The Water-Wise Vegetable Garden:
An Analysis of the Potential for Irrigation through Rainwater Harvesting in Sunny Northern California

LA 222: Hydrology for Planners

Professor G. Mathias Kondolf

Adrienne Smith and Elisabeth Esterer-Vogel

Spring 2009

Abstract

In drought-prone northern California, homeowners can collect rainwater to irrigate their water-intensive summer vegetable gardens. Rainwater harvesting requires a three-part system: a method of collection (commonly the roof), a form of storage (cistern) and a method of distribution (a pump, filter and soaker hose are proposed here). To optimize and properly size a rainwater harvesting system, homeowners should consider both their rainwater supply and their garden's water demand. Gardeners can reduce demand by planting early to take advantage of spring rains and by grouping crops according to irrigation needs. The authors analyze the water use of a sample garden, which they adapt to both Berkeley and Sacramento. In both of these cities, one can collect more than enough rainwater to support a small vegetable garden: an individual homeowner's water supply is more likely to be limited by storage capacity than rainfall. Ultimately, although rainwater harvesting can supply adequate quantities of water to irrigate vegetable gardens, the level of water treatment required to safely irrigate food crops adds dramatically to the cost of a system. For a smaller investment, rainwater harvesting can be used to irrigate landscaping vegetation.

Introduction

As Californians settle in for another drought, homeowners are once again facing restrictions on their summer water usage. Some have replaced thirsty lawns with water-saving Mediterranean landscaping, while others are looking for a way to maintain one of their favorite summer pastimes: the vegetable garden. Although vegetables are notoriously water-intensive, local food production is also considered an enjoyable part of the sustainable lifestyle. A juicy homegrown tomato is, for some, an essential part of summer. We wanted to find out whether we could responsibly maintain our backyard vegetable gardens by harvesting rainwater for their irrigation. Even in a dry year, here in the Berkeley and inland in Sacramento, we get between 10 and 20 inches of precipitation throughout the winter. If we can save some of that winter water for the summer growing season, we should be able to maintain a vegetable garden without tapping the state's limited reservoirs. In this paper we study the potential for rainwater harvesting at four case study homes located in Berkeley and Sacramento, California. By analyzing both the potential rainwater supply and a garden's demand, we seek to optimize these systems for the needs of a typical homeowner.

Methods

It was important to us in this study to develop a set of guidelines that could be interpreted by numerous homeowners and applied to their varied situations and circumstances. To this end, we chose to examine four case study houses, each of which has differing constraints on its potential water supply and irrigation needs. One generalized solution should then be adaptable to each of these residences.

In support of this flexible approach we have sought to attain a broad understanding of the water needs of a 'typical' vegetable garden. In this study we develop a sample garden with a variety of popular crops and then apply guidelines from the Food and Agricultural Organization of the United Nations to estimate the water demand of our garden. Based on the water supply available at each of the case study houses and the water demand of the sample garden we are able to optimize a rainwater harvesting system to meet the homeowners' various needs.

Case Study Homes

We are interested in the warmer climates of northern California and we hope that by examining two different climates of densely urban areas, our results may be broadly applied by many homeowners. We have chosen to study four houses: two in Berkeley and two in Sacramento (Figure 1). The Berkeley homes are located in the city's sunnier flats where the microclimate is more supportive of vegetable gardening. The East Bay's foggy hills present their own unique challenges and opportunities to gardeners, which are beyond the scope of our water use study. In contrast to the mild coastal climate, we also chose study homes further inland where soaring summer temperatures promote ripening of vegetables, but also make irrigation of paramount importance.

The homes in Berkeley, which we will refer to as Berkeley A and Berkeley B, are small. Typical of the area, each has a footprint of less than 2,000 square feet, and the homes are sited on small lots, limiting the available space for water storage. Our Sacramento houses, Sacramento A and B, are much larger: each is over 3,000 square feet, located on a large suburban lot with ample yard. The size of the lots and houses determine not only the space available for water storage, but also the size and location of the vegetable beds and the possible catchment areas. We are proposing vegetable beds 2 ½ feet wide and 16 feet long. This width is comfortable for reaching across and can be watered with a single irrigation line. The length is practical for the landscaping configuration at each of the study houses. We have designed two such beds for each Sacramento house, to be located in sunny parts of the backyards. Berkeley house A can also accommodate two backyard vegetable beds, but at Berkeley house B there is space and sun for only one bed in the front of the house.

At each of our case study houses, the obvious source for rainwater harvesting is the roof. The roofing material has implications for the purity of the harvested water, so it is important to note that three of our four case study houses have composite asphalt shingles, while Berkeley house B is roofed with tarpaper. These are common roofing materials throughout northern California, representing a certain set of constraints in terms of the water quality. While not an ideal material for a catchment surface, the water collected from these roofs can still be safely treated, as we discuss later in this paper.

Calculating Water Supply

The water supply for each of the case study homes is simple to determine: it is based on the roof area and rainfall. The total roof area represents the maximum possible catchment area at each house (Figure 2). Multiply this area by the number of inches of rain expected in a wet, dry or average year and then by an efficiency factor to determine the volume of water potentially collected in one year. We use 1983 and 1959, the wettest and driest years on record[1], to calculate the volume of water expected in "wet" and "dry" years (Table 1). Only about 10% of rainwater is lost when collected from a composite roof,[2] which means that even in a dry year the homeowners at each of the case study houses could collect between 10,000 gallons (at Berkeley B) and 26,000 gallons of water (at Sacramento A).

Calculating Water Demand

In order to properly size the cistern for this project, we needed to understand not only the quantity of water which could be collected at each house, but also the vegetable garden's actual water

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[1] Western Regional Climate Center, http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?caberk+sfo (accessed April 21, 2009).

[2] Texas. Texas Water Development Board. *The Texas Manual on Rainwater Harvesting,* Third Edition (Austin, TX: State of Texas, 2005) 6.

demand. The water demand depends on the size of the area planted, the type of crops being grown, the time of planting and type of soil, as well as the climate where the crops are being grown. We first created a crop list, which includes a wide variety of popular vegetables, and then developed the planting schedule. Our planting guide can be easily adapted to a gardener's preferences by increasing or decreasing the square-footage devoted to a particular crop (Figure 3). Our garden includes eleven popular vegetables: tomatoes, summer squash, eggplant, spinach, cucumbers, cabbage, melon, lettuce, snap or green beans, carrots and peppers. The first five of these crops have somewhat lower water demands and have been grouped together in one "dry bed" of 40 square feet. The latter six vegetables require slightly more water, so their irrigation should be separately controlled in the second "wet bed," which we also sized at 40sf.

The next step we took to reduce the water demands of our garden was to consider our planting schedule. Wherever possible we have started vegetables as early as gardening guides (Golden Gate Gardening[3] and the UC Davis Vegetable Research and Information Center[4]) permit, in order to take advantage of spring rains and reduce the amount of irrigation required. (These planting guides are included as Appendices A and B.) With lettuce, spinach and cabbage, we have capitalized on the crops' abilities to grow during the rainy season. In the spring, we suggest harvesting and replacing these leafy vegetables with warm weather crops to provide year-round variety in the garden. Detailed planting calendars for both Berkeley and Sacramento are included as Figures 4 and 5.

With the crops and planting schedule in place we could begin the complicated task of assessing the garden's actual water demand. Numerous factors affect a garden's water need, including both

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[3] Peirce, Pam. *Golden Gate Gardening: Year-Round Food Gardening in the San Francisco Bay Area and Coastal California*. Revised Edition. (Seattle, WA: Sasquatch Books, 2002).

[4] Norris, Robert. *Vegetable Planting Guide.* ceyolo.ucdavis.edu/files/63483.pdf accessed May 19 2009.

environmental factors such as precipitation, temperature, evapotranspiration and soil type, as well as plant-specific factors including crop type, plant maturity, length of growing period and time of planting and harvesting.

All of these factors are difficult to accurately measure and predict, thus it was not surprising that our research uncovered numerous rules of thumb and generalized guidelines for watering. The East Bay Municipal Utilities District, for example, has published drip irrigation scheduling guidelines.[5] Unfortunately, this guide is designed primarily for irrigation of landscape trees and shrubs, which, once established are not as water-needy as annual vegetables. Furthermore, the guide does not clearly state what climate data it is based on, and how specific the guidelines are to the East Bay. Another promising study we found from Cornell University's New York State Agricultural Experiment Station focuses on irrigating tomatoes. The author assumed a water need of 1 inch per week for a bed of tomatoes, but these numbers had to be strongly adapted when using the calculated values on real tomatoes.[6]

We finally chose to use a calculation method described by the Food and Agricultural Organization of the United Nations developed in Rome in 1986.[7] This method considers numerous environmental parameters, as well as crop-specific need guidelines. These calculations are completed in a three-step process, which relates local climate data to the water need of a specific crop throughout various stages of its development. Using this procedure we are able to calculate the specific water needs

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[5] East Bay Municipal Utility District. *Drip Irrigation Guidelines.* (Oakland, CA: EBMUD, 1991) 6, 11-12.

[6] Cornell University. *Watering Tomatoes Drip by Drip*. (New York State Agricultural Experiment Station: http://www.nysaes.cornell.edu/pubs/ask/irrigation.html) accessed on April 19, 2009.

[7] All references in this section from Brouwer, C. and Heibloem, M. *Irrigation Water Management: Irrigation Water Needs. Training Manual No 3.* prepared for the FAO, Rome, 1986.

for each of our selected crops at the specified time of year for the Berkeley and the Sacramento climates. The calculation methods of the Food and Agricultural Organization (FAO) are based on the following principal:

Irrigation Demand (I_m) = Crop Water Need (E_T) - Effective Rainfall (P_e)

Finding the Irrigation Demand (I_m) is the ultimate goal of this process, but to arrive there we need to understand the mysterious Crop Water Need (E_T). Crop Water Need is based on climate-related evapotranspiration and a factor specific to the crop type at a particular stage of development, as represented in the following equation:

Crop Water Need (E_T) = Evapotranspiration Factor (E_{To}) x Crop Factor (K_c)

The Evapotranspiration Factor (E_{To}) is determined using the Blaney-Criddle Method, which is expressed by the following equation:

Evapotranspiration Factor (E_{To}) = Location Factor (p) x (0.46 x Monthly Avg. Temperature + 8)

Beginning with this last equation and working our way back up to Irrigation Demand we now describe our calculation methods. The Evapotranspiration Factor (E_{To}) can be determined either by conducting a pan-evaporation experiment to measure evaporation rates in a given climate, or by applying the Blaney-Criddle Method. Due to the time constraints of our project, we opted for the latter. In the Blaney-Criddle Method evapotranspiration for a given site is predicted based on hours of daylight and temperature. The Location Factor (p) represents the mean daily percentage of annual daytime hours for a given location based on its latitude (Table 3). We chose to calculate our Irrigation Demand, and thus Crop Water Need and Evapotranspiration Factor on a monthly basis. Therefore, we use the mean monthly temperature (°C) in this equation (Table 2). Our results and calculations of the Evapotranspiration (E_{To}) using the Blaney-Criddle Method can be found in Table 4.

Using E_{To} we now need to find the Crop Factor (K_c) to calculate the Crop Water Need. The Crop Factor is different in each of a plant's four growth stages: the initial stage, the crop development stage, the mid season stage and the late season stage. We referred to the FAO table of Crop Factors by growth stage (Table 5) and then averaged where necessary to apply the proper factor to the given month in a crop's development. Table 6 shows the length of each growth stage by type of crop. In our calculations we found we needed to adapt the FAO suggested growth duration of individual crops to the growth durations given in local vegetable planting guides (Golden Gate Gardening and the UC Davis Vegetable Research and Information Center). Furthermore, we assumed that all crops except for carrots are transplanted to our vegetable beds as seedlings and not grown directly from seed. With all this combined data we found an average monthly Crop Factor (K_c) for each type of vegetable.

To apply the final equation to calculate the actual Irrigation Demand (I_m) the last missing factor is the Effective Rainfall (P_e). This factor is used because it is assumed that not all measured rainfall can reach a plant's roots. The FAO manual includes a table that relates the total monthly rainfall to the effective monthly rainfall (Table 7). The table shows that precipitation of less than 20 mm (0.79 inches) per month cannot be utilized by plants. We decided to calculate the Irrigation Demand based on a worst-case scenario and used data from the very dry year 1959 for our calculations (Table 1).

This method of determining Irrigation Demand has been extremely useful. It accounts for the affect Sacramento's higher temperatures will have on vegetables' evapotranspiration and the differing precipitation amounts in Berkeley and Sacramento, which reduce the need for irrigation. The Blaney-Criddle Method also allows us to tailor our irrigation demand to different types of vegetables at different growth stages, with the use of the Crop Factor. One factor we do find missing from this method of calculating irrigation demand is the soil type. We know from experience that a sandy soils with a high infiltration rate will dry out faster than a clay soil and will thus require more frequent irrigation. When applying our calculated irrigation values to an actual vegetable garden, a garden is likely to find that they need to adjust their irrigation amounts up or down based on their soil type.

We are also able to check these calculations against the more generalized irrigation guidelines from Cornell University. In that study researchers found they needed to provide their tomatoes with more than the 1-inch of water per week, which they had predicted.[8] The FAO calculation methods yield an irrigation need of about 3.3 gallons of water per month for tomatoes. This can be converted to 5.3 inches of water per month, which yields 1.3 inches of irrigation per week. This checks with the Cornell University study results and increases our confidence in the FAO methods.

Results and Discussion

In this section we discuss the results of our water demand calculations, the resulting design proposals for each of the four case study houses, and the steps for implementing rainwater harvesting systems.

Calculation Results

Based on the FAO calculations described above, we applied these crop-specific irrigation demands to our sample vegetable beds in Sacramento and Berkeley (Tables 8 and 9). We created a list of irrigation-demand per square-foot that allows us to directly compare the crop water needs. The water needs of individual vegetable crops lie between 310 and 36 gallons of water for a growing season (Figure 9). The lowest is need is for short-lived rainy-season spinach in Berkeley, while the highest need belongs to summer peppers grown in Sacramento. Generally one can see that vegetables planted in Sacramento require more water than in Berkeley due to Sacramento's higher temperatures and lower levels of precipitation. Water need also varies because of differing durations of growth and differing growing seasons. The winter vegetables spinach and cabbage have a lower water demand since some of their requirement is met by effective rainfall. We recommend utilizing winter and spring rainfall

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[8] Cornell University.

whenever a plant's growth cycle will allow. To save water it is best to plant as early as possible, as illustrated by the example of lettuce (Figure 6). When planted in the winter, most of the crop water need is satisfied by effective rainfall.

In spite of our planting schedule, the vegetables in our two beds each require differing amounts of water every month. Here we face a problem that constrains water-efficiency when using a soaker hose for irrigation: the vegetable with the highest water demand in a given month drives the irrigation of the entire bed. This is due to the even distribution of water from the soaker hose across its full length. The most water-efficient irrigation method would be to use a watering can and carefully measure the proper amount of water for each vegetable, but we found this to be an unrealistic expectation for the hobby gardener. To minimize the water demand as far as seems reasonable, we have split the year in two periods. The first period, the primary growing season, extends from March to September. This is the period of intensive use of the vegetable beds, during which we propose running the soaker hose according to the requirements of the most water-needy crop. During the period from October to February, only a few vegetables occupy small parts of the bed. It would be much more efficient during this 'off' season to use a watering can. Based on these dual irrigation calculations for soaker-hose and hand-watering we determined the actual volume of water needed to irrigate a vegetable garden at each case study house.

Berkeley A	both wet and dry beds	1860 gallons/year
Berkeley B	either wet or dry bed	960 gallons/year
Sacramento A	both wet and dry beds	2,050 gallons/year
Sacramento B	both wet and dry beds	2,050 gallons/year

We have used this data to size the proposed cisterns and to define the catchment area that is necessary to collect this amount of water during the rainy season of a year.

Design Proposals

At each of the case study houses we have determined that a small portion of the roof area will collect sufficient rainwater to irrigate the vegetable garden (Figure 7). At both Berkeley A and Sacramento A the small buildings behind the main house offer sufficient collection surface and convenient access to storage locations. At Berkeley A, we propose draining a portion of the roof of the auxiliary structure to a set of modular storage units mounted along the property's fence. At Berkeley B, we similarly propose installing the space-saving modular units along the fence close to the vegetable bed. As an alternate solution, at Berkeley B the existing wooden deck in the backyard has a sufficient size and height to accommodate the necessary storage underneath it. The Sacramento case study houses have more available space for water storage; so economical cylindrical cisterns make sense to use at both of these sites. The tanks can be located close to the roof and downspouts, but out of the way of the primary garden space.

Rainwater Harvesting System

In order to manage the volumes of water our case study gardens demand, we propose a multi-part rainwater harvesting system (Figure 8). We divide the system into three stages: collection, storage and distribution. Each of the components of this system needs to be sized according to demand, designed to ensure water quality and satisfy performance criteria. In this section of the paper, we discuss the components necessary for a rainwater harvesting system that can be used for vegetable irrigation on a small scale.

Collection

Catchment Surface

In this paper we discuss only the use of rainwater collected from roofs. Roofs are a convenient source for rainwater in part because the water can be brought to a storage tank by use of gravity. Not only the size of the roof, but also its material affect the quality and quantity of harvested rainwater. Some roof materials absorb rainwater and decrease yield. The roofs of our four study sites are clad with composite shingles or tarpaper. This material absorbs about 10% of the rainwater, slightly reducing the volume of water harvested.[9] The asphalt composite contains lead and PAH (polycyclic aromatic hydrocarbonates). Rainwater can dissolve some of these toxins and carry them to the cistern, meaning that water collected from asphalt roofs cannot be considered potable. Nevertheless, the Texas Water Development Board suggests its use for landscape irrigation.[10]

In California no rainwater regulations or standards currently exist. Some studies have been done on irrigation with wastewater, but the potential contaminants in those situations are quite different from what we face in this case. It would be valuable to understand which contaminants in rainwater might accumulate in vegetables. This is an area for further study, which will help to clarify the opportunities and constraints inherent in rainwater harvesting. In the absence of data or regulations indicating otherwise, we have concluded for the purposes of this paper that the rainwater harvested from asphalt roofs must be filtered to a potable standard for irrigation of food crops.

'Cleaner' roofing materials more suitable to harvesting potable water are Galvalume® and coated clay or concrete tiles. Galvalume® is a commonly used product for rainwater harvesting roofs. It is made of sheet steel that is alloyed with 55 percent aluminum and 45 percent zinc. The metal can be coated with baked enamel or painted with epoxy paint. Clay or concrete tiles should also be coated with a special sealant to reduce bacterial growth and water loss from pore-space. These materials do not

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[9] Kinkade-Levario, Heather. *Design for Water.* (Canada: New Society, 2007) 38.

[10] Texas 6.

require any further filtration than the removal of sediment.[11]

Gutters and Downspouts

Gutters and Downspouts deliver water from the catchment surface to the cistern. Similar to the catchment area it is important to keep both of these elements clean. The gutters can ideally be protected from pollution by installing leaf-screens across the top of the gutter. These screens are commonly made out of wire mesh in a metal frame. The leaf-screens also reduce mosquito breeding habitat. Again, the material of the gutters and downspouts can contribute to rainwater pollution through leaching. It is best to avoid copper and PVC gutters and downspouts and to ensure if possible that the solder used on metal gutters or downspouts does not contain lead. For water quality, a safer choice is vinyl.

Gutters are typically 5 or 6 inches wide. Downspouts should be sized according to the catchment area. For every 100 square feet of catchment area 1 square inch is required in the downspout cross-section.[12]

Minimum downspout diameters for the case study houses are

Berkeley A	275 square foot collection area	3 inch diameter downspout
Berkeley B	190 square foot collection area	2 inch diameter downspout
Sacramento A	440 square foot collection area	5 inch diameter downspout
Sacramento B	450 square foot collection area	5 inch diameter downspout

First-Flush-Device

Although captured rainwater is among the cleanest of water sources, on its way from the roof to

[11] Texas 6.

[12] Kinkade-Levario 18-19.

the cistern it can become polluted by several sources.[13] We have discussed the leaching of roof material into rainwater, but this water will also convey sediment accumulated on the roof.

> "The rain can wash bacteria, molds, algae, fecal matter, other organic matter, and/or dust into storage tanks. The longer the span of continuous number of dry days (days without rainfall), the more catchment debris is washed off the roof by a rainfall event (Thomas and Grenne, 1993; Vasudevan, 2002)."[14]

For this reason, especially in the summer-dry climate of California, the first storm in the fall can carry a large quantity of pollutants into the cistern. To deal with these relatively large particles a first flush diverter should be installed. This device is integrated into the downspout. It is a standpipe that diverts the "first flush" of rainwater coming from the roof, which is thought to carry the greatest contaminant load. As a rule of thumb, the first flush diverter should have the capacity to hold back 10 gallons of water for every 1000 square feet of collection area. Once the first flush diverter is filled, the rest of the rainwater flows directly into the cistern.[15] After a rain storm the first flush diverter has to be opened and emptied to allow it to fill again with the next rain.

Storage

Cistern

There are many of different cistern types available. They differ in capacity, material and form. Most readily available and commonly used materials for cisterns are fiberglass, polypropylene and galvanized sheet metal. For galvanized sheet metal tanks it is important to pay attention to the coating, which affect water quality. For the purpose of vegetable irrigation, we suggest using only cisterns of

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[13] Texas 23.

[14] Texas 23.

[15] Texas 8.

food grade plastic or those certified for potable water storage.

For our case studies we propose the use of a single cylindrical cistern at the Sacramento sites and a series of smaller modular cisterns for the Berkeley sites. The suburban lots in Sacramento are much more spacious and allow the placement of a large, freestanding cistern. On the small Berkeley lots a modular cistern such as the Rainwater HOG[16] makes efficient use of tight spaces. Since water is very heavy (8 pounds per gallon) it is important to install the cistern on a stable ground surface, preferably a concrete pad.[17] The Rainwater HOG cisterns can be stabilized against a wall or fence or placed under a deck. To minimize the distance between water collection, storage and distribution we propose locating Rainwater HOGs along the fence at each Berkeley site. The rainwater HOG stackable tanks each contain 50 gallons and are connected to each other to operate as a single storage unit. They are made from virgin polyethylene, which is considered a food grade plastic that complies with FDA, HPB and AS2070 standards.[18] For each Sacramento site we propose a 2,500 gallon cylindrical cistern. These are commercially available in varying materials and dimensions.

Distribution

Pump

A pump is necessary to supply the pressure for the irrigation system that is connected to the cistern. To irrigate our vegetable gardens we propose using a soaker hose, which operates with a very low pressure of 10–12 pounds per square-inch (psi).[19] As a general rule water pressure increases 1

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[16] Rainwater HOG. http://rainwaterhog.com/, accessed on 05/05/09.

[17] Texas 10-13.

[18] Rainwater HOG. http://rainwaterhog.com/products/, accessed on 05/05/09.

[19] Seattle Public Utilities. *Success with Soaker Hoses.*

pound per square inch for every 2.31 feet the volume of water is elevated.[20] To operate the system without a pump the minimum water level would need to be between 23.1' and 27.72' above the vegetable beds. Heavy water tanks require strong structural support, and the higher the water has to be lifted into the air the more expensive the structure would be. We propose instead locating the cisterns as close to the ground as possible and using a pump to generate the necessary pressure.

For water quality a floating intake pump is to be recommended. This means that the pump, located next to the cistern, has a water-intake in the cistern that floats in the middle of the water column. A floating intake ensures that water with the best quality is used, since "water in a storage cistern will typically consist of three layers:" the top layer, the middle layer and "the bottom layer, the anaerobic zone, will be a mixing water that contains the most solids." The best water that contains neither the pollutants floating on the surface nor those settling on the bottom will be utilized when a floating intake pump is used.[21]

Filter

As discussed in the section "Catchment Surface" we propose treating rainwater intended for food crop irrigation to a potable standard. This can be achieved with a two-step filtering process, using first particle filters and then UV light as disinfection. Although the quality of stored water can improve over time due to the settlement of the particles, many contaminants are very small and may not settle quickly. Algae and bacteria may also grow for a period of time in the storage tanks, but without light, the growth should be limited and a particle filter can remove these contaminants prior to irrigation. If you plan to

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www.savingwater.org/docs/successwithsoakerhoses.pdf, downloaded 04/20/09.

[20] Texas 16.

[21] Kinkade-Levario 28.

use your rainwater as drinking water, we recommend testing your water quality during the warm season. (Water testing consultants: California wide: Basiclab http://www.basiclab.com/homeowners/index.php, San Francisco: Anresco http://www.anresco.com/, Sacramento: http://www.deltaenvironmentallab1.com/home.nxg)

The contaminants in rainwater that result from asphalt-roofs are attached to particles[22] and can therefore be removed using the suggested particle filters. A filter needs to be capable of removing very small particles with attached PAHs and lead. Filters commonly used for creating potable water can remove particles as small as 5 micrometers. Usually a series of a 5-micron particle filter, a 0.5-micron carbon filter and a UV-disinfection system is installed.[23] Depending on the required water-pressure for the final water supply system (in our case the soaker hose), the filters range in capacity (gallons/minute). A filter for a high-pressure system for the whole house can be very expensive. The low-pressure soaker-hose irrigation system has a capacity of 30 gallons/hour. Therefore it is sufficient to install a filter that can clean 0.5 gallons/minute. Commonly available "under-sink" filter systems can operate at 2 gallons/minute, which would be more than sufficient for this purpose. "Filters connected to a cistern should be changed more frequently than suggested by the manufacturer."[24] Typical under-sink filters have a capacity of about 2500 gallons before they need to be replaced. Following the advice of Kinkade-Levario, this would suggest an annual replacement of the filter cartridges.

Valve/Back-flow Preventer/Timer

A typical soaker-hose irrigation system can be connected to the municipal water supply by using

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[22] Texas 6.

[23] Texas 18-19.

[24] Kinkade-Levario 30-31.

a timer that opens and closes the valve at desired times. In our case when the soaker hose is connected to the cistern water supply system the pump regulates the sufficient water supply. Therefore the valve and the pump need to be set on individual timers. We recommend setting the timer of the valve a little earlier than the timer of the pump to prevent a back-up in the system.

Additionally, after the valve-timer a back-flow preventer should be installed. This is a device that can be screwed into the hose and prevents water from the hose flowing back into the system and polluting the filtered water from the side of the outlet.

Soaker Hose

Comparing different irrigation systems with regards to their water efficiency reveals that using a watering can is the most efficient solution. The water can be directly applied to a plant and daily adapted to its specific water needs. Nevertheless, irrigation by hand can be painstaking and is sure to go awry if the gardener is away from home for a few days at a time. The second best water-wise alternative is installing a drip-irrigation or soaker hose system.

> "You can reduce the amount of water that normally is applied to a vegetable garden by hose, sprinkler, or flood irrigation by as much as 70 percent. Because drip irrigation gets the water to the root zone, you will have less problems with weeds and will have an increase in productivity over conventional watering methods. Nevertheless, an alternative to the drip system for vegetables is soaker tubing or drip tape. [...] With either system, water your vegetables preferably in early morning or late afternoon when evaporation will be minimal."[25]

Although the drip irrigation system might be slightly more water efficient, for a vegetable bed that has a varying planting layout we suggest the use of a soaker hose system.

A typical soaker-hose is a rubber hose (manufactured from recycled tires) with a diameter of ½ inch. The first part of the soaker-hose system consists of a closed hose that delivers the water from the outlet, in our case the filters, to the beds. In the beds the hose is perforated and allows water to slowly

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[25] O'Keefe, John M. *Water-Conserving Gardens and Landscapes.* (Vermont, 1992) 117-118.

flow out along its entire length. The water spreads over the soil about one foot in each direction, so one line of soaker-hose can irrigate a strip two feet wide. The actual width of irrigated soil depends on the soil type.[26] Soil with a higher infiltration rate (like sand) will decrease the surface flow and therefore deliver the water only to a narrower planting strip.

A soaker hose system should not be longer than 100 feet[27] and can deliver about 30 gallons of water per hour for a 100-foot stretch of hose.[28] We propose 2.5-foot-wide vegetable beds for easy maintenance and harvesting. One line of soaker-hose can supply the water for the entire width of such a bed. Two rows of vegetables can be planted on either side of the hose. The plants should be set at least 1–2 inches from the soaker hose.[29] For easy maintenance and control the soaker-hose can be laid directly on the soil surface. It is best to cover it with a layer of coarse mulch to reduce evaporation and also for aesthetic purposes.

Other Techniques to Reduce Irrigation Demand

Vegetables with lower water demand

For the calculations in our paper we did not choose particularly low-water-use vegetables. We were more interested in understanding the water need of very common and popular vegetables. The water-wise gardener, however, can certainly find varieties of vegetables that use less water if the reduction of irrigation water is the highest priority. Some "low-water-use vegetables" that can be grown in California are "Cylindra beets, Tepary beans, Desert King watermelons, Hopi orange lima beans,

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[26] Cornell University.

[27] Seattle Public Utilities.

[28] Cornell University.

[29] Seattle Public Utilities.

Swiss Chard, and Hopi blue corn." Additional water-savers could include "green peppers, purple cauliflower, cabbage, broccoli, eggplant, tomatoes, squash, beets, and herbs, such as sage, rosemary and thyme."[30] It is also good to know that lettuce, carrots, melons, spinach and yellow corn are among the most water-needy vegetables.[31]

Mulching

"Mulching also will reduce water needs considerably for vegetables … by using a good moisture-retaining mulch around vegetables, you can cut back watering."[32] "Mulch … keeps the roots moist and cool; extends the period between waterings; … prevents valuable topsoil from drying out and blowing away."[33] Numerous materials can be used as mulch, including fallen leaves, aged sawdust, gravel (which should not touch the plants, because it reflects heat and can burn plants), wood-chips and bark fragments. It is important not to use fresh materials, such as fresh sawdust, because these require nutrients as they break down, which are then not available for the plants.

Utilizing Clay Soil

In the Bay Area the clay soils are common. They are known to be rich in nutrients and have a great capacity for moisture storage. To enable plants to root through the fine clay particles to use the soil's moisture, however, one generally needs to amend the soil with organic material such as compost. One technique to apply compost is to use the old French method of double digging. While gardeners

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[30] O'Keefe 117-118.

[31] O'Keefe 117-118.

[32] O'Keefe 117-118.

[33] O'Keefe 65-67.

generally agree on the use of compost to improve soil for plant growth, the question of how it should be added is still under debate. Some argue compost should be applied on top and allowed to slowly mix and break down, mimicking a natural process of soil building, while other support the intermixing of the double digging method. Double digging is likely to destroy soil horizons, but when applied carefully it can speed up the process of soil amendment.

Conclusions

We have seen that a very small rainwater catchment area can provide ample water for summer irrigation. The limiting factors may be the space available to store the rainwater and the cost of installing a system. In the more spacious suburbs it is easier to accommodate a large cistern on an existing lot, whereas the densities in the bay area make this difficult. We recommend that rainwater harvesting be considered during the design and construction of new houses. This would allow for a cistern to be integrated into the building aesthetically and structurally. A basement in particular would provide a convenient location to store rainwater, and would require the additional cost of only a pump, rather than structural support for the storage tanks.

For an average homeowner the cost of installing a rainwater harvesting system will be an important factor in their decision to collect their own water. The storage tank is the largest portion of the cost of a system, with the 2,500-gallon cylindrical tanks we recommend in this study running about $800. The level of filtration required also impacts the costs, and so the materials used throughout the system, primarily on the roof, will be of great importance. The level of filtration required from an asphalt roof greatly increases the cost of the system, typically adding $400-$500 for the particle and UV filtration we recommend. A pump such as we have described should cost less than $100, and the installation of new gutters, downspouts, leaf screens and a first-flush diverter could add to the price of a system. These costs may well preclude the hobby gardener from investing in the schemes we have described for the sole purpose of irrigating a summer vegetable garden. In this case we might suggest that the harvested rainwater be used for general irrigation, rather than food production. This would eliminate the need for costly filtration and at the same time reduce a household's water usage.

Because the space available for water storage is the limiting factor for many homeowners, it becomes extremely important to optimize water usage. Vegetable gardens are quite water intensive, even when 'low water' crops are selected. This means that planting time is an important control gardeners have to limit their water use. If we dedicate the space for water storage, vegetable gardens and attractive landscaping can be possible even in drought years.

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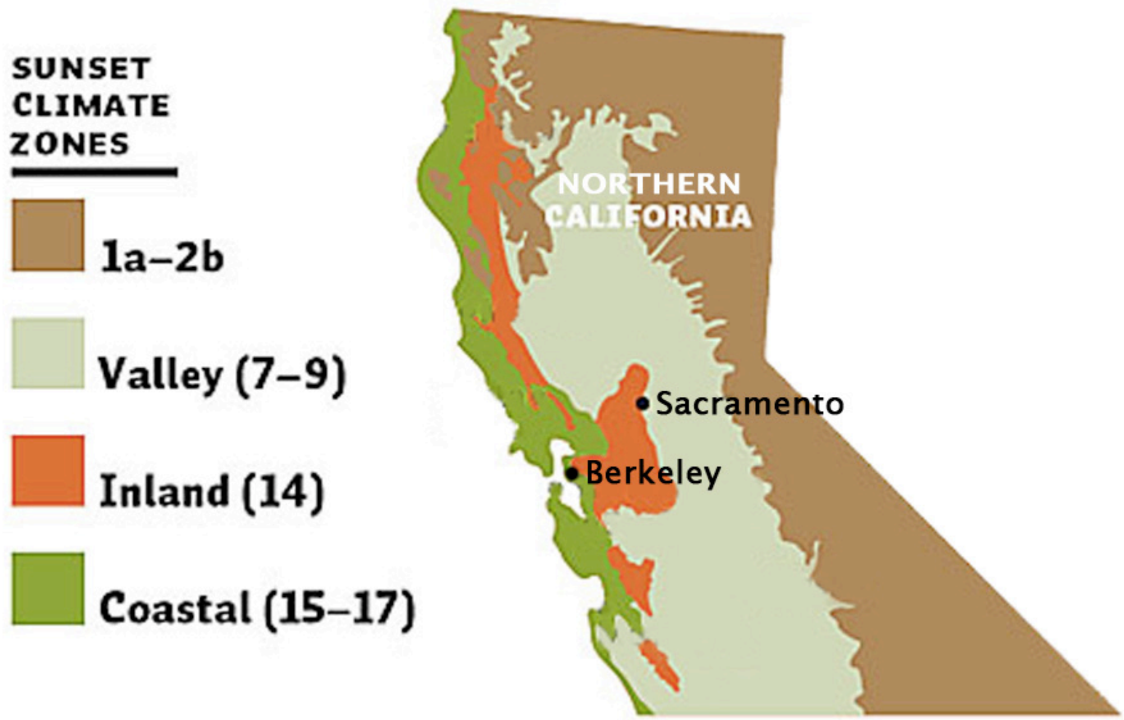
Appendices

Appendix A: Planting Guides for Berkeley: From *Golden Gate Gardening*

Appendix B: Planting Guides for Sacramento: From the UC Davis Vegetable Research and Information Center

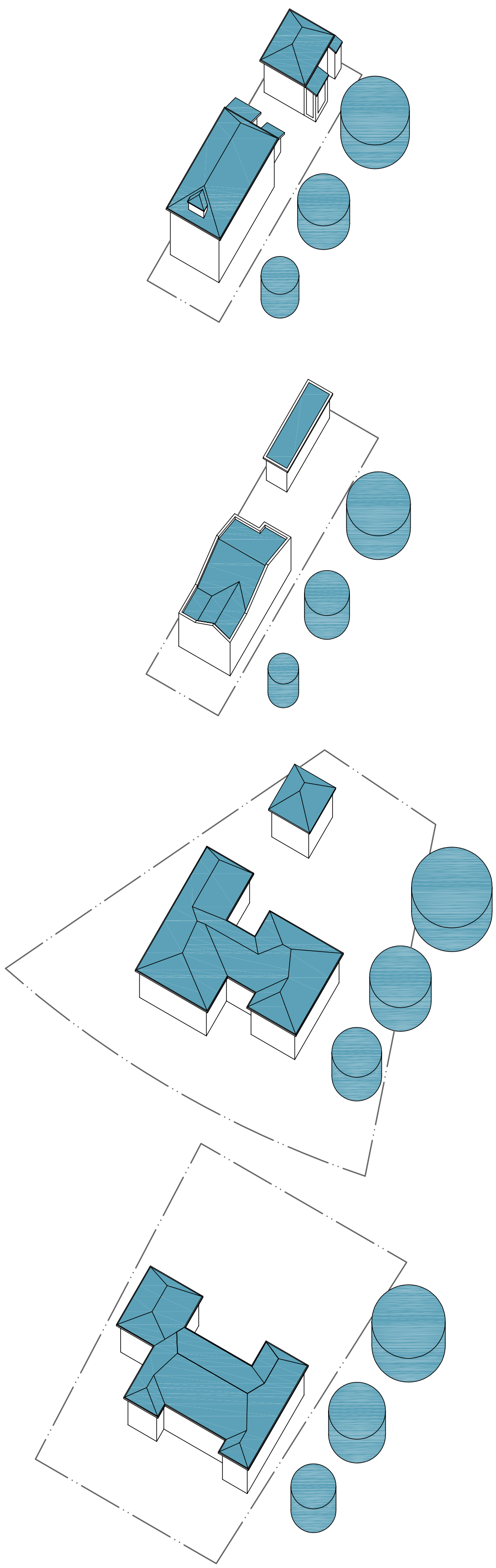
Figure 1 Site Climate Map for Case Study Houses



The case study houses used in this paper are located in Berkeley and Sacramento, California. Berkeley falls in the Sunset Western Garden Zone 17, identified here as "coastal," while Sacramento is in Zone 14, "inland."

Climate Zone Map adapted from Sunset.Com "Northern California May Garden Checklist" http://www.sunset.com/garden/garden-basics/no-california-checklist-may-00400000023483/ accessed 19 May 2009.

Figure 2 Potential for Rainwater Harvesting at Case Study Houses



Berkeley A

Total Collection Area	1,850 square feet
Wet Year rainwater collection	50,250 gallons
Average Year rainwater collection	24,390 gallons
Dry Year rainwater collection	15,040 gallons

Berkeley B

Total Collection Area	1,600 square feet
Wet Year rainwater collection	43,460 gallons
Average Year rainwater collection	21,090 gallons
Dry Year rainwater collection	10,080 gallons

Sacramento A

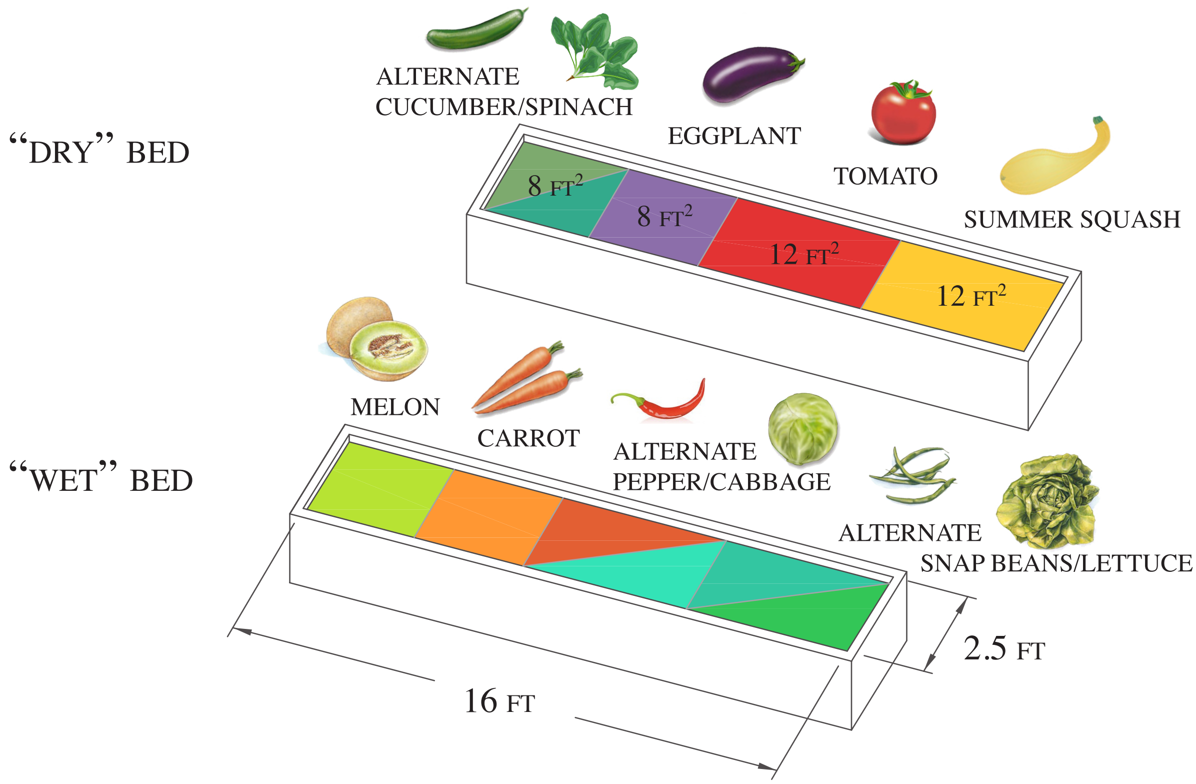
Total Collection Area	3.660 square feet
Wet Year rainwater collection	68,660 gallons
Average Year rainwater collection	35,830 gallons
Dry Year rainwater collection	26,220 gallons

Sacramento B

Total Collection Area	3.050 square feet
Wet Year rainwater collection	57,220 gallons
Average Year rainwater collection	29,860 gallons
Dry Year rainwater collection	21,850 gallons

Figure 3 Sample Vegetable Beds

Berkeley



Sacramento

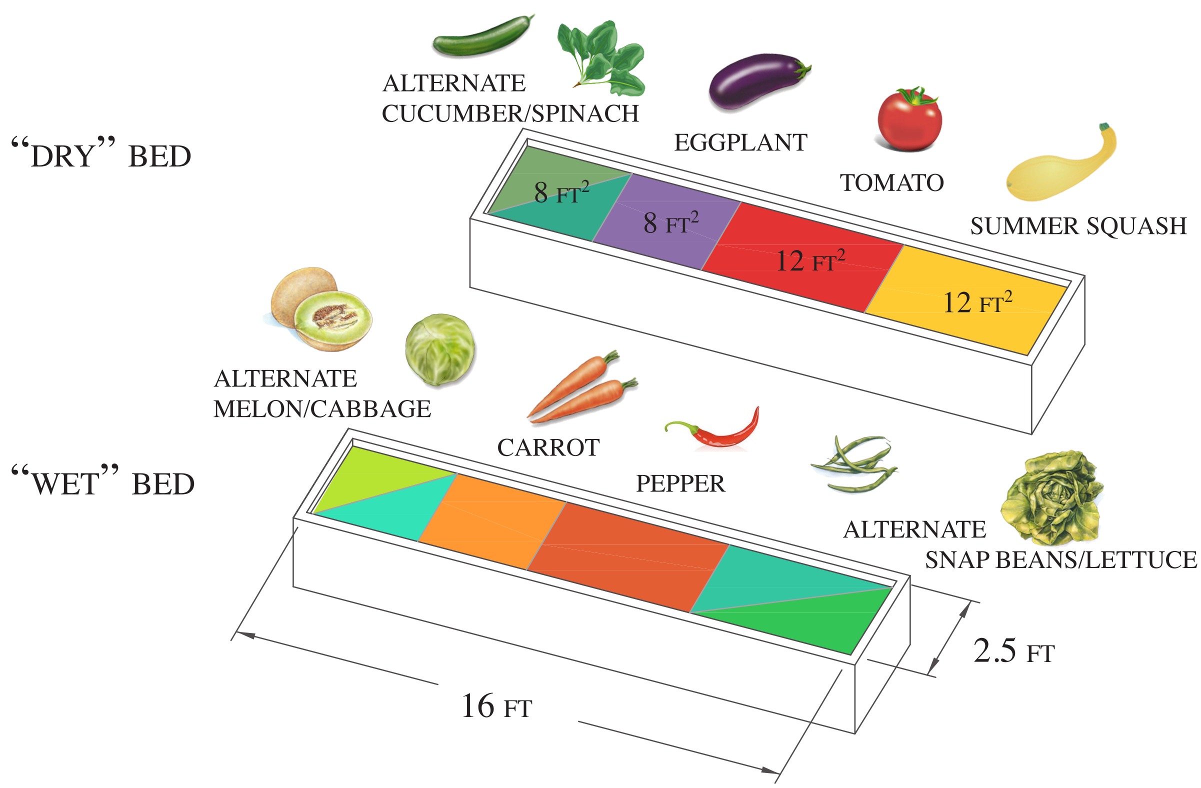


Figure 4 **Planting Calendar for Sample Gardens**

Berkeley

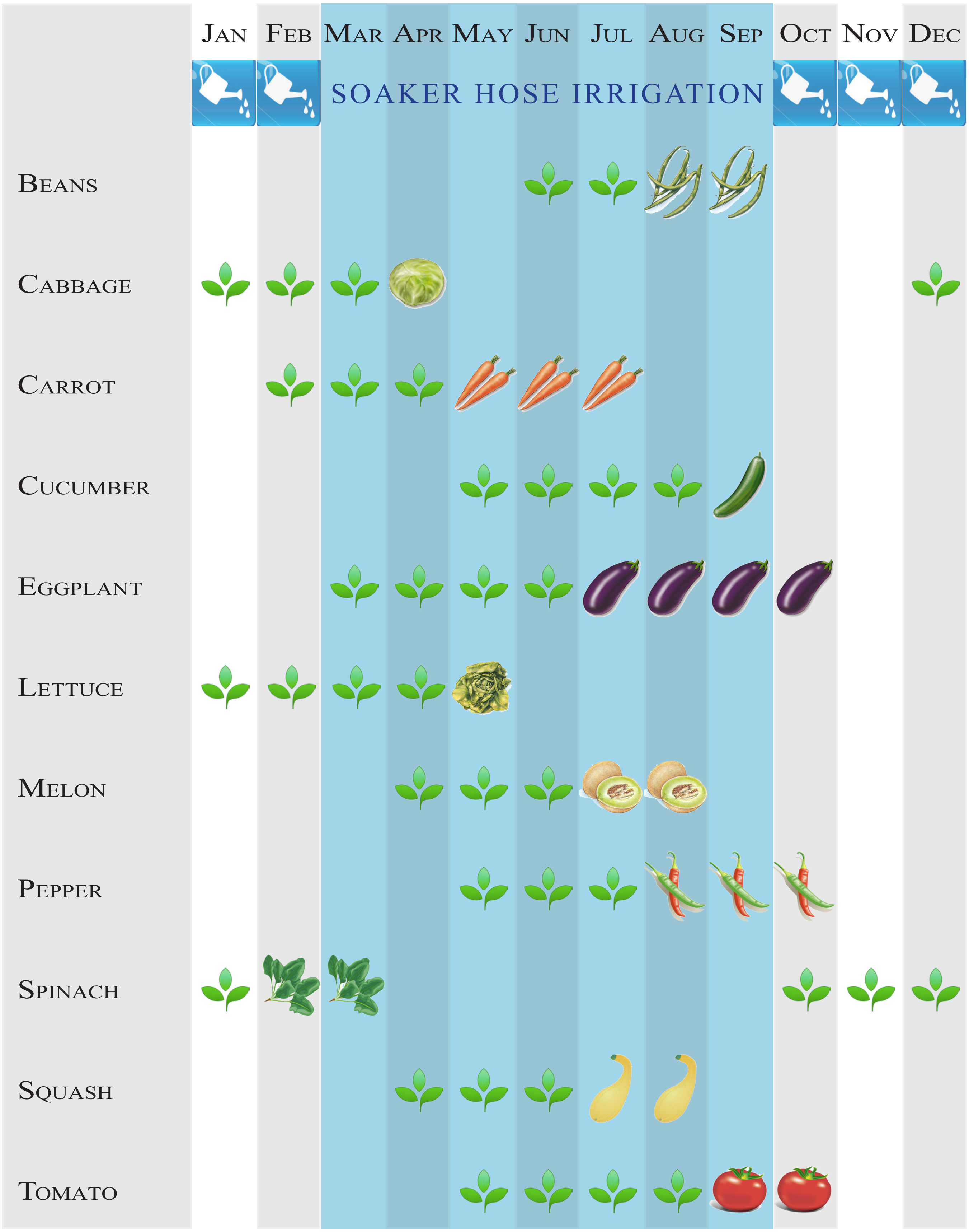


Figure 5 **Planting Calendar for Sample Gardens**

Sacramento

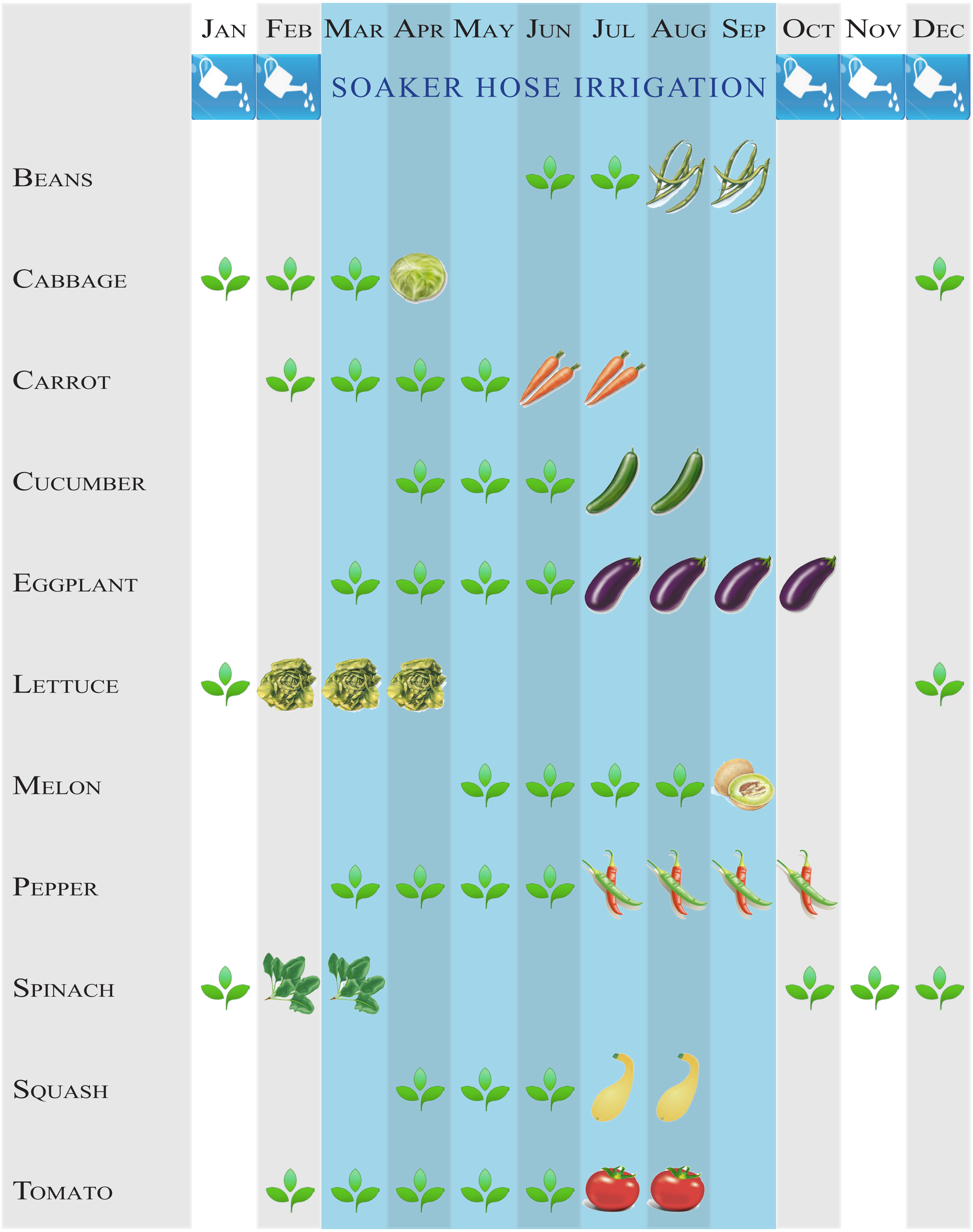
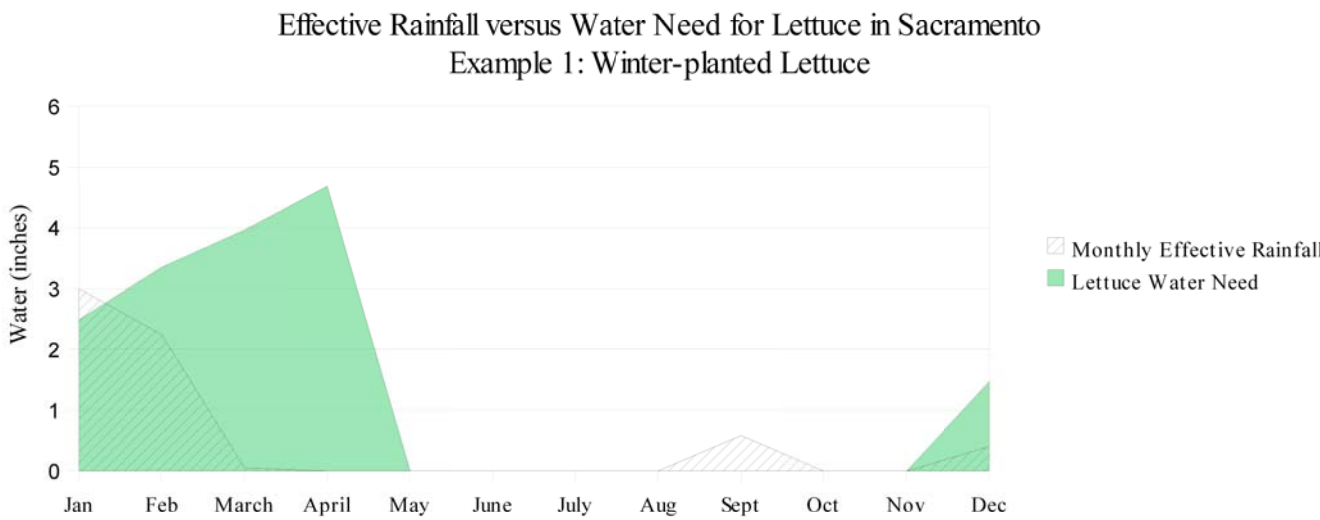


Figure 6 Lettuce: Potential to meet Crop Water Need with Effective Rainfall



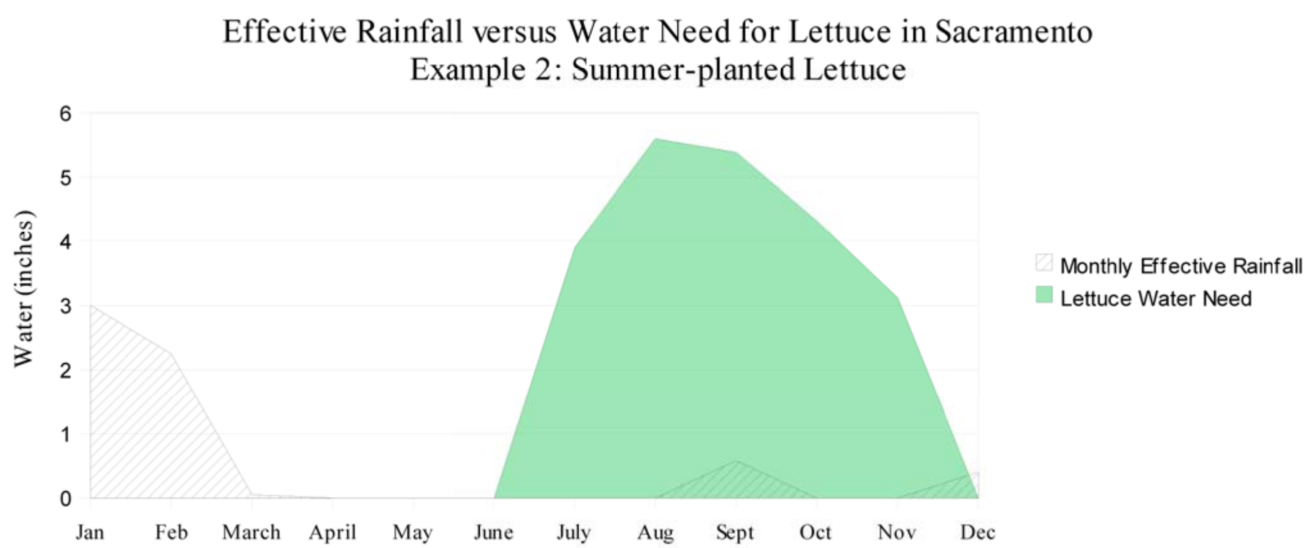
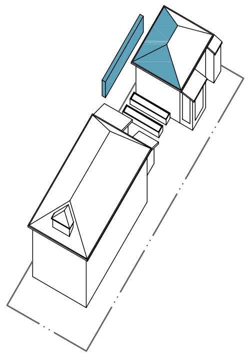
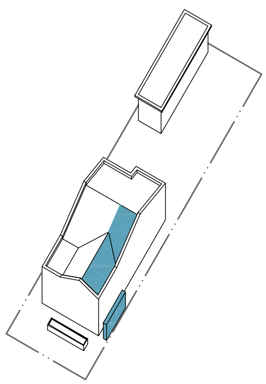


Figure 7 Proposed Configurations for Rainwater Harvesting at Case Study Houses



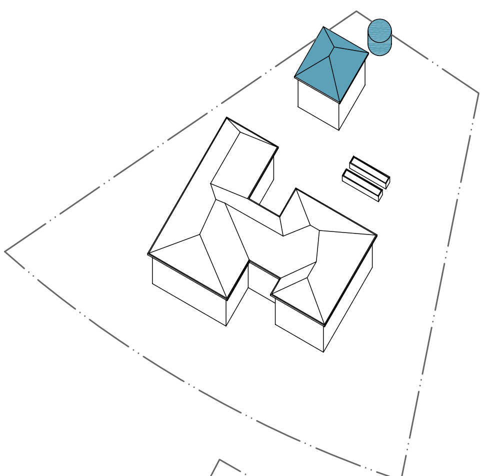
Berkeley A

Proposed Collection Area	275 square feet
Dry Year rainwater collection	2,240 gallons
Required Storage Capacity (for two vegetable beds)	1,860 gallons
Proposed Storage	38 modular tanks 1,900 gallons



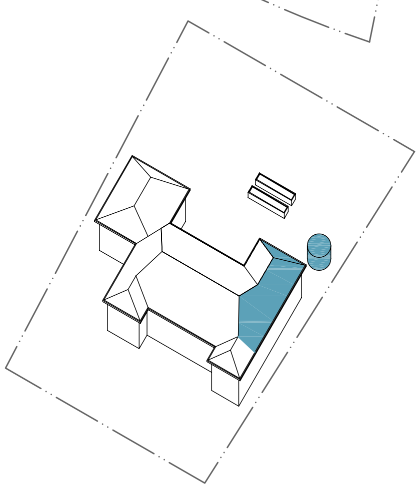
Berkeley B

Proposed Collection Area	190 square feet
Dry Year rainwater collection	1,560 gallons
Required Storage Capacity (for one vegetable bed)	960 gallons
Proposed Storage	20 modular tanks 1,000 gallons



Sacramento A

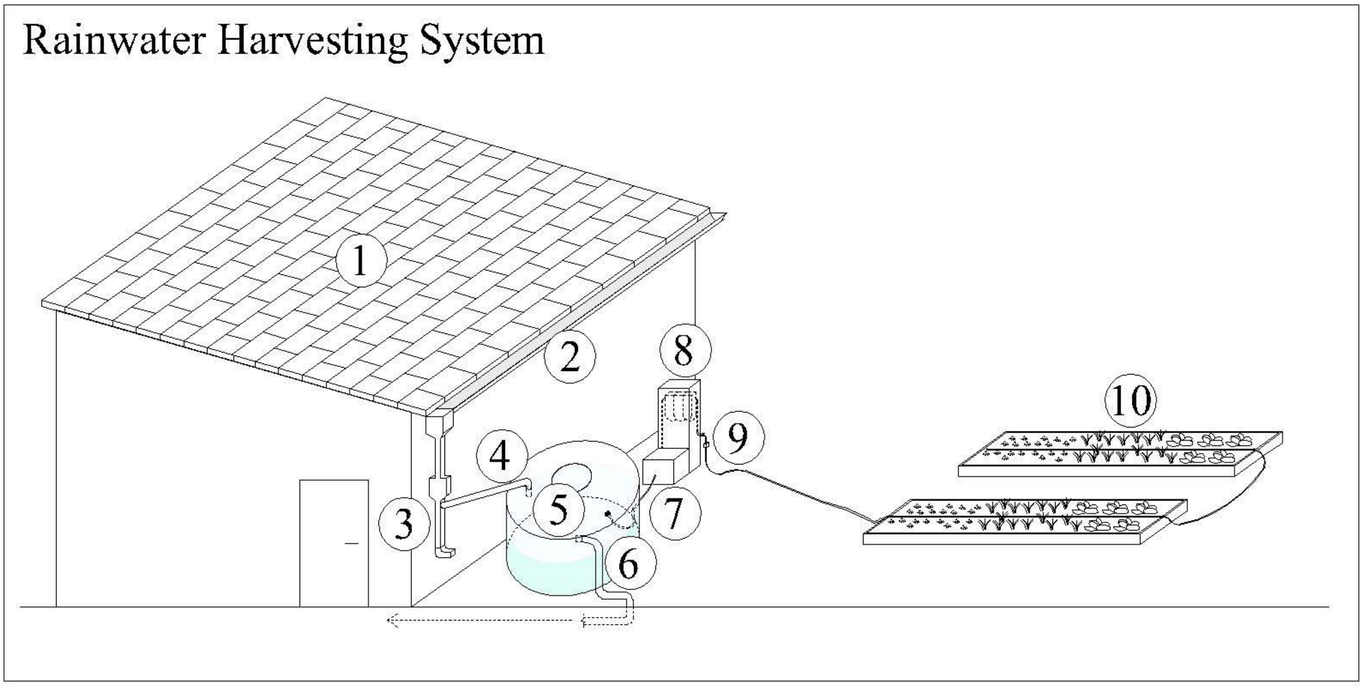
Proposed Collection Area	440 square feet
Dry Year rainwater collection	3,150 gallons
Required Storage Capacity (for two vegetable beds)	2,050 gallons
Proposed Storage	1 cylindrical tank 2,500 gallons



Sacramento B

Proposed Collection Area	450 square feet
Dry Year rainwater collection	3,220 gallons
Required Storage Capacity (for two vegetable beds)	2,050 gallons
Proposed Storage	1 cylindrical tank 2,500 gallons

Figure 8 Rainwater Harvesting System Components



1. Catchment Area
2. Gutter
3. Downspout and First-Flush Diverter
4. Cistern Inlet
5. Cistern
6. Overflow to Storm Sewer
7. Floating Intake Pump and Timer
8. Particle Filter
9. Valve, Timer and Back-Flow Preventer
10. Soaker Hose

Figure 9 Water Demand by Crop Species

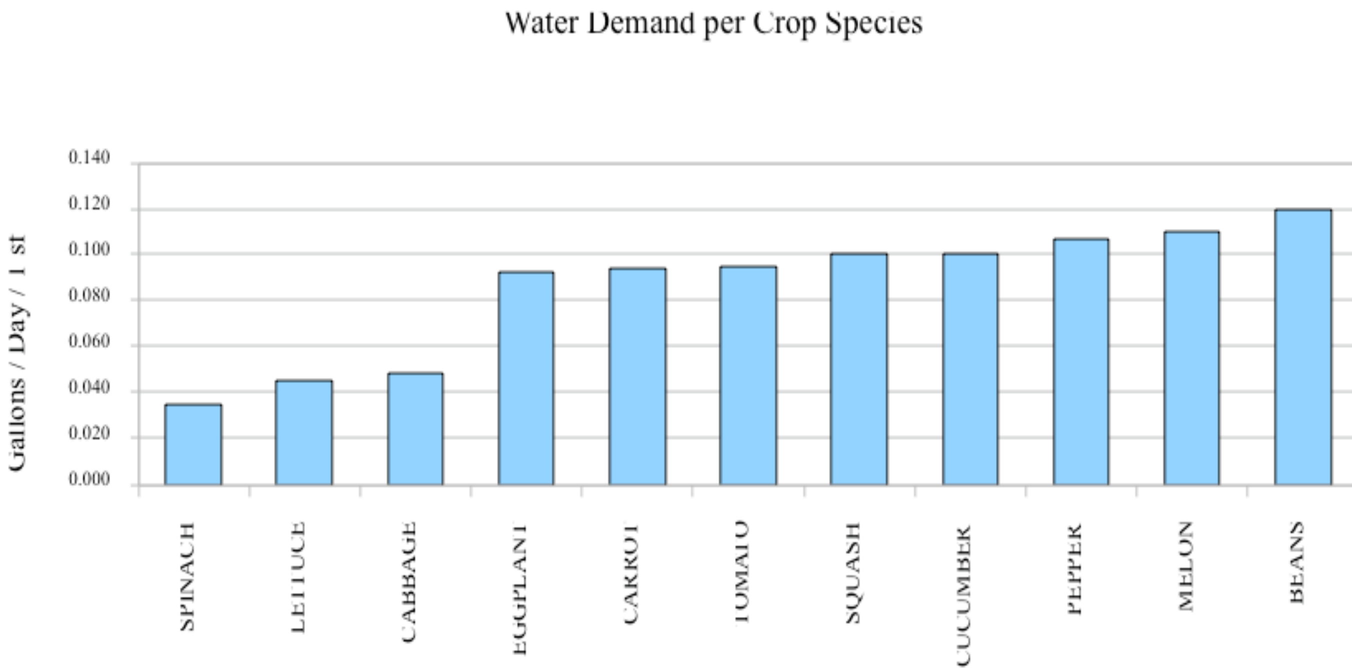


Table 1 Precipitation Data

Berkeley

Total Monthly Precipitation in a dry (1959) and a wet (1983) year and the average

(Period of Record: 1919 - 2006)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1959	4.69	4.63	0.58	0.36	0.03	0	0	0	2.62	0.04	0	1.54	14.49
1983	6.74	9.02	11.74	4.11	0.38	0	0	0.37	0.49	0.39	7.86	7.32	48.42
Mean	4.77	4.21	3.28	1.78	0.64	0.18	0.03	0.07	0.26	1.25	2.89	4.31	23.5

http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?caberk+sfo (accessed April 21, 2009)

Sacramento

Total Monthly Precipitation in a dry (1959) and a wet (1983) year and the average

(Period of Record: 1941 - 2009)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1959	4.93	4.11	0.53	0.21	0	0	0	0	1.61	0	0.2	1.36	12.77
1983	4.92	5.56	6.75	4.21	0.25	0.4	0	0.11	0.66	0.4	4.92	5.26	33.44
Mean	3.62	3.11	2.42	1.26	0.53	0.14	0.02	0.05	0.25	0.91	2.11	3.01	17.45

http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?ca7630 (accessed April 21, 2009)

Table 2 Temperature Data (T_m)

Berkeley

Monthly and Annual Temperature Data

(Period of Record: 1/ 1/1919 to 12/31/2005)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average Max. Temperature (F)	56.2	59.3	61.5	63.8	66.5	69.6	69.8	70.0	71.8	69.7	63.5	57.0	64.9
Average Min. Temperature (F)	42.9	45.4	46.4	47.8	50.4	52.9	54.0	54.6	55.1	52.7	48.3	44.1	49.6
Mean (F)	**49.55**	**52.35**	**53.95**	**55.8**	**58.45**	**61.25**	**61.9**	**62.3**	**63.45**	**61.2**	**55.9**	**50.55**	**57.25**
Mean (C)	**9.75**	**11.31**	**12.19**	**13.22**	**14.7**	**16.25**	**16.61**	**16.83**	**17.47**	**16.22**	**13.28**	**10.31**	**14.03**

http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?caberk+sfo

Sacramento

Monthly and Annual Temperature Data

(Period of Record: 1971-2000 Monthly Climate Summary)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average Max. Temperature (F)	53.9	60.1	65.0	71.6	80.1	87.4	92.3	91.4	87.2	78.1	61.6	54.0	73.8
Average Min. Temperature (F)	38.9	41.9	44.2	46.4	50.9	55.4	58.2	58.1	55.8	50.4	41.7	37.9	48.5
Mean (F)	**46.4**	**51**	**54.6**	**59**	**65.5**	**71.4**	**75.25**	**74.75**	**71.5**	**64.25**	**51.65**	**45.95**	**61.15**
Mean (C)	**8**	**10.56**	**12.56**	**15**	**18.61**	**21.89**	**24.03**	**23.47**	**21.94**	**17.92**	**10.92**	**7.75**	**16.2**

http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?ca7630

Table 3 Location Factor (p)

Latitude	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
40	0.22	0.24	0.27	0.3	0.32	0.34	0.33	0.31	0.28	0.25	0.22	0.21
35	0.23	0.25	0.27	0.29	0.31	0.32	0.32	0.3	0.28	0.25	0.23	0.2
37.5	**0.23**	**0.25**	**0.27**	**0.3**	**0.32**	**0.32**	**0.33**	**0.32**	**0.28**	**0.25**	**0.23**	**0.21**

Brouwer and Heibloem. Part II, Chapter 3.1.3.

Table 4 Monthly Evapotranspiration for Berkeley and Sacramento

Calculation of Evapotranspiration by the Blaney-Criddle Method. Brouwer and Heibloem.

$E_{To} = (p) \times (0.46 \times T_m + 8)$

E_{To} is the evapotranspiration factor in mm/day
p is a location factor representing the mean daily percentage of annual daytime hours for the given location based on latitude
T_m is the mean monthly temperature in °C

Calculation of E_{To} for Berkeley

	p x (0.46 x T_m + 8) =	**E_{To}** (mm/day)
Jan	0.225 x (0.46 x 9.75 + 8) =	2.81
Feb	0.245 x (0.46 x 11.31 + 8) =	3.23
Mar	0.270 x (0.46 x 12.19 + 8) =	3.67
Apr	0.295 x (0.46 x 13.22 + 8) =	4.15
May	0.315 x (0.46 x 14.70 + 8) =	4.65
Jun	0.320 x (0.46 x 16.25 + 8) =	4.95
Jul	0.330 x (0.46 x 16.61 + 8) =	5.16
Aug	0.315 x (0.46 x 16.83 + 8) =	4.96
Sep	0.280 x (0.46 x 17.47 + 8) =	4.49
Oct	0.250 x (0.46 x 16.22 + 8) =	3.87
Nov	0.225 x (0.46 x 13.28 + 8) =	3.17
Dec	0.205 x (0.46 x 10.31 + 8) =	2.61

Calculation of E_{To} for Sacramento

	p x (0.46 x T_m + 8) =	**E_{To}** (mm/day)
Jan	0.225 x (0.46 x 8.00 + 8) =	2.63
Feb	0.245 x (0.46 x 10.56 + 8) =	3.15
Mar	0.270 x (0.46 x 12.56+ 8) =	3.72
Apr	0.295 x (0.46 x 15.00 + 8) =	4.40
May	0.315 x (0.46 x 18.61 + 8) =	5.22
Jun	0.320 x (0.46 x 21.89 + 8) =	5.78
Jul	0.330 x (0.46 x 24.03 + 8) =	6.29
Aug	0.315 x (0.46 x 23.47 + 8) =	5.92
Sep	0.280 x (0.46 x 21.94 + 8) =	5.07
Oct	0.250 x (0.46 x 17.92 + 8) =	4.06
Nov	0.225 x (0.46 x 10.92 + 8) =	2.93
Dec	0.205 x (0.46 x 7.75 + 8) =	2.37

Table 5 Crop Factor (Kc)

Values of the crop factor (K_c) for various crops and growth stages

Crop	Initial Stage	Crop development stage	Mid-season stage	Late season stage
Green Bean	0.35	0.7	1.1	0.9
Cucumber/Squash	0.45	0.7	0.9	0.75
Eggplant/Tomato	0.45	0.75	1.15	0.8
Lettuce/Spinach	0.45	0.6	1	0.9
Melon	0.45	0.75	1	0.75
Pepper, fresh	0.35	0.7	1.05	0.9
Cabbage/Carrot	0.45	0.75	1.05	0.9

Brouwer and Heibloem. Part II, Chapter 3.2.3., Table 7.

Table 6 Crop Growth Stage Duration

Approximate duration of growth stages for various field crops

Crop	Initial Stage	Crop development stage	Mid-season stage	Late season stage
Green Bean	15	25	25	10
Cabbage	20	25	60	15
Carrot	20	30	30	20
Cucumber	20	30	40	15
Eggplant	30	40	40	20
Lettuce	20	30	15	10
Melon	25	35	40	20
Pepper	25	35	40	20
Spinach	20	20	15	5
Squash	20	30	30	15
Tomato	30	40	40	25

Generally the Initial Stage can be shortened to about 15 days, if crops are not directly sown but seedlings are transplanted.

Brouwer and Heibloem. Part II, Chapter 3.2.4., Table 8.

Table 7 Estimation of Effective Rainfall (P_e)

Rainfall (P) and effective rainfall (P_e) in mm/month and inch/month

P (mm/month) [inches/month]	**P_e** (mm/month) [inches/month]	**P** (mm/month) [inches/month]	**P_e** (mm/month) [inches/month]
0	0	130 [5.07]	79 [3.08]
10 [0.39]	0	140 [5.46]	87 [3.39]
20 [0.78]	2 [0.08]	150 [5.85]	95 [3.71]
30 [1.17]	8 [0.31]	160 [6.24]	103 [4.02]
40 [1.56]	14 [0.55]	170 [6.63]	111 [4.33]
50 [1.95]	20 [0.78]	180 [7.02]	119 [4.64]
60 [2.34]	26 [1]	190 [7.41]	127 [4.95]
70 [2.73]	32 [1.25]	200 [7.8]	135 [5.27]
80 [3.12]	39 [1.52]	210 [8.19]	143 [5.58]
90 [3.51]	47 [1.83]	220 [8.58]	151 [5.89]
100 [3.9]	55 [2.15]	230 [8.97]	159 [6.20]
110 [4.29]	63 [2.46]	240 [9.36]	167 [6.51]
120 [4.68]	71 [2.77]	250 [9.75]	175 [6.83]

Brouwer and Heibloem. Part II, Chapter 3

Calculation of Crop Water Need

SACRAMENTO
Dry Bed Crops

	12 sq ft	APR	MAY	JUN	JUL	AUG
PXH	Squash	P	X	X	H	H
D_m		30	30	30	30	30
D_g		15/15	15/15	15/15	30	30
K_C		0.45/0.7	0.7/0.9	0.9/0.75	0.75	0.75
K_{CM}		0.58	0.8	0.83	0.75	0.75
ET_o		4.4	5.22	5.78	6.29	5.92
ET_d (mm)		2.53	4.18	4.77	4.72	4.44
ET_d (inches)	0.04	0.1	0.16	0.19	0.19	0.17
ET_m	30	2.99	4.94	5.64	5.58	5.25
ET_m /cubic inches	1728	5167.51	8529.46	9739.64	9635.47	9068.68
ET_m /gallons	0.0043	22.37	36.92	42.16	41.71	39.26
P		0.21	0	0	0	0
P_e		0	0	0	0	0
P_e/inches	1728	0	0	0	0	0
P_e/gallons	0.0043	0	0	0	0	0
I_{dm}		22.37	36.92	42.16	41.71	39.26
I_{dtot}	**182.43**					

	12 sq ft	FEB	MAR	APR	MAY	JUN	JUL	AUG
PXH	Tomato	P	X	X	X	X	H	H
D_m		30	30	30	30	30	30	30
D_g		15/15	25/5	30	5/25	30	30	30
K_C		0.45/0.75	0.75/1.15	1.15	1.15/0.8	0.8	0.8	0.8
K_{CM}		0.6	0.82	1.15	0.86	0.8	0.8	0.8
ET_o		3.15	3.72	4.4	5.22	5.78	6.29	5.92
ET_d (mm)		1.89	3.05	5.06	4.49	4.62	5.03	4.74
ET_d (inches)	0.04	0.07	0.12	0.2	0.18	0.18	0.2	0.19
ET_m	30	2.23	3.61	5.98	5.31	5.47	5.95	5.6
ET_m /cubic inches	1728	3860.32	6230.43	10335.03	9169.17	9444.5	10277.84	9673.26
ET_m /gallons	0.0043	16.71	26.97	44.74	39.69	40.89	44.49	41.88
P		4.11	0.53	0.21	0	0	0	0
P_e		2.25	0.05	0	0	0	0	0
P_e/inches	1728	3888	86.4	0	0	0	0	0
P_e/gallons	0.0043	16.83	0.37	0	0	0	0	0
I_{dm}		0	26.6	44.74	39.69	40.89	44.49	41.88
I_{dtot}	**238.28**							

	8 sq ft	OCT	NOV	DEC	JAN	FEB	MAR
PXH	Spinach	P	X	X	X	H	H
D_m		30	30	30	30	30	30
D_g		15/15	30	30	30	30	30
K_C		0.45/0.6	0.6	1	1	0.9	0.9
K_{CM}		0.53	0.6	1	1	0.9	0.9
ET_o		4.06	2.93	2.37	2.63	3.15	3.72
ET_d (mm)		2.13	1.76	2.37	2.63	2.84	3.35
ET_d (inches)	0.04	0.08	0.07	0.09	0.1	0.11	0.13
ET_m	30	2.52	2.08	2.8	3.11	3.35	3.96
ET_m /cubic inches	1152	2902.39	2393.81	3227.14	3581.18	3860.32	4558.85
ET_m /gallons	0.0043	12.56	10.36	13.97	15.5	16.71	19.74
P		0	0.2	1.36	4.93	4.11	0.53
P_e		0	0	0.4	3	2.25	0.05
P_e/inches	1152	0	0	460.8	3456	2592	57.6
P_e/gallons	0.0043	0	0	1.99	14.96	11.22	0.25
I_{dm}		12.56	10.36	11.98	0.54	5.49	19.49
I_{dtot}	**60.42**						

Legend

PXH	Crop Planting/Growing/Harvesting Season
D_m	Days of Month
D_g	Days of Growth Stage
K_C	Crop-Factor for Growth Stage
K_{CM}	Crop-Factor for Month
ET_o	Evapotranspiration
ET_d (mm)	Water demand/day [mm]
ET_d (inches)	Water demand/day [inches]
ET_m	Water demand/month [inches]
ET_m /cubic inches	Water demand/month/area [cubic inches]
ET_m /gallons	Water demand/month/area [gallons]
P	Precipitation [inches] – dry year
P_e	Effective Precipitation [inches]
P_e/inches	Effective Precipitation/area [inches/sqft]
P_e/gallons	Effective Precipitation/area [gallons]
I_{dm}	Actual Irrigation Demand/area/month [gallons]
I_{dtot}	Total Irrigation Demand/area/growing period [gallons]

SACRAMENTO
Dry Bed Crops

	8 sq ft	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT
PXH	Eggplant	P	X	X	X	H	H	H	H
D_m		30	30	30	30	30	30	30	30
D_g		15/15	15/15	25/5	30	30	30	30	30
K_C		0.45/0.7	0.7/0.9	0.9/0.75	0.75	0.75	0.75	0.75	0.75
K_{CM}		0.58	0.8	0.88	0.75	0.75	0.75	0.75	0.75
ET_o		3.72	4.4	5.22	5.78	6.29	5.92	5.07	4.06
ET_d (mm)		2.14	3.52	4.57	4.34	4.72	4.44	3.8	3.05
ET_d (inches)	0.04	0.08	0.14	0.18	0.17	0.19	0.17	0.15	0.12
ET_m	30	2.53	4.16	5.4	5.12	5.58	5.25	4.49	3.6
ET_m /cubic inches	1152	2912.6	4793.06	6219.4	5902.81	6423.65	6045.79	5177.73	4146.27
ET_m /gallons	0.0043	12.61	20.75	26.92	25.55	27.81	26.17	22.41	17.95
P		0.53	0.21	0	0	0	0	1.61	0
P_e		0.05	0	0	0	0	0	0.58	0
P_e/inches	1152	57.6	0	0	0	0	0	668.16	0
P_e/gallons	0.0043	0.25	0	0	0	0	0	2.89	0
I_{dm}		12.36	20.75	26.92	25.55	27.81	26.17	19.52	17.95
I_{dtot}	**177.04**								

	8 sq ft	APR	MAY	JUN	JUL	AUG
PXH	Cucumber	P	X	X	H	H
D_m		30	30	30	30	30
D_g		15/15	15/15	25/5	30	30
K_C		0.45/0.7	0.7/0.9	0.9/0.75	0.75	0.75
K_{CM}		0.58	0.8	0.88	0.75	0.75
ET_o		4.4	5.22	5.78	6.29	5.92
ET_d (mm)		2.53	4.18	5.06	4.72	4.44
ET_d (inches)	0.04	0.1	0.16	0.2	0.19	0.17
ET_m	30	2.99	4.94	5.98	5.58	5.25
ET_m /cubic inches	1152	3445.01	5686.31	6886.62	6423.65	6045.79
ET_m /gallons	0.0043	14.91	24.62	29.81	27.81	26.17
P		0.21	0	0	0	0
P_e		0	0	0	0	0
P_e/inches	1152	0	0	0	0	0
P_e/gallons	0.0043	0	0	0	0	0
I_{dm}		14.91	24.62	29.81	27.81	26.17
I_{dtot}	**123.32**					

SACRAMENTO
Wet Bed Crops

	8 sq ft	FEB	MAR	APR	MAY	JUN	JUL
PXH	Carrot	P	X	X	X	H	H
D_m		30	30	30	30	30	30
D_g		20/10	20/10	20/10	30	30	30
K_C		0.45/0.75	0.75/1.05	1.05/0.9	0.9	0.9	0.9
K_{CM}		0.55	0.85	1	0.9	0.9	0.9
ET_o		3.15	3.72	4.4	5.22	5.78	6.29
ET_d (mm)		1.73	3.16	4.4	4.7	5.2	5.66
ET_d (inches)	0.04	0.07	0.12	0.17	0.19	0.2	0.22
ET_m	30	2.05	3.74	5.2	5.55	6.15	6.69
ET_m /cubic inches	1152	2359.08	4305.58	5991.32	6397.1	7083.38	7708.38
ET_m /gallons	0.0043	10.21	18.64	25.94	27.69	30.66	33.37
P		4.11	0.53	0.21	0	0	0
P_e		2.25	0.05	0	0	0	0
P_e/inches	1152	2592	57.6	0	0	0	0
P_e/gallons	0.0043	11.22	0.25	0	0	0	0
I_{dm}		0	18.39	25.94	27.69	30.66	33.37
I_{dtot}	**136.05**						

	12 sq ft	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT
PXH	Pepper	P	X	X	X	H	H	H	H
D_m		30	30	30	30	30	30	30	30
D_g		15/15	20/10	30	30	30	30	30	30
K_C		0.35/0.7	0.7/1.05	1.05	0.9	0.9	0.9	0.9	0.9
K_{CM}		0.53	0.82	1.05	0.9	0.9	0.9	0.9	0.9
ET_o		3.72	4.4	5.22	5.78	6.29	5.92	5.07	4.06
ET_d (mm)		1.95	3.59	5.48	5.2	5.66	5.33	4.56	3.65
ET_d (inches)	0.04	0.08	0.14	0.22	0.2	0.22	0.21	0.18	0.14
ET_m	30	2.31	4.25	6.48	6.15	6.69	6.3	5.39	4.32
ET_m /cubic inches	1728	3988.99	7342.36	11194.92	10625.06	11562.57	10882.42	9319.91	7463.28
ET_m /gallons	0.0043	17.27	31.79	48.46	46	50.05	47.11	40.35	32.31
P		0.53	0.21	0	0	0	0	1.61	0
P_e		0.05	0	0	0	0	0	0.58	0
P_e/inches	1728	86.4	0	0	0	0	0	1002.24	0
P_e/gallons	0.0043	0.37	0	0	0	0	0	4.34	0
I_{dm}		16.89	31.79	48.46	46	50.05	47.11	36.01	32.31
I_{dtot}	**308.62**								

	12 sq ft	JUN	JUL	AUG	SEP
PXH	Beans	P	X	X/H	H
D_m		30	30	30	30
D_g		15/15	10|20	5|25	30
K_C		0.35/0.7	0.7/1.1	1.1/0.9	0.9
K_{CM}		0.53	0.97	0.93	0.9
ET_o		5.78	6.29	5.92	5.07
ET_d (mm)		3.03	6.1	5.51	4.56
ET_d (inches)	0.04	0.12	0.24	0.22	0.18
ET_m	30	3.59	7.21	6.51	5.39
ET_m /cubic inches	1728	6197.95	12461.88	11245.17	9319.91
ET_m /gallons	0.0043	26.83	53.95	48.68	40.35
P		0	0	0	1.61
P_e		0	0	0	0.58
P_e/inches	1728	0	0	0	1002.24
P_e/gallons	0.0043	0	0	0	4.34
I_{dm}		26.83	53.95	48.68	36.01
I_{dtot}	**165.47**				

SACRAMENTO
Wet Bed Crops

	12 sq ft	DEC	JAN	FEB	MAR	APR
PXH	Lettuce	P	X	X/H	H	H
D_m		30	30	30	30	30
D_g		15/15	15/15	30	30	30
K_C		0.45/0.6	0.6/1	0.9	0.9	0.9
K_{CM}		0.53	0.8	0.9	0.9	0.9
ET_o		2.37	2.63	3.15	3.72	4.4
ET_d (mm)		1.24	2.1	2.84	3.35	3.96
ET_d (inches)	0.04	0.05	0.08	0.11	0.13	0.16
ET_m	30	1.47	2.49	3.35	3.96	4.68
ET_m /cubic inches	1728	2541.38	4297.41	5790.48	6838.28	8088.28
ET_m /gallons	0.0043	11	18.6	25.07	29.6	35.01
P		1.36	4.93	4.11	0.53	0.21
P_e		0.4	3	2.25	0.05	0
P_e/inches	1728	691.2	5184	3888	86.4	0
P_e/gallons	0.0043	2.99	22.44	16.83	0.37	0
I_{dm}		8.01	0	8.24	29.23	35.01
I_{dtot}	**80.49**					

	8 sq ft	MAY	JUN	JUL	AUG	SEP
PXH	Melon	P	X	X	X	H
D_m		30	30	30	30	30
D_g		15/15	20/10	30	30	30
K_C		0.45/0.75	0.75/1	1	0.75	0.75
K_{CM}		0.6	0.83	1	0.75	0.75
ET_o		5.22	5.78	6.29	5.92	5.07
ET_d (mm)		3.13	4.81	6.29	4.44	3.8
ET_d (inches)	0.04	0.12	0.19	0.25	0.17	0.15
ET_m	30	3.7	5.69	7.43	5.25	4.49
ET_m /cubic inches	1152	4264.73	6556.06	8564.87	6045.79	5177.73
ET_m /gallons	0.0043	18.46	28.38	37.08	26.17	22.41
P		0	0	0	0	1.61
P_e		0	0	0	0	0.58
P_e/inches	1152	0	0	0	0	668.16
P_e/gallons	0.0043	0	0	0	0	2.89
I_{dm}		18.46	28.38	37.08	26.17	19.52
I_{dtot}	**129.61**					

	8 sq ft	DEC	JAN	FEB	MAR	APR
PXH	Cabbage	P	X	X	X	H
D_m		30	30	30	30	30
D_g		15/15	10|20	30	10|20	30
K_C		0.45/0.75	0.75/1.05	1.05	1.05/0.9	0.9
K_{CM}		0.6	0.95	1.05	0.95	0.9
ET_o		2.37	2.63	3.15	3.72	4.4
ET_d (mm)		1.42	2.5	3.31	3.53	3.96
ET_d (inches)	0.04	0.06	0.1	0.13	0.14	0.16
ET_m	30	1.68	2.95	3.91	4.18	4.68
ET_m /cubic inches	1152	1936.29	3402.12	4503.7	4812.12	5392.19
ET_m /gallons	0.0043	8.38	14.73	19.5	20.83	23.34
P		1.36	4.93	4.11	0.53	0.21
P_e		0.4	3	2.25	0.05	0
P_e/inches	1152	460.8	3456	2592	57.6	0
P_e/gallons	0.0043	1.99	14.96	11.22	0.25	0
I_{dm}		6.39	0	8.28	20.58	23.34
I_{dtot}	**58.59**					

Calculation of Crop Water Need

BERKELEY
Dry Bed Crops

	12 sq ft	APR	MAY	JUN	JUL	AUG
PXH	Squash	P	X	X	H	H
D_m		30	30	30	30	30
D_g		15/15	15/15	15/15	30	30
K_C		0.45/0.7	0.7/0.9	0.9/0.75	0.75	0.75
K_{CM}		0.58	0.8	0.83	0.75	0.75
ET_o		4.15	4.65	4.95	5.16	4.96
ET_d (mm)		2.39	3.72	4.08	3.87	3.72
ET_d (inches)	0.04	0.09	0.15	0.16	0.15	0.15
ET_m	30	2.82	4.4	4.83	4.57	4.4
ET_m /cubic inches	1728	4873.91	7598.09	8341.04	7904.46	7598.09
ET_m /gallons	0.0043	21.1	32.89	36.11	34.22	32.89
P		0.36	0.03	0	0	0
P_e		0	0	0	0	0
P_e/inches	1728	0	0	0	0	0
P_e/gallons	0.0043	0	0	0	0	0
I_{dm}		21.1	32.89	36.11	34.22	32.89
I_{dtot}	**157.21**					

	12 sq ft	MAY	JUN	JUL	AUG	SEP	OCT
PXH	Tomato	P	X	X	X	H	H
D_m		30	30	30	30	30	30
D_g		15/15	25/5	30	5/25	30	30
K_C		0.45/0.75	0.75/1.15	1.15	1.15/0.8	0.8	0.8
K_{CM}		0.6	0.82	1.15	0.86	0.8	0.8
ET_o		4.65	4.95	5.16	4.96	4.49	3.87
ET_d (mm)		2.79	4.06	5.93	4.27	3.59	3.1
ET_d (inches)	0.04	0.11	0.16	0.23	0.17	0.14	0.12
ET_m	30	3.3	4.8	7.01	5.04	4.25	3.66
ET_m /cubic inches	1728	5698.56	8290.49	12120.17	8712.47	7336.65	6323.57
ET_m /gallons	0.0043	24.67	35.89	52.47	37.72	31.76	27.37
P		0.03	0	0	0	2.62	0.04
P_e		0	0	0	0	1.18	0
P_e/inches	1728	0	0	0	0	2039.04	0
P_e/gallons	0.0043	0	0	0	0	8.83	0
I_{dm}		24.67	35.89	52.47	37.72	22.93	27.37
I_{dtot}	**201.05**						

	8 sq ft	OCT	NOV	DEC	JAN	FEB	MAR
PXH	Spinach	P	X	X	X	H	H
D_m		30	30	30	30	30	30
D_g		15/15	30	30	30	30	30
K_C		0.45/0.6	0.6	1	1	0.9	0.9
K_{CM}		0.53	0.6	1	1	0.9	0.9
ET_o		3.87	3.17	2.61	2.81	3.23	3.67
ET_d (mm)		2.03	1.9	2.61	2.81	2.91	3.3
ET_d (inches)	0.04	0.08	0.07	0.1	0.11	0.11	0.13
ET_m	30	2.4	2.25	3.09	3.32	3.44	3.9
ET_m /cubic inches	1152	2766.56	2589.88	3553.94	3826.28	3958.36	4497.58
ET_m /gallons	0.0043	11.98	11.21	15.39	16.56	17.14	19.47
P		0.04	0	1.54	4.69	4.63	0.58
P_e		0	0	0.52	2.78	2.7	0.06
P_e/inches	1152	0	0	599.04	3202.56	3110.4	69.12
P_e/gallons	0.0043	0	0	2.59	13.86	13.46	0.3
I_{dm}		11.98	11.21	12.79	2.7	3.67	19.17
I_{dtot}	**61.52**						

Legend

PXH	Crop Planting/Growing/Harvesting Season
D_m	Days of Month
D_g	Days of Growth Stage
K_C	Crop-Factor for Growth Stage
K_{CM}	Crop-Factor for Month
ET_o	Evapotranspiration
ET_d (mm)	Water demand/day [mm]
ET_d (inches)	Water demand/day [inches]
ET_m	Water demand/month [inches]
ET_m /cubic inches	Water demand/month/area [cubic inches]
ET_m /gallons	Water demand/month/area [gallons]
P	Precipitation [inches] – dry year
P_e	Effective Precipitation [inches]
P_e/inches	Effective Precipitation/area [inches/sqft]
P_e/gallons	Effective Precipitation/area [gallons]
I_{dm}	Actual Irrigation Demand/area/month [gallons]
I_{dtot}	Total Irrigation Demand/area/growing period [gallons]

BERKELEY
Dry Bed Crops

	8 sq ft	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT
PXH	Eggplant	P	X	X	X	H	H	H	H
D_m		30	30	30	30	30	30	30	30
D_g		15/15	15/15	25/5	30	30	30	30	30
K_C		0.45/0.7	0.7/0.9	0.9/0.75	0.75	0.75	0.75	0.75	0.75
K_{CM}		0.58	0.8	0.88	0.75	0.75	0.75	0.75	0.75
ET_o		3.67	4.15	4.65	4.95	5.16	4.96	4.49	3.87
ET_d (mm)		2.11	3.32	4.07	3.71	3.87	3.72	3.37	2.9
ET_d (inches)	0.04	0.08	0.13	0.16	0.15	0.15	0.15	0.13	0.11
ET_m	30	2.49	3.92	4.81	4.39	4.57	4.4	3.98	3.43
ET_m /cubic inches	1152	2873.45	4520.72	5540.27	5055.18	5269.64	5065.39	4585.4	3952.23
ET_m /gallons	0.0043	12.44	19.57	23.98	21.88	22.81	21.93	19.85	17.11
P		0.58	0.36	0.03	0	0	0	2.62	0.04
P_e		0.06	0	0	0	0	0	1.18	0
P_e/inches	1152	69.12	0	0	0	0	0	1359.36	0
P_e/gallons	0.0043	0.3	0	0	0	0	0	5.88	0
I_{dm}		12.14	19.57	23.98	21.88	22.81	21.93	13.97	17.11
I_{dtot}	**153.39**								

	8 sq ft	MAY	JUN	JUL	AUG	SEP
PXH	Cucumber	P	X	X	X	H
D_m		30	30	30	30	30
D_g		15/15	15/15	25/5	30	30
K_C		0.45/0.7	0.7/0.9	0.9/0.75	0.75	0.75
K_{CM}		0.58	0.8	0.88	0.75	0.75
ET_o		4.65	4.95	5.16	4.96	4.49
ET_d (mm)		2.67	3.96	4.52	3.72	3.37
ET_d (inches)	0.04	0.11	0.16	0.18	0.15	0.13
ET_m	30	3.16	4.68	5.34	4.4	3.98
ET_m /cubic inches	1152	3640.75	5392.19	6147.91	5065.39	4585.4
ET_m /gallons	0.0043	15.76	23.34	26.61	21.93	19.85
P		0.03	0	0	0	2.62
P_e		0	0	0	0	1.18
P_e/inches	1152	0	0	0	0	1359.36
P_e/gallons	0.0043	0	0	0	0	5.88
I_{dm}		15.76	23.34	26.61	21.93	13.97
I_{dtot}	**101.61**					

BERKELEY
Wet Bed Crops

	8 sq ft	FEB	MAR	APR	MAY	JUN	JUL
PXH	Carrot	P	X	X	XH	H	H
D_m		30	30	30	30	30	30
D_g		20/10	20/10	20/10	30	30	30
K_C		0.45/0.75	0.75/1.05	1.05/0.9	0.9	0.9	0.9
K_{CM}		0.55	0.85	1	0.9	0.9	0.9
ET_o		3.23	3.67	4.15	4.65	4.95	5.16
ET_d (mm)		1.78	3.12	4.15	4.19	4.46	4.64
ET_d (inches)	0.04	0.07	0.12	0.16	0.16	0.18	0.18
ET_m	30	2.1	3.69	4.91	4.95	5.27	5.49
ET_m /cubic inches	1152	2419	4247.71	5650.91	5698.56	6066.21	6323.57
ET_m /gallons	0.0043	10.47	18.39	24.46	24.67	26.26	27.37
P		4.63	0.58	0.36	0.03	0	0
P_e		2.7	0.06	0	0	0	0
P_e/inches	1152	3110.4	69.12	0	0	0	0
P_e/gallons	0.0043	13.46	0.3	0	0	0	0
I_{dm}		0	18.09	24.46	24.67	26.26	27.37
I_{dtot}	**120.86**	0					

	12 sq ft	MAY	JUN	JUL	AUG	SEP	OCT
PXH	Pepper	P	X	X	X/H	H	H
D_m		30	30	30	30	30	30
D_g		15/15	20/10	30	30	30	30
K_C		0.35/0.7	0.7/1.05	1.05	0.9	0.9	0.9
K_{CM}		0.53	0.82	1.05	0.9	0.9	0.9
ET_o		4.65	4.95	5.16	4.96	4.49	3.87
ET_d (mm)		2.44	4.04	5.42	4.46	4.04	3.48
ET_d (inches)	0.04	0.1	0.16	0.21	0.18	0.16	0.14
ET_m	30	2.89	4.78	6.4	5.28	4.78	4.12
ET_m /cubic inches	1728	4986.24	8260.16	11066.24	9117.7	8253.73	7114.01
ET_m /gallons	0.0043	21.59	35.76	47.91	39.47	35.73	30.8
P		0.03	0	0	0	2.62	0.04
P_e		0	0	0	0	1.18	0
P_e/inches	1728	0	0	0	0	2039.04	0
P_e/gallons	0.0043	0	0	0	0	8.83	0
I_{dm}		21.59	35.76	47.91	39.47	26.9	30.8
I_{dtot}	**202.42**						

	12 sq ft	JUN	JUL	AUG	SEP
PXH	Beans	P	X	X	H
D_m		30	30	30	30
D_g		15/15	10|20	5|25	30
K_C		0.35/0.7	0.7/1.1	1.1/0.9	0.9
K_{CM}		0.53	0.97	0.93	0.9
ET_o		4.95	5.16	4.96	4.49
ET_d (mm)		2.6	5.01	4.61	4.04
ET_d (inches)	0.04	0.1	0.2	0.18	0.16
ET_m	30	3.07	5.92	5.45	4.78
ET_m /cubic inches	1728	5307.94	10223.1	9421.63	8253.73
ET_m /gallons	0.0043	22.98	44.26	40.79	35.73
P		0	0	0	2.62
P_e		0	0	0	1.18
P_e/inches	1728	0	0	0	2039.04
P_e/gallons	0.0043	0	0	0	8.83
I_{dm}		22.98	44.26	40.79	26.9
I_{dtot}	**134.92**				

BERKELEY
Wet Bed Crops

	12 sq ft	JAN	FEB	MAR	APR	MAY
PXH	Lettuce	P	X	X/H	X	H
D_m		30	30	30	30	30
D_g		15/15	15/15	30	30	30
K_C		0.45/0.6	0.6/1	0.9	0.9	0.9
K_{CM}		0.53	0.8	0.9	0.9	0.9
ET_o		2.81	3.23	3.67	4.15	4.65
ET_d (mm)		1.48	2.58	3.3	3.74	4.19
ET_d (inches)	0.04	0.06	0.1	0.13	0.15	0.16
ET_m	30	1.74	3.05	3.9	4.41	4.95
ET_m /cubic inches	1728	3013.19	5277.81	6746.36	7628.72	8547.85
ET_m /gallons	0.0043	13.04	22.85	29.21	33.02	37
P		4.69	4.63	0.58	0.36	0.03
P_e		2.78	2.7	0.06	0	0
P_e/inches	1728	4803.84	4665.6	103.68	0	0
P_e/gallons	0.0043	20.8	20.2	0.45	0	0
I_{dm}		0	2.65	28.76	33.02	37
I_{dtot}	**101.43**	0				

	8 sq ft	APR	MAY	JUN	JUL	AUG
PXH	Melon	P	X	X	H	H
D_m		30	30	30	30	30
D_g		15/15	20/10	30	30	30
K_C		0.45/0.75	0.75/1	1	0.75	0.75
K_{CM}		0.6	0.83	1	0.75	0.75
ET_o		4.15	4.65	4.95	5.16	4.96
ET_d (mm)		2.49	3.87	4.95	3.87	3.72
ET_d (inches)	0.04	0.1	0.15	0.2	0.15	0.15
ET_m	30	2.94	4.58	5.85	4.57	4.4
ET_m /cubic inches	1152	3390.54	5274.34	6740.24	5269.64	5065.39
ET_m /gallons	0.0043	14.68	22.83	29.18	22.81	21.93
P		0.36	0.03	0	0	0
P_e		0	0	0	0	0
P_e/inches	1152	0	0	0	0	0
P_e/gallons	0.0043	0	0	0	0	0
I_{dm}		14.68	22.83	29.18	22.81	21.93
I_{dtot}	**111.43**					

	12 sq ft	DEC	JAN	FEB	MAR	APR
PXH	Cabbage	P	X	X	X	H
D_m		30	30	30	30	30
D_g		15/15	10|20	30	10|20	30
K_C		0.45/0.75	0.75/1.05	1.05	1.05/0.9	0.9
K_{CM}		0.6	0.95	1.05	0.95	0.9
ET_o		2.61	2.81	3.23	3.67	4.15
ET_d (mm)		1.57	2.67	3.39	3.49	3.74
ET_d (inches)	0.04	0.06	0.11	0.13	0.14	0.15
ET_m	30	1.85	3.16	4.01	4.12	4.41
ET_m /cubic inches	1728	3198.55	5452.44	6927.13	7121.16	7628.72
ET_m /gallons	0.0043	13.85	23.6	29.99	30.83	33.02
P		1.54	4.69	4.63	0.58	0.36
P_e		0.52	2.78	2.7	0.06	0
P_e/inches	1728	898.56	4803.84	4665.6	103.68	0
P_e/gallons	0.0043	3.89	20.8	20.2	0.45	0
I_{dm}		9.96	2.81	9.79	30.38	33.02
I_{dtot}	**85.96**					

Table 9 Actual Irrigation Demand Per Bed: Berkeley and Sacramento

BERKELEY

Wet Bed Crops

Crop Irrigation Need: Gallons/Square Feet	SF	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
CABBAGE	12	0.23	0.82	2.53	2.75								0.83
PEPPER	12					1.8	2.98	4.00	3.29	2.24	2.57		
LETTUCE	12	0	0.22	2.4	2.75	3.08							
BEANS (GREEN)	12						1.92	3.69	4.00	2.24			
MELON	8				1.84	2.85	3.65	2.85	2.74				
CARROT	8		0	2.26	3.06	3.08	3.28	3.42					
Square Feet Irrigated		12	12, 12	40	40	40	40	40	40	40	12	0	12
Wet Bed Irrigation: Gallons/Month		2.8	12.5	101	122	123	146	160	160	90	30.8	0.0	10.0

Wet Bed Irrigation Total: Gallons/Year 958

Dry Bed Crops

Crop Irrigation Need: Gallons/Square Feet	SF	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
SPINACH	8	0.34	0.46	2.4							1.5	1.4	1.6
CUCUMBER	8					1.97	2.92	3.33	2.74	1.75			
EGGPLANT	8			1.52	2.45	3	2.74	2.85	2.74	1.75	2.14		
TOMATO	12					2.06	2.16	4.37	3.14	1.91	2.28		
SQUASH	12				1.76	2.74	3.01	2.85	2.74				
Square Feet Irrigated		8	8	40	40	40	40	40	40	40	8, 12	8	8
Dry Bed Irrigation: Gallons/Month		2.72	3.68	96	98	120	120	175	126	76.4	56.6	11.2	12.8

Dry Bed Irrigation Total: Gallons/Year 898

SACRAMENTO

Wet Bed Crops

Crop Irrigation Need: Gallons/Square Feet	SF	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
CABBAGE	8	0	1.04	2.57	2.92								0.8
MELON	8					2.3	3.55	4.64	3.27	2.44			
LETTUCE	12	0	0.69	2.44	2.92								0.67
BEANS (GREEN)	12						2.24	4.5	4.1	3			
PEPPER	12			1.4	2.65	4.04	3.83	4.17	3.93	3	2.7		
CARROT	8		0	2.3	3.24	3.46	3.83	4.17					
Square Feet Irrigated		0	8, 12	40	40	40	40	40	40	40	12	0	8, 12
Wet Bed Irrigation: Gallons/Month		0	16.6	103	130	162	153	186	164	120	32.4	0	14.4

Wet Bed Irrigation Total: Gallons/Year 1080

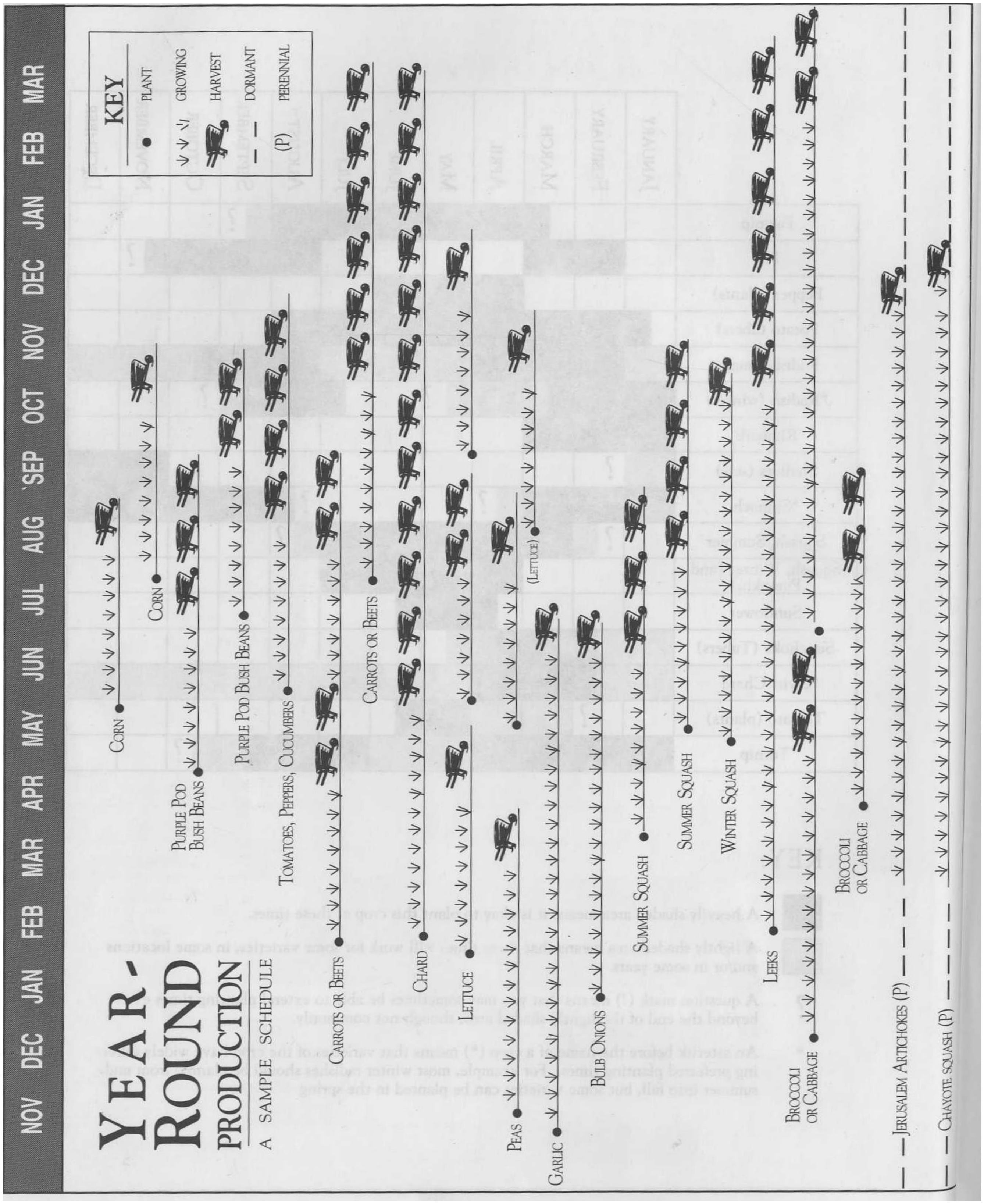
Dry Bed Crops

Crop Irrigation Need: Gallons/Square Feet	SF	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
SPINACH	8	0.07	0.69	2.44							1.57	1.3	0.25
CUCUMBER	8				1.86	3.08	3.73	3.45	3.27				
EGGPLANT	8			1.54	2.59	3.37	3.19	3.48	3.27	2.44	2.24		
TOMATO	12		0	2.22	3.73	3.31	3.41	3.71	3.49				
SQUASH	12				1.86	3.08	3.51	3.48	3.27				
Square Feet Irrigated		8	8	40	40	40	40	40	40	40	8, 8	8	8
Dry Bed Irrigation: Gallons/Month		0.56	5.52	97.6	149	135	149	148	140	97.6	30.5	10.4	2

