to understand exactly what the annual return of each investment opportunity is.

IRR analysis provides the answer to this hurdle by applying the *NPV analysis in reverse*. Instead of determining the value of a project's cash flow based on the decision maker's required rate of return, we start out by looking for a range of discounting rates that would yield non-negative NPVs; among these, we choose the highest one. Due to the continuity of the NPV, the discounting rate would yield an NPV of zero.

The discounting rate that secures NPV=0 is the IRR. In the NPV profiles figure, we can therefore read of the IRR where the curve intersects the NPV=0 axis. The 10-year GWS intersects at 8.14% and the 5-year GWS intersects at 15.24%.

The IRR indicates how much a project generates in return without taking the opportunity cost of capital into account. In order to apply the IRR for capital budgeting we test whether this IRR is sufficient *in comparison* to the opportunity cost; this means that we simply have to check if the IRR is higher than our required cost of capital.

Calculation

In order to find the IRR of a project, we generally need to employ numerical techniques. In certain simple cases, we can calculate the IRR directly, but these cases are rare in practice.

From the definition of an NPV and the condition, that the IRR secures NPV=0 we get:

$$\sum_{i=1}^{T} \frac{CF_i}{(1 + IRR)^i} - I_0 = 0$$

Here CF_i, T, and I_0 are defined as in the NPV analysis.

Shortcomings

The IRR is an effective and informative metric that can help us understand the viability of an investment opportunity even without knowing our discounting rate exactly. As a decision rule, however, it comes with two shortcomings: 1) We cannot use it as a ranking criteria, and 2) if the cash flow stream is nonconventional (i.e. the sign of the cash flow shifts more than once), the IRR may not be unique, and thus non-informative.

IRR analysis does not provide a ranking criterion. Some analysts, mistakenly, calculate the IRRs for a range of mutually exclusive projects and then choose the one with the highest IRR. The problem with this approach is scale; an IRR is the annualized return on the initial investment, I_0, and if the initial investments differ from project to project, the individual IRRs do not tell us anything about the actual values that each project create. A low IRR on a large investment could easily be preferable to a large IRR on a small investment.

As described in the NPV analysis, a conventional investment would have a single initial capital investment (outflow) followed by a sequence of returns (inflow). The NPV profile for such investments are downward sloping, and we can find a unique IRR where the curve intersects the NPV=0 axis.

If the discounting rate is higher than the IRR, the NPV has slopes further down, and the NPV is thus negative. Similarly, if the discounting rate is lower than the IRR, the corresponding NPV would be positive. For conventional investments, the IRR and the NPV decision rules thus yield the exact same results.

Nonconventional investments, however, can intersect the NPV=0 axis multiple times, which renders IRR analysis useless. For this reason, it is advisable to accompany the IRR analysis with an NPV profile to ensure that the IRR actually provide us with the information that we expect, and that we interpret it correctly.

Profitability indices and the Benefit-Cost Ratio method

There are many other capital budgeting techniques in use, and two methods that are quite common and come quite close to the NPV analysis deal with Profitability Indices (PIs) and Benefit-Cost (B-C) ratios.

Profitability Index (PI)

A profitability index is calculated by dividing the present value of all future incremental cash flow with the initial investment. Formally,

$$PI = \frac{\sum_{i=1}^{T} \frac{CF_i}{(1+r)^i}}{I_0}$$

It follows directly from the definition of an NPV that the profitability index will be higher than one, exactly when an investment is financially viable. When used in this way, the PI method is perfectly valid.

When used as a ranking criteria—which is often the case—we face the same issues as we saw with the IRR analysis. The initial investments can differ from project to project, and the fact that one opportunity has a higher PI than all other alternatives, does not mean that it is the most viable option; only that the *present value return* on the initial investment is higher.

Benefit-Cost (B-C) ratio

A very similar approach calculates the ratio between the present value of all future benefit and the present value of all future costs. If this ratio exceeds one, then the investment opportunity is deemed financially viable.

This, Benefit-Cost ratio method has the same problems as the PI method insofar as it is true that a project is indeed financially viable if its B-C ratio is higher than one. It is, however, not true, that projects with higher B-C ratios necessarily are *more* viable than others. Again, the problem is one of scalability. The B-C ratio gives us an indication of how well future revenues (or savings) can recover current and future costs.

Just like the profitability index, the B-C ratio method needs mention only because it is widely applied. We will however not focus on these two metrics in our analysis, but choose to report them in some cases when it is the only way to compare our results with the existing literature.

Greywater Viability

Points of analysis

In order to assess the viability of greywater systems, we will generate NPV profiles and IRRs for residential and commercial systems, such as laundry-to-landscape; shower-to-toilet; direct reuse laundry-to-laundry.

Largely, all of these systems present conventional investments, and the IRR analysis should therefore be perfectly applicable. In cases where we need to take maintenance and similar costs into account, the NPV profile will reveal how sensitive the NPV is to changes in discounting rates; and whether the IRR is indeed unique as required.

We will in some cases also include the payback time in the analysis; not for its analytical merit, but because it may illuminate important aspects of end-user preferences.

Investment environment

While the analysis of individual systems follows a well-established approach, that reveals both the viability and sensitivity to parameter changes, the investment "environment" is rather complex.

When GWS investments are made by the end-user, the end-user covers the total costs of the system, while the total benefits are shared with the remaining service area. For this reason, we include an estimate of externalized benefits in the analysis. This metric helps inform optimal subsidizing and local governments' ideal involvement in promoting and sponsoring greywater programs.

Externalized benefits are calculated based on water savings, risk reductions, and other impacts and are not necessarily reported in monetary values. Utility companies face numerous state and federally imposed restrictions and requirements. The value of, say, direct water saving and incremental groundwater recharging from greywater need to be taken into account when we evaluate utilities' involvement, promotion, and support for greywater programs.

While the NPV for the utility company can be very difficult to determine, we can still find a range of needed monetary and educational support and weigh these against the prospective benefits.

Laundry-to-Landscape Greywater Systems

The simplest greywater system to be covered in this research is the Laundry-to-Landscape (L2L for short) system. In California, greywater from laundry can be applied for subsurface irrigation without any treatment. This does not include diaper washes, as the wastewater in these cases can contain fecal matter and is considered blackwater.

Art Ludwig from Oasis Design has spearheaded the L2L awareness for a couple of decades. This, as a response to California's continuous exposure to extended drought periods, has resonated both for its simplicity (see figure below) and because this system as opposed to rain barrel and other rain water capture installations, provides a year round supply of greywater.

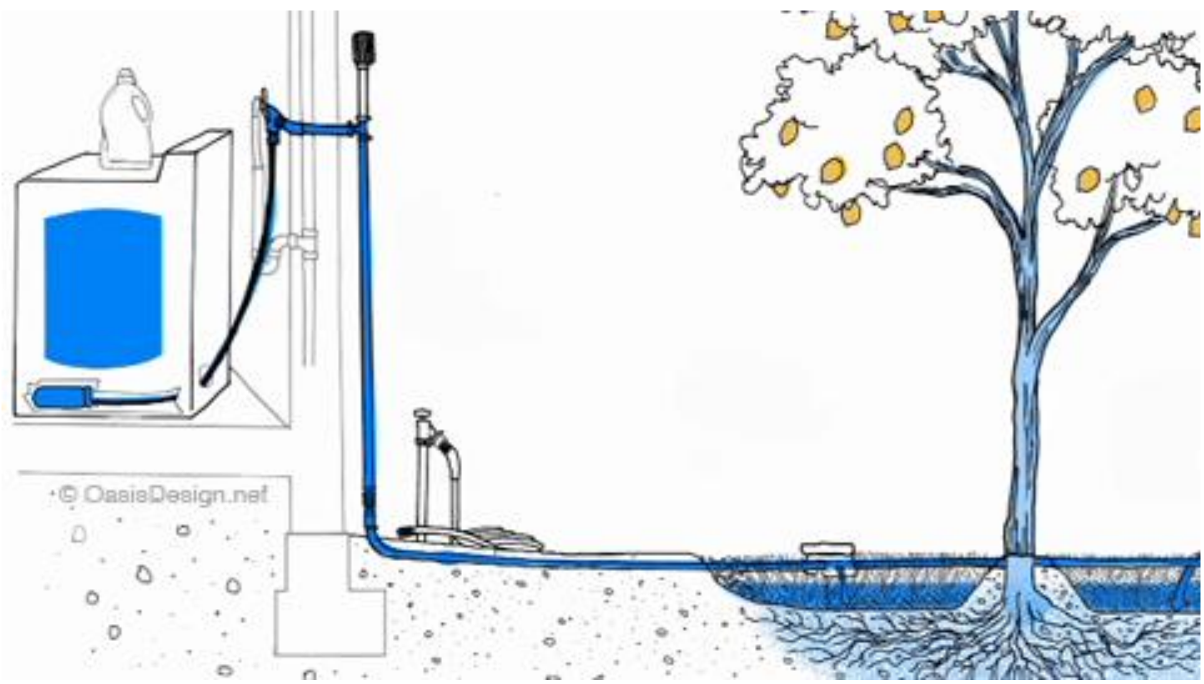


Figure 5. Simple L2L design. Source: Oasis Design.

Figure 6 (left)
3-way valve for L2L system where the laundry room is next to an exterior wall.

Figure 7 (right)
Auto vent, AAV, or inline vent.

In Pasadena, the L2L system can be installed without obtaining any permit, which drastically reduces the total cost of the system. There are two different cases for L2L installation depending on whether the laundry machine is located next to an exterior wall or not.

If the laundry room is located next to an exterior wall, the greywater pipe can travel directly outside. The flow of greywater from the washing machine is controlled by a 3-way valve, which enables the homeowner to divert greywater to the landscaping area or to the sewer as needed. An auto vent on the outside of the house allows air to enter the system and presents siphoning of water from the washing machine. The system is depicted in the figures above.

When the Laundry room is not located next to an exterior wall, the greywater must be directed through the floor to reach the irrigation area. As opposed to the case where the laundry room has an exterior wall, the auto vent must be installed inside the house. The

Figure 8
3-way valve for L2L system where the greywater pipe leaves through the floor, typically via a crawlspace, to the irrigation area.

The auto vent in the case, must be installed system is depicted in the figure to the right.[15]

Cost Savings

The economic life of a typical L2L system is 10 years.[16] In this period, the system provides the same volume of greywater as the laundry machine uses. For the cost savings estimation, we will reasonably assume that all the greywater that the L2L system produces can be used for irrigation, thus providing 100% efficient direct water savings.

In order to estimate the cost savings, we need to estimate the annual greywater output (i.e. the water usage for laundry) and then estimate the cost of this water based on PWP's tier rates.

Greywater output

According to Home Water Works, high-efficiency washing machines use from 14 gallons to 25 gallons per wash, while older and less efficient machines use 40-45 gallons per wash;[17] according to National Park Services the distribution is very uneven, with an average usage of 41 gallons per load.[18]

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[15] Greywater Action's website: greywateraction.org/greywater-system-examples/ contains detailed systems descriptions, sample material costs, and installation guidelines.

[16] According to systems seller Landscape Warehouse, who has distributed L2L systems as a part Pasadena Department of Water & Power's *Laundry-to-Landscape Greywater Program*. Further indication that 10 year is the reasonable expected economic life of L2L systems can be found on Greywater Action's website: greywateraction.org/laundry-to-landscape-with-exterior-wall/

[17] See home-water-works.org

[18] See National Park Services website: nps.gov/articles/laundry.htm

There are relatively few studies of the laundry frequency by household size, but one comprehensive study by Professors Turner (Univ. Technology Sydney), Fyfe (Western Sydney Univ.), Retamal (Australian National Univ.), and White (Univ. Technology Sydney) suggests a logarithmic relationship between the number of laundry loads and the household size. The relationship is close-to-linear for household sizes between 2 and 4 occupants. In this range, two loads per week per occupant is normal (see figure of the study's full range here above).

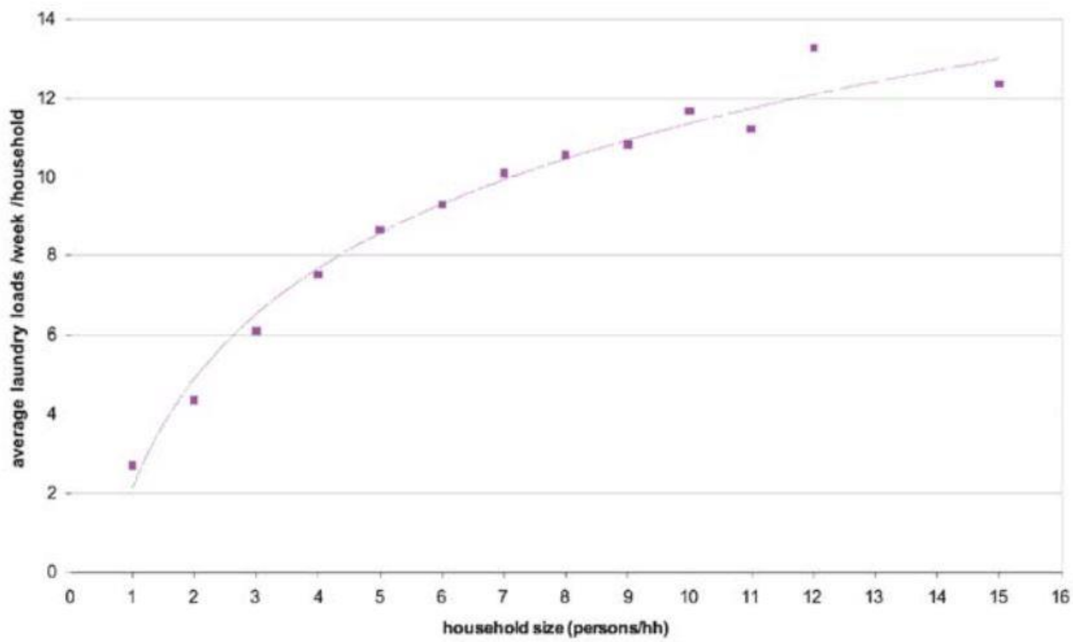


Figure 9. Estimated weekly laundry loads by number of occupants.

For the 18,860 SFR households in PWP's service area, we can extract the distribution of households by number of occupants.[19] The figure below illustrates this distribution. As can be seen, the majority of SFR customers are households of sizes two or three, while the median household size is three. This is consistent with United States Census Bureau, who reports City of Pasadena's average household to be 2.51.[20]

[19] Data extracted from 2018 SFR water usage report via the WaterSmart platform.
[20] See https://www.census.gov/quickfacts/pasadenacitycalifornia

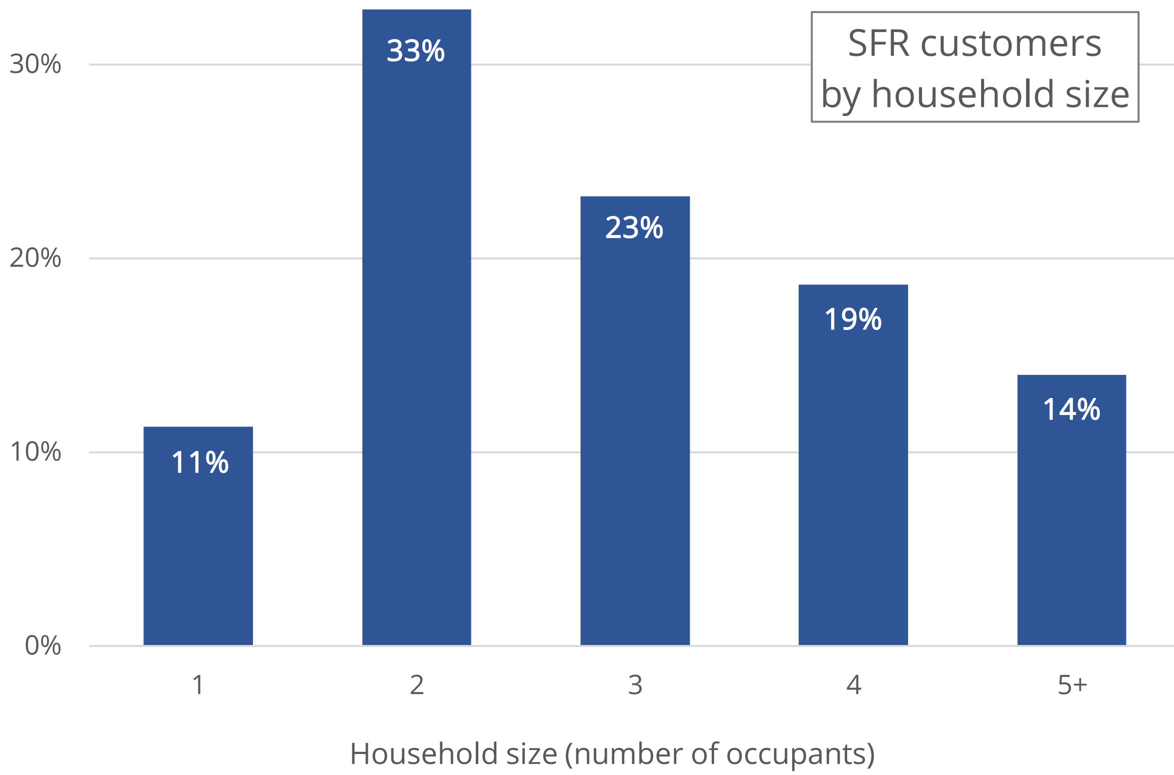


Figure 10. Distribution of SFR customers by household size.

In order to estimate the annual greywater output for a specific SFR household we can now multiply the household size with a factor two (2) to get the weekly number of laundry loads; we multiply this number with 52 to get the annual number of loads; and finally we multiply that number with the efficiency (gallons per wash) of the laundry machine.

For example, if we consider a typical family of three who has an old laundry machine that is as efficient as the average efficiency (41 gallons per wash) reported by the National Park Services, the estimated annual greywater output can be found like this:

3 occupants X 2 loads per week per occupant X 52 weeks per year X 41 gallons per load,

which equals 12,792 gallons (17.1 HCF) per year. The table below shows estimated annual greywater outputs for SFR households between one and five occupants with either high, medium, or low efficiency laundry machines.

Annual greywater output (in HCF) from L2L systems by laundry machine efficiency and household size.

Water usage per load \ Household size	1 occupant	2 occupants	3 occupants	4 occupants	5 occupants
15 gallons	2.1	4.2	6.3	8.3	10.4
30 gallons	4.2	8.3	12.5	16.7	20.9
45 gallons	6.3	12.5	18.8	25.0	31.3

Water rates

With the estimated annual greywater outputs, we now turn to finding the expected annual cost savings. Assuming that the L2L greywater replaces potable water (in the same amount) that would otherwise be purchased, we can back out the cost savings from PWP's water rates.

The PWP water is made up of a flat *Distribution and Customer Charge*, which is determined by the household's meter size (the relevant meter sizes for SFR households are: 5/8", 3/4", 1", 1½", 2", and 3");[21] the *Water Commodity Rate*, which is determined by block consumption and location (i.e. whether the customer is located inside city limits or not); and the *Capital Improvement Charge* (CIC) and sewercharge, which are determined by total consumption. The individual block rates and the CIC are furthermore determined by the season (during the summer, April through September, the rates are higher than during the winter, October through March), and by the location of the customer.[22] All rates are available on PWP's website and in the *Code of Ordinances, Chapter 13.20: Water and Service Rates*.[23]

[21] See "Pasadena, California – Code of Ordinances, Title 13, Chapter 13.20: Water and Service Rates".
[22] In the course of this research project Pasadena has eliminated the winter/summer rate differentials. This change was effective August 2019. We have however kept the analysis in the report as it may prove beneficial for other water utilities.
See https://ww5.cityofpasadena.net/water-and-power/waterrateadjustment/
[23] See ww5.cityofpasadena.net/water-and-power/rates/

The commodity rates fall in four blocks, where the block rate (per 100 HCF) increases with monthly consumption. This means that a household's monthly cost of water is a piecewise linear and convex function of monthly water usage.

Figures 11 through 15 show the monthly cost of water for the varying meter sizes relevant to SFR households. Each figure show the costs for customers inside (solid lines) and outside (dashed lines) of Pasadena, in the summer (red) and winter (blue) periods.

For meter sizes 5/8 " and ¾" the block consumption levels are 0 to 9 HCF/month for Block 1; 9 to 25 HCF/month for Block 2; 25 to 35 HCF/month for Block 3; and 35 HCF/month and above for Block 4. The thresholds 9, 25, and 35 HCF/month are the points in Figure 11 where curve gets steeper.

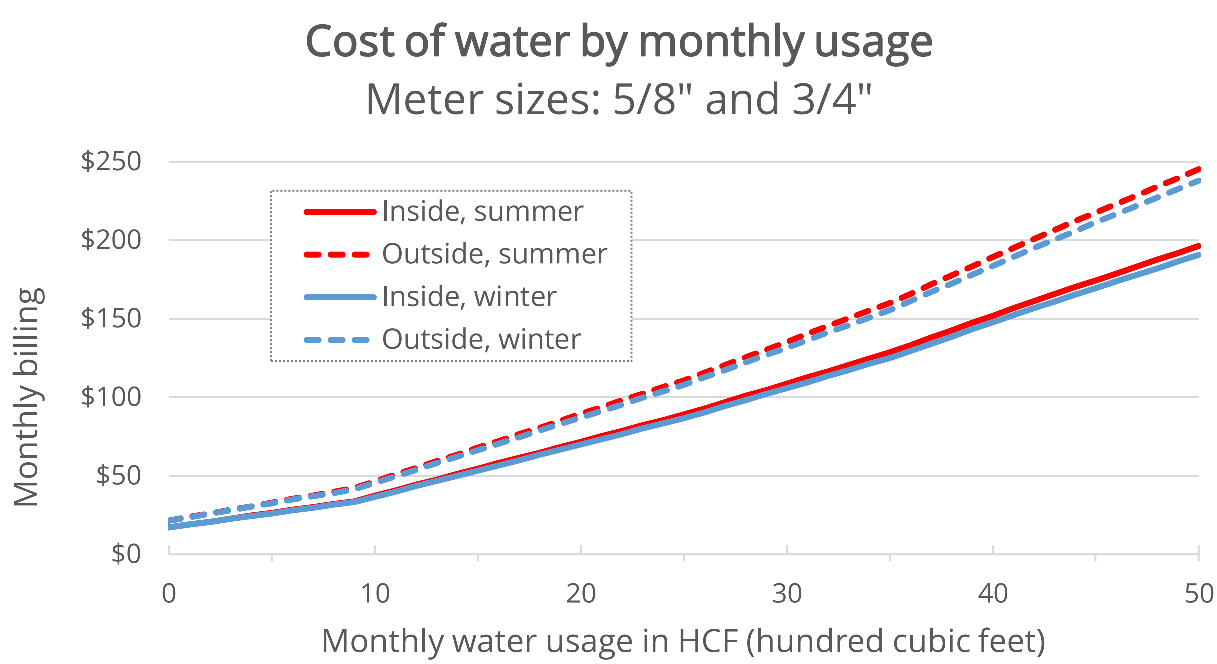


Figure 11. Monthly cost of water for small SFR households. Meter sizes: 5/8" and 3/4"

The estimated annual cost saving thus depends on the applicable block rate in that, the incremental saving from the L2L system is the marginal cost multiplied by the greywater output. The marginal cost is the sum of the applicable Water Commodity Rate, the CIC and the sewage rate. The two tables below show the relevant marginal costs per HCF across the four tiers for water customers inside and outside Pasadena.

Inside Pasadena	Block 1	Block 2	Block 3	Block 4
Av. Commodity rate	$0.89711	$2.46705	$2.96046	$3.70058
Av. CIC	$0.60663	$0.60663	$0.60663	$0.60663
Sewer	$0.32	$0.32	$0.32	$0.32
Marginal Cost per HCF	**$1.82374**	**$3.39368**	**$3.88709**	**$4.62720**

Outside Pasadena	Block 1	Block 2	Block 3	Block 4
Av. Commodity rate	$1.12139	$3.08381	$3.70057	$4.62571
Av. CIC	$0.81889	$0.81889	$0.81889	$0.81889
Sewer	$0.32	$0.32	$0.32	$0.32
Marginal Cost per HCF	**$2.26028**	**$4.22270**	**$4.83946**	**$5.76460**

Note that the marginal cost is independent of the meter size. The only way that meter size becomes important is when determining block thresholds. The thresholds are available in "Pasadena, California – Code of Ordinances, Title 13, Chapter 13.20: Water and Service Rates" and summarized in the table below.

Block allocation in HCF per month.

Meter size	Block 1	Block 2	Block 3	Block 4
5/8 ", ¾"	0 - 8	9 - 24	25 - 34	35>
1"	0 - 12	13 - 40	41 - 60	61>
1½"	0 - 22	23 - 86	87 - 132	133>
2"	0 - 48	49 - 188	189 - 290	291>
3"	0 - 116	117 - 500	501 - 860	861>

As in the case with the smallest meter sizes, the block thresholds determine the water usage levels where the marginal cost increases occurs.

The piecewise linear cost curves are shown in Figures 12 through 15 here below.

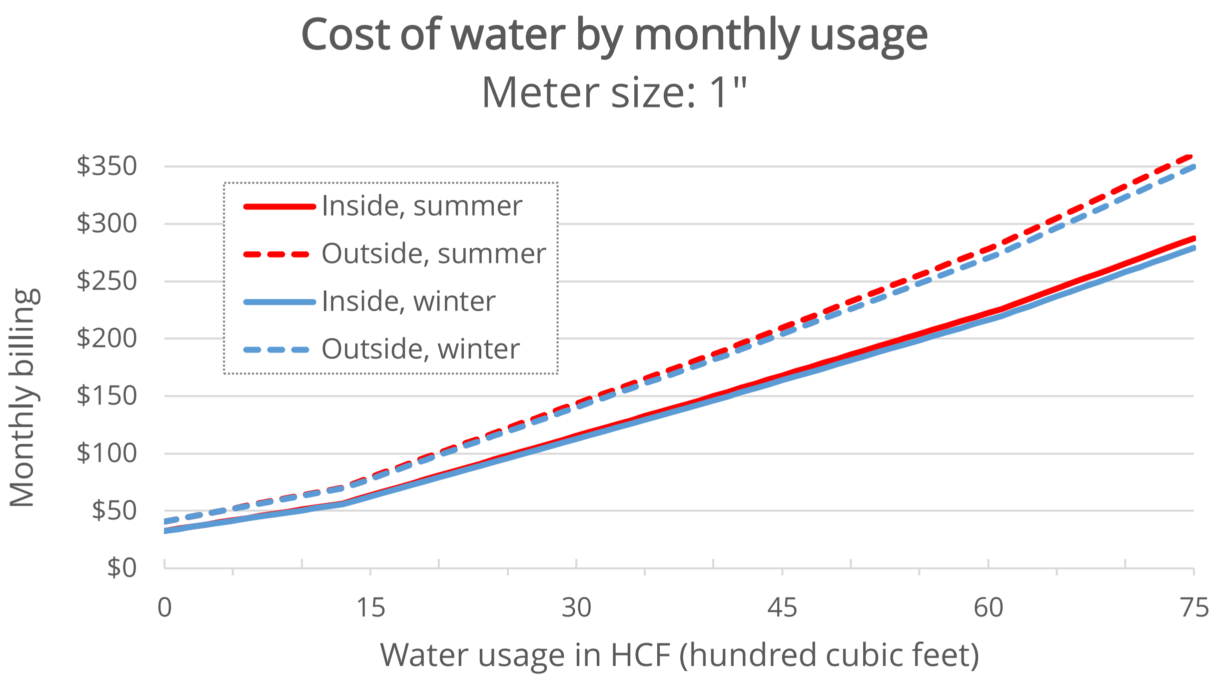


Figure 12. Monthly cost of water for medium SFR households. Meter size: 1"

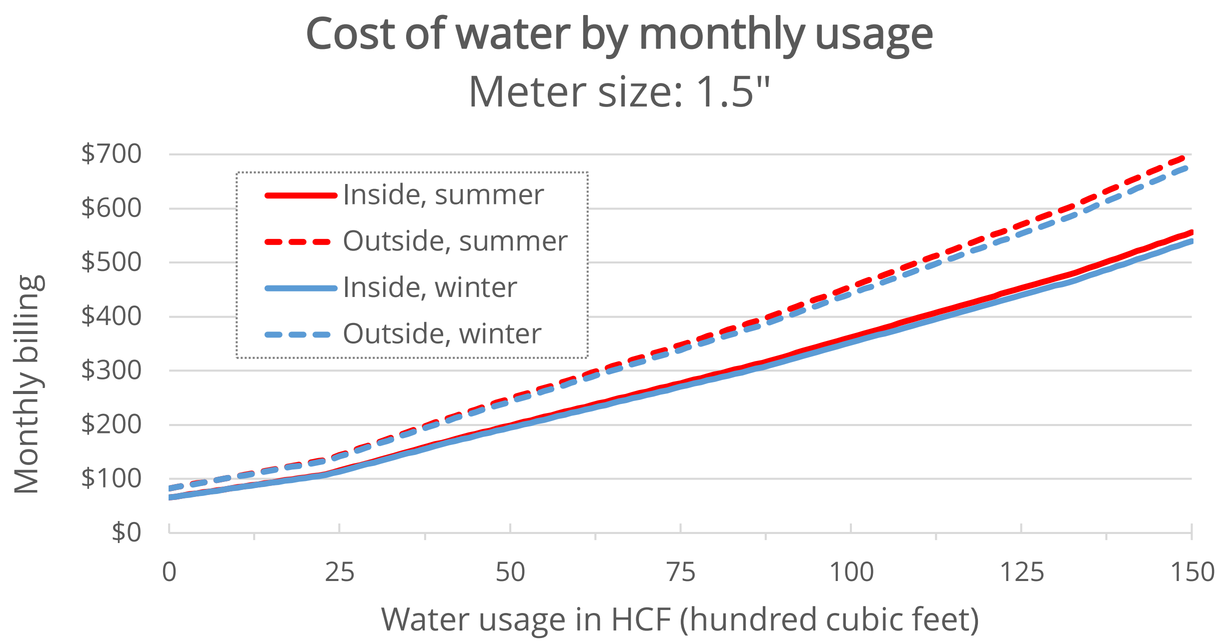


Figure 13. Monthly cost of water for large SFR households. Meter size: 1½"

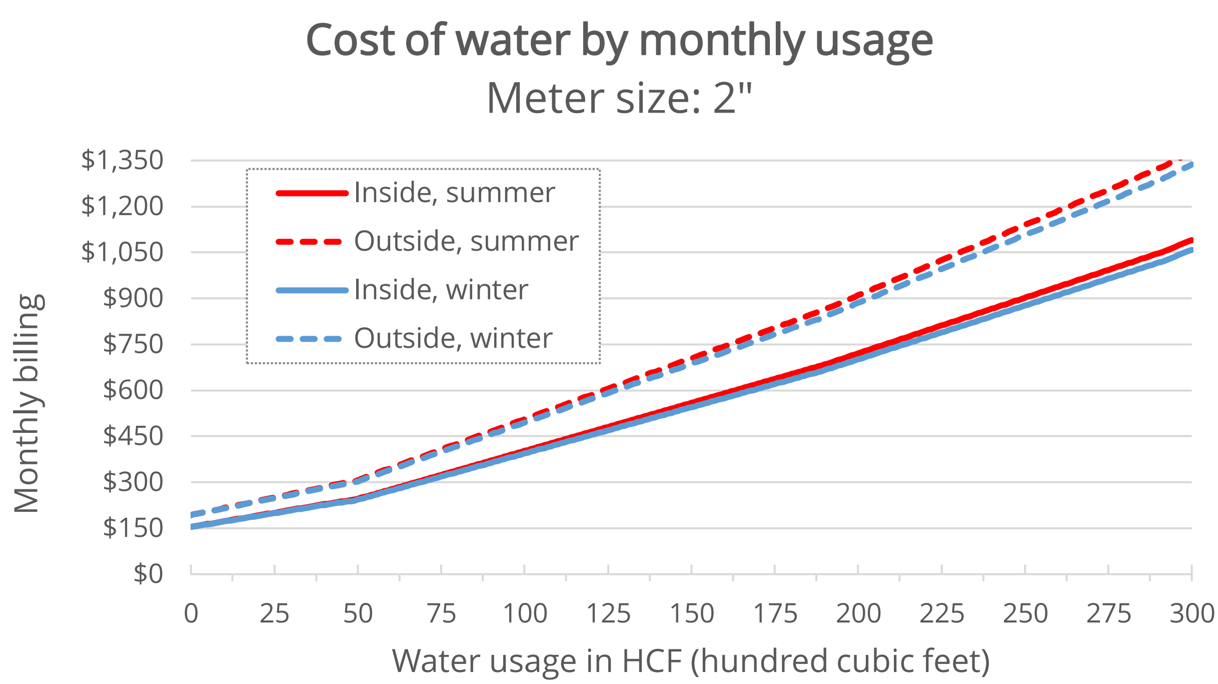


Figure 14. Monthly cost of water for large SFR households. Meter size: 2"

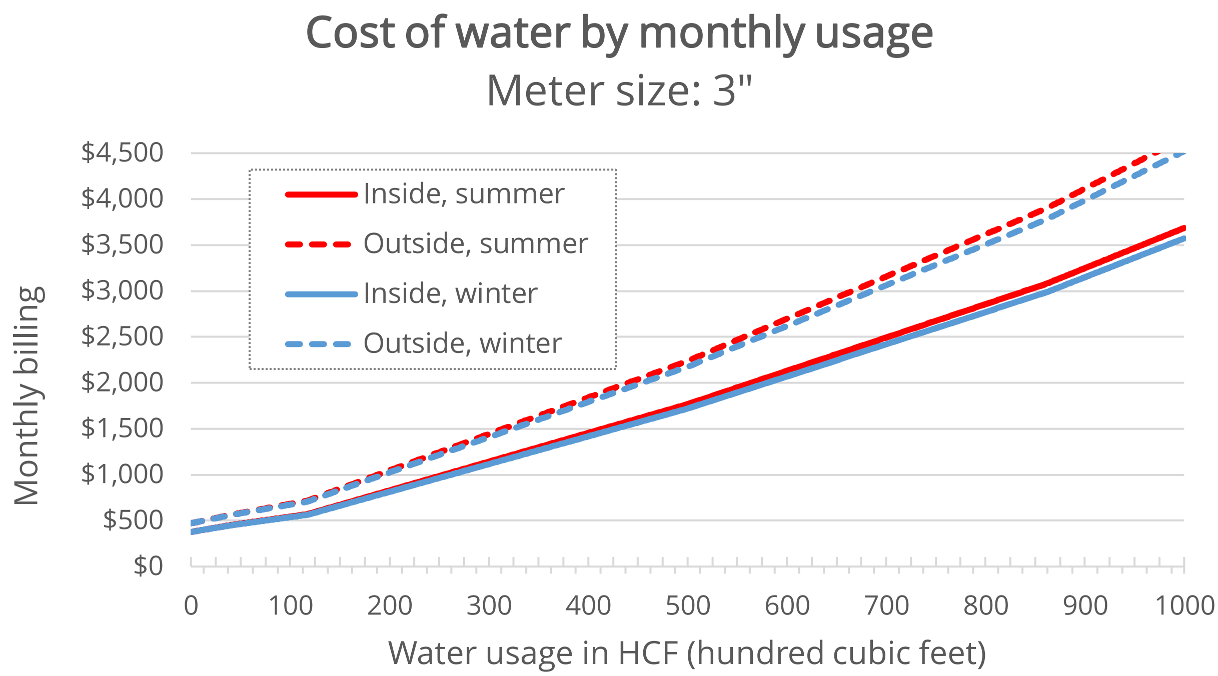


Figure 15. Monthly cost of water for large SFR households. Meter size: 3"

By multiplying the marginal costs with the annual greywater output, we can then estimate the annual cost savings across household sizes, block rates, and laundry machine efficiencies. The results for customers inside and outside of Pasadena are presented in the tables below.

Table 1. Estimated annual cost savings from L2L for customers inside city limits.

INSIDE PASADENA		Number of occupants				
Gallons per load	**Block**	**1**	**2**	**3**	**4**	**5**
15 gallons	**1**	$3.80	$7.61	$11.41	$15.21	$19.02
	2	$7.08	$14.16	$21.23	$28.31	$35.39
	3	$8.11	$16.21	$24.32	$32.43	$40.53
	4	$9.65	$19.30	$28.95	$38.60	$48.25
30 gallons	**1**	$7.61	$15.21	$22.82	$30.43	$38.04
	2	$14.16	$28.31	$42.47	$56.62	$70.78
	3	$16.21	$32.43	$48.64	$64.85	$81.07
	4	$19.30	$38.60	$57.90	$77.20	$96.50
45 gallons	**1**	$11.41	$22.82	$34.23	$45.64	$57.05
	2	$21.23	$42.47	$63.70	$84.93	$106.17
	3	$24.32	$48.64	$72.96	$97.28	$121.60
	4	$28.95	$57.90	$86.85	$115.80	$144.75

Table 2. Estimated annual cost savings from L2L for customers inside city limits.

OUTSIDE PASADENA		Number of occupants				
Gallons per load	**Block**	**1**	**2**	**3**	**4**	**5**
15 gallons	1	$4.71	$9.43	$14.14	$18.86	$23.57
	2	$8.81	$17.61	$26.42	$35.23	$44.03
	3	$10.09	$20.19	$30.28	$40.37	$50.46
	4	$12.02	$24.04	$36.07	$48.09	$60.11
30 gallons	1	$9.43	$18.86	$28.28	$37.71	$47.14
	2	$17.61	$35.23	$52.84	$70.45	$88.07
	3	$20.19	$40.37	$60.56	$80.74	$100.93
	4	$24.04	$48.09	$72.13	$96.18	$120.22
45 gallons	1	$14.14	$28.28	$42.43	$56.57	$70.71
	2	$26.42	$52.84	$79.26	$105.68	$132.10
	3	$30.28	$60.56	$90.84	$121.12	$151.39
	4	$36.07	$72.13	$108.20	$144.27	$180.34

L2L Systems Cost

From PWP's Laundry-to-Landscape Program, we learned that the equipment is rather inexpensive, retailing at approximately $120, with little to no maintenance associated. The cost of installing the system, however, greatly depends on the plumbing requirements involved. The installation costs sampled from the L2L program ranged from $800 to $1,200.

Financial Viability

For our IRR analysis, we consider two cases. One where the customer buys and installs the system at total upfront cost of $120. In the second case the customer furthermore pays for installation and the total cost is $1,000. For the NPV analysis, we determine the maximum upfront cost to the customer at discount rate levels of 0%, 5%, and 10%.

IRR

As explained in the Capital Budgeting chapter, the internal rate of return, IRR, of an investment measures the annualized return of an investment and gives us a reliable indication of its financial viability.

Calculating the IRR for the L2L system requires a simple numerical analysis of the prospective cost savings and the initial equipment and installation costs. Since the cost savings differ between households due to different household sizes, laundry machine efficiency, and applicable block rates, we calculate the full distribution of IRRs across all user groups.

Tables 3 and 4 show these distributions for customers inside and outside Pasadena where there is no need for installation, i.e. the tables show the viability of the systems themselves. The distributions reveal how the viability of the L2L system decreases with the efficiency of the laundry machine, and increases with household size and block rate as expected.

Table 3. Viability of L2L systems excluding installation costs. Inside city limits.

Internal Rate of Return (IRR) for L2L systems excluding installation costs, by number of occupants, laundry machine efficiency, and block rate.

INSIDE PASADENA

		Number of occupants				
Gallons per load	**Block**	**1**	**2**	**3**	**4**	**5**
15 gallons	1	n.a.	n.a.	n.a.	4.57%	9.39%
	2	n.a.	3.12%	11.99%	19.68%	26.73%
	3	n.a.	5.88%	15.45%	23.84%	31.61%
	4	n.a.	9.73%	20.34%	29.80%	38.68%
30 gallons	1	n.a.	4.56%	13.79%	21.84%	29.26%
	2	3.12%	19.68%	33.41%	46.12%	58.39%
	3	5.88%	23.84%	39.03%	53.29%	67.16%
	4	9.73%	29.80%	47.24%	63.87%	80.20%
45 gallons	1	n.a.	13.79%	25.61%	36.32%	46.50%
	2	11.99%	33.41%	52.29%	70.43%	88.31%
	3	15.45%	39.03%	60.26%	80.85%	101.24%
	4	20.34%	47.24%	72.06%	96.39%	120.58%

Table 4. Viability of L2L systems excluding installation costs. Outside city limits.

Internal Rate of Return (IRR) for L2L systems excluding installation costs, by number of occupants, laundry machine efficiency, and block rate.

OUTSIDE PASADENA		Number of occupants				
Gallons per load	**Block**	**1**	**2**	**3**	**4**	**5**
15 gallons	1	n.a.	n.a.	3.10%	9.19%	14.63%
	2	n.a.	7.66%	17.70%	26.57%	34.85%
	3	n.a.	10.78%	21.69%	31.46%	40.67%
	4	0.03%	15.15%	27.38%	38.54%	49.18%
30 gallons	1	n.a.	9.19%	19.65%	28.96%	37.68%
	2	7.66%	26.57%	42.78%	58.11%	73.08%
	3	10.78%	31.46%	49.56%	66.89%	83.92%
	4	15.15%	38.54%	59.55%	79.92%	100.09%
45 gallons	1	3.10%	19.65%	33.37%	46.07%	58.33%
	2	17.70%	42.78%	65.62%	87.91%	110.02%
	3	21.69%	49.56%	75.42%	100.84%	126.13%
	4	27.38%	59.55%	90.02%	120.18%	150.26%

If we look at a medium sized household of three occupants inside Pasadena city limits, we can read off the IRRs in the middle data column of Table 3. If we look at the extreme case where the household has a high efficiency laundry machine and only consumes their Block 1 water allocation, the L2L system is not viable; the annual cost savings of $11.41 (Table 1) for ten years cannot justify the equipment cost of $120. In Table 3 and 4, cases where the system is not viable (even when we ignore the time-value of money) are indicated “n.a.”

If we look at the other extreme where the medium sized household has a very inefficient laundry machine, and consumes so much water that their marginal cost is the Block 4 rate, the L2L system delivers an annual $86.85 (Table 1) cost saving for ten years. With an initial investment of $120, the IRR is thus 90.02% as reported in Table 3.

If we look at the case where the initial investment is $1,000, however, only very few extreme cases can provide a positive IRR to the customer. For customers inside Pasadena, households with five occupants and an inefficient laundry machine, would realize IRRs of 1%, 4%, and 7% in Block 2, 3, and 4 respectively. Households with four occupants could realize a 3% IRR for Block 4 allocated water, but the system would not be viable otherwise.

If we look at customers outside of Pasadena, the range of viability broadens a little bit because the rates are generally higher, and thus the annual cost savings are greater. However, the IRRs are all relatively low; the most extreme case shows an IRR of 12.46%.

(Adjusted) NPV Profile

We can illustrate thee viability of L2L systems for individual groupings of households for varying investment levels.

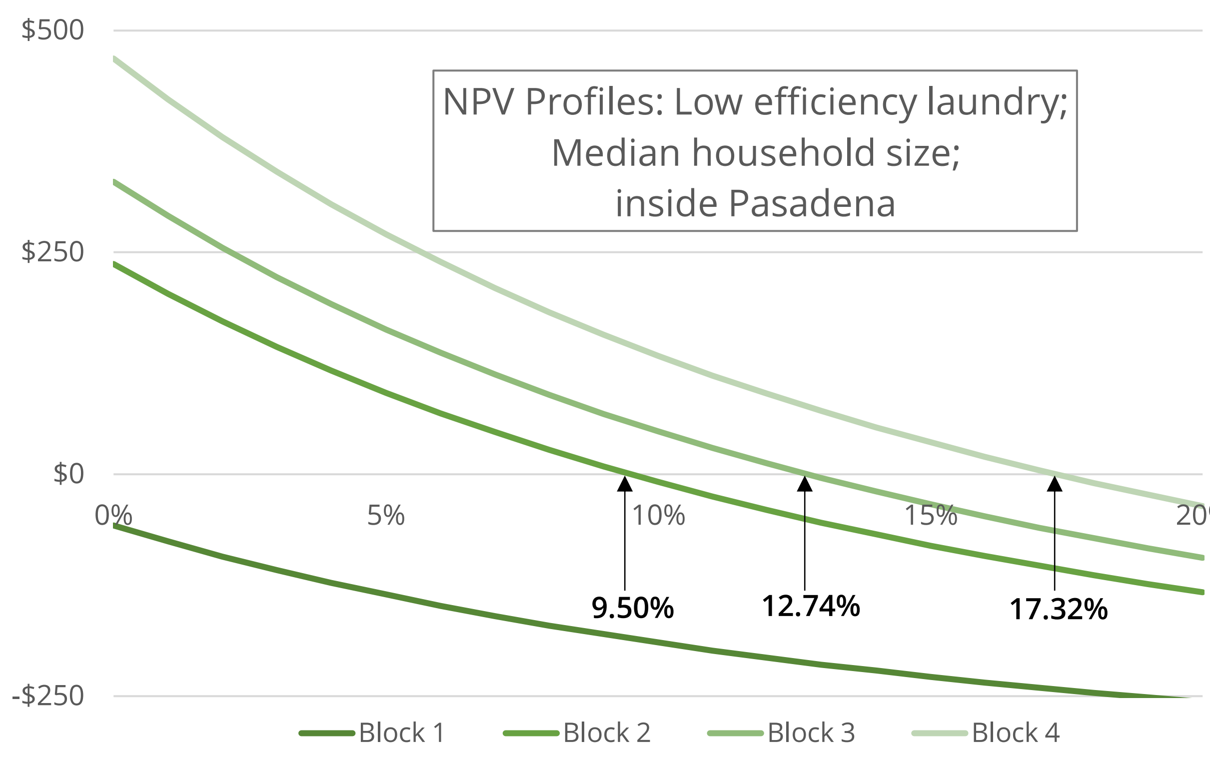


Figure 16. NPV profiles for households of three occupants within Pasadena city limits who have a low efficiency laundry machine.

Figure 16 shows an example of the NPV profiles for a median sized household with a low efficiency laundry machine. The initial investment is assumed to be $400, which can be interpreted as the original equipment and installation cost after a subsidy.

We can see that if the household's Block 1 allocation suffice, then the L2L system will not be viable. For Blocks 2-4 customers, the L2L system becomes more and more valuable.

The IRR for Block 2 through 4 customers are 9.50%, 12.74%, and 17.32% respectively. This is consistent with our observation in the Capital Budgeting chapter the IRR investment IRR and NPV investment criteria are consistent.

Any sample of NPV profiles will follow the same basic pattern. In order to get a better idea about the value of L2L systems for customers, we can furthermore calculate the present values of future cost savings at various discounting rate levels. The tables below illustrate the full distributions of present values for all customers.

Red indicates that the present value is lower than the equipment cost ($120), which means that the system will have a negative net present value. Yellow indicates present values between $120 and $500; green indicates present values above $500.

r=0%	Inside Pasadena					
Gallons	Block	1	2	3	4	5
15	1	$38.04	$76.07	$114.11	$152.14	$190.18
	2	$70.78	$141.55	$212.33	$283.11	$353.89
	3	$81.07	$162.14	$243.20	$324.27	$405.34
	4	$96.50	$193.01	$289.51	$386.01	$482.52
30	1	$76.07	$152.14	$228.21	$304.28	$380.35
	2	$141.55	$283.11	$424.66	$566.22	$707.77
	3	$162.14	$324.27	$486.41	$648.54	$810.68
	4	$193.01	$386.01	$579.02	$772.02	$965.03
45	1	$114.11	$228.21	$342.32	$456.42	$570.53
	2	$212.33	$424.66	$636.99	$849.33	$1,061.66
	3	$243.20	$486.41	$729.61	$972.81	$1,216.01
	4	$289.51	$579.02	$868.53	$1,158.04	$1,447.55

r=0%	Outside Pasadena					
Gallons	Block	1	2	3	4	5
15	1	$47.14	$94.28	$141.42	$188.56	$235.70
	2	$88.07	$176.13	$264.20	$352.27	$440.33
	3	$100.93	$201.86	$302.79	$403.72	$504.65
	4	$120.22	$240.45	$360.67	$480.90	$601.12
30	1	$94.28	$188.56	$282.84	$377.12	$471.39
	2	$176.13	$352.27	$528.40	$704.53	$880.67
	3	$201.86	$403.72	$605.58	$807.44	$1,009.30
	4	$240.45	$480.90	$721.35	$961.79	$1,202.24
45	1	$141.42	$282.84	$424.25	$565.67	$707.09
	2	$264.20	$528.40	$792.60	$1,056.80	$1,321.00
	3	$302.79	$605.58	$908.37	$1,211.16	$1,513.95
	4	$360.67	$721.35	$1,082.02	$1,442.69	$1,803.36

r=5%	Inside Pasadena					
Gallons	Block	1	2	3	4	5
15	1	$29.37	$58.74	$88.11	$117.48	$146.85
	2	$54.65	$109.30	$163.96	$218.61	$273.26
	3	$62.60	$125.20	$187.79	$250.39	$312.99
	4	$74.52	$149.03	$223.55	$298.07	$372.59
30	1	$58.74	$117.48	$176.22	$234.96	$293.70
	2	$109.30	$218.61	$327.91	$437.22	$546.52
	3	$125.20	$250.39	$375.59	$500.79	$625.98
	4	$149.03	$298.07	$447.10	$596.14	$745.17
45	1	$88.11	$176.22	$264.33	$352.44	$440.55
	2	$163.96	$327.91	$491.87	$655.83	$819.78
	3	$187.79	$375.59	$563.38	$751.18	$938.97
	4	$223.55	$447.10	$670.65	$894.21	$1,117.76

r=5%	Outside Pasadena					
Gallons	Block	1	2	3	4	5
15	1	$36.40	$72.80	$109.20	$145.60	$182.00
	2	$68.00	$136.01	$204.01	$272.01	$340.01
	3	$77.94	$155.87	$233.81	$311.74	$389.68
	4	$92.83	$185.67	$278.50	$371.34	$464.17
30	1	$72.80	$145.60	$218.40	$291.20	$364.00
	2	$136.01	$272.01	$408.02	$544.02	$680.03
	3	$155.87	$311.74	$467.61	$623.48	$779.35
	4	$185.67	$371.34	$557.00	$742.67	$928.34
45	1	$109.20	$218.40	$327.60	$436.80	$546.00
	2	$204.01	$408.02	$612.03	$816.04	$1,020.04
	3	$233.81	$467.61	$701.42	$935.22	$1,169.03
	4	$278.50	$557.00	$835.51	$1,114.01	$1,392.51

r=10%	Inside Pasadena					
Gallons	Block	1	2	3	4	5
15	1	$23.37	$46.74	$70.11	$93.48	$116.85
	2	$43.49	$86.98	$130.47	$173.96	$217.45
	3	$49.81	$99.62	$149.44	$199.25	$249.06
	4	$59.30	$118.59	$177.89	$237.19	$296.48
30	1	$46.74	$93.48	$140.23	$186.97	$233.71
	2	$86.98	$173.96	$260.94	$347.92	$434.90
	3	$99.62	$199.25	$298.87	$398.50	$498.12
	4	$118.59	$237.19	$355.78	$474.38	$592.97
45	1	$70.11	$140.23	$210.34	$280.45	$350.56
	2	$130.47	$260.94	$391.41	$521.87	$652.34
	3	$149.44	$298.87	$448.31	$597.75	$747.19
	4	$177.89	$355.78	$533.67	$711.56	$889.45

r=10%	Outside Pasadena					
Gallons	Block	1	2	3	4	5
15	1	$28.97	$57.93	$86.90	$115.86	$144.83
	2	$54.11	$108.23	$162.34	$216.45	$270.57
	3	$62.02	$124.03	$186.05	$248.07	$310.09
	4	$73.87	$147.75	$221.62	$295.49	$369.36
30	1	$57.93	$115.86	$173.79	$231.72	$289.65
	2	$108.23	$216.45	$324.68	$432.91	$541.13
	3	$124.03	$248.07	$372.10	$496.14	$620.17
	4	$147.75	$295.49	$443.24	$590.98	$738.73
45	1	$86.90	$173.79	$260.69	$347.58	$434.48
	2	$162.34	$324.68	$487.02	$649.36	$811.70
	3	$186.05	$372.10	$558.15	$744.20	$930.26
	4	$221.62	$443.24	$664.85	$886.47	$1,108.09

Total Benefits

The present value tables above show how much individual households would be able to pay for the L2L system (incl. installation). Having learned the market rates for installation as well as the equipment costs, PWP can easily back out the necessary subsidy that water customers would need in order to consider the system. If this subsidy is lower than the benefit PWP receives from residential greywater reuse, the subsidy is viable.

For a long time, PWP has taken a progressive stand on water conservation. From sponsoring events and workshops to spearheading residential customer water savings programs such as, turf replacement, rain barrel rebates, toilet rebates, and of course the Laundry-to-Landscape Greywater Program. All of these initiatives contribute to PWP's ambition to save potable water and ensure long-term sustainability.

A final benefit that is shared with the entire service area (and adjacent service areas) is the positive impact greywater for landscaping can have on groundwater recharge. In our analysis we have assumed that greywater will replace otherwise "new" potable water. In many cases, however, irrigation needs are not met entirely simply due to aggressive conservation measures during drought periods. L2L systems provide a steady supply of greywater throughout the year, which means that the water percolates in a steady return stream to the groundwater basin.

The value of this incremental return stream is shared with everyone who benefits from the groundwater basin.

Financing Models

In this chapter, we analyze the scope of leasing agreements for greywater systems. Based on a discounted cash flow model we find a lower bound on periodical water savings which secures viability of leased greywater systems. We identify regions in a (Saving, Payment) that comprehensively identifies for which savings- and payment levels a greywater system will be either leased, bought, or neither leased nor bought.

Later chapters will deal with conflicts of interests between financiers, but as an intermediate result, we find that unless leasing is offered exclusively to low tier savings levels, leasing will compete with debt traditional financing in the market for relatively lucrative greywater systems. This needs to be taken into account in water utilities' strategies in relation to leased greywater systems.

Debt financing

There are several options for debt financing available to residential customers who are looking to invest in greywater systems.

The most common options are home improvement loans (e.g. from banks and credit unions), lines of credit, HELOC (Home equity lines of credit), and government sponsored loans under the PACE (property assessed clean energy financing).

When financing greywater systems with debt, the viability of the investment is assessed by

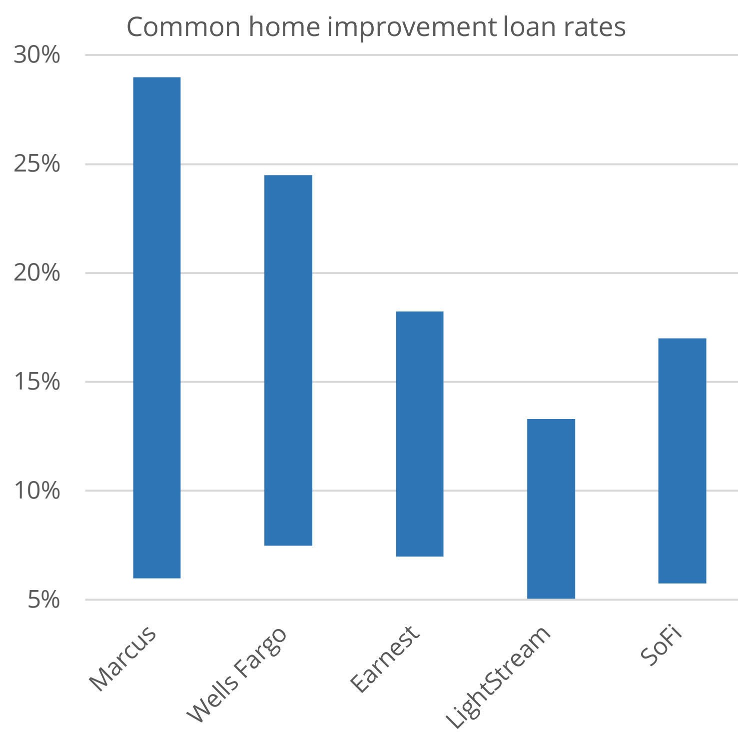


Figure 17. Interest rate range from popular financers (US). Source: NerdWallet analysis: nerdwallet.com/blog/loans/personal-loans-for-home-improvement/

calculating the present value of the system using the cost of debt as the discounting rate; we elaborated on this point in the Capital Budgeting chapter earlier.

The relatively high cost of debt for home improvements (See figure above) makes debt financed greywater investments problematic. The benefits of greywater systems typically materialize over a long time horizon; e.g., the L2L system considered previously has a 10-year economic life. The time-value of money in these cases, prevent seemingly viable investments. The value of a long-term investment in general is very sensitive to the applicable discounting rate.

Leasing

A lease establishes a legal agreement between a *lessor* who owns the leased asset, and a *lessee* who is granted the right to use said asset. In return for the right to use the asset, the lessee must make periodical payments to the lessor. In our case, the asset in question is a greywater system and the lessee is any one of PWP's customers.

Operating leases

Traditionally, many manufacturers offered asset maintenance as a part of the leasing agreement. Today, this type of lease is called an *operating lease*, and has a couple of interesting characteristics:

- Operating leases are typically not amortized, i.e. the aggregated lease payments do not recover the initial asset cost.
- Lessor maintains and insures the asset throughout the lease period.
- An operating lease typically has a cancellation option, which gives the lessee the right to switch outdated equipment before the lease term.

Financial leases

In contrast—and much more common today—*financial leases* have the opposite characteristics:

- They are fully amortized
- They offer no maintenance,
- They generally cannot be cancelled prematurely, but
- They do however, often come with the option to renew upon expiration.

The leases we focus on in this report are financial leases; greywater systems require relatively little maintenance and it is most likely not viable for any manufacturer to offer contracts where the customer has the option to cancel a lease before expiration.

Much of the leasing literature has focused on the financial viability from the point of view of the lessor. An immediate finding is that no leasing would be possible if lessor and lessee are simply swapping cash flow streams and are discounting at the same rates. In these cases the leasing mechanism is simply a zero-sum game between lessor and lessee that, at best, would make the lessee indifferent between leasing and buying.

Two core findings in this context are that leasing agreements provide value because lessors can exploit the tax deductibility of asset costs more efficiently than lessees can, and because lessors' discounting rates (stemming from their cost of capital) generally are much lower than the average lessee's discounting rates. For these reasons, lessors see an NPV premium relative to regular customers and are thus able the engage as financial intermediaries between greywater system manufacturers and end-users.

Leveraged Leases

A *Leveraged Lease* is a three-sided financial lease between lessor, lessee, and a *lender*. This type of agreement is typically governed by a nonrecourse loan (to the lessor), where the lessor is not obligated to the lender in case of default, but the lender has first lien on the asset, and in the event of a default, lease payments are transferred directly to the lender.

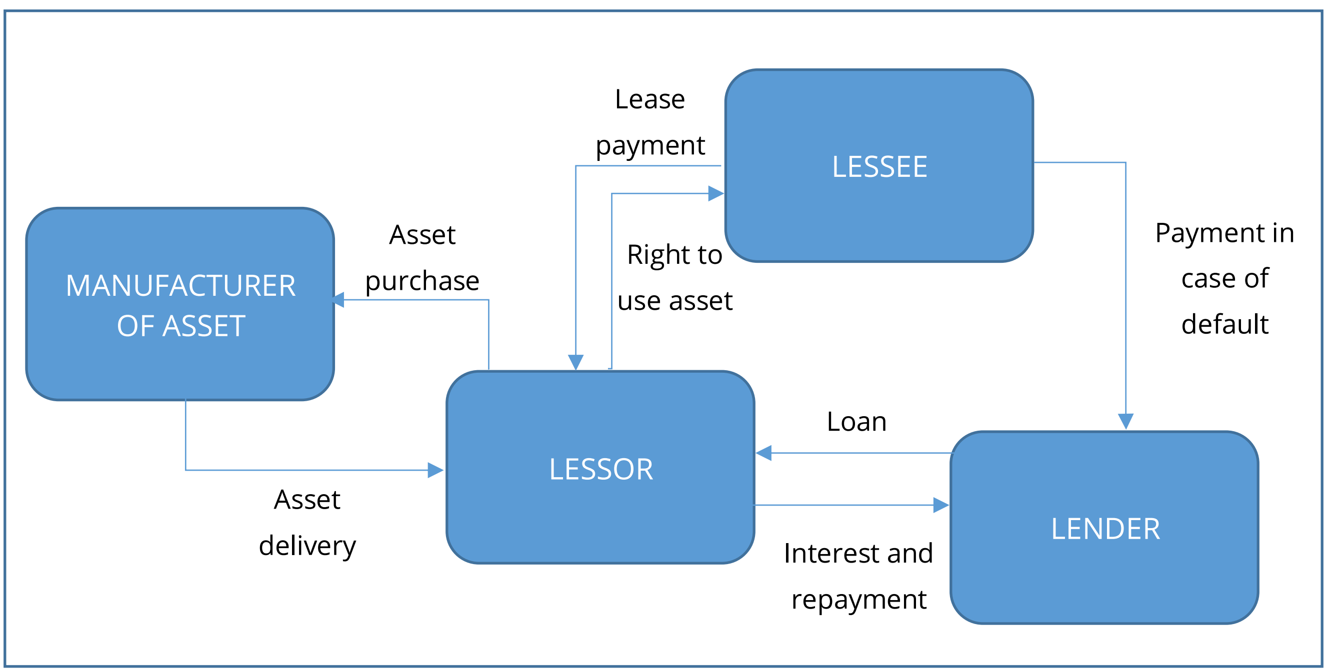


Figure 18. Leveraged lease structure with nonrecourse debt.

Lessee Viability

As we carefully went through the cost saving estimation techniques in the Laundry-to-Landscape Chapter, we will here assume that this estimation has been completed for any particular greywater system that we wish to consider. We will furthermore assume that the greywater system in question has a stated economic life (in most cases supported by a manufacturer's warranty).

Since water rates are set at a fixed level for long periods (i.e. they do not fluctuate rapidly as a market price would do), we will therefore assume that the applicable cost savings are somewhat steady, and model these as regular annuity cash flow streams. As explained in the Capital Budgeting chapter, this will not restrict us from using the same setup and analyze cost savings as growing annuities instead—it simply eases notation.

A greywater lease will be viable for the lessee if the present value of incremental cash flows from the greywater system and the lease outweighs any upfront cost (we denote any upfront cost to the lessee as "Installation" costs). The incremental cash flows from a grey water system (without significant lessee maintenance costs) are the cost savings from reduced potable water demand less the periodical lease payments.

The leased greywater system is thus viable whenever:

$$\mathrm{NPV_{Lease}} = \mathrm{PV(cost\ savings)} - \mathrm{PV(lease\ payments)} - \mathrm{Installation} > 0$$

Since the cost savings and lease payments materialize throughout the economic life of the greywater system, and since both of these are annuities, we can simplify this expression to:

$$\mathrm{NPV_{Lease}} = \mathrm{PVIFA(r,T)} \times (\mathrm{periodical\ cost\ saving} - \mathrm{periodical\ lease\ payment}) - \mathrm{Installation} > 0$$

This, in turn means that as long as the periodical lease payment is lower than the periodical cost saving, the greywater lease will be viable whenever:

$$\mathrm{PVIFA(r,T)} > \frac{\mathrm{Installation}}{\mathrm{periodical\ cost\ saving} - \mathrm{periodical\ lease\ payment}}$$

Clearly, if the lessor absorbs the installation costs, the greywater lease will be viable for the lessee whenever the cost savings are higher than the new lease payments.

When there are installation cost for the lessee, the viability depends on how well the net gain from the difference between periodical cost savings and lease payments offset these installation costs. Figure 19 illustrates how the range of periodical payments that are acceptable to the lessee depends on the installation costs. The intersections between the green and the red curve is maximum periodical payment that the lessee can accept ($203 in this case) if the installation costs are $750. If the lease payment is higher, the present value of cost savings net of lease payments cannot offset the initial upfront cost of $750.

The exact maximum periodical payments can be found by numerical analysis, case by case. For installation costs of $250 and $500, the maximum lease payments are $268 and $235 respectively.

Lessor Viability

As mentioned above, when we analyze the financial viability from the lessor's point of view, we must take into account the greywater system comes with a tax advantage in the sense that the purchase price of the system can be written off during its economic life. Furthermore, the lessor's discounting rate is usually lower than the average lessee.

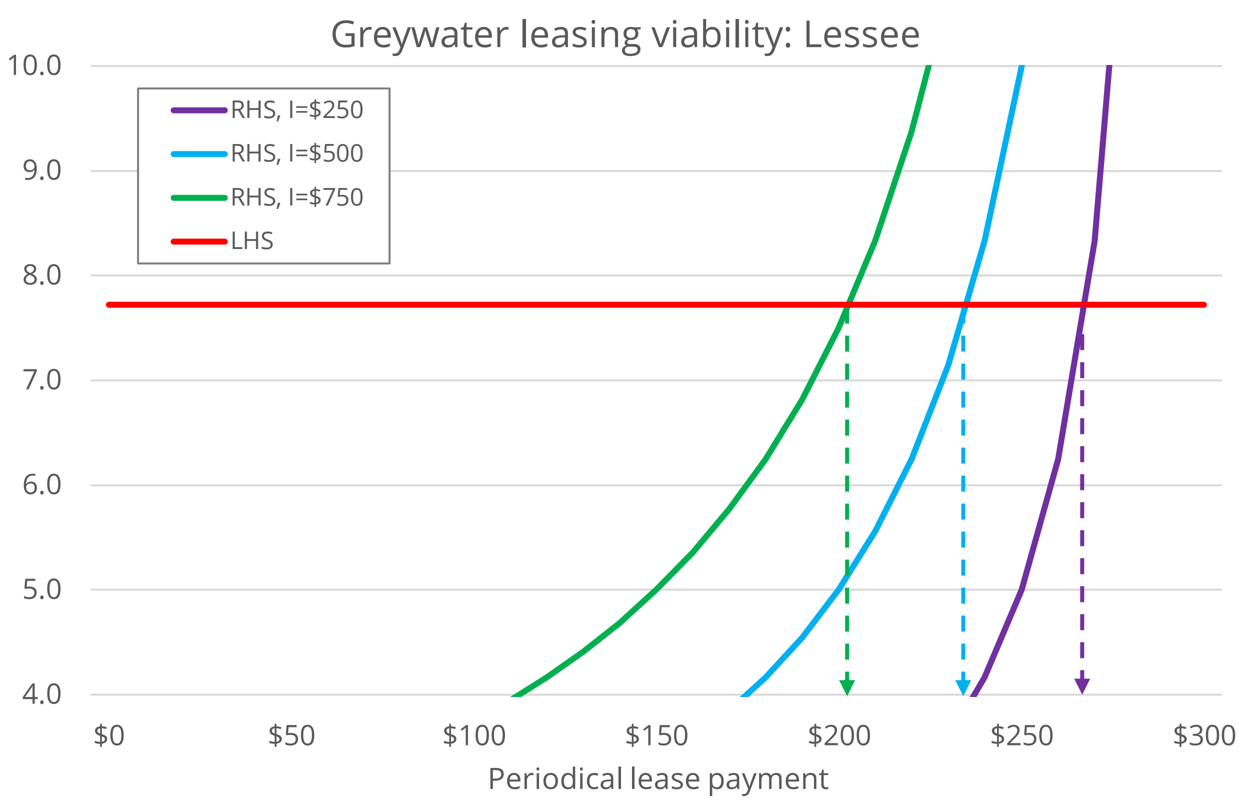


Figure 19. Greywater leasing viability for a GWS that provides $300 of cost savings per year for ten years. The lessee discounts future cash flows at 5%. The green, blue, and purple curves represents the right-hand side of the lessee's decision mechanism for installation costs of $250, $500, and $750. The red curve represents the left-hand side of the lessee's decision mechanism.

The relevant incremental cash flow for the lessor's NPV are the after-tax periodical payments net of any depreciation of the system. To simplify, we denote:

- GWS: The purchase price of the greywater system
- T_C: The lessor's marginal tax rate
- T: The greywater systems economic life (this is also the term of the leasing agreement).
- $PVIFA_{Lessor}$: The Present Value Interest Factor for Annuities calculated with the lessor's discounting rate and *T*.
- Payment: The periodical leasing payment from lessee to lessor.

With these parameters we can write up the lessor's NPV as:

$$NPV_{Lessor} = PVIFA_{Lessor} \text{ x } ((1-T_C) \text{ x Payment + Depreciation x } T_C) - GWS$$

Assuming (as a benchmark) that the greywater system depreciates with a linear schedule, we get:

$$NPV_{Lessor} = PVIFA_{Lessor} \text{ x } ((1-T_C) \text{ x Payment + GWS/T x } T_C) - GWS$$

After rearranging this expression, we see that the lessor's NPV will be positive whenever:

$$\text{Payment} > \text{GWS} \times \left[\frac{1}{\text{PVIFA}_{\text{Lessor}}(1-\text{T}_\text{C})} - \frac{\text{T}_\text{C}}{\text{T}}\right] \equiv \mathbf{P_0}$$

Now, if we combine this result with the viability analysis from the point of view of the lessee, we can find the range of viable periodical payments:

$$\text{GWS} \times \left[\frac{1}{\text{PVIFA}_{\text{Lessor}}(1-\text{T}_\text{C})} - \frac{\text{T}_\text{C}}{\text{T}}\right] < \text{Payment} < \text{Savings} - \frac{\text{Installation}}{\text{PVIFA}_{\text{Lessee}}}$$

Finally, we can use this range to determine the minimum periodical cost saving needed for a viable leasing agreement to exist at all. Isolating the periodical savings in the inequality above gives us the result directly:

$$\mathbf{Savings} > \mathbf{GWS} \times \left[\frac{1}{\text{PVIFA}_{\text{Lessor}} \times (1-\text{T}_\text{C})} - \frac{\text{T}_\text{C}}{\text{T}}\right] + \mathbf{Installation} \times \left[\frac{1}{\text{PVIFA}_{\text{Lessee}}}\right] \equiv \mathbf{S_0}$$

Screening

The lower bound, S_0, on the periodical savings provides a screening mechanism with which we can easily determine the potential for leasing agreements. The higher the savings, the more likely it is that leasing can be offered.

