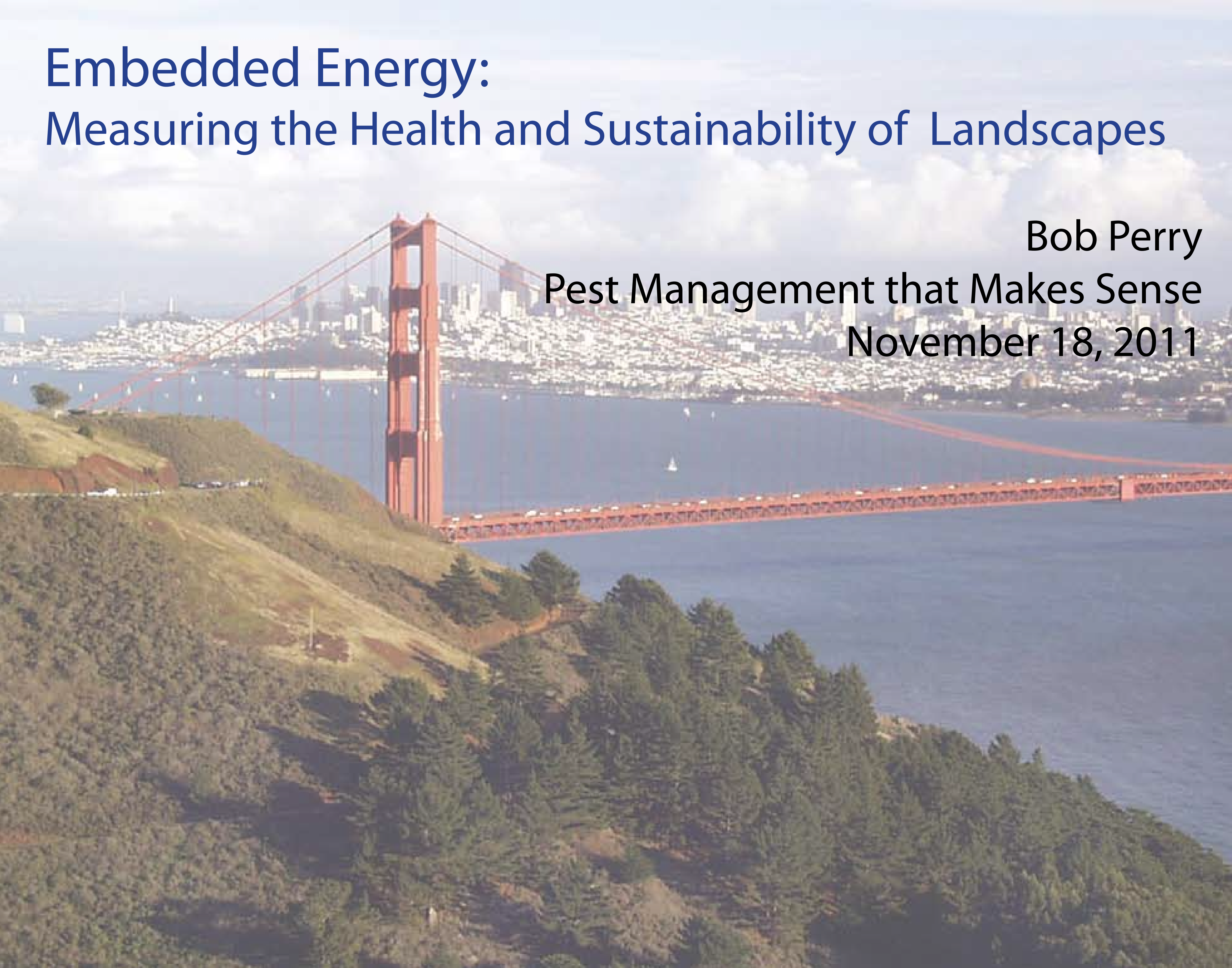
Embedded Energy:
Measuring the Health and Sustainability of Landscapes

Bob Perry
Pest Management that Makes Sense
November 18, 2011



Bay-Friendly Landscaping Practices

1. Landscape Locally
2. Landscape for less to the Landfill
3. Nurture the Soil
4. Conserve Water
5. **Conserve Energy**
6. Protect Water & Air Quality
7. Create Wildlife Habitat

The Strategy of Ecosystem Development

Eugene Odum, Science: 1969

Community Energetics	Early	Mature
1. Biomass supported/unit of energy flow	Low	High
2. Net Community Production	High	Low
3. Food Chains	Linear	Weblike

Community Structure	Early	Mature
1. Total Organic Matter	Small	Large
2. Species Diversity	Low	High
3. Biochemical Diversity	Low	High

Overall Homeostasis	Early	Mature
1. Entropy	High	Low
2. Information	Low	High

Highway 58 Natural Landscape

Highway 58 Natural Landscape

Plant Structure - Root, Stem and Leaf

Capable of indeterminate growth until limited by environmental conditions

Plant Physiology - Fourth Edition, Taiz and Zeigler

Leaves

Capture sunlight energy and CO_2 - Convert into biological energy.

Stems

Structural support of plant foliage; transport of moisture, nutrients and energy.

Roots

Obtain water and nutrients from soil, anchor and support plant stem and foliage

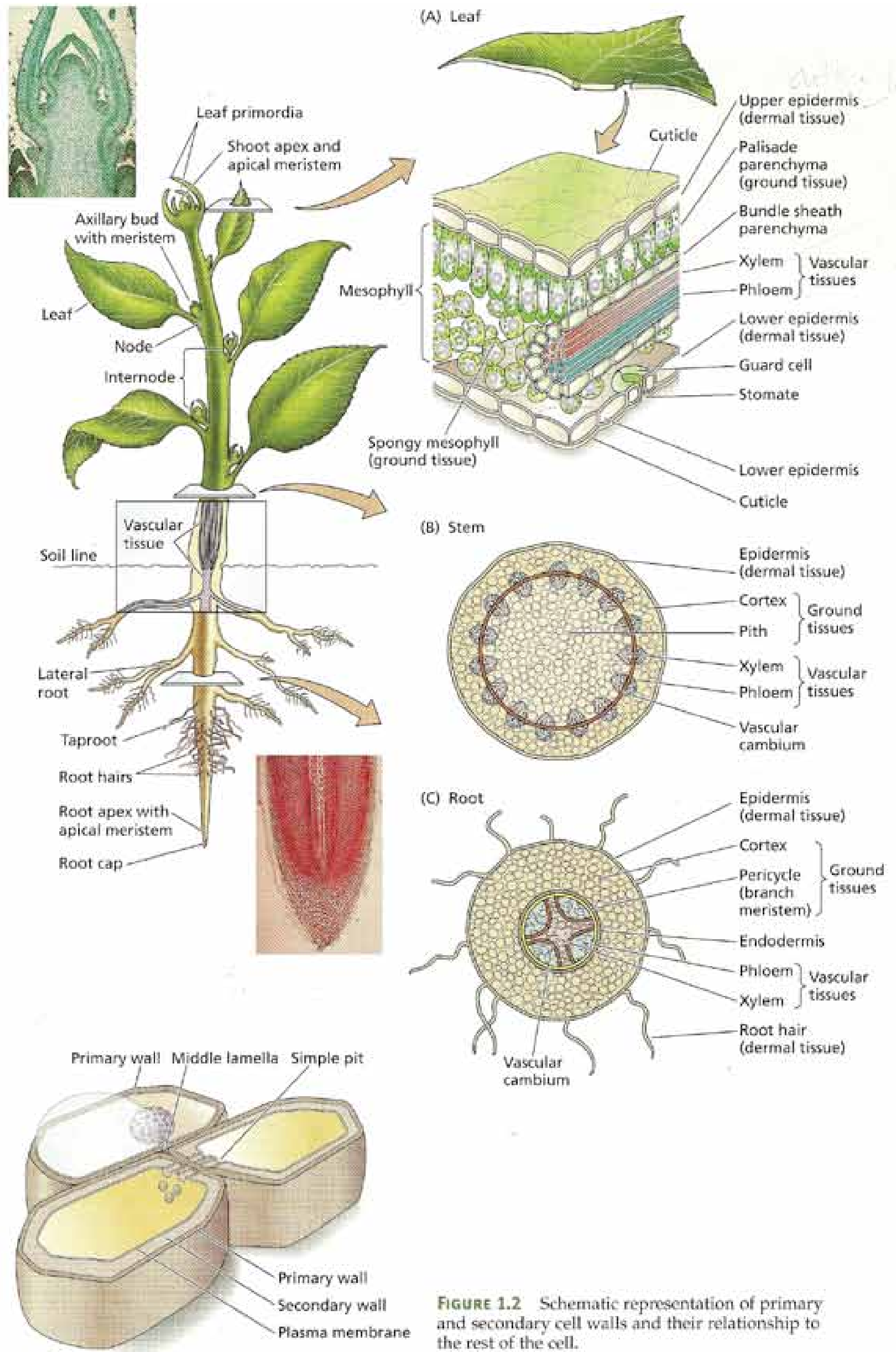


FIGURE 1.2 Schematic representation of primary and secondary cell walls and their relationship to the rest of the cell.

Environmental Factors and Conditions

Influences on Plant Growth and Adaptations

Conditions that create limitations to the growth and survival of plants

Physiography

Latitude/Longitude/Growing Season
Adjacent Land/Water Masses
Topography/Elevation/Slope/Aspect
Geology/Parent Material
Soils - Physical/Chemical/Organic

Hydrology

Surface/Subsurface Moisture

Atmosphere

Humidity/Aridity
Pollution
CO_2 Level

Climate

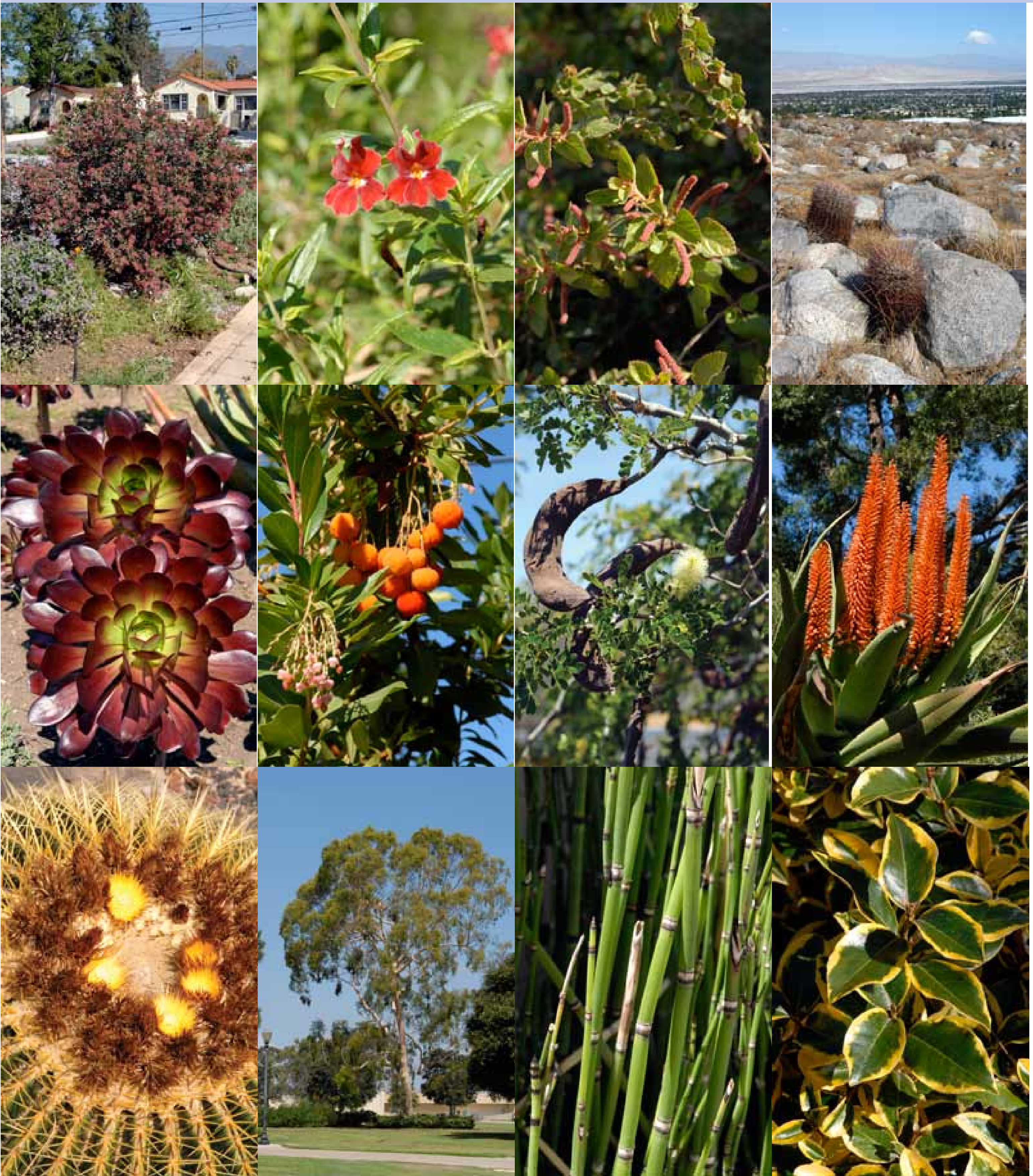
Temperature - Cold/Heat
Precipitation - Rain/Snow/Fog
Exposure - Sun/Shade
Humidity/Aridity
Wind