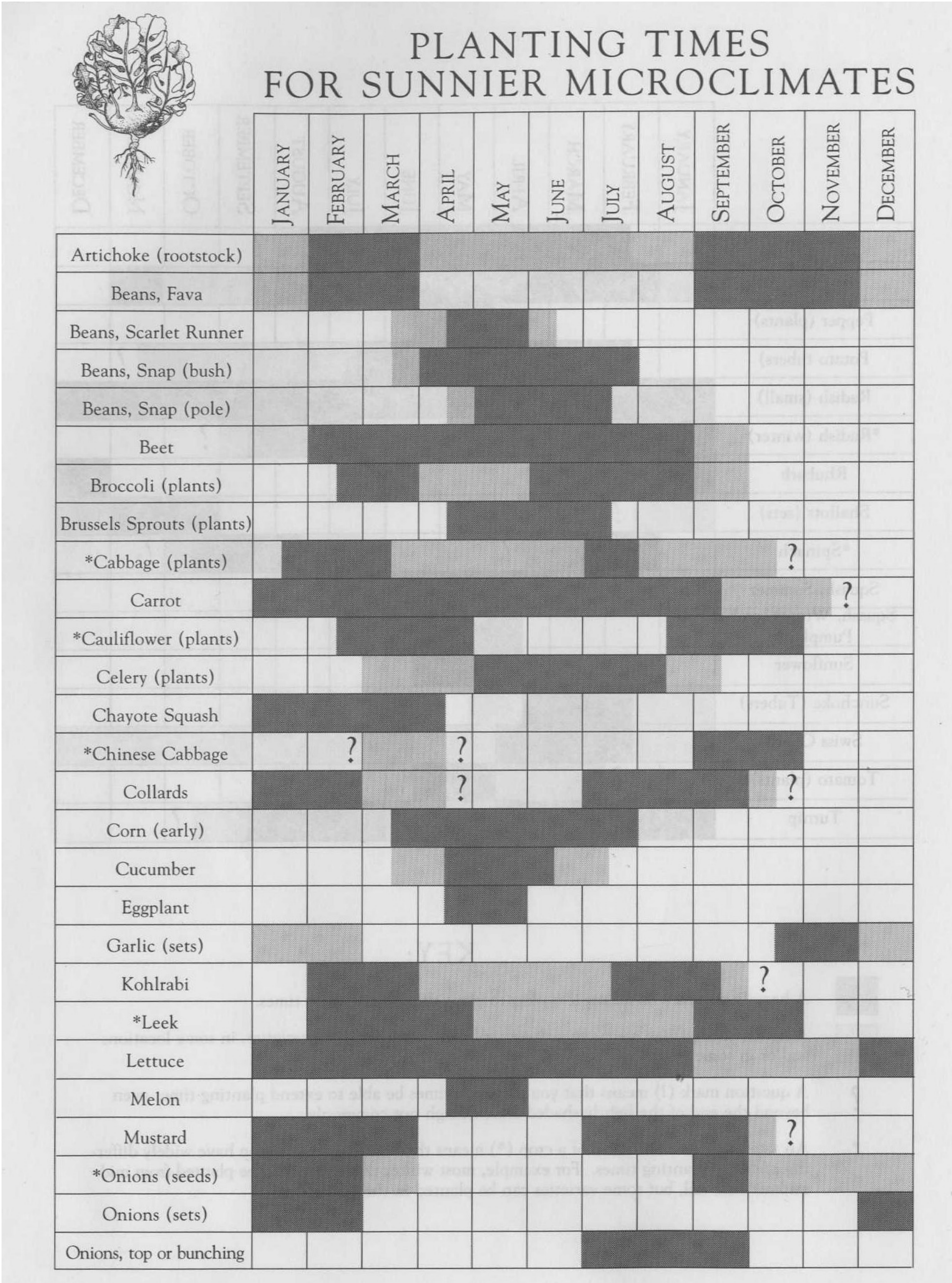
Dry Bed Irrigation Total: Gallons/Year 965

(shaded) Irrigation with Soaker Hose according to the most water-needy crop from March through September

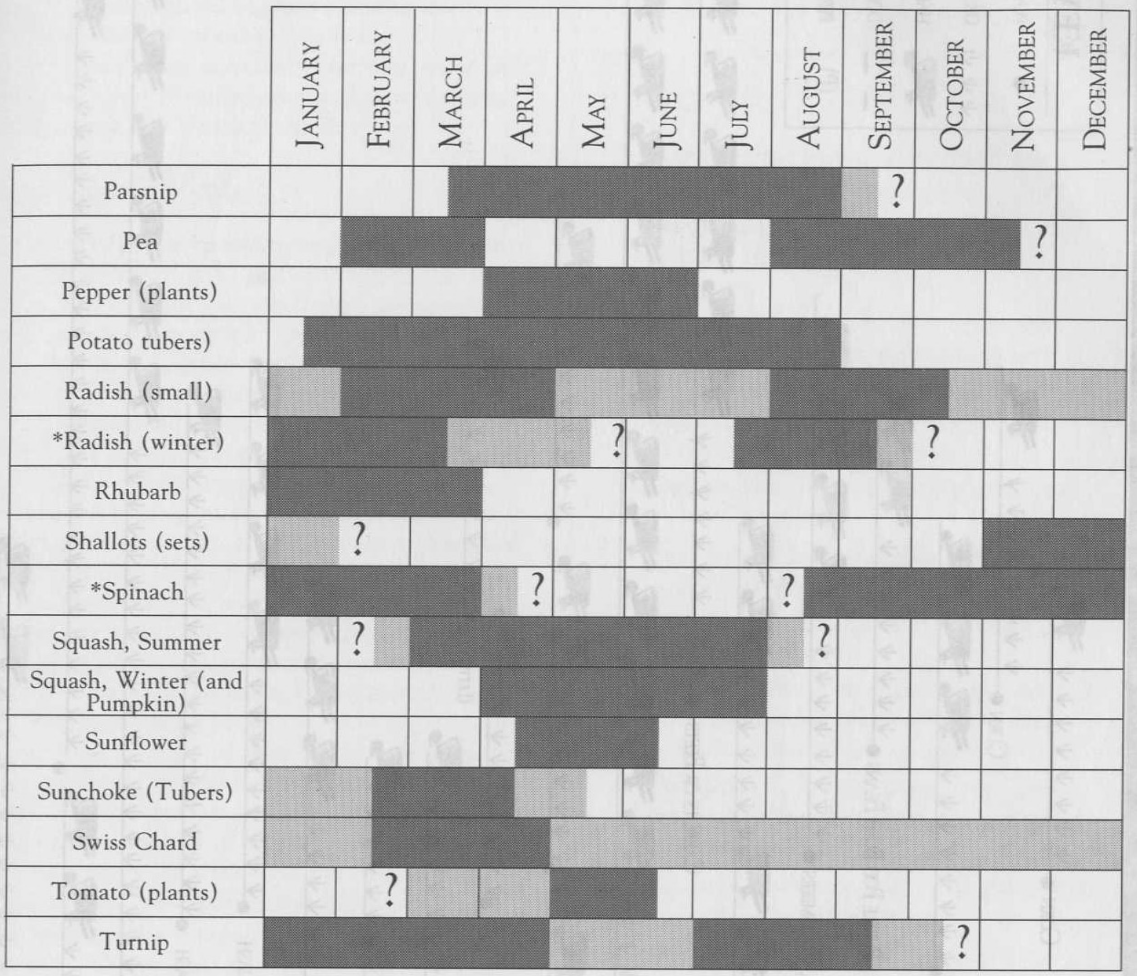
Appendix A Planting Guide from *Golden Gate Gardening*



Peirce, Pam. *Golden Gate Gardening: Year-Round Food Gardening in the San Francisco Bay Area and Coastal California.* Revised Edition. (Seattle, WA: Sasquatch Books, 2002).



Peirce, Pam. *Golden Gate Gardening: Year-Round Food Gardening in the San Francisco Bay Area and Coastal California.* Revised Edition. (Seattle, WA: Sasquatch Books, 2002).



KEY:

A heavily shaded area means it is okay to plant this crop at these times.

A lightly shaded area means that these times will work for some varieties, in some locations and/or in some years.

? A question mark (?) means that you may sometimes be able to extend planting times even beyond the end of the lightly shaded area, though not commonly.

* An asterisk before the name of a crop (*) means that varieties of the crop have widely differing preferred planting times. For example, most winter radishes should be planted from midsummer into fall, but some varieties can be planted in the spring.

Peirce, Pam. *Golden Gate Gardening: Year-Round Food Gardening in the San Francisco Bay Area and Coastal California.* Revised Edition. (Seattle, WA: Sasquatch Books, 2002).

Appendix B **Planting Guide from UC DavisVegetable Information and Research Center**

Vegetable Planting Guide

preferred time to seed in a greenhouse or other protected area (e.g. coldframe, well lit window)

preferred time to transplant

preferred time to direct seed

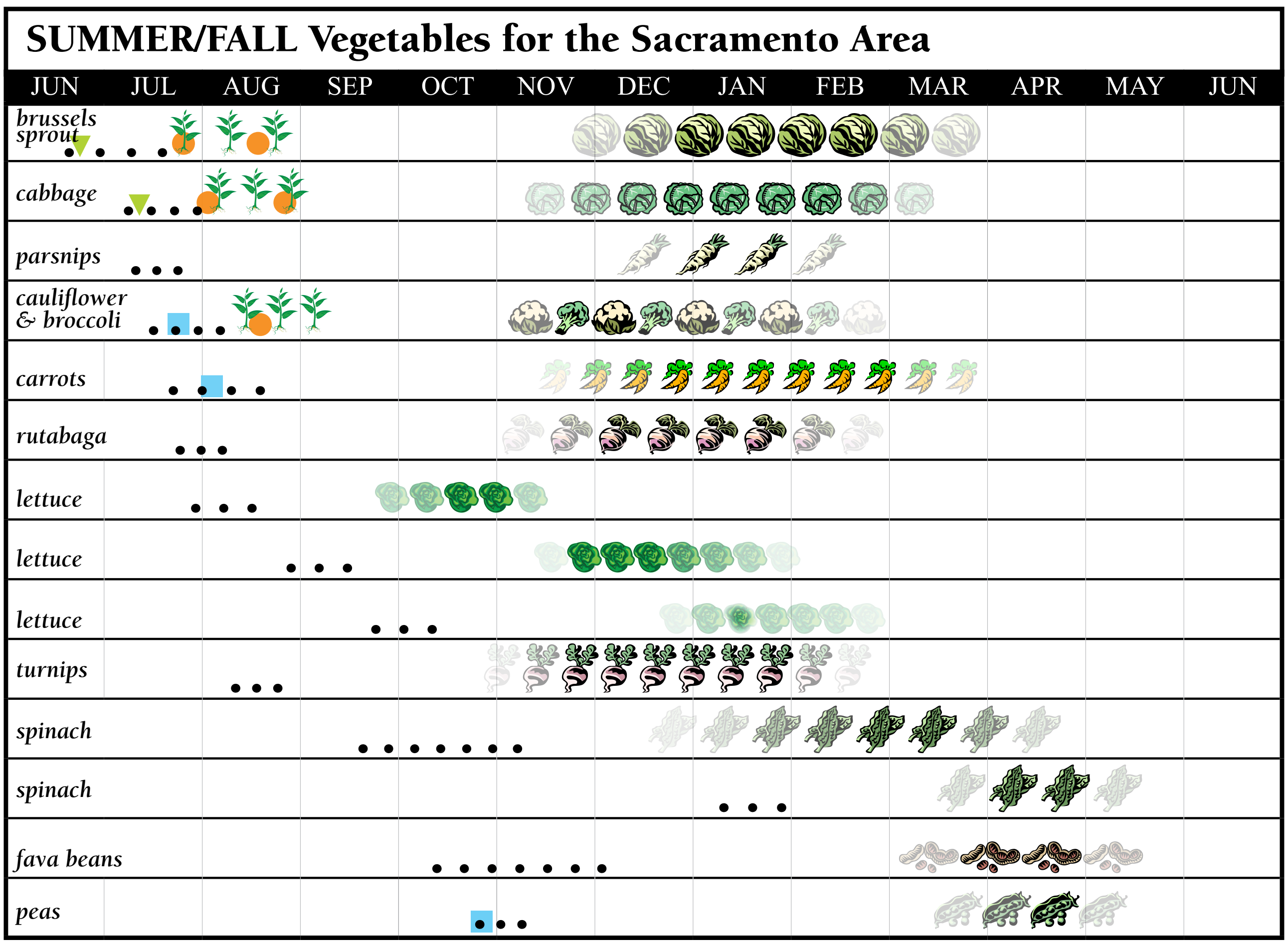
seeding

transplanting

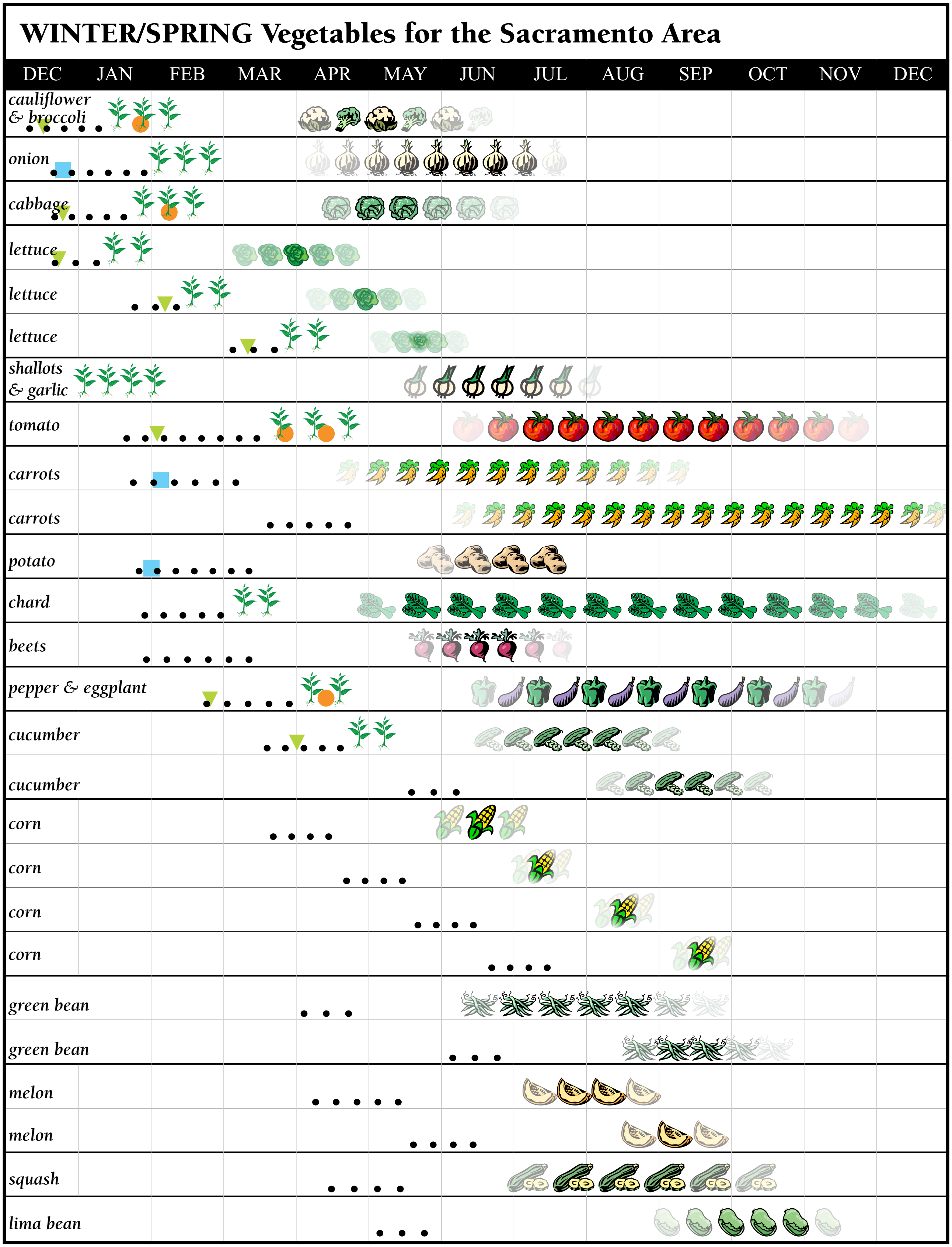
Seeding and transplanting dates may vary between varieties. Please check seed package or nursery for additional information.

Weather can modify planting and harvesting dates.

Information provided by Robert Norris, Department of Plant Sciences, 2008



Norris, Robert. Vegetable Planting Guide. ceyolo.ucdavis.edu/files/63483.pdf accessed May 19 2009.



Norris, Robert. Vegetable Planting Guide. ceyolo.ucdavis.edu/files/63483.pdf accessed May 19 2009.