The lower bound (the right-hand side in the inequality above) has the neat feature that the parameters “GWS” and “Installation” relate to the greywater systems characteristic. Meanwhile, the two square brackets relate to the leasing market place (i.e. the time-value of money among lessors and their tax brackets), and the customers in PWP’s service area (i.e. the customers time-value of money). This means that the values in the square brackets are independent of any specific greywater system and can thus be applied in a broad analysis of all potential greywater systems as long as these have the same economic life.

In later chapters, we will apply this screening mechanism to assess leasing viability for various greywater systems for SFR and MFR households as well as commercial customers.

Buy-versus-Lease decisions

As noted in the Capital Budgeting chapter, one of the core strengths of NPV analysis is NPV Rankings. Considering two mutually exclusive opportunities, we can be certain that the one with the higher NPV will be more lucrative for the decision maker.

In our case, if the decision is between buying a greywater system or leasing it, we must simply calculate the NPV of both and then determine which one is higher.

After some calculations, we find that leasing will be preferred to buying whenever:

$$\text{Payment} < \frac{\text{GWS}}{\text{PVIFA}_{\text{Lessee}}} \equiv \mathbf{P_1}$$

Note that this does not mean that leasing necessarily is viable. Only that, faced with the choice between leasing and buying, the customer would go with leasing. Further note, that the decision criteria is independent of installation costs. This is perfectly reasonable since the customer would incur these costs whether buying or leasing.

Finally, we can find the minimum savings level, S_1, where the greywater system is a viable option by simply manipulating the NPV calculation for the purchase decision. We get,

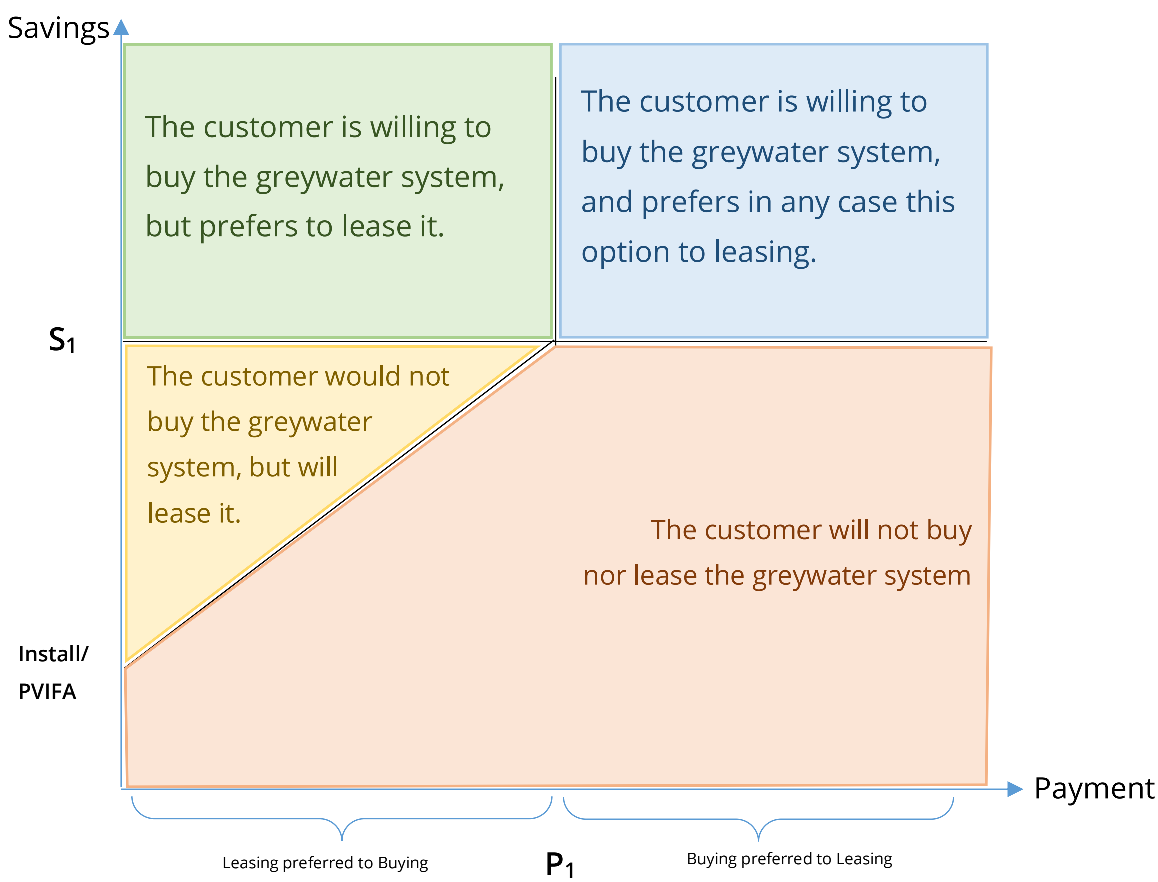
$$\frac{\text{GWS} + \text{Install}}{\text{PVIFA}_{\text{Lessee}}} \equiv \mathbf{S_1}$$

Scenario Analysis

Based on the analysis above, we can identify four different regions in a (Payment, Savings)-diagram (see figure below), that comprehensively shows the water customer's (the potential lessee) preferences.

In the largest red region, the cost savings are too low to offset the initial investment. At the same time, the proposed lease payments are too high to offset the installation costs.

In the blue region, the cost savings are high enough to offset both systems and installation costs. The proposed lease payment, however are too high to make leasing preferable. Note that in this region, leasing can be viable, but customers would always prefer to purchase the system themselves.

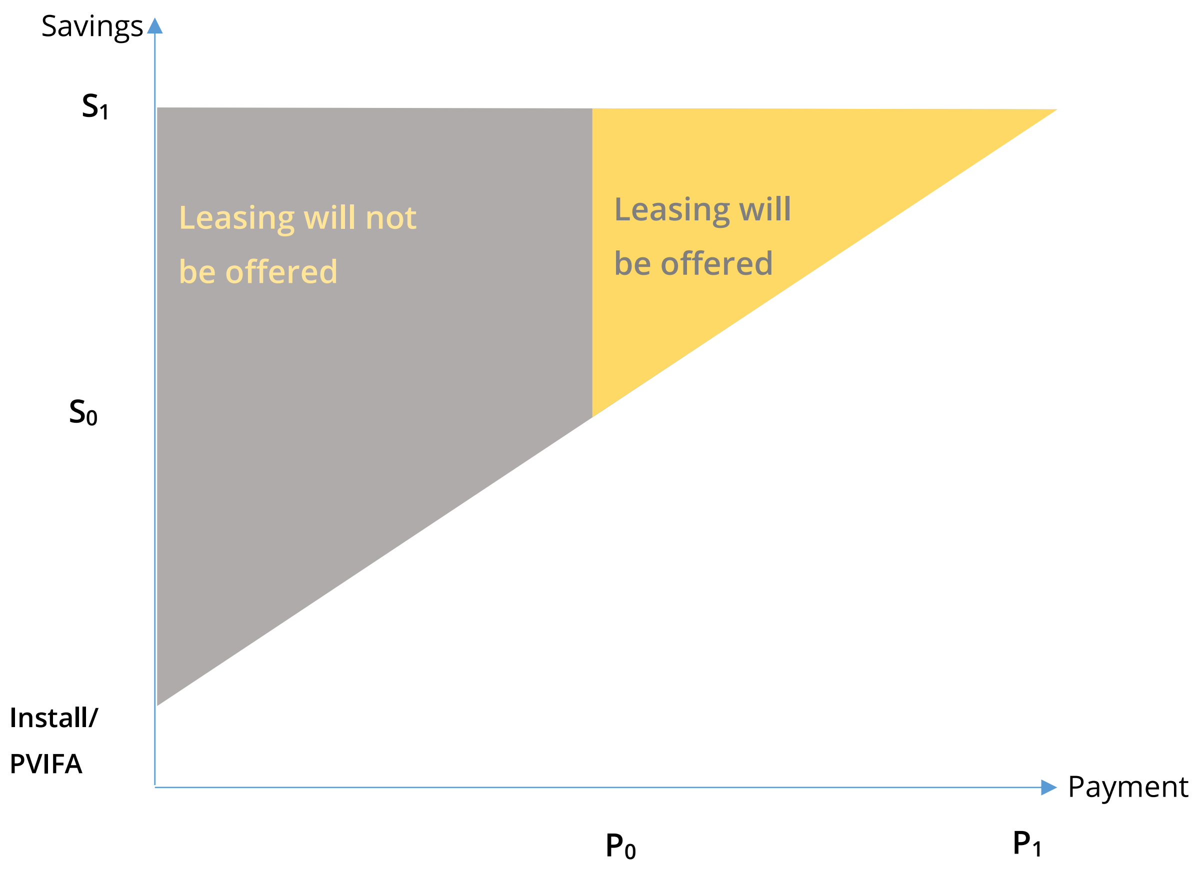


In the green region, the cost savings are still high enough to offset the purchase and installation costs, but the proposed leasing option's periodical payments are so low, that the customer prefers to lease rather than buy.

In the yellow region, the cost saving are too low to offset purchase and installation costs, but leasing is offered with such low periodical payments that this option is viable. This region is particularly interesting, and deserves a closer analysis.

Direct Leasing Impact

If we zoom in on the yellow region from the figure above and include the lower bound on savings that ensure that leasing will indeed be viable for both lessor and lessee, we get a region that looks something like this.



In the region of the (Payment, Savings) diagram, leasing agreements open up a market that cannot sustain itself without some kind of intermediation. The periodical savings cannot justify residential greywater investments, but because of the lessors' lower discounting rates and tax advantage, the systems can be offered via leasing agreements.

This region is of great importance for products that are on the margin of financial viability. We can get an idea of the determinants of the regions size by examining the savings range between the lower bound, S_0, and the upper bound, (GWS + Installation)/$PVIFA_{Lessee}$.

The difference between the two can be written as:

$$\frac{\mathbf{GWS}}{\mathbf{PVIFA_{Lessee}}} \times \left[1 - \frac{\mathbf{PVIFA_{Lessee}}}{\mathbf{PVIFA_{Lessor}}} \times \frac{1}{1 - T_C} + \frac{\mathbf{PVIFA_{Lessee}}}{\mathbf{T}} \times T_C\right]$$

Note that:

- $\frac{\mathbf{GWS}}{\mathbf{PVIFA_{Lessee}}}$ is the cut-off savings level without installation costs. We interpret this as the inverse viability of the greywater system. The higher this number is, the less appealing is the buy option to relative to the leasing option as noted above.
- $\frac{\mathbf{PVIFA_{Lessee}}}{\mathbf{PVIFA_{Lessor}}}$ is the relative time value of money between lessee and lessor. This number is an indicator of how important leasing options are for prospective lessees. It is an inverse indicator in the sense that the lower the number the more important is the leasing company. Naturally, the yellow region expands as this number decreases.
- $\frac{\mathbf{PVIFA_{Lessee}}}{\mathbf{T}}$ is the lessee's inverse time value of money as explained in the Capital Budgeting chapter. The higher this number is, the more patient is the lessee. The yellow region expands as the lessee becomes more patient because the present value of future cost savings easily outweigh the upfront installation costs.

Risk and Sensitivity

Summary

This chapter presents a sensitivity analysis of the leasing framework that we developed in the Financing Models chapter. A deep understanding of how the model responds to changes in the surrounding economic environment and the technological developments of greywater systems are crucial for the assessment of impact and performance of water savings policies and programs.

We find no abnormalities and the model is robust for all parameter changes. By this we mean that changes in discounting rates, marginal corporate tax levels, economic life (or planning horizon), greywater systems and installation costs result in monotonic responses in the model statistics.

We find that The Savings Threshold for Leasing, S_0, increases in discounting rates for both lessor and lessee. This reflects the fact that the net present value of the benefits of greywater leasing are reduced from the point of view of the lessee, and the net present value of future lease payments is reduced from the point of view of the lessor. The threshold will also increase with the marginal corporate tax rate, which reflect a reduced net gain from the point of view of the lessor. If the systems and/or installation costs increase, S_0 will increase as well. This reflect the fact that both the lessor and the lessee needs compensation for a larger upfront investment.

For the same reasons, the Savings Threshold for Purchase, S_1, increases in the lessee's discounting rate as well as the greywater system and/or installation costs. This threshold is furthermore unaffected by changes in the lessor's discounting rate and marginal corporate tax level.

The Minimum Lease Payment, P_0, increases in the lessor's discounting rate and marginal corporate tax level, as well as the greywater system cost (but not installation cost). This was expected insofar as the minimum lease payment is determined by the lessor's participation constraint, i.e. the lessor's valuation of future lease payments relative to the upfront investment in the greywater system.

The Payment Threshold for Purchase Preference, P_1, increases in the lessee's (or end-user's) discounting rate and in the greywater system cost (but not installation cost). This is also as we would expect, because the marginal upfront investment is exactly the cost of the greywater system, and as the discounting rate increases, the valuation of future net cost savings will decrease, which in turn makes the leasing option more attractive.

Next, we explore to what extent water agencies such as Pasadena Water & Power can benefit from either value-based or quantify-based reward-risk ratios in their risk management. We conclude that the contributions from such risk assessment tools are very limited relative to their applications. We therefore suggest that water agencies focus on the demand management applications of our model.

The chapter is concluded by a demand management application of the model. In a simple setting, we provide assessments of both benefits and costs of a water agency's policy to subsidize greywater installation costs in the presence of greywater leasing. This application links the distribution of (lessee) discounting rates from an entire service area to the achieved water savings from any policy to subsidize installation costs.

Recap

The *Financing Models* chapter revealed a couple of novel insights about prospective greywater leasing markets. In a setting where greywater systems require a fixed one-time initial investment and provide a fixed cost-saving for a known number of years, we can find the total leasing potential as a "right triangle" in a (savings, payment) diagram.

The size of the prospective greywater leasing market is determined by four statistics:

- **The Savings Threshold for Leasing, S_0**
  Whenever a greywater system provides periodical savings above this level, leasing will be viable and can be offered to the mutual benefits of both lessor and lessee.

  Formally, the threshold is given by:

$$\mathbf{S_0} = \mathbf{GWS} \times \left[\frac{1}{\mathrm{PVIFA_{Lessor}} \times (1 - \mathrm{T_C})} - \frac{\mathrm{T_C}}{\mathrm{T}}\right] + \mathbf{Install} \times \left[\frac{1}{\mathrm{PVIFA_{Lessee}}}\right]$$

- **The Savings Threshold for Purchase, S_1**
  Whenever a greywater system provides periodical savings above this level, it will be viable for the end-user to purchase the system. In a sense, for savings this high, there will be a market for the system even without leasing.

  Formally, the threshold is given by:

$$\mathbf{S_1} = \frac{\mathbf{GWS + Install}}{\mathrm{PVIFA_{Lessee}}}$$

- **The Minimum Lease Payment, P_0**
  When the periodical lease payments exceed this level, the leasing contract is viable from the lessor's point of view. The Lessee's willingness to make periodical lease payments will grow proportionally to the savings level.

  Formally, the threshold is given by:

$$\mathbf{P_0} = \mathbf{GWS} \times \left[\frac{1}{\mathrm{PVIFA_{Lessor}} \times (1 - \mathrm{T_C})} - \frac{\mathrm{T_C}}{\mathrm{T}}\right]$$

- **The Payment Threshold for Purchase Preference, P_1**
  This is the maximum possible periodical lease payment. If a greywater system provides savings at the Savings Threshold for Purchase, S_1, leasing will still be viable as long as the periodical payments are lower than P_1. If savings are higher than S_1, but the periodical lease payment is higher than P_1, the end-user will choose to purchase the system directly.

  Formally, the threshold is given by:

$$\mathbf{P_1} = \frac{\mathbf{GWS}}{\mathrm{PVIFA_{Lessee}}}$$

Example: Base case, Greywater Leasing Potential

Consider a greywater system with an economic life of 10 years (T=10); $5,000 in equipment costs (i.e. GWS=$5,000); and $1,500 in installation costs (i.e. Install=$1,500). Assume that the end-user's discounting rate is r_{Lessee}=15% and the prospective lessor's discounting rate is r_{Lessor}=3% while the relevant marginal corporate tax rate is T_C=30%.

Knowing the applicable discounting rate as well as the economic life of the greywater system, we can calculate the relevant Present Value Interest Factor for Annuities ("PVIFA") for both prospective lessee and lessor:

$$\mathbf{PVIFA_{Lessee}} = {}^{1-(1+15\%)^{-10}}/_{15\%} = \mathbf{5.02} \text{ and } \mathbf{PVIFA_{Lessor}} = {}^{1-(1+3\%)^{-10}}/_{3\%} = \mathbf{8.53}$$

Based on these calculations and the formulas above, we can find the four necessary statistics directly:

S_0	S_1	P_0	P_1
$986	$1,295	$687	$996

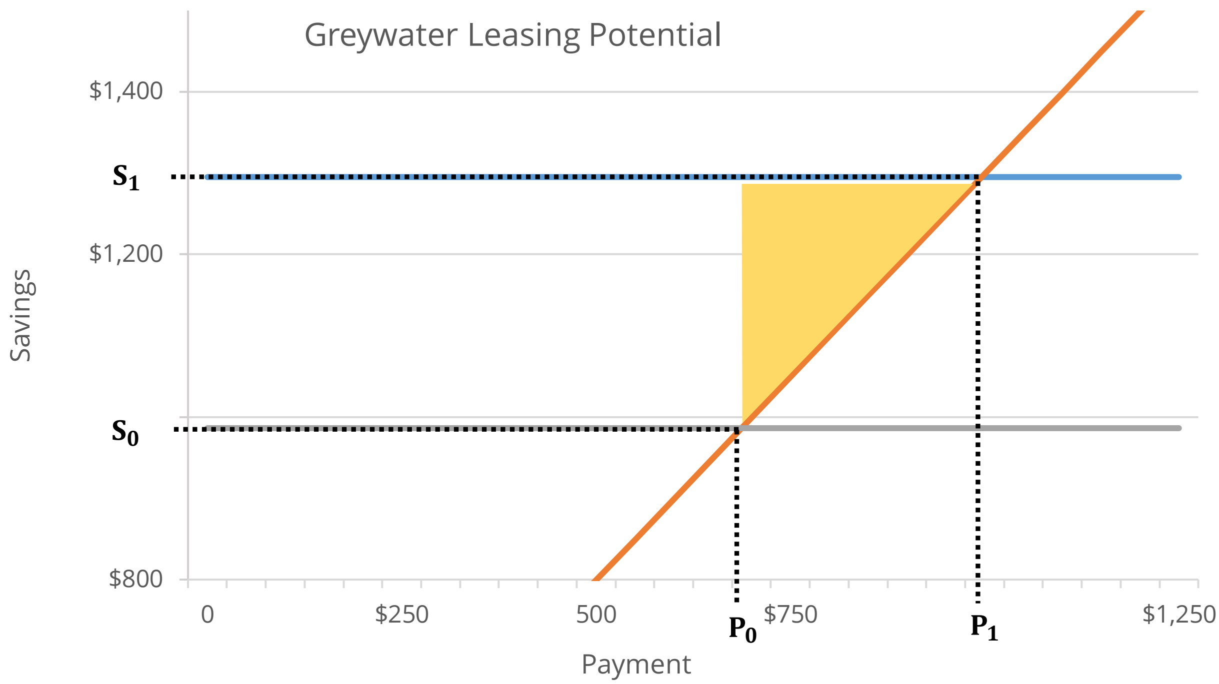
These statistics show that, if the greywater system provides annual cost savings below $986 (**$S_0$**), then the system is not viable neither for leasing nor for purchase. The reason for this is that the lessee still has to cover the installation costs of $1,500, and with savings below $986 (**$S_0$**), it is not possible for the lessor to offer a contract with annual lease payments that are low enough to compensate for this upfront cost.

If on the other hand, the annual cost savings are in between $986 ($S_0$) and $1,295 ($S_1$) then it is possible for a prospective lessor to offer the system at an annual payment between $687 ($P_0$) and $996 ($P_1$). The higher the annual savings, the higher the potential payment.

Furthermore, in the savings range $986 ($S_0$) to $1,295 ($S_1$), leasing is the only viable option for the end-user (i.e. the lessee). When periodical savings are higher than $1,295 ($S_1$), leasing will be preferred as long as the annual lease payment does not exceed $996 ($P_1$), in which case, the end-user would prefer to purchase the system themselves.

The figure here below illustrates the Greywater Leasing Potential (the yellow triangle) in a savings-payment diagram.

As this example illustrates, the greywater leasing potential is determined by the four statistics: S_0, S_1, P_0, and P_1. We will therefore provide a detailed sensitivity analysis, to understand how changes in the underlying parameters affect each of these.



After this analysis, we provide a discussion and preliminary reward-risk assessment from the point of view of Pasadena Water and Power. First, however, we need to understand when a greywater leasing market can exist.

Determinants for Greywater Leasing Potential

As explained in the *Financing Models* chapter, there are two predominant reasons why a greywater leasing markets could exist:

- Lessors have lower financing costs than their prospective clients do, which in turn lowers their discounting rates and thus their time-value of money.
- Lessors can write off the depreciated value of the greywater system throughout its economic life, which effectively allows them to "spread out" the initial investment.

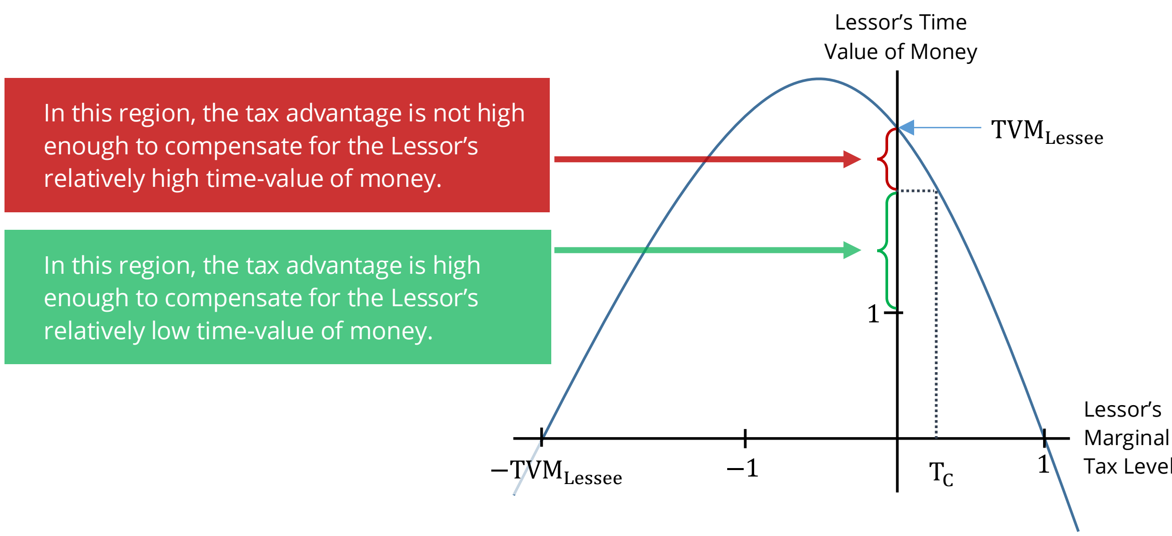
We can use the four statistics: S_0, S_1, P_0, and P_1 to quantify exactly how these two points interact with each other. A leasing market for greywater exists if S_0 is lower than S_1, and if P_0 is lower than P_1. If we measure the time-value of money for lessee and lessor by:

$\text{TVM}(\text{Lessee}) = \frac{\text{T}}{\text{PVIFA}_{\text{Lessee}}}$ and $\text{TVM}(\text{Lessor}) = \frac{\text{T}}{\text{PVIFA}_{\text{Lessor}}}$, it can be shown directly that the conditions: $S_0 < S_1$ and $P_0 < P_1$ are both equivalent to:

$$\text{TVM}(\text{Lessor}) < [\text{TVM}(\text{Lessee}) + \text{T}_\text{C}] \times [1 - \text{T}_\text{C}]$$

This states that not only does the lessor's time-value of money has to be lower than the lessee's; it has to be so by a margin that is growing in the marginal corporate tax rate.

This illustrates the dual relationship: The lessor needs to pay taxes on the periodical payments, but can on the other hand write of the initial purchase price of the greywater system throughout the leasing period. The figure here below illustrates how leasing markets exist only when the lessor's time-value of money is low relative to the lessee's time-value of money and the marginal tax rate.



Sensitivity Analysis

Our model has six underlying parameters:

- Lessee's (end-user) discounting rate, r_{Lessee}
- Lessor's discounting rate, r_{Lessor}
- Lessor tax rate, T_C
- Planning horizon, T
- Greywater system costs, GWS
- Installation costs, Install

We will evaluate the sensitivity of each parameter by first order differentiation of the four statistics: S_0, S_1, P_0, and P_1 with respect to each of these six parameters.

Lessee's (end-user) discounting rate, r_{Lessee}

The lessee's discounting rate is influenced by their time-value of money, risk aversion, financial exposure and access to capital. The higher the discounting rate, the more reluctant the end-user will be to take on investments such as a greywater system.

If we look at the first order derivatives, it becomes clear that if the lessee's discounting rate increases, all statistics increase except the lessor's participation constraint, P_0.

Formally,

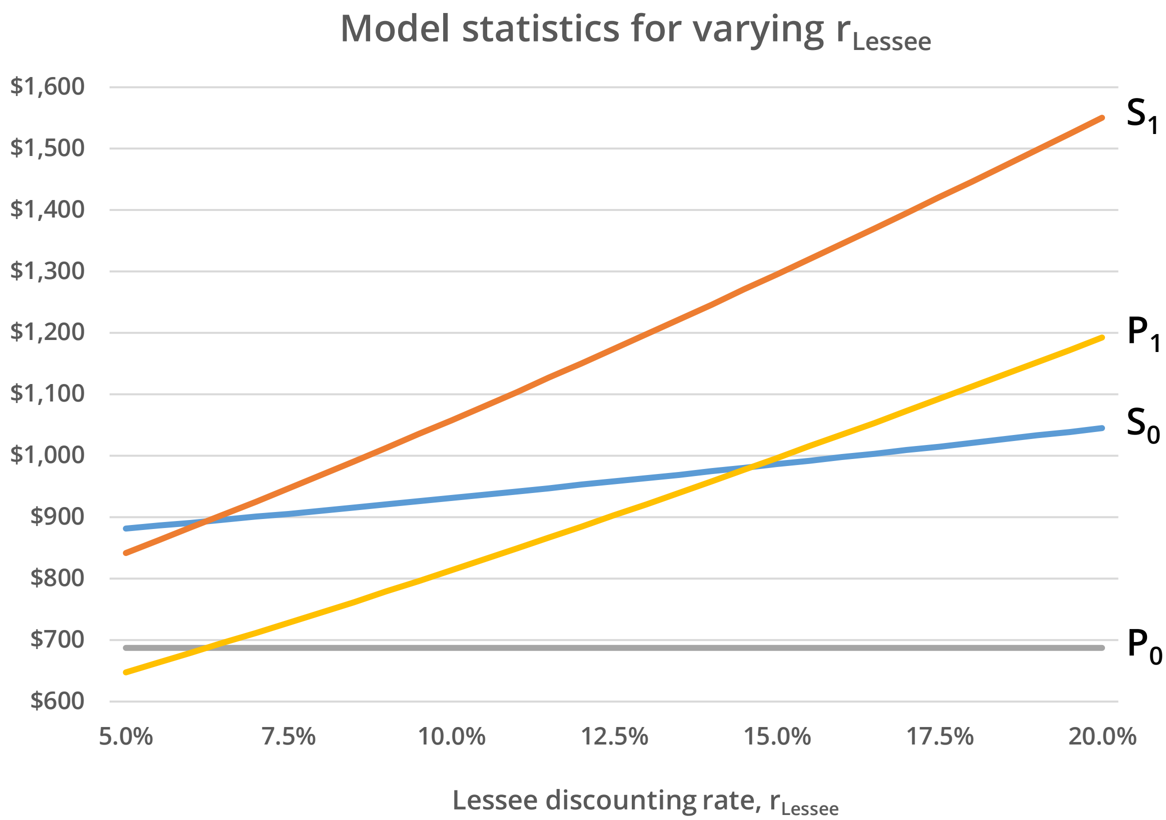
$$\frac{\partial S_0}{\partial r_{Lessee}} = \frac{\partial 1/PVIFA_{Lessee}}{\partial r_{Lessee}} \times Install > 0$$

$$\frac{\partial P_0}{\partial r_{Lessee}} = 0$$

$$\frac{\partial S_1}{\partial r_{Lessee}} = \frac{\partial P_1}{\partial r_{Lessee}} = \frac{\partial 1/PVIFA_{Lessee}}{\partial r_{Lessee}} \times GWS > 0$$

Graphically, this means that if the lessee's discounting rate increases, the yellow triangle in the savings-payment diagram indicating the greywater leasing potential moves upwards and expands to the right.

This illustrates two effects: S_0 increases because the future savings net of lease payments are discounted at a higher rate which means the lessee requires higher savings in order to trade off the initial installation costs; furthermore, S_1 and P_1 increase because future savings are also discounted at a higher rate which makes the purchase option less appealing.



The figure above shows how the model statistics: S_0, S_1, and P_1 all increase with the lessee's discounting rate, while P_0 is unaffected as explained previously. All other parameters are as in the base case example from the beginning of this chapter.

Lessor's discounting rate, r_{Lessor}

The lessor's discounting rate is influenced by their time-value of money, risk aversion, the risk associated with offering greywater leasing, but most importantly financial exposure and access to capital. The higher the discounting rate, the more reluctant the lessor will be to take on greywater system investments and offer leasing options.

If we look at the first order derivatives, it becomes clear that if the lessor's discounting rate increases, S_0 and P_0 both increase, while S_1 and P_1 are unaffected.

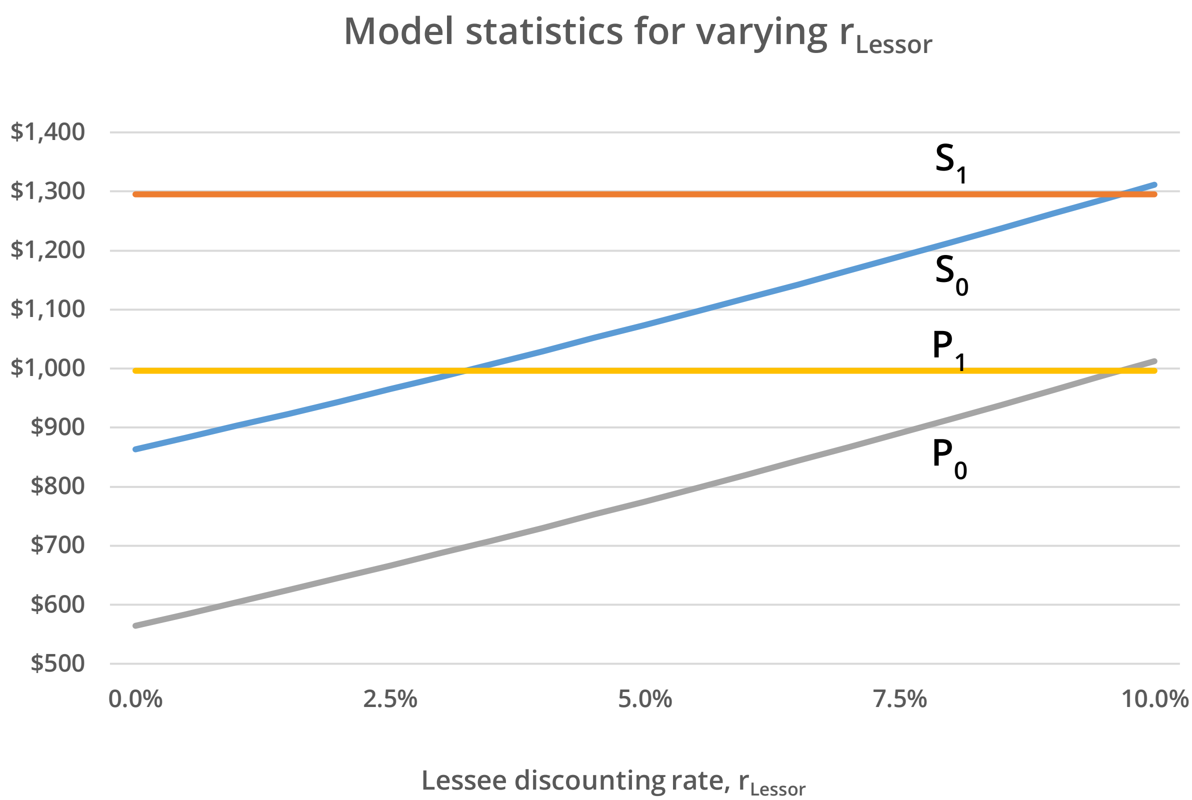
Formally,

$$\frac{\partial S_0}{\partial r_{Lessor}} = \frac{\partial P_0}{\partial r_{Lessor}} = \frac{\partial 1/PVIFA_{Lessor}}{\partial r_{Lessor}} \times \frac{GWS}{1 - T_C} > 0$$

$$\frac{\partial S_1}{\partial r_{Lessor}} = \frac{\partial P_1}{\partial r_{Lessor}} = 0$$

Graphically, this means that if the lessor's discounting rate increases, the yellow triangle in the savings-payment diagram indicating the greywater leasing potential shrinks such that the point (P_1, S_1) remains unchanged, while the point (P_0, S_0) moves towards (P_1, S_1).

This illustrates that the present value of future lease payments have become less valuable to the lessor, which means that their participation would require higher periodical payments and in order to secure the lessee's participation, in turn only offer leasing of greywater systems that provide higher periodical savings.



The figure above shows how the model statistics: S_0 and P_0 increase with the lessor's discounting rate, while S_1 and P_1 are unaffected as explained previously. All other parameters are as in the base case example from the beginning of this chapter.

Lessor tax rate, T_C

The tax rate has a similar effect as the lessor's discounting rate. The higher the tax rate the lower the net income potential from offering greywater leasing. The lessor will therefore be reluctant to take on greywater system investments and offer leasing options. On the other hand, the corporate tax rate has no impact on the lessee's decision to purchase the greywater system herself.

If we look at the first order derivatives, it becomes clear that if the tax rate increases, S_0 and P_0 both increase, while S_1 and P_1 are unaffected.

Formally,

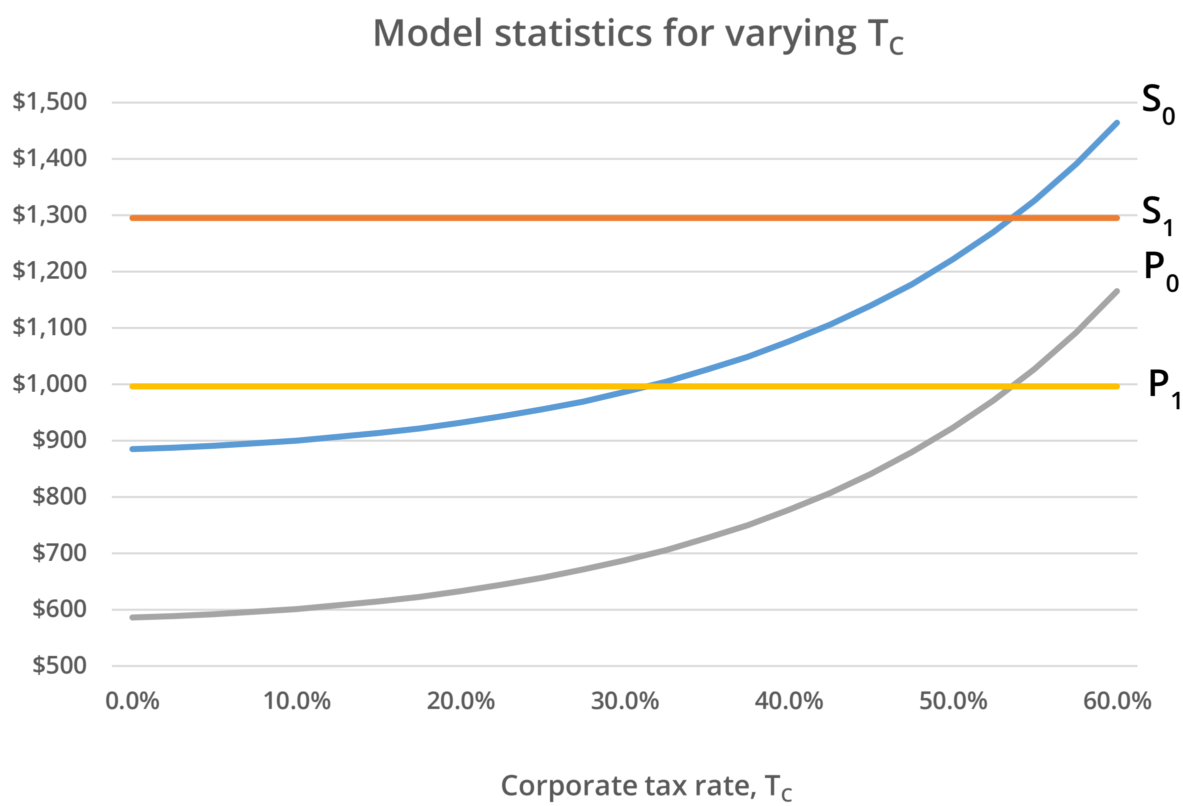
$$\frac{\partial S_0}{\partial T_C} = \frac{\partial P_0}{\partial T_C} = \mathrm{GWS} \times \left[\frac{1}{\mathrm{PVIFA}_{\mathrm{Lessor}}(1 - T_C)^2} - \frac{1}{T}\right] > 0$$

$$\frac{\partial S_1}{\partial T_C} = \frac{\partial P_1}{\partial T_C} = 0$$

Graphically, this means that if the lessor's marginal tax rate increases, the yellow triangle in the savings-payment diagram indicating the greywater leasing potential shrinks such that the point (P_1, S_1) remains unchanged, while the point (P_0, S_0) moves towards (P_1, S_1).

This illustrates that the lessor's net income decreases, which means that they have to charge higher periodical lease payments in order to trade off the initial purchase price of the greywater system. In turn, the lessee needs to realize higher periodical savings in order to accept the higher lease payments.

The figure below shows how the model statistics: S_0 and P_0 increase with the corporate tax rate, while S_1 and P_1 are unaffected as explained previously. All other parameters are as in the base case example from the beginning of this chapter.



Planning horizon, T

As the economic life of the greywater system increases, all model statistics decrease. Here it is important to keep in mind that the sensitivity analysis is partial in the sense that we are holding all other parameters constant while considering the impact of marginal changes for each parameter.

Everything else being equal, a longer economic life means that the system will provide the same level of savings (either net of lease payments or as direct savings for the purchased system) for more periods.

This makes the system more valuable, and in turn, the lessor can offer systems with lower periodical savings (and thus charge lower lease payments). Similarly, the end-user would be willing to invest in the system themselves at a lower savings level, and the payment level above which they prefer to purchase the system decreases as well.[24]

[24] $\frac{\partial S_0}{\partial T}$ and $\frac{\partial P_0}{\partial T}$ are evaluated numerically. The inequalities $\frac{\partial S_0}{\partial T} < 0$ and $\frac{\partial P_0}{\partial T} < 0$ apply within all the most relevant parameter sets.

Formally,

$$\frac{\partial S_0}{\partial T} = \text{GWS} \times \left[\frac{\partial 1/\text{PVIFA}_{\text{Lessor}}/\,\partial T}{1 - T_C} + \frac{T_C}{T^2}\right] + \text{Install} \times \frac{\partial 1/\text{PVIFA}_{\text{Lessee}}}{\partial T}$$

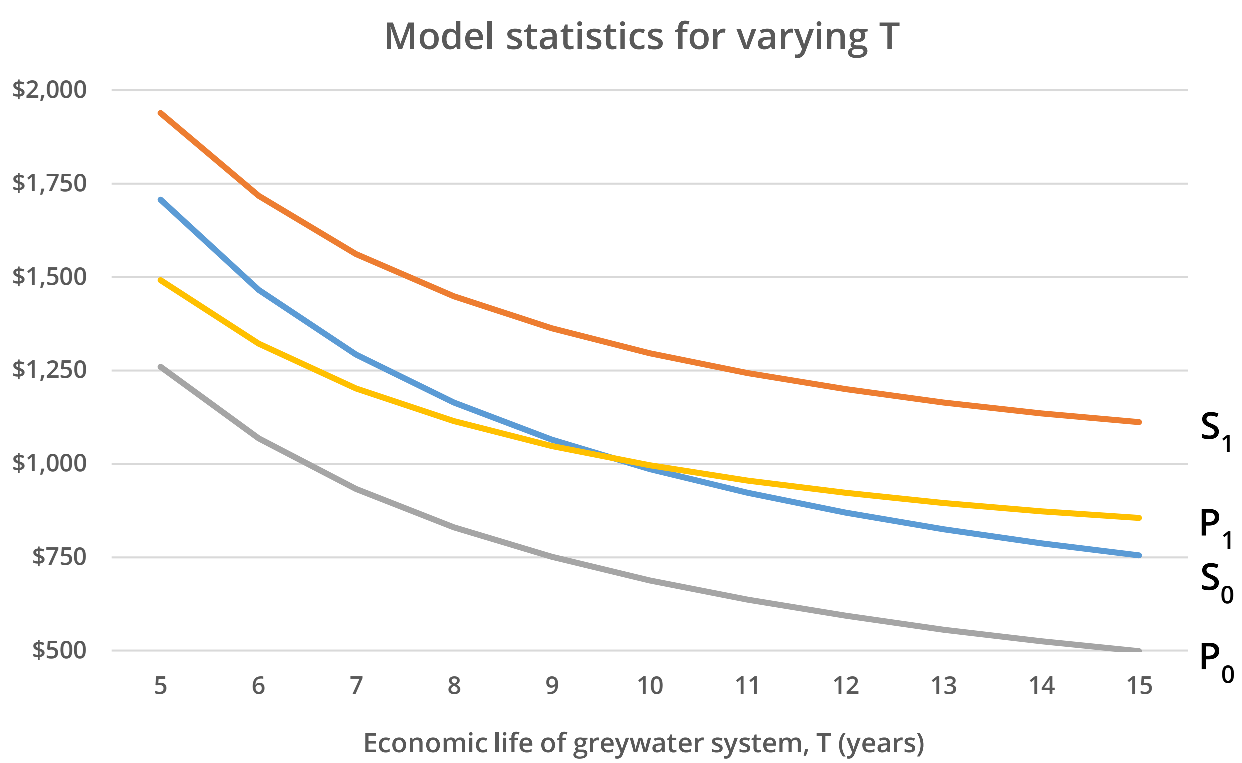
$$\frac{\partial S_1}{\partial T} = [\text{GWS} + \text{Install}] \times \frac{\partial 1/\text{PVIFA}_{\text{Lessee}}}{\partial T} < 0$$

$$\frac{\partial P_0}{\partial T} = \text{GWS} \times \left[\frac{\partial 1/\text{PVIFA}_{\text{Lessor}}/\,\partial T}{1 - T_C} + \frac{T_C}{T^2}\right]$$

$$\frac{\partial P_1}{\partial T} = \text{GWS} \times \frac{\partial 1/\text{PVIFA}_{\text{Lessee}}}{\partial T} < 0$$

Graphically, this means that if the economic life increases, the yellow triangle in the savings-payment diagram indicating the greywater leasing potential expands and moves upwards and to the right.

This illustrates that the lessor needs the system to provide higher periodical savings in order to justify the higher lease payment, while the lessee (or end-user) needs the system to provide higher direct savings before it will be an attractive investment.



The figure above shows how the model statistics: S_0, S_1, P_0, and P_1 decrease with the economic life of the greywater system as explained previously. All other parameters are as in the base case example from the beginning of this chapter.

Greywater system costs, GWS

If the greywater systems cost increase, the participation constraints from both parties move upwards. Higher system costs means that the lessor needs higher periodical payments and in turn, the must provide higher periodical savings in order to justify these higher payments.

Similarly, if the end-user were to invest in the system themselves, they would need higher periodical direct savings. This means that the payment level, where they prefer to purchase rather than lease the system increases as well.

If we look at the first order derivatives, it becomes clear that if the system cost, **GWS**, increases, all four statistics: S_0, S_1, P_0, and P_1 will increase.

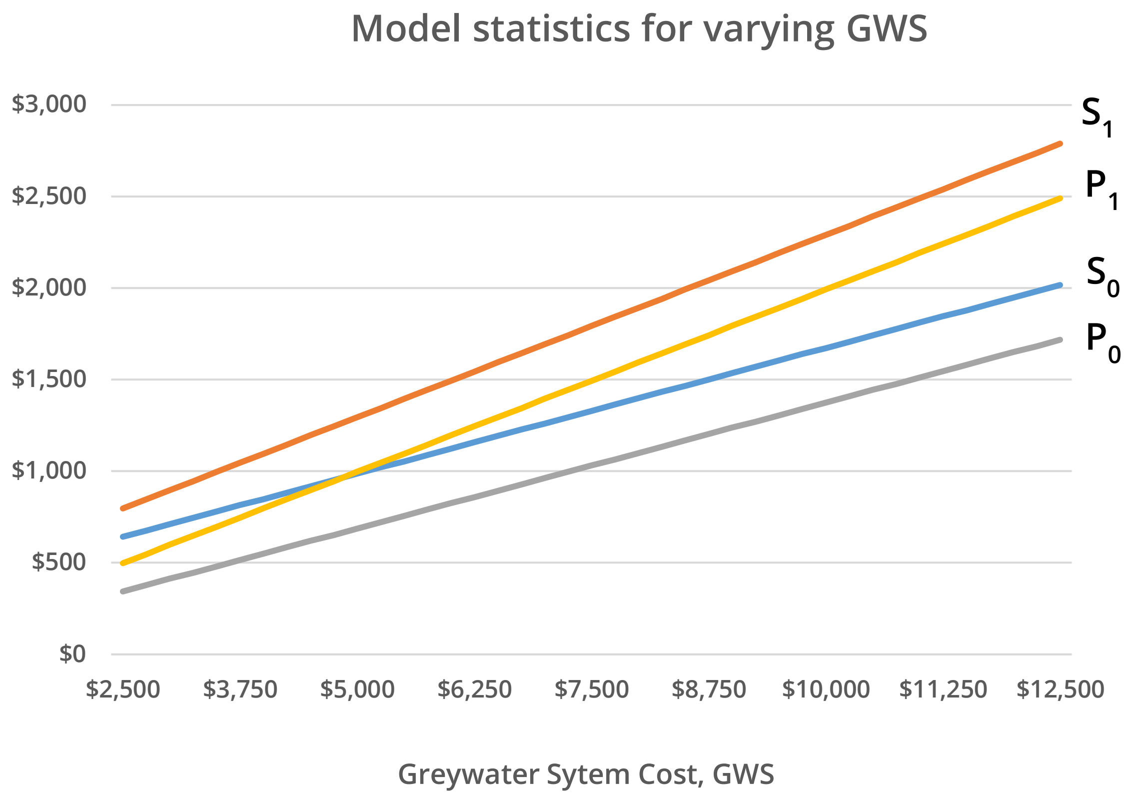
Formally,

$$\frac{\partial S_0}{\partial \text{GWS}} = \frac{\partial P_0}{\partial \text{GWS}} = \frac{1}{\text{PVIFA}_{\text{Lessor}}(1 - T_C)} - \frac{T_C}{T} > 0$$

$$\frac{\partial S_1}{\partial \text{GWS}} = \frac{\partial P_1}{\partial \text{GWS}} = \frac{1}{\text{PVIFA}_{\text{Lessee}}} > 0$$

Graphically, this means that if the greywater system cost increases, the yellow triangle in the savings-payment diagram indicating the greywater leasing potential expands and moves upwards and to the right. This illustrates that the lessor needs the system to provide higher periodical savings in order to justify the higher lease payment, while the lessee (or end-user) need the system to provide higher direct savings before it will be an attractive investment.

