Irrigating San Francisco Bay Area Landscapes with Recycled Water

WATEREUSE CALIFORNIA

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About this Publication

This *Guide* is a tool to help landscape owners, designers and managers use recycled water effectively and successfully in San Francisco Bay Area landscapes. It is designed to help you understand the basic components of how to evaluate site conditions, adjust existing landscapes, design new landscapes, and care for landscapes irrigated with recycled water.

Many people and organizations were involved with the development and review of a larger body of work that has been summarized and condensed into this *Guide*. The original review team included landscape professionals, scientists and water engineers and managers. The breadth of experience and knowledge of these professionals is represented in the topics and recommendations provided here.

Sponsors for this work were the WateReuse Association, the Bay Area Clean Water Association, Dublin San Ramon Services District, the City of Palo Alto, the City of Redwood City, the City of San José, Valley Crest Landscape (now BrightView), Silicon Valley Clean Water, South Bay Water Recycling, Stanford University, Sonoma County Water Agency, and Santa Clara Valley Water District.

Recycled water is a local, sustainable source of water that is climate resistant. The time is right to expand the use of recycled water for landscape irrigation in the Bay Area. This guide was developed to share the best recycled water landscape practices from experts and experiences from recycled water landscape projects in our Bay Area climate. By using this knowledge and recycling our water, we hope to help keep our landscapes green and continue to make the Bay Area a great and sustainable place to live.

Jennifer West
Managing Director, WateReuse California

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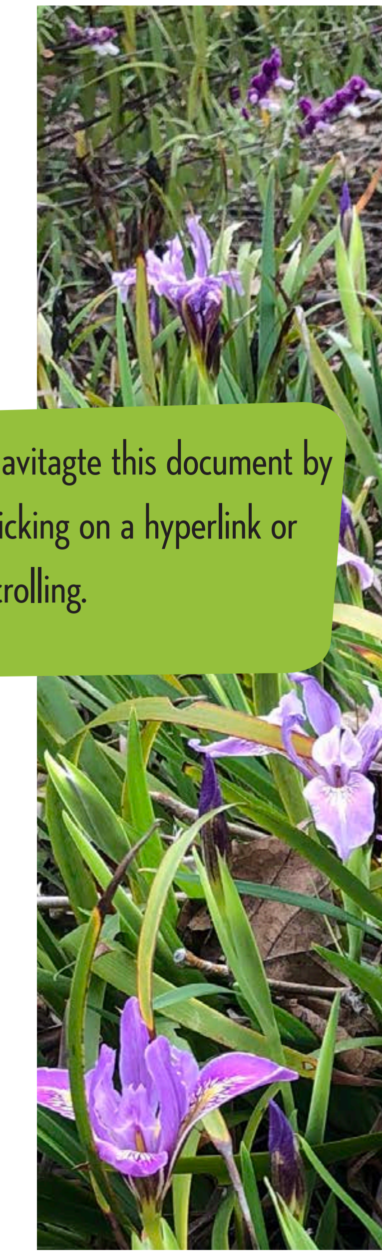

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Getting Started

Landscape irrigation with recycled water is an integral component of California's efforts to deal with limited water supplies in the face of growing demand. It is safe, reliable, and more available than potable (drinking) water during droughts and periods of water use restrictions.

This *Guide* is a tool to help landscape owners, designers and managers use recycled water effectively and successfully in San Francisco Bay Area landscapes. It is designed to help you understand the basic components of how to evaluate site conditions, adjust existing landscapes, design new landscapes, and care for landscapes irrigated with recycled water.

Using recycled water for landscape irrigation has a long history in the Bay Area, beginning in Golden Gate Park in 1948. The Livermore Municipal Golf Course has irrigated with recycled water since the 1960s. The City of Santa Clara started delivering recycled water to irrigate the Santa Clara Golf and Tennis Club in 1989. San Francisco Bay Area water agencies began studying the feasibility of using recycled water in the early 1990s. Its use for landscape irrigation has increased steadily since that time.

Recycled water is currently supplied for landscape irrigation to portions of Alameda, Contra Costa, Marin, Napa, San Francisco, San Mateo, Sonoma, and Santa Clara Counties (see map below). Plans are underway to greatly expand the availability of recycled water for landscape irrigation throughout the Bay Area. There are currently 19 agencies in the Bay Area supplying recycled water.

In the San Francisco Bay Area, many established landscapes are being converted from irrigation with potable water to recycled water. These landscapes are composed of a large variety of plants growing in a wide range of soils. In fact, each landscape is unique with respect to plant species and soil conditions; no two are exactly the same.

With multiple water retailers in the Bay Area, the recycled water supplied to these landscapes vary as well, particularly with respect to salt and specific ion concentrations.

By using recycled water to irrigate landscapes we can keep landscapes green and communities healthy places to live, work and play.

Locations in the Bay Area where recycled water is now available for landscape irrigation or will soon be available.

Regulations Regarding Recycled Water for Landscape Irrigation

AB 324, California's Water Conservation in Landscaping Act, was signed into law in 1990. The statute required that the design, installation, and maintenance of landscapes be water efficient. In 2006, AB 1881, Water Conservation in California, required an update to the Model Water Efficient Landscape Ordinance.

By the end of 2008, Governor Schwarzenegger had declared a state of emergency due to drought conditions. With so many demands on our water resources, the State Water Resources Control Board adopted the Recycled Water Policy in 2009, and most recently amended in 2018/19. The policy was developed to increase the production of recycled water, make recycled water available to water suppliers, and substitute the use of recycled water for potable water as much as possible. The Recycled Water Policy set a goal of increasing the 0.6 million acre-feet of recycled water used in 2009 to 2.5 million acre-feet per year by 2030.

Recycled water quality is tightly controlled and monitored to protect human health and the environment. The State Water Board, Division of Drinking Water establishes and enforces the standards for recycled water used for human contact. The State Water Resources Control Board (the State Water Board), through regional water boards, sets and monitors the quality of recycled water to protect the environment and public health (for example, see California Code of Regulations Title 17 and Title 22, Chapter 3, Division 4). In addition, regional boards monitor recycled water quality and manage recycled water permitting, use, application, and associated runoff to protect waters of the State. Refer to Appendix 4 for further description and relevant portions of these documents.

In July 2009, the State Water Board adopted the General Permit for Landscape Irrigation Uses of Municipal Recycled Water (the General Permit, see https://www.waterboards.ca.gov/water_issues/programs/water_recycling_policy/docs/draft_genpermit032809.pdf). The General Permit allows the use of recycled water for landscape irrigation in

- parks, greenbelts, and playgrounds
- schoolyards
- athletic fields
- golf courses
- cemeteries
- residential landscaping, common areas (individually owned residences are not included in the General Permit)
- commercial landscaping, except eating areas
- industrial landscaping, except eating areas
- freeway, highway, and street landscaping

Laws That Regulate Recycled Water for Landscape Irrigation

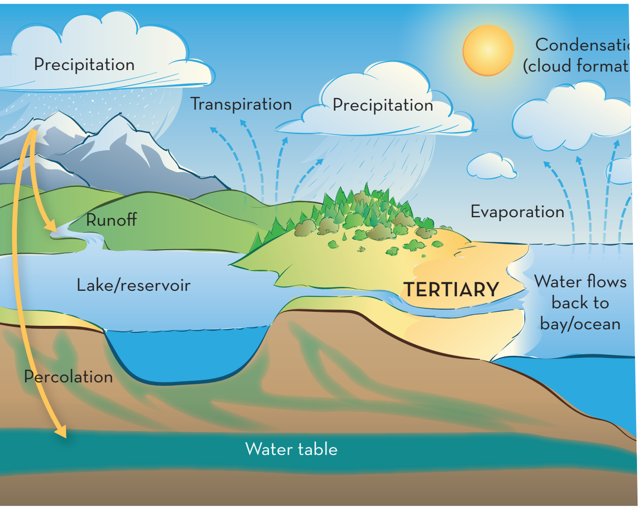
Water Recycling in Landscaping Act (SB 2095, 2000)
https://leginfo.legislature.ca.gov/

Health and Safety Code, Water Code
https://leginfo.legislature.ca.gov/

Title 17, Division 1, Chapter 5
www.calregs.com

Title 22, Division 4, Chapter 3
www.calregs.com

How Water is Recycled



Water is naturally recycled and purified through the hydrologic cycle of evaporation, transpiration, condensation, precipitation and runoff.

Water covers about 70% of the earth's surface and is fundamental to life. The amount of water on earth never changes. Water continually moves through the water cycle via the processes of evaporation, transpiration, condensation, precipitation, and runoff.

Nature recycles water through the water cycle. All of the water we consume has been used before and cycled through nature's cleaning processes. Municipal water is recycled using similar processes involving filtration and biological decomposition.

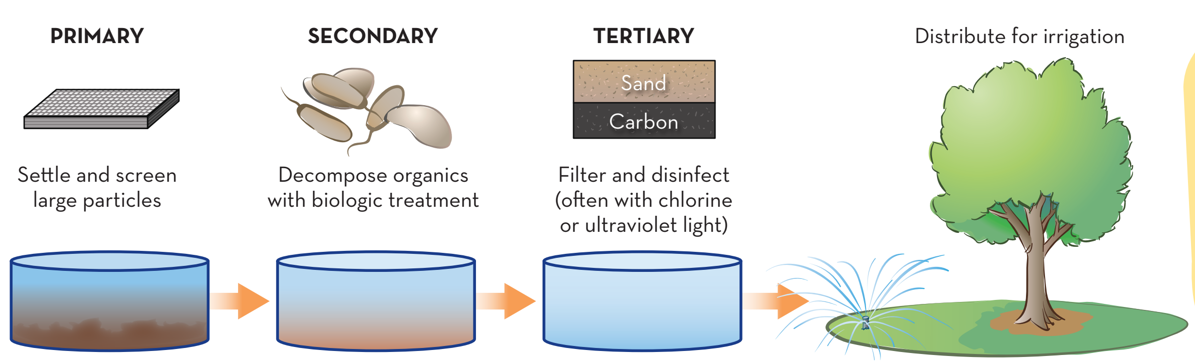
Recycled water, also called treated wastewater or reclaimed water, is water that has been previously used for municipal, industrial, or agricultural purposes and has undergone a level of purification or treatment. By law, wastewater is treated to meet local, state, and federal standards, making it suitable for irrigation.

There are several wastewater treatment processes; each step further improves the quality of the water.

- Primary treatment: Initial step where raw sewage flows through bar screens, removing large objects.
- Secondary treatment: Biodegradables and colloidal organic matter are removed using aerobic or anaerobic biological treatment processes.
- Tertiary treatment: Any remaining particulates are removed through sand and/or carbon filtration followed by chemical or nonchemical disinfection (chlorine, ultraviolet light, hydrogen peroxide, or ozone).
- Advanced treatment: While not required by the Department of Public Health, some agencies further treat recycled water using microfiltration followed by reverse osmosis (MF/RO) to remove dissolved salts that cannot be removed through previous treatments. MF/RO treatment is expensive and energy intensive.

During tertiary recycled water treatment, particulates and other organic materials are removed. However, many of the dissolved constituents, including minerals, salts, and other metals, remain in solution unless they are removed through advanced treatment described above.

Disinfected tertiary treatment including coagulation, filtering, and disinfection is required for irrigation of parks, playgrounds, schoolyards, and spray irrigation of food crops. All recycled water used for landscape irrigation in the Bay Area has undergone approved tertiary and disinfection treatment.



In the San Francisco Bay Area, recycling wastewater for landscape irrigation involves at least three categories of treatments: primary, secondary, and tertiary.

Water Quality

All water contains the same major constituents, but the composition and concentration can vary from location to location. The concentration of the constituents is used to assess the quality of the water for the intended use.

In the context of landscape irrigation, water quality refers to the presence and concentration of total salts (TDS, EC_w), several specific ions (Cl^-, Na^+, B^+), bicarbonate, pH, trace elements, and the nutrients nitrogen, phosphorus and potassium. Water that is recycled contains more salts than it did when it was first used unless it goes through advanced treatment such as reverse osmosis.

Salinity

Salinity is the most important measure of water quality for landscapes. Salts are compounds that dissolve in water, separating into positively or negatively charged ions. For example, when table salt (NaCl) dissolves in water, it separates into sodium (Na^+) and chloride (Cl^-). Water salinity is measured and expressed as total dissolved solids (TDS) and electrical conductivity (EC_w), where the subscript "w" stands for "water." Most recycled waters in the Bay Area contain 500 to 1,000 ppm TDS and EC_w 0.85 to 1.6 dS/m.

Specific ion concentration

Irrigation water with elevated concentration of specific ions (Cl^-, Na^+ and/or B^+) can injure sensitive plants even when total salinity is within tolerable range. The concentration of specific ions is usually expressed in ppm, mg/l, or meq/l.

Sodium and chloride concentrations are particularly important if irrigation water will be sprayed onto foliage, either directly by sprinklers or through drift in the wind. Many plants absorb sodium and chloride through their foliage. For this reason, interpretation of water quality is different for foliar-applied water (e.g., spray irrigation that wets plant foliage) than for soil-applied water (e.g., bubbler or drip irrigation).

Bicarbonate

Bicarbonate (HCO_3^-) affects plants through its influence on pH and interaction with sodium. High bicarbonate concentrations, which may occur in both potable and recycled waters, affect the availability of some nutrient elements, thereby affecting plant nutrition. Water that is high in bicarbonate, calcium, or magnesium can form precipitates that clog drip emitters and increase wear of valves.

Nutrients

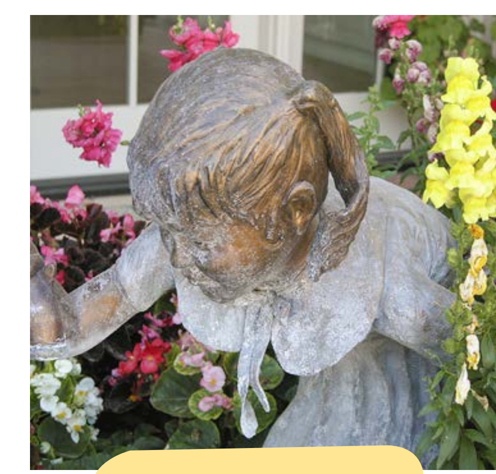
One of the advantages of using recycled water for landscape irrigation is that it contains nitrogen, phosphorus, and sulfur which are needed for plant growth. The need for added fertlizers is reduced.

Chlorine and Chloride: What's the Difference?

Chlorine (Cl_2) is a chemical element that under standard conditions is a gas. Commonly, chlorine is added to recycled water as a tertiary treatment before it is distributed. Chlorine eventually dissipates as a gas and is not a significant concern in landscapes unless concentrations are abnormally high (above 5 mg/l total residual chlorine).

Chloride (Cl^-) commonly occurs as a constituent of salts, such as sodium chloride (NaCl). Chloride salts are soluble in water and occur in high concentrations in seawater.

Recycled water contains chloride that was present in the potable water from which it was derived. Although chloride is an essential plant element, it can accumulate in soils and may be too high for sensitive plants. In soils where chloride has accumulated to higher levels, leaching is required to lower the concentration to a tolerable level.



Water that is high in bicarbonate left a white coating on the parts of this bronze statue that were wetted during irrigation.

Soil Quality

The clayey soil above is compacted and lacks structure. The soil in the photo below has good structure. It drains well and holds moisture and nutrients for plant roots. The structure was restored over years of incorporaing compost and maintaining wood chip mulch.

Landscape soils in the Bay Area are often composed of layers that restrict water movement and root development. Here, the soil profile reveals four layers of soils of different origin, colors, structure, and chemical characteristics.

Soil is a complex physical, chemical, and biological system that holds water and nutrients for plants. For our purposes, soil quality refers to the capacity of the soil to support landscape plants. Soil conditions have a significant effect on landscape performance, regardless of irrigation water source. It is particularly important, however, when the landscape is irrigated with recycled water because salts in irrigation water can build up in the soil over time.

Soil texture and structure

Many soils in the S. F. Bay Area are clayey in texture. Clayey soils hold more water and nutrients and drain more slowly than sandy soils. In urban areas, clayey soils tend to have poor structure, especially where the land has been graded and compacted for construction purposes. Such soils typically have low infiltration rates, drain very slowly, and are poorly aerated. It is difficult to manage salinity with leaching treatments in clayey, compacted soils.

Soil depth and layering

Urban soils in the San Francisco Bay Area often are composed of layers having different textures. A shallow, dense clay layer reduces the soil volume available for root growth and restricts drainage. In a soil with no noticeable layering, the effective root depth may be more than 5 feet; in a compacted soil or a soil with a shallow clay or other impermeable layer it may be less than 12 inches. Knowing if the soil profile on a site is layered and the depth to a restrictive layer is important to determining how best to manage irrigation and leaching.

Soil aeration and drainage

Soil aeration and drainage are intimately linked because water and air occupy soil pores. Maintaining a balance between air (oxygen) and moisture is important to the survival of plant roots and soil organisms. See page 16 for a discussion of drainage problems.

Soil pH

Soil reaction, expressed as pH, refers to the acidity or alkalinity of a soil. A pH of 7.0 is neutral; pH greater than 7.0 is alkaline; below 7.0, acidic. Many plants grow in soils with a wide range of pH, from about 5.5 to 8.3, particularly if the soil is well drained. An optimal pH for the availability of all essential nutrients without becoming toxic is in the range of 5.5 to 7.0. Most soils in the S. F Bay Area are alkaline. Plants native to the region and similar climate zones, such as the Mediterranean, are adapted to alkaline conditions and are able to maintain adequate nutrition at the higher pH.

Soil salinity

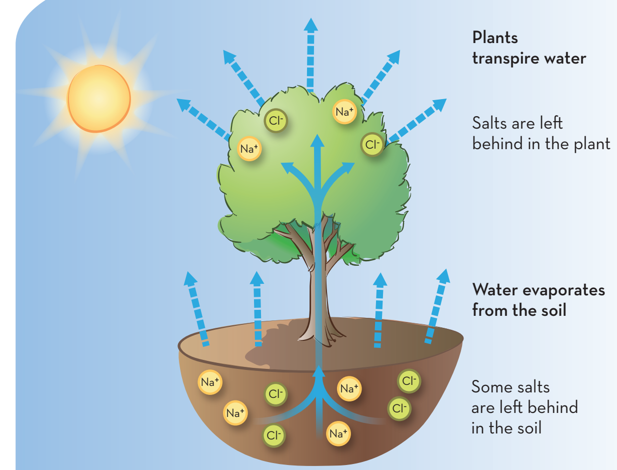
Soils naturally contain a mixture of salts that are necessary for plant growth and function. Those that contain high concentrations of soluble salts are considered to be saline. Salts may be present from the soil parent material or may accumulate in the soil from irrigation water, high groundwater tables, fertilizers and incorporation of saline soil amendments.

Alkali, or sodic, soils have excess sodium and usually have a pH greater than 8.5. Such soils are very slow to drain and are poorly aerated. Prolonged irrigation with water high in sodium and bicarbonate can create an alkali condition.

Evaluating Salinity

The concentration of soluble salts (salinity) in soil and water is commonly described by measuring its electrical conductivity (EC), and expressed as EC_w for water, and EC_e for soils. Conductivity is a measure of the ability of water to transfer an electrical current. Pure (distilled) water does not conduct electricity; water containing ions does. The higher the salinity, the greater the conductance. EC is usually expressed in units of millimhos per centimeter (mmhos/cm), microsiemens per centimeter (μS/cm), or decisiemens per meter (dS/m).

Another common way to describe water salinity is total dissolved solids (TDS), an expression of concentration of all the metals, minerals, and salts in the water. TDS meters measure the electrical conductivity and apply a conversion factor; different TDS meters use different conversion factors. The conversion is an estimate that can vary with salt concentration and composition. TDS is usually expressed in parts per million (ppm). Guidelines for evaluating water quality data and soil salinity are provided on page 14.



When irrigation water is applied, the constituents that are in the water become part of the soil water solution. As the plant transpires, roots pull water and salts from the soil, leaving some of the salts behind, and carrying some through the plant. The salt ions can reach a concentration that damages plants. Salt accumulation in the soil and plant tissue takes time, usually several years in Bay Area landscapes.

How do Salts Affect Soils and Plants?

When irrigation water is applied to the soil, the salts and other constituents that are in the water become part of the soil water solution. In well-drained soils, heavy rains lower salt concentrations in the root zone. But in areas with limited rainfall or poor drainage, salts accumulate in the soil over time.

As plants transpire, roots pull water out of the soil, carrying some of the salts with it. When water vapor is transpired from the foliage, salts are left behind. If chloride, sodium and/or boron ions reach damaging concentrations, leaf chlorosis and/or burn symptoms develop.

High concentrations of salts in soil and water affect plant physiological and biochemical processes. Three major effects of high salinity on plants and soils are

- plant water stress due to inability of roots to absorb water because of an increasing osmotic gradient (referred to as a physiological drought)
- salt (specific) ions, notably sodium, chloride, and boron, accumulating in cells to a harmful concentration
- slow water infiltration and soil permeability due to excess sodium breaking down soil aggregates and dispersing clays and organic matter.

Plant species vary widely in their tolerance or sensitivity to salts and specific ions (see pages 31-32 for plant salt tolerance ratings). Plants with moderate to high salt tolerance, including most drought tolerant plants, are adapted to sites that contain elevated concentrations of salt that may be too high for salt-sensitive species.

When irrigating with category 2 or 3 recycled water, salt acumulation in soils to concentrations where landscape plants are visibly damaged takes time - typically several years. In most cases, for plantings with moderate and high salt tolerant plants, the salt concentration can be managed with winter rainfall and leaching treatments.

Drought tolerant landscapes tend also to be recycled water-friendly landscapes. Drought tolerant plants tend to be more salt tolerant than plants native to humid climates.

Recycled Water and Landscapes

All landscapes, whether irrigated with recycled or potable water, rely on appropriately matching the plants to the site and space. How a landscape responds to irrigation with recycled water depends on the components of the specific water (water quality), the soil conditions such as texture and drainage, the salt sensitivity of the species in the landscape, and how the landscape is irrigated and managed.

Successful landscapes require careful attention to irrigation management and fostering healthy soils regardless of the water source. While most landscapes perform well when irrigated with recycled water, salt-sensitive plants that are irrigated with certain recycled waters may need extra care.

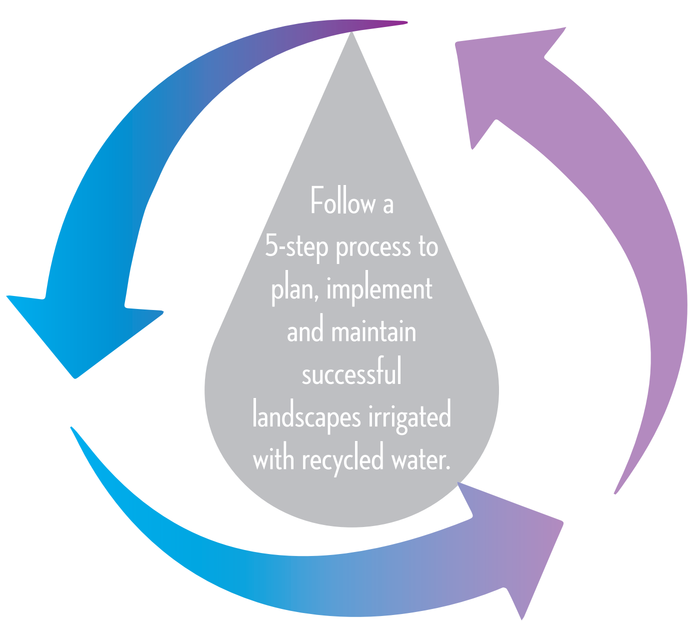
Plants that do well when irrigated with recycled water often include drought-tolerant native species as well as those from similar Mediterranean and dry climates. Some landscapes, however, are comprised of a variety of plants having a range of salt tolerance and soil that responds differently to recycled water.

This *Guide* is designed to help you design and manage landscapes irrigated with recycled water by following five steps: investigate the water, site and plant conditions; plan for irrigation with recycled water; implement the planned design and site modifications; monitor the landscape response to recycled water; and adjust landscape management as needed to maintain a healthy and attractive landscape.

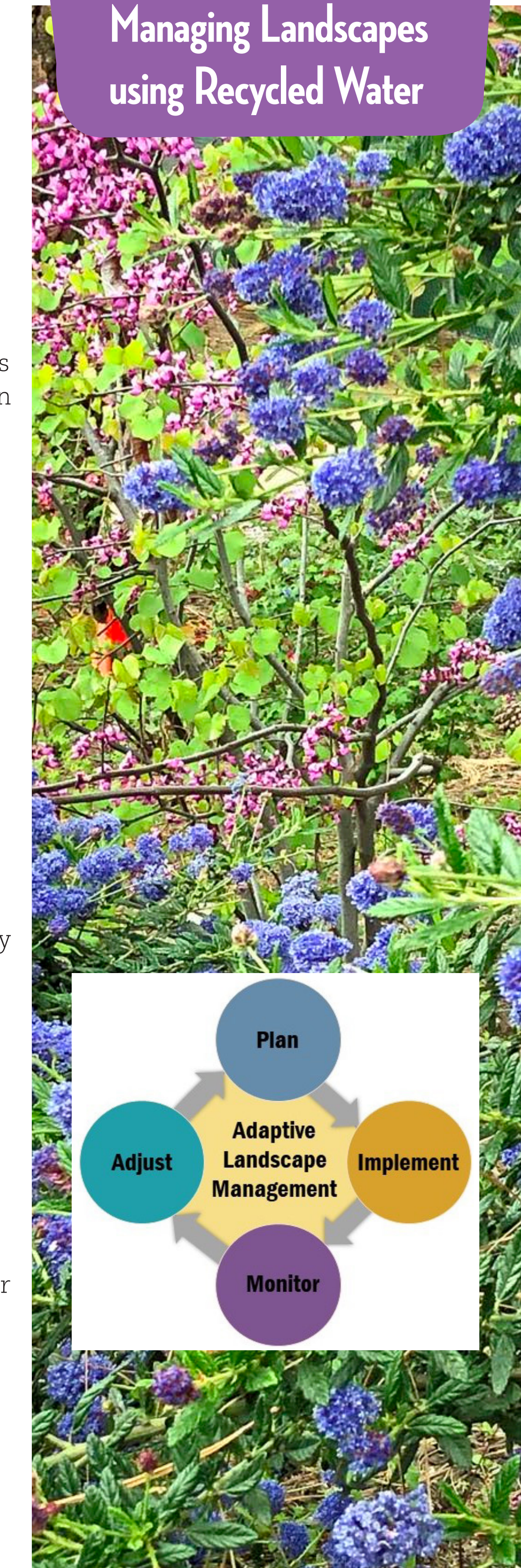
An overview of each step is provided on the next page and discussed in greater detail in the following pages.

One Size Doesn't Fit All

Recycled water produced in different locations in the Bay Area varies in the amount of salt it contains. Because of this and differences in local site conditions and plants, landscapes may respond differently to irrigation with local recycled water. Understanding these differences is a key factor to designing and managing attractive, healthy landscapes with recycled water.



5 Steps to Designing and Managing Landscapes using Recycled Water



1. Investigate

Understanding the site you have to work with is the first step in successfully using recycled water. Do this by identifying existing conditions, assessing how the landscape is likely to respond to the specific recycled water that will be used for irrigation, and considering appropriate adjustments to the irrigation system, landscape design, and maintenance.

2. Plan

The second step is to take the information learned about the site in step one and consider what adjustments or treatments should be made to successfully irrigate with recycled water in existing and new landscapes.

3. Implement

In the third step, the designs for new landscapes and retrofit plans for existing landscapes are applied. The management goals are to provide site- and plant species-appropriate care and to minimize the accumulation of salts in the soil.

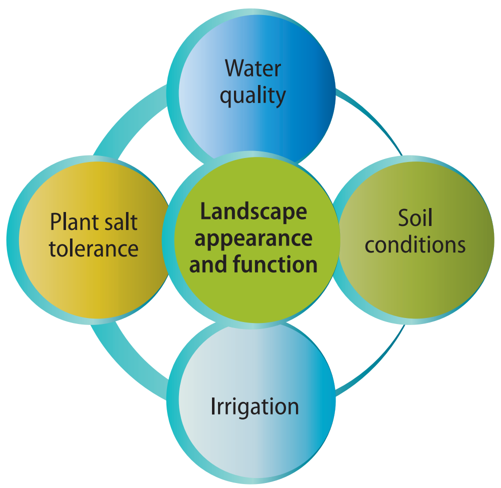
4. Monitor

Monitoring landscape performance is a normal part of managing any landscape. By checking the landscape regularly for changes in plant health and growth, the manager determines how the landscape is performing and assesses if any changes in management practices are needed. This adaptive management approach is effective whether the landscape is irrigated with potable or recycled water.

5. Adjust

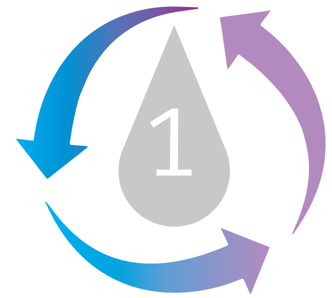
In an adaptive management program, the landscape manager devises maintenance activities in response to the conditions observed during monitoring. For example, if routine soil analyses reveal that the soil salinity is nearing the allowable threshold, leaching treatments should be scheduled to lower the soil salt concentration.

5 Steps to Designing and Managing Landscapes using Recycled Water



How a landscape responds to irrigation with recycled water depends on the quality of the water, soil conditions, salt sensitivity of the plants, and how the landscape is irrigated.

Inventory plant species in the landscape and categorize their salt tolerance.



1. Investigate

Understanding the site you are working with is the first step in successfully using recycled water. Perform a landscape evaluation by identifying existing conditions, assessing how the landscape is likely to respond to the specific recycled water that will be used for irrigation, and considering appropriate adjustments to the landscape design and maintenance. Here is a step-by-step overview of how to perform a landscape evaluation.

Establish the recycled water quality available at the site.

Water quality is the aggregated chemical characteristics of water. For landscapes, we are primarily interested in the concentration of salts (EC_w, TDS) and specific ions (chloride, sodium, boron) that can affect plants and soils.

To assess water quality…

1. Review water quality reports from the recycled water provider or collect samples for analysis.
2. From the laboratory report, determine the water quality category from table on page 14.

The amount of salt and specific ions in recycled water in the San Francisco Bay Area varies by location, and ranges from category 1 (low salinity) to category 3 (moderate salinity); none are in category 4 (high salinity).

Identify plants and assess tolerance to recycled water.

Landscape species exhibit a wide range of tolerance to salts (see Plant Salt Tolerance p. 31-32). Some, like coast redwoods, are highly sensitive and show stress at a relatively low soil salinity (EC_e = 1.5 dS/m), while others, like most drought tolerant plants, can tolerate relatively high soil salinity (EC_e > 4.0 dS/m).

To assess plant tolerance to recycled water…

- Identify plants in the landscape.
- Categorize each as having high, moderate, or low salt tolerance.

Investigate site and soil conditions.

Soil is vital to landscape health and appearance; it is the reservoir that holds water and plant nutrients, and it provides physical support for plants. As irrigation water percolates through the soil profile and is absorbed by plants, most of the water's constituents, such as salts, are left behind.

Predicting how a landscape will respond to irrigation with a given quality of recycled water requires managers to know specific information about the soil, such as its pH, salinity, texture, and drainage.

To assess site and soil conditions…

- Investigate the soil profile (see photo on right).
- Collect samples for laboratory analysis.
- Evaluate drainage by performing a percolation test (see page 14).

Check irrigation system equipment and performance.

How, when, how long, and where water is applied to the landscape all affect soil and plant response. Having a functional irrigation system that delivers water consistently and at a rate the soil can absorb is critical to any landscape in the San Francisco Bay Area.

To assess the irrigation system…

- Identify how water is applied: sprinkler, drip, bubbler, etc.
- Look for irrigation equipment problems (see page 15).
- Evaluate irrigation uniformity by performing an irrigation water audit or catch can test.

Summing up the landscape evaluation

Once the site assessment has been completed, it is time to put all the information together. How will the recycled water, soil, and plant species work together to create an attractive and healthy landscape?

Assess landscape response to recycled water.

For greatest success, water quality should be appropriate for the salt tolerance of the plants in the landscape and the soil drainage conditions. In short, it should be fit for the intended use.

- Category 1 water is suitable for any Bay Area landscape.
- Prolonged irrigation with category 2 or 3 water would likely damage salt-sensitive species such as coast redwood or Japanese maple, but not salt-tolerant species such as olive and Canary Island pine.
- Landscapes having poorly drained soils are less suitable for category 2 or 3 water if plant salt tolerance is moderate to low.

Determine maximum soil salinity for landscape.

Over time and prolonged irrigation, the concentration of salts increases and may reach the point where sensitive plants are affected or drainage is impaired if the soil cannot be adequately leached (leaching is implemented in step 3). The soil salinity concentration at which plant damage occurs is called the salt tolerance threshold.

Landscape plant salt tolerance	Estimated EC_e threshold
high	6 dS/m
moderate	3 dS/m
low	1.5 dS/m

Results of Soil Investigations

The results of soil investigations should give you a good understanding of

- preexisting conditions that could affect landscape performance
- how readily water is likely to move into and through the soil
- the potential for salt accumulation in the root zone and restrictions to leaching
- the water-holding capacity of the soil for use in developing irrigation schedules
- the fertility of the soil for managing plant nutrition

Soil profiles are investigated by digging backhoe pits (top) or using a bucket auger (bottom) to remove soil to four feet deep or more. Soils that comprise the profile are described and samples collected at appropriate depths.

Evaluating water quality and soil conditions

Recycled water quality interpretive guide for irrigating San Francisco Bay Area landscapes

Parameter	Category 1	Category 2	Category 3	Category 4
Salinity				
TDS, mg/l	<640	640–830	830–1,600	>1,600
EC_w, dS/m	<1.0	1.0–1.3	1.3–2.5	>2.5
Specific ion				
boron (mg/l)	<0.5	0.5–1.0	1.0–2.0	>2.0
chloride (mg/l)	<100	100–200	200–350	>350
sodium (mg/l)	<70	70–150	150–200	>200
sodium adsorption ratio (SAR)	<3	3–6	6-9	>9
bicarbonate (mg/l)	<90	90–200	200–500	>500
residual chlorine (mg/l)	<1.0	1–2.5	2.5–5.0	>5.0

How to evaluate water quality from a lab report

Request an annual recycled water quality report from a recycled water provider (or do an internet search). This report has important information for assessing how a landscape is likely to respond to irrigation.

Step 1: Identify key water quality parameters: electrical conductivity, total dissolved solids, sodium, boron, and chloride. Note that there are no values provided for sodium adsorption ratio (SAR) or bicarbonate; the laboratory would probably provide that data if requested. Note the annual average as well as the range (annual high and low) of each value.

Step 2: Compare each of the constituents to the ranges in water quality table (above) and note the water quality category. If the unit of measurement of a constituent is different than noted in table 1 you will need to convert to equivalent units.

Constituent	Average	Range	Water Quality Category
Electrical Conductivity (dS/m)	1.2	1.0–1.3	2
Total Dissolved Solids (mg/l)	595	498–722	2
Sodium mg/l)	128	112–159	2
Boron (mg/l)	0.4	<0.2- 0.6	1
Chloride (mg/l)	141.6	88.8–157.7	2

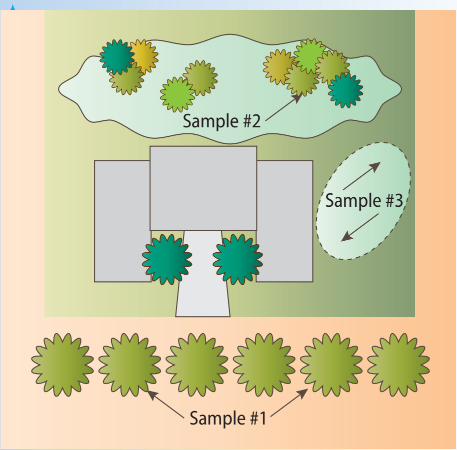
Step 3: Based on the analyses provided, the recycled water is primarily category 2. This means that the recycled water is fair quality and presents low risk to landscapes except those with plants sensitive to salt and poorly drained soils that cannot be leached. Boron is within category 1 range and poses no risk.

Soil salinity interpretative guide for landscapes in the San Francisco Bay Area

	Approximate soil salt thresholds based on landscape salt tolerance		
Salt assessment	Low	Moderate	High
salinity (EC_e, dS/cm)	2.0	2.0–4.0	>4.0
sodium adsorption ratio (SAR)	<6	7-9	>9
sodium, mg/l	–	>230	–
boron, mg/l	0.5	2	>3
chloride, mg/l	<120	250	>300

How to collect a soil sample

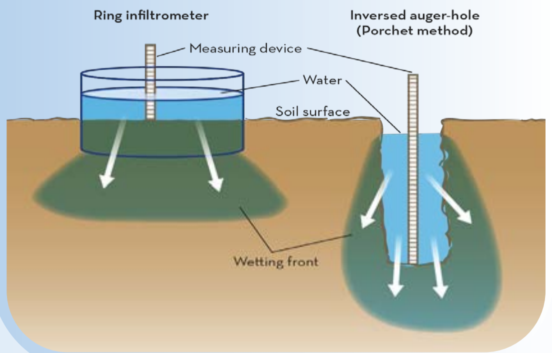
- Determine sampling areas. Divide the site into sampling areas of similar conditions. A single sample should represent only one soil type or growing condition. In this example the street trees, shrub bed and low-lying turf area are sampled separately.



- **Determine appropriate sampling depth.** Samples should be collected from within the existing or proposed plant rooting area, for instance 6 inches for turf, 18 inches for shrubs and trees.
- **Collect samples using a shovel, soil probe or auger.** About two cups of soil is needed for each sample.
- **Package the samples** and send them to a horticultural soil testing laboratory.

How to measure water infiltration rate into soil

- Infiltration rate can be determined by measuring the rate at which water moves into moist soil. Two methods are: ring infiltrometer and inverse auger hole. Wet the soil with 1 in. of water before measuring.
- Field measurements are more representative of site conditions than lab methods.
- Generally, infiltration rate for wetted sandy and silty soils is 0.4-0.8 inches/hour; for clayey soils, 0.04-0.2 inches per hour.



Clues to possible irrigation problems

During the site inspection, perform a cursory assessment of irrigation patterns, looking for dry spots, wet areas, and obvious irrigation equipment problems. Older irrigation systems are often a hodgepodge of equipment and spray heads with different water application rates and patterns. This can cause variation in water distribution over the site.

- Look for turf and ground cover areas that are brown and dry. This aerial view of a park taken mid-summer readily reveals dry areas and problems with sprinkler irrigation uniformity.

- Plants that are scorched may be a sign of insufficient water supply. In this photo, note that the English ivy in full sun is burned, while ivy in the shade is not. Plants in full sun require more water than those in shade. If the shaded and full sun areas are irrigated on the same valve, they receive the same amount of water regardless of need.

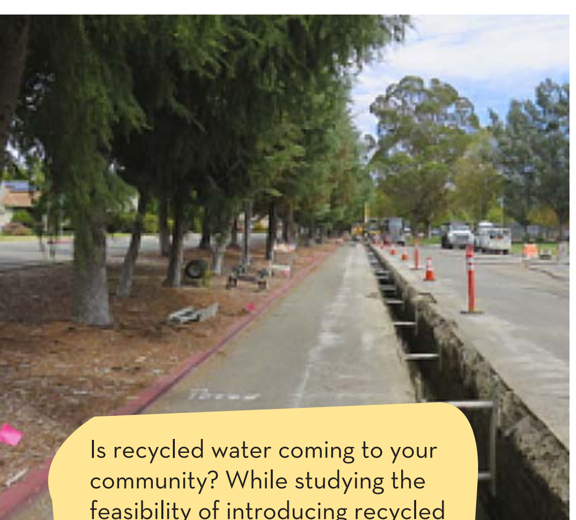
- Signs of excessive irrigation include soggy soils and algae and moss on pavement or soil.

- Soils that are wet, blue-black in color and smell of rotten eggs are another indicator of excessive irrigation and/or poor drainage.

- Poor irrigation performance may be due to damaged or offset sprinkler heads, dirt and debris in the spray nozzles, plugged emitters, dysfunctional valves, or plants blocking spray patterns.

Recycled water irrigation systems are regulated by the California Department of Public Health.

Check with local recycled water suppliers for specific requirements of retrofit or newly installed landscape projects irrigated with recycled water.



Is recycled water coming to your community? While studying the feasibility of introducing recycled water to existing landscapes, consider protecting trees and other vegetation during installation of distribution systems. In this example, the water lines were moved into the street farther from the trees to reduce tree root and crown damage.

2. Plan

The second step is to take the information learned about the site in step one, and consider what adjustments or treatments should be made to successfully irrigate with recycled water.

For existing landscapes

Assess how plants will likely perform.

Consider the plant species present, their cultural requirements and current condition, and site characteristics to assess how plants will likely perform with the specific recycled water to be applied.

- Identify salt-sensitive plants that may not tolerate the recycled water, considering the quality of the soils and water.
- Identify locations where site soils and plant exposure are unfavorable for particular species.

Determine what treatments are needed to improve soils and drainage.

Treat adverse soil conditions that may contribute to salt accumulation over time.

- Identify locations where treatments are needed to improve soil drainage.
- Determine where organic amendments and/or treatments to reduce soil chemical problems are needed.

Identify repairs and improvements needed to the irrigation system.

Plant performance relies greatly on the design, function, and management of irrigation systems, especially when irrigating with recycled water. Irrigation problems lead to plant problems.

- Identify worn, broken, and mismatched irrigation components that need to be repaired or replaced.
- Plan to modify irrigation systems (if needed) to match precipitation rates with infiltration rates and improve distribution uniformity.
- Plan to replace equipment with components specifically designed for use with recycled water (see *Key considerations for recycled water irrigation systems* on the next page).

For new landscapes

Select plants that are well suited to the site ***and*** tolerant of the recycled water that will be applied.

It is important to select plants that are well suited to the site. In addition to plant salt tolerance, consider species growth and structural characteristics, climatic tolerance, cultural requirements, maintenance requirements, and pest tolerance.

- Select plants that are compatible with the water quality that will be applied. If salts are relatively high (category 3 or 4 recycled water), chose species with a high tolerance to salts or specific ions (see *Plant Salt Tolerance*, page 31-32).
- Select plants that require irrigation only once or twice a month (low and very low WUCOLS water use rating) or less when established. Infrequent irrigation reduces the potential for salt buildup in the soil, and many drought tolerant plants are also salt tolerant.

Design the irrigation system using equipment intended for use with recycled water.

When using recycled water, you must consider cross-connections, meters, valves, pipes, emitters, and backflow devices and adhere to local and state regulations. For new irrigation systems...

- Select equipment specifically designed for use with recycled water (see sidebar at right).
- Avoid spray irrigation that would wet foliage of sensitive plants. Use low-trajectory nozzles to minimize foliage wetting.

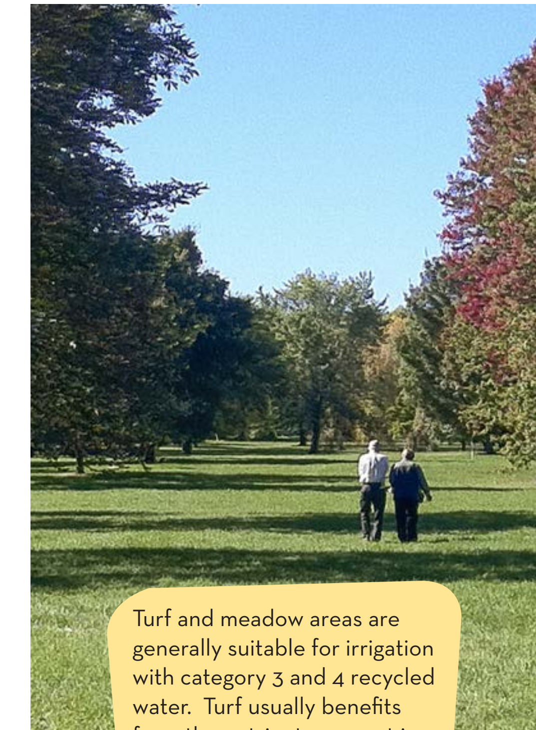
Specify soil treatments if needed to improve conditions for the landscape.

Whether using recycled or potable water, preplant soil treatments are the same, especially when soils have good drainage and are low in salts. Soils can be modified to improve plant performance and reduce maintenance, but there are limits to what is both reasonable and effective. See *Improving soil conditions* on the following page.

Design drainage systems or specify treatments to solve drainage problems.

Identify locations where either surface or internal drainage are inadequate (see *Solving drainage problems* on p.19). Where drainage cannot be improved...

- Select species that are tolerant of wet soils and higher salt concentrations.
- Consider planting on mounds and raised beds to increase rooting area above saturated zones.



Turf and meadow areas are generally suitable for irrigation with category 3 and 4 recycled water. Turf usually benefits from the nutrients present in recycled water. If trees are present, their tolerance to salts should be assessed.

Key considerations for recycled water irrigation systems

Meet health and safety regulations

- Control cross-connections.
- Use purple pipe and include signage.
- Protect public areas from overspray, runoff, and ponding.

Select appropriate equipment

- Valves resistant to chlorine and other chemicals.
- Low-trajectory spray nozzles to reduce drift in windy conditions and avoid wetting plant foliage.
- Large-orifice, turbulent-flow drip emitters with micro-disc filtration.
- Incorporate central control with ET-based scheduling and flow sensors.

Design for success

- Use checklists for regulatory requirements and evaluation procedures.
- Check with your recycled water supplier for local requirements.
- Incorporate recycled-water friendly irrigation technology into your design.

Improving site soil conditions

Soil treatments for landscapes irrigated with recycled water are no different than standard treatments for landscapes irrigated with potable water, especially when soil is well-drained and low in salts. If soil is restrictive, for example, poorly draining or already containing salts or high pH, additional treatments may be needed, especially when category 3 or 4 water is to be applied.

A site that is less than ideal can sometimes be modified to improve plant performance and ease of maintenance. Site modification should not be considered a substitute for designing and planting landscapes that are well matched to site conditions, however. There are limits to what can be done to modify site conditions effectively and reasonably (see table below). For example, efforts to change soil texture are rarely effective.

It is unlikely that a single treatment or application will significantly alter soil characteristics or soil quality. More commonly, repeated treatments over time - possibly years - is needed to make lasting changes to soil organic matter or pH, for instance. In most cases, the best way to improve soil structure, water-holding capacity, chemical characteristics and biological activity is to incorporate quality compost and maintain an organic mulch on the soil surface, reapplying every two to three years.

Dealing with compacted soils

Compaction should be remediated before planting. Cultivation and the incorporation of soil amendments can break up compacted soils. The objective is to improve soil structure over time and increase macropore spaces that hold water and air. Commonly, surface decompaction is accomplished by cultivating with tillers or backhoes. Where compacted soil is present deeper than 6 to 8 in., fracturing, trenching, or ripping will be needed before tilling the surface soil.

Following cultivation, it is good to incorporate organic amendments. Combining amendments with different decomposition rates, such as compost and fine bark, can provide both short- and long-term benefits (see table below).

Importing landscape soil

When existing site soil is poor quality, topsoil is sometimes brought in and placed on top of the site soil before planting. This treatment usually is not as helpful as one might hope. Water movement and plant root development usually are restricted between the site soil and the topsoil, even when the interface is tilled to relieve compaction.

Topsoil is in short supply in the Bay Area. In fact, most soil sold as "topsoil" is actually excavated from deeper in the soil profile and then mixed with organic amendments. In most cases, you can accomplish the same thing by amending the site soil appropriately.

Comparison of ability to modify site conditions before and after planting

	Ability to Modify	
Site Characteristics	Preplant	Postplant
Soil texture		
increase coarseness	low	low
increase fineness	low	low
replace soil	good	moderate to low
Soil structure		
reduce compaction	moderate*	low
increase aeration	moderate*	low
Soil moisture		
increase water-holding capacity	moderate*	low
increase water percolation	good to moderate	moderate to low
increase surface drainage	good	good to low
increase internal drainage	good to low	moderate to low
lower water table	good to low	good to low
Soil chemical characteristics		
raise pH	good	moderate
lower pH in sodic soil	good to moderate	moderate to low
lower pH in high lime soil	low	low
lower salinity	good to moderate	good to moderate
lower boron	moderate	moderate

Note: ***Effects are usually short-term.**

Characteristics and principal uses of selected soil amendments

	Principal use in soil			
Material	Increase water holding capacity	Increase aeration/ drainage	Improve soil structure over time	Comments
peat	yes	no	yes	Acidic and can lower soil pH; expensive; generally texture too fine for Bay Area soils but is useful in sands. Hydrophobic when dry (needs to be wetted).
wood sawdust and shavings	no	yes	yes	High carbon to nitrogen ratio can lead to nitrogen deficiency in plants.
ground bark	no	yes	yes	Decomposes slowly. Has a high carbon to nitrogen (C:N) ratio.
leaf mold	yes	no	yes	Decomposes rapidly because of low C:N ratio.
composted manure	yes	no	yes	If not well leached, can have high salt content. Avoid amendment with salinity (EC_e) greater than 3.0 dS/m.
compost	yes	no	yes	Screened, mature compost with C:N of 20:1 to 30:1 is suitable as amendment.
sand	no	yes	no	Decreases drainage and aeration unless incorporated at rate of 50% or more by volume. Not recommended for use in most soils.

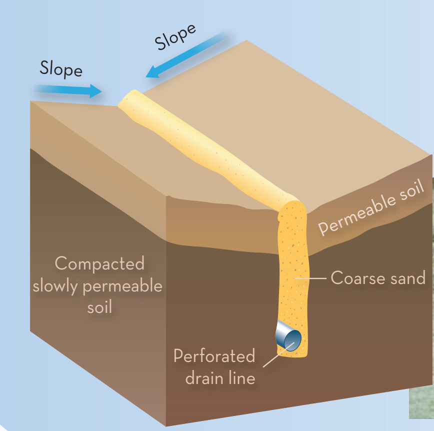
Solving drainage problems

Good drainage is important to landscape performance regardless of irrigation source: plants grow and function best in an aerated, well-drained soil. When landscapes are irrigated with recycled water, however, adequate drainage is even more important because without it, any increase in salt in the soil cannot be removed.

Drainage issues can include surface accumulation of water in low-lying areas as well as internal drainage that may be impeded by conditions in the soil profile. The causes should be investigated so that appropriate treatments can be incorporated into the design and implemented.

Guidelines for improving soil drainage caused by compaction, layers, and high water table

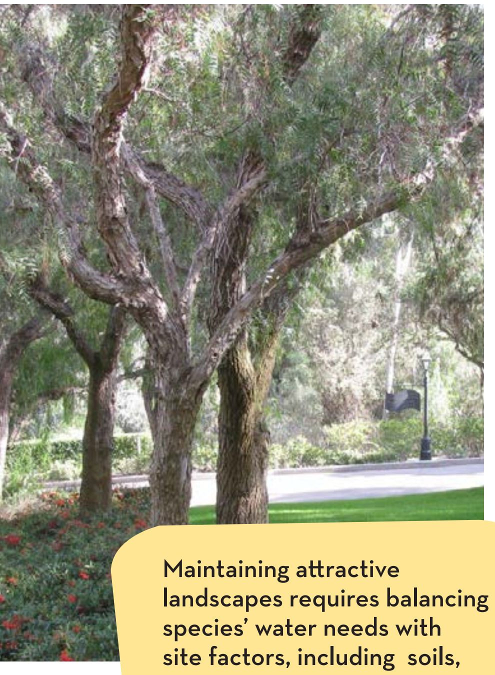
Problem	Possible causes	Treatments
standing water at soil surface (poor surface drainage)	compacted surface soil caused by construction or traffic	Thoroughly incorporate organic matter through depth of compaction.
	low-lying area with no outlet for ponded runoff	Adjust irrigation to reduce the amount of runoff.
		Fill in low area with soil the same texture as the native soil.
		Install a French drain with at least 2% fall to an area with a more permeable soil or outlet at a lower grade (see illustration below).
	dispersed soil caused by high sodium concentration (SAR greater than 6, pH greater than 8.3)	Incorporate gypsum into the soil (determine rate based on soil analysis).
		Apply several leaching irrigations; allow the soil to drain between the irrigations.
	high water table	Install a drainage system; spacing and depth depend on depth to water table, texture of soil, and depth of plant roots.
	impervious layer beneath surface prohibiting soil drainage	If pervious soil lies below the impervious layer, excavate holes through the layer to water to drain into lower profile (see photo below).
		If there no pervious soil below, install drainage system.
	coarse-textured soil underlain by fine-textured soil (clay)	Install drainage system above fine-textured soil.
saturated soil beneath the surface (poor internal drainage)	impervious layer less than 2 ft thick underlain with permeable soil	Deep-rip in two directions below depth of layer; subsoilers and slip plows can rip to depths of 5 to 7 ft; soil must be very dry; alternatively, break up layers with backhoe.
	impervious layer greater than 2 ft thick underlain with permeable soil or where ripping is impractical	1. Bore hole 4 to 6 inches in diameter in bottom of planting hole through the hardpan (see photo below).
		2. Fill the hole with aggregated soil of the same or coarser texture than site soil.
		3. Irrigate to settle soil.
	impervious layer less than 4 ft below surface, not underlain with permeable soil	Increase soil depth by creating mounds or raised beds.
		Use shallow-rooted plants.
	impervious layer greater than 4 ft from the surface, not underlain with permeable soil	Install a drainage system at least 4 ft below finish grade; the drain lines must have a continuous fall to an outlet at a lower elevation than the lines.
	fine-textured soil underlain by a coarse-textured soil	Thoroughly mix the two layers together to create a blended soil.
		Vertical mulch by digging vertical holes or trenches through the fine-textured soil into the coarse-textured soil; backfill with coarse-textured soil.



French drains can be used to improve surface drainage and thereby minimize water puddling or ponding. The French drain on this golf course channels water out of a low-lying area.

Above, impervious soil layers are being broken through using an auger. The size, depth, and spacing of auger holes should be specified for the soil conditions at the site.

5 Steps to Designing and Managing Landscapes using Recycled Water



Maintaining attractive landscapes requires balancing species' water needs with site factors, including soils, environmental conditions, and the performance of the irrigation system.

MWELO and recycled water

The Model Water Efficient Landscape Ordinance (MWELO) is a state regulation that restricts landscape water use to certain delivery methods, application rates and total use. Local agencies must either adopt MWELO or an alternative that is at least as effective for water conservation.

MWELO Section 492.14 includes the following requirements regarding use of recycled water:

- The installation of recycled water irrigation systems shall allow for the current and future use of recycled water.
- Landscapes using recycled water are considered Special Landscape Areas. The ET Adjustment Factor for new and existing (non-rehabilitated) Special Landscape Areas shall not exceed 1.0.

3. Implement

In the third step, the designs for new landscapes and retrofit plans for existing landscapes are applied The management goals are to provide site and plant species-appropriate care and to minimize the accumulation of salts in the soil.

Correct soil and drainage problems

Remediate soil conditions identified in step 2 that may contribute to salt accumulation by improving soil drainage and capacity to be leached if needed. These may include...

- Breaking through impervious soil layers and/or installing drainage systems.
- Incorporating organic and/or chemical amendments (gypsum or sulfur, for example) to improve soil physical and chemical qualities.

Repair and prepare existing irrigation system

Implement the repairs and equipment replacement identified in step 2.

- Flush irrigation system.
- Repair and replace irrigation components as needed.
- Adjust water application patterns to maximize uniformity.
- Install chemical-resistant valves to prevent premature diaphragm and solenoid corrosion.
- Check that local and state regulations and requirements for recycled water irrigation systems have been met.

Adjust fertilization programs

Because most recycled water contains nitrogen, phosphorus and potassium, you can reduce and in some instances eliminate applying fertilizers which contain these elements.

- Test soil and plant tissue for nutrient content to determine nutrient concentrations and if specific fertilizers are needed.

Develop a water budget

A water budget is an analysis of how much water a landscape will require based on supply and demand. It is used both as a design tool where water resources are limited and a management tool to help plan for and schedule irrigation. To develop a water budget...

- Know the factors affecting water supply and plant demand.
- Estimate the amount of water that is available in the soil for plant use by determining the water-holding capacity of the soil, the size of the soil moisture reservoir and plant water use (see page 19).

Establish a soil salinity threshold and leaching program

The soil salinity threshold is the concentration below which soil salinity should be maintained to avoid plant damage. If the landscape includes plants having a range of salt tolerance, determine the threshold for the most salt-sensitive species.

- Begin leaching treatments when soil salinity measurements (EC_e) reveal that the threshold is being approached.
- Repeat leaching treatments until soil analyses indicate that salinity measurements are below the threshold (see guidelines on page 16).

Modify irrigation schedules

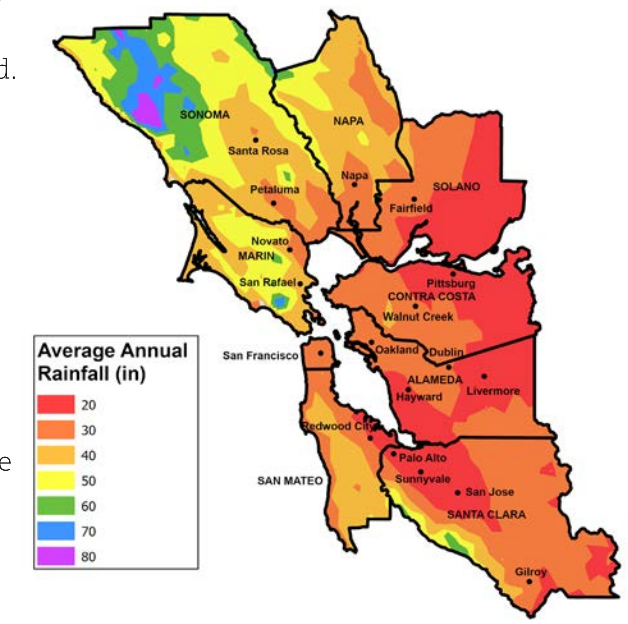
The objective of irrigation scheduling is to supply enough water to meet plant needs without wasting water.

- Modify irrigation systems if needed to match precipitation rates with soil infiltration rates and improve distribution uniformity.
- When using recycled water, keep soil moist (50% of field capacity or greater) for plants having moderate to low salt tolerance.
- When the soil salinity threshold is approached, increase irrigation as needed to include the leaching requirement (see page 16).
- Install "smart" ET-based controllers that adjust irrigation run times based on local weather conditions.

Replace salt-sensitive plants if needed

If soil salinity cannot be maintained below the soil salinity threshold, consider replacing sensitive plants identified in step 2 with more tolerant species. See p. 28-29 for discussion of plant species salt tolerance ratings.

- For sensitive species noted as being drought tolerant, consider withdrawing irrigation and applying mulch to the soil surface.
- If the species salt tolerance is not known, wait to see how it performs before considering replacement.



The average annual rainfall in the Bay Area varies dramatically, from a low of 20 inches to a high of 80 inches. The effectiveness of rainfall in reducing soil salinity also varies. In Marin County, for example, rainfall may provide all the leaching that is needed. In Livermore, on the other hand, leaching irrigation will likely be necessary.

The soil moisture reservoir that holds the water available to this tree is limited by the walls of this raised planter. Because of this restriction, the tree may need supplemental watering to maintain a healthy appearance even though it is drought tolerant.

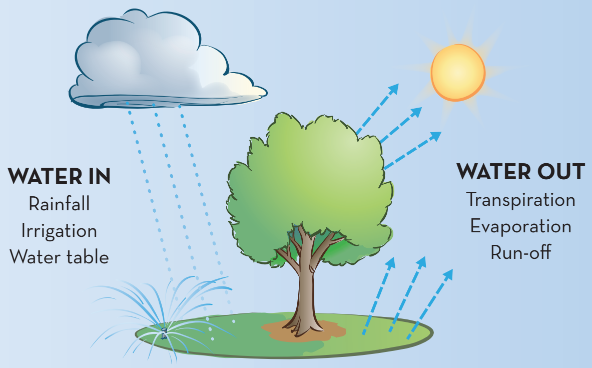
Determining irrigation schedules

Water management is of primary importance to successful maintenance of San Francisco Bay Area landscapes. Water budgeting, which is is based on supply and demand, is a good way to estimate irrigation schedules. The goal is to provide sufficient water through irrigation to meet plant needs. The challenge is to apply just enough water, not too much or too little.

Elements of a water budget

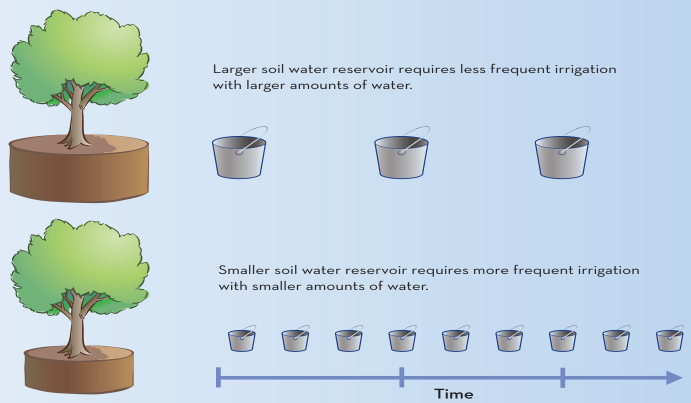
The elements of a water budget include inputs (precipitation and irrigation, along with capillary rise from groundwater) minus the outputs (evapotranspiration, runoff, and percolation beyond the plant root zone).

The rate that water transpires from the plant and evaporates from the soil (evapotranspiration, ET_0) is used to estimate how much water is needed for optimal plant growth. By deducting ET_0 from the amount of water stored in the soil water reservoir, the amount and frequency of irrigation can be estimated. This is basic water budgeting.



Soil water reservoir

The volume of the soil moisture reservoir affects irrigation frequency. Each irrigation should be of sufficient volume to fill the soil moisture reservoir.



Deciding when and how much to irrigate

The soil moisture reservoir is the volume of soil occupied by plant roots and the available water they can extract. The best time to irrigate is when half of the plant-available water in the soil moisture reservoir is depleted. For instance, in a sandy loam soil with a plant rooting depth of 12 inches, scheduled irrigation of non-drought tolerant plants after 50% of the available water (0.3-0.35 in.) is depleted. Drought-adapted plants that are established in the landscape and have reached mature size often can be maintained with only a few irrigations each year to extend the rainy season.

Soil texture	Depth of soil (ft)	Water-holding capacity (in)	Plant-available water (in)
Sandy loam	1	1.2–1.4	0.6–0.7
	2	2.4–2.8	1.2–1.4
	3	3.6–4.2	1.8–2.1
Silty loam	1	2.0–2.5	1.0–1.3
	2	4.0–5.0	2.0–2.6
	3	6.0–7.5	3.0–3.9
Clay loam	1	1.8–2.0	0.9–1.0
	2	2.6-4.0	1.8–2.0
	3	4.2–6.0	2.7–3.0

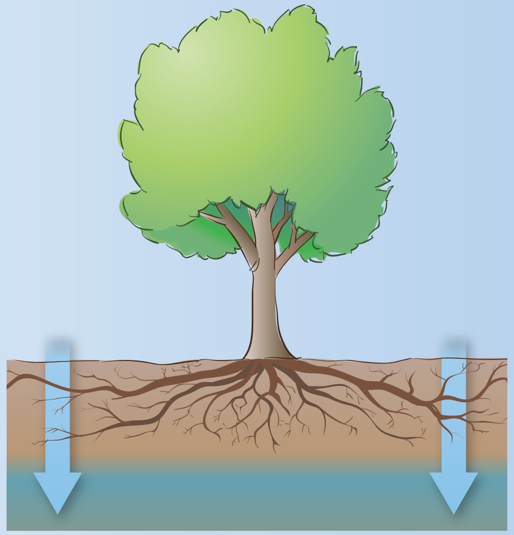
Source: Adapted from USDA National Research Initiative Competitive Grants CAP Project, http://passel.unl.edu/pages/informationmodule.php?idinformationmodule=1130447039&topicorder

Leaching to manage salt accumulation in soil

What's so important about leaching?

Leaching is our best management tool for controlling salt concentration in the landscape root zone. To leach soil salts, apply water to flush salts in the root zone deeper in the soil profile, beyond the reach of roots. As water moves downward, it carries salts in the soil solution along with it, out of the range of absorbing plant roots.

In the S. F. Bay Area, leaching occurs naturally in the winter months when rain repeatedly wets the soil. Note, however, that the average annual rainfall in the Bay Area varies widely - from 15 to 70 inches, so the effectiveness of rainfall to leach soils varies with location. Of course, in dry years less leaching occurs.



How to lower soil salinity with leaching treatments

Leaching during the dry season is accomplished by adjusting irrigation run times to apply enough water to meet the landscape's water requirements plus extra water to wet the soil deeper than the plant roots extend. The extra water moves the salts deeper into the soil and away from plant roots. Anything that impedes water movement through the soil, such as layers of different soil textures, compaction, or a high water table, limits the salt movement downward and makes leaching treatments ineffective. It is not possible to lower the salt content of the soil below the salt content of the water source used for leaching.

What is the leaching requirement?

The amount of extra water needed to flush excess salts below the roots is called the *leaching requirement*. In most landscapes in the Bay Area using category 2 and 3 recycled water, an appropriate leaching requirement is 10 to 20% more water than is applied to meet the landscape's irrigation needs. The higher the salinity of the water, the poorer the soil quality and the more salt-sensitive the landscape, the greater the leaching requirement needed (see *Water Quality Interpretive Guide*, p. 14,)

Estimated leaching requirement based on water quality, landscape water requirement, and soil conditions.

		Estimated leaching requirement (% increase of landscape water requirement)	
Water quality category[a]	Landscape water requirement	Coarse, well-drained soil	Heavy or poorly drained soil
1	very low to low	0	0
	moderate	0	0
	high	0	0
2	very low to low	0	0
	moderate	10%	10%
	high	10%	15%
3	very low to low	0	10%
	moderate	10%	15%
	high	20%	25%
4	very low to low	10%	10%
	moderate	20%	25%
	high	25%	30%

[a]see Water Quality Interpretive Guide, page 14.

What is the soil salinity threshold?

The *soil salinity threshold* is the concentration below which soil salinity should be maintained to avoid plant damage. The threshold depends on the salt sensitivity of the plants in the landscape, the quality of the recycled water being applied, and the texture and chemical characteristics of the soil. As a guideline, consider the thresholds shown in the table on the right.

Soil salinity threshold based on plant salt tolerance.

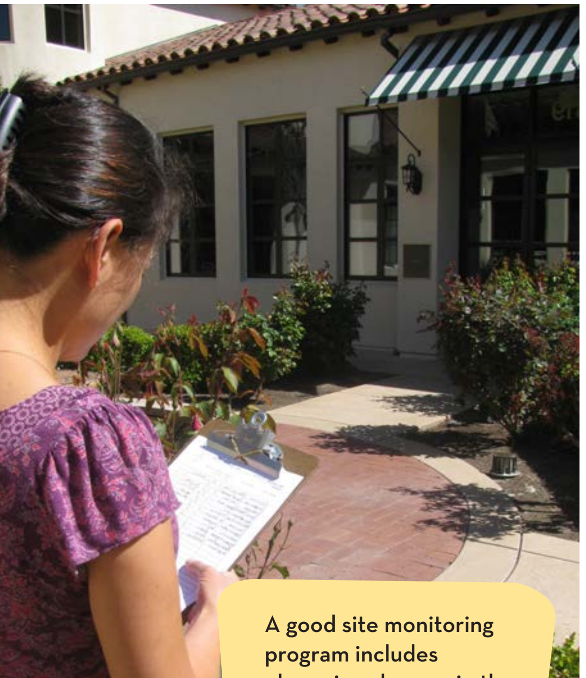
Plant salt tolerance	Soil salinity (EC_e) threshold
low	2 dS/m
moderate	4 dS/m
high	6 dS/m

What to do when soil salinity is approaching the threshold?

When soil salinity measurements (EC_e) reveal that the threshold is being approached, leaching treatments should begin and repeated until soil analyses indicate that salinity measurements are below the threshold.

5 Steps to Designing and Managing Landscapes using Recycled Water

4. Monitor



A good site monitoring program includes observing changes in the landscape and keeping careful records.

Monitoring landscape performance is a normal part of managing any landscape. By checking the landscape regularly for changes in plant health and growth, the manager determines how the landscape is performing and assesses if any changes in management practices are needed. This adaptive management approach is effective whether the landscape is irrigated with potable or recycled water.

Here are the components of a successful landscape monitoring program.

Establish a baseline

Document the current condition of the landscape to establish a baseline against which changes in the landscape can be compared.

- Inventory species present.
- Evaluate the overall condition of each species in the landscape area.
- Define what an acceptable landscape looks like. Plants with dead or dying foliage is unacceptable. Some marginal leaf burn on older leaves is usually acceptable as long as the damage is not clearly visible from a distance.

Observe plant appearance and health

By closely monitoring plant appearance, stress-related problems can be identified and early corrective action taken.

- Know what is normal and abnormal for the species.
- Accurately diagnose plant problems. Landscapes can be affected by a variety of biotic (living) and abiotic (non-living) factors, some of which cause similar symptoms (see page 27 for some examples).
- Plant symptoms of water deficit (drought) and salt damage can appear the same: marginal leaf burn. Plant foliage analysis of sodium, boron, and chloride are needed to determine the cause and so you can provide appropriate treatments.

What is an acceptible appearance? Even though there is marginal burn on some of this Brisbane box's interior foliage, the tree has an attractive, full, green canopy.

Test and observe soil conditions

Soil conditions should be assessed and monitored through observation, sampling, and laboratory analysis to identify when treatments such as fertilization or leaching are needed.

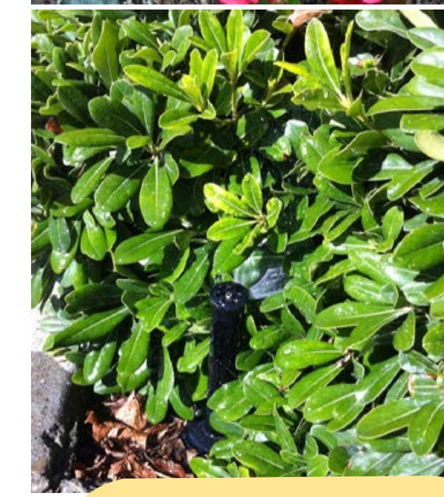
- In most cases, soil should be sampled at the beginning of the irrigation season in the spring and again at the end in the fall.
- Soil samples should be collected at the beginning and end of the irrigation season to monitor soil chemical changes and identify if the soil salinity threshold is being approached (see *Evaluating Soil Condition,* page 14).
- Watch for changes in soil infiltration and percolation (drainage).

Observe irrigation system performance

Failures in the irrigation system are common in any landscape. Finding line breaks, broken or misaligned nozzles and other problems early can avoid damage to the landscape from excessive or insufficient water resulting from system malfunctions.

Sample landscape monitoring and sampling program

Activity	When	Instructions	Criteria
visual plant inspection: trees	beginning, midway, and end of irrigation season	rate visual quality from a distance (15–20 feet)	good, fair, poor
visual plant inspection: shrubs, groundcover	beginning, midway, and end of irrigation season	rate visual quality of foliage (1–3 feet)	good, fair, poor
landscape condition	beginning, midway, and end of irrigation season	rate visual quality against criteria for acceptable appearance	good, fair, poor
foliage sampling	beginning and end of irrigation season	make composite sample and send to lab	
soil sampling	beginning and end of irrigation season	collect composite sample and send to lab	see p. 8 for interpretative guidelines
water sampling	review water agency's reports monthly for category 3 and 4 water, and annually for category 1 and 2 water	analyze for EC_w, pH, SAR, Cl, and Na	see p. 6 for interpretative guidelines
weather conditions	daily ET, temperature, rainfall		CIMIS website, by zip code or weather station



Some of the most common causes of poor irrigation performance are irrigation heads that are broken (top) or obstructed by large shrubs (bottom).

Tip

Keep in mind that maintenance practices, especially water management, can affect plant appearance regardless of water quality. Do not assume that all plant conditions observed result from use of recycled water.

Sampling Techniques for Monitoring

Soil sampling

- See "How to collect a soil sample", p. 8.
- Plan to sample soils at the beginning (spring) and end (fall) of the irrigation season.
- Analyze soil samples for EC_e, pH, SAR, Cl, Na, and B. If you plan to fertilize, include nutrient analyses.
- After receiving the lab report, compare the analyses to the interpretive guide on page 8.

Foliage Sampling

- Select fully mature leaves. When sampling conifers, choose needles that are at least one season old. About 100 grams of leaves are needed (25 to 50 leaves, depending on size).
- Where possible, collect leaves from different plants of the same species with and without symptoms. Keep the samples separated.
- Package in small paper bags, label, and send to the lab.
- If testing for salt injury, analyze for Cl, Na, and B. If testing for nutritional problems, include macro and micro elements.
- Note: Check with the laboratory that will be performing the analyses to see if they have additional sampling requirements.

A link to soil, water and tissue sampling labs is providing in Helpful Resources, page 33.

A soil sampling probe, auger or shovel can be used to collect soil samples. Remove surface vegetation before collecting the sample.

This David viburnum shrub's symptoms are leaf tip and marginal necrosis. To help diagnose the cause, the landscape manager removed about 20 leaves showing symptoms, and packaged them for shipment to a laboratory for analysis. The laboratory report noted high concentrations of chloride and sodium in the tissue, which supported a diagnosis of salt injury.

Leaf tissue analyses interpretive guide for landscape plants

(These are general values; specific values for most landscape species have not been established. Values have not been established for fields that are blank.)

Element	Normal range		Deficient		Toxic		
	%	ppm	%	ppm	%	ppm	meq/l
N	2.0-2.5						
P	0.2-0.4						
K	1.5-2.0						
Ca	0.5-1.0						
Mg	0.2-0.3						
S	0.2-0.3						
Fe		50-100					
Zn		25-50		<15		>200	
Cu		3-15		<5		>70	
Mn		50-100		<20		>200; 300-400 tree crops	
Mo	0.1-3.0			<0.1		>70	
Cl	0.2-0.4	2000-4000			0.5-1.0	5000-10,000	>28
B		30-50		<20		>200; 375-400 tree crops	
Na	0.1-0.3	1000-3000			0.5-1.0	5000-10,000	>22

Salt Look-Alike Disorders

Symptoms of salt injury can look similar to those caused by other factors. When in doubt, test - don't guess. Collecting and analyzing soil and foliage samples will identify if salts are the likely culprit or not (see previous page for sampling guidelines, and page 11 for soil analyses interpretive guide).

Salt injury due to chloride

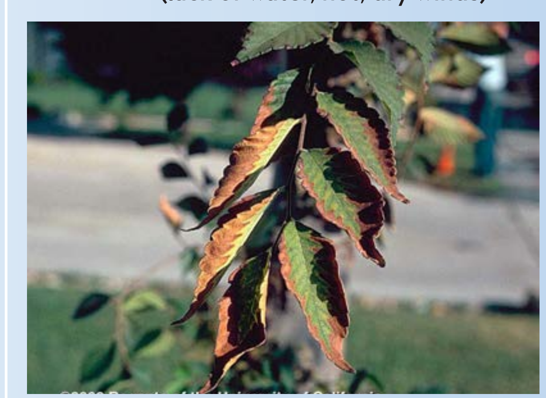
Salt injury due to boron

Natural seasonal leaf senescence

Cold temperature injury

Herbicide injury

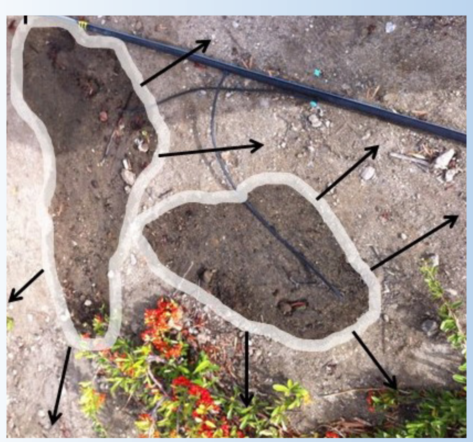
Desiccation injury
(lack of water, hot, dry winds)



5 Steps to Designing and Managing Landscapes using Recycled Water

5. Adjust

In an adaptive management strategy the landscape manager monitors landscape conditions, compares conditions to desired thresholds, and adjusts treatments accordingly.



Under prolonged drip irrigation, salts can accumulate at the outside edge of the wetted area. This is illustrated in the photo by the white band drawn around each drip emitter's wetting zone. Salts can be leached by doubling drip irrigation run times to wet a larger volume of soil and move salts outward. This treatment is most effective if performed in the winter during rain events that carry salts deeper into the soil profile and away from plant roots.

In an adaptive management program, the landscape manager devises maintenance activities in response to the conditions observed and measured during monitoring. For example, if routine soil analyses reveal that the soil salinity is nearing the allowable threshold, leaching treatments should be scheduled to lower the soil salt concentration.

Landscape managers need to know the cultural requirements of the species in the landscape, including water, pruning and nutritional requirements.

Adjust irrigation schedules

Knowing plant water needs is essential for successful landscape management, and it is particularly so for landscapes irrigated with recycled water. Water needs, however, change over time.

As soils dry, the salt concentration in the soil solution increases. For landscapes with low and moderate salt tolerance, water budgets should allow adequate irrigation to maintain moist soil to dilute soil solutes, avoid water stress, and minimize plant damage. It is not necessary to maintain moist soils for drought and salt-tolerant plants.

Adjustments should be made to irrigation schedules in response to...

- seasonal changes in day length, temperature, and humidity;
- periods of warmer or cooler weather than normal and sudden temperature changes;
- less or more rainfall than normal;
- extended or short rainy season;
- wind that disrupts spray patterns;
- leaching treatments.

Leach to maintain soil salinity below threshold

When soil salinity measurements (EC_e) reveal that the threshold is being approached, leaching treatments should begin and be repeated until soil analyses indicate that salinity measurements are below the threshold (see p. 17).

- Adjust irrigation duration to apply extra water to move salts deeper into the soil profile.
- In low rainfall years, consider applying leaching irrigations in the winter to augment rainfall.

Manage sodium concentrations in soils.

If soil sodium concentrations become too high, drainage will become impaired, especially in clayey soils. Incorporating calcium in the form of gypsum (calcium sulfate) into the soil and then leaching can regain soil structure, improve percolation and often lower pH.

- As a general guideline, apply gypsum when the SAR is greater than 6 or increases by more than 2 units above baseline values. For instance, if the baseline SAR was 3, plan to apply gypsum if the SAR reaches 5. Send a soil sample to a lab for a gypsum requirement test to determine how much gypsum is needed to reduce the SAR (see *Helpful Resources*, page 33 for link).
- In existing landscapes, large amounts of gypsum cannot be tilled into the soil. Split the applications over a few months. Applying pelletized gypsum through the winter months is ideal because rainfall helps the leaching process.
- Leach sodium by applying approximately 1 inch of water within 24 hours of gypsum application.
- Allow the soil to drain for 4 to 5 days and repeat leaching treatment. Plan to do this twice.
- Sample the soil a few weeks after the last leaching treatment to determine effectiveness in lowering SAR below 6.0.

Adjust fertilizer programs

Because recycled water contains nitrogen, phosphorus, and potassium, you can reduce, and in some instances eliminate, fertilizer applications. Many fertilizers contain soluble salts; choose those with a low salt index.

- In many cases, fertilizer application can be reduced by 50%, and in some cases eliminated.
- Keep in mind that many woody plants do not need to be fertilized, and unnecessary applications can adversely affect the health and appearance of the plants and pollute nearby water resources.
- When fertilization is deemed necessary based on soil and plant tissue analyses, use organic or controlled-release fertilizers to reduce the potential for salt buildup.
- Nutrient deficiencies may occur if soil pH is too high. Most plants tolerate a wide range in soil pH. Acid-requiring plants, which tend be poorly adapted to Bay Area soils, may develop micronutrient deficiencies regardless of irrigation water quality. If sodium is causing pH to rise, gypsum applications may help (see above).

Restore soil organic matter

Where leaving leaf litter is not an option, maintaining an organic mulch is the primary source for restoring soil organic matter.

- If you are using a coarse organic mulch that resists decomposition, such as bark chunks, scatter compost over the mulch and it will settle on the surface of the soil.
- Replace mulch before it becomes so thin that the soil surface is visible. Expect to replace every two to three years.

Tip

Gypsum does not "break up" or "soften" clay soils. It improves drainage only if excess sodium is present in the soil.

Keep your soil healthy

In the S. F. Bay Area's warm climate, soil organic matter is quickly decomposed. In natural systems, the organic component is replenished by natural leaf and twig litter.

In landscapes, leaf litter is often removed so that over time, soil organic matter is depleted. Soil organic matter is important to maintaining a porous, fertile, and resilient soil that supports a healthy landscape.

5 Step Overview

5 Steps to Designing and Managing Landscapes using Recycled Water

Like any healthy and attractive landscape, those irrigated with recycled water require skilled management that is appropriate to the site conditions and plant requirements. Five steps are designed to help you successfully incorporate recycled water into existing and new landscapes.

1. Investigate

- Determine the quality of recycled water available at the site.
- Identify plants and assess tolerance to recycled water.
- Investigate site and soil conditions.
- Check irrigation systems equipment and performance.
- Consider how the recycled water, soil, and plant species will work together to create an attractive and healthy landscape.

2. Plan

For existing landscapes

- Assess how plants will likely perform.
- Determine what treatments are needed to improve soils and drainage.
- Identify needed irrigation system repairs and improvements.

For new landscapes

- Select plants that are well suited to the site *and* tolerant of the recycled water that will be applied.
- Design the irrigation system using equipment intended for use with recycled water.
- Specify soil treatments to improve conditions for the landscape.
- Design drainage systems or specify treatments to solve drainage problems.

3. Implement

- Repair and prepare existing irrigation system.
- Correct soil and drainage problems.
- Adjust fertilization programs.
- Develop a water budget.
- Establish a soil salinity threshold and leaching program.
- Modify irrigation schedules.
- Replace salt-sensitive plants if needed.

4. Monitor

- Establish a baseline for plant appearance and soil conditions.
- Observe plant appearance and health over time and note changes.
- Test and observe soil conditions.
- Observe irrigation system performance.
- Keep records of condition and changes in the landscape, and treatments applied.

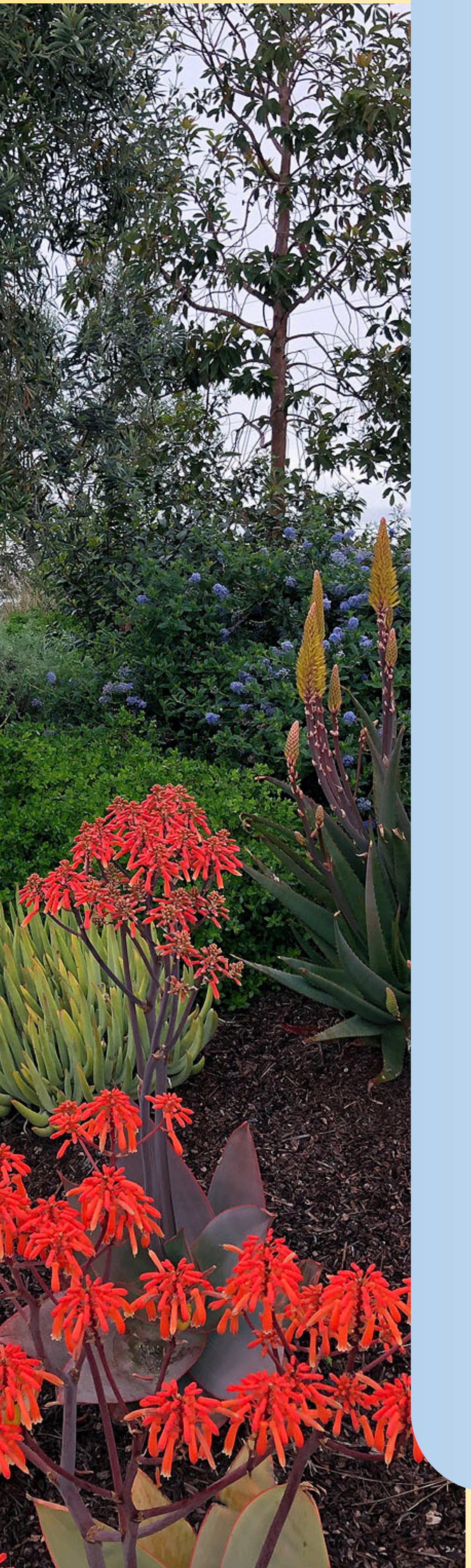
5. Adjust

- Adjust irrigation schedules to respond to weather, rainfall, and actual plant water use.
- Leach to maintain soil salinity below the soil sanity threshold for the landscape.
- Manage sodium concentrations to keep SAR below 6.0.
- Adjust fertilizer programs to account for nutrients supplied by recycled water and results of testing.
- Restore soil organic matter by retaining leaf litter where possible, and maintain 3 to 4 inches of organic mulch over the soil surface.

Become a Recycled Water Landscape Management Expert

Maintaining a healthy landscape with recycled water can be accomplished successfully with knowledge of the unique conditions in the San Francisco Bay Area. Monitoring plant responses to these conditions is the key to achieving a high level of aesthetic, environmental, and economic benefits from your landscape. By incorporating monitoring strategies into your site management program you will know whether adjustments are needed, and when and how to make them a timely manner.

The systematic approach outlined in this *Guide* will help you to look more closely at your landscape and take corrective action such as leaching early in order to meet soil and plant quality goals. A good place to start is by developing your own landscape monitoring program that includes soil and foliage sampling, keeping good records of your findings, regularly evaluating your management practices for effectiveness, and adapting maintenance activities to changing conditions.



Requirements for a Site Supervisor

From: *Rules and Regulations, South Bay Water Recycling*, City of San José

A Site Supervisor must be designated for each site using recycled water. The Site Supervisor represents the property owner, tenant, or property manager as a liaison to the agency providing recycled water. The Site Supervisor has the authority to carry out any requirements of the agency. It is recommended that the site supervisor be an employee who is permanently stationed at the use site. At a minimum, the Site Supervisor must make frequent visits to the use site and be knowledgeable about the operations of all water to the site (potable and nonpotable water).

Site Supervisors must be trained and certified through a formal recycled water educational program such as a training workshop.

The Site Supervisor:

- **is responsible for the appropriate use of recycled water at the site.**

  Some inappropriate uses include: a cross connection with the potable water supply, runoff to a storm drain or natural water body or stream, overspray on the general public, etc.

- **is responsible for the operation, maintenance, and prevention of potential violations on the inappropriate use of the recycled water system.**

  All irrigation systems must be maintained. If a site uses recycled water, the Site Supervisor must be notified of any system failures or breaks to assure proper safeguards are maintained and to assure any system failures are reported to the water retailer annually, as required.

- **must ensure there are no cross-connections made between the potable and recycled water systems.**

  Since recycled water for nonpotable uses is not approved for drinking, all recycled water systems must have oversight to ensure the system is not connected to the potable water supply. Before connecting a site to recycled water for nonpotable irrigation, a cross-connection test is performed by a certified American Water Works Association Cross-Connection Test Specialist.

- **must be present at all cross-connection tests.**

  The Site Supervisor must witness and document when a cross-connection test is performed to ensure the event is recorded and retain these records as part of the maintenance requirements.

- **must inform the water retailer of all changes or modifications/ improvements to the recycled water system.**
  All modifications or changes to the recycled water irrigation systems must be approved by the local water retailer to assure that all protections to the potable water supply are maintained. It is not unusual for the retailer to also obtain approval from a higher authority, should changes be necessary. Maintaining good communication with your local water retailer on the use and operation of the recycled water system is good practice since rules and regulations may change over the lifetime of the recycled water system and it is important to be informed of these changes.

- **must inform the water retailer of all failures, violations and emergencies that occur involving the recycled or potable water systems.**

  An example of an emergency is when there is a recycled water line break and recycled water is running into a natural water body for a long period of time. If the recycled water has a high level of chlorination, this could impact the health of a natural habitat. Calling the local water retailer is a way to get additional support to help manage this failure and incorporate appropriate measures to prevent an occurrence like this from happening in the future.

- **is expected to know the provisions contained in California Code of Regulations Title 17 and Title 22, relating to the safe use of recycled water and the maintenance of accurate records.**

  Recycled water for nonpotable uses is a valuable resource that reduces our demand on our limited potable water supplies. The use of recycled water is regulated under the California Code of Regulations Titles 17 and 22 to ensure the public potable water supply is not contaminated with nonpotable recycled water that is not suitable for drinking. Understanding what these codes require is included as part of the Site Supervisor training and is a requirement for all Site Supervisors managing recycled water. Some retailers may choose to be their own Site Supervisor and not delegate this authority to the customer, in this case oversight is covered by the local water retailer.

- **is expected to know the basic concepts of backflow and cross-connection prevention, system testing, and related emergency procedures.**

  These concepts are explained during the Site Supervisor training. Understanding how these systems operate will help ensure the system is operating properly.

- **is responsible for training personnel at the use site on the proper uses of recycled water.**

  Anyone working on the maintenance of a recycled water irrigation system is expected to be trained or under the supervision of a trained Site Supervisor.

- **must conduct an annual self-inspection of the use site and provide a written report to the water retailer.**

  Some water retailers are required by a higher authority to have an annual inspection program for all sites receiving recycled water for nonpotable uses. Some retailers may choose to be their own Site Supervisor and not delegate this authority to the customer, in this case oversight is covered by the local water retailer. Please contact your local water retailer to find out what requirements are in place for your existing or prospective recycled water system.

- **must conduct annual testing and submit records to the water retailer for all backflow prevention devices on the site.**

  Backflow prevention devices, like a Reduced Pressure Principle Backflow Preventer or RP or RPP, must have an annual test performed by a licensed Backflow Prevention expert or service.

Plant Salt Tolerance List

The Plant Salt Tolerance for San Francisco Bay Area Landscapes list contains over 500 trees, shrubs, vines, perennials and grasses. The list includes ratings for salt tolerance, water use, plant type, and whether the plant is native to California and/or invasive. Salt tolerance ratings are approximations of salt tolerance category. The category rating is based on scientific research when available, but most often is based on experience and anecdotal information. Considerable variation in ratings among plant lists is common because of differences in climate, soil conditions, salt type, whether ratings were based on soil or water salinity, length of the study, and other variables in reports. These variables were considered when assigning a salt tolerance rating for this list.

The list is available at https://watereuse.org/sections/watereuse-california as a spreadsheet that can be downloaded and then searched and sorted. On the "Instructions" tab is a description of how the list was developed, the parameters for use, and limitations to salt tolerance ratings.

Example of plants having low, moderate and high salt tolerance

In this example, the site soil is assumed to be favorable, with low potential for salt or specific ion accumulation when managed properly. For sites with restrictive soils, refer to step 2 on page 35 for adjustments to salt tolerance category. This list does not consider boron tolerance (boron concentration in water is assumed to be less than 0.5 ppm).

Plant type	Low	Moderate	High
trees	coast redwood (*Sequoia sempervirens*)	London plane (*Platanus × hispanica*)	goldenrain tree (*Koelreutaria paniculata*)
	Japanese maple (*Acer japonica*)	sawleaf zelkova (*Zelkova serrata*)	Nichol's willow-leafed peppermint (*Eucalyptus nicholii*)
	michelia (*Michelia doltsopa*)	Brisbane box (*Lophostemon confertus*)	Canary Island pine (*Pinus canariensis*)
shrubs	heavenly bamboo (*Nandina domestica*)	Japanese barberry (*Berberis thunbergii*)	blue mist (*Caryopteris · clandonensis*)
	Japanese aucuba (*Aucuba japonica*)	abelia (*Abelia grandiflora*)	*Ceanothus* spp.
	princess flower (*Tibouchina urvilleana*)	gardenia (*Gardenia augusta*)	toyon (*Heteromeles arbutifolia*)
groundcovers	creeping mahonia (*Mahonia repens*)	*Cotoneaster microphyllus*	*Acacia redolens*
	Pachysandra terminalis	dwarf periwinkle (*Vinca minor*)	*Juniperus horizontalis*
	baby tears (*Soleirolia solerolii*)	creeping St. Johnswort (*Hypericum calycinum*)	prostrate rosemary (*Rosmarinus officinalis* 'Prostratus'
herbaceous perennials	bear's breach (*Acanthus mollis*)	Shasta daisy (*Chrysanthemum maximum*)	sage (*Salvia* spp.)
	lily of the Nile (*Agapanthus orientalis*)	coral bells (*Heuchera* hybrid)	*Coreopsis grandiflora*
	western sword fern (*Polystichum munitum*)	big blue lily turf (*Liriope muscari*)	New Zealand flax (*Phormium tenax*)
grasses	colonial bentgrass (*Agrostis capillaris*)	Kentucky bluegrass (*Poa pratensis*)	red fescue (*Festuca rubra*)
	annual bluegrass (*Poa annua*)	perennial ryegrass (*Lolium perenne*)	buffalograss (*Buchole dactyloides*)
	hard fescue (*Festuca trachyphylla*)	creeping bentgrass (*Agostis stolonifera*)	blue grama (*Bouteloua gracilis*)

How to Develop a Salt Tolerant Plant Palette

To develop a plant palette for sites that will be irrigated with recycled water, follow these steps:

1. Identify the recycled water quality category (1, 2, 3, 4)

Water quality	Description	Laboratory analyses*
Category 1	Good water quality with no restrictions on site use.	ECw <1.0 dS/m, TDS <640 mg/l, B <0.5 mg/l, Cl <100 mg/l, and/or Na <70 mg/l.
Category 2	Moderately good water quality that is appropriate for all landscapes except those with salt- and/or boron-sensitive plants and poorly drained soils that cannot be leached.	ECw 1.0–1.3 dS/m, TDS 640–830 mg/l, B 0.5–1.0 mg/l, Cl 100–200 mg/l, and/or Na 70–150 mg/l.
Category 3	Fair water quality that can be used where plants have at least moderate salt and/or boron tolerance and soils are at least moderately drained. Landscapes on poorly drained sites must be comprised of plants with good salt and/or boron tolerance.	ECw 1.3–2.5 dS/m, TDS 830–1,600 mg/l, B 1.0–2.0 mg/l, Cl 200–350 mg/l, and/or Na 150–200 mg/l.
Category 4	Low water quality that is appropriate only for sites with salt- and/or boron-tolerant plants and moderate to good drainage.	ECw >2.5 dS/m, TDS >1,600 mg/l, B >2.0 mg/l, Cl >350 mg/l, and/or Na >200 mg/l.

2. Classify the soil conditions as favorable or restrictive.

Category	Description	Examples/laboratory analyses
Favorable	Low potential for salt or specific ion accumulation	Sandy to loam texture, well-aggregated clay loam, non-compacted granular structure, percolation rate at least 0.5 inch/hour, EC_e <1.5 dS/m, B <1.0 mg/l, Cl <100 mg/l, Na <230 mg/l, pH <8.0, SAR <6.0, and/or water table below 5 feet of soil surface.
Restrictive	Moderate to high potential for salt or specific ion accumulation.	Silty or clayey texture with compacted, massive, or platy structure; percolation rate less than 0.5 in/hr, EC_e >1.5 dS/m, B >1.0 mg/l.

3. Select trees, shrubs, ground covers, herbaceous plants, and grasses of the appropriate salt tolerance.

Water quality category[1]	Plant salt tolerance[2]	
	Favorable soil[3]	Restrictive soil[4]
1	low	low
2	moderate	moderate
3	moderate	high
4	high	high

[1]See Interpretive Guidelines for Recycled Water Quality, page 14.
[2]See page 31 for examples. Full plant list is available at https://watereuse.org/sections/watereuse-california.
[3]Favorable: low potential for salt or specific ion accumulation.
[4]Restrictive: moderate to high potential for salt or specific ion accumulation.

Helpful Resource Links

These resources provide technical details in inspecting landscapes and implementing solutions.

Online Educational Resources
WUCOLS - Water Use Classification of Landscape Species
MWELO - Model Water Efficient Landscape Ordinance
CIMIS - California Irrigation Management Information System
Estimating Soil Moisture by Feel and Appearance
California Center for Urban Horticulture
Stopwaste
Selectree
Bay-Friendly Landscape Guidelines
Web Soil Survey
UC Master Gardener Program
US Composting Council
The California Garden Web
UC Davis Arboretum Plant Database
Salinity Management Guide
Salinity Leaching
California Invasive Plant Council (Cal-ipc)

Below is a partial list of agencies providing, regulating and providing information on recycled water.

Water Agencies and Groups
South Bay Water Recycling
Palo Alto Regional Water Quality Control Plant
Sunnyvale Water Pollution Control Plant
South County Regional Wastewater Authority
Dublin San Ramon Services District/EBMUD (DERWA)
East Bay Municipal Utility District
City of Pleasanton, DERWA
Livermore Water Reclamation Plant
City of Hayward
Central Contra Costa Sanitary District
Delta Diablo Sanitation District
Ironhorse Sanitary District
North Coast County Water District
North San Mateo County Sanitation District
Napa Sanitation District
Town of Yountville/Veterans Home of California Joint Wastewater Treatment Plan
San Francisco Public Utilities Commission
Marin Water
North Marin Water District
City of Petaluma
North Bay Water Recycling Authority
Santa Rosa Subregional Water Reuse
Town of Windsor
Suisun Sewer District
Silicon Valley Clean Water
State Water Resources Control Board (State Water Board)
Bay Area Clean Water Agencies (BACWA)
Bay Area Water Supply & Conservation Agency (BAWSCA)
WateReuse California

Below is a partial list laws and regulations related to recycled water.

Laws and Regulations
Water Recycling in Landscaping Act
Health and Safety Code, Water Code
Title 17, Division 1, Chapter 5
Title 22, Division 4, Chapter 3
General Permit for Landscape Irrigation Uses of Municipal Recycled Water
Recycled water policy

Below is a partial list of organizations involved in horticulture related to recycled water.

Related Organizations
International Society of Arboriculture, Western Chapter
Bay Area Landscape Supervisors' Forum
Bay Area Urban Forest Ecosystem Council
Canopy
California Urban Forests Council
San Francisco Urban Forest Council
Our City Forest
California Landscape Contractors Association (CLCA) San Francisco Bay Area Chapter
California Testing Labs
ReScape California

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Tribute to Dr. Bahman Sheikh

With much gratitude for his devoted editorial review, the authors dedicate this Bay Area Recycled Water Landscape Guide to Dr. Bahman Sheikh who passed away on July 28, 2020 at his home in San Francisco, California. Bahman was a true water reuse pioneer and teacher of the safety and importance of locally sustainable water supplies, who for half a century helped countless communities recycle their water, across the United States and around the world.

Born in Mashad, Iran, Bahman came to California in 1962 and received his MS and Ph.D. at UC Davis in Irrigation and Soil Physics. His major effort was the demonstration project that became known as the Monterey Wastewater Reclamation Study for Agriculture. From its inception in 1976 through the publication of its final report in 1987, Bahman and his team evaluated the agricultural use of recycled water, tracking the fate and transport of pathogens and firmly establishing recycled water's safety for irrigation of California's "salad bowl."

Bahman also worked closely with local farmers and health authorities to communicate the significance of the study and garner acceptance for the concept of water reuse, and today recycled water is used to irrigate 12,000 acres in northern Monterey County.

Bahman evaluated opportunities for urban reuse in San Jose, Santa Rosa and Los Angeles. That work led to his appointment in 1989 as the first Executive Director of the Los Angeles Office of Water Reclamation, where he set water recycling goals, established funding mechanisms, ran pilot projects, and developed policy and legislative recommendations.