Rainwater Harvesting and Graywater Reuse

Methods and Design Applications for Residential and Commercial Non-Potable Uses

UC Davis Landscape Architecture
Senior Project
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Abstract

Over the course of life on Earth, one elemental constant has remained present, the need for water. In today's society water is looked at as an infinite commodity and in most cases used very inefficiently. This document aims to focus on how we can manage our water resources in better ways, specifically through the use of rainwater harvesting and graywater reuse. Examples of three land uses were adapted from the Davis West Village Implementation Plan. A single family house, apartment cluster and a mixed-use site were analyzed to determine the viability of rainwater and graywater as a realistic future water supply for non-potable uses such as landscape irrigation and toilet flushing. Calculations of graywater and rainwater supplies compared to non-potable demands showed that with water conscious landscaping, much or all of toilet flushing and irrigation demands can be met. However, if intensive treatment is required, costs could limit these use of these systems on a large scale.

Erik is characterized by his animated and playful personality. His upbringing included year round sports and outdoor exploration. As an avid baseball player for 17 years, he has learned that teamwork and collaboration are crucial to the success of any endeavor. As a student of landscape architecture he has taken a special interest in resource conservation, particularly water. Erik aspires to be a steward of the Earth, working both personally and professionally to change our environment for the better, one step at a time. He enjoys water skiing, biking, plant propagation and rain in June.

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Contents

Preface

California is very diverse and complex in terms of its geology, people, culture, topography and climate. Just as intricate, are the water issues that California faces. As California grows, so does the need for a reliable water supply. It is expected that California's population will increase by 12 million people by 2030 (Corbett et al., 2006). Much of California exists as a Mediterranean climate, meaning warm dry summers and cool wet winters. The seasonality of water supply and water consumption are in conflict; most rainfall occurs in the months when it is needed least, leaving the issue of how to store and supply water for the warm dry months.

Thus far, this has been achieved by large water projects with dams, reservoirs and aqueducts, as well as ground water pumping. Today, most of our waterways are influenced by such structures and our groundwater supplies are continually over-drafted in many areas. Two overlooked water sources that could prove to be partial solutions to California's water struggle are the capturing of rainwater and the reuse of graywater. When taking a closer look at this depletion of a vital resource, one must examine the importance of as well as the issues associated with graywater and rainwater harvesting as a viable water source for the future.

It is no accident that humans have settled by or near water sources throughout history. Rivers, streams, lakes and oceans have not only been sources for food, but, more importantly, drinking water. In instances where human settlements were removed from a source of clean water, ways were devised to direct water from great distances through structures like the aqueducts and canal systems. We can even see further examples of this today. Many communities in California receive water from hundreds of miles away and in some cases from different states. With a limited supply of fresh water and growing populations, it is imperative that water be used efficiently and to utilize local renewable sources of water. These two sources of relatively clean water are very under utilized in much of the developed world and have the potential to serve a significant portion of non-potable uses. This project is meant to analyze the viability of rain and gray water as reliable future sources of water.

California and other Mediterranean climates are posed with the problem of receiving rainfall when is needed least and little to no rainfall during the months when demand for water peaks. Increasing populations and droughts are adding stress on existing water supplies. Determining and effectively using alternative sources of water are critical. Over the last 75 years California has experienced three major droughts lasting from one to five years (Corbett et al, 2006). To many, water was thought to be an infinite resource. "Of all the Earth's water only 2.5 percent is freshwater, and of that, three-quarters is sequestered in glaciers and permanent snow cover. Only 0.3 percent of water is surface water found in rivers and lakes, and thus readily accessible." (Kilbert, 2005) With this in mind, we use high quality treated drinkable water to flush toilets and irrigate landscapes, when a lesser quality water would be more than sufficient. Much of the water produced from showers, sinks and clothes washers as well as rainwater with minimal to no treatment is clean enough for these purposes.

The seasonality of rainfall in Mediterranean climates poses the issue of larger scale water storage for up to months at a time. Issues can arise for stored water such as algal growth, mosquito breeding, anaerobic conditions causing odor, and bacterial growth, with the later two being more of a problem with gray water. Moreover, adding the infrastructure to a project is often an increase in up front development costs.

There are many benefits of rainwater and graywater. It reduces the need for infrastructure to move large quantities of water, therefore a reduction in potential storm water, meaning less runoff, less erosion potential and reduces chances of flooding. It can provide a year round source of water for domestic and landscape uses that do not require pristine water sources.

In the following chapters I will provide:

1. a brief history and background of rainwater harvesting and graywater reuse;

2. an overview of the current and future state of rainwater and graywater systems;
3. review relevant water policy and graywater code;
4. show the process for determining graywater supply and toilet demands, monthly landscape irrigation demands and runoff volumes and;
5. hypothetical designs of rainwater and graywater systems

1 Background and History

Rainwater Harvesting

Rainwater harvesting is the capture and storage of rainfall for later use. The idea of capturing rainwater is not a new one, evidence suggests that water harvesting has been practiced as far back as 5,000 years ago in Iraq, ranging from simple ways of diverting runoff for agriculture, to complex reservoirs dug into mountains (Oweis et al. 2004). There is also evidence that water harvesting was also used in India and China more than 4,000 years ago. The need for water harvesting was essential because other water sources had yet to be made available, mainly the ability to pump ground water supplies (Oweis et al. 2004). It is estimated that there are 250,000 roof systems in the United States (Thompson, 2000).

As technology and development have advanced, large amounts of water have been made available from reservoirs, ground water and canal systems, often times hundreds of miles in length. Because of this, much of the rainwater harvesting techniques have been abandoned, except in the developing parts of the world where clean water is scarce. In Bermuda, law requires new construction to include rainwater harvesting. In places like China, Brazil and Thailand rainwater harvesting is commonplace (Gould, 1999).

Graywater

In contrast, the idea of graywater is more recent, due to the recent advent of plumbing fixtures like sinks and showers. Graywater is wash water coming from showers, washing machines and sinks. Kitchen sinks and dish washers are not included because of the organic matter commonly found in each. While not a

Right: Graphs showing California water usage at the State and Urban scales.

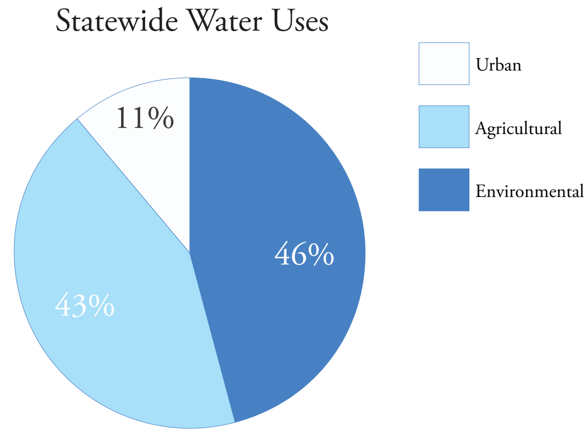
mainstream idea, it is an under utilized source of water that is produced on a daily basis by any building that contains people. According to Oasisdesign.net, it is estimated that there are 1.7 million graywater systems in California and of that, approximately 200 of those systems have been permitted. The major obstacle for graywater in California has been the restrictive code associated with it; this will be discussed in more detail in section 3.

Combining the Two

Most literature about rainwater harvesting only briefly mentions graywater and most graywater literature only briefly mentions rainwater harvesting. While it is certain that dual systems exist, either combined or working independently of each other, it is important to consider both, as reliance on any one water supply would not be wise, nor an effective use of resources.

Water Use in California

Water can be divided into three broad categories, urban, agricultural and environmental. Environmental water use is not as self explanatory, but it is water used for the Bay /Delta estuary, maintaining instream flows



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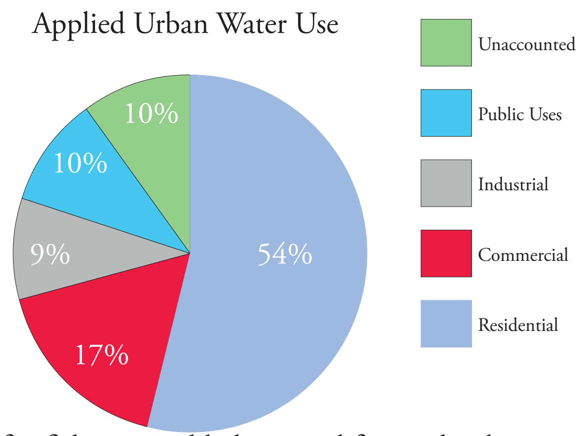
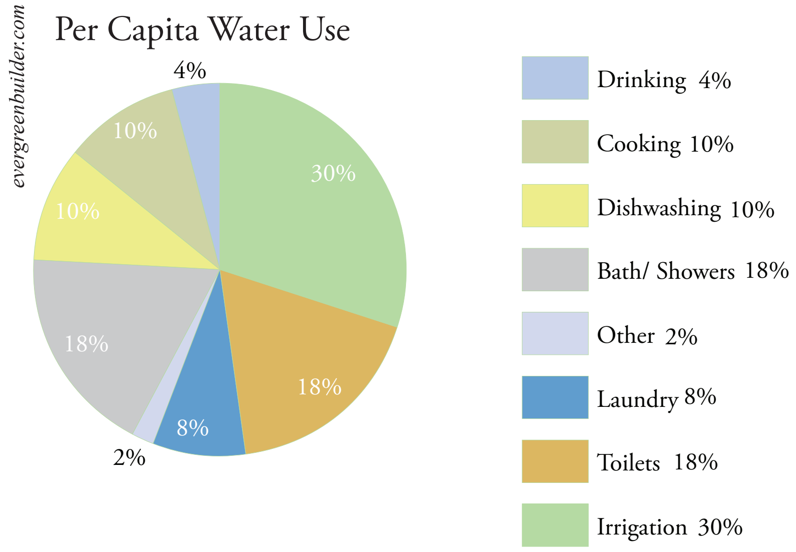


Jeff Loux

for fisheries and habitat and for wetlands.

This project deals with the urban water sector, specifically the commercial and residential applications of water, which makes up approximately 71 percent of California's urban water use. Other water users are industrial and public (including parks). Unaccounted for water refers to pipeline leaks, evaporation from reservoirs, treatment plant losses and non-



Left: Graphs showing average per capita water use in California

metered water use.

Individual Water Use

Water use per capita varies greatly depending on location and lot size. In general 50% - 80% of indoor domestic waste water would be considered graywater and therefore have the potential for reuse (Oasisdesign.net). The largest user of water is in the landscape and it is the opinion

LeafsXGutter Covers

Above: Specialized gutter that sheds debris. Preliminary screening of large objects like twigs and leafs can increase water quality and reduce maintenance

Right: Schematic the "wet system" delivery method

Below: Simple rain barrel connected to downspout

Heather Kinkade-Levario

2 Overview of Rainwater and Graywater Systems

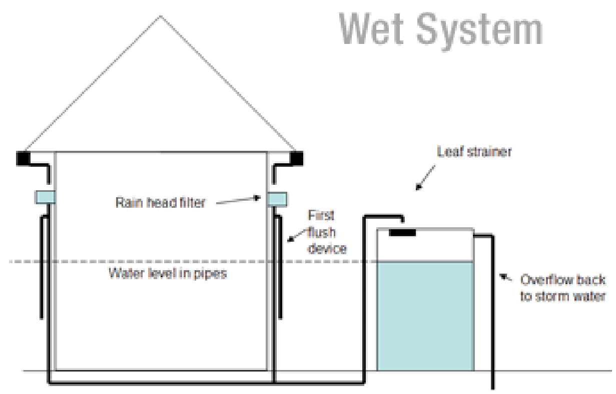
This section will briefly describe the parts that make up typical rainwater harvesting and graywater systems, as well as future applications of both.

Typical Components of a Rainwater Harvesting System

Adapted from "Design with Water"

1. Catchment area
2. Conveyance: pipes, channels, gutters
3. Roof washing
4. Storage
5. Distribution

For most projects, much of the needed infrastructure for a rainwater harvesting system is already included. For example all buildings come with a roof for rainwater catchment. Depending on the materials used, estimated runoff varies, as a metal roof will shed more water than a wood shingled roof. Buildings also assume the cost of gutters and downspouts which convey rainwater. A more complicated approach would be to use a "wet system" which relies on the head pressure to deliver water, the benefit of this is that storage



Storm Sustainability

tanks do not need to be located right next to a structure, allowing for a more flexible design without the need for pumping.

Other items like roof washing includes

leaf guards and various screens for gutters to filter out debris and first flush devices that allow a determined volume of water to be directed away from the storage unit to minimize pollutants and contaminants.

Typically storage is the largest investment for a rain harvesting system and can be divided into three classes: Surface or above ground storage, Below-grade/ underground storage and

Rainwell.com

storage built into buildings or other structural units (Kinkade-Levario, 2007).

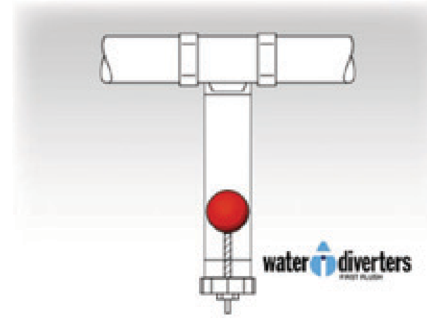
Storage also contains other minor parts, including water inlet, water outlet, overflow, maintenance access and a sturdy foundation to minimize soil settling. Storage tanks come in many shapes, colors and materials. Typical tanks are made of plastics, fiberglass, wood and metals, while larger tanks are often constructed with concrete. A common complaint of rainwater harvesting systems is that the tanks are considered unsightly. This does not have to be the case, the wide variety of shapes, colors and materials allow tanks to be adapted to fit many design aesthetics.

Stored rainwater can be distributed by gravity or the use of pumps, but because most

Keep it Green LLC

irrigation systems require a minimum of 20 psi, pumps are usually needed (Melby, 2002).

The last component of a rainwater harvesting system is purification, but because this document will not deal with potable water supplies purification will be discussed further in the graywater components section to follow. (Kinkade-Levario, 2007)



Rainharvesting.com

Above: First Flush Diagram, Water enters the vertical section from above and fills until the red float reaches the top, blocking the entry. The remainder higher quality water is directed through the horizontal section

Far Left: Above ground metal tank

Left: Two below ground plastic tanks

Below: Large storage tank showing first flush device and overflow piping.

ARCSA

PuraUV.com

Above: nano filters and UV disinfection

Below: Graywater filter

Matala USA

Below: Wash machine graywater pumped directly to the garden

Tim Drew

Graywater Systems

1. Graywater sources
2. Conveyance; plumbing
3. Storage
4. Distribution; pumps
5. Purification

Similar to rainwater, much of graywater system infrastructure is already assumed in design and construction. Buildings include the sources of graywater, which is wash water coming from sinks, showers and washing machines and excludes water from kitchen sinks and dish washers due to the organic materials.

Water and waste water plumbing are also assumed costs. The main difference when plumbing with graywater is that instead of sending all waste water to a septic or sewer system, graywater is piped separately. Additionally, when using non-potable water to flush toilets a separate pressure piping system must be implemented.

It is recommended that graywater storage should be limited to no more than 24 hours before it is completely drained (Melby, 2002). This is because of the multiplication of bacteria that can cause septic conditions and unpleasant odors.

Most home graywater systems are simple, releasing the water to the landscape by gravity as it is produced. More complex systems can require pumps, and storage, but maintenance can become an issue.

Treatment of graywater should include some form of filtration and disinfection (depending on its end use), to allow for increased storage times and the possibility for alternative forms of irrigation other than subsurface, which is water released through perforated piping below a layer of soil or mulch. To minimize extra costs, over treatment of water should be avoided.

Ways to filter rain and graywater include sand filters which are effective at removing particulate matter and if filtered slow enough the sand can support microorganisms that can breakdown pollutants and other harmful bacteria. Similarly, coarse soils with plant materials can be used to filter out particulates. Other methods include activated charcoal, reverse osmosis and nano-filtration (Kinkade-Levario, 2007).

Some disinfection can take place during the filtration process, but for higher levels of water quality additional means should be considered. Other methods for disinfection are chemical treatments, ultraviolet light and ozonization (Kinkade-Levario, 2007). Although chemicals should generally be avoided or used sparingly because of the toxicity to plants, such as chlorine.

Similar to recycled water, graywater contains higher levels of salts and is therefore more alkaline. Special attention should be placed on plant selection as salts can damage plants and alkaline conditions restrict the plant pallatte, although it has been found that when water is applied directly to the soil surface, many salt sensitive plants show little or no symptoms of stress (Wu et al. 1999).

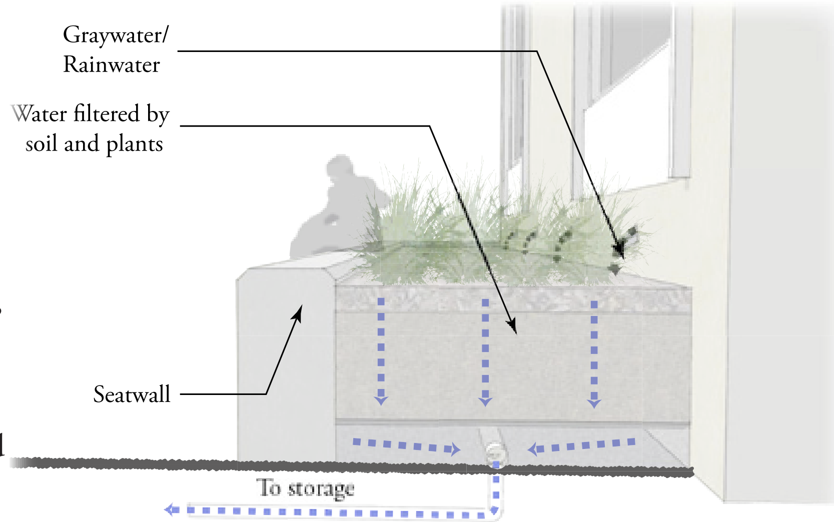
Future technology and ideas

Graywater and rainwater can prove themselves as a viable water supply of the future, but innovations in technologies and more importantly better regulations can help provide assistance into making them commonplace.

Incorporating water treatment, storage or conveyance into other design elements, such as planted seatwalls and shade canopies, offer multi-funtionality as wells as more transparency in design, adding an educational element.

Some companies have developed stackable units that have enough structural integrity to support large vehicles, while maintaining over 90 percent void space to allow for increased water storage. This is compared to the void space of backfilled gravel of approximately 30 percent. The major constraint with products like these, typically increase costs due to excavation and materials.

For graywater to increase its utility, storage is necessary and preferable on larger projects, because of the fluctuations in seasonal irrigation demand. For longer storage times without foul smelling or bacteria infested water, graywater must be treated. One way of achieving this, at least partially, would be the incorporation of



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Left: Section of a flow through planter. Graywater and rainwater are filtered by the plants and soil, then directed to storage, sewer system or other outfall.

Below: A water wall that allows sunlight to penetrate. Water walls act as a thermal mass to moderate indoor temperatures. In the future they may serve as storage for rainwater and graywater, for dual benefits.

David Bainbridge

Below: Shade canopies that also collect rainfall

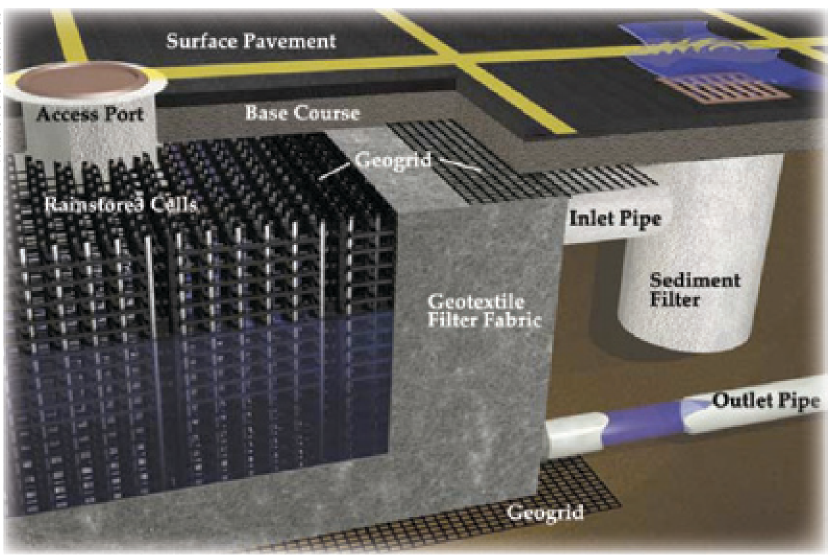
Heather Kinkade-Levario

Oasis Rainwater

Above: Cistern that mimics a tree trunk. To provide more visual interest storage can take many forms

Below: Stackable units that has 94% void space and provides enough structural integrity for vehicle loading

Invisible Structures



infiltration or flow through planters that can provide a preliminary filtration and disinfection of gray and rainwater. Soils can filter out particulates, pollutants and bacteria. Due to soil temperature, moisture and the presence of other microorganisms, some bacteria found in waste waters have a difficult time surviving (Hygnstrom, 2006). Infiltration planters can be situated along the walls of buildings, providing a multi-functional design element that not only provides preliminary treatment for rain and graywater, but acts as a seating element for relaxation and encouraging social interactions.

Storage could also be incorporated into architectural and building elements like seatwalls, building columns and walls. Water walls have been used for passive solar designs to moderate indoor temperatures by providing as a thermal mass (Bainbridge, 2005). They could also be used as a method to store rain and graywater, while occupying minimal space and buffering temperatures.

To increase the potential of rainwater collection, shade structures can be used to increase the total catchment area, while providing shade as well as visual interest for occupants.

3 Graywater Code and Water Policy

Graywater Code

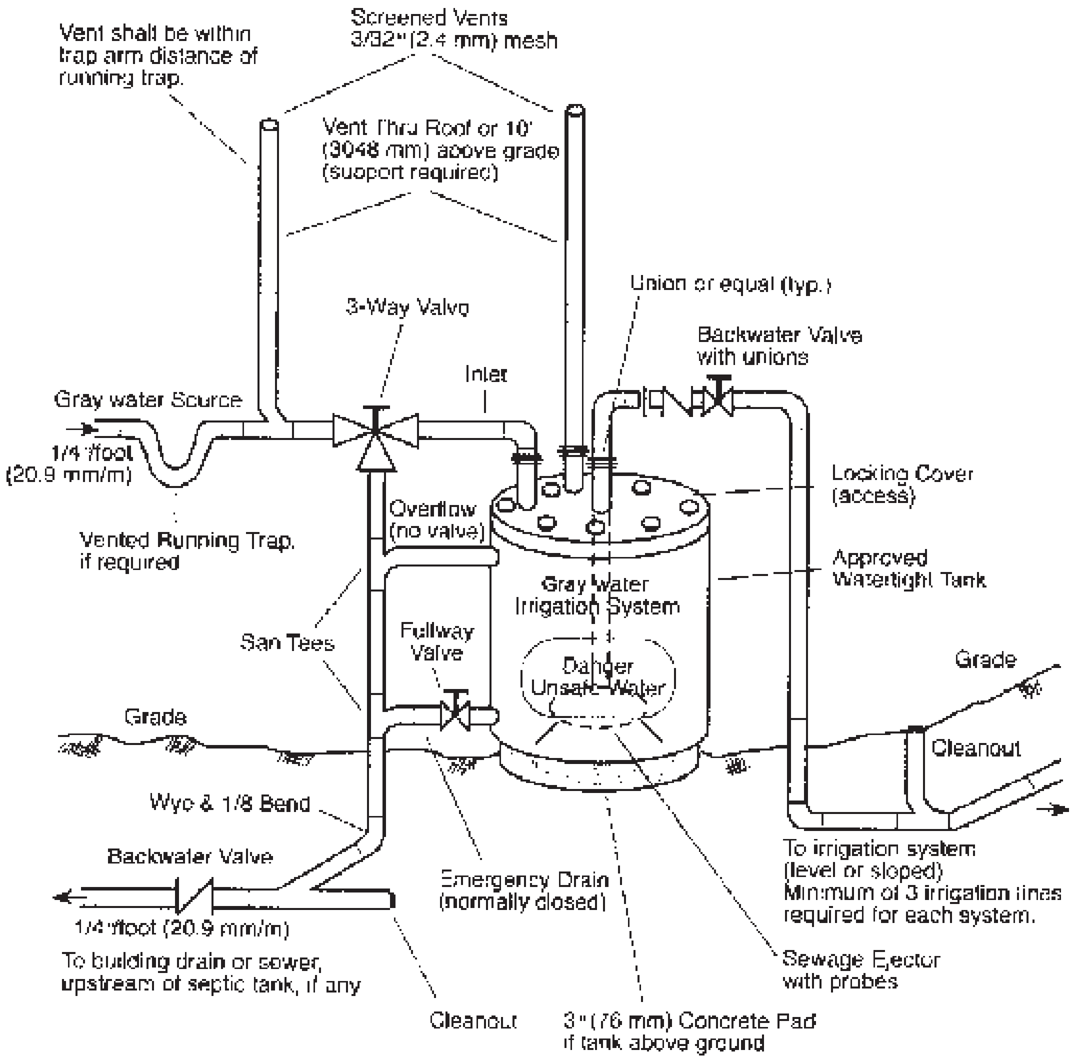
Chapter 16 of the 2007 California Plumbing Code is adapted from sewage leach field disposal code, because of this there are many restrictions and very low conformity. Advocates of graywater feel that they are unnecessarily stringent for water 1,000 times cleaner than combined sewage (Oasisdesign.net). Graywater code is currently under review in California and has been open to comment by consultants, the public and others interested in graywater. Here are some key components of current graywater code:

1. All gray water systems require a permit
2. Irrigation of graywater cannot be within five (5) vertical feet of the highest seasonal water table
3. No graywater can be discharged to a body of water
4. Soils must meet a maximum and minimum absorption capacity over a twenty-four hour period
5. Graywater systems shall be designed to distribute the total amount of estimated graywater on a daily basis, i.e no storage over 24 hours
6. Soil types determine area needed for irrigation/ disposal
7. All piping and storage shall be permanently marked with "GRAY WATER IRRIGATION SYSTEM, DANGER---UNSAFE WATER"
8. Graywater must not daylight, meaning that irrigation must be covered by 10 inches soil or mulch, to reduce human contact.
9. Holding tanks shall be made of steel, protected from corrosion by an approved coating. Other materials can be used but they

Table G-2 Mini-Leachfield Design Criteria of Six Typical Soils

Type of Soil	Minimum sq. ft. of irrigation area per 100 gallons of estimated graywater discharge per day	Maximum absorption capacity, minutes per inch, of irrigation area for a 24-hour period
1. Coarse sand or	20	5
gravel	25	12
2. Fine sand	40	18
3. Sandy loam	60	24
4. Sandy clay		
5. Clay with considerable sand or gravel	90	48
6. Clay with small		60
amount of sand or gravel	120	

Above: Chart detailing soil absorption criteria and minimum irrigation/ disposal area for different soil types



Above: Schematic for a graywater system with a pump. Some feel that the diagrams provided in the California Plumbing Code are too complicated for the average person

must be approved by the authority having jurisdiction.

A meeting was held in April of 2009 by the Department of Housing and Community Development for the triennial code adoption cycle to be implemented into 2009/ 2010 California Plumbing Code regarding graywater code. The purpose of this meeting was to receive stakeholder input to draft new language into the graywater code. Generally participants wanted to see fewer restrictions. The key revisions to the draft of Chapter 16 and if approved will be adopted into the new code for graywater are as follows:

1. Permits will not be required for a Clothes Washer System or a Single Fixture System, which are defined as a graywater system utilizing only a single domestic clothes washing machine or a graywater system collecting graywater from only one plumbing fixture respectively. This is based on the premise that these systems would be relatively simple for the average person the construct and have minimal impacts.

2. Graywater can be used for indoor uses such as toilet flushing and urinals if it is treated by an on-site water treatment system approved by the enforcing agency, meeting Title 22 standards.

3. Subsurface drip irrigation can be used as long graywater does not surface and it is covered a minimum 8 inches below the surface.

Senate Bills 221 and 610

For large residential subdivisions of generally 500 units or more or 10 percent of a total water purveyors connections, a water supply assessment must be done to ensure that the development will have an adequate and reliable water supply without compromising existing water users (Loux, 2004). Senate Bills 221 and 610 can encourage increases in the use of graywater and rainwater by reducing the amount of water need for proposed developments.

Requiring water supply assessments is crucial when it comes to managing our water supply effectively. Developers may be able to use gray and rainwater to provide much of a proposed developments non-potable water demands, putting less pressure on existing water purveyors and making it easier to get projects built, especially in areas with limited available water supplies. Rainwater harvesting and graywater can work together with SB 221, 610 and developers to move our water supplies to a more reliable framework.

The Water Conservation in Landscaping Act of 1992

Title 23 in the California Code of Regulations, seeks to establish methods of water conservation and required Cities and Counties to adopt a water-efficient landscape ordinance by January of 1993 (Loux, 2004). No penalties were enforced for non compliance. Title 23 was updated with increased restrictions on water use and will be applied to all local agencies, cities and counties by January of 2010. The Water Conservation in Landscaping Act can work to help increase the cost effectiveness of gray and rainwater systems by reducing landscape irrigation needs and therefore storage requirements, which is usually the largest up front cost.

Jeff Loux

Many policy and management strategies aim to increase irrigation efficiency (above) and to reduce irrigation requirements, especially by limiting lawn areas (below)

Jeff Loux

4 Determining Non-Potable Water Supplies and Demands

To develop a meaningful senior project it was necessary to calculate the water supply and demand volumes to make informed design decisions. Three land use examples were adapted from a proposed development, West Village, in Davis, California, to provide the basis for the calculations. Floor plans were used to determine areas and plumbing fixture counts.

Determining Graywater Supply and Toilet Demands

According to Appendix A of the 2007 California Plumbing Code, all water using fixtures are associated with a Water Supply Fixture Unit.

Example:

Sinks. 1.0
Clothes Washer. 4.0
Dishwasher. 1.5
Bathtub or Combination Bath/Shower. . . 4.0
Shower. 2.0
Water Closet 1.6 GPF. 2.5

All fixtures were counted based on the provided floor plans for the West Village development. The total count of each fixture was then multiplied by its respective fixture unit and added to the multiplied totals of all the other fixtures.

Example:

24 sinks at 1.0 units each. 24.0
12 Water Closets at 2.5 units each. 30.0
10 Showers at 2.0 units each. 20.0
2 Dishwashers at 1.5 units each. 3.0
5 Clothes Washers at 4.0 units each. 20.0

97.0 total fixture units

To determine the volume of graywater, all the units from each of the graywater sources are added up then divided by the total number of fixture units.

Example based on numbers above:

24 units from sinks, 20 units from showers and 20 units from clothes washers.

24 + 20 + 20 = 64 units from graywater sources.

64 / 97 = 66% of the total water used is graywater.

The same process is done for toilet demands

30 / 97= 31% of the total water is used for toilet flushing

The volumes are then derived based on these percentages of total use. This document assumes that each resident uses 85 gallons of water per day for indoor domestic. Based on the example calculated above this means that 56 gallons per day per person will be graywater and 26 gallons will be used for toilets.

Determining Landscape Irrigation Demands

All landscape irrigation volumes were estimated using "A Guide To Estimating Irrigation Water Needs of Landscape Plantings in California The Landscape Coefficient Method and WUCOLS III"

Table 3—
Summary Table
Values for Landscape Coefficient Factors

	High	Moderate	Low	Very Low
Species Factor* (k_s)	0.7-0.9	0.4-0.6	0.1-0.3	<0.1
Density (k_d)	1.1-1.3	1.0	0.5-0.9	
Microclimate (k_{mc})	1.1-1.4	1.0	0.5-0.9	

This method uses a series of coefficients to estimate monthly irrigation needs. The Landscape Coefficient is based on the product of 3 factors, species, density and microclimate. The species factor is based on the species of plant used and can be found using the WUCOLS list.

The density factor is based on the existing or proposed densities of plantings, a value of 1.0 indicates and average density or about 70%-100% canopy cover. When multiple tiers of planting are used in higher densities i.e. shrubs mixed with trees would constitute high density and be assigned a value over 1.0.

The Microclimate factor is based on site conditions. In areas like parking lots or south facing walls that will absorb heat and increase evaporation would be assigned values over 1.0, conversely protected areas would be assigned values less than 1.0.

Reference evapotranspiration is the

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Above: This group of plantings would be considered of low density (0.5-0.9)

Below: Shrub massing of a single species with a canopy cover of 70-100% is consider an moderate density (1.0)

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Right: Example worksheet to estimate landscape water needs. Adapted from "Guide To Estimating Irrigation Water Needs of Landscape Plantings in California The Landscape Coefficient Method and WUCOLS III"

Below: Monthly precipitation compared to evapotranspiration. Adapted from Cunningham Engineering worksheets.

Month	Precip	ET	Net
Jan	3.7	1.2	2.5
Feb	3.0	1.5	1.5
Mar	2.2	3.2	-1.1
Apr	1.2	4.7	-3.5
May	0.4	6.2	-5.8
Jun	0.1	7.7	-7.6
Jul	0.0	8.1	-8.1
Aug	0.0	7.1	-7.1
Sep	0.2	5.1	-5.0
Oct	0.9	3.4	-2.5
Nov	1.9	1.4	0.5
Dec	3.2	0.7	2.5
Total	16.8	50.3	-33.5

Worksheet for Estimating Landscape Water Needs

Step 1: Calculate the Landscape Coefficient (K_L)

K_L formula: $K_L = k_s \times k_d \times k_{mc}$ .... k_s = species factor; k_d = density factor; k_{mc} = microclimate factor

k_s = ______ (range = 0.1-0.9) (see WUCOLS list for values)

k_d = ______ (range = 0.5-1.3) (see Chapter 2)

k_{mc} = ______ (range = 0.5-1.4) (see Chapter 2)

K_L = _____ x _____ x _____ = _____ .
(k_s) (k_d) (k_{mc})

Step 2. Calculate Landscape Evapotranspiration (ET_L)

ET_L formula: $ET_L = K_L \times ET_o$ .... K_L = landscape coefficient; ET_o = reference evapotranspiration

K_L = ______ (calculated in Step 1)

ET_o = _____ inches (listed in Appendix A for month and location)

ET_L = _____ x _____ = _____ inches.
(K_L) (ET_o)

Step 3. Calculate the Total Water to Apply (TWA)

TWA formula: $TWA = \frac{ET_L}{IE}$ .... ET_L = landscape evapotranspiration; IE = irrigation efficiency

ET_L = ______ (calculated in Step 2)

IE = _______ (measured, estimated, or set) (see Chapter 5)

$TWA = \frac{ET_L}{IE}$ = ______ inches

amount of water lost due to evaporation and plant transpiration.

Irrigation efficiency is based on the idea that a typical system does not deliver all the water to made available to plants i.e. some is lost to runoff, wind spray or leakage. To simplify the estimation, overhead sprays and rotors are estimated to be about 65%-75% efficiency, as opposed to drip systems which can work at greater than 90% efficiency.

To calculate the total number of inches required to irrigate a given landscape, divide the product of the Landscape coefficient and reference evapotranspiration and divide it by the irrigation efficiency used as a fraction.

Once you have determined the inches required, you can multiply that by the total square footage of the planting area in question. To convert this to gallons multiply by the conversion factor of 0.62. This will be the number of gallons required to irrigate the given landscape during a given month.

Determining Rainwater Runoff Volumes

For the purposes of this document runoff was only assumed to be collected from two types of surfaces, rooftops and paving. Different surfaces are associated with different runoff efficiencies. Metal sloped rooftops can be expected to have a runoff efficiency of around 90%, whereas paved surfaces have runoff efficiencies around 80%. Rainfall is also needed to determine runoff volumes. Sample Calculation:

April has an average rainfall of 1.23 inches and you expect to collect water from a 1,000 square foot roof top (Note: The area is independent of the slope of the roof, it is based on the horizontal area) and 2,000 square feet of paving.

Rooftop
1,000 ft^2 X 90% X (1.23 in /12 inches per foot) = 92.25 cubic feet/ month (Note: 1.23 in divided by 12 to convert units to feet) = 690 gallons

Paving
2,000 ft^2 X 80% X (1.23 in /12) = 164 cubic feet = 1,226 gallons

Formula for calculating runoff:
Area X runoff coefficient X Rainfall

One cubic foot = 7.48 gallons

5 Applied Designs

The following section contains hypothetical designs for combined graywater and rainwater systems. Building design character, footprints and arrangement were adapted from the City of Davis West Village Implementation Plan. The designs of the surrounding landscapes and water systems are that of the author. Other assumptions used in the designs are as follows:

1. Per capita indoor water use was assumed to be 85 gallons per day, all graywater production and toilet flushing volumes are based on this.

2. Treated graywater will be allowed only for flushing toilets and is of high enough quality to allow for storage of more that 24 hours and irrigation above the surface, irrigation efficiency estimations reflects surface irrigation.

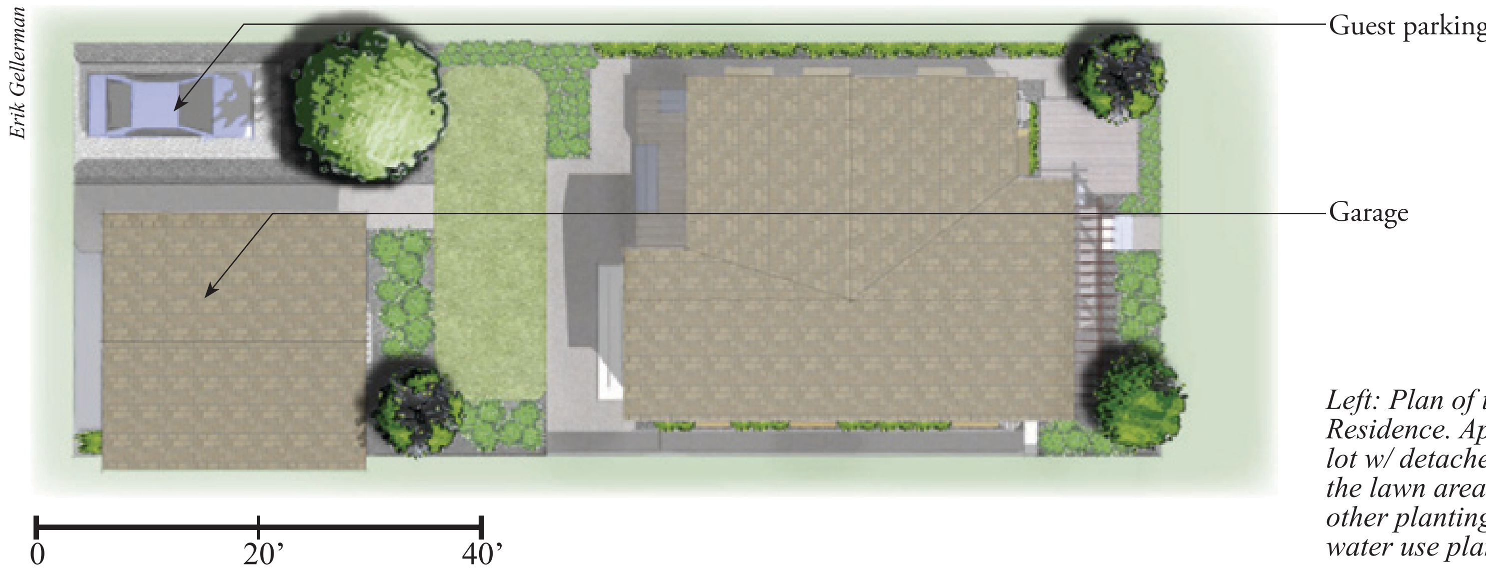
3. Other than turf grass areas and bioswales, all other irrigated plantings are assumed average as low water using plants taken from WUCOLS and the landscape coefficient method. On a scale of 0.1 to 0.9, 0.3 was the assumed average species factor for the drought tolerant planting areas.

4. All turf grass was assumed to be warm season varieties, therefore using less water.

5. Storage was determined by adding the peak daily toilet flushing demands and the peak weekly irrigation demands.

6. An effective rain volume of 50% was used, meaning that only 50% of the total rain volume was assumed to be used by plants.

7. Storage requirements were determined by adding the volumes of peak daily toilet flushing demands and peak weekly irrigation demands. This was done in the absence of an irrigation schedule, which would offer more accurate storage calculations.



Left: Plan of the Single Family Residence. Approximately 4,500 sf lot w/ detached garage. Other than the lawn area in the backyard all other plantings are considered low water use plantings

Authors Note

A conscious effort was made to design areas that are not only water conserving, but realistic and applicable in a real world context. Landscape water needs could have been made next to nothing by proposing more paving, large non-irrigated mulched areas and very low water use plantings; instead, adequate turf grass areas were designed where appropriate, planting variety was allowed some flexibility by assuming an average species factor on the higher end of low water use and sufficient landscaped areas were provided to avoid large unused mulch areas where possible.

Single Family Residence

Single family detached homes are a prominent form of housing in the United States and therefore are important to analyze the applications of gray and rainwater in this setting. It should be noted that this example is not a typical single family lot size and would be considered a small lot by American standards, being around 10 density units per acre. Although with increasing costs of land, housing developments of comparable densities will become more commonplace. As a result of the smaller lot size, total irrigated landscape area is also diminished, making rainwater harvesting

Sanjib Lemar

Above: Typical single family house with excessive lawn and boring landscaping.

Above Right: Front yard showing diverse drought tolerant landscaping and metal cisterns.

Below Right: Back yard with adequate lawn area surrounded by drought tolerant plantings. Reserve rainwater cistern attached to the garage.

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and graywater reuse a more viable option as a non-potable water supply because of the overall decrease in water demand.

Project Specifics

Lot Size: *4,500 ft^2*

Catchment Area: *1,000 ft^2 house footprint with 600 ft^2 garage*

Total Storage: *600 gallons below deck, 400 gallons in above grade cisterns*

Left: Schematic of graywater and rainwater flows

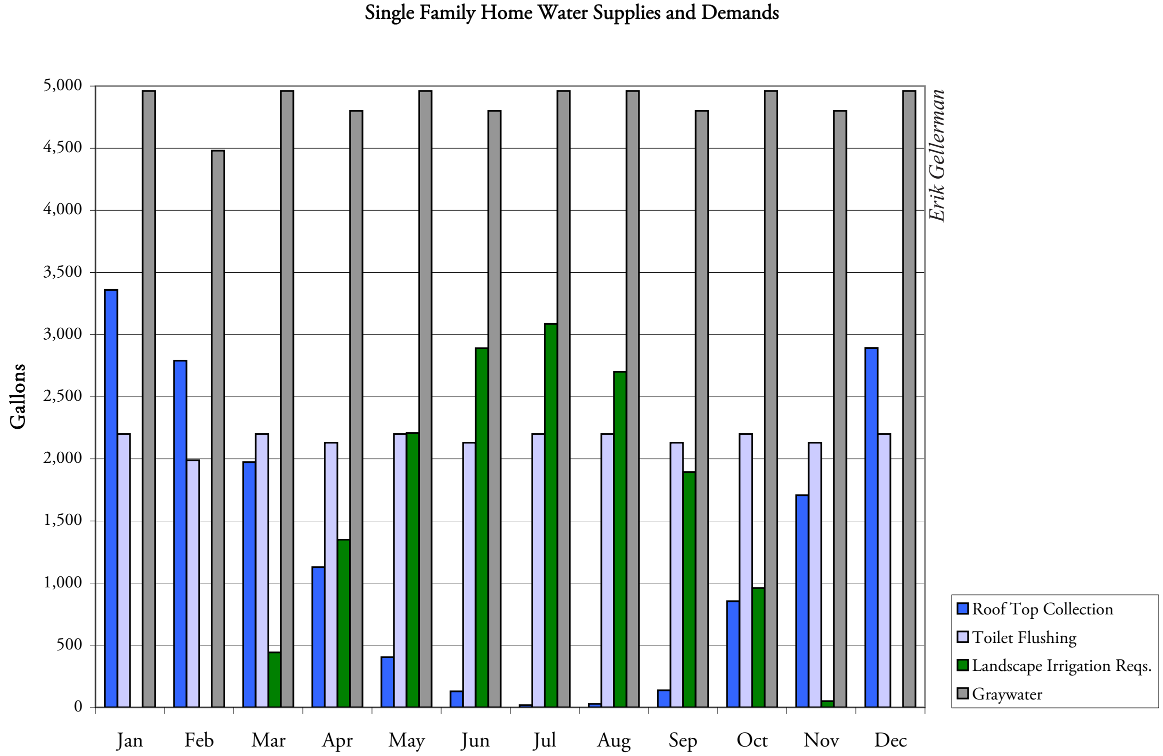
Total Irrigated Landscape: 1,*170 ft²*. *(870 ft² drought tolerant plantings and 300 ft² lawn)*
Occupants: *Three (3)*

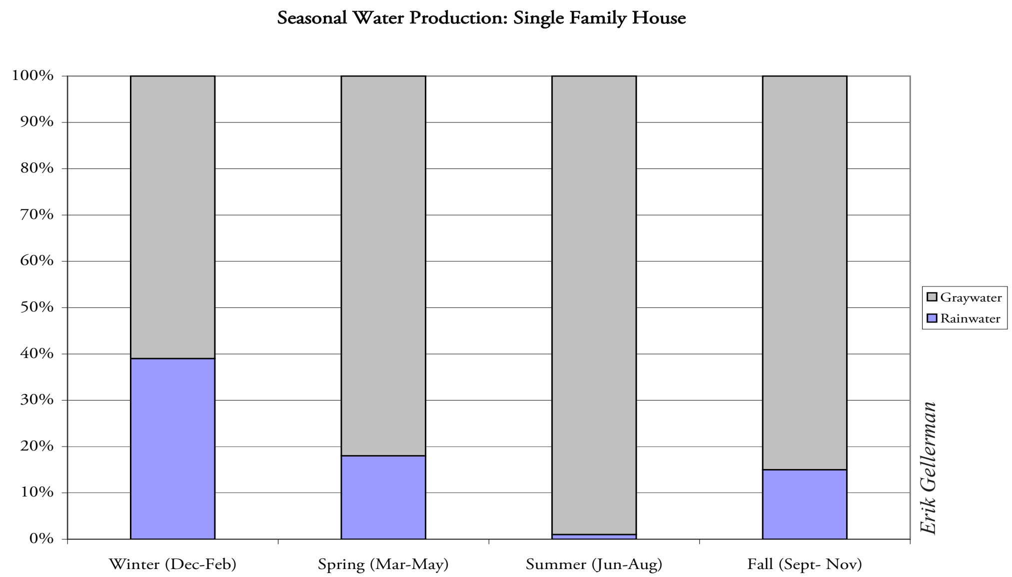
In this design, rainwater is collected only from the rooftops of the garage and the house and directed into above ground cisterns as well as a series of connected tanks below the deck in the back of the property. Two 100 gallon cisterns are located by the front of the property and a 200 gallon cistern located next to the garage as a back up water supply.

All graywater produced by the residents is filtered and disinfected to allow for increased storage times, then directed to the below deck tanks with a capacity of 600 gallons or 80 cubic feet. From here water will be extracted as needed for landscape irrigation and to refill the above ground cisterns. These cisterns will be used to supply the house with its toilet flushing demands and some adjacent irrigation needs for the thin planting strips along the side of the house. When the below deck tanks become full, overflow will be directed to the sewer system. In contrast, cistern overflow due to rainfall will be directed

Above Right: Chart showing monthly water demands from irrigation and toilet flushing as well as graywater and rainwater production.

Below Right: Seasonal variation in storage water composition. About 40% rainwater to graywater in the Winter compared to almost none in the Summer.





to the below deck tanks to maximize the ratio of rainwater to graywater.

On average only three months out the year (December – February) will not require supplemental irrigation. In the wet months the cisterns will remain generally full with some fluctuations. May through September, when irrigation demands are higher, water levels in the tanks will drop to almost empty after an irrigation cycle then slowly be filled by the extra graywater throughout the week.

The cisterns surrounding the house will provide all the irrigation needs except in June and July when the 200 gallon reserve tank by the garage will fulfill the remaining irrigation needs until demands decrease in the fall.

Right: Plan of apartment cluster

Below: Typical apartment complex, excessive use of lawn areas requires large amounts of irrigation

Apartment Cluster

In the Master Plan for the Davis West Village project, there is a substantial section of apartment style housing for students. The apartments are divided into clusters of three to four buildings that run along a pedestrian pathway called the Ramble. A single cluster was analyzed and used as a prototype. Each cluster is arranged around a central open space or courtyard.

Project Specifics

Lot Size: *20,000 ft²*

Catchment Areas: *3 buildings, 8,900 ft² building footprints, 3,500 ft² paving*

Total Storage: *3,000 gallons above ground cisterns, 11,000 gallons below courtyard*

Total Irrigated Landscape: *16,700 ft². 12,200ft² drought tolerant, 2,000sf turf and 2,500sf swales*

Occupants: *114*

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Left: Entry to apartment cluster. Two wooden cisterns frame the entrance and help to distinguish the clusters from each other.

Below Left: The courtyard has grass and seating for social interactions. The plantings by the seating intercept runoff from paving and direct to the cistern below the paving. There are four 20' tall cisterns facing the courtyard

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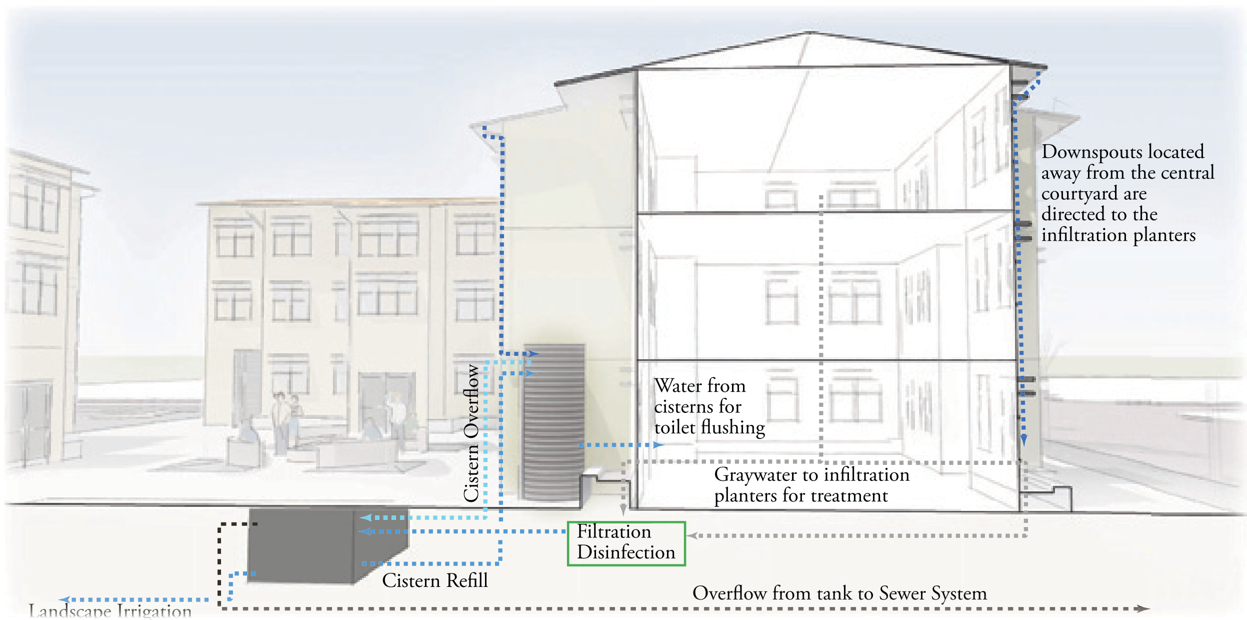
To celebrate the idea water capture and reuse, two cisterns were placed at the entry, which can also be used to distinguish each of the clusters in the development. Four other cisterns are located on the courtyard side of the buildings.

Graywater from the buildings is directed to various infiltration planters along the sides of each building, filtering through the plants and soil. The partially treated graywater will go through another stage of micro-filtration and disinfection. After the final treatment, the water will then settle in the underground storage unit below main courtyard. Irrigation

Right: Schematic detailing the movement of graywater and rainwater



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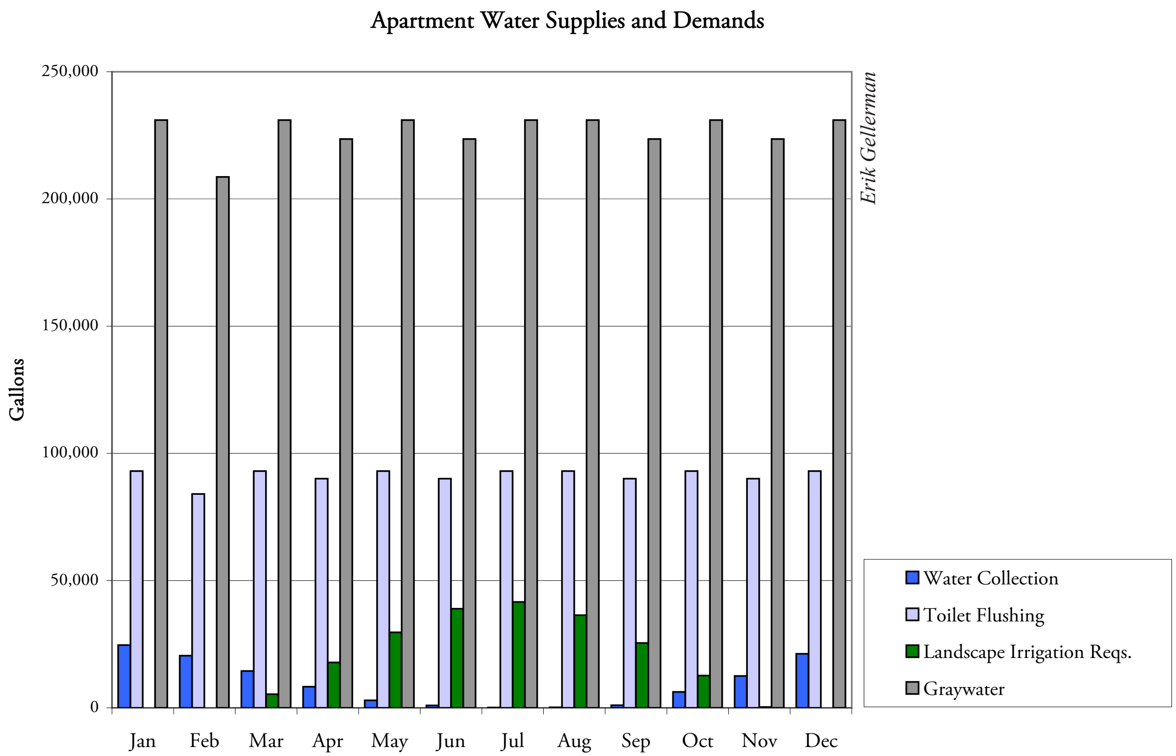
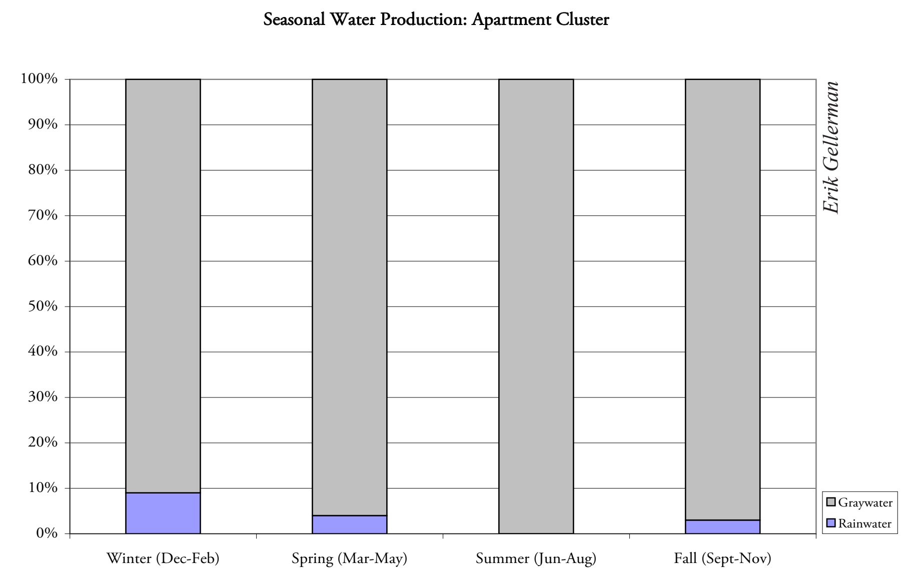
needs and cistern refilling will be taken from the underground storage unit as needed.

Rainwater is collected from all the rooftops as well as a portion of the paved area in the central courtyard. Rain on the rooftops will be direct to the above ground cisterns located along the courtyard side of the buildings where possible, while the rest will be sent to the infiltration planters to filter with the graywater.

Runoff from the courtyard will flow into the planters for filtration, then enter the below ground cistern. The above ground cisterns will provide the buildings with toilet flushing needs and be refilled when necessary from the underground storage unit.





Left: Chart showing monthly water demands as well as gray and rainwater production. Notice the difference between graywater volumes and all others.

Below Left: Seasonal variation in storage water composition. Less than 10% rainwater to graywater in the Winter compared to almost none in the Summer.

Right: Plan of the Village Square

Village Square

In the heart of the West Village development is a mixed- use area called the Village Square. Adapted from the West Village Implementation Plan, this area is meant to provide housing, jobs, retail opportunities and act as a social gathering area.

The Village Square was used as a model for more urban applications for gray and rainwater. It is composed of two, three stories buildings, with the first level being retail and office, while the top two stories are housing. A

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Left: The Village Square, with drought tolerant gardens, adequate lawn and plenty of seating, provides an interesting place for occupants. Two cisterns are located along the corners of each building to meet toilet flushing demands.

paved courtyard, turf area and garden area were included to encourage social activity.

Project Specifics

Lot Size: *24,000 ft²*

Catchment Area: *2 Buildings, 12,000 ft² total, 15,000 ft² from parking lot*

Total Storage: *13,000 gallons. 2,000 above ground cisterns, 11,000 below grade cistern*

Total Irrigated Landscape: *15,300 ft².*
5,000 ft² turf, 9,600 ft² drought tolerant, 700 ft² parking lot planters

Occupants: *56*

Rainwater is collected from the rooftops as well as a portion of the adjacent parking lot. Rain from the roof is directed into the cisterns where possible, while the rest will be directed to the infiltration planters on the sides of the buildings. Runoff from the parking lots is graded towards planters on the backside of the buildings, where the water flows through curb cuts and infiltrates into the soil and piped to underground storage unit located between the two buildings.

Similar to the apartment example, all

Right: Runoff from the parking lot is directed to the planters for filtering, then piped to the underground cistern located between the two buildings

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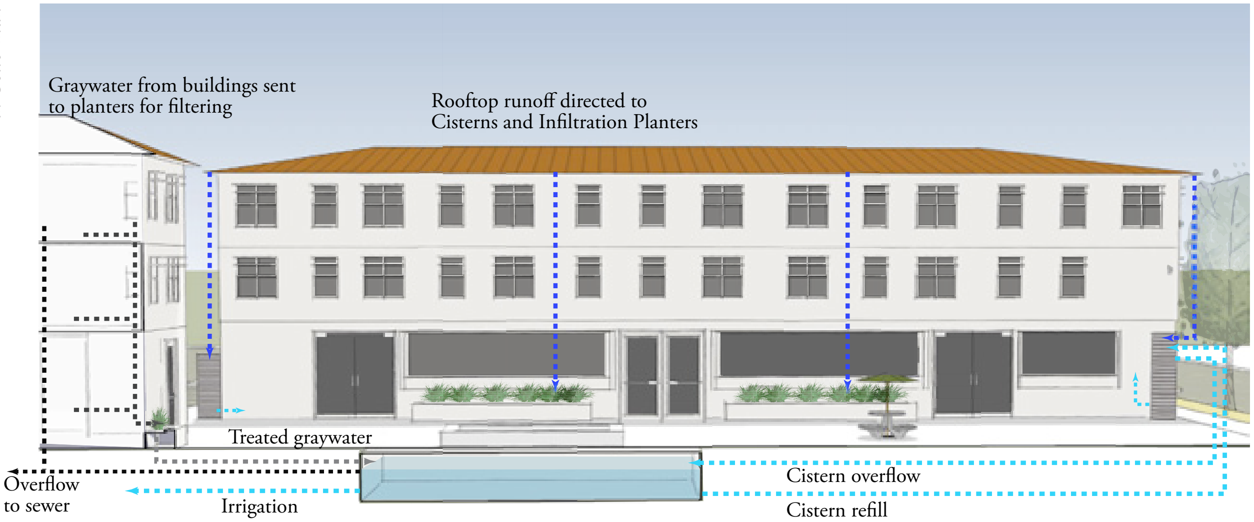
graywater is directed to infiltration planters located along the sides of the buildings for preliminary treatment. Secondary treatment of the graywater is provided by micro-filtration and disinfection and then sent to the below ground storage unit where it is pumped as needed for landscape irrigation and refilling the above grade cisterns.



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Left: Schematic of graywater and rainwater flows

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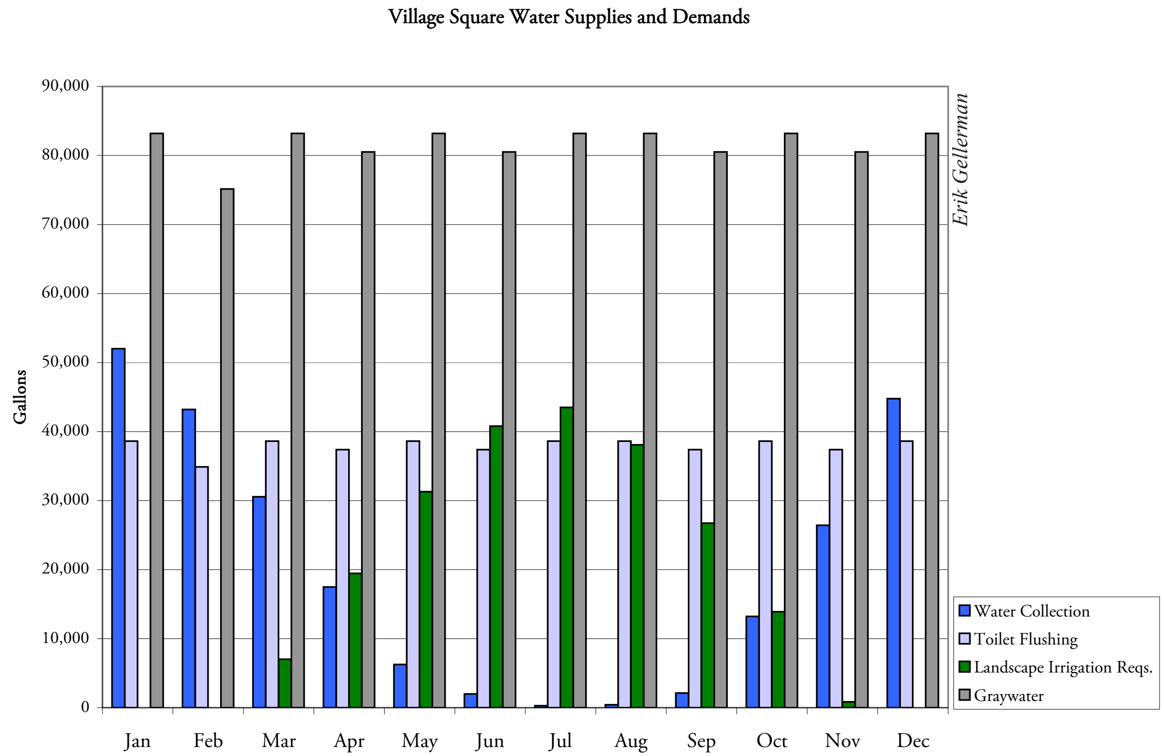
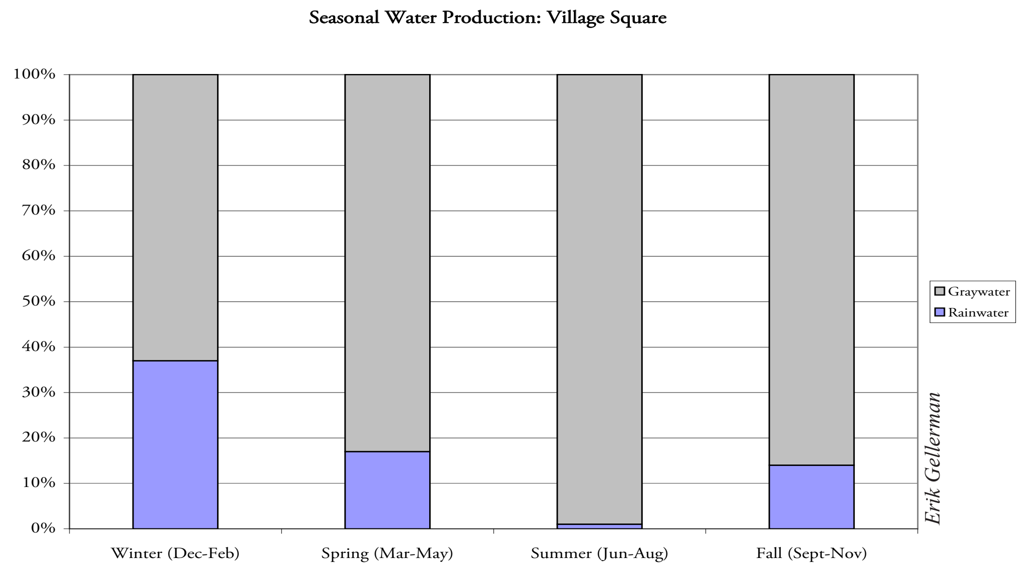


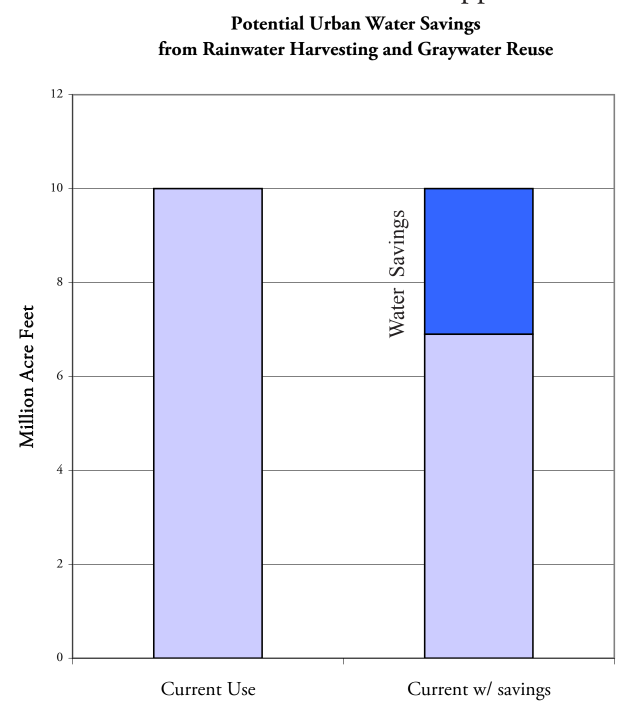


6 Conclusions

Growing populations and the danger of droughts will continue to stress our finite water supply. Water conservation is an important part of mitigating the problem, but can only take us so far. As conservation measures become better, the less we can rely on them to help us during water shortages. There is no reason potable water should be used only once when much of it has the potential for reuse in areas that do not require high water quality standards. Additionally, rainwater should not be neglected as it provides a seasonal supply of clean water.

If graywater and rainwater systems similar to ones proposed in this project, are adopted statewide by single family homes and apartment or loft style buildings, California could expect to save 3.1 million acre feet of water per year, a 31 percent reduction in urban use. However, the urban sector only uses about 11% of California's water. This means an overall reduction of about five percent in California's total water use.

Even with stressed water supplies it is



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unlikely that a rapid shift in rainwater harvesting and graywater reuse will occur in the near future. The costs of building retrofits for graywater and rainwater systems are more expensive than in new construction (Kinkade- Levario, 2007). Likewise, because of the added project costs, implementation of graywater and rainwater systems in new construction is not appealing when compared to the relatively low costs of municipal water. However, with water arguably our most important resource, it is imperative that we utilize every drop and reuse it when possible. Graywater and rainwater are relatively clean and produced on site. There are few reasons why we should not be using graywater and rainwater as a reliable water source for the future.

The Future of Rainwater Harvesting

In all cases rainwater alone was not enough to satisfy the water demands of toilet flushing and landscape irrigation, moreover, the unpredictable nature of rainfall, coupled with its seasonal fluctuations would make it difficult to rely on by itself as a supplemental water source.

In California, rainwater systems alone can require large catchment areas and large amounts of storage to supply water into the dry months as it is being drained and little to no rainfall enters. Many single family residences simply do not have the space to accommodate large tanks, whereas apartment complexes might have more flexibility in this area. Does this mean that it should be abandoned if enough storage can not be accommodated to supply 100 percent of non-potable needs, ? No, as the design examples showed, rainwater alone was not enough to meet even one of the demands without massive storage. Even if the start of the irrigation season is only delayed by a week or a month, harvesting rainwater is a very responsible way of saving our water resources and taking advantage of a very clean water source that might otherwise go down a drain.

The Future of Graywater

On the other hand, graywater, remains fairly constant throughout the year with some limitations, advances in water efficient fixtures will also reduce the amount of graywater produced. Nonetheless, it provides steady input throughout the year.

The major benefits to this is that there is a lower storage requirement, because of the constant water inputs. Additionally, water won't be stored as long giving it less chance for bacteria to multiply. Rainwater has the problem of seasonal flucuations, graywater has health and safety issues. This has made it difficult to implement graywater reuse on a large scale, partly because it is a relatively unknown subject and that public opinions are unsure of graywater. The health issues are a valid concern and graywater should not be used if it will damage human or environmental health. However, there has never been a report of illness due to exposure from graywater (Oasis design).

Regulations will likely loosen on graywater as public education is improved and its validity as an additional water supply are realized. This will inevitably increase the implementation of graywater systems. There are emerging technologies that filter and disinfect graywater. This is a promising field as it will allow for longer storage times and the possibility to use other forms of irrigation other than a subsurface leach field.

With so much Graywater, is Rainwater Harvesting worthwhile?

In the apartment and mixed-use designs larger quantities of graywater were produce in relation to the rainwater collected. In these instances should rainwater harvesting be ignored? No, if the investment is going to be made to treat, store and use graywater, it would be little added effort to include rainwater as well, assuming they use the same facilities. It is much cleaner than graywater, requires less treatment and would dilute graywater concentrations.

Architecture v.s. Landscape Architecture

At first glance, rainwater harvesting and graywater reuse seem to be more tied with architecture than landscape architecture. With irrigation as the highest water use in the residential sector, landscapes are a very important part of a well design rainwater and/ or graywater system. The best way to reduce water demands is by having a water conscious landscape, this in turn, reduces storage requirements and therefore costs. In addition to drought tolerant landscapes, salt tolerant plant selections are also important to insure a healthy landscape, because of the elevated salt levels in graywater.

It is also important to point out that graywater and rainwater can provide their own design aesthetic. Rainwater and graywater systems don't need to be hidden behind buildings, they can be visible and act as an important design elements, whether it be shade, seating or sculpture. They can also provide an educational element to users. Rainwater and graywater systems can and should be integrated functionally as well as aesthetically into the built environment.

Rainwater, Graywater and Scale

In the design examples, all systems were collected, treated and stored on site. This is not to say that it can't and shouldn't be done at larger scales.

Instead of house by house, neighborhoods could collectively send their roof runoff and graywater to a more centralized facility where it could be treated and redistributed, much like a waste water treatment plant would. A problem with this approach is that water has to be moved over longer distances, treated at a much larger scale then piped back the user from which it originally came. Additionally because of the large volumes of water a more intensive treatment facility would be required, meaning more coordination during the planning, not to mention the extra land needed to accommodate the facility.

A similar idea would be to have larger scale storage after it has been locally treated. In the design examples, the overflow water was piped to a sewer. This water could be sent to larger storage units, such as wetlands where habitat could be created and groundwater recharged.

Rainwater and graywater as a commodity

Another way that could promote the increased use of rainwater harvesting and graywater reuse is if it could be traded like a commodity. Current plumbing code restricts graywater to on site use only, but if it could be bought, sold and transferred, it would decrease the times that the systems pay for themselves by providing revenue, although this would probably only make sense at larger scales. For example, a large 20 story office and apartment building with little or no landscaping, would likely produce more graywater than it needs, the rest could be sold to neighboring lots as a supplemental water source. In the instances where surplus graywater or rainwater are produced, they would have the opportunity to be used instead being sent to a sewer system.

Parting shots

Based on the research, calculations and design prototypes, rainwater and graywater combined, offer significant volumes of water that have the potential to make a serious difference. Right now lack of knowledge and cost effectiveness are keeping rainwater harvesting and graywater reuse from reaching their potential. While simple home systems can be relatively inexpensive, the proposed designs are fairly complex, with treatment and large amounts of storage. The long terms costs of maintenance, particularly with the treatment, would likely make it more expensive than a municipal water source.

Because of the current regulations, treatment is an integral part for the advancement of graywater reuse. If effective ways to achieve adequate water quality standards are developed, the ways in which graywater can be used will dramatically increase with minimal risks to people and the environment. Conversely, less restrictive regulations would allow more use of graywater for landscape applications. Loosening restrictions should be done with caution by allowing graywater to meet its potential without endangering human or environmental health. Less restrictive code might be unavoidable for indoor uses like toilet and urinal flushing that need to meet Title 22 standards. Ultimatley meaning that indoor uses of graywater will require high levels of treatment and therefore incur high costs.

California is in great need of solving its water supply problems. Solutions will come in the form of not one, but many. Other solutions include the use of recycled water and conservation, both indoors and in the landscape. California needs to adapt its water portfolio to growing needs, rainwater and graywater are just two of those ways.

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Glossary

Acre-foot: The volume of water that it would take to cover an acre to a depth of one foot.

Black water: Waste water from toilets and kitchen sinks

Catchment area: The horizontal area of the surface that rain water falls on, to be diverted and stored, such as the horizontal area of a roof top.

Cistern: A holding tank or storage facility for rain water.

Drip irrigation: Application of water directly to the root zone at slow rates to maximize absorption, while minimizing runoff.

Drought: A dry year followed by one or more dry years.

Effective Rain Volume: The estimated fractional amount of rain that plants can take up from the soil. This document assumes 50% of precipitation.

Evapotranspiration: The amount of water that is evaporated or transpired by plants or other surfaces.

First flush- The removal of accumulated pollutants on surfaces during the first rain after an extended period of dryness.

Graywater (Greywater) - Water that comes from baths, sinks, showers, dish and clothes washing machines, not from toilets of kitchen sinks.

Landscape Coefficient Method: A method for determining landscape water needs based on a series of coefficients dealing with planting densities, planting species,   , reference evapotranspiration and irrigation efficiency.

Rain Barrel: Similar to a cistern, but usually around 50 gallons in volume.

Rainwater harvesting: Storage of rain water for later use.

Recycled Water: Waste water that has been treated by a waste water treatment facility to a level suitable for its end use.

WUCOLS: (Water Use Classifications of Landscape Species) A standardized way to estimate landscape water use based on plant species, see also “Landscape Coefficient Method”

Appendix A: Single Family Home Calculations

The following charts and graphs in the appendices, units of volume will be gallons unless otherwise specified.

Single Family House Water Budget

Month	Avg. Rainfall (In.)	Roof Top Collection	Graywater	Toilet Flushing	Landscape Irrigation Reqs.
Jan	3.66	3,359	4,960	2,201	0
Feb	3.04	2,790	4,480	1,988	0
Mar	2.15	1,973	4,960	2,201	442
Apr	1.23	1,129	4,800	2,130	1,349
May	0.44	404	4,960	2,201	2,208
Jun	0.14	128	4,800	2,130	2,890
Jul	0.02	18	4,960	2,201	3,086
Aug	0.03	28	4,960	2,201	2,701
Sep	0.15	138	4,800	2,130	1,893
Oct	0.93	854	4,960	2,201	961
Nov	1.86	1,707	4,800	2,130	50
Dec	3.15	2,891	4,960	2,201	0
Annual	16.8	15,419	58,400	25,915	15,582

Single Family Landscape Water Requirments

Jan Est. Precipit 3.7

	Sq Ft	Ks	Kd	Kmc	KL	ETo	IE	ETL (in.)	Volume needed (gal)	Vol (cuf)	Volume (gal)	Effective Rain Volume (gal)	Make up Irrigation (gal)
Turf	300.0	0.6	1.0	1.0	0.6	1.2	0.7	0.7	191	26	681	340	None
DT	870.0	0.3	1.1	1.0	0.3	1.2	0.8	0.4	267	36	1,974	987	None
								Totals	458	61	2,655	1,327	0

Feb Est. Precipit 3.0

	Sq Ft	Ks	Kd	Kmc	KL	ETo	IE	ETL in.	Volume needed (gal)	Vol (cuf)	Volume (gal)	Effective Rain Volume (gal)	Make up Irrigation (gal)
Turf	300.0	0.6	1.0	1.0	0.6	1.5	0.7	0.9	239	32	565	283	None
DT	870.0	0.3	1.1	1.0	0.3	1.5	0.8	0.5	334	45	1,640	820	None
								Totals	573	77	2,205	1,103	0

Mar Est. Precipit 2.2

	Sq Ft	Ks	Kd	Kmc	KL	ETo	IE	ETL in.	Volume needed (gal)	Vol (cuf)	Volume (gal)	Effective Rain Volume (gal)	Make up Irrigation (gal)
Turf	300.0	0.6	1.0	1.0	0.6	3.2	0.7	1.9	510	68	400	200	310
DT	870.0	0.3	1.1	1.0	0.3	3.2	0.8	1.1	712	95	1,160	580	132
								Totals	1,222	163	1,560	780	442

Apr Est. Precipit 1.2

	Sq Ft	Ks	Kd	Kmc	KL	ETo	IE	ETL in.	Volume needed (gal)	Vol (cuf)	Volume (gal)	Effective Rain Volume (gal)	Make up Irrigation (gal)
Turf	300.0	0.6	1.0	1.0	0.6	4.7	0.7	2.8	749	100	229	114	635
DT	870.0	0.3	1.1	1.0	0.3	4.7	0.8	1.6	1,046	140	663	332	714
								Totals	1,795	240	892	446	1,349

Note: Turf refers to lawn and DT is short for "drought tolerant" and both represents the two hydrozones for the single family house.

May Est. Precipit 0.4

	Sq Ft	Ks	Kd	Kmc	KL	ETo	IE	ETL in.	Volume needed (gal)	Vol (cuf)	Volume (gal)	Effective Rain Volume (gal)	Make up Irrigation (gal)
Turf	300.0	0.6	1.0	1.0	0.6	6.2	0.7	3.7	988	132	82	41	948
DT	870.0	0.3	1.1	1.0	0.3	6.2	0.8	2.0	1,380	184	237	119	1,261
								Totals	2,368	317	319	160	2,208

Jun Est. Precipit 0.1

	Sq Ft	Ks	Kd	Kmc	KL	ETo	IE	ETL in.	Volume needed (gal)	Vol (cuf)	Volume (gal)	Effective Rain Volume (gal)	Make up Irrigation (gal)
Turf	300.0	0.6	1.0	1.0	0.6	7.7	0.7	4.6	1,228	164	26	13	1,215
DT	870.0	0.3	1.1	1.0	0.3	7.7	0.8	2.5	1,713	229	76	38	1,676
								Totals	2,941	393	102	51	2,890

Jul Est. Precipit 0.0

	Sq Ft	Ks	Kd	Kmc	KL	ETo	IE	ETL in.	Volume needed (gal)	Vol (cuf)	Volume (gal)	Effective Rain Volume (gal)	Make up Irrigation (gal)
Turf	300.0	0.6	1.0	1.0	0.6	8.1	0.7	4.9	1,291	173	4	2	1,290
DT	870.0	0.3	1.1	1.0	0.3	8.1	0.8	2.7	1,802	241	11	5	1,797
								Totals	3,094	414	15	7	3,086

Aug Est. Precipit 0.0

	Sq Ft	Ks	Kd	Kmc	KL	ETo	IE	ETL in.	Volume needed (gal)	Vol (cuf)	Volume (gal)	Effective Rain Volume (gal)	Make up Irrigation (gal)
Turf	300.0	0.6	1.0	1.0	0.6	7.1	0.7	4.3	1,132	151	6	3	1,129
DT	870.0	0.3	1.1	1.0	0.3	7.1	0.8	2.3	1,580	211	16	8	1,572
								Totals	2,712	363	22	11	2,701

Sept Est. Precipit 0.2

	Sq Ft	Ks	Kd	Kmc	KL	ETo	IE	ETL in.	Volume needed (gal)	Vol (cuf)	Volume (gal)	Effective Rain Volume (gal)	Make up Irrigation (gal)
Turf	300.0	0.6	1.0	1.0	0.6	5.1	0.7	3.1	813	109	28	14	799
DT	870.0	0.3	1.1	1.0	0.3	5.1	0.8	1.7	1,135	152	81	40	1,094
								Totals	1,948	260	109	54	1,893

Oct Est. Precipit 0.9

	Sq Ft	Ks	Kd	Kmc	KL	ETo	IE	ETL in.	Volume needed (gal)	Vol (cuf)	Volume (gal)	Effective Rain Volume (gal)	Make up Irrigation (gal)
Turf	300.0	0.6	1.0	1.0	0.6	3.4	0.7	2.0	542	72	173	86	456
DT	870.0	0.3	1.1	1.0	0.3	3.4	0.8	1.1	757	101	502	251	506
								Totals	1,299	174	675	337	961

Nov Est. Precipit 1.9

	Sq Ft	Ks	Kd	Kmc	KL	ETo	IE	ETL in.	Volume needed (gal)	Vol (cuf)	Volume (gal)	Effective Rain Volume (gal)	Make up Irrigation (gal)
Turf	300.0	0.6	1.0	1.0	0.6	1.4	0.7	0.8	223	30	346	173	50
DT	870.0	0.3	1.1	1.0	0.3	1.4	0.8	0.5	312	42	1,003	502	None
								Totals	535	71	1,349	675	50

Dec Est. Precipit 3.2

	Sq Ft	Ks	Kd	Kmc	KL	ETo	IE	ETL in.	Volume needed (gal)	Vol (cuf)	Volume (gal)	Effective Rain Volume (gal)	Make up Irrigation (gal)
Turf	300.0	0.6	1.0	1.0	0.6	0.7	0.7	0.4	112	15	586	293	None
DT	870.0	0.3	1.1	1.0	0.3	0.7	0.8	0.2	156	21	1,699	850	None
								Totals	267	36	2,285	1,143	0

Annual	19,211	2,568		15,582

Rootop Collection

Jan

Surface	Total Sq ft	Runoff Volume(cf)	Runoff (gal)
Rooftop	1,636	449	3,359
	Totals	449	3,359

Feb

Surface	Total Sq ft	Runoff Volume(cf)	Runoff (gal)
Rooftop	1,636	373	2,790
	Totals	373	2,790

Mar

Surface	Total Sq ft	Runoff Volume(cf)	Runoff (gal)
Rooftop	1,636	264	1,973
	Totals	264	1,973

Apr

Surface	Total Sq ft	Runoff Volume(cf)	Runoff (gal)
Rooftop	1,636	151	1,129
	Totals	151	1,129

May

Surface	Total Sq ft	Runoff Volume(cf)	Runoff (gal)
Rooftop	1,636	54	404
	Totals	54	404

Jun

Surface	Total Sq ft	Runoff Volume(cf)	Runoff (gal)
Rooftop	1,636	17	128
	Totals	17	128

Jul

Surface	Total Sq ft	Runoff Volume(cf)	Runoff (gal)
Rooftop	1,636	2	18
	Totals	2	18

Aug

Surface	Total Sq ft	Runoff Volume(cf)	Runoff (gal)
Rooftop	1,636	4	28
	Totals	4	28

Sept

Surface	Total Sq ft	Runoff Volume(cf)	Runoff (gal)
Rooftop	1,636	18	138
	Totals	18	138

Oct

Surface	Total Sq ft	Runoff Volume(cf)	Runoff (gal)
Rooftop	1,636	114	854
	Totals	114	854

Nov

Surface	Total Sq ft	Runoff Volume(cf)	Runoff (gal)
Rooftop	1,636	228	1,707
	Totals	228	1,707

Dec

Surface	Total Sq ft	Runoff Volume(cf)	Runoff (gal)
Rooftop	1,636	387	2,891
	Totals	387	2,891

Annual	2,061	15,419

Appendix B: Apartment Calculations

Apartment Cluster Water Budget

Month	Avg. Rainfall (In.)	Water Collection	Graywater	Toilet Flushing	Landscape Irrigation Reqs.
Jan	3.66	24,662	231,012	93,062	0
Feb	3.04	20,484	208,656	84,056	0
Mar	2.15	14,487	231,012	93,062	5,355
Apr	1.23	8,288	223,560	90,060	17,846
May	0.44	2,965	231,012	93,062	29,663
Jun	0.14	943	223,560	90,060	38,944
Jul	0.02	135	231,012	93,062	41,626
Aug	0.03	202	231,012	93,062	36,422
Sep	0.15	1,011	223,560	90,060	25,497
Oct	0.93	6,267	231,012	93,062	12,701
Nov	1.86	12,533	223,560	90,060	335
Dec	3.15	21,225	231,012	93,062	0
Annual	16.8	113,202	2,719,980	1,095,730	208,389

Note: Turf refers to lawn, DT means "drought tolerant" and Swale refers to the bioswale

Apartment Landscape Water Requirments

Jan Est. Precipi 3.7

	Sq Ft	Ks	Kd	Kmc	KL	ETo	IE	ETL (in.)	Volume needed (gal)	Vol (cuf)	Rain Volume (gal)	Effective Rain Volume (gal)	Make up Irrigation (gal)
Turf	2,000.0	0.6	1.0	1.0	0.6	1.2	0.7	0.7	1,275	171	4,538	2,269	None
DT	12,200.0	0.3	1.1	1.0	0.3	1.2	0.8	0.4	3,744	501	27,684	13,842	None
Swale	2,500.0	0.5	1.0	1.0	0.5	1.2	0.8	0.6	1,163	155	5,673	2,837	None
								Totals	6,182	826	37,896	18,948	0

Feb Est. Precipi 3.0

	Sq Ft	Ks	Kd	Kmc	KL	ETo	IE	ETL in.	Volume needed (gal)	Vol (cuf)	Rain Volume (gal)	Effective Rain Volume (gal)	Make up Irrigation (gal)
Turf	2,000.0	0.6	1.0	1.0	0.6	1.5	0.7	0.9	1,594	213	3,770	1,885	None
DT	12,200.0	0.3	1.1	1.0	0.3	1.5	0.8	0.5	4,680	626	22,995	11,497	None
Swale	2,500.0	0.5	1.0	1.0	0.5	1.5	0.8	0.8	1,453	194	4,712	2,356	None
								Totals	7,728	1,033	31,476	15,738	0

Mar Est. Precipi 2.2

	Sq Ft	Ks	Kd	Kmc	KL	ETo	IE	ETL in.	Volume needed (gal)	Vol (cuf)	Rain Volume (gal)	Effective Rain Volume (gal)	Make up Irrigation (gal)
Turf	2,000.0	0.6	1.0	1.0	0.6	3.2	0.7	1.9	3,401	455	2,666	1,333	2,068
DT	12,200.0	0.3	1.1	1.0	0.3	3.2	0.8	1.1	9,984	1,335	16,263	8,131	1,853
Swale	2,500.0	0.5	1.0	1.0	0.5	3.2	0.8	1.6	3,100	414	3,333	1,666	1,434
								Totals	16,486	2,204	22,261	11,131	5,355

Apr Est. Precipi 1.2

	Sq Ft	Ks	Kd	Kmc	KL	ETo	IE	ETL in.	Volume needed (gal)	Vol (cuf)	Rain Volume (gal)	Effective Rain Volume (gal)	Make up Irrigation (gal)
Turf	2,000.0	0.6	1.0	1.0	0.6	4.7	0.7	2.8	4,995	668	1,525	763	4,233
DT	12,200.0	0.3	1.1	1.0	0.3	4.7	0.8	1.6	14,665	1,961	9,304	4,652	10,013
Swale	2,500.0	0.5	1.0	1.0	0.5	4.7	0.8	2.4	4,553	609	1,907	953	3,600
								Totals	24,213	3,237	12,735	6,368	17,846

May Est. Precipi 0.4

	Sq Ft	Ks	Kd	Kmc	KL	ETo	IE	ETL in.	Volume needed (gal)	Vol (cuf)	Rain Volume (gal)	Effective Rain Volume (gal)	Make up Irrigation (gal)
Turf	2,000.0	0.6	1.0	1.0	0.6	6.2	0.7	3.7	6,590	881	546	273	6,317
DT	12,200.0	0.3	1.1	1.0	0.3	6.2	0.8	2.0	19,345	2,586	3,328	1,664	17,681
Swale	2,500.0	0.5	1.0	1.0	0.5	6.2	0.8	3.1	6,006	803	682	341	5,665
								Totals	31,941	4,270	4,556	2,278	29,663

Jun Est. Precipi 0.1

	Sq Ft	Ks	Kd	Kmc	KL	ETo	IE	ETL in.	Volume needed (gal)	Vol (cuf)	Rain Volume (gal)	Effective Rain Volume (gal)	Make up Irrigation (gal)
Turf	2,000.0	0.6	1.0	1.0	0.6	7.7	0.7	4.6	8,184	1,094	174	87	8,097
DT	12,200.0	0.3	1.1	1.0	0.3	7.7	0.8	2.5	24,025	3,212	1,059	529	23,496
Swale	2,500.0	0.5	1.0	1.0	0.5	7.7	0.8	3.9	7,459	997	217	109	7,351
								Totals	39,669	5,303	1,450	725	38,944

Jul Est. Precipi 0.0

	Sq Ft	Ks	Kd	Kmc	KL	ETo	IE	ETL in.	Volume needed (gal)	Vol (cuf)	Rain Volume (gal)	Effective Rain Volume (gal)	Make up Irrigation (gal)
Turf	2,000.0	0.6	1.0	1.0	0.6	8.1	0.7	4.9	8,609	1,151	25	12	8,597
DT	12,200.0	0.3	1.1	1.0	0.3	8.1	0.8	2.7	25,273	3,379	151	76	25,198
Swale	2,500.0	0.5	1.0	1.0	0.5	8.1	0.8	4.1	7,847	1,049	31	16	7,831
								Totals	41,729	5,579	207	104	41,626

Aug Est. Precipi 0.0

	Sq Ft	Ks	Kd	Kmc	KL	ETo	IE	ETL in.	Volume needed (gal)	Vol (cuf)	Rain Volume (gal)	Effective Rain Volume (gal)	Make up Irrigation (gal)
Turf	2,000.0	0.6	1.0	1.0	0.6	7.1	0.7	4.3	7,546	1,009	37	19	7,528
DT	12,200.0	0.3	1.1	1.0	0.3	7.1	0.8	2.3	22,153	2,962	227	113	22,040
Swale	2,500.0	0.5	1.0	1.0	0.5	7.1	0.8	3.6	6,878	920	47	23	6,855
								Totals	36,577	4,890	311	155	36,422

Sept Est. Precipi 0.2

	Sq Ft	Ks	Kd	Kmc	KL	ETo	IE	ETL in.	Volume needed (gal)	Vol (cuf)	Rain Volume (gal)	Effective Rain Volume (gal)	Make up Irrigation (gal)
Turf	2,000.0	0.6	1.0	1.0	0.6	5.1	0.7	3.1	5,421	725	186	93	5,328
DT	12,200.0	0.3	1.1	1.0	0.3	5.1	0.8	1.7	15,913	2,127	1,135	567	15,345
Swale	2,500.0	0.5	1.0	1.0	0.5	5.1	0.8	2.6	4,941	661	233	116	4,824
								Totals	26,274	3,513	1,553	777	25,497

Oct Est. Precipi 0.9

	Sq Ft	Ks	Kd	Kmc	KL	ETo	IE	ETL in.	Volume needed (gal)	Vol (cuf)	Rain Volume (gal)	Effective Rain Volume (gal)	Make up Irrigation (gal)
Turf	2,000.0	0.6	1.0	1.0	0.6	3.4	0.7	2.0	3,614	483	1,153	577	3,037
DT	12,200.0	0.3	1.1	1.0	0.3	3.4	0.8	1.1	10,609	1,418	7,035	3,517	7,091
Swale	2,500.0	0.5	1.0	1.0	0.5	3.4	0.8	1.7	3,294	440	1,442	721	2,573
								Totals	17,516	2,342	9,629	4,815	12,701

Nov Est. Precipi 1.9

	Sq Ft	Ks	Kd	Kmc	KL	ETo	IE	ETL in.	Volume needed (gal)	Vol (cuf)	Rain Volume (gal)	Effective Rain Volume (gal)	Make up Irrigation (gal)
Turf	2,000.0	0.6	1.0	1.0	0.6	1.4	0.7	0.8	1,488	199	2,306	1,153	335
DT	12,200.0	0.3	1.1	1.0	0.3	1.4	0.8	0.5	4,368	584	14,069	7,035	None
Swale	2,500.0	0.5	1.0	1.0	0.5	1.4	0.8	0.7	1,356	181	2,883	1,442	None
								Totals	7,212	964	19,258	9,629	335

Dec Est. Precipi 3.2

	Sq Ft	Ks	Kd	Kmc	KL	ETo	IE	ETL in.	Volume needed (gal)	Vol (cuf)	Rain Volume (gal)	Effective Rain Volume (gal)	Make up Irrigation (gal)
Turf	2,000.0	0.6	1.0	1.0	0.6	0.7	0.7	0.4	744	99	3,906	1,953	None
DT	12,200.0	0.3	1.1	1.0	0.3	0.7	0.8	0.2	2,184	292	23,827	11,913	None
Swale	2,500.0	0.5	1.0	1.0	0.5	0.7	0.8	0.4	678	91	4,883	2,441	None
								Totals	3,606	482	32,615	16,308	0

Annual	259,133	34,644		208,389

Water Collection Sources for Student Housing

Jan

Surface	Total Sq ft	Runoff Volume(cf)	Runoff (gal)
Rooftop	8,900	2443.1	18,274
Paving	3,500	854.0	6,388
	Totals	3297.1	24,662

Feb

Surface	Total Sq ft	Runoff Volume(cf)	Runoff (gal)
Rooftop	8,900	2029.2	15,178
Paving	3,500	709.3	5,306
	Totals	2738.5	20,484

Mar

Surface	Total Sq ft	Runoff Volume(cf)	Runoff (gal)
Rooftop	8,900	1435.1	10,735
Paving	3,500	501.7	3,752
	Totals	1936.8	14,487