The figure below shows how the model statistics: S_0, S_1, P_0, and P_1 increase with the cost of the greywater system as explained previously. All other parameters are as in the base case example from the beginning of this chapter.



Installation costs, Install

If the installation costs increase, it affects the lessee (or end-user) directly, but only has an indirect impact on the lessor. This is because the lessee covers installation costs themselves whether they choose leasing or purchase. This means that the lessor's minimum lease payment, P_0, will be unaffected by changes in installation costs, and it means that the payment level, P_1, above which the end-user would prefer to purchase the system themselves is unaffected as well. However, because the net savings (from both leasing and purchase) now have to trade off higher initial costs, both savings levels, S_0 and S_1, will increase with higher installation costs.

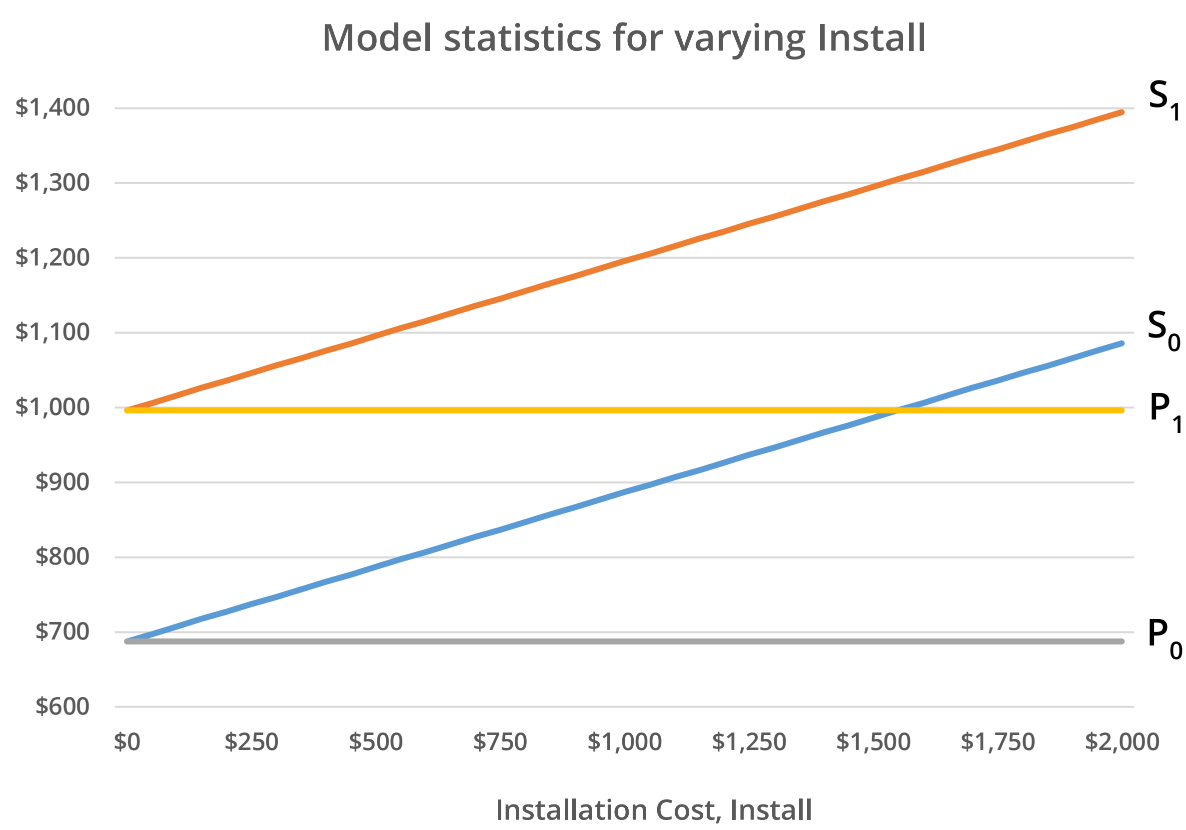
If we look at the first order derivatives, it becomes clear than if the system cost, GWS, increases, all four statistics: S_0, S_1, P_0, and P_1 will increase.

Formally,

$$\frac{\partial S_0}{\partial \text{Install}} = \frac{\partial S_1}{\partial \text{Install}} = \frac{1}{\text{PVIFA}_{\text{Lessee}}} > 0$$

$$\frac{\partial P_0}{\partial \text{Install}} = \frac{\partial P_1}{\partial \text{Install}} = 0$$

Graphically, this means that if the installation costs increase, the yellow triangle in the savings-payment diagram indicating the greywater leasing potential moves upwards. This illustrates that the lessor needs are unaffected, while the lessee (or end-user) needs the system to provide higher direct savings before it will be an attractive system to install.



The figure above shows how the model statistics: S_0 and S_1 increase with the installation costs of the greywater system, while P_0 and P_1 are unaffected as explained previously. All other parameters are as in the base case example from the beginning of this chapter.

Summary

The table below summarizes the sensitivity analysis for all parameters and model statistics. The model is robust in the sense that all statistics respond monotonically to parameter changes. All four statistics can be evaluated based on the financial conditions of the end-users in Pasadena Water and Power's service area; the market conditions for leasing companies; and the equipment and installation costs of various greywater systems.

The Savings Threshold for Leasing, S_0, can be lowered by a reduction in any of the underlying parameters (except the economic life of the greywater system). The Savings Threshold for Purchase, S_1, can be lowered by a reduction in the lessee's discounting rate or the greywater equipment/installation costs. The Minimum Lease Payment, P_0, can be lowered by reductions in the lessor's discounting rate (e.g. by lowering lessor's cost of capital), by a reduced marginal tax rate, or by a reduction in the greywater system costs. The Payment Threshold for Purchase Preference, P_1, can be lowered by reductions in the lessee's discounting rate and/or the greywater system costs.

Coordinates / Parameters	S_0	S_1	P_0	P_1
r_{Lessee}	Increasing ↗	Increasing ↗	No impact	Increasing ↗
r_{Lessor}	Increasing ↗	No impact	Increasing ↗	No impact
T_C	Increasing ↗	No impact	Increasing ↗	No impact
T	Decreasing ↘	Decreasing ↘	Decreasing ↘	Decreasing ↘
GWS	Increasing ↗	Increasing ↗	Increasing ↗	Increasing ↗
$Install$	Increasing ↗	Increasing ↗	No impact	No impact

Reward-Risk Analysis

Utility companies' obligations have traditionally been to secure and provide a steady supply of water and power to their service areas. They are regulated differently from private companies and are, for instance, not allowed to accumulate profits or pay out dividends. All excess revenues pass through to their customers in some form, e.g. savings; maintenance of existing assets; and infrastructure investments. Furthermore, in recent years utilities have been tasked with implementing environmental policies such as water reclamation and reductions.

For these reasons, we cannot back out a utility's benefit directly, as would be the case for a profit-maximizing private entity. In that case, the objective would simply be to maximize the present value of future cash flows. Non-profit entities such as utility companies have different objectives.

The most common approach in the case of non-profit entities, is to minimize costs subject to certain constraints such as: maintaining a specific groundwater recharge rate; secure a minimum local groundwater quality; meet specific water use efficiency targets, etc. This approach is problematic insofar as it subordinates (or ranks) certain objectives of the utility company.

Another, yet more complex approach, is to consider the utility company's problem as a multi-objective optimization, where the various challenges that the utility faces compete for scarce resources such as capital and labor. This approach typically involves determining the importance or urgency of each objective; then assign them a weight; and finally optimize on a weighted average representation of the utility's objectives.

In a slightly more sophisticated version of the latter we can determine the company's *utility function*, where measurable statistics related to the company's objectives are included as arguments, and then optimize on this function instead. This approach is preferable whenever we have a clear idea of how individual objectives "trade off" each other.

A standard example from finance relates to portfolio decisions, where risk averse investors seek to maximize expected returns while minimizing portfolio risks. These objectives are clearly in conflict, but by knowing the investor's utility function we can determine the optimal combination of assets in the portfolio anyway.

Reward Assessment

Pasadena Water and Power is a committed early adopter of various environmental measures. In the preparation for the upcoming Water System and Resources Plan 2019 the following objectives were included for consideration:

1. Replenish groundwater and improve groundwater levels
2. Maximize local water supply
3. Improve local groundwater quality
4. Maintain high quality of life and preserve cultural values
5. Increase water use efficiency (conservation)
6. Support regional water suppliers
7. Increase storage for long term emergencies

Greywater initiatives contribute positively to some, but not all of these. When greywater is used for irrigation, it helps via percolation to replenish and improve groundwater levels. If, however, greywater replaces potable water used for irrigation, the incremental contribution is much smaller and basically provides the same value, but at a much lower cost since the greywater is sourced on-site.

As the groundwater from Raymond Basin makes up the most important local water supply, greywater initiatives contribute positively to bullets 1, 2, 3, and obviously 5.

One can argue that on-site greywater reuse contributes positively to bullet number 4 as well. Greywater systems provide a steady supply of water even in drought periods. Many areas throughout California (and the US West in general) are exposed to extended periods of drought, where especially landscaping and irrigable areas in general suffer the most. In these periods, the supply of greywater from a laundry-to-landscape system will be unaffected by the drought.

On the other hand, greywater initiatives do not contribute to bullets 6 and 7, and it is even possible that the reduction in potable water demand could have an adverse effect on regional water suppliers.

Reward-Risk Ratios

Financial assets can be evaluated based on how well they compensate investors for the risk that the asset exposes investors to. The simplest measure in this evaluation is the Sharpe ratio, which is the fraction of the expected return net of the risk-free return as the numerator and the volatility of the return as the denominator:

$$\text{Sharpe ratio} = \frac{\text{Expected Return} - \text{Risk Free Return}}{\text{Volatility of Return}}$$

The intuition behind this measure is that it tells us something about how well the asset is expected to compensate the investor for each “unit” of risk that the investor is willing to accept.

Sharpe ratios and similar measurements of portfolio risks are essential to risk management. They are often constructed to include very portfolio specific information, e.g. portfolios of natural resources such as oil typically include information about risks associated with storage, distribution, quality, and of course demand.

For greywater investments, a reward-risk ratio has very limited applicability for the end-user. While the reward is straightforward to determine as the direct cost-saving (or net savings in case the system is leased), the risk, on the other hand, is infinitesimal since the greywater supply is steady and the water rates typically are highly predictable.

When the denominator becomes this small, the ratio itself becomes highly sensitive to otherwise negligible changes in the underlying risk. This renders the reward-risk measurement impractical to include in the greywater investment decision at the end-user level.

From the utility company’s point of view, there is some, albeit limited, merit in the reward-risk ratio approach. The challenge is that, in order to define a ratio that is comparable to the ratios of competing initiatives, we need to consider the monetary value (e.g. for Pasadena Water and Power) of service area wide greywater investments.

As explained in the previous section, utility companies have many objectives, so determining the specific value of a demand reduction measure becomes extremely sensitive to how we determine (or define) its equivalent monetary value.

Value-Based Ratio

If we know the monetary value of the cost reduction, the applicable reward-risk ratio is very similar to the Sharpe ratio insofar as we calculate the net return by subtracting the incremental costs of the greywater initiative from the value created from the demand reduction, and divide this number by the volatility of the value of the demand reduction.

$$\frac{\text{Value of Demand Reduction} - \text{Cost of Initiative}}{\text{Volatility of Value of Demand Reduction}}$$

While this Value-based ratio does provide some insights about the viability of specific greywater initiatives, it is highly depended of the valuation function that needs to be constructed, if we use this approach.

Quantity-Based Ratio

Alternatively, we can consider a reward-risk ratio of the demand reduction itself. While this Quantity-Based approach overcomes the valuation issue of a Value-Based Ratio, it comes at a cost: The ratio is defined as the fraction between water quantities rather than monetary values, which means that it is not comparable to other investments, unless these are measured in the same way.

For greywater investments, the Quantity-Based Ratio can be expressed as:

$$\frac{\text{Expected Demand Reduction}}{\text{Volatility of Demand Reduction}}$$

The demand reduction is specific to the given greywater system. Whether an end-user in PWP's service area would be interested in leasing, purchasing, or neither lease nor purchase, is determined by the discounting rate, r_{Lessee}, as explained in the Financial Models chapter. The distribution of discounting rates for all PWP customers thus determine how big a fraction of these would be expected to install the greywater system, thus giving us the Expected Demand Reduction for the numerator. The same distribution would give us the volatility for the denominator.

The resulting ratio expresses the reward-risk relationship in a case where end-users are drawn from a sample rather than the case where every end-user in PWP's service area is aware of the demand reducing initiative, and in turn opt-in (i.e. self-selects). This feature limits the relevance of the quantity-based ratio to cases where PWP's end-user do not know the full scope of a given greywater initiative.

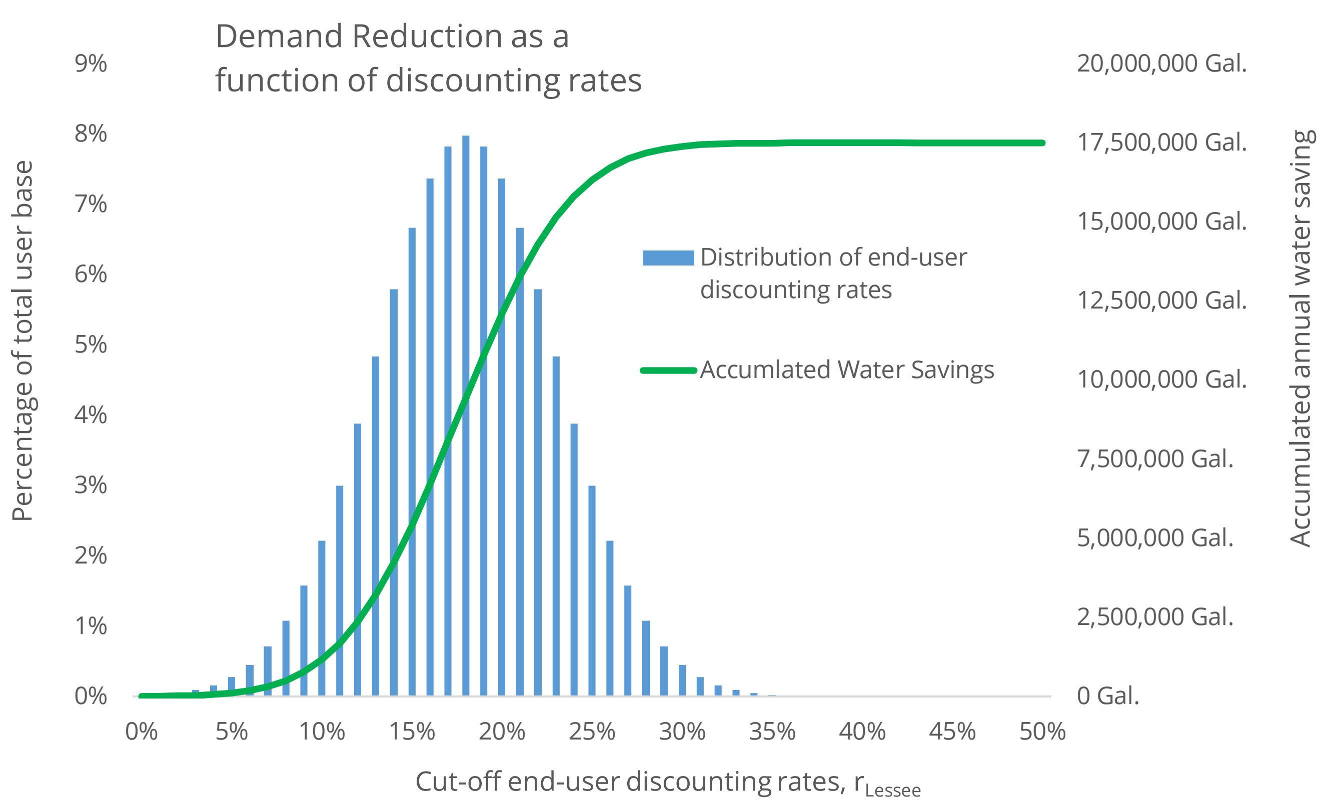
Another interpretation of the quantity-based ratio relates to the uncertainty about the distribution of end-user discounting rates itself. In this case, the expected value and the volatility are derived from a range of possible distributions. The challenge in this case is to collect information that can tell us something about the distribution possible distributions of discounting rates.

This is an experiment beyond the scope of this research, and the already limited applicability of the quantity-based ratio, prompts us to look for alternative risk management tools. The following section outlines how the model we developed in the Financing Models chapter can be useful for demand management.

The motivation for this approach is straightforward. If we know—or have an approximation of—the distribution of end-user discounting rates throughout PWP's service area, we can use our model to identify how big a portion of end-users will be willing to purchase, lease, or neither purchase nor lease for any given greywater system and lease offering. The water savings (by volume) are typically given directly from the greywater systems manufacturer, and when it is not, it is straightforward to estimate.

The figure below illustrates a case where the distribution of discounting rate is assumed to follow a conditional normal distribution between 0% and 50% with mean value equal to 18% and standard deviation equal to 5%. We can then determine the service area wide water savings by calculating the cut-off end-user discounting rate (where the end-user would be indifferent). Any end-user with a lower discounting rate would prefer the greywater system, while any end-user with a higher discounting rate would opt-out.

The higher the cut-off discounting rate, the more greywater systems would be installed. From this we can find the number of end-users who would install the system and multiply this number by the annual water savings; the accumulated water savings (green solid line)



then follow directly. In this example, we consider a small greywater system that provides an annual 500 Gallon water saving, but the approach is independent of scale, i.e., we could use the same approach for any subset of PWP's end-users where a larger greywater system is in question.

In the next chapter, we analyze the relationship between water agencies, end-users, and leasing companies in a three-player model. The scope of this work is to understand how we can use the model from the Financial Models chapter to predict (and to some extent control) changes in the service area-wide water demand due to subsidies and leasing. Before we do so, however, the last section of this chapter provides a brief description of the water demand management approach.

Demand Management

If we take the limited applicability of the value-based and the quantity-based reward-risk ratios into account, it is advisable to look for alternative risk management tools. One such alternative is to back out a demand management statistic from the model presented in the Financing Models chapter.

Specifically, we are interested to know how the minimum viability savings level, S_0, can be affected and in a sense *controlled*, if we know the distribution of discounting rates within the service area.

Modelling

We can build a simple demand management model by making a couple of non-restrictive assumptions, and by using some of the insight from the previous sensitivity analysis.

Consider a greywater system that provides a constant annual water saving, WS, and assume that this system is available for leasing. The leasing market is competitive, which means that Lessor will charge P_0 for this system. The population of end-users can be characterized by their discounting rates, $\{r_{Lessee}\}$, and we can find (or estimate) the distribution of these rates. We denote the cumulative distribution of discounting rates by F, such that F(r) is the percentage of end-users with discounting rates lower than or equal to r. From the Financing Models chapter, we can identify the marginal end-user with discounting rate, r^*_{Lessee}, such that this particular end-user is indifferent between leasing and "neither lease nor buy" option. Any end-user with a lower discount rate than r^*_{Lessee}

would prefer to lease the system, while any end-user with a higher discount rate than r^*_{Lessee} would neither lease nor buy the system.

In this setting we can find the total change in water demand, ΔD, as the product of the water savings from the system; the end-user population; and the fraction below r^*_{Lessee}, i.e.:

$$\Delta \mathrm{D} = \mathrm{WS} \times \mathrm{Population} \times \mathrm{F}(\mathrm{r}^*_{\mathrm{Lessee}})$$

In order for the marginal end-user to consider the leasing option the savings must exactly offset the lease payment, P_0 and installation costs. This means that:

$$\mathrm{Savings} = \mathrm{P}_0 + \frac{\mathrm{Install}}{\mathrm{PVIFA}^*_{\mathrm{Lessee}}}$$

As a technical constraint, the savings level must also be equal to the product of water savings and water rates. Thus, we can rewrite the identity above such that:

$$\mathrm{WS} \times \mathrm{Av.rate} = \mathrm{P}_0 + \frac{\mathrm{Install}}{\mathrm{PVIFA}^*_{\mathrm{Lessee}}}$$

Now, if we consider subsidizing installation costs, all we have to do is subtract this subsidy from 'Install' in the equation above, and subsequently isolate the subsidy to find that:

$$\mathrm{Subsidy} = \mathrm{Install} - [\mathrm{WS} \times \mathrm{Av.rate} - \mathrm{P}_0] \times \mathrm{PVIFA}^*_{\mathrm{Lessee}}$$

In order for this equation to balance, the higher the subsidy, the higher the resulting marginal end-users discounting rate. For any subsidy level, we can thus use this equation to back out the cut-off discounting rate, and in turn the percentage, F(r), of end-users who would lease the system.

Knowing the population and the water savings level, we can thus use the equation at the top of this section to predict, and to some extent control, the total water savings from greywater leasing. In the same setting, we can find the total cost, C, of subsidizing, as the product of the subsidy and the total number of end-users, who would opt in for the easing option:

$$\mathrm{C} = \mathrm{Subsidy} \times \mathrm{F}(\mathrm{r}^*_{\mathrm{Lessee}}) \times \mathrm{Population}$$

Pairing this cost with the total water savings level, gives PWP insight into the cost of subsidized water savings, which then, can be compared to the costs of alternative programs. This approach ultimately informs the optimal policy similar to NPV ranking as explored in the Capital Budgeting chapter.

Goal Setting and Mechanisms

Summary

This chapter provides a roadmap for PWP's long-term strategy to stimulate the adaptation of greywater systems within its service area. Based on previous chapters we argue that a Distributed Demand Management System would be both feasible and viable, and that PWP can play a central role as an information intermediary between its water customers and the vendors who are looking to serve Pasadena.

Efficient information intermediation is possible, only to the extent that PWP has expert knowledge about the *distribution* of greywater viability throughout the service area. To this end, we propose a segmentation of all PWP customers (SFRs, MFRs, and corporate accounts) that is granular enough to identify systems-costs/benefits as well as aggregate water-savings.

All of this information can be presented in a Greywater Benefit-Cost Matrix, which is constructed in such a way that PWP could exercise water savings options where they are most cost efficient; e.g. measured by Gallons of Water Savings per Dollar in Subsidy.

The suggested roadmap as well as PWP's long-term strategy speak to a new role that utility companies play. From the traditional role as a guarantor of cost efficiency and water quality, water utilities, in particular, are tasked with combating environmental challenges. Utilities are in this way incentivized and in some cases required to spearhead conservation and reuse initiatives.

Our roadmap suggest that PWP build its Greywater Benefit-Cost Matrix on a segment-by-segment basis, where PWP internally decides on a specific segment; collects the required information; executes its greywater initiative; and collects performance data. This approach allows PWP to adjust data collection processes and quickly learn from each initiative, while driving actual water conservation.

Natural Monopolies and Water Supply

Before analyzing how greywater leasing can support PWP's strategic goals we present a brief note about the underlying micro-economics of water supply. This is important for our understanding of the traditional revenue caps and other regulations that public utilities must abide by.

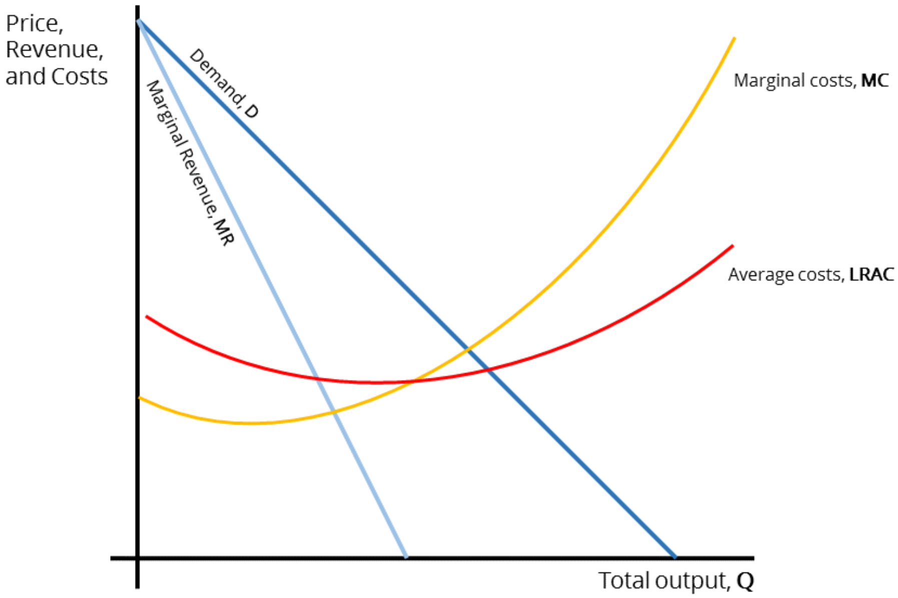
A natural monopoly occurs in the presence of very high fixed (or startup) costs combined with very low marginal costs. In this way, a natural monopoly benefits from huge economies of scale. Put differently, a natural monopoly is a special case of industrial organization where a single entity can supply the entire market at a lower unit cost than in the case with multiple suppliers in a competitive environment.

The case we consider here is also referred to as a "strong" natural monopoly as opposed to a "weak" natural monopoly in which, the average cost will be increasing in supply. Weak natural monopolies are exposed to market entrance, because increasing average costs drive down the incentive to supply additional units to the market. In this way, without intervention, existing firms leave portions of the market open. Certain industries, such as postal services, are good examples of weak natural monopolies. It is, of course, in society's best interest that the entire market is served, and a reasonable concern in this context is that new market entrants would compete for the customers with the highest willingness to pay, and leave the remainder of the market untouched. For this reason, weak natural monopolies are sometimes government sanctioned monopolies, under the provision that the entire market is serviced.

There are several examples—and candidate examples—of industries where (strong) natural monopolies emerge; and the regional supply and distribution of water and power are common cases throughout the world. The reason that, for instance, water supply is dominated by natural monopolies is the initial infrastructure investment. In most cases, it is simply impossible to justify side-by-side competition by overlaying networks of supply lines. However, once the infrastructure investment is made, it is much less cumbersome to expand the customer base.

Therefore, the costs associated with water supply fit perfectly into the typical cost structure of a natural monopoly: The fixed costs are enormous, while the marginal costs are negligible. For this reason, the average costs of water supply will continue to fall as new customers are added to the grid. This is also referred to as internal economy of scale.

Consequently, the long-run average cost ("LRAC") decrease in total output (i.e. total water supply), and thus, the largest supplier's competitive edge will continue to improve; to the extent that only one supplier will be left in the market.

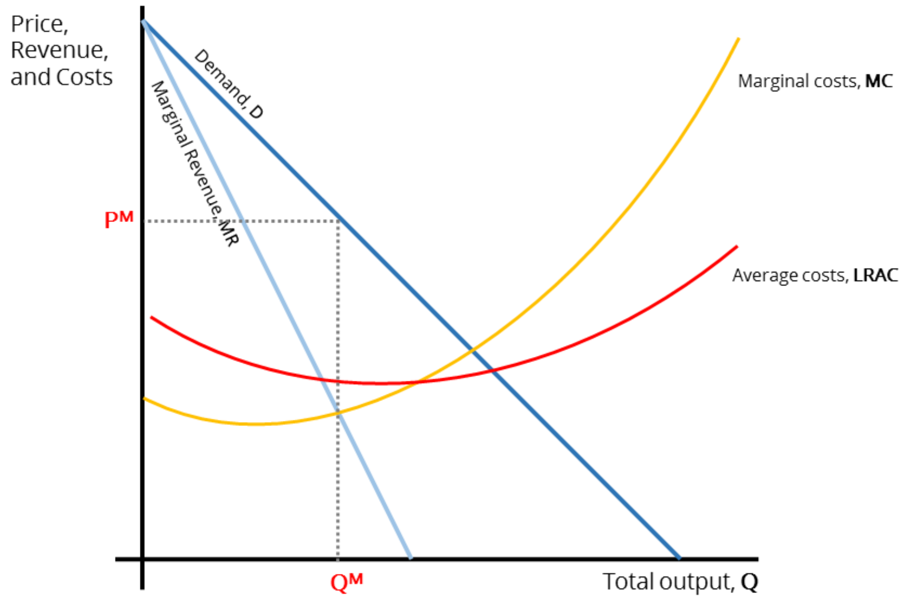


To illustrate, we turn first to the case of a regular monopoly. If we consider a monopolist faced with a normal (downward sloping) demand curve, and a production technology that creates economies of scale for a limited output, and diseconomies of scale for larger outputs, we can use the figure here below to understand the monopolist's decision problem and why its solution is not in the best interest of society.

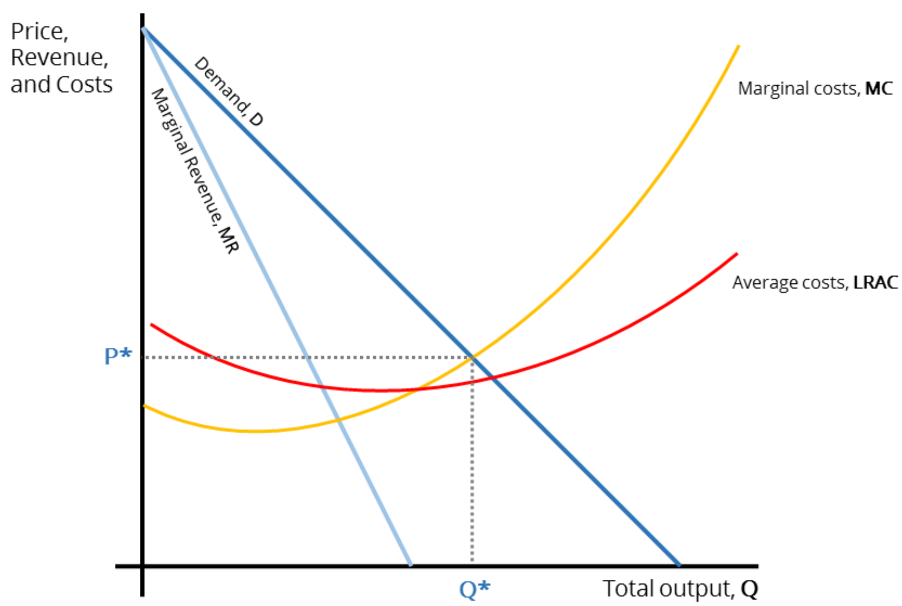
The monopolist wishes to maximize profits, and would to this end set the total output such that marginal revenues exactly offset marginal costs. We can illustrate this output/price combination as the intersection between the sky-blue MR curve and the yellow MC curve.

As illustrated here below, the monopolist indirectly sets the price, P^M, by producing the monopoly output Q^M.

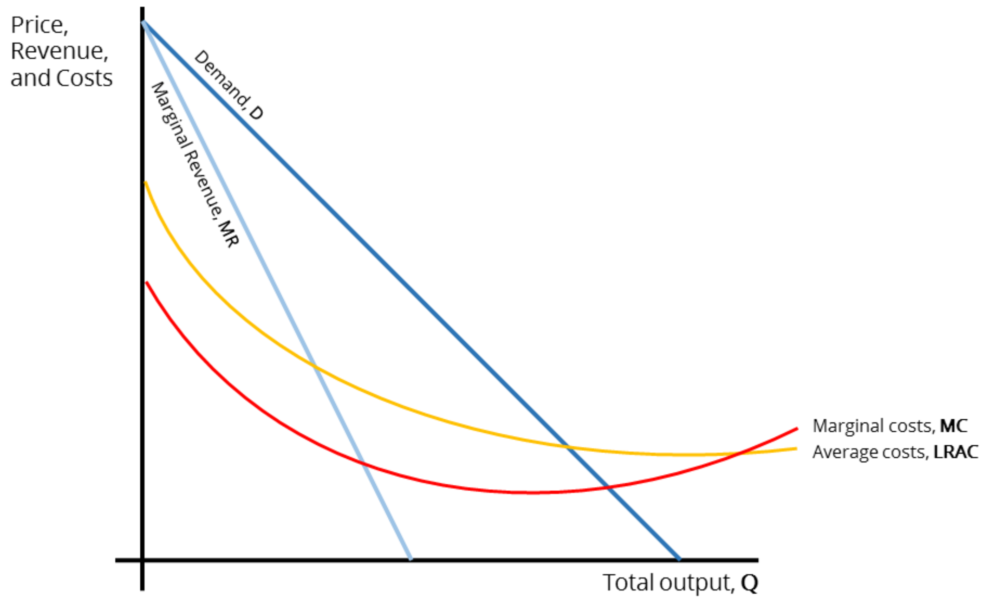
From society's point of view, the social optimum is reached when the marginal benefits from the output offsets the supplier's marginal costs. This output/price mix can be found where the dark blue demand curve intersects the monopolist's marginal costs, as shown here below.



Notice here that the monopolist can charge a price P* that is higher than the average costs, LRAC, which is important because the monopolist in this case effectively can be regulated via a price control.

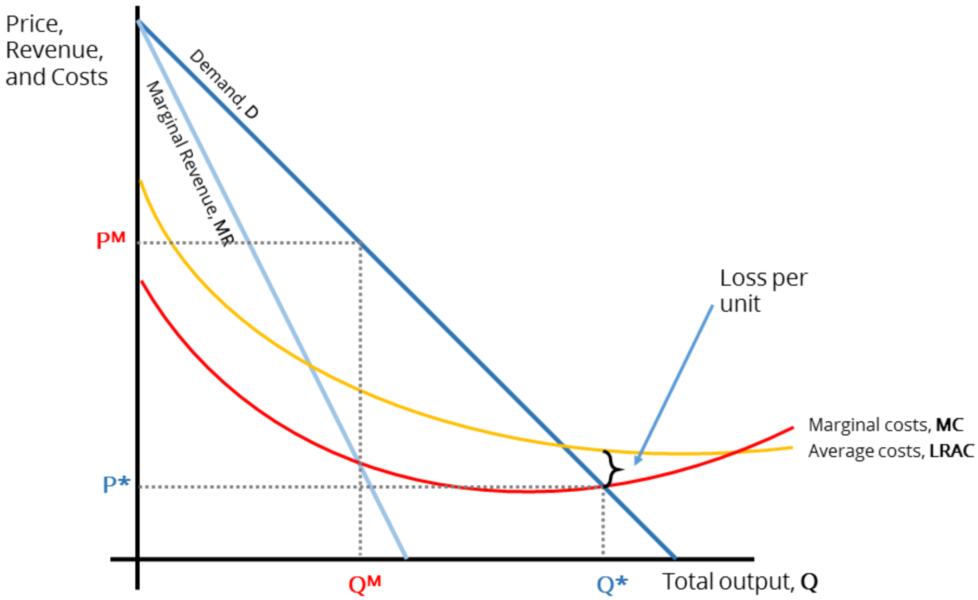


For natural monopolies, the situation is slightly different, insofar as the demand intersects the long run average costs while the latter is downward sloping as illustrated below. Consequently, society would at first glance be better off if a single firm provided the total output, than if the market were in competition.



However, if a single firm operates in the market, and this firm is allowed to set outputs and prices freely, the profit maximizing output, Q^M, which is determined by the intersection of the sky-blue MR curve and the red MC curve, is much lower than the socially efficient output, which we can find as the intersection between the red MC curve and the dark blue demand curve.

Furthermore, if the firm was forced to produce at the socially efficient level, its long run average costs would exceed the price it could charge, thus the monopolist would in this case go out of business. This situation is illustrated in the figure here below.



As can be seen, faced with the requirement that the socially optimal output must be provided, the marginal benefit (as illustrated by the demand curve) cannot cover the monopolist's long run average costs. In turn, the monopolist would inevitably go out of business.

In order to solve this puzzle, society's alternatives are therefore, either to provide the services itself, or to subsidize the natural monopolist such that the marginal costs shift downward until marginal costs (with subsidies) offset the marginal revenues exactly at the socially efficient output, Q*.

Public Utilities – Then and Now

Private and public water utilities were formed to secure a source of reliable and high quality water. As explained in the previous section, the potential for private enterprises to provide these services in a competitive market are hampered by high entry costs.

In combination with consistently decreasing marginal costs this gives rise to monopolistic outcomes that in turn require regulatory control and targeted subsidies in the case of private utilities and price control (via revenue caps) in the case of public utilities.

In Pasadena, water customers were serviced by competing private enterprises up until 1913 when the Water Department started operations. In this way, the city acquired (sometimes in full, and sometimes in part) local providers to ensure a steady supply and quality of water to its service area.

In context of the illustration above, the Water Department made strides to secure an output level as close to the socially efficient output Q* as possible. Without the profit maximizing incentive, the output could be increased up until the point where the marginal benefits (or demand) offset the Water Department's long run average costs.

In response to the apparent effects of climate change, such as the risk of prolonged drought periods, the California legislature in 2018 signed into law Senate Bill 606 (Hertzberg) and Assembly Bill 1668 (Friedman). Among other things, these bills signal the role that water utilities will play in terms of water conservation. Naturally, the development puts additional pressure on the individual utility's need for demand management.

There are several ways that a water utility can ensure water conservation throughout its service area. Increasing the marginal cost of water via rate hikes are effective, but imprecise. If a utility has a specific water demand target, it is very difficult to estimate the required rate increase to meet this target. The reason is that the elasticity of water demand within each rate tier is influenced by e.g. seasonal, demographic, and income effects. Combined with the fact that rate increases require a lengthy approval process, this option cannot stand alone, if a water utility such as PWP wishes to meet a specific demand target.

Our chapter on Laundry-to-Landscape Greywater Systems explained how the financial viability of greywater systems can be assessed based on rate payer water usage and systems specifications. The analysis included an estimation of the demand reduction that each system creates.

If sourced correctly, this information could prove crucial in PWP's demand management as explained in the concluding section of the Risk and Sensitivity chapter. Because the water savings are system specific, and the total savings scales up with the number of installed systems, the total demand reduction is more predictable than the one that could be achieved with rate hikes. For this reason, it is strongly suggested that onsite reuse of greywater is considered a viable option in PWP's effort to manage water demand.

The Need for Private Investments

The leasing initiative itself speaks to a broader realization within the environmental economics community. In order to lift the environmental challenges that we face today, a substantial part of green investments have to be financed with private sector capital.

As a proxy for the importance of private sector participation, we can look at the required participation of private capital in clean energy investments. Within OECD countries, the private sector accounts for about one third of all sustainable energy infrastructure investments, and OECD estimates that a $6.9 trillion investment each year in 15 years is necessary to meet the 2 degree Celsius cap from the Paris Agreement. Of this figure, $6.3 trillion are needed in order to meet the global development needs, while an additional $0.6 trillion are needed in order to make these investments climate compatible.[25]

What is important to note here, is that the green energy infrastructure investments will require substantial subsidies and other incentives to attract private capital. The most common types are direct tax subsidies and green bonds (which carries a relatively low tax on coupon/interest payments).

In our model of PWP's greywater leasing initiative, we consider subsidies directly tied to each greywater systems costs, and indirectly tied to PWP's role as an educational hub and facilitator of workshops etc., and as we will explain later in this chapter, as an informational intermediary.

The greywater initiative requires capital investments to cover:

1. Greywater systems cost
2. Installation costs
3. Maintenance costs (if applicable)

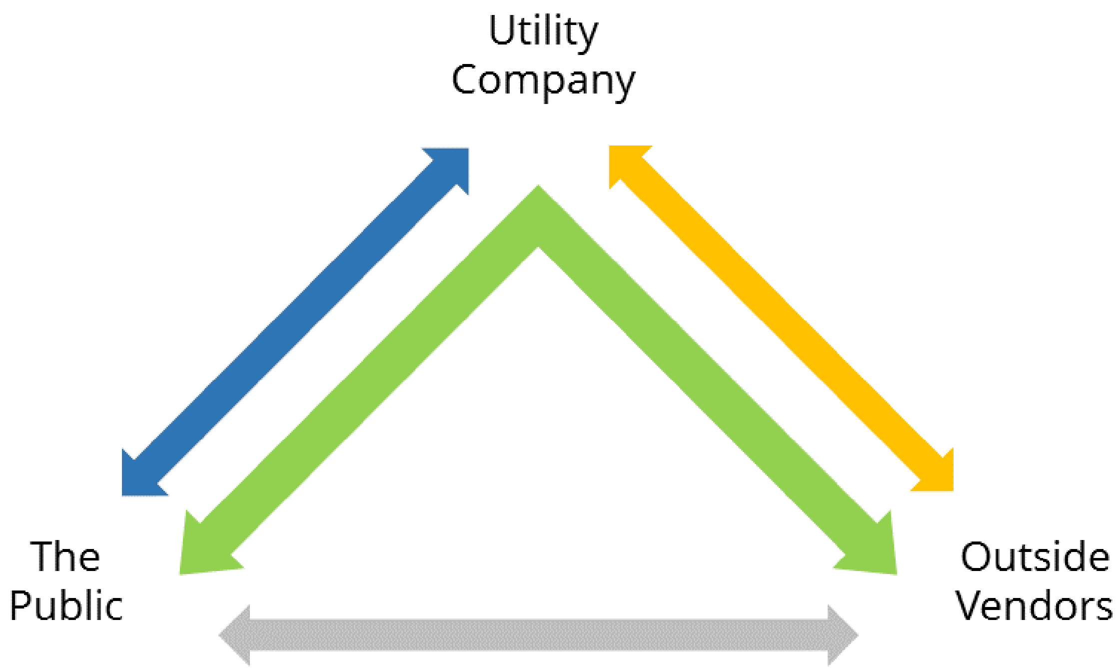
In addition, internal resources need to be committed to:

4. Education content
5. Information production

[25] See "Mapping Channels to Mobilise Institutional Investment in Sustainable Energy", OECD Publishing, Paris 2015 and "Investing in Climate, Investing in Growth", OECD Publishing, Paris 2017 for further details.

A Three-player Framework

In this section, we consider a non-trivial three-player game between PWP (the "Utility Company"), Pasadena's ratepayers ("The Public"), and providers of leasing options ("Outside Vendors"). The purpose of this setup is to get an understanding of why greywater leasing is not available to the Pasadena public today and how PWP might be able to act as an intermediary between lessor ("Outside vendors") and lessee ("The Public").



Objectives

Firstly, the relationship between the Utility Company and The Public is one of *common agency*. This is a typical modelling of the relationship between a population and the government agency servicing that population. It means that every member of the population is considered a principal, who as a group *share the agent*.

As with any other principal-agent relationship, asymmetric information between principal and agent may lead to issues of adverse selection and moral hazards. For this reason, the common agent's (the "Utility Company") actions are governed by measures to guarantee goal alignment and transparency to mitigate any adverse effects of this information asymmetry.

Unless we have specific reasons to believe otherwise, it is fair to assume that the Utility Company's objectives are aligned with the interests with The Public (e.g. cost reduction). We do however, have to take into account that water utilities by law are required to reduce water demand as explained in the previous section.

The latter objective is not necessarily aligned with the short-term objectives of The Public; the literature often refers to this type of problem as a *free-rider problem*. The intuition here is that the long-term problem persists, because everyone benefits from the self-sacrifice of others, but no one has the incentive to make that sacrifice themselves. In these cases, the group ("The Public") needs a mechanism to enforce the common optimal action. Traditionally, the Utility Company's role in this context has been to enforce e.g. water conservation and similar group actions exposed to free-rider problems.

We think of Outside Vendors as profit-maximizing private entities. For this reason, and aligned with the objectives of The Public, a crucial role of the Utility Company is to create competition among outside vendors to ensure the socially efficient price-quality mix.

Hurdles

The challenge in case of greywater leasing is that the Utility Company needs to bridge an information gap – and potentially a financial gap – between The Public and Outside Vendors while staying aligned with the best interests of The Public.

As explained in our chapter about Laundry-to-Landscape Greywater Systems, many ratepayers will find that the resulting cost savings are somewhat low relative to systems- and installation costs. Adding to this, the commitment of time to seek out the best greywater option might deter ratepayers from considering greywater options altogether.

Naturally, the same hurdle emerges on the greywater systems provider or leasing provider. Since the long-term financial benefits, that these systems provide, for many ratepayers (or lessees) are slim compared to the upfront installation cost and/or time commitment, the viability of market entrance is at odds with the profit-maximizing goals of the Outside Vendor.

The hurdles faces by The Public as well as Outside Vendors only exist because of lack of transparency. If each ratepayer had full knowledge of the available greywater options relevant to their water usage and onsite potential, the financial viability of these options could be ranked immediately. Similarly, if Outside Vendors had full knowledge of the monetary benefits of greywater systems throughout the Utility Company's service area, greywater leasing could (and would) be provided directly.

Feasibility

The three-player framework reveals that value could be added if *some* entity could secure accurate and actionable information to The Public as well as Outside Vendors. Water utilities are perfectly positioned to cater to this need.

The Financing Models chapter illustrated that greywater leasing is viable for a much larger group of The Public than the option to purchase greywater systems. This means that with the right information, a larger portion of ratepayers would adapt to greywater reuse on market conditions.

The challenge, however, is to collect and organize the relevant information in a way that aligns with the Utility Company's objective to manage water demand. This is the topic for the remainder of this chapter.

Long-term Strategy Components

The overarching goal of this research is to identify market-based mechanisms that will stimulate investments in greywater systems. From a water utility's point of view, this can prove a highly valuable component of the overall demand management challenge, and in this section, we briefly recap the main insights from the proposed leasing model and discuss how the informational asymmetry between The Public and Outside Vendors could help shape the role of PWP.

Demand Management

We start out assuming that a greywater system that provides a constant annual water saving, WS, is available from a competitive leasing market. The population of end-users are characterized by their discounting rates, $\{r_{Lessee}\}$, and we find (or estimate) the distribution of these rates. The cumulative distribution of discounting rates is denoted by F, such that F(r) is the percentage of end-users with discounting rates lower than or equal to r.

We identify the marginal end-user with discounting rate, r^*_{Lessee}, such that this particular end-user is indifferent between leasing and "neither lease nor buy" option. Any end-user with a lower discount rate than r^*_{Lessee} would prefer to lease the system, while any end-user with a higher discount rate than r^*_{Lessee} would neither lease nor buy the system.

We then find the total change in water demand, ΔD, as the product of the water savings from the system; the end-user population; and the fraction below r^*_{Lessee}, i.e.:

$$\Delta D = WS \times Population \times F(r^*_{Lessee})$$

The marginal end-user prefers the leasing option if the savings exactly offset the lease payment, P_0 and installation costs. This means that:

$$Savings = P_0 + \frac{Install}{PVIFA^*_{Lessee}}$$

Since the savings level is equal to the product of water savings and water rates, this identity is rewritten as:

$$WS \times Av.rate = P_0 + \frac{Install}{PVIFA^*_{Lessee}}$$

If the Utility Company subsidizes installation costs, we subtract this subsidy from 'Install' in the equation above to find that:

$$Subsidy = Install - [WS \times Av.rate - P_0] \times PVIFA^*_{Lessee}$$

To balance this equation, the higher the subsidy, the higher the resulting marginal end-users discounting rate. For any subsidy level, we can thus use this equation to back out the cut-off discounting rate, and in turn the percentage, F(r), of end-users who would lease the system.

Information Intermediation

At this point, it is clear that if the Utility Company knows the distribution of discounting rates, the population size, and the water savings level, the total water savings from greywater leasing can be controlled via the Subsidy level.

In this setting, we also found the total cost, C, of generating the desired reduction in water demand via subsidizing in the presence of greywater leasing as:

$$C = Subsidy \times F(r^*_{Lessee}) \times Population$$

It is important to note here that the Utility Company's role as an information intermediary is created by a combination of three components:

- Knowledge about the population size and discounting rates.
- Knowledge about the local greywater potential.

- Communication to attract Outside Vendors.
- Fixing (and committing to) a specific subsidy level.

Segmentation

From a water utility's point of view, it might seem the obvious choice to segment the market based on historical water demand. However, in light of the available options and technologies for capturing and reusing greywater, this approach is not optimal. Different water customers have different opportunities and limitations in term of capturing and reusing greywater, and for this reason, we suggest that PWP segments its water customers based on "who they are" rather than "how much they use".

The first segmentation step separates water customers by types: 1) Single-family residential (SFR), 2) Multi-family residential (MFR), and 3) Commercial accounts. As the purpose of the segmentation in this context is to assess water savings potentials, we need to capture all relevant information as it pertains to water reuse potential as well as the actual historical usage.

Single-family residential (SFR)

The suggested segmentation layers for SFRs are shown here below:

1) **Single-family residential (SFR)**
   a) Size: Lot
   b) Size: House
   c) Layout: Number of floors
   d) Layout: Number of rooms
   e) Household: Size
   f) Household: Age distribution
   g) Equipment (overview of laundry machines, toilet, faucets, etc.)
   h) Technical barriers (e.g. does the layout allow for L2L installation and shower-to-toilet flushing)
   i) Onsite reuse potential (landscaping, toilet flushing, etc.)

As indicated, each SFR is first categorized by size (a and b) and then by number of floors (c) and rooms (d). This information has some explanatory power, but is far from sufficient. It is convenient to apply these two layers first as the information can be sourced from publicly available resources (in fact, in most cases, the information is already available to PWP). This segmentation layer provides a rough overview of PWP's SFR water customers.

Next, each SFR is categorized by their household size (e) and composition (f). This is important for several reasons: The household size is directly linked to the total water usage as explained previously, and the composition (especially the number of small children) is linked to how the total water demand is distributed onto laundry, showers, toilet flushing etc.

While bullets a) through f) provides valuable insight for predicting water demand at the individual SFR level, they do not give us an accurate insight about the actual reuse potential. For that, we need information about the household's equipment such toilets, faucets, laundry machines, washing machines etc. This information (g) will allow PWP to make a projection of how the household's water demand is allocated onto separate uses. This is of course important because certain sources produce greywater, while other produce black-water.

Finally, PWP needs to estimate the actual onsite reuse potential. As a rule of thumb, greywater should not be stored for more than 24 hours, which means that once captured, its value is highly depended on the specific needs of the individual SFR. To this end, PWP would need information about any technical barriers that might prevent specific applications of greywater (h) as well as the immediate needs of the SFR (i).

Based on this information, paired with the individual SFR's water rate information, PWP can estimate reuse potentials and cost saving at the customer level, and in turn assess the viability of the greywater leasing options as presented in Financing Models chapter. In this way PWP will able to intermediate between segments of its customers and greywater leasing providers:

- The water customers need to understand which greywater-system options are available and applicable to their specific needs.
- The greywater-system provider and/or greywater leasing provider needs to understand the market potential within PWP's service area.

As explained in the Risk and Sensitivity chapter PWP can subsidize the transaction in order to stimulate greywater installations. The actual level of subsidy should be determined by the water saving requirement at the time of the installation, as highlighted in the Demand Management section of the Risk and Sensitivity chapter.

Multi-family residential

The suggested segmentation layers for MFRs are shown here below:

2) **Multi-family residential (MFR)**
    a) Number of units
    b) Distribution of unit sizes
    c) Distributed water demand (with as much level of detail as practically possible)
    d) Layout of water usage facilities
    e) Technical barriers
        1. In-unit capture
        2. Collective capture
    f) Onsite reuse potential
        1. Landscaping
        2. Adjacent potential uses

MFR-targeted greywater systems are slightly different from the ones available to SFRs, and the decision-making will for a large part be centralized rather than distributed onto the individual household. Furthermore, the relatively lower reuse potential for landscaping needs caps the incremental value-added from water-savings. The total savings per decision-maker, however, is much bigger and for that reason, MFRs could present substantial greywater reuse potentials.

The suggested segmentation layers divide into three groups. Firstly, PWP needs to understand the MFR customer size; this can be achieved by recording the number of units (a) and the distribution of unit size (b). If possible, this record can be augmented with the water demand for each unit (c), if available. In this way, layers a) through c) provides a categorization of the entire MFR and in turn some insight into the potential greywater capture.

Apartment complexes differ greatly in their layout of especially laundry facilities. Each layout presents opportunities, hurdles, and not the least installation costs, and it is therefore important to capture these differences in water usage facilities (d) and the technical barriers (e) they present before estimating the greywater potential.

Finally, and as mentioned above, MFRs are likely to have a significant mismatch between greywater capture and its potential for onsite reuse. Most apartment buildings have very limited water demand for landscaping relative to the total output of greywater. It is therefore essential that the final segmentation layer records all onsite reuse potentials along with any nearby potentials; e.g. parks, recreational areas, and other areas with a water demand that potentially could be met by the given MFR's greywater.

This layered segmentation for MFRs will enable PWP to better assess the technological and regulatory requirements as well as the financial viability of greywater systems. As was the case with SFRs, PWP is aggregating information about water users as well as potential greywater system providers and lessors. This role as an information intermediary could potentially stimulate greywater investments with minimum levels of subsidies.

Commercial accounts

The suggested segmentation layers for Commercial accounts are shown here below:

3) **Commercial accounts**
    a) Sector/Industry/Main business
    b) Governance and control
    c) Size (E.g. measured by annual revenues, number of employees, or total assets. Alternatively, periodical water demand could be used as a proxy for company size.)
    d) Relative size (I.e. the specific company's position within its industry.)
    e) Water usages
    f) Quality and/or contamination level of water output
    g) Onsite reclamation potential:
        1. Portion of water output that is greywater
        2. Portion of water output that could be treated onsite to produce greywater
        3. Portion of water output that cannot be treated onsite to produce greywater
    h) Onsite reuse potential

Commercial accounts are first categorized by the account holder's line of business (a). The reason for this segmentation is twofold. Firstly, sector/industry information is publicly available and can be paired with PWP's in-house water usage data. Secondly, account holders who are in the same line of business will have similar usages of potable water and similar water outlets in terms of water quality. This means that within each grouping, the main differences pertain to scale and affordability. The second layer addresses the discretionary power of the account holder (b). It is reasonable to assume that some portion of PWP's commercial account holders are divisions of other entities outside of Pasadena, and hence do not make decisions related to cost savings etc. For operational reasons, it is important to capture this information in order to understand which challenges PWP might face when reaching out to these companies.

The next layers capture information about the commercial account holder's size (c) and relative strength with PWP's service area (d). The combination of these two pieces of information can inform PWP's communications strategy and in some cases help identifying early adapters.

Before assessing the on-site reuse potential, it is important to understand how the commercial account holder uses water (e). It is expected that there will be some correlation of water usages for each segment or "line of business" and that most of the variation between account holders pertain to their relative sizes (e.g. due to large fixed investments that small entities cannot take on). Next, we capture the output quality/contamination level for the account holder (f) as well as the reclamation potential (g). Some of the account holder's activities might produce readily available grey water; some activities might produce treatable black water; while other activities might produce output water that requires offsite treatment/decontamination. This step should provide enough detail to estimate the *minimum cost* function of onsite greywater production.

Just as was the case with residential account holders (SFRs and MFRs), each commercial account holder's entry in the segmentation concludes with an assessment of the onsite reuse potential. The purpose of this is to understand the potential water saving and in turn the viability of greywater systems installations.

Impact assessment

The water customer segmentation above will provide PWP with a framework to more accurately assess water savings for various programs; targeted as well as service-area-wide programs. The strength of PWP's position lays with the access to the individual water customer's usage data and applicable rates. This information will allow PWP to estimate future rate savings on the customer level, and in turn calculate the needed subsidy.

It is crucial that the impact assessment takes into account the cost of water savings; e.g. in some cases the greywater will be readily available without the need for treatment, while other cases call for some form of cleaning or filtering. It is suggested therefore that PWP focus on these varying cost functions for each segment (or customer grouping), and thoroughly understand if water-saving are achievable through or if some form of subsidy is necessary.

The more complete the customer segmentation, the better informed PWP will be about the water-savings per subsidized dollar. The full segmentation would theoretically provide a complete picture of which customer groups should be targeted to achieve the most cost-efficient water savings, and in turn how big a subsidy is necessary to achieve PWP's demand management goals.

Greywater Benefit-Cost Matrix

The idea behind the segmentation is to divide PWP ratepayers into groups with very little in-group variability in terms of the onsite benefits and costs for as broad a spectrum of greywater system investments as possible.

For demand management purposes, the Utility Company needs to estimate the minimum cost associated with various greywater output levels. To this end, for each segment, it is important to understand the available sources of greywater and the costs (system and installation) associated with capturing the greywater. The cost function should be constructed such that the cheapest sources are captured first.

In order to estimate the actual water saving potential for each segment, the Utility Company should furthermore collect information about the onsite reuse potential. The reason for this is that the reuse potential caps the viability set of greywater investments.

Finally, the population size (e.g. the number of households in each SFR grouping; the number of apartment buildings in each MFR grouping; and the number of companies in each Commercial grouping).

Here below is an example of how this information is summarized in a Benefit-Cost Matrix. The matrix can be augmented with information about each group's marginal user's discounting rate; specific performance targets; or any order information that the Utility Company see fit to include in the analysis. The point of this structure is that it informs the Utility Company about which segments and Outside Vendors to approach in order to meet specific (total) demand management targets.

Grouping	Av. Onsite GW Cost Function	Av. Onsite GW Reuse Potential	Population size
SFR_1			
SFR_2			
SFR_3			
…			
SFR_n			
MFR_1			
MFR_2			
MFR_3			
…			
MFR_n			
$Comm_1$			
$Comm_2$			
$Comm_3$			
…			
$Comm_n$			

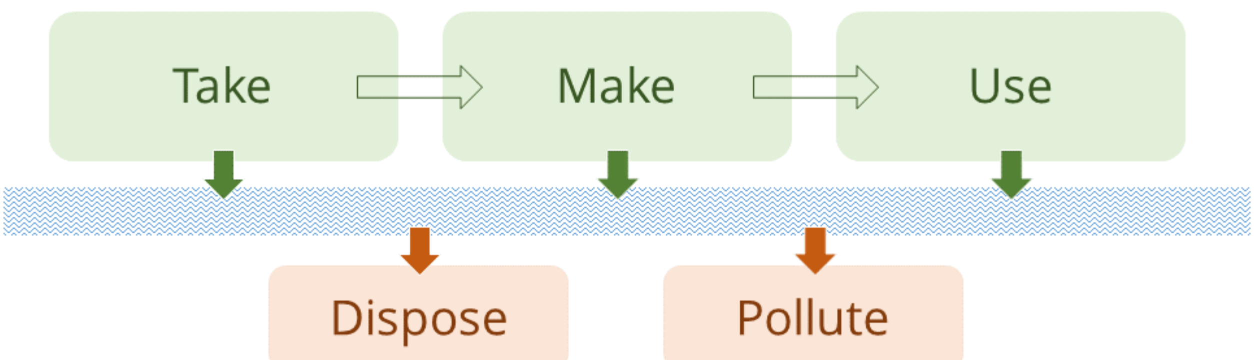
Public Water Utilities in the Circular Economy

The Circular Economy

Dating back as far as the early 60s, economists, political philosophers, and social scientists alike, have attempted to challenge an inherent flaw in the way that we model and think about economic systems. Specifically, traditional economic theory (and thinking) evolves around an "open economy" perspective of society.

In the open economy or "open-loop economy", economic agents do not account for input scarcity, not do they concern themselves with the disposal of undesired output. The only thing that matters are the *immediate* trade-offs between the benefits and costs of our economic activity.[26]

Several economist have challenged this point of view, stating that whether we think in terms of open-looped systems or not, the adverse effects of our decisions today become apparent and relevant over time. One obvious consequence of open-looped planning is of course the environmental impacts of our decisions as described in David W. Pearce and R. Kerry Turner's "Economics of Natural Resources and the Environment" from 1989.



In this work, the authors identify an indirect mechanism that is inherent to any open-looped economy where the environment serves as a waste reservoir, as illustrated in the figure above.

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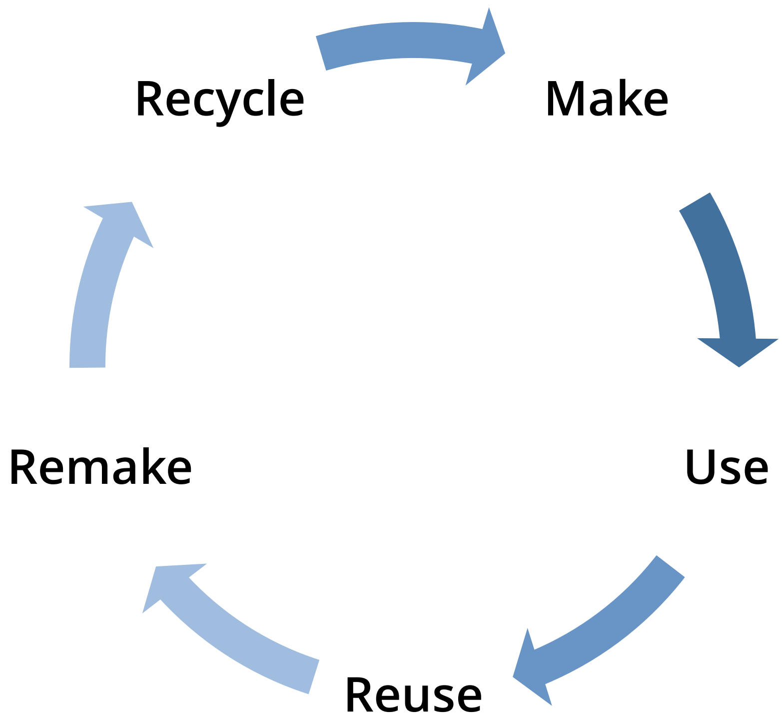
[26] See Kenneth Boulding: "The Economics of the Coming Spaceship Earth" in H. Jarrett (ed.) Environmental Quality in a Growing Economy, Resources for the Future, Johns Hopkins University Press, Baltimore, 1966.

The idea of the “closed-loop” or “circular economy” emerged in response to this discovery. It is an attempt to apply our understanding of natural environments and ecosystems as boundary conditions for economic activity. I.e., we apply a long-term planning framework that accounts for all effects of our immediate actions and decisions.

The most common illustration of the circular economy is shown here below. The figure indicates that in a circular economy, the entire supply of resources stem from previous economic activity: Reuse only what has been used; Remake only from what has been reused; Recycle only what has been remade; and Make only from what has been recycled.



This supply chain is incredibly ambitious and to some extent unnecessarily restrictive. One of its shortcomings is that it does not account for the interplay between the economy and the natural environment that surrounds it. For water management, it would simply be impossible, not to include the natural environment in the supply chain.

However, the key message from circular economic thinking is an important one:

Every drop of water that is utilized must be accounted for, and once it has entered into the supply chain, it must be reused, remade, and recycled without causing harm to the surrounding environment!

Change-Agents

From the sourcing of water supply to the safe reuse of water, public utilities today play an active role in the sustainability management of water resources; and they will play an integral role in the circular economy as well.

As the tremendously ambitious goals of the circular economy gains foothold—as a matter of public policy as well as a promising business opportunity—public utilities are required to play an active role in water conservation by exploring innovative ways of more efficient water usage.

California's challenges with extended drought periods and a growing population have prompted a progressive stand that puts pressure on local water utilities to explore any opportunity for conservation, reuse, recycling, and even sourcing of water. The water utility is thus incentivized to become an *agent of change* within the circular economy. For many—such as PWP—this role is perfectly aligned with in-house goal setting and years of experience with implementing sustainable usage of water.

PWP's greywater leasing initiative is also aligned with this role. What is innovative about this initiative, however, is that that it seeks to release and advance the use of private risk-willing capital in order to boost the impact of the resources that PWP and its ratepayers are already committing to greywater reuse.

As explained in previous sections of this chapter, the greywater leasing initiative requires a redefinition of the role that the utility company plays between its water customers and outside vendors. When leasing options are not available today, it is primarily because of information asymmetries; both in terms of reuse technologies (from the point of view of the ratepayer) and in terms of market opportunities (from the point of view of the leasing company).

Implementation

To build a Distributed Demand Management System is a work-intensive endeavor that requires a firm grasp of its purpose as well as a commitment to its implementation. PWP will need to leverage several internal resources and reach consensus in regards to its implementation and timeline early on.

It is suggested that PWP initiate this work by consolidating the experiences that are already present with in-house staff to create a framework for SFR accounts and simultaneously initiate a pilot project for a selected sector/industry of medium size. Both workflows are described here below.

SFR segmentation

The segmentation of single-family-resident accounts should be informed by a combination of:

- In-house experiences from various conservation programs.
- Local greywater vendor experiences from vendors who have already collaborated in initiatives such as PWP's Laundry-to-Landscape programs.
- Common educational resources and knowledge hubs such as Greywater Action.

As explained previously, the goal is to find easy-to-identify information that determines both benefit and cost functions of greywater for SFRs.

The following workflow template captures the necessary requirements:

- Staff ideation to establish first draft of SFR segmentation
- Feedback
  - Local greywater systems installers
  - Educational experts
- Adjust SFR segmentation
- Testing
- Share results for comments by
  - Local greywater systems installers
  - Educational experts
- Adjust SFR segmentation
- Testing and calibration
- Determine greywater leasing potential
  - Overview of affected SFRs
  - Determine demand management needs
  - Analysis
    - Feasibility
    - Viability
    - Optimality

Pilot program for commercial accounts

It is recommended that PWP identify a single sector or industry with 25 to 50 companies within its service area.

This medium sized sample is large enough to provide meaningful insights while small enough for PWP to capture important information in the work process. Since this pilot program is a first of its kind, it is essential that PWP extract and record as many operational experiences as possible.

The following workflow template captures the necessary requirements:

- Sector/Industry selection based on staff ideation.
- Initial segmentation
- Testing
- Calibrate/update segmentation
- Ratepayer survey to assess interest
- Ratepayer segment selection
    - Segment survey to assess benefit and cost functions
    - Analysis of leasing viability
- Technology/vendor survey based on ratepayer segmentation
- Communication to ratepayers about leasing availability
- Follow-up and performance measurement
    - Adjustment of greywater benefit and cost functions in the Benefit-Cost Matrix
- Critique and adjustment of workflow

Conclusion

This research project analyzes a leasing model for greywater systems. The motivation behind the analysis was to understand if and how financial leasing could help accelerate adaptation of residential and commercial greywater systems.

We survey various greywater systems and find that largely they take the shape of conventional investments with relatively high initial capital outlays, little to no maintenance requirements, followed by a series of periodical benefits. For this reason, we consider a leasing model where the lessor and lessee evaluate the greywater systems as an annuity.

In this context we find closed form solutions for both Lessor and Lessee, and we determine the range of possible leasing applications in a (lease payment, water savings) grid.

Furthermore, we consider an augmented microeconomic model of common agency with three groups of active players: the Public (the Principal), PWP (the Agency), and "Stakeholders" (vendors, installers, technology providers, financiers, leasing companies, etc.). In this setting, we discuss which roles water utilities can play to enable crucial information production and exchange between greywater system manufacturers, installers, leasing companies and water customers.

We find that water utilities need to play a more active role as information intermediaries, and we suggest a specific roadmap to provide such intermediation.

The report consists of an introduction and six chapters where we present:

- **Survey results from Pasadena Water and Power's service area**
  As a part of our research, we survey PWP customers to learn more about their interests in and ability to take part in greywater and other water conservation programs. The survey is open throughout the research, and we compile survey responses on an ongoing basis.
- **A general presentation of relevant capital budgeting practices**
  Here we introduce capital budgeting practices and outline which metrics we will apply in the financial viability analysis of greywater systems. It is important to remember that we are interested in analyzing the role of the utility company as well as the end-user. We augment the capital budgeting techniques applied to the end-user's investment decision with the value created for the utility company. This

addition is non-standard and necessary when we evaluate the utility's decision to subsidize. The utility's goal is modelled via an externally given water conservation target.

- **A detailed analysis of PWP's Laundry-to-Landscape program**
  In this chapter we outline the basic benefit-cost tradeoff from the point of view of the water customer. PWP has accumulated experiences and feedback from their customers over two years. We leverage these experiences and a broader presentation of the greywater systems available today.
- **An overview of relevant financing models and a detailed presentation of the viability of leasing of greywater systems**
  In this chapter, we analyze the scope of leasing agreements for greywater systems. Based on a discounted cash flow model we find a lower bound on periodical water savings which secures viability of leased greywater systems. We identify regions in a (Saving, Payment) that comprehensively identifies for which savings- and payment levels a greywater system will be either leased, bought, or neither leased nor bought.
- **A risk and sensitivity analysis**
  This chapter presents a sensitivity analysis of the leasing framework. We find no abnormalities and the model is robust for all parameter changes. By this we mean that changes in discounting rates, marginal corporate tax levels, economic life (or planning horizon), greywater systems and installation costs result in monotonic response in the model statistics.
- **A roadmap for how PWP's greywater initiative can leverage the leasing model**
  This chapter provides a roadmap for PWP's long-term strategy to stimulate the adaptation of greywater systems within its service area. We argue that a Distributed Demand Management System would be both feasible and viable, and that PWP can play a central role as an information intermediary between its water customers and the vendors who are looking to serve Pasadena. To this end, we propose a segmentation of all PWP customers (SFRs, MFRs, and commercial accounts) that is granular enough to identify systems-costs/benefits as well as aggregate water-savings. All of this information can be presented in a Greywater Benefit-Cost Matrix, which is constructed in such a way that PWP could exercise water savings options were they are most cost efficient; e.g. measured by Gallons of Water Savings per Dollar in Subsidy.