Catastrophic Events

Fire
Earthquake
Volcanoes
Floods
Hurricanes
Tornadoes

The Global Landscape

Estimated 400,000 Plant Species Worldwide



Non-Seed Plants

Algae	8,000-10,000
Mosses	22,000-24,000
Ferns	11,000-13,000

Seed Plants

Cycads	160
Ginkgo	1
Conifers (Gymnosperms)	630
Flowering Plants (Angiosperms)	
Monocots	60,000
Dicots	200,000

The California Landscape

Over 5,800 Species, Subspecies & Varieties: Over 2,100 Endemic Species

Life Sustaining Benefits of Plants

Energy capture Carbon sequestration, Oxygen production

Energy:

Each pound of Biomass contains approximately 7,650 BTU's of energy.

Carbon:

Each pound of Biomass contains approximately 1/2 pound of carbon (.45#).

Oxygen:

Approximately one pound (.9#) of oxygen is released into the atmosphere for each pound of biomass accrued.

Life Sustaining Benefits of Plants

Energy capture Carbon sequestration, Oxygen production

Each pound of biomass contains enough energy to sustain one person for approximately one day.

1,930 Calories of food energy

7,655 Btu's of heat energy

2.25 Kw hours of electrical energy

Costs Associated with Maintaining Landscapes

Energy Use for supplying water, mowing, fertilizing, vehicles

Energy to provide water:

- Importing water
- Pumping and Irrigation Energy

Energy for fertilizer:

- Manufacturer/Packaging
- Shipping/Applying

Energy for Pesticides and Herbicides:

- Manufacturer/Packaging
- Shipping/Applying

Energy for Gasoline/Diesel:

- Service Vehicles, Cranes, Chippers, Lawnmowers, Edgers, Blowers

Definition of Sustainability in Landscaping
Energy capture Carbon sequestration, Oxygen production

A sustainable landscape is achieved when the biological energy accrued by plants in their biomass is greater than the amount of fossil fuel energy consumed during the design, installation, manufacture of products, use of water, and maintenance that goes into the landscape.

Landscape Benefits: Biomass Accrual

A benefits to cost approach

Energy to Provide Water:

Source: NRDC Document, ENERGY DOWN THE DRAIN: The Hidden Costs of California's Water Supply

Approximately 32.25 Btu's of energry are needed to transport each gallon of water to Southern California from the State Water Project.

Annual Supplemental Water Needs for Different Hydrozones

Eto = 50" /year

Plant Factor	Inches	Gallons of Water/Year	Btu's of Energy/Year to Import Water
Very Low <10%	5"	135,036	4,354,911 Btus (569# Biomass)
Low 10-30%	5-15"	135,036-405,108	4,186,116-13,064,733 (569-1,707# Biomass)
Mod 40-60%	20"-30"	540,144 - 810,276	17,419,644-26,131,401 (2,276-3,414# Biomass)
High 70-90%	35"-45"	945,253 - 1,215,324	30,484,409-39,194,199 (3,982-5,120# Biomass)

Energy for Spray Irrigation at 60 PSI:

Approximately 9.2 Btu's of energy are needed for spray Irrigation

Energy to Provide Irrigation Water for Different Hydrozones

Plant Factor	Inches	Gallons of Water/Year	Btu's of Energy/Year to Import Water
Very Low <10%	5"	135,036	1,242,331 Btus (162# Biomass)
Low 10-30%	5-15"	135,036-405,108	1,242,331-3,726,994 (162-487# Biomass)
Mod 40-60%	20"-30"	540,144 - 810,276	4,969,325-7,454,539 (649-974# Biomass)
High 70-90%	35"-45"	945,253 - 1,215,324	8,696,328-11,180,981 (1,136-1,461# Biomass)

Energy for Drip Irrigation at 30 PSI:

Approximately 4.1 Btu's of energry are needed for spray Irrigation

Energy to Provide Irrigation Water for Different Hydrozones

Plant Factor	Inches	Gallons of Water/Year	Btu's of Energy/Year to Import Water
Very Low <10%	5"	135,036	621,166 Btus (81# Biomass)
Low 10-30%	5-15"	135,036-405,108	61,166-1,863,497 (81-144# Biomass)
Mod 40-60%	20"-30"	540,144 - 810,276	4,969,325-7,454,539 (325-487# Biomass)
High 70-90%	35"-45"	945,253 - 1,215,324	4,348,164-5,590,491 (568-731# Biomass)

Fertilizer and Pesticide Use:

Source: University of California Sustainable Agriculture Research and Education Program

Sustainable Agriculture
University of California
Sustainable Agriculture Research and Education Program

Embodied energy per pound of Macronutrient:

	Manufacture	Package	Transport	Apply	Total:
Nitrogen:	29,899 Btu's	1,110 Btu's	1,936 Btu's	688 Btu's	33,642 Btu's
Phosphate:	3,313 Btu's	1,110 Btu's	2,452 Btu's	645 Btu's	7,529 Btu's
Potash:	2,573 Btu's	774 Btu's	1,979 Btu's	430 Btu's	5,936 Btu's

Application of Nitrogen varies 2-4# per year for turf species

2# Nitrogen per 1,000 s.f. = 87#/Acre/Year = 2,930,890 Btu's = 383# Biomass
4# Nitrogen per 1,000 s.f. =174# Acre/Year = 5,861,780 Btu's = 766# Biomass

Energy Embodied in Fossil Fuels:

Operational Energy of Fossil Fuel:

Gasoline:

1 gallon of gasoline contains 124,000 Btu's of energy x 52 = 6,448,000 = 842# Biomass

Diesel

1 gallon of diesel contains 140,000 Btu's of energy x 52 = 7,280,000 = 951# Biomass

Blaisdale Community Park:

Claremont, California.   AB 1881 Compliant: 50% Turf Grass - 50% Sage Scrub/Mediterranean

Blaisdale Community Park:

Tall Fescue Turfgrass = 10,890# Standing Biomass

Blaisdale Community Park:

Sage Scrub/Mediterranean Perimeter Planting w/Organic Mulch = 12,650# Standing Biomass

Blaisdale Community Park:

Sage Scrub Energy Assessment

1 Acre of Sage Scrub

Biomass after 10 years Growth:

Shrubs: 12,650#

12,650# x 7,655 Btu's = 96,835,750 Btu's

Energy Costs per Year:

Import Water:	5"/year =	4,353,911 Btu's
Apply Water:	5"/year =	553,648 Btu's
Fertilizer:	0/year =	0 Btu's
Mowing:	0/year =	0 Btu's
Vehicles:	10 gal/year =	1,250,000 Btu's
		6,157,559 Btu's

After 15.7 Years of maintenance - costs exceed landscape benefits

(96,835,750/6,157,559 = 15.7 Years)

Blaisdale Community Park:

Sage Scrub Perimeter Planting w/Organic Mulch

1 Acre of Tall Fescue Turf Grass

Biomass after 10 years Growth:

Turf grass biomass value: 10,890#/Acre

10,890# x 7,655 Btu's = 83,362,950 Btu's

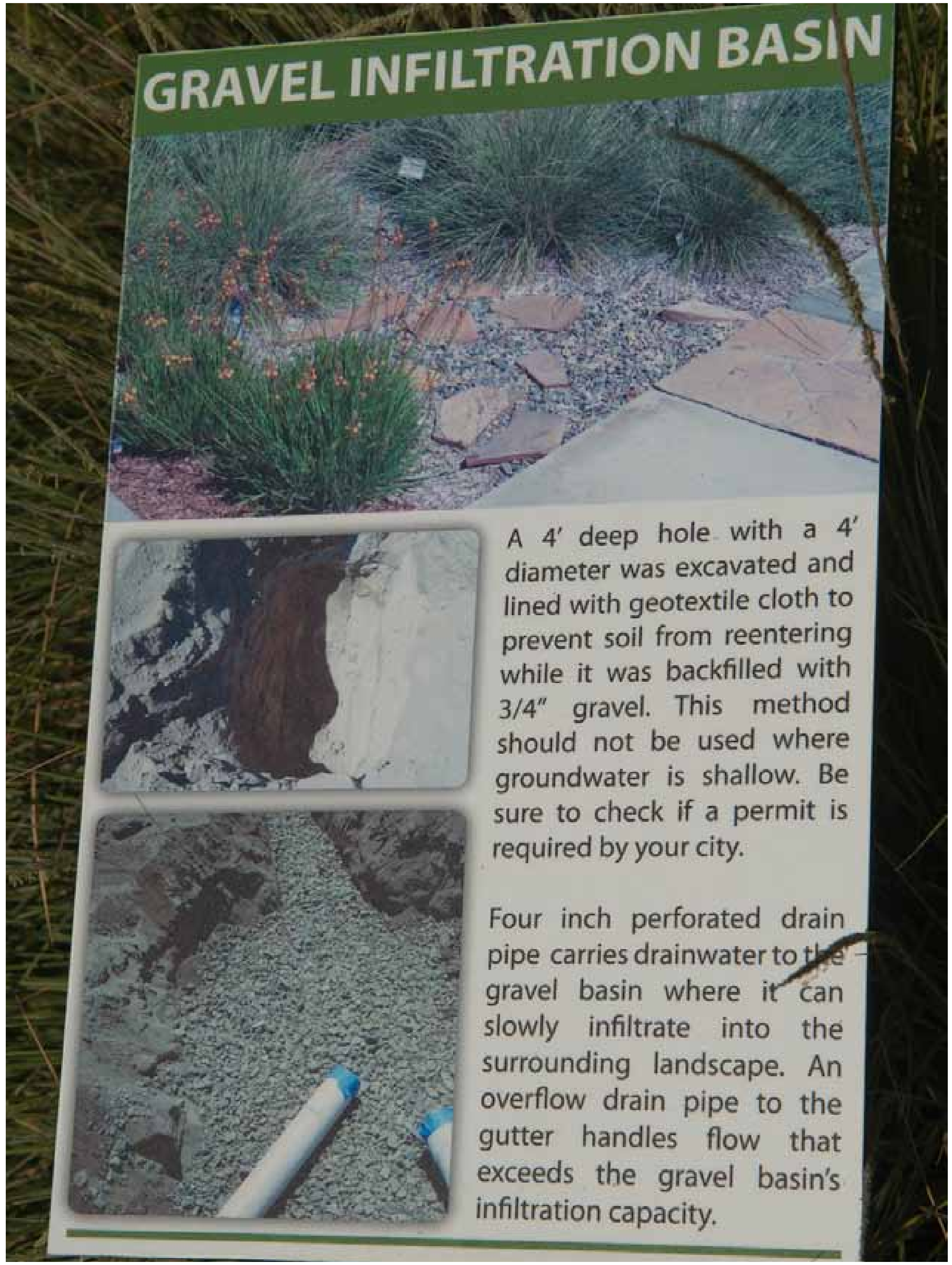
Energy Costs per Year:

Import Water:	42"/year =	36,581,240 Btu's
Irrigation:	42"/year =	10,435,582 Btu's
Fertilizer:	2x/year =	2,930,890 Btu's
Mowing:	20 gal/year =	2,480,000 Btu's
Vehicles:	25 gal/year =	3,500,000 Btu's
		55,927,712 Btu's

After 1.5 Years of maintenance - costs exceed turfgrass benefits

(83,362,950/55,927,712 = 1.5 years)

Rainfall Capture and Infiltration:
University of California Cooperative Extension Demonstration Garden, Irvine

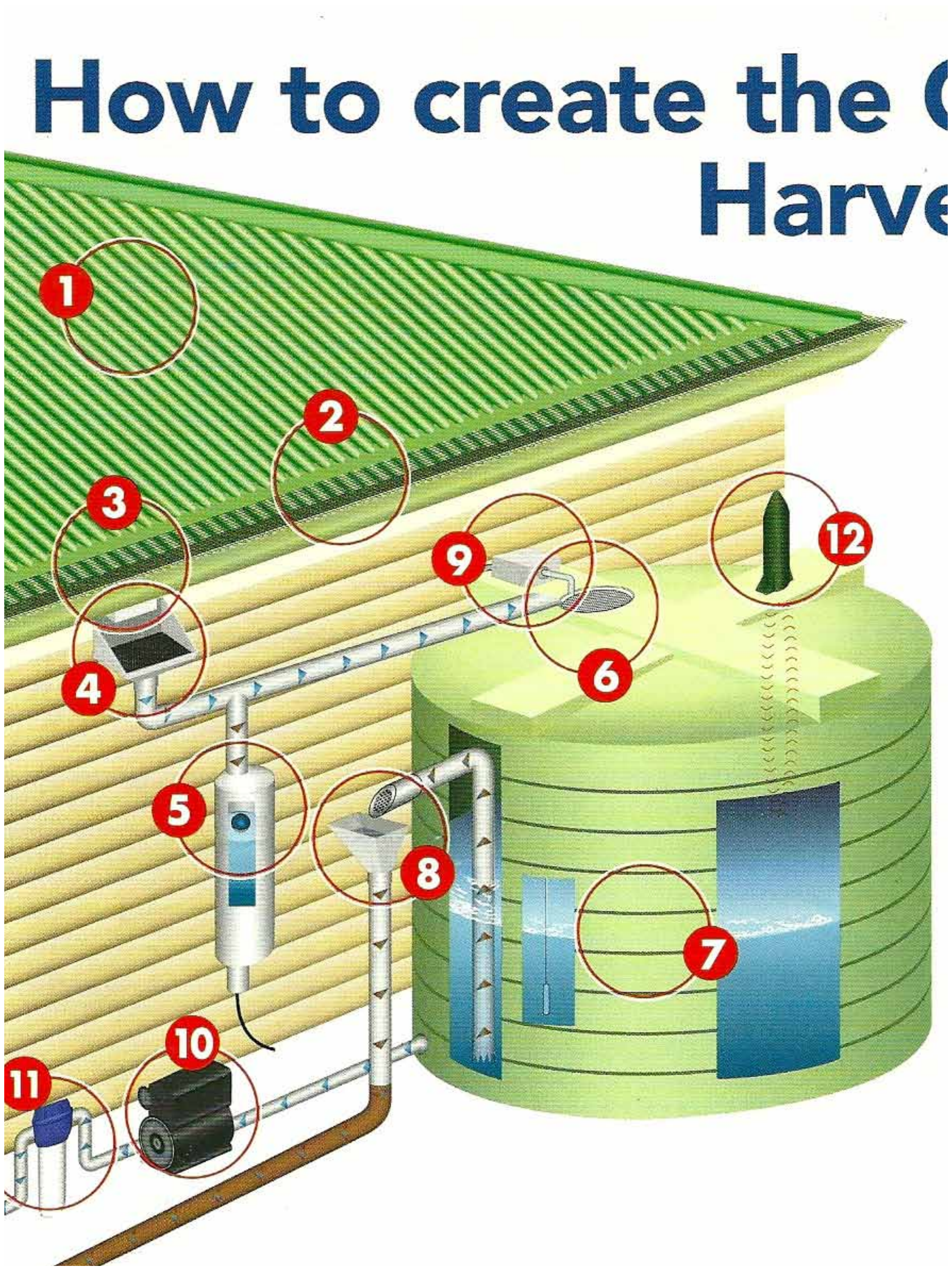


Rainfall Capture and Infiltration:

University of California Cooperative Extension Demonstration Garden, Irvine

Stormwater Capture and Infiltration:

Embodied Energy evaluation of 5,000 Gallon Rain Barrel



One Pound of Polyethylene embodies 48,500 Btu's of Energy

A 5,000 Gallon tank weighs 805#

A 5,000 Gallon tank embodies 38,930,000 Btus of energy.

Pumping water at 32.25 Btu's per gallon to fill this tank once each year (5,000 gallons) will take 249 years to equal the embodied energy in this tank.

Plant Palette

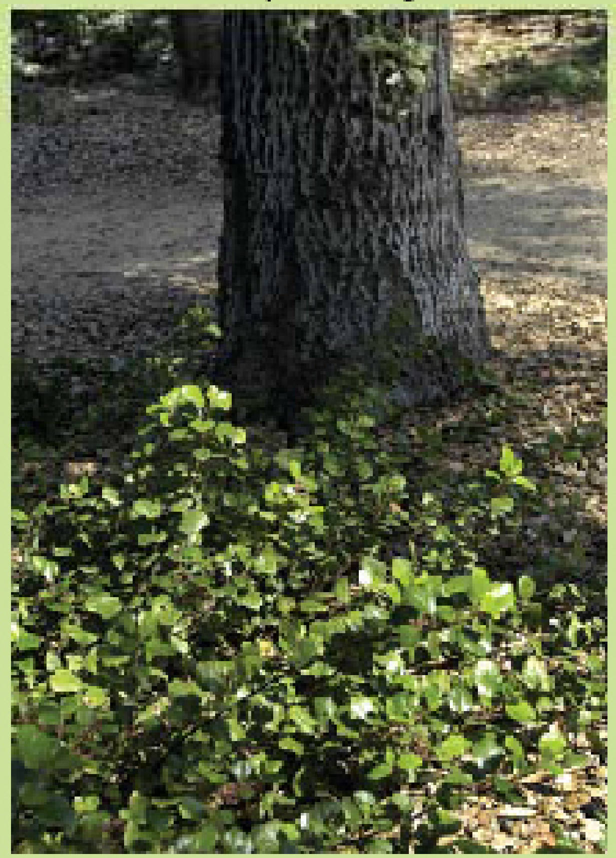
Coast Live Oak

The coast live oak is a widely recognized and valued native tree that can be found growing in large numbers from north to south throughout California's coastal ranges. In recent years, cities and counties have established ordinances to prevent the widespread loss of native oaks due to urban development. This palette is designed to work with existing coast live oaks that occur in developed areas and when additional landscape plantings are needed. Some plants are adapted to understory conditions within the dripline where they grow with limited summer water and adapt to shade. Others are best suited for perimeter locations. Many of these plants naturally occur in association with coast live oaks.

While there are many plant types that grow well around established oaks, new planting should always be approached with care. In many instances planting within the canopy is not recommended in order to avoid disturbance to roots and the introduction of supplemental water during summer months. This zone can be covered with fallen oak leaves and be left alone. Perimeter plantings outside the dripline can often provide a good balance of design character around existing trees to reduce the need for understory plants. When new plants are placed within the dripline they should be adapted to low amounts of summer water and be placed in areas of sun and shade according to their adaptation.

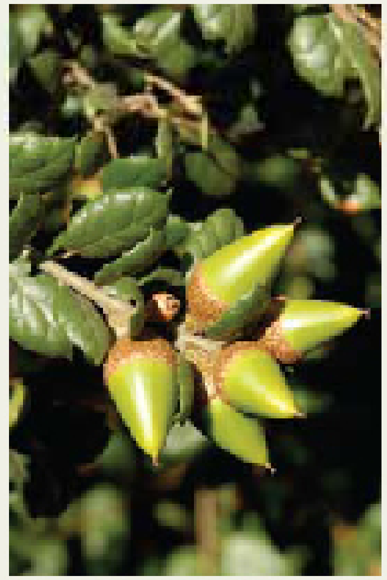
Again, this palette addresses existing coast live oaks and compatible native species. The Oak Palette on pages 136-137 presents other combinations of oak trees and associated plants.

Below: ***Ribes viburnifolium*** is one of the best understory ground covers for use inside the dripline of existing coast live oak.



Above: A mature coast live oak grouping growing without understory plants or supplemental irrigation within their canopies. These trees have been preserved in place without attempting to landscape around them.

Shrubs and Ground Covers		PF	IG
Arctostaphylos edmundsii	Little Sur Manzanita	M/L	2
Arctostaphylos edmundsii 'Carmel Sur'	Carmel Sur Manzanita	M/L	2
Arctostaphylos 'John Dourley'	John Dourley Manzanita	M/L	2
Arctostaphylos hookeri	Monterey Manzanita	M/L	2
Arctostaphylos hookeri 'Monterey Carpet'	Monterey Carpet Manzanita	M/L	2
Arctostaphylos 'Howard McMinn'	McMinn Manzanita	M/L	2
Arctostaphylos 'Lester Roundtree'	Lester Roundtree Manzanita	M/L	2
Berberis 'Golden Abundance'	Golden Abundance Barberry	M/L	2
Berberis repens	Creeping Barberry	M/L	2
Arctostaphylos 'Pacific Mist'	Pacific Mist Manzanita	M/L	2
Arctostaphylos uva-ursi 'Point Reyes'	Point Reyes Manzanita	M/L	2
Arctostaphylos uva-ursi 'Green Supreme'	Green Supreme Manzanita	M/L	2
Baccharis pilularis 'Pigeon Point'	Prostrate Coyote Brush	M/L	2
Berberis repens	Creeping Barberry	M/L	2
Ceanothus 'Concha'	Concha Ceanothus	M/L	2
Ceanothus 'Dark Star'	Dark Star Ceanothus	M/L	2
Ceanothus 'Ray Hartman'	Ray Hartman Ceanothus	M/L	2
Ceanothus 'Wheeler Canyon'	Wheeler Canyon Ceanothus	M/L	2
Carpenteria californica + cv	Bush Anemone	M/L	2
Comarostaphylis diversifolia	Summer Holly	M/L	2



Above: ***Quercus agrifolia*** acorns

Management Practices

Often the best management practice for existing oaks is to leave the understory area within their dripline undisturbed. Altering the natural soil level and adding new plantings that need supplemental irrigation during summer months can pose significant threats to a tree's health. Fallen leaf litter can be used as a surface mulch, seasonal rains can provide the best balance of moisture and for nutrient exchange with reduced risk from harmful fungus and diseases. Grading and compaction should not occur within the dripline.

Below: ***Ribes viburnifolium***

Above: *Rhamnus californica*

Grading Practices

Changing drainage patterns or existing grades near mature oaks, particularly within the canopy area where roots obtain essential nutrients and moisture, is not advised. Additionally, avoid soil compaction during construction. Decomposed granite and pea gravel are recommended for walkways. Permeable pavements and raised decks are encouraged for larger areas. Avoid trenching for drainage, irrigation lines or lighting conduits throughout the dripline of trees. Roots over 2 in. in dia. should not be cut and surface feeder roots should be protected.

Shrubs and Ground Covers continued		PF	IG
Ceanothus t. griseus 'Hurricane Point'	Carmel Creeper	M/L	2
Ceanothus t. griseus 'Yankee Point'	Carmel Creeper	M/L	2
Eriogonum arborescens	Santa Cruz Island Buckwheat	L/VL	2
Eriogonum cinereum	Ashyleaf Buckwheat	L/VL	2
Eriogonum fasciculatum + cvs	California Buckwheat	L/VL	2
Eriogonum giganteum	St. Catherine's Lace	L/VL	2
Galvezia juncea + cv	Baja Bush Snapdragon	L/VL	2
Galvezia speciosa + cv	Island Bush-Snapdragon	M/L	2
Garrya elliptica + cvs	Coast Silktassel	M/L	2
Keckiella cordifolia	Heartleaf Penstemon	M/L	2
Ribes speciosum	Fuchsia-flowered Gooseberry	M/L	2
Ribes viburnifolium	Evergreen Currant	M/L	2
Rosa californica	California Rose	M/L	2
Heteromeles arbutifolia + cvs	Toyon	M/L	2
Iva hayesiana	Poverty Weed	M/L	2
Philadelphus lewisii + cv	Western Mock Orange	M/L	2
Prunus ilicifolia ssp. ilicifolia	Hollyleaf Cherry	M/L	2
Rhamnus californica + cvs	California Coffeeberry	M/L	2
Rhus ovata	Sugar Bush	L/VL	2
Salvia 'Allen Chickering'	Allen Chickering Sage	L/VL	2
Salvia apiana	White Sage	L/VL	2
Salvia brandegei	Santa Rosa Island Sage	L/VL	2
Salvia clevelandii + cvs	Cleveland Sage	L/VL	2
Salvia 'Bee's Bliss'	Bee's Bliss Sage	L/VL	2
Salvia leucophylla 'Point Sal Spreader'	Point Sal Spreader Sage	L/VL	2
Salvia 'Mrs. Beard'	Mrs. Beard Sage	L/VL	2
Salvia sonomensis	Creeping Sage	L/VL	2
Trichostema lanatum	Woolly Blue Curls	M/L	2
Verbena lilacina 'De La Mina'	Lilac Verbena	M/L	2

Perennials		PF	IG
Lupinus excubitus	Grape Soda Lupine	L/VL	2
Mimulus aurantiacus + cvs	Sticky Monkey Flower	L/VL	2
Penstemon eatonii	Firecracker Penstemon	L/VL	2
Penstemon heterophyllus + cv	Foothill Penstemon	L/VL	2
Penstemon spectabilis	Showy Penstemon	L/VL	2
Romneya coulteri + cv	Matilija Poppy	L/VL	2
Salvia sonomensis	Creeping Sage	L/VL	2
Salvia spathacea	Hummingbird Sage	L/VL	2
Sisyrinchium bellum	Blue-eyed Grass	M/L	2

Below: *Carpenteria californica*

Below: *Ceanothus* 'Concha'

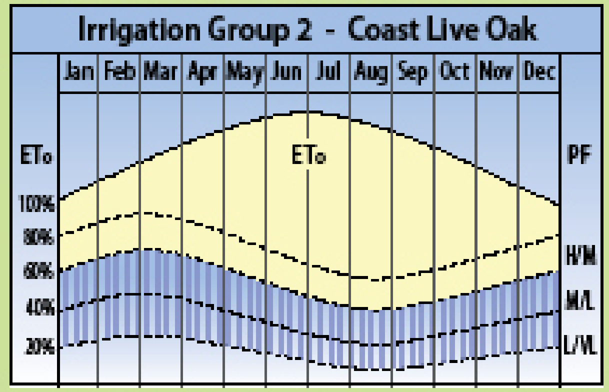
Below: *Berberis* 'Golden Abundance"

Plant Palette
Coast Live Oak

Seasonal Moisture and Irrigation Schedules

Existing oaks have often grown and adapted to climate and soil conditions of their site without the influence of supplemental irrigation. However, when development occurs, historic moisture patterns above and below ground are likely to change. Additionally, there is often a desire to add new plantings within the understory and surrounding area of these trees. This palette contains native plants with two sets of plant factors; moderate to low, and low to very low. Plants in each set should be organized into separate hydrozones with dedicated irrigation systems.

Supplemental watering should be scheduled mostly for fall and winter months with the goal of subsidizing the natural rainfall season during dry spells and drought cycles. Spring and summer irrigation should be minimal; mostly in support of newer ground cover and shrub plantings until they are established. A baseline irrigation schedule is shown below that illustrates seasonal irrigation around existing oaks.



Below: *Vinca major*, a member of Irrigation Group 1 is planted within the dripline of established coast live oaks, resulting in conflicting water requirements.

Arlington Park, Pasadena

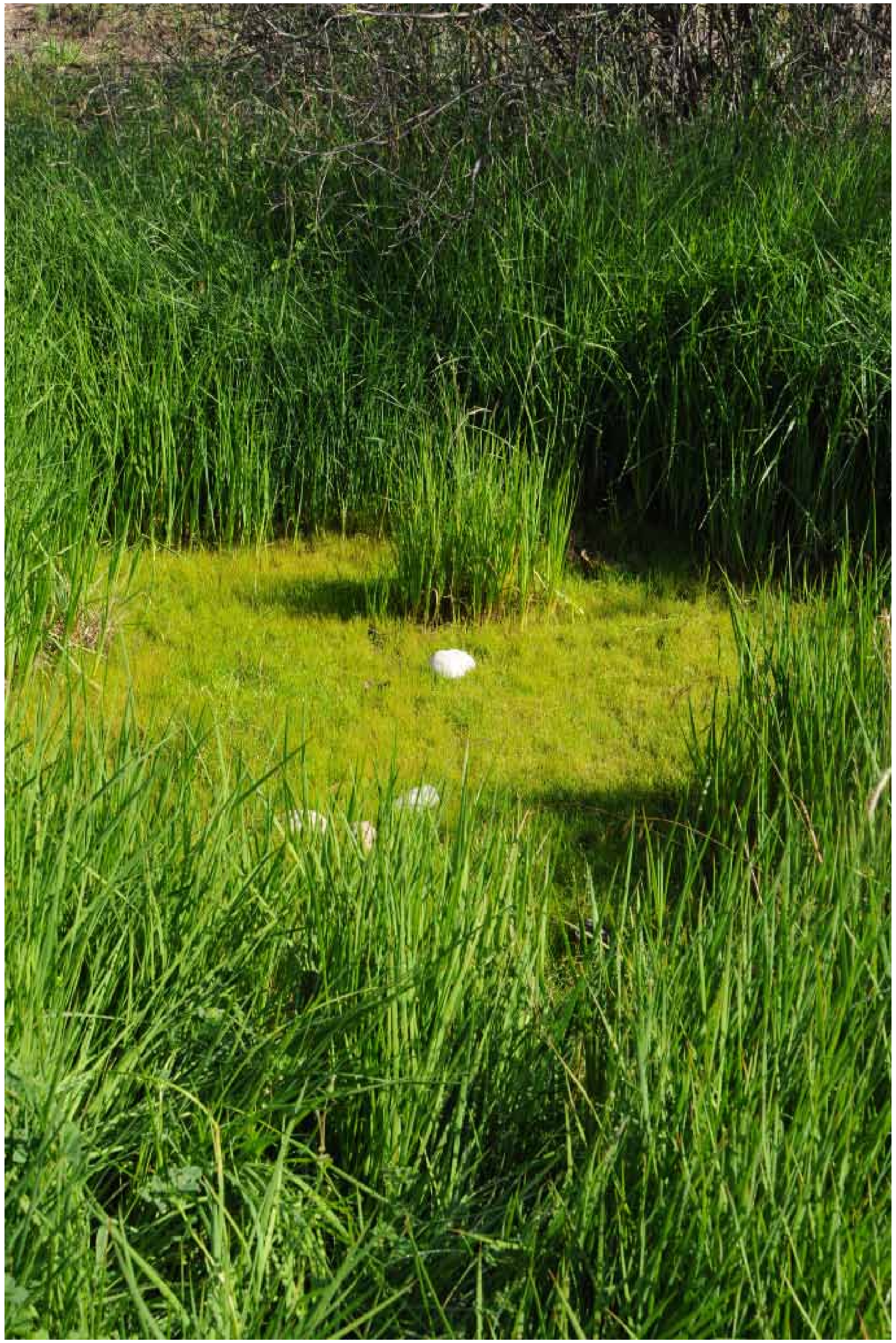
Native Plant Species - Field Lupine, Coast Live Oak

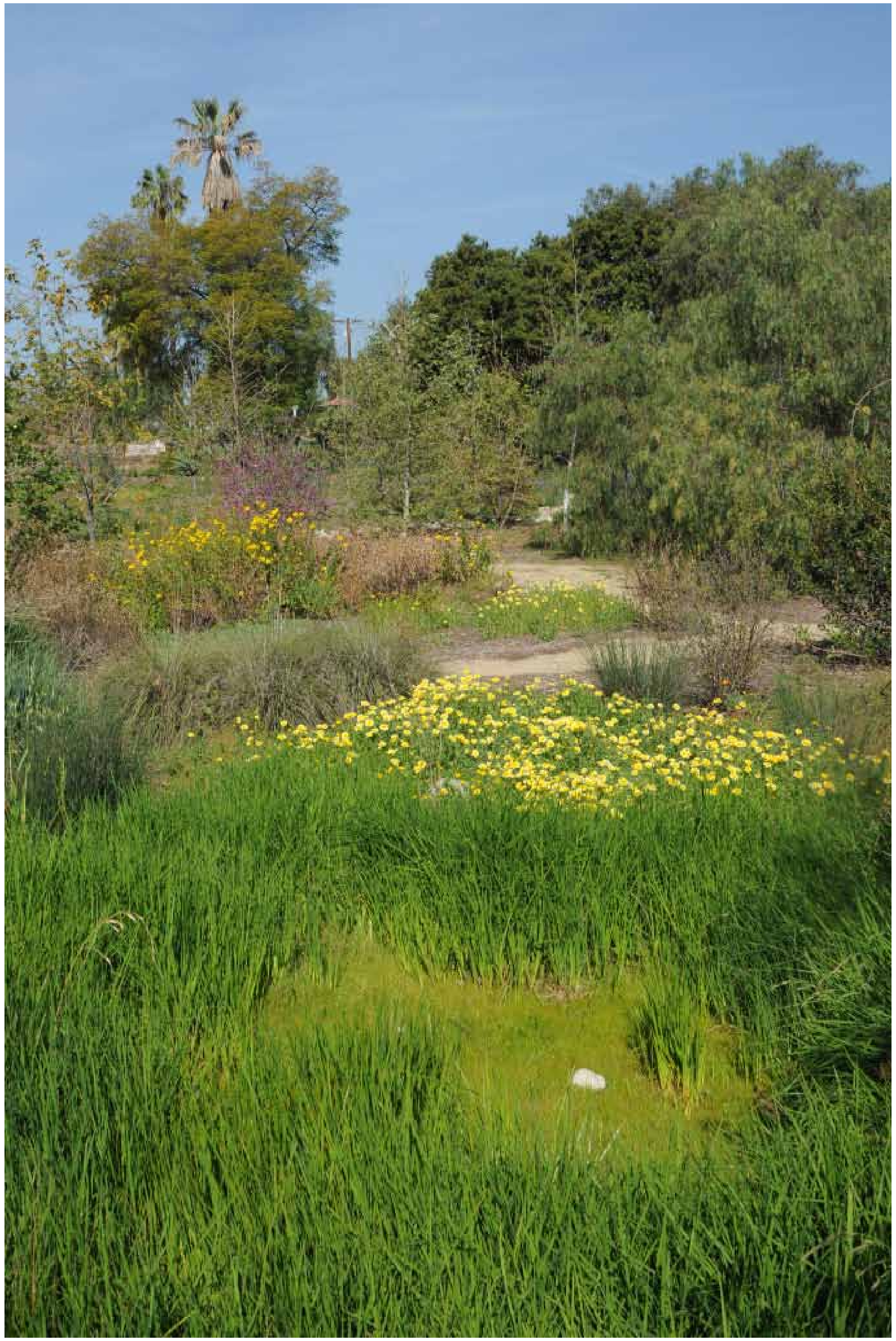
Arlington Park, Pasadena

Native Plant Species - Field Lupine, Coast Live Oak

Arlington Park, Pasadena

Bioswale/Vernal Pool - On site retention and infiltration of water





Arlington Park, Pasadena

Historical, Cultural - Reinvention and Renewal

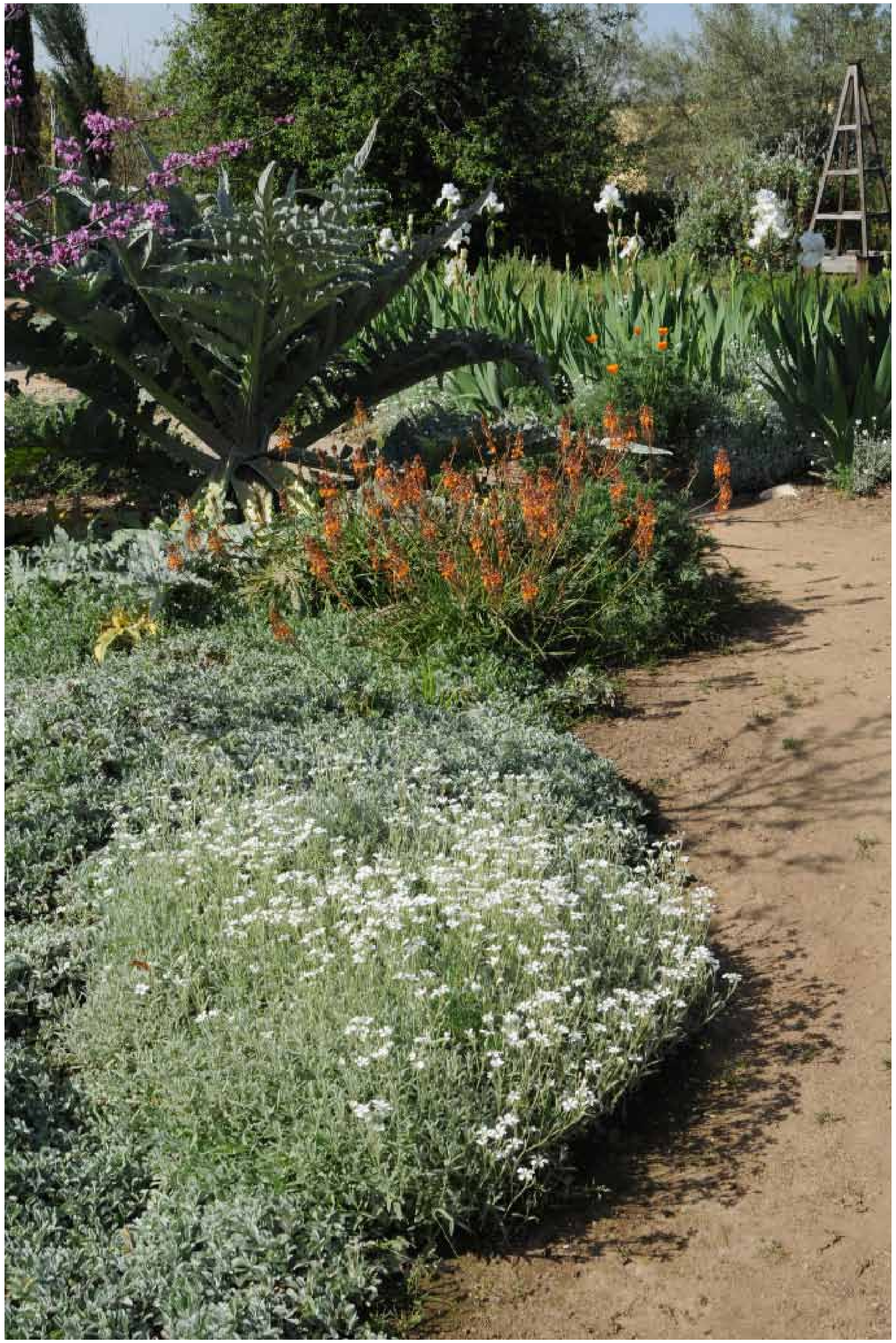
Arlington Park, Pasadena

Historical, Cultural - Native & Exotic

Arlington Park, Pasadena
Historical, Cultural - Native & Exotic

Arlington Park, Pasadena

Exotic Plant Species - Edible, Horticultural



Arlington Park, Pasadena

Exotic Plant Species - Mediterranean

Arlington Park, Pasadena

Beneficial Reptiles and Insects

Arlington Park, Pasadena

Historical, Cultural - Native & Exotic

Embedded Energy:
Measuring the Health and Sustainability of Landscapes

A sustainable landscape is achieved when the biological energy accrued by plants in their biomass is greater than the amount of fossil fuel energy consumed during the design, installation, manufacture of products, use of water, and maintenance that goes into the landscape.