Apr

Surface	Total Sq ft	Runoff Volume(cf)	Runoff (gal)
Rooftop	8,900	821.0	6,141
Paving	3,500	287.0	2,147
	Totals	1108.0	8,288

May

Surface	Total Sq ft	Runoff Volume(cf)	Runoff (gal)
Rooftop	8,900	293.7	2,197
Paving	3,500	102.7	768
	Totals	396.4	2,965

Jun

Surface	Total Sq ft	Runoff Volume(cf)	Runoff (gal)
Rooftop	8,900	93.5	699
Paving	3,500	32.7	244
	Totals	126.1	943

Jul

Surface	Total Sq ft	Runoff Volume(cf)	Runoff (gal)
Rooftop	8,900	13.4	100
Paving	3,500	4.7	35
	Totals	18.0	135

Aug

Surface	Total Sq ft	Runoff Volume(cf)	Runoff (gal)
Rooftop	8,900	20.0	150
Paving	3,500	7.0	52
	Totals	27.0	202

Sept

Surface	Total Sq ft	Runoff Volume(cf)	Runoff (gal)
Rooftop	8,900	100.1	749
Paving	3,500	35.0	262
	Totals	135.1	1,011

Oct

Surface	Total Sq ft	Runoff Volume(cf)	Runoff (gal)
Rooftop	8,900	620.8	4,643
Paving	3,500	217.0	1,623
	Totals	837.8	6,267

Nov

Surface	Total Sq ft	Runoff Volume(cf)	Runoff (gal)
Rooftop	8,900	1241.6	9,287
Paving	3,500	434.0	3,246
	Totals	1675.6	12,533

Dec

Surface	Total Sq ft	Runoff Volume(cf)	Runoff (gal)
Rooftop	8,900	2102.6	15,728
Paving	3,500	735.0	5,498
	Totals	2837.6	21,225

Annual	15,134	113,202

Appendix C: Village Square Calculations

Village Square Water Budget

Month	Avg. Rainfall (In.)	Water Collection	Graywater	Toilet Flushing	Landscape Irrigation Reqs.
Jan	3.66	52,016	83,204	38,626	0
Feb	3.04	43,204	75,152	34,888	0
Mar	2.15	30,556	83,204	38,626	7,030
Apr	1.23	17,481	80,520	37,380	19,469
May	0.44	6,253	83,204	38,626	31,291
Jun	0.14	1,990	80,520	37,380	40,790
Jul	0.02	284	83,204	38,626	43,512
Aug	0.03	426	83,204	38,626	38,081
Sep	0.15	2,132	80,520	37,380	26,745
Oct	0.93	13,217	83,204	38,626	13,893
Nov	1.86	26,434	80,520	37,380	837
Dec	3.15	44,768	83,204	38,626	0
Annual	16.8	238,762	979,660	454,790	221,649

Note: Turf refers to lawn, DT means "drought tolerant" and PLP refers to the parking lot planters

Landscape Water Requirments for the Village Square

Jan Est. Precipit 3.66

	Sq Ft	Ks	Kd	Kmc	KL	ETo	IE	ETL (in.)	Volume needed (gal)	Vol (cuf)	Rain Volume (gal)	Effective Rain Volume (gal)	Make Up Irrigation
Turf	5,000.0	0.6	1.0	1.0	0.6	1.2	0.7	0.7	3,189	426	11,346	5,673	None
DT	9,600.0	0.3	1.1	1.0	0.3	1.2	0.8	0.4	2,946	394	21,784	10,892	None
PLP	700.0	0.5	1.0	1.0	0.5	1.2	0.8	0.6	326	44	1,588	794	None
								Totals	6,460	864	34,719	17,359	0

Feb Est. Precipit 3.04

	Sq Ft	Ks	Kd	Kmc	KL	ETo	IE	ETL in.	Volume needed (gal)	Vol (cuf)	Rain Volume (gal)	Effective Rain Volume (gal)	Make Up Irrigation
Turf	5,000.0	0.6	1.0	1.0	0.6	1.5	0.7	0.9	3,986	533	9,424	4,712	None
DT	9,600.0	0.3	1.1	1.0	0.3	1.5	0.8	0.5	3,683	492	18,094	9,047	None
PLP	700.0	0.5	1.0	1.0	0.5	1.5	0.8	0.8	407	54	1,319	660	None
								Totals	8,075	1,080	28,837	14,419	0

Mar Est. Precipit 2.2

	Sq Ft	Ks	Kd	Kmc	KL	ETo	IE	ETL in.	Volume needed (gal)	Vol (cuf)	Rain Volume (gal)	Effective Rain Volume (gal)	Make Up Irrigation
Turf	5,000.0	0.6	1.0	1.0	0.6	3.2	0.7	1.9	8,503	1,137	6,665	3,333	5,170
DT	9,600.0	0.3	1.1	1.0	0.3	3.2	0.8	1.1	7,857	1,050	12,797	6,398	1,458
PLP	700.0	0.5	1.0	1.0	0.5	3.2	0.8	1.6	868	116	933	467	401
								Totals	17,227	2,303	20,395	10,197	7,030

Apr Est. Precipit 1.2

	Sq Ft	Ks	Kd	Kmc	KL	ETo	IE	ETL in.	Volume needed (gal)	Vol (cuf)	Rain Volume (gal)	Effective Rain Volume (gal)	Make Up Irrigation
Turf	5,000.0	0.6	1.0	1.0	0.6	4.7	0.7	2.8	12,489	1,670	3,813	1,907	10,582
DT	9,600.0	0.3	1.1	1.0	0.3	4.7	0.8	1.6	11,539	1,543	7,321	3,660	7,879
PLP	700.0	0.5	1.0	1.0	0.5	4.7	0.8	2.4	1,275	170	534	267	1,008
								Totals	25,303	3,383	11,668	5,834	19,469

May Est. Precipit 0.4

	Sq Ft	Ks	Kd	Kmc	KL	ETo	IE	ETL in.	Volume needed (gal)	Vol (cuf)	Rain Volume (gal)	Effective Rain Volume (gal)	Make Up Irrigation
Turf	5,000.0	0.6	1.0	1.0	0.6	6.2	0.7	3.7	16,474	2,202	1,364	682	15,792
DT	9,600.0	0.3	1.1	1.0	0.3	6.2	0.8	2.0	15,222	2,035	2,619	1,309	13,913
PLP	700.0	0.5	1.0	1.0	0.5	6.2	0.8	3.1	1,682	225	191	95	1,586
								Totals	33,378	4,462	4,174	2,087	31,291

Jun Est. Precipit 0.1

	Sq Ft	Ks	Kd	Kmc	KL	ETo	IE	ETL in.	Volume needed (gal)	Vol (cuf)	Rain Volume (gal)	Effective Rain Volume (gal)	Make Up Irrigation
Turf	5,000.0	0.6	1.0	1.0	0.6	7.7	0.7	4.6	20,460	2,735	434	217	20,243
DT	9,600.0	0.3	1.1	1.0	0.3	7.7	0.8	2.5	18,905	2,527	833	417	18,488
PLP	700.0	0.5	1.0	1.0	0.5	7.7	0.8	3.9	2,089	279	61	30	2,058
								Totals	41,454	5,542	1,328	664	40,790

Jul Est. Precipit 0.0

	Sq Ft	Ks	Kd	Kmc	KL	ETo	IE	ETL in.	Volume needed (gal)	Vol (cuf)	Rain Volume (gal)	Effective Rain Volume (gal)	Make Up Irrigation
Turf	5,000.0	0.6	1.0	1.0	0.6	8.1	0.7	4.9	21,523	2,877	62	31	21,492
DT	9,600.0	0.3	1.1	1.0	0.3	8.1	0.8	2.7	19,887	2,659	119	60	19,828
PLP	700.0	0.5	1.0	1.0	0.5	8.1	0.8	4.1	2,197	294	9	4	2,193
								Totals	43,607	5,830	190	95	43,512

Aug Est. Precipit 0.0

	Sq Ft	Ks	Kd	Kmc	KL	ETo	IE	ETL in.	Volume needed (gal)	Vol (cuf)	Rain Volume (gal)	Effective Rain Volume (gal)	Make Up Irrigation
Turf	5,000.0	0.6	1.0	1.0	0.6	7.1	0.7	4.3	18,866	2,522	93	47	18,819
DT	9,600.0	0.3	1.1	1.0	0.3	7.1	0.8	2.3	17,432	2,330	179	89	17,343
PLP	700.0	0.5	1.0	1.0	0.5	7.1	0.8	3.6	1,926	257	13	7	1,919
								Totals	38,224	5,110	285	142	38,081

Sept Est. Precipit 0.2

	Sq Ft	Ks	Kd	Kmc	KL	ETo	IE	ETL in.	Volume needed (gal)	Vol (cuf)	Rain Volume (gal)	Effective Rain Volume (gal)	Make Up Irrigation
Turf	5,000.0	0.6	1.0	1.0	0.6	5.1	0.7	3.1	13,551	1,812	465	233	13,319
DT	9,600.0	0.3	1.1	1.0	0.3	5.1	0.8	1.7	12,522	1,674	893	446	12,075
PLP	700.0	0.5	1.0	1.0	0.5	5.1	0.8	2.6	1,383	185	65	33	1,351
								Totals	27,456	3,671	1,423	711	26,745

Oct Est. Precipit 0.9

	Sq Ft	Ks	Kd	Kmc	KL	ETo	IE	ETL in.	Volume needed (gal)	Vol (cuf)	Rain Volume (gal)	Effective Rain Volume (gal)	Make Up Irrigation
Turf	5,000.0	0.6	1.0	1.0	0.6	3.4	0.7	2.0	9,034	1,208	2,883	1,442	7,593
DT	9,600.0	0.3	1.1	1.0	0.3	3.4	0.8	1.1	8,348	1,116	5,535	2,768	5,580
PLP	700.0	0.5	1.0	1.0	0.5	3.4	0.8	1.7	922	123	404	202	720
								Totals	18,304	2,447	8,822	4,411	13,893

Nov Est. Precipit 1.9

	Sq Ft	Ks	Kd	Kmc	KL	ETo	IE	ETL in.	Volume needed (gal)	Vol (cuf)	Rain Volume (gal)	Effective Rain Volume (gal)	Make Up Irrigation
Turf	5,000.0	0.6	1.0	1.0	0.6	1.4	0.7	0.8	3,720	497	5,766	2,883	837
DT	9,600.0	0.3	1.1	1.0	0.3	1.4	0.8	0.5	3,437	460	11,071	5,535	None
PLP	700.0	0.5	1.0	1.0	0.5	1.4	0.8	0.7	380	51	807	404	None
								Totals	7,537	1,008	17,644	8,822	837

Dec Est. Precipit 3.2

	Sq Ft	Ks	Kd	Kmc	KL	ETo	IE	ETL in.	Volume needed (gal)	Vol (cuf)	Rain Volume (gal)	Effective Rain Volume (gal)	Make Up Irrigation
Turf	5,000.0	0.6	1.0	1.0	0.6	0.7	0.7	0.4	1,860	249	9,765	4,883	None
DT	9,600.0	0.3	1.1	1.0	0.3	0.7	0.8	0.2	1,719	230	18,749	9,374	None
PLP	700.0	0.5	1.0	1.0	0.5	0.7	0.8	0.4	190	25	1,367	684	None
								Totals	3,769	504	29,881	14,940	0
							Annual		270,795	36,203			221,649

Rain Water Collection Sources for Village Square

Jan

Surface	Total Sq ft	Runoff Volume(cf)	Runoff (gal)
Rooftop	12,000	3,294	24,639
Paving	15,000	3,660	27,377
	Totals	6,954	52,016

Feb

Surface	Total Sq ft	Runoff Volume(cf)	Runoff (gal)
Rooftop	12,000	2,736	20,465
Paving	15,000	3,040	22,739
	Totals	5,776	43,204

Mar

Surface	Total Sq ft	Runoff Volume(cf)	Runoff (gal)
Rooftop	12,000	1,935	14,474
Paving	15,000	2,150	16,082
	Totals	4,085	30,556

Apr

Surface	Total Sq ft	Runoff Volume(cf)	Runoff (gal)
Rooftop	12,000	1,107	8,280
Paving	15,000	1,230	9,200
	Totals	2,337	17,481

May

Surface	Total Sq ft	Runoff Volume(cf)	Runoff (gal)
Rooftop	12,000	396	2,962
Paving	15,000	440	3,291
	Totals	836	6,253

Jun

Surface	Total Sq ft	Runoff Volume(cf)	Runoff (gal)
Rooftop	12,000	126	942
Paving	15,000	140	1,047
	Totals	266	1,990

Jul

Surface	Total Sq ft	Runoff Volume(cf)	Runoff (gal)
Rooftop	12,000	18	135
Paving	15,000	20	150
	Totals	38	284

Aug

Surface	Total Sq ft	Runoff Volume(cf)	Runoff (gal)
Rooftop	12,000	27	202
Paving	15,000	30	224
	Totals	57	426

Sept

Surface	Total Sq ft	Runoff Volume(cf)	Runoff (gal)
Rooftop	12,000	135	1,010
Paving	15,000	150	1,122
	Totals	285	2,132

Oct

Surface	Total Sq ft	Runoff Volume(cf)	Runoff (gal)
Rooftop	12,000	837	6,261
Paving	15,000	930	6,956
	Totals	1,767	13,217

Nov

Surface	Total Sq ft	Runoff Volume(cf)	Runoff (gal)
Rooftop	12,000	1,674	12,522
Paving	15,000	1,860	13,913
	Totals	3,534	26,434

Dec

Surface	Total Sq ft	Runoff Volume(cf)	Runoff (gal)
Rooftop	12,000	2,835	21,206
Paving	15,000	3,150	23,562
	Totals	5,985	44,768

Annual	31,920	238,762