1991

Mitigation of summer urban heat islands in Mediterranean climate zones through development of urban forests in parking lots

Karl Schiavo
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lots**

Schiavo, Karl John, M.S.

San Jose State University, 1991

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**MITIGATION OF SUMMER URBAN HEAT ISLANDS
IN MEDITERRANEAN CLIMATE ZONES
THROUGH DEVELOPMENT OF URBAN FORESTS IN PARKING LOTS**

**A Thesis
Presented to
The Faculty of the Department of
Geography and Environmental Studies
San Jose State University**

**In Partial Fulfillment
of the Requirements for the Degree
Master of Science**

**by
Karl Schiavo
December, 1991**

APPROVED FOR THE DEPARTMENT OF
GEOGRAPHY AND ENVIRONMENTAL STUDIES

Handwritten signature of Wanna D. Pitts in black ink, written over a horizontal line.

Wanna D. Pitts, Committee Chairperson,
Professor of Biology

Handwritten signature of Richard Ellefsen in black ink, written over a horizontal line.

Richard Ellefsen
Professor of Geography

Handwritten signature of Mark Beaudoin in black ink, written over a horizontal line.

Mark Beaudoin
San Jose City Arborist

APPROVED FOR THE UNIVERSITY

Handwritten signature of M. Lou Lewandowski in black ink, written over a horizontal line.

ABSTRACT

Parking lots comprise roughly 10% of the urban land area. The materials used in their construction absorb solar energy. This sensible heat is reradiated into the surrounding air and ground long after the sun has set. This heat is a major component of the Summer Urban Heat Island (SUHI). Trees are efficient and inexpensive absorbers of solar radiation and can be employed in parking lots to cool them and thereby reduce city temperatures. Only trees that are capable of withstanding heat, aridity, drought, and air pollution should be considered for this purpose. Properly sized planting wells filled with prepared soil mixes are also necessary to ensure vigorous growth of root systems. The mitigation of heat by the tree canopy not only improves the growing conditions for the trees, but also reduces the heat contribution of parking lots to the SUHI.

This thesis addresses the conditions for the viability of trees grown within parking lots. Suggestions are offered for designers, planners, and those who create ordinances pertaining to parking lots, specifically regarding tree canopy coverage and planting well designs.

TABLE OF CONTENTS

<u>Chapter</u>	<u>Page</u>
ABSTRACT	iii
LIST OF TABLES	ix
LIST OF FIGURES	x
1. PROBLEM STATEMENT	1
2. HYPOTHESIS	3
3. SUMMER URBAN HEAT ISLAND EFFECT	7
Winds	9
4. ENERGY CONSERVATION	10
5. PARKING LOTS	14
Historical Evolution	14
Percentage of City Area	14
Benefit of Trees in Parking Lots	15
Adverse Affects of Parking Lots on Trees	18
Temperature	18
Drought	19
Soil Compaction	19
Light	20
Pollution	20
6. PLANTING WELL SPECIFICATIONS	22
7. PARKING LOT DESIGN CONSIDERATIONS	33
Overview	34
Tree Use by Parking Lot Type	36
Trees Adjacent to Buildings	39
Parking Lot Structural Requirements	39
Retrofitting Parking Lots	44

TABLE OF CONTENTS (Continued)

<u>Chapter</u>	<u>Page</u>
8. ALTERNATIVE PARKING LOT DESIGNS	46
City of Dayton, Ohio	46
Cook College Campus, Rutgers University, New Brunswick, New Jersey	46
University of Delaware, Newark, Delaware	49
Miles Laboratories	49
Analysis of Alternative Parking Lots	48
City of Dayton, Ohio	48
Cook College Campus, Rutgers University	49
University of Delaware	49
Miles Laboratories	49
9. RECOMMENDATIONS FOR PLANTING TREES IN PARKING LOTS	51
Existing Lot Configurations	51
Alexian Brothers Hospital	51
Avantek	53
Brandon's	53
Cadence	53
Fry's Electronics	53
Piedmont Hills High School	58
Safeway-Longs	58
U. S. Post Office	58
Yellow Freight	62
Zitel	62
Items to Incorporate into Reconfigured Lots	65
Suggested Changes in Each Lot	66
Alexian Brothers Hospital	67
Avantek	67
Brandon's	67
Cadence	67
Fry's Electronics	67
Piedmont Hills High School	67
Safeway-Longs	74
U. S. Post Office	74
Yellow Freight	74
Zitel	74

TABLE OF CONTENTS (Continued)

<u>Chapter</u>	<u>Page</u>
10. PARKING SPACE SIZE AND LOT LAYOUT	79
11. INDIVIDUAL FACTORS IN LOT DESIGN	101
Artificial Lighting	101
Water	102
Air Pollution	103
High Albedo Pavement	104
Roots	105
Fruit	106
Brittle Wood and Peeling Bark	106
12. CRITERIA FOR PARKING LOT TREE SELECTION IN MEDITERRANEAN CLIMATES	107
Tree Selection Process	109
List of Suitable Trees	110
Species Descriptions	111
13. REFERENCES	125
APPENDIX A. Root Measurements for Determining Planting Well Sizes	

LIST OF TABLES

<u>Table</u>	<u>Page</u>
1. Tree Canopy Coverage (TCC)	13
2. Estimates of the Urban Fabric	16
3. Soil Volume Methodology	24
4. Density of Urban Soils	30
5. Temperature Ranges for Various Materials	38
6. Pavement Design by Subgrade Soil Class	43
7. Recommended Minimum Parking Space Requirements	81

LIST OF FIGURES

<u>Figure</u>	<u>Page</u>
1. Side View of Standard Planting Well	26
2. Planting Well Specifications	27
3. Truncated Design Planting Well	40
4. Structural Requirements for DI-2 Parking Lot	42
5. Alexian Brothers Hospital - Existing Parking Lot	52
6. Avantek - Existing Parking Lot	54
7. Brandon's Restaurant - Existing Parking Lot	55
8. Cadence - Existing Parking Lot	56
9. Fry's Electronics - Existing Parking Lot	57
10. Piedmont Hills High School - Existing Parking Lot	59
11. Safeway-Longs - Existing Parking Lot	60
12. U. S. Post Office - Existing Parking Lot	61
13. Yellow Freight - Existing Parking Lot	63
14. Zitel Corporation - Existing Parking Lot	64
15. Alexian Brothers Hospital - Proposed Parking Lot	68
16. Avantek - Proposed Parking Lot	69
17. Brandon's Restaurant - Proposed Parking Lot	70
18. Cadence - Proposed Parking Lot	71
19. Fry's Electronics - Proposed Parking Lot	72
20. Piedmont Hills High School - Proposed Parking Lot	73
21. Safeway-Longs - Proposed Parking Lot	75
22. U. S. Post Office - Proposed Parking Lot	76

LIST OF FIGURES (Continued)

<u>Figure</u>	<u>Page</u>
23. Yellow Freight - Proposed Parking Lot	77
24. Zitel Corporation - Proposed Parking Lot	78
25. Parking Lot Configuration Terminology	80
26. Key for Standard Parking Space Layouts	82
27. Standard Parking Space Layout - 45° U'	83
28. Standard Parking Space Layout - 45° U	84
29. Standard Parking Space Layout - 60° U'	85
30. Standard Parking Space Layout - 60° U	86
31. Standard Parking Space Layout - 90° U'	87
32. Standard Parking Space Layout - 90° U	88
33. Key for Compact Parking Space Layouts	90
34. Compact Parking Space Layout - 45° U'	91
35. Compact Parking Space Layout - 45° U	92
36. Compact Parking Space Layout - 60° U'	93
37. Compact Parking Space Layout - 60° U	94
38. Compact Parking Space Layout - 90° U'	95
39. Compact Parking Space Layout - 90° U	96
40. Alternative Layout to Reduce Number of Parking Spaces	97

CHAPTER 1

PROBLEM STATEMENT

Temperatures in large urban areas are increasing above their pre-urban recordings. These higher temperatures are especially pronounced during the hotter summer months. This heat adds to personal discomfort, has a significant effect on energy costs for air conditioning, and is also a contributing factor in air pollution. A number of factors that produce this heating effect are present throughout the year; however, in winter, they do not produce the range of heat or pollution problems and can even reduce heating costs.

Urban areas have become increasingly susceptible to higher temperatures based in part on the materials used in their development. As towns grow into cities, they often lose tree cover and open vegetated areas. In place of this vegetation are buildings and parking lots made of impervious, high density materials. As a consequence, the solar energy that was previously absorbed by trees and plants is now absorbed by these high density materials. These materials do not use the solar energy in a photosynthetic process or in evapotranspirational cooling, as does vegetation. They absorb, store, and reradiate this sensible heat back into the city during the day and even far into the night (Garbesi et al. 1989, 56 and Thurow 1983, 1).

If these materials did not absorb and reradiate the sun's energy, cities would be about the same temperature as the countryside around them. That cities are 2° to 5°C warmer than the countryside can be attributed to heat storage and release by these materials. This phenomenon is called the Summer Urban Heat Island (SUHI).

Scientists at the University of California Lawrence Berkeley Laboratory (LBL) in California have concluded that trees and light-colored surfaces, which have a high albedo of reflection, can be used to intercept or prevent high density materials from absorbing solar energy, thereby reducing the need for cooling homes and buildings and thus saving

electrical energy. Discussed at a 1989 conference were a number of means by which society could lower energy requirements. The main theme of the conference was the reduction of energy consumption based on avoidance of solar absorption by homes and small buildings.

Trees growing in parking lots can block solar radiation from the black pavement, thereby lowering the parking lot temperature. This lowering of the heat contribution of parking lots to cities provides a substantial mitigation of SUHIs. Cities also benefit by enhanced removal of air pollution through the trees' photosynthetic process, and by aesthetic enhancement. The focus of this research is to determine the proper conditions required to encourage the vigorous tree growth that will produce this beneficial urban forest canopy in parking lots.

CHAPTER 2

HYPOTHESIS

It is this author's contention that an urban forest composed of trees covering parking lots is of major importance in reducing the adverse effects of SUHIs. Trees are effective absorbers of solar radiation and prevent much of the solar radiation from reaching high density materials on the ground. In addition to intercepting the solar radiation, the leaves release moisture in a gaseous state through evapotranspiration, thereby cooling the surrounding air. Surface temperatures are reduced considerably as the shadow of a tree moves opposite of the sun's arc.

The extent of heat reduction through tree planting is unknown, although it should be substantial based on the calculations presented in Chapter 4. Any cooling will have an effect on the entire city.

The following formulas provide tools for approximating the possible heat reduction (U.S. Department of Agriculture 1975, 109):

$$R_n = LE + A + S \text{ or } R_n = A + S$$

Where: R_n = Net radiation or radiant energy absorbed by the Earth.

LE = Evaporating water from plants

A = Heating the air

S = Heating materials on buildings and below the surface soil heat flux

In 1970, the length of California's municipal streets totalled 76,200 miles. The number of trees that could have been planted along these streets, assuming an 18-meter (58-foot) center spacing between trees, is 8,300,000 (International Union of Forestry Research Organizations 1976, 267). This figure does not include parking lot areas. The spacing above is nearly twice the 30-foot center-to-center distance that San Jose City arborist Mark Beaudoin recommends for most average street trees (Beaudoin 1991). (This

center-to-center distance is dependent upon tree species and can be less than 30 feet.) Twice as many trees could be planted in the same area using 9-meter (29-foot) centers, totalling more than 16.5 million trees. Most street trees do not have 30-foot crowns and can therefore be planted on closer centers. Trees of this size leave 28-foot open gaps in the 18-meter (58-foot) spacing scenario but form a contiguous canopy at 9-meter (29-foot) spacing.

In addition to aesthetic benefits, these trees would provide for increased comfort produced by the shade, evapotranspirational cooling, sound absorption, and pollutant removal. The decision regarding what types of trees to plant is an important one.

In large part, the work on SUHIs has been directed toward the energy savings resulting from mitigation. The University of California LBL published the results of proceedings held on this topic: "Controlling Summer Heat Islands" (Garbesi et al.). The main thrust of their research, and much of the data presented by other conference participants, is that energy used to cool human environments at home, work, and shopping can be saved by application of specific measures.

Air conditioning of buildings requires the consumption of a substantial amount of energy which produces a substantial quantity of heat that is vented to the atmosphere. "Research shows that for every degree of increased heat, electricity generation rises by 1% to 2%, and smog production increases by 2% to 5%" (U.S. Environmental Protection Agency Office of Policy, Planning, and Evaluation 1990, pamphlet).

As the title of the University of California study indicates, summer is the time of maximum solar radiation and consequently the peak of the Urban Heat Island effect. (There can, however, be a significant variation in summer solar radiation in different microclimates within a larger region.) An example of this summer maximum is shown below for average solar radiation received at a 50°N latitude location (Geiger 1950, 380):

December: 52 calories/cm²/day

June: 518 calories/cm²/day

Smog does not develop in temperatures below 70°F (21°C) (Garbesi et al. 1989, 14). Certainly this places the SUHI effect past the late fall, winter, and early spring months for most cities between 25° and 50° north or south latitude. Mediterranean climates are denoted as Csa and Csb throughout this thesis based on Koeppen's classification system (Critchfield 1961, 169), in which:

C = mesothermal climates; mild winters

s = dry season in summer

a = mean temperature warmest month > 22°C

b = mean temperature warmest month < 22°C

Rural areas adjacent to urban areas that experience this effect do not retain their incoming solar radiation for prolonged periods. Soils absorb solar radiation to a lesser depth and do not store it as efficiently as impervious, high-density, industrially manufactured materials. Therefore, rural areas do not experience the delayed sensible heating of their urban counterparts.

Rural areas benefit from large areas of vegetation that transpire moisture into the daytime air. This evapotranspiration produces a cooling effect throughout the day. The energy required to vaporize one gram of water at 28° Celsius is 580 calories of energy (Barbour et al. 1987, 346). However, cities are functionally drier than their adjacent rural countrysides because the cities' asphalt surface areas and roof areas do not absorb the precipitation (Geiger, 383).

Commercial and industrial areas of cities have reduced vegetation and bare land and thereby have less surface area for water accumulation, absorption, and evaporation. Their limited number of trees is incapable of intercepting sufficient solar radiation to cool the city. Instead, parking lots quickly channel precipitation runoff from the asphalt into storm drains

and channels. Solar radiation is absorbed within the city by the building materials of steel, cement, asphalt, stone, brick, and tile.

One of the objectives of this thesis is to develop data for planners to use in constructing guidelines and ordinances for parking lots within cities and counties. Planting well size, soil planting mixes, tree species, orientation of parking spaces, canopy coverage based on tree size, and spacing are all factors that must be considered.

CHAPTER 3

SUMMER URBAN HEAT ISLAND EFFECT

Cities, with their large amounts of high density materials and reduced vegetation, tend to warm up more slowly than rural areas. This is because high density materials take longer to absorb an amount of solar radiation sufficient to allow the sensible heat to be reradiated into the atmosphere. This heating of the air adds to the natural atmospheric heating process. The sensible heat release continues long after the sun sets and blurs the normal diurnal heat and evening cooling periods by maintaining heat into the early evening hours. This retained heat prevents cool downdrafts from cooling and cleansing the cities of hot, polluted air. As a result, the city begins the new day still warmed by the release of heat from its high density materials. This process does not stop as winter approaches, although the heating effects are reduced as both the daylight hours and the angle of the sun decrease in north and south latitudes between 25° and 90°. Because of this process, temperature extremes in rural areas are greater between day and night than in urban areas.

Akron, Ohio was the site of a citywide study to determine maximum temperature when correlated to population and land-use zoning patterns. The data indicated that an Urban Heat Island (UHI) formed in the same part of the city during all four seasons. A temperature differential of 9°F (5°C) in the spring, 6°F (3.3°C) in summer, 14°F (7.8°C) in autumn, and 7°F (3.9°C) in winter was noted between the warmer UHI and the edges of the city. The center of the UHI was located 1.5 miles northwest of the center of the Central Business District (CBD) in a mix of residential and low-profile commercial buildings with large paved parking areas (U.S. Department of Agriculture 1975, 94). Ellefsen states that the space required for parking automobiles exceeds the footprint of the building(s) where people shop at urban shopping centers (Garbesi et al. 1989, 230). Akron represents a typical example of what occurs in major cities all across the United States.

Most cities grow vertically as well as horizontally. The combination of growth in both directions affects the weather profile for a given area. The horizontal growth removes and/or reconfigures the vegetation and replaces it with streets, parking lots, homes, and buildings. The vertical growth causes buildings to be projected into the air flow that normally moves over and through the city. These tall buildings cause the air to slow, allowing more air pollutants to be retained in the already foul air.

During the summer, this heated air becomes increasingly polluted as air temperatures exceed 70°F and air flow is affected by tall buildings. In winter, the air flow continues to be affected, causing a storm to disgorge more rain or snow than it does in the adjacent countryside.

In older areas of cities, two divergent activities occur side by side simultaneously. New multistory buildings are erected on increasingly expensive land. Old buildings cannot compete economically with skyscrapers and often are torn down to lower their owners' tax burdens. In their places, parking lots are constructed to serve the skyscrapers in the CBD (International Union of Forestry Research Organizations 1976, 365). These parking lots represent short-term economic activities that hold the land available for future development. In the short term, they become large absorbers of solar radiation.

Because parking lots are a major contributor to SUHIs and trees are capable of absorbing solar radiation, the two need to be joined together. The planting of trees, according to the United States Department of Agriculture (USDA), is probably the most important means of controlling solar radiation in urban areas (U.S. Department of Agriculture 1975, 36). Parking lots exhibit the worst extremes of an urban area: full open sun and wind areas, heat, dryness, and heavily compacted soils. To expect trees to thrive in such an environment requires that we modify those factors that are within our control.

Winds

Winds contribute to the heating and cooling differential that exists between cities and their adjacent rural areas. Winds from the countryside flow into the city in much the same way air streams into an open fire. This confluence of air over the city may be partly responsible for macroclimatic weather changes (Geiger 1950, 384-385).

Height, orientation, location, and concentration of buildings affect the wind's direction and velocity in the canyon areas between them. The duration of time required for an air mass to traverse a city is dependent on the buildings' profiles and locations. Wind moving through the open countryside or over a forest is presented with a relatively uniform surface. As wind travels over and through a city it encounters an irregularly configured surface that alters its speed and direction.

A consequence of the air being slowed in its passage over the city is that smoke particulates and air pollution readily accumulate. This accumulation produces unhealthy conditions for trees as well as for humans. Trees often suffer due to their lack of mobility and their inability to remove or filter airborne impurities. It is the heat retention of the urban areas and air pollution which concerns many scientists.

CHAPTER 4

ENERGY CONSERVATION

Scientists who spoke at and published papers for the University of California Proceedings developed the proposition that trees and high albedo surfaces are two of the most efficient means of saving energy in an urban setting. Their focus is on the economics of reducing energy consumption rather than on aesthetically enhancing our world while correcting planning flaws in our cities. There is little difference between their goals and this author's, yet there exists a difference in their philosophical approach to reaching these goals. The author objects to the use of only technocratic solutions that lessen our energy demands without enhancing the overall urban environment. Even if much of our energy requirements could be reduced, pollution and a warmer climate would remain a part of our city landscapes. These energy reductions would not have reclaimed our city's microenvironments nor contributed to the increase in their environmental quality.

The scientists who are focused on energy conservation through the use of trees and light-colored surfaces use statistics to support their perspectives and theories. The following figures are taken from "Controlling Summer Heat Islands" (Garbesi et al. 1989):

1. Of the 50 million single-family homes in America, 25 million can be cooling enhanced by the planting of a tree on the east, south, and west sides. This amounts to 75 million trees with an energy savings of 0.5 quadrillion Btu's (0.5×10^{15} Btu) per year (19).
2. In 1987, the people of the world burned 300 quads (quadrillion Btu's) of fuel, which released 5.4 billion tons of carbon into the atmosphere. This amount of carbon is two to five times the amount released through deforestation (32).
3. In 1986, the U.S. energy consumption was 74 quads per year. Mitigation of the heat island via light-colored surfaces and urban trees to cool homes may save 0.5

quads per year and decrease CO₂ emissions by about 17 million tons per year (33).

4. Total U.S. residential energy consumption in 1987 was 100 billion kwh or 1.2 quads. In the same year, commercial buildings used 670 billion kwh or 8.04 quads of energy of which 20% (130 billion kwh or 1.5 quads) was used for cooling (35).
5. Planting additional trees around half of the 2 million small commercial buildings will add another 25 million trees to cities. Trees sequester 13 pounds of carbon per year. The 100 million trees are capable of sequestering 0.65 million tons of carbon (36).
6. Another perspective is to consider that to sequester the amount of carbon saved by the planting of 100 million urban trees would require the planting of 1.5 billion forest trees corresponding to 1.5 million hectares of forest. In comparison, the total area of Connecticut is about 1.3 million hectares (37).
7. The cost of conserved energy (CCE) and the cost of conserved carbon (CCC) by using light-colored surfaces and urban trees is about 0.2 to 1.0 cents per kilowatt-hour and 0.3 to 1.3 cents per pound of carbon. This figure is ten times more effective than increasing the automobile's average fuel consumption from 26 to 36 miles per gallon (37).
8. Where a tree shades a wall that was in direct sunlight, a temperature reduction of 24°F (13.3°C) is a normal occurrence (47).
9. Lawrence Berkeley Laboratory scientists already know that it is very cost-effective to plant trees which shade buildings directly. They believe that trees on streets, highways, and parks are less cost-effective, although still probably very valuable (19).

It is this author's contention that an urban forest composed of trees covering parking lots and streets is of major importance in reducing the adverse effects of SUHIs. The U.S. will approach 42,000,000 acres of urban land usage by the year 2000 (International Union of Forestry Research Organizations 1976, 235). At a 10% ratio, this calculates to 4,200,000 acres of parking lot coverage. Clearly the impact of an urban forest of this size merits consideration.

The total potentially sequestered carbon from trees in parking lots will equal or exceed the LBL figure obtained from trees planted around homes and small businesses (100 million trees). The 4,200,000 acres could be planted at approximately 25 trees to the acre which equals 105,000,000 urban trees.

A properly designed parking lot would have trees planted around its periphery as well as within the parking area. Using the above figures, one can determine the amount of surface shielded from solar radiation by comparing total parking lot area with the percent of tree canopy cover (TCC) (Table 1).

Trees planted within the parking area do not grow well due to a host of environmentally stressful factors. Even in parking lots where trees can grow well, the tree canopy coverage is not more than 20 to 30%. This low figure is the result of the perpendicular layouts of most double aisle, 90° configuration parking lots. Proper tree selection and parking lot site preparation can result in coverage of 50% or greater. It is this level of TCC that will provide a marked improvement in the climate of cities. Watson and Hennen (1989, 77) were echoing the author's beliefs regarding parking lots when they said that as we tackle the enormous problem of global warming, we should also attempt to cool the hot spots of our cities--hot spots that contribute to global warming and perhaps depict the problem in miniature.

TABLE 1
TREE CANOPY COVERAGE (TCC)

<u>% TCC</u>		<u>Total Parking Area</u>		<u>Area Shielded</u>
10	x	4,200,000 acres	=	420,000 acres
25	x	4,200,000 acres	=	1,050,000 acres
33	x	4,200,000 acres	=	1,386,000 acres
50	x	4,200,000 acres	=	2,100,000 acres
66	x	4,200,000 acres	=	2,772,000 acres
80	x	4,200,000 acres	=	3,360,000 acres

CHAPTER 5

PARKING LOTS

Historical Evolution

Parking lots are a relatively recent phenomenon. In 1908, Henry Ford built the Model T, the first mass produced horseless carriage that was inexpensive enough for the general public. In 1915, the one millionth car rolled off the Ford assembly line (Purchasing Magazine [1990], 77). Up to this time, land travel had been by foot, bicycle, horse and buggy, train, and streetcar trolley. Roads and streets were not paved in most cities, compacted dirt and gravel being the general rule. Trees were planted along streets and boulevards to provide aesthetically pleasing views. Equally important, trees provided shade and cooling to the people who travelled on them. The limited carriage or horse travel that existed was accommodated by streets and livery stables.

With the advent of the automobile, the character of towns, and the movement of people into and out of them, changed. As the towns expanded into the surrounding rural farm lands, the economy began to change. Agricultural work was replaced by factory and office jobs. Transportation was necessary to reach one's job and to return home daily. Shopping for food and supplies became a necessity requiring travel to or within the city with its commercial shopping centers. With this change in travel patterns, several modifications to cities occurred as a result of increased vehicular traffic. Streets were widened to provide additional lanes and speed traffic flow. In many cities, this meant the removal of trees that had been planted in front of homes and commercial buildings in the easement areas (Weiner 1975, 64). Parking space was required to accommodate the increasing number of cars that remained in the city during the day. With the addition of more streets and parking lots and the removal of trees, warming within cities increased.

These changes began in earnest during the 1920s as streetcar trolley lines were improved with paving in a number of western cities (McCaleb 1981, 67). By the 1930s, the trolley lines were replaced by buses and automobiles. The die was cast and the growth pattern set for cities across America. In some cities in the Eastern U.S., growth and traffic patterns occurred during the age of the steam locomotive. Some of these cities still offer considerable travel to and from by train. But these cities have more recently been affected by the automobile, and travel in many of these older cities is more difficult than in newer cities that were planned for travel by automobile.

Percentage of City Area

Each automobile theoretically has three parking spaces available to it: one at home, one at work, and one at shopping centers, restaurants, sports centers, hospitals, educational institutions, and entertainment centers. Table 2 shows the impact of parking lots (under note "Impervious Other †") and how they constitute approximately 10% of most large cities (Akbari and Rosenfeld 1989, 7; Santamour 1975, 33). Even our transportation centers for planes, trains, and ships have large, profit-generating parking lots to accommodate the private automobile. When street area is added to the parking lot area, the figure exceeds 10% of total urban land use.

Yet we have become so accustomed to parking lots that we seldom notice their numbers, types, and sizes, or how much of our environment they cover. When traveling by car, it is from one parking space to another. When we are about to travel by air, train, bus, or ship, we leave from one parking space and must park in a parking space where that form of transportation is located. Our accommodation to the automobile has strongly affected the planning of our cities.

Benefit of Trees in Parking Lots

Charles Thurow (1983, 16), in his book Improving Street Climate Through Urban Design, states that any design feature that aids cooler air in moving into the warmer areas of

TABLE 2
ESTIMATES OF THE URBAN FABRIC
 Based on Measurements in Sacramento, California

AREA	RESIDENTIAL (46% OF TOTAL)	COMMERCIAL/ INDUSTRIAL (25% OF TOTAL)	TOTAL*
	%	%	%
Rooftop	23	43	22
Impervious Street	22	15	17
Impervious Other†	22	42	22
Green	33	~0	39
Total	100	100	100

* Includes schools, parks, open space, and freeways as well as residential and commercial/industrial areas.

† Includes parking lots, driveways, sidewalks, etc.

Source: Akbari, H. and A. Rosenfeld, "White Surfaces and Urban Trees for Mitigation of Summer Heat Islands: Setting Up Priorities" (Berkeley, Calif: Lawrence Berkeley Laboratory, 1989), 7.

a city during the day or allows heat to radiate out into the night sky will help dissipate a SUHI. The American Society of Landscape Architects (ASLA) states that shade is the most obvious product of the forest under the sun (American Society of Landscape Architects Foundation 1977, 17). This cooling is the major objective of the parking lot designs recommended in this thesis.

Parking lots can be uncomfortable to pedestrians in the summer because they are:

1. Too hot with no protection from the sun.
2. Too bright for visual comfort.
3. Arid.
4. Areas of high concentrations of auto exhaust.

Studies by ASLA have shown that solar radiation and light intensity decrease from the top of the canopy to the forest floor; they decrease rapidly through the canopy, and then more slowly through the trunk space; and that up to 80% of the light on an overcast day and more than 90% on a sunny day are caught in the crown space (American Society of Landscape Architects Foundation 1977, 17). Establishing methods for depriving the pavement of solar radiation is a major goal.

Many authors maintain that the main reason for including trees in parking lots is to screen parking lots from unsightly views. Edward Stone states that the primary function for landscaping parking facilities is clearly to enhance aesthetics (Stone 1987, 16). Gary Robinette views problems of visual appearance and its relationship to character and scale of the lots as being largely alleviated by screening the view of cars from above and from the edges of the parking lots (Robinette 1976, 92). (The literature contains several articles on use of trees for cooling in parks or around buildings, but none on parking lots.) Several authors discuss the aesthetics of properly landscaped lots. Studies have been conducted on individual problems such as soil compaction, drought, heat, light intensity and duration, disease, and pollution. Most of the material has been written for cities in the temperate

Northeast and Central U.S., and much of this work has been directed toward urban street trees. Uniform criteria and hard data do not exist for tree selection and use in parking lots by climate zones.

Adverse Affects of Parking Lots on Trees

Trees evolved over hundreds of millions of years to adapt to various climatological and niche conditions (Elias and Irwin 1976, 111). For example, *Sequoiadendron giganteum* and *Sequoia sempervirens* grow in a limited range of conditions; whereas walnuts, pine, and oak grow over a broader range, and some trees, such as *Ailanthus altissima*, grow nearly anywhere. In the short span of several thousand years, humans have built large cities and planted trees within them. Building an urban environment alters the range of temperatures, rainfall, light intensity/duration, and soil aeration from that to which trees would naturally be subjected in a particular region. We have not been able to create hybrid trees to solve the problems encountered in urban areas and parking lots in particular. "We can establish ideal criteria . . . but there may never be an ideal tree." (U.S. Department of Agriculture 1975, 7). Therefore, specific niche trees must be chosen to live in parking lots. Making parking lots approximate a tree's natural habitat will improve that tree's chances of flourishing. "Instead of expecting trees that have adapted to forest environments to live in urban settings, we should make those city settings as close to forest environments as we possibly can" (Watson and Hennen 1989, 73).

Several adverse city conditions are described below.

Temperature. Temperatures in urban environments are usually 2°C to 3°C warmer than the surrounding rural lands. Dark-colored pavement and roof surfaces cause temperature increases by facilitating absorption of solar radiation. In cold winter climates, this stored heat may aid a tree's roots by preventing the ground around it from freezing. However, in Mediterranean climates, this heat stresses the roots in the summer by drying the soil and elevating the subsoil temperatures to unnaturally high levels.

Drought. Most trees do not thrive when they are exposed to prolonged periods of drought. Little or no rain falls from late spring to early fall in Mediterranean climates (Lenz and Dourley 1981, 2-3). A parking lot's impervious surface excludes rainfall from all but the exposed soil surrounding the tree's trunk. Without the addition of supplemental irrigation, most trees in parking lots would expire in the first few years due to drought-like conditions. Gary Watson and Gary Hennen (1989, 28) delineated the differences between urban and natural tree environments in the four points below:

1. Most urban trees are more widely spaced and develop larger crowns than forest trees.
2. A larger amount of leaf surface area is exposed to sun and wind, causing water loss from the leaves of urban trees.
3. A correspondingly higher demand is placed on the urban trees' root systems to replace the water lost.
4. Water evaporates four times as fast from exposed urban soil as from protected forest soils.

Soil Compaction. Parking lots require highly compacted gravel bases. In most instances, water and air pore spaces are compressed out of the soil during site preparation, leaving the soil with a bulk density of 1.80 grams per cubic centimeter (g/cm^3). This compares with cinder block at 1.70 g/cm^3 , brick at 1.75 g/cm^3 , asphalt at 2.19 g/cm^3 , and cement at 2.26 g/cm^3 (U.S. Department of Agriculture 1975, 97). Singh and Gupta (Santamour 1975, 93) suggest that the optimum bulk density for agricultural crops is 1.33 g/cm^3 . As bulk density increases, soil compaction increases, pore space decreases, oxygen content in the soil decreases, and water holding capability decreases. Tree roots require even lower soil density than agriculture crops in order to develop the structure necessary to satisfy the tree's water requirements. One solution to this soil compaction problem is: 1) provide these trees with a planting well of sufficient size to allow full root development (see

Chapter 6) and 2) use a soil mixture that provides 50% air and water pore spaces. Without these two conditions, a tree's roots will not thrive. A tree cannot grow at a vigorous rate nor to normal size without a fully developed root system. The result is a stunted, drought-stricken tree that may suffer an early death.

Light. Trees are fairly sensitive to the changes in light intensity and duration, both daily and throughout the year. The tree depends on changes in day length and sunlight intensity to trigger growth or dormancy. In parking lots, trees receive additional reflected light from the pavement onto the underside of their canopies in addition to solar radiation. They may receive additional radiation from artificial lighting sources in the parking lot. Due to artificial light sources, trees in cold climates may continue to grow even at the onset of autumn. There is, however, considerable debate and skepticism on this issue in the scientific community (Hightshoe 1978, 84). Ultimately, cold weather triggers dormancy in trees and some trees that are stimulated by artificial light may suffer foliage damage. Studies on the extended hours of artificial lighting are being conducted on various species of trees and may produce mixed results. In Mediterranean climates, the onset of winter is neither as extreme nor as damaging to tree species as it is in colder climates, except perhaps at high altitudes. Therefore, artificial lighting may not prove to be a serious problem in Mediterranean climates.

Pollution. Normally, air pollution is more concentrated in urban than rural areas. Calender et al. have shown that approximately 65% of controllable hydrocarbon emissions are the result of fuel combustion from transportation sources (Pinchot Institute of Environmental Forestry Research 1977, 6). "Air pollution is primarily a product of urban/industrial developments and generally becomes more severe as population density increases" (7). Ozalin et al. stated that 60% of all air pollution released in the U.S. is confined to just 2% of the land mass (25). Air travelling through an urban area moves more slowly and accumulates more pollutants and particulate matter than in a rural area.

Many trees are sensitive to or are damaged by ozone, sulfur dioxide, polyaromatic nucleics (PAN), and other chemical byproducts. Care must be taken to choose trees that exhibit the highest tolerances to these pollutants so that tree survival will be enhanced.

CHAPTER 6

PLANTING WELL SPECIFICATIONS

Parking lot trees are often viewed as a frill or a window dressing to enhance or create an exterior ambience. Trees should be viewed as a vital part of the infrastructure. This doesn't imply that plants aren't considered other than in the artistic phase of design; rather, that landscape architects don't perform heat avoidance calculations and they don't perform soil compaction studies. Landscaping contractors add trees as amenities after the soil has been compacted and the building construction begun. Landscape contractors should be required to open and aerate the soil prior to beginning their phase of construction.

It is essential to understand the requirements for growing trees. These data must be made available to landscape architects and should be incorporated into city and county ordinances governing parking lot construction. Parking lot designers fully understand the physical and technical requirements for building parking lots. What is needed is to devise methods that first meet the requirements of trees to enable their vigorous growth in parking lots.

Planting wells are the tree planting sites within the parking lot. Use of a large planting well concept (described below) based on tree root measurements is important for tree growth, especially where soil at the planting site has not been protected during the construction phase.

Attempts could be made to identify and protect sites where it has been determined that trees are going to be planted. The results would be of mixed value since most of these areas would receive varying degrees of soil compaction anyway. This is because the construction of buildings requires total access to all parts of the land surrounding the project. It is understood that avoidance and protection of tree planting sites during the

construction phase increases the costs of constructing the buildings, but it is a standard requirement of most enlightened city governments.

Although the costs to recreate natural conditions for trees may initially seem high, they must be compared to the following costs incurred by not creating these conditions:

1. Stunted tree growth due to compacted soils.
2. Death of trees due to compacted soils.
3. Replanting to replace dead and dying trees.
4. Lack of the desired shade and ambience created by unhealthy trees.

Where water and air are relatively abundant below the surface, there is little surface root disturbance. Where water is applied only at the surface level, roots predominate at the surface and cause damage to sidewalks, pavement, and lawns. Trees planted in sufficiently large planting wells and watered deeply will cause less surface root damage to the surrounding area. Deep watering when the trees are young enables them to develop roots downward and away from the hot, dry surface, as is naturally done by drought-tolerant species. Deeply aerated soils and initial deep watering via subsurface irrigation systems appear to be the most viable methods of sustaining early tree growth and deep root development.

Soil volume and water usage are factors in determining the appropriate size of the trench or planting well for the tree. The methodology in Table 3 is recommended for determining proper size. A general method for computing the cubic feet of friable soil needed to support a tree species is to multiply the ultimate tree canopy diameter desired by the average tree root depth for that species.

Several types of planting wells are recommended, based on measurements and the concept that sufficiently sized planting wells will allow the trees to grow large enough to send roots below and beyond their original planting well. Use of proper wells will enable trees to develop deep root growth that will not damage adjacent parking surfaces. Deep

TABLE 3
SOIL VOLUME METHODOLOGY

Estimated critical soil volumes are presented for a representative range of U.S. cities using the soil volume methodology. The tree in this example has a crown diameter of 20 ft. and is about 35 ft. in height. Calculations were based on a tree with a crown projection of 315 ft. and an average leaf area ratio of 4.

City	One Day Soil Volume ¹ (Cu. Ft.)	Rainfall Frequency ² (Days)	Approximate Total Soil Volume (Cu. Ft.) If AWHC ³ of Soil Is:	
			10%	15%
Ithaca, NY	28	10	400	300
Seattle, WA	30	20	900	600
Mobile, AL	32	10	500	300
Indianapolis, IN	33	15	750	500
Minneapolis, MN	35	10	500	350
Miami, FL	36	10	550	350
Denver, CO	45	15	1,000	700
Phoenix, AZ	68	80	8,200	5,400

- 1 Calculated using the highest mean monthly pan evaporation value for 20-30 years of data for each city to determine whole-tree water use. Assumes a soil available water holding capacity of 15%.
- 2 Defines the critical rainfall. A minimum of 92% of all dry periods (less than 1/10" of rain) lasted this number of days or fewer for each city. Derived from 10 years of data for each city.
- 3 Available water holding capacity of the soil. This represents the percent of the total water, on a volume basis, that is actually available for root uptake. Two available water holding capacities are presented for comparison here: a low (10%) and a high (15%). The AWHC of any soil mix can be determined in a lab test.

Source: Goldstein, Jan, Nina Bassuck, Patricia Lindsey, and James Urban, "Soil Volume Methodology," Landscape Architecture. (Washington, D.C.: American Society of Landscape Architects, January 1991), 68.

growing root systems are also less likely to be damaged during repaving and maintenance work. This concept specifically refers to trees that are commonly termed "problem root" trees. Certain trees have genetic coding for surface roots (flood plain trees) where stem root attachment to the trunk is horizontal rather than vertical. All trees have surface roots; however, when planted in an undersized planting well and/or when watered only from the surface, these trees overdevelop surface roots which disrupt paved surfaces and lawns.

Figure 1 is a side view of a standard sized planting well 8 feet by 10 feet by 4 feet deep, providing 320 cubic feet of volume. Subtracting 6 inches from the depth to allow for a mulch cover leaves 280 cubic feet for proper soil mix in which the tree roots can vigorously grow. The surface of the well is raised slightly higher than the pavement to prevent water runoff from entering the well. A curb can also be used which would provide a base for the concrete or steel grate to rest on or nestle in.

A grate covers the entire planting well. The material may be steel or cement turfblock and is intended to prevent the soil from being compacted. The 6-inch space between the grate and the soil accommodates a lightweight gravel mulch. Alternately, 4-inch pea gravel or decomposed granite could be used. The mulch aids in moisture retention and deters the growth of volunteer plants in this sterile material. Light shining through the grate will strike light-colored gravel and not exposed soil. Gases and nutrients can easily pass through this mulch.

Recommended specifications for optimum planting wells are listed below and depicted on Figure 2. Well sizes were determined based on measurements taken on the trees listed in Appendix A.

1. Planting wells should be 96 inches by 120 inches by 48 inches deep with a steel or concrete grate cover. The grate protects the soil from compaction, primarily caused by pedestrians. There should be a 6-inch space between the soil over the tree roots and the grate. This space is filled with lightweight

Fig. 1. Side View of Standard Planting Well

Fig. 2. Planting Well Specifications

gravel/rock (e.g., volcanic) which will:

- a. Retain moisture in the soil by acting as a mulch.
 - b. Prevent vegetation from germinating and establishing roots in the soil.
 - c. Enhance the nitrogen gas and oxygen/carbon dioxide exchanges from the roots to the atmosphere.
2. Alternatively, planting wells could be created by digging a trench 96 inches wide which runs the entire length of the parking row. Other details regarding dimensions remain the same.
 3. The planting well can also take the form of a round concrete pipe 92 inches in diameter and 36 inches high above the ground. This well is to be used where the height of a mature tree is too low to allow unobstructed vehicular clearance. It also provides safety for the tree from contact with vehicles. Concrete pipe planting wells have been shown to be effective containments for trees of up to 20-foot height and 7-inch diameter at breast height (dbh) (measurements taken while standing on top of the planting well) (Schiavo 1990). The bottom of the pipe opening is set just below the asphalt paving to stabilize the planting well and to allow the roots to grow into a planting well with aerated soil beneath it.
 4. A concrete pipe planting well is recommended where roots need to be contained in a finite space. The 92-inch diameter pipe is placed in the ground 1 inch above surface level and extends down 24 inches below the asphalt surface and through the crushed rock base. Prolific roots will be contained within the pipe or may grow below it where they will pose no problem to the asphalt rock base.

All planting wells described above are intended to be large enough for adequate root and tree growth during the tree's first 20 years and are all capable of being excavated by backhoe.

Planting wells should be filled with a mix of aerated soil. Hightshoe (1978, 88) describes an ideal soil mix as being composed of sand, silt, and clay which form roughly 45% of a hypothetical ideal soil for plant growth. The remaining 55% is composed of 5% organic matter, 25% air space (N₂ forming 79.2% in soil atmosphere, O₂ forming 20.6% and CO₂ forming 0.2%), and 25% water space. Where oxygen content in the soil falls below 10% by volume, some trees cease to grow.

One of the major stress factors that adversely affects urban trees is soil compaction. It reduces the air and water pore spaces leaving a soil devoid of either. This produces anaerobic conditions which further retard root growth and cause root decay organisms to flourish.

Bulk density (BD) is used as an index of soil compaction. Total pore space can be calculated when BD and particle density (PD) are known: $100 \text{ BD/PD} \times 100 = \text{total percent pore space}$. Peterson conducted an experiment to determine urban soil densities. Four commonly used construction materials were tested: cinder block, brick, asphalt, and concrete. Table 4 reveals that most urban soils are indeed as dense as concrete.

Four soil samples from the mall at 7th and Washington Drive in Washington, D.C., averaged a bulk density of 2.00 or greater (U.S. Department of Agriculture 1975, 97).

When small planting wells are dug in highly compacted soils, tree roots do not have sufficient room to grow before encountering impervious soils. The roots cannot penetrate the very soil from which they should obtain air, water, and nutrients. Trees with root systems stunted by the confines of a small planting well surrounded by compacted soils experience the following stresses:

1. Inability to obtain sufficient water for growth, vitality, and transpiration.
2. Inadequate pore space to allow for the carbon dioxide/oxygen exchange.
3. Insufficient oxygen in the soil to keep aerobic bacteria alive.
4. Roots that do not grow down and out but ball up and become rootbound.

TABLE 4
DENSITY OF URBAN SOILS

<u>Material</u>	<u>Bulk Density</u> (g/cm ³)	<u>Average Density</u> (g/cm ³)	<u>Particle Density</u> (g/cm ³)	<u>Calculated Pore Space (%)</u>
Cinder block	1.67-1.71	1.70	2.64	35.6
Brick	1.43-2.01	1.75	2.72	35.7
Asphalt	2.17-2.22	2.19	2.35	6.8
Concrete	2.23-2.27	2.26	2.47	8.5

Source: Hightshoe, Gary L., Native Trees for Urban and Rural America: A Planting Design Manual for Environmental Designers. (Ames, Iowa: Iowa State University Research Foundation, 1978), 88-89.

5. Insufficient amounts of nutrients recycling through the soil to the roots.

Where trees are planted in adequately sized planting wells, they have enough vigor so that by middle age their roots are capable of penetrating a larger soil area. The key, then, is to provide trees with sufficiently large planting wells and a planting soil mixture that encourages root growth and vigor. In their study of tree root systems, Watson and Hennen found that the greater the porosity of the soil, the deeper the root development (1989, 72). Healthy trees with healthy roots penetrate some compacted soils owing to the vigor and size of the tree. Adjacent soil compaction is not as serious a problem to a healthy, mature tree with a strong root system as it is for a young, rootbound sapling. It is necessary to provide as natural a set of growing conditions as possible for healthy tree growth to occur. Watson and Hennen (73) stated their belief that instead of expecting trees that have adapted to forest environments to live in urban settings, we should make our city settings as close to forest environments as we possibly can. Once the trees are capable of creating their own shade and microclimate modifications, they will be more capable of dealing with some of the obvious urban stresses on their own. The U.S. Department of Agriculture (1975, 123) makes this point quite clearly when they state that stresses placed on urban trees by man are equal to all of the natural stresses they receive.

The importance of water availability to tree roots is linked to the effect that occurs when heat induces stomata to open. Evapotranspirational cooling and the carbon dioxide/oxygen exchange that occur during photosynthesis are part of the process that triggers water consumption. Without adequate water availability to the tree, increased heat precipitates a shutting down of the stomata (Arbor Day Magazine [1990], 6). Compacted soils have little or no water pore spaces. Tree roots in these soils are not able to access water, and as a consequence, the tree becomes stunted and eventually dies. Dehydration and stress occur when a tree is demanding increased water uptake but its root system cannot provide it (U.S. Department of Agriculture 1975, 78). The stomata close when this

condition occurs, thereby preventing the carbon dioxide from being absorbed and converted during the photosynthetic process, which may cause leaf and root cells to produce more solutes, such as sugars, to draw in more water by osmosis. Such chemical changes may reduce a tree's natural ability to repel insect pests. If the attempt to draw in more water fails, the cell's cytoplasm shrinks and pulls away from the cell wall, causing cell death and damage to the tree's system (Arbor Day Magazine [1990], 6).

CHAPTER 7

PARKING LOT DESIGN CONSIDERATIONS

This thesis presents a number of complementary concepts incorporated into a single cohesive concept to create an environment that encourages tree growth and development while reducing solar heat gain and aesthetically enhancing our cities. The concepts are applicable to all geographical areas although the trees selected for use will be specific to certain climates.

The climate of a parking lot is generally warmer and drier than undeveloped land around it. To aid trees in surviving these conditions, the types of trees chosen are as important as providing those trees with the proper physical conditions in which to grow (described in Criteria for Tree Selection). As trees grow and produce more shade, they cool the ground and air around them. The cooling modifies the microclimate so that it is not as hot and dry to the trees.

Most parking lots fall into one or more of the following types:

1. Flat, open with no trees.
2. Flat, open with trees on the periphery.
3. Flat, open with trees in the lot.
4. Flat, open with trees in the lot and on the periphery.
5. Flat, open with large trees around which the parking spaces and buildings have been located.
6. Multistory lots with trees around the first floor periphery.
7. Multistory lots with no trees.
8. Multistory lots with trees around the first floor periphery and above-ground planters for small trees on the top story.
9. Subterranean lots with trees at ground level.

10. Subterranean lots with no trees at ground level.

Overview

The automobile driver approaching a commercial area encounters two very different views of a landscaped parking lot. The first view is through the trees to the store area: "Are the stores I seek in this complex? Are they open? Does the parking lot look safe to enter?" The second view is locating the entrance and the signs that help the driver navigate through the lot to the store(s). Of the ten parking lots the author surveyed, only one (Alexian Brothers Hospital) had clearly marked directional signs. The U.S. Post Office had entry signs. The remaining eight lots had one directional sign each or none.

The following fundamental questions must be considered by designers:

1. Is there adequate vertical clearance between the pavement and the trees' understory to allow for a clear view of pedestrians, other vehicles, parking spaces, store signs, entrances to the mall?
2. Does the auxiliary lighting provide a safe nighttime environment for pedestrians and drivers?
3. Are there adequate parking spaces for the shoppers?

Store owners also have a perspective regarding the parking lot they've created for shoppers visiting their stores:

1. Will the motorist be able to see the store through the trees?
2. Are the owners providing a salubrious environment for shoppers as they walk to the stores from their cars?
3. How much lighting is required, and at what expense, to provide nighttime shoppers with a safe comfort level?
4. Does landscaping the parking lot reduce the number of shoppers who can park near the stores and is it a luxury that is too expensive?
5. Do light-colored aggregates bother peoples' eyes due to increased solar reflection?

6. Will automobile exhaust fumes become trapped under the tree cover and make the lot foul smelling?

The National Arbor Day Foundation reports that people linger, and therefore shop longer, along tree-lined streets. In addition, apartments and offices rent more quickly and tenants stay longer in green, wooded areas (U.S. Department of Agriculture 1988, 6).

Shoppers require a safe, clean, well-lighted environment for shopping and walking to and from their cars. Pavement surfaces must be smooth and free of irregularities so that people can push carts and strollers comfortably across them. Lighting must be directed onto walking areas. Surfaces must be free of water or debris that may cause someone to fall and become injured.

Parking lots are associated with all types of activities: industrial, commercial, restaurants, hospitals, entertainment sites, sports, and educational establishments. These lots may be large open areas or they may be small pockets between buildings. In many instances, they are narrow ribbons adjacent to buildings and have only one or two parking rows. Providing the proper design for each type must be handled on an individual basis.

Trees that are chosen for parking lots must:

1. Provide vertical clearance for vehicles.
2. Be single trunked and capable of being pruned to achieve a first crotch height of 8 to 10 feet.
3. Possess a rounded or spreading canopy of a diameter greater than 50% of the tree height.
4. Live a reasonable length of time to provide a fair return on investment.

The amount of canopy coverage should be decided upon before the parking lot is laid out. This allows the designer to use a computer-aided design (CAD) system for layout and overlaying canopy coverage on various parking angle configurations. The types of trees

required to achieve this coverage and the ratio of deciduous to evergreens can be factored in for different combinations of trees.

The type of trees, deciduous versus evergreen, and their placement and percentage of distribution throughout the lot are important to the designer. A tree's ability to withstand the conditions found in a parking lot are of prime consideration.

Tree Use by Parking Lot Type

Ribbon parking lots with only one or two rows for parking require trees with spreading or rounded canopies. Those selected must have clear trunks (no branches or foliage below the crotch) and an understory height sufficient to display advertising signs in front of or on the stores. Due to the limited size of the lot, the potential range of trees for use is limited.

In shopping malls, large trees can be planted on perimeter berms for shielding the lot from street views and noises. These lots usually have a marquee announcing the stores in the mall, obviating the need for clear trunked trees to enable motorists to see store names.

Perimeter planting on large mall lots can be placed on berms which provide ample space for tree root development. A disadvantage of berms, however, is that water flows off and is not absorbed into the soil as readily as in flat planting wells. Berms should not be used on ribbon lots since the berms tend to obscure the view of the store fronts. Berms may also be considered a negative safety factor for shoppers and store owners who are hidden from view by the berm.

Berms are generally larger than individual planting wells and provide a planting well area for a number of trees. Berms are not practical within the lot because they consume too much space. They also facilitate root growth that can lead to disruption of the pavement. Berms might also be used by pedestrians or playing children, resulting in soil compaction. Finally, berms expose a larger area of soil to evaporation than does a flat, small, grate-covered planting well. The health of a tree's roots, conservation of soil moisture, and tree trunk safety are key considerations in the design of planting wells.

Perimeter trees should be of sufficient size and shape to cast large shadows. Late afternoon shadows are important in cooling the pavement temperatures.

Deciduous trees are capable of intercepting up to 74% of available solar radiation while in a winter leafless condition (U.S. Department of Agriculture 1975, 35). In experiments conducted by Kelly and Ittner of the University of California, using artificial shade for livestock, they noted one factor of great importance that is seldom considered: the movement of shadows over the ground and the speed of cooling as the shadow covers a new area. They found that bare ground temperatures cooled as much as 40°F (22°C) five minutes after arrival of the shadow line (Deering 1952, 63).

Perimeter trees can be either deciduous or evergreen depending on the amount of winter radiation the architect wants to warm the lot. The same is true for trees within the parking lot.

Trees within the parking lot should be oriented in north-south rows. This pattern enhances maximum solar interception during summer mornings and afternoons (McPherson 1990). The relationship of trees to the midday sun is less relevant because the summer sun is close to being vertical.

Trees and vegetation absorb solar radiation with their leaves, needles, and blades which lowers the total available solar energy which can be absorbed by high density materials. Shadows, as Kelly and Ittner demonstrated, can cool exposed pavement and buildings (Deering 1952, 59). This mitigation is a compelling reason for increasing tree canopy coverage and shadow production in parking lots. Table 5 provides an example of temperature ranges in degrees Centigrade for various materials in June and January. High density materials tend to have the highest temperatures. Shadows could cool these high-density materials to approximately the same temperature as grassy ground.

TABLE 5
TEMPERATURE RANGES FOR VARIOUS MATERIALS

<u>Materials</u>	<u>Air Temperature (°C)</u>	
	<u>June</u>	<u>January</u>
Air Temperature at 1.2 Meters	14.2	6.6
Tar-Macadam	32.6	6.8
Sand	25.9	5.4
Earth	25.0	5.4
Gravel	21.1	5.7
Grassy Ground	16.0	3.3
Clay Soil	11.5	5.0

Source: Deering, Robert B., Technology of the Cooling Effect of Trees and Shrubs,"
Proceedings for Housing and Building in Hot-Humid and Hot-Dry Climates. (Washington,
D.C.: National Research Council National Academy of Sciences, 1952), 59.

Distribution of evergreen and deciduous trees within the rows can be configured to create desired effects of temperature and light balances during the entire year. A high percentage of evergreen trees would result in more shade and cooler temperatures in the winter; more deciduous trees would result in more winter sunlight and warmth. Each parking lot develops a character based on its region, physical orientation, size, and relationship to the type of facility it serves.

Trees Adjacent to Buildings

Trees planted next to buildings in ribbon parking lots offer a special challenge. Whether the trees are next to a tall central business district building or alongside a one-story suburban complex, selecting trees takes special consideration. Trees planted in sidewalk planting wells must endure highly compacted soils and residues from prior construction.

One solution to the constricted planting well is the conical or truncated design shown on Figure 3. An alternate method is to plant trees in above-ground containers to avoid the problems of compacted soils. Still another method is to create a trench or space large enough (i.e., 36 by 96 by 36 inches deep) in which several trees could be planted together. This would allow root growth to occur in the upper soil horizon without immediately contacting compacted soils.

Parking Lot Structural Requirements

The following is an overview of existing parking lot technology regarding construction and layout. The National Stone Association's "Design Guide for Parking Areas" lists parking lots with medium light traffic (considerable in-out movement, some small trucks) as DI-2 (design index - 2). Based on U.S. Army Corps of Engineers' design charts, a compacted crushed stone base for a DI-2 parking lot should be 6 inches thick with a 2-inch thick bituminous paving overlay (Figure 4). These figures are used where the subgrade soil is rated as good (Table 6) (National Stone Association 1985, 16-17). The data in Table 6 indicate that a combined crushed stone and paving thickness of 11 inches is required

Fig. 3. Truncated Design Planting Well

where the subgrade soil is rated as fair. The literature does not indicate the depth of compaction that occurs to either the good or fair subsoil. For purposes of this thesis, it has been assumed that the subgrade soil is compacted equal to or greater than the paving and compacted gravel above it.

Based on calculations in Table 6, "good" soil for DI-2 requires an 8 to 16 inch depth of compaction of the subgrade soil. For a DI-2 parking lot built on "fair" soil, an 11 to 22 inch depth of compaction is required of the subgrade soil.

By adding the compacted subgrade soil (CSS) figures to the Total Pavement Structure (TPS) figures we come up with Total Depth of Compaction (TDC) figures. These figures delineate the total depth to which compaction occurs in a parking lot.

<u>Good Soil</u>	<u>Fair Soil</u>
8" TPS	11" TPS
8-16" CSS	11-22" CSS
16-24 TDC	22-33 TDC

It is apparent from these figures that planting wells need to be sufficiently large and deep to provide the volume and depth of soil required for roots to grow vigorously. Trees planted in restrictively small planting wells have stunted roots and become stunted; tree death can result (Hightshoe 1978, 88).

Parking lot construction methods are responsible for compacting the subsurface soil. Even those areas that are dug up for light standards and drainage areas do not experience appreciable loosening of the soils. The National Stone Association Design Guide states that all trenching operations for drainage pipe and electrical conduit should be completed at the earliest stages of parking lot construction, backfilled, and compacted properly to prevent future settlement of the paved surface (National Stone Association 1985, 4). Parking lots are areas of high soil compaction that eliminate water and air pore spaces from

Fig. 4. Structural Requirements for DI-2 Parking Lot

TABLE 6
PAVEMENT DESIGN BY SUBGRADE SOIL CLASS

Subgrade Soil		Design Thickness, Total Pavement Structure (inches) for Indicated Traffic Intensity Categories					
Class	CBR	DI-1	DI-2	DI-3	DI-4	DI-5	DI-6
Excellent	15+	5.0	6.0	7.0	8.0	9.0	10.0
Good	10-14	7.0	8.0	9.0	10.0	11.0	12.0
Fair	7-9	9.0	11.0	12.0	14.0	15.0	17.0
Poor*	3-6	13.5	16.5	18.5	20.5	23.0	26.0
Any class, minimum asphalt surfacing thickness (in)		1.0**	2.0	2.5	3.0	3.5	4.0

* Poor soils should be upgraded by means of stone stabilization at the rate of 100 to 300 lbs/sq yd or capped with subbase material to improve support to fair or better class.

** Use surface treatments, or increase to 1.5 inches including a prime coat on the compacted stone base if hot mixed asphalt is preferred as the surface.

Source: National Stone Association, Design Guide for Parking Areas (Washington, D.C.: National Stone Association, 1985), 17.

the soil. These soils present the roots of trees with a medium in which they cannot grow.

Retrofitting Parking Lots

Planting trees in existing parking lots would be most compatible by accommodating them to existing parking spaces and orientations. The cost to reorient and convert the spaces would be prohibitive. Perhaps 10% of existing parking lots would be reoriented with proper lighting and trees installed by their owners. Among the changes the author considered in retrofitting parking lots with trees are the following:

1. Are entrances and exits designed in a manner that does not impede traffic flow?
2. Do lighting standards need to be reoriented, replaced, or receive supplemental units for the new layout to provide adequate lighting?
3. Will all lighting have to be replaced with under-the-canopy standards?
4. Will removing and relocating direction marking signs be necessary?
5. Is the parking lot surface angled to direct surface runoff water and does this need to be repaved for the newer layout?
6. Do existing planting wells and trees need to be removed and relocated or the planting wells enlarged?
7. Do existing parking space designations need to be removed and reapplied in the new layout?
8. Can a small or ribbon-shaped parking lot be reoriented at all?
9. Will trees being added to the parking lot remove too many parking spaces?
10. Will the parking lot surface be repaved with light-colored paving materials?

Berms can be placed around the perimeter of the parking lot to provide a visual break from the street traffic and to raise the height of trees planted on them. Increasing the height of trees above the parking lot surface increases the amount and length of shadow produced during early morning and late afternoon periods. Aesthetic screening of the buildings from street traffic occurs sooner than if the trees are planted at the same level as the parking lot.

The berm also provides more uncompacted soil in which the roots can grow than might a flat planting well parallel to the parking surface.

Cement pipe planters can be set on top of the pavement for planting of shorter trees. A 3-foot-high cement pipe planter can support a tree 15 to 20 feet in height. A number of tree species such as the Feather Tree and Honey Mesquite that are otherwise too short and of marginal use become usable with this method.

CHAPTER 8

ALTERNATIVE PARKING LOT DESIGNS

Several alternative, ecologically oriented, parking lots have been designed and constructed in the United States. Each is compared and evaluated below with respect to the principles developed in this thesis.

City of Dayton, Ohio

In 1981, The City of Dayton, Ohio, funded the construction of an experimental parking lot composed of precast concrete blocks overlaying compacted earth (Spirm 1984, 81). The open spaces in the concrete blocks were filled with soil and planted in grass creating a uniformly open pattern of pavement with limited trees, grass, and concrete. The high albedo of the precast concrete and the solar absorption of the vegetation reduced air temperature 4°F (2.2°C) when compared to a nearby asphalt parking lot. The grass converted some of the incoming solar radiation into energy for plant growth. The precast concrete had a high albedo which reflected solar radiation back into the atmosphere. The lot was called the Green Parking Lot Project (Smith 1981, 1). I contacted the City of Dayton in November of 1989 and was told that the lot had been converted to another use. Prior to the lot's removal, however, it had been conclusively demonstrated that vegetation can aid in cooling parking lots.

Cook College Campus, Rutgers University, New Brunswick, New Jersey

Cook College conducted a study in a parking lot to compare balled and burlapped to bare-root *Acer rubrum* L. and *Fraxinus pennsylvanicum* L. (Heisler et al. 1982, 1). In the experiment, planting wells were dug 2.6 meters by 2.6 meters by 45 centimeters deep (101 inches by 101 inches by 10 inches). One hundred percent of the trees survived the transplanting, although some trees grew better than others. The results indicated that soil moisture is generally the most important factor in plant survival and growth. The bare-root

and the balled and burlapped trees grew equally well, although the bare-root trees were less expensive to purchase. The following quote fairly well summarizes the point of this thesis (Heisler et al. 1981, 6): "Parking lots seem to be promising sites for establishment of Urban Forests . . . at least where good quality planting soil is used in adequate planting openings and where soil moisture is ample, survival and growth should be excellent."

University of Delaware, Newark, Delaware

In 1973, the University of Delaware created an ecological parking lot based on a design by Edward R. Bachtle and Associates (Robinette 1976, 63). The plan provided for a tree canopy coverage of approximately 40% of the total asphalt area. The design stipulated porous asphalt paving with light-colored aggregates. These materials were used to increase water recharge to the water table and to lower solar heat absorption.

Mr. Roger K. Bowman, Grounds Supervisor, was contacted by this author in February of 1990. He reported that in 1973, Willow Oaks of 2 to 2-1/2 inches dbh were planted down the center of the lot and had achieved a size of 6 inches dbh. The planting well is about 8 feet wide and runs the entire length of each parking row. They have not experienced surface root problems of any type. Reflected sunlight from the light-colored asphalt does not seem to cause problems to the underside of the leaves. There is no protective covering over the soil, and from the photographs he provided, the trees appear to be planted on a berm approximately 3 inches higher than the pavement. Soil compacting does not seem to be a problem, although it has been in other lots at the University. Mr. Bowman stated that the lot holds the cold longer than traditional lots. Maintenance costs on this lot are low, and construction costs may actually be less when compared to more traditional lots with their catch basins, pipes, and other structures necessary to direct storm water runoff. Mr. Bowman attributed some of the slow tree growth to the use of native soils with no specially aerated planting mixes. From the photographs, it appeared that it will be another 15 to 30 years before the approximate 40% canopy coverage is attained.

Miles Laboratories

In 1961, Miles Laboratories created a parking lot design for the company's various facilities. The company was interested in building parking parks, rather than parking lots. The design was based on the philosophy that mobility is a fact of modern life, and the car, in its ever-increasing numbers, is creating further environmental imbalances because of the ever-increasing requirements for parking. The design published in Miles' 1971 book was a revision of the 1961 design and was based on their evolving philosophy incorporating intangibles such as beauty, good citizenship, environment preservation and enhancement, and water conservation (Robinette 1976, 69).

The Miles lot design incorporates the addition of improved soil mixes, with gravel being used in the soil and as a mulch ground cover. Parking lot water and snow are drained into the planting trenches where gravel channels on each side of the planting trench intercept the water runoff and return it to the ground water table. The planting trench is 8 to 10 feet wide and accommodates trees, light standards, and drainage channels. This parking lot concept most closely approximated the principles and philosophy presented in this thesis (p. 30).

Analysis of Alternative Parking Lots

City of Dayton, Ohio. The Green Parking Lot experienced a number of problems with the precast concrete turfstone. Its installation in the parking lot, its maintenance problems, and its performance in inclement weather showed it to be a poor choice (Smith 1981, 4-7). The use of turfstone materials only for aisleways in a parking lot might make sense. Its use in car parking spaces would allow oil and fuel spills to contaminate the ground water supply. It is impractical for pedestrians to push carts or strollers over its rough surface. The lot design was innovative and clever in its incorporation of many techniques to improve tree viability and to create a cooler environment, such as grass growing in dirt spaces, moisture passing down through the soil, and gaseous exchange from roots to the

atmosphere through the turfstone. The lot did not provide me with many usable ideas for purposes of this thesis.

Cook College, Rutgers University. The Cook College study (Heisler et al. 1982, 1) involved evaluating whether trees grew better from bare-root or balled and burlapped stock. The experiment also included a planting well design that was dimensionally close to that proposed in this thesis. Also in agreement with this thesis is the statement that parking lots are promising sites for the establishment of Urban Forests, although the extent of coverage for solar interception was never a consideration in their research. There was some addition of fertilizers to the soil, but this provided mixed results and was discontinued by the experimenters. They did, however, have a clever planting well orientation for parking lots: they rotated the box well design to form a diamond which affects the parking space less.

University of Delaware. The University of Delaware's ecological parking lot did attempt to address several environmental issues: ground water recharging, lowered temperatures through the use of light-colored paving materials, and absorption of solar radiation by trees. The majority of what they attempted has been accomplished. However, although the trees are living they do not seem to be vigorously growing. This could be the result of planting instructions which recommended tamping the soil very tightly and planting wells that are only 2 feet deep and 3 feet in diameter. Surely the roots are encountering compacted soil. Rootbound trees produce stunted trees (Robinette 1976, 66). It would be interesting to install in this lot some of the planting wells and aerated soil mix proposed in this thesis to compare tree growth differences.

The researchers believed that a factor contributing to the reduced health of their trees may have been the use of soil from the parking lot itself. This soil may have been compacted and/or may have been low in the proper nutrient levels and humus.

Miles Laboratories. The general layout of the Miles lot exhibits clear thinking on a broad range of issues, among them the mixing of gravel within the planting trench and its

use as a mulch covering the soil; and the installation of light standards beneath the tree canopy on 10-foot-tall standards. The planners were innovative and creative in their concepts, and they addressed more items than in all of the other lots combined. They deserve to be complimented for all that they have accomplished. Yet they failed to address other key issues.

There was no clever or innovative thinking regarding orientation of parking stalls to improve the overall shading of the parking lot by the tree canopy. They captured water from the surface of the lot and deposited it alongside the tree's roots. Flooding trees' roots and the introduction of gasoline and oil residues are hazardous to trees, the soil, and the ground water supply. In addition, the planting wells seem to be both too narrow and too shallow, although the width might be adequate if the water drainage basins directly adjacent to the trees were included (Robinette 1976, 78). But the water drainage basins actually negatively affect the planting trench. Also, neither the developers of this lot nor any of the others considered pedestrian safety as a component of their studies.

None of these experimental parking lot designs were sited in the dry Western U.S., a region where tree viability requirements will be quite different from those in the Mid-West or East Coast areas. Aridity is the most important factor in the West, followed by warmer winters and summer temperatures. The layout, planting well size, compaction of soils, and human safety issues remain constant over all regions.

CHAPTER 9

RECOMMENDATIONS FOR PLANTING TREES IN PARKING LOTS

Investigation by the author reveals that the average percentage of tree canopy coverage in the existing parking lots studied in the local area is less than 20%. The parking lots described in this chapter were measured during the summer of 1991 in San Jose, Milpitas, and Fremont, California. Each provides an example of a particular type of facility (electronics manufacturing, restaurant, shopping center, government facility, hospital, and industrial yard) and each lot contained at least a few trees (lots with no trees were not measured).

On subsequent pages, each of the identified parking lots is depicted in two ways: as it existed at the time the measurements were taken; and as it would look if planting recommendations in this paper were incorporated. The combined effect of incorporating these recommendations would be an increase in canopy coverage and a reduction in parking lot surface area exposed to sunlight. If parking spaces were reoriented and tree planting recommendations were implemented, a further increase would occur.

It is recommended in this thesis that trees have at least an 8- to 10-foot height to the first crotch. Consequently, all reconfigured depictions will be with trees of this size or larger. This will result in greater coverage of the lots than they currently exhibit. In many cases, these trees were constrained from vigorous growth by small planting wells. This condition will also be corrected in the reconfigured depictions.

Existing Lot Configurations

Alexian Brother's Hospital. The hospital lot in San Jose (Figure 5) exhibited a combination of designs. The south lot contained ash trees in 36-inch-square planting wells. The northeast lot had no trees and used angled spaces throughout, whereas the south, northwest, and north lots were 90° opposed. The northeast and northwest lots had

Fig. 5. Alexian Brothers Hospital - Existing Parking Lot

large pines surrounding them and casting large shadows. The northwest lot also had several camphor trees. The north lot used pines here and there to create visual barriers rather than to cool or break up the space throughout the lot. There was a limited mix of species and mixed watering.

Avantek. In Avantek's Milpitas parking lot (Figure 6), most trees grew in large berms around the perimeter of the property. In the back, west parking lot, the trees were growing well in both trenches and planting wells. The ash trees were cracking the curb sides of their 60-inch-square planting wells. This portends more serious problems for the ash trees in Cadence's 36-inch-square planting wells (below). Pines were planted on the berms in the east and south areas. Ash was planted on the north side of the lot where the trees create no shadows. The lot is watered.

Brandon's. Brandon's parking lot in Milpitas (Figure 7) utilized trees that will never provide much coverage. Plums in the center trench and liquid amber on the end wells were not sited or sized to produce much shielding of the parking surface. This lot seemed to exhibit a purely decorative use of trees and it appears that few trees were used so that the view of restaurant would not be obstructed. Pines were planted on the north side berm adjacent to the lot for aesthetic purposes only.

Cadence. Cadence's parking lot in San Jose (Figure 8) was well laid out for coverage although the planting wells were smaller than this author recommends and are smaller than Avantek's 60-inch planting wells for the same species. They did cover the exposed soil with 3-inch-plus diameter rocks. Trees in the lot were ash, pear in the end planters, with pines on the north grass strip area. Planting wells in the lot were too small and needed to be larger because the tree roots will uplift the asphalt and break the planting well curbs. The lot is watered.

Fry's Electronics. Fry's Electronics in Fremont (Figure 9) utilized medium-sized sycamore trees to obtain coverage. Trees in the lot were camphor, sycamore in the end

Fig. 6. Avantek - Existing Parking Lot

Fig. 7. Brandon's Restaurant - Existing Parking Lot

Fig. 8. Cadence - Existing Parking Lot

Fig. 9. Fry's Electronics - Existing Parking Lot

planters, with a variety of pines, redwoods, and elder on the periphery. The camphors were quite small. Most parking lots, including this one, could be oriented to provide for north-south orientation of the planting wells. The lot was watered.

Piedmont Hills High School. This San Jose high school (Figure 10) utilized liquid amber in 78-inch by 92-inch planting wells with no watering. Trees in the south lot were far apart and represented a monoculture. The bus lane and island had no tall trees, for bus clearance, at the interface zone. The northeast faculty lot had no trees at the sidewalk to parking lot and parking lot to grass zones. The northwest lot had too few trees and no trees at the parking lot periphery zones. Large trees to the north and west on the northwest lot would cast larger shadows if they were at the parking lot interface. The trees appeared unhealthy, with many sick and dying, and several dead. Redwoods and pines were planted to the north and west of the northwest lot 15 to 20 feet from the edge of the parking lot where they only cast shadows in the early evening. There was almost no mix of species.

Safeway-Longs. The parking lot serving Safeway, Longs, and many small shops in San Jose (Figure 11), had numerous aisles running through and around it. Plantings within the lot were few, but the Chinese elms were large. In several places, the elms were planted in 3-foot-high, 87-inch-diameter pipes to raise them up and protect the trunks. There was an insufficient mix of species. Planting wells were large, 12 feet by 16 feet, and there was no evidence of watering. Trees were planted on the north border of the lot for aesthetic screening purposes. Trees were too far apart and were not planted at the periphery interface to the parking lot. There were no plantings at the interface of the lot to the sidewalks in front of the stores. Parking spaces were angled but the aisles were large and encouraged two-way traffic in the aisles.

U.S. Post Office. The post office on Lundy in San Jose (Figure 12) utilized light-colored asphalt. The south parking lot measured constituted about 1/16 of the area behind a locked fence for additional parking, large mail truck loading, and unloading, plus parking

Fig. 10. Piedmont Hills High School - Existing Parking Lot

Fig. 11. Safeway-Longs - Existing Parking Lot

Fig. 12. U. S. Post Office - Existing Parking Lot

for mail delivery vehicles with few trees. The south lot utilized ash trees planted in trenches that were somewhat narrow. People walked on the exposed dirt and roots could be seen at the surface in the 42-inch-wide trench. There was no mix of species. Trees in the southwest and south parking lots were ash with a mix of liquid amber and redwoods near the street in a grass and berm area. The north parking lot's trees were small but were predominantly liquid amber. Light-colored asphalt materials were used. The planting wells/trenches in the north lot were too small for vigorous tree development. No trees were planted at parking lot/building interface zones.

The north lot was unimaginative with planting wells 36 inches square and trenches 46 inches wide and as long as the adjacent parking row. This lot was very large, but was smaller than the truck loading areas behind it. The lot consisted of predominantly liquid amber with a mixture of ginkgo and a few other trees. All trees were small, 10 to 16 feet tall, and there were only 84 trees total in the 375-foot by 383-foot lot.

Yellow Freight. Yellow Freight's parking lot in San Jose (Figure 13) consisted of large planting trenches 9- to 10-foot wide, with eucalyptus. The south side had several ash trees in a similar trench. All trees are on the periphery but not at the parking lot/periphery interface. The trees were planted 5 or 6 feet back from the parking lot edge. All areas were watered. None of these trees will be exceptionally tall at maturity.

Zitel. In Zitel's Milpitas parking lot (Figure 14), the oak trees grew best where the wells were larger and where the trench plantings had a box addition that expanded the planting well at that point. The planting trenches were too narrow and the ivy competed for nutrients and water. The trees on the south end wells were not healthy. There were no trees planted at the interface between the parking lot and sidewalks and periphery. The lot was watered.

Fig. 13. Yellow Freight - Existing Parking Lot

Fig. 14. Zitel Corporation - Existing Parking Lot

Items to Incorporate into Reconfigured Lots

Reconfigured parking lots will adhere to the following guidelines:

1. Parking surfaces are to be repaved with light-colored asphalt materials.
2. Plantings wells and plantings trenches are to conform to the sizes prescribed in this thesis.
3. Properly aerated soil mix is to be used in all planting wells and trenches.
4. Trees used will have a height to the first crotch of 8 to 10 feet.
5. Tree height and breadth of canopy are to be factored into the design layout of each parking lot and for tree selection within same.
6. Trees are to be planted on approximately 30-foot centers.
7. Trees are to be planted at the interface of the parking lot and at all areas bordering it.
8. Rows of trees should be oriented north-south wherever possible.
9. Trees are to be mixed species with an 0:20 or 70:30 mix of deciduous: evergreen.
10. Light standards 10-feet tall are to be installed in tree space rows midway between the trees.
11. The use of curbs and their height are determined by their location: within the lot, at the interface between the parking lot and all peripheral areas, and the slope of the lot for water runoff. Grates should be on the same plane as the surrounding surface unless surface runoff water is being directed toward it.
12. Steel grates are to be used within the parking lot where car tires could make contact with the planting well grate. Cement gratings may be used elsewhere.
13. Parking spaces should be angled at 45° or 60° in most areas.
14. Single aisle parking rows are to be used wherever possible.
15. Compact-sized vehicle parking spaces should account for 70% of the parking spaces with 30% accounting for regular-sized vehicle parking spaces.

16. Safety and viewing of people and stores is of prime importance in tree selection and placement within the lot.
17. Directional signs should be visible, lighted, and clearly marked.
18. Trees will be given deep watering for several years after planting in order to develop deep roots.

Suggested Changes in Each Lot

Each of the lots measured requires implementation of most of the following suggestions to achieve the coverages shown in the redesigned lots below. These lots are large and can accommodate 200 to 300 trees in their nearly 4 acres of combined area.

1. Increase variety of species.
2. Use an 80:20 or 70:30 ratio of deciduous to evergreen trees.
3. Plant trees at the interface between the parking lot and sidewalks; plant grass areas and the periphery using medium to large trees.
4. Plant trees within the parking lots on approximately 30-foot centers using medium to large trees.
5. Use planting wells and trenches with grates as depicted in Figures 2 and 3 (Chapter 6).
6. If reorientation of parking spaces is not desired, then increase the density (as in the Cadence lot) which can be done relatively easily.
7. Resurface the parking spaces with light-colored asphalt.
8. Place lighting on 10-foot standards in tree rows between trees.
9. Provide deep watering of trees for several years after planting to facilitate deep root growth.
10. Use 50- to 60-foot tall trees on the east and west sides and in the middle of large parking lots to create long shadows during early morning and late afternoon.

Trees shown in the following redesigned lots have 15-foot canopy diameters. As they mature to 30-foot crowns, the percent of canopy coverage in the lot will double.

Alexian Brothers Hospital (Figure 15). In general, the north and northeast parking lots are large areas with no or few trees within them. All Alexian lots could benefit from improved canopy coverage and tree viability by planting trees in all areas not covered in Figure 5.

Avantek (Figure 16). Ribbon parking lots to the north, east, and south specifically require suggestions 3 and 6 (above) to cover large areas of asphalt. The lots would benefit from long shadows created by tall trees in the center of each north-south oriented row of the three-tree planting configuration. The west lot would benefit most from a Cadence-style tree layout (Figure 8).

Brandon's Restaurant (Figure 17). The ribbon parking lot to the east requires suggestions 3 and 6 to cover a large area of asphalt with no trees. Liquid amber and plum trees provide scant shade due to the size of those trees. With only one acre of area and approximately 80 proposed trees (in the new configuration), the use of tall trees is limited to areas away from the restaurant.

Cadence (Figure 18). The lot is large enough to incorporate tall trees. Trees for the sidewalk and in the middle of the lot, with a north-south orientation to provide morning and afternoon shadows, need only be high enough to let pedestrians walk beneath them.

Fry's Electronics (Figure 19). The planting trenches need enlarging. The use of 50- to 60-foot high trees on the east and west ends of the lot and in planting wells on both driveways will produce long shadows in the early morning and late afternoon.

Piedmont Hills High School (Figure 20). The south parking lot would benefit from long shadows created by tall trees in the center of each north-south oriented row of the three-tree planting configuration. Tall trees could also be planted on the east and west peripheries of the lot for the same reason. Trees along the bus loading lane and island need

Fig. 15. Alexian Brothers Hospital - Proposed Parking Lot

Fig. 16. Avantek - Proposed Parking Lot

Fig. 17. Brandon's Restaurant - Proposed Parking Lot

Fig. 18. Cadence - Proposed Parking Lot

Fig. 19. Fry's Electronics - Proposed Parking Lot

Fig. 20. Piedmont Hills High School - Proposed Parking Lot

to be tall enough to clear the height of the buses. The faculty lot and bus lane in the north parking lot have the same tree height requirement.

Safeway-Longs (Figure 21). Use of the existing lot orientation provides insufficient canopy coverage. The lot would benefit from long shadows created by tall trees in the center of each north-south oriented row. Trees should be planted at the edge of the lot adjacent to the parking spaces. The lots in front of both Safeway and Longs have aisles pointed toward their stores (east-west and north-south oriented, respectively) resulting in less coverage in the Safeway lot.

U.S. Post Office (Figure 22). The trees in the south and north lots at the east and west peripheries should be tall to provide early morning and late afternoon shadows.

Yellow Freight (Figure 23). Tall trees could be planted in the lot in a manner that allows for backing trucks up to the docks. Tall trees in raised planters could be planted between the loading docks at the building/parking lot interface. Periphery trees should be the tallest and broadest crowned possible. The practical application of additional trees within the yard area is limited due to trailers being parked perpendicular to the periphery and the movement of trucks to the terminal.

Zitel Corporation (Figure 24). A Cadence-style layout would dramatically increase the canopy coverage as would planting trees along the periphery at the parking lot interface zone. Planting tall trees in the trenches and at the east and west peripheries at the center of north-south oriented rows would provide early morning and late afternoon shadows.

Fig. 21. Safeway-Longs - Proposed Parking Lot

Fig. 22. U. S. Post Office - Proposed Parking Lot

Fig. 23. Yellow Freight - Proposed Parking Lot

Fig. 20. Zitel Corporation - Proposed Parking Lot

CHAPTER 10

PARKING SPACE SIZE AND LOT LAYOUT

The following parking lot configurations provide variations of parking lot designs and the terminology associated with them (example shown in Figure 25). The layouts are intended to familiarize the reader with alternative layouts and space requirements of each (National Stone Association 1985, 7-11). Table 7 lists recommended minimum requirements for cars, by facility type.

The parking spaces depicted in Figures 26 through 32 are typical design requirements for standard sized cars, showing space requirements depending on single or overlapping row configurations. Standard size car spaces are 8 feet 6 inches wide by 19 feet long. Small car spaces are 7 feet 6 inches wide by 15 feet long. With automobiles being manufactured smaller than they were in the 1960s, it would seem appropriate and timely that our parking space designs reflect this reality. An example of this need for redesign is provided by student parking areas. In a four-year high school, freshman outnumber seniors. For the purpose of modeling, the assumption is made that all four grade levels are equal in population. Table 7 indicates one parking space per room, which covers the faculty and administrative personnel. It indicates one parking space per ten students, which is very deceiving. A 1,200 student population, for example, divided by four grades equals 300 students per grade level. Usually only junior and senior grade level students are old enough to qualify for a license. One space per ten students equals 120 parking spaces. This computation actually indicates that there are 120 parking spaces for 600 potentially licensable drivers or one space for every five students.

Schools in particular, and commercial buildings in general, should increase the number of small car spaces. Up to 80% of their automobile population is composed of small sized

Fig. 25. Parking Lot Configuration Terminology

TABLE 7
RECOMMENDED MINIMUM PARKING SPACE REQUIREMENTS

<u>Type of Facility</u>	<u>Criteria</u>
Theaters, auditorium, etc.	1 per 3 seats
Motels	1 per room*
Retail stores, general office use	1 per 300-400 sq ft of net leasable area
Hospitals	1 per bed*
Restaurants	1 per 300 sq ft
Trade schools	1 per 3 students
High schools	1 per classroom plus 1 per 10 students
Medical office/clinic	1 per 175 sq ft of gross floor area
Industrial plants	1 per 1,000 sq ft plus 1 per 350 sq ft of office space
Nursing home	0.5 per bed

* Additional parking must be provided for ancillary uses.

Note: Minimum recommendations as made by the Parking Consultants Council of the National Parking Association, Washington, D.C., 1981.

STANDARD SIZE CARS

N	S	A	C	U	S'	U'
90°	19'0"	24'0"	9'0"	62'0"	19'0"	62'0"
60°	21'0"	18'0"	10'5"	60'0"	18'9"	55'6"
45°	19'10"	13'0"	12'9"	52'8"	16'7"	46'2"

Fig. 26. Key for Standard Parking Space Layouts

Fig. 27. Standard Parking Space Layout - 45° U'

Fig. 28. Standard Parking Space Layout - 45° U

Fig. 29. Standard Parking Space Layout - 60° U'

Fig. 30. Standard Parking Space Layout - 60° U

Fig. 31. Standard Parking Space Layout - 90° U'

Fig. 32. Standard Parking Space Layout - 90° U

cars. Yet in many lots, allocation of compact or small car spaces account for less than 30% of all parking spaces (National Stone Association 1985, 5).

In considering how to provide maximum tree canopy coverage, it is essential that we either reduce the parking space or use very large trees. It would be easier to reorient parking spaces, reduce aisle widths, and shrink parking space sizes than it would be to grow very large canopied trees. The list of potential trees that possess the characteristics demanded of Western U.S. parking lot environments is relatively small (this list is provided in Chapter 12). However, through proper parking lot design and tree species selection, the overall goal of reducing SUHIs can be achieved.

Note that Figures 33 through 39 have been redrawn to reduce the overall size of aisles, etc. Contrast this small sized car design with that of the standard sized car designs in Figures 25 through 32. This comparison does not imply that all spaces within a parking lot can or will be converted to those for small cars only. A reasonable ratio of small vehicles to standard sized vehicles is 80:20 or 70:30. This change alone would add parking spaces to a lot. These ratios are in keeping with current consumer trends and the general downsizing of cars by the automobile industry.

Practically speaking, the reconfiguring of parking lots would have standard sized car spaces located on the outer perimeter of the lot farthest from the stores. This arrangement reduces the movement of large cars through the narrower aisles of the small car parking areas. It also allows pickup trucks and vans to move about without interference with overhead branches or tight corner radii. Parking spaces on the perimeter are shaded by large trees planted on berms.

Figure 40 depicts an alternative layout that marginally reduces the total number of parking spaces. It does, however, provide for >90% tree canopy coverage with medium sized trees (trees with 30-foot-diameter canopies).

COMPACT CARS

N	S	A	C	U	S'	U'
90°	15'0"	15'0"	7'6"	45'0"	15'0"	45'0"
60°	17'0"	15'0"	9'6"	49'0"	13'6"	42'0"
45°	13'0"	15'0"	8'0"	41'0"	13'0"	41'0"

Fig. 33. Key for Compact Parking Space Layouts

Fig. 34. Compact Parking Space Layout - 45° U'

Fig. 35. Compact Parking Space Layout - 45° U

Fig. 36. Compact Parking Space Layout - 60° U'

Fig. 37. Compact Parking Space Layout - 60° U

Fig. 38. Compact Parking Space Layout - 90° U'

Fig. 39. Compact Parking Space Layout - 90° U

Fig. 40. Alternative Layout to Reduce Number of Parking Spaces

A variety of trees can be used in any of the parking lot designs. Their size at maturity helps to determine the amount of coverage of the parking area. Their years to maturity will determine the coverage they will provide as a function of time. Trees that provide 50% coverage in one layout may provide 60% coverage in another.

Gary O. Robinette, a well-respected member of the American Society of Landscape Architects, is the author of many landscape books. One of them is Parking Lot Landscape Development (1976). The majority of the examples presented in the book are beautifully illustrated and possess high aesthetic quality. They do not, however, address tree coverage from the perspective of cooling SUHIs. He cites the University of Delaware's "ecological" parking lot as one which addressed a tree canopy coverage of around 40%. As previously described, the trees are growing very slowly and the coverage is less than anticipated.

In Robinette's book, the primary emphasis in parking lot landscaping is geometric designs for aesthetic tree plantings. Trees are used to screen, shield, or block things like storage areas, parking lots, and unsightly views from people driving by. The distribution and location of trees depends generally on the view it will present to pedestrians and motorists. The trees provide a certain amount of shade and cooling in spite of the parking lot design. Trees are not considered, in the design, as modifiers of the microclimate for pedestrian comfort by most landscape architects or planners.

The following list provides criteria for tree placement in generic parking lots.

1. Orient the rows of trees within the parking lot in a north-south direction for maximum shade production during early morning and late afternoon summer days.
2. Place low berms along the perimeter between the streets and the parking lot. This reduces the street noise and provides a planting area where very large trees have sufficient room for growth.

- a. Select trees for perimeter planting spaces that are tall and full-canopied when mature and are drought-resistant.
 - b. Distribute tree plantings on a 70% deciduous and 30% evergreen basis to provide shade in summer and light in winter.
3. Designate perimeter parking spaces for pickup trucks, vans, and standard sized cars. This placement reduces large vehicle movement within the inner lot areas with their lower tree clearance and tighter turning areas.
 - a. Orient parking spaces 45° or 60° to the aisles to narrow the aisle width.
 - b. Designate aisles for one-way traffic and make them larger than interior, small car aisles to accommodate emergency vehicles.
4. Design interior parking rows with openings midway down the aisle to allow drivers to turn into another aisle. Drivers have the option to proceed down an aisle or to cut over to another aisle going in the opposite direction.
 - a. Orient parking spaces 45° or 60° to the aisles.
 - b. Limit interior parking spaces to compact or small sized cars only to reduce aisle size and thereby improve canopy coverage.
 - c. Make entrance aisles and aisles directly in front of the stores wide enough to accommodate emergency vehicles.
 - d. Locate handicapped parking spaces directly in front of the stores on these aisles to accommodate small or standard sized cars.
5. Provide clearly marked information signs, to communicate where vehicles are to park and where stores are located, that are placed in highly visible locations at the lot entrance and along aisle ways below canopy level.
6. Plant large, clear trunked, and large crowned deciduous trees at all aisle corners to bridge the aerial space between the two corners. The height to the first crotch of

these trees should be 10 to 15 feet above the ground. Plant these trees in extra large planting wells to accommodate their root size.

7. Plant interior trees within the parking rows that are medium to large size with clear trunks and a height to the first crotch of 8 to 10 feet above the ground.
 - a. Distribute tree plantings on a 70% deciduous and 30% evergreen basis as in 2b above. Orient the rows, where at all possible, north-south as in 1 above.
 - b. Select trees with spreading to rounded canopies to provide maximum shade production.
8. Plant trees in close proximity, 25 to 30 feet between centers, to produce a larger shade canopy.
9. Place lighting under the tree canopy on 10-foot-high standards.
 - a. Alternatively, hang lights on wires down the middle of aisles under the canopy.
 - b. Direct lighting onto the parked cars, on pedestrian areas, and on aisles and corners.
 - c. Use low pressure sodium lights which provide sufficient lumens for safety and are less attractive to insects.
 - d. Provide lighting at all crosswalks and aisle intersections.
10. Construct pavement to drain away from planting wells and berms so that the soil does not become flooded or contaminated with oil, gasoline, or other chemicals.

CHAPTER 11

INDIVIDUAL FACTORS IN LOT DESIGN

Key factors that must be considered by designers of parking lots with trees are artificial lighting, water, air pollution, and high albedo pavements; as well as tree characteristics such as root problems, fruit bearing, brittle wood, or peeling bark.

Artificial Lighting

Artificial lighting for parking lots is being investigated for potential problems it may cause for trees. Mercury vapor lights accounted for 75% of the 12.5 million street and highway lights found on America's roads and are the same types of lights that are installed in many parking lots. Mercury vapor lamps emit radiation at 405, 436, 546, and 576 nanometers (U.S. Department of Agriculture 1975, 69). The wavelengths that trees use from the sunlight fall into the 380 to 760 nanometer range. Normally, light standards are placed high above the parking lot to project the maximum amount of light over the largest possible area at an affordable cost. Because these wavelengths are in the middle of the tree's absorbed range, trees can use these wavelengths for growth during the night. However, the amount of light emitted from these lights cannot compare with direct or slightly diffused sunlight.

Two situations can occur when light standards are placed too high above the pavement:

1. Any design with high density tree canopy coverage will not allow sufficient light to reach the ground for pedestrian safety.
2. The light shining onto the tree canopy may cause the trees to experience extended photoperiods which may be detrimental to the health of the trees (U.S. Department of Agriculture 1975, 70).

Trees require rest from the growing process. Light received during the night may precipitate growth-related problems. One concern for artificially lighted trees in the Eastern

U.S. is that trees may continue to grow at the onset of winter. This may cause tree damage from frost to occur or it may damage buds for the next year's growth (U.S. Department of Agriculture 1975, 71-72). This problem should not be serious at low elevations in C_{sa} or C_{sb} climates.

Lighting is best installed beneath the canopy. Lights on 10-foot standards spaced between the trees or lights hung from cables down the middle of aisles under the canopy are the two most practical solutions.

Water

When the roots of a tree are deprived of sufficient amounts of water, the tree becomes stressed, experiences water starvation, and may die. Channeling runoff rainfall into the planting wells (one possible solution) produces a multitude of problems. Trees may become subject to root rot if the water stands for too long in the planting well. The planting well can become a mud pit and soil from it can flow onto the paving surface. Large volumes of water flowing into the planting wells are liable to destabilize the compacted rock base under the pavement, causing expensive maintenance repairs. Gasoline and oil spills collect on the pavement surface in concentrated amounts. They would be channeled into the planting wells along with runoff water. Such contaminants could poison the tree, affect the pH of the soil, and contaminate the ground water.

Nonporous pavement in parking lots tends to seal in whatever moisture collects beneath it. This collected water may come from trees being watered, surface creeks nearby, natural subsurface water flow, or leaks from pipes. Trees planted in parking lots use this water or they may tap into high ground water and perched water tables. In most instances, trees living in parking lot environments have the advantage of not competing for water with grasses and other trees as do their forest counterparts. This is a significant difference, since most forest trees receive more shade and protection from the wind and therefore require less water.

Water for parking lot trees should be applied beneath the trees at a depth that is reachable by the roots but which is not disruptive to the pavement. A measured and regulated amount of water needs to be applied to young trees to foster good root growth. Allocation of existing supplies is divided among industry, farming, and residential users. Therefore, trees with low water requirements must be given preferential treatment in parking lot planning. The list of trees that will thrive in a parking lot environment in C_{sa} or C_{sb} climates would be larger if limited water availability was not an issue.

Many trees with high water requirements may be more familiar to the average person than those with low water requirements. These trees are generally large and easy to obtain, and they grow in more regions of the country than do trees with low water requirements.

Air Pollution

A tree's resistance or ability to tolerate air pollutants is a factor in tree selection. Carbon monoxide, carbon dioxide, polyaromatic nucleics, ozone, and a host of other chemicals are known to exist at high levels in urban areas. The tolerance of noncommercial tree species to these gases has not been well researched. Data have been gathered primarily through visual observations regarding the general health and vitality of certain species. Generally, the observations are those of urban foresters and nursery personnel. There have been a limited number of experiments performed under scientific conditions to study absorption and physiological responses to specific pollutants ((U.S. Department of Agriculture 1975, 343). The physical size of facilities and the length of time required for comprehensive research into these areas present a formidable obstacle. Moreover, most studies are conducted only on commercially important species. It would be impractical to build a facility large enough to enclose a large street tree. It would have to be moved to the tree location to monitor various gases applied to the tree and the tree's response. One could build glass enclosed modules, portable greenhouse structures, and monitor the tree's respiration under various conditions. It should remain in place for several years to build a

seasonal and yearly profile. Then the data would have to be compared to other similar species to see if the results of similar experiments produced similar results. This process would have to be replicated for each species studied and should be performed at other locations within the same city and in other climatological zones. If this were not done, the results attained would be too specific to a particular species at a particular spot within a specific city in a specific climatological zone. It would produce results applicable only to that area.

High Albedo Pavements

Studies by Akbari et al. (1989) have shown that light-colored, high-albedo pavements and surfaces aid in cooling pavements and buildings. Light-colored pavements should be required in all parking lot and street applications through city ordinances and by industry specification. During the first years of a new parking lot, the light-colored pavement will account for the majority of the cooling when compared to the young trees' shade production. As the trees mature and their canopy coverage and shadow production increase proportionately, they will produce the majority of the cooling. Ultimately, the light-colored pavement will be nearly shielded from the sun during the summer months.

Unfortunately, confusion and misunderstanding surround the issues of warmer cities and the warming of the planet. An example of this confusion is found in the response the author received from John W. Rugg, Jr., staff engineer at the National Asphalt Pavement Association. His misstatement follows: "studies have shown hot mix asphalt (HMA) absorbs heat because of its black surface and Portland Cement Concrete reflects heat due to its white surface. In theory, P.C.C. may reflect a significant amount of heat during summer days. This reflection of heat could be a major contributor to the increasing over-heat condition known as the Greenhouse Effect. Every weather forecaster around major cities acknowledges that downtown areas have temperatures of five to six degrees higher than surrounding suburban areas. This is probably caused by the heat being reflected by

the buildings, sidewalks and pavements which are mostly Portland Cement Concrete in the major cities . . . " (Rugg 1989). Architects, designers, and construction company owners do not interface with research scientists on a normal basis. The confusion between SUHIs and the Greenhouse Effect needs to be clarified and solutions for each made abundantly clear to those who are most intimately associated with planning and building our cities.

Parking lots have evolved from grass-covered land and livery stables for horses to bituminous-covered, compacted gravel areas for cars. They have gone from "no tech" to "low tech." Existing technologies could bring them into the high tech arena.

Shades or screens of porous, highly reflective, synthetic materials could be suspended high above the parking surface from poles. This shading would permit air to circulate beneath the cover and would allow filtered light to pass through it. Lighting of the area at night would be accomplished by reflecting light off the underside of the cover to background illuminate all parking spaces. The pavement could be any color since it would not be exposed to direct sunlight. Trees would not be required to provide cooling, which would increase the number of parking spaces and would eliminate costs for tree care.

Roots

Root problems are not discussed in great detail in this thesis because they can largely be mitigated by the recommended large plantings wells, aerated soil, and deep watering. Many trees are used for landscaping in lawns and other areas where water is applied frequently, for short intervals, at the surface. This encourages roots to grow near the surface. Irrigation water applied by pipe to an area 2 to 3 feet below the soil surface will encourage root growth downward during the early years.

Trees that grow in areas of good subsurface water develop roots that grow downward toward that source of supply (if there is adequate oxygen). A personal study of trees of the same species in two different water supply areas within the City of San Jose, California, substantiates this statement. Alum Rock Park is a hillside park with good streams and

subsurface water supplies. Trees in this park have no surface root disruption. The same species of trees near the City Hall are lifting sidewalks and curbs. Water in this area is not plentiful and is received by the trees from surface applications to lawns.

Chapter 3 includes a discussion of selecting planting well sizes to accommodate root growth.

Fruit

Fruit drop is a negative factor and excludes a tree from the acceptable list for parking lots. Fruit, whether hard or soft, is referred to here as that which is sufficiently large or abundant to cause a hazard or nuisance to pedestrians or automobiles.

Brittle Wood and Peeling Bark

Brittle wood and peeling bark limit a tree's use within a parking lot. Trees with brittle wood drop branches on cars and pedestrians. These problems do not exclude a tree from the enclosed list, however, because these trees may be used in large perimeter planting areas. Such areas do not have tree branches or canopies overhanging parking spaces.

CHAPTER 12

CRITERIA FOR PARKING LOT TREE SELECTION IN MEDITERRANEAN CLIMATE ZONES

The parking lot designs offered in this paper suggest planting a mixture of compatible species to prevent a monoculture. Many municipal foresters and other vegetative managers prefer physical and species uniformity of trees to facilitate planting and maintenance (U.S. Department of Agriculture 1975, 73). According to Frank Santamour, a good rule of thumb is that of the trees planted in the same area no more than 10% should be of the same species (Krakauer 1990, 171).

Other criteria for optimum tree selection and development in parking lot design are listed below.

1. Most trees within the lot should be deciduous to allow the sun to warm and brighten the area in winter. The ratio of deciduous to evergreen trees should be 70:30 or 80:20.
2. Most trees should have rounded or spreading crowns for maximum area coverage and interception of solar radiation.
3. Tree trunks must be protected from contact with vehicles if the trees are to survive.
4. Supplemental watering should be provided during the first five years of growth.
5. Trees selected for ground level plantings must have a minimum height, at the time of planting, of 10 feet to the first crotch for vehicle clearance and lighting requirements.
6. Moderate to rapid growing trees are preferred because they will achieve canopy coverage and cooling goals more quickly than will slow-growing species.

7. Trees with excess leaf drop, fruit, or sap drop should be avoided since they are potentially hazardous to pedestrians or damaging to vehicles.
8. Protection of the soil around the tree is critical to prevent soil compaction from adversely affecting tree growth.

The following are important characteristics to consider for trees to be planted in parking lots:

1. Drought tolerance.
2. Heat and aridity tolerance.
3. Ability to thrive in urban environments.
4. Moderate to rapid growth.
5. Pollution tolerance.
6. Shape of the tree canopy (rounded or spreading).
7. Crown spread 50% or more of height.
8. Thirty to 70-foot height at maturity.
9. Long life span.
10. Good root growth in compacted soil.
11. Low maintenance.
12. No adverse odor or messy fruit.
13. Disease and insect resistance.
14. Strong wood.
15. No tendency toward surface root problems.
16. Compatibility with other species within the lot (in terms of disease susceptibility, root space, and soil requirements).

Not all of these characteristics carry the same weight in each parking lot design.

Growth is only critical in relation to how fast the parking lot will be shielded. In many

cases, a life span past 30 or more years is not important since the buildings and parking lot may be torn down and something else built in their place.

Two impressive tree selection charts can be found in A Planters Guide to the Urban Forest (Tree People [1983], 55-65) and "Street Trees Recommended for Southern California" (Degan et al. 1983). Both of these charts list numerous characteristics and application-specific locations for the trees. They were easily readable and cross-indexed.

Tree Selection Process

The preponderance of American urban tree studies appear to have been conducted on species suited to the Northeastern quadrant of the U.S. The New Jersey Tree Commission has researched and sponsored many studies on trees in this area. Their concerns for climatic conditions in this part of the U.S. have little application to Csa and Csb climate conditions. They are concerned with snow, ice, and the windy conditions that exist when the first two weather conditions are present. Mediterranean Csa and Csb climates are concerned with heat and drought, where rain falls only several months a year. As valuable as the Commission's studies are to similar parking lot projects in the northeast and central regions of the U.S., they are not relevant to Mediterranean climates.

Many listings the author reviewed were of trees with commercial value. Often they were of species that would not grow in the West without large amounts of water (Grey and Dendke 1986, 129-134). Other lists reflected over-concern for the aesthetic qualities of a tree, giving them equal weight to the characteristics that make it suitable to urban conditions.

It is pragmatic to select the most viable urban trees for landscaping. It is prudent to learn how to landscape with the most visually pleasing of those trees. Creating the proper mix is the challenge of the planner.

Several books and their authors are noteworthy for their extensive work in the field of tree research. Each author was thorough and analytical in all of the details covered. The

amount of work involved in the accumulation and compilation was immense. The books are:

1. Plant a Tree: A Working Guide to Regreening America (Weiner, 1975).
2. California Native Plants with Commercial Sources (Saratoga Horticultural Foundation, 1979).
3. Native Trees for Urban and Rural America (Hightshoe, 1978).
4. Trees and Shrubs for Dry California Landscapes (Perry, 1981).

List of Suitable Trees

Trees suitable for planting in Mediterranean climate parking lots are listed below.

Detailed descriptions of their characteristics follow (alphabetically by scientific name).

<u>Common Name</u>	<u>Scientific Name</u>
Tree-of-Heaven (Female)	<i>Ailanthus altissima</i>
Chinese Toon	<i>Cedrela sinensis</i>
European Hackberry	<i>Celtis australis</i>
Italian Cypress	<i>Cupressus sempervirens</i>
Red Gum	<i>Eucalyptus camaldulensis</i>
White Ironbark	<i>E. leucoxylon</i>
Red Spotted Gum, White Gum	<i>E. maculosa</i>
Coolibah	<i>E. microtheca</i>
Willow-Leafed Peppermint	<i>E. nicholli</i>
Snow Gum	<i>E. niphophila</i>
Silver Dollar Gum	<i>E. polyanthemos</i>
Maidenhair Tree	<i>Ginkgo biloba</i>
Goldenrain Tree	<i>Koelreuteria paniculata</i>
White Mulberry	<i>Morus alba</i>
Desert Ironwood	<i>Olneya tesota</i>

Canary Island Date Palm	<i>Phoenix canariensis</i>
Canary Island Pine	<i>Pinus canariensis</i>
Coulter Pine	<i>P. coulteri</i>
Aleppo Pine	<i>P. halepensis</i>
One Leaf Pine	<i>P. monophylla</i>
Italian Stone Pine	<i>P. pinea</i>
Four Leaf Pine	<i>P. quadrifolia</i>
Chinese Pistache	<i>Pistacia chinensis</i>
London Plane Tree ('Yarwood')	<i>Platanus acerifolia</i>
S. American Thornless Mesquite	<i>Prosopis alba</i>
Coast Live Oak	<i>Quercus agrifolia</i>
Blue Oak	<i>Q. douglasii</i>
Holly Oak	<i>Q. ilex</i>
Valley Oak	<i>Q. lobata</i>
Cork Oak	<i>Q. suber</i>
Southern Live Oak	<i>Q. virginiana</i>
African Sumac	<i>Rhus lancea</i>
Black Locust	<i>Robinia pseudoacacia</i>
California Peppertree	<i>Schinus molle</i>
Brazilian Peppertree	<i>S. terebinthifolius</i>
Athel Tamarisk	<i>Tamarix aphylla</i>

Species Descriptions

Name: *Ailanthus altissima*, Tree-of-Heaven (Female), Deciduous.

Dimensions: 50 to 80 feet high, 35-foot spread, 1-1/2-foot diameter trunk.

Life Span: Long lived - 75 years.

Description: Green leaves on top, lighter colored leaves beneath. Tolerant of heat, wind, smog, drought, dusty cities, and smoky factory districts. Provides an ornamental, tropical tree appearance. Fast growing, aggressive, trees often growing out of cracks in concrete. Not susceptible to parasitic or other diseases. Can withstand roots being submerged in brackish water. Recommended for alleyways, dirty streets, and urban yards inhospitable to most other plant life. Male trees produce flowers with an objectionable odor. Pruning required. Wood sometimes is brittle and is best controlled by pruning.

Application: Within the parking lot or along the perimeter.

Name: *Cedrela sinensis*, Chinese Toon, Deciduous.

Dimensions: 50 to 75 feet high, 35-foot spread, 1-1/2-foot diameter trunk.

Life Span: Long lived.

Description: Broad leafed, producing dense shade. A hardy urban tree tolerant of stressful conditions and recommended for street use. Like *Ailanthus altissima* in characteristics ; tolerant of drought, heat, smog, dust, and poor soils, but the flowers do not produce the disagreeable odor. Fast growing. Prune for shaping.

Application: Within the parking lot or along the perimeter.

Name: *Celtis australis*, European Hackberry, Deciduous.

Dimensions: 40 to 75 feet high, 40-foot spread, 20-inch diameter trunk.

Life Span: Long lived.

Description: Dark green, broad leaves, rounded canopy similar to elms. Tolerates heat, drought, and is hardy for urban conditions and along highways.

Moderately fast growing.

Application: Within the parking lot or along the perimeter.

Name: *Cupressus sempervirens*, Italian Cypress, Evergreen.

Dimensions: 40 to 60 feet high, 5-foot spread.

Life Span: Long lived.

Description: Columnar shape, blue-green and dark green color. Good tolerance of heat, wind, smog, and drought. Prefers loose soils. Develops deep roots when watered deeply and infrequently when young. Moderately fast growing.

Application: Along the perimeter to create shadows and for screening purposes.

Name: *Eucalyptus camaldulansis*, Red Gum, Evergreen.

Dimensions: 60 to 140 feet high, 40-foot spread, 2- to 3-foot diameter trunk.

Life Span: Long lived.

Description: Green leaves, bark of trunk peels off in long strips. Very good tolerance of heat, drought, cold, desert conditions, wind, and alkaline soils. Produces large shadows morning and evening. Fast growing.

Application: Perimeter plantings to create long shadows.

Name: *Eucalyptus leucoxylon*, White ironbark, Evergreen.

Dimensions: 30 to 60 feet high, 30-foot spread, 1-1/2-foot diameter trunk.

Life Span: Long lived.

Description: Gray-green leaves, cream colored flowers, and white peeling bark. Prefers deep soils. Tolerates smog, moderate drought, alkalinity, and temperatures

to 18°F. Moderately fast growing. Pruning may be required to give structure.

Application: Perimeter plantings to create shadows.

Name: *Eucalyptus maculosa*, Red Spotted Gum, White Gum, Evergreen.

Dimensions: 50-70 feet high, 30-40-foot spread, 1-1/2-foot diameter trunk.

Life Span: Long lived.

Description: Gray-green leaves with clusters of small yellow-white flowers. White bark with patches of red and pale brown. Prefers sandy, well-drained soils. Will become chlorotic and die in alkaline/clay soils. Cold-hardy to 19-23°F. Best grown in groups like Birches. No pruning required. Open structure with drooping branches. Strong wood with little branch breakage. Fast growing. Drought tolerant.

Application: Within the parking lot or along the perimeter.

Name: *Eucalyptus microtheca*, Coolibah, Evergreen.

Dimensions: 40 feet high, 40-foot spread, 1-foot diameter trunk.

Life Span: Long lived.

Description: Gray-green leaves. Dense shade tree. Hardy to 10°F. Withstands desert conditions, heat, aridity, drought, and wind. Fast growing.

Application: Within the parking lot or along the perimeter.

Name: *Eucalyptus nicholli*, Willow-leafed Peppermint, Evergreen.

Dimensions: 35-40 feet high, 20-30-foot spread, 1-foot diameter trunk.

Life Span: Moderate lived.

Description: Light blue-green leaves 3-5 inches long. Crushed leaves smell like peppermint. Billowing, willowy form. Prefers well-drained gravel soils. Becomes chlorotic and dies in alkaline/clay soils. Cold hardy to 12-15°F. Wood is weak and limb breakage results. Fast growing. Drought tolerant. Requires no pruning.

Application: Along the perimeter to create shadows.

Name: *Eucalyptus niphophila*, Snow Gum, Evergreen.

Dimensions: 20 feet high, 10-foot spread, 6-inch diameter trunk.

Life Span: Short lived.

Description: Blue-green leaves. Very cold tolerant tree. Accepts wind and drought in all areas of California. Moderate growth.

Application: Along the perimeter in groupings for screening purposes.

Name: *Eucalyptus polyanthemos*, Silver Dollar Gum, Evergreen.

Dimensions: 30 to 80 feet high, 20- to 30-foot spread, 10-inch diameter trunk.

Life Span: Short lived - 40 years.

Description: Blue-gray foliage. Tolerates heat, aridity, moderate drought, and cold to 24°F. Prefers loose, well-drained soils. Does not do well in wet soils. Moderately fast growing.

Application: Within the parking lot and perimeter plantings to create shade and long shadows.

Name: *Ginkgo biloba*, Maidenhair Tree (Male), Deciduous.

Dimensions: 50 to 70 feet high, 20- to 40-foot spread, 2-foot diameter trunk.

Life Span: Long lived.

Description: Oddly shaped, dull green leaves. Accepts low and high desert and coastal conditions. Tolerates alkaline soils. Fully cold hardy. It resists dust, smoke, smog, drought, wind, ice, pests, and disease. Seeds of female have unpleasant odor. Shiny yellow leaves in the fall. Slow growing.

Application: Within the parking lot.

Name: *Koelreuteria paniculata*, Goldenrain Tree, Deciduous.

Dimensions: 20 to 30 feet high, 20-foot spread, 1-foot diameter trunk.

Life Span: 40 years.

Description: Leaves 8- to 14 inches long, yellow flowers in late summer. Prefers full sun and dry loam soils. Frost resistant. Slow to moderate growth. May develop surface root problems.

Application: Within the parking lot in above-ground cement pipe planting wells.

Name: *Morus alba*, White Mulberry (Fruitless), Deciduous.

Dimensions: 20 to 60 feet high, 40-foot spread, 1-foot diameter trunk.

Life Span: Short lived - 40 years.

Description: Large, dark green leaves with a rounded canopy. Hardy in cities, drought tolerant. Surface roots are prevalent where watering is shallow at the surface. Fast growing. Pruning required annually.

Application: Within the parking lot with cement pipe planting wells in the ground to contain roots or along the perimeter in the berms.

Name: *Olneya tesota*, Desert Ironwood, Evergreen.

Dimensions: 30 feet high, 30-foot spread, 10-inch diameter trunk.

Life Span: Long lived.

- Description:** Gray-green foliage casts dense shade. Lavender flowers in large quantity are produced in the spring. Tree branches have sharp thorns that require careful handling during pruning. Slow growing.
- Application:** Within the parking lot or alongside buildings in ribbon lots. Raised planters place branches above contact with pedestrians.
- Name:** *Phoenix canariensis*, Canary Island Date Palm, Evergreen.
- Dimensions:** 50 feet high, 30-foot spread, 2- to 3-foot diameter trunk.
- Life Span:** Long lived.
- Description:** Large green palm leaves. Tolerates hot, dry, arid regions. Popular street tree. Seldom injured by cold. Moderate growth. Should be planted as large trees due to spines on palm fronds.
- Application:** Perimeter plantings and within the lot to cast shade and create an open green forest ambience.
- Name:** *Pinus canariensis*, Canary Island Pine, Evergreen.
- Dimensions:** 60 to 80 feet high, 20- to 30-foot spread, 16-inch diameter trunk.
- Life Span:** Long lived.
- Description:** Tolerates extreme urban conditions, dust, and smog. Accepts most drought conditions but requires deep watering in desert landscapes. Pest free. Fast growing.
- Application:** Along the perimeter for creating shadows or alongside buildings with narrow space.
- Name:** *Pinus coulteri*, Coulter Pine, Evergreen.
- Dimensions:** 35 feet high, 30-foot spread, 1- to 2-foot diameter trunk.

- Life Span:** Long lived.
- Description:** Tolerates heat, aridity, and high desert conditions. Very drought tolerant. Moderately fast growing. Pine cones are extremely heavy; should be pruned for safety.
- Application:** Perimeter planting to create shadows.
-
- Name:** *Pinus halepensis*, Aleppo Pine, Evergreen.
- Dimensions:** 40 to 60 feet high, 40-foot spread, 1- to 2-foot diameter trunk.
- Life Span:** Short lived - 40 years.
- Description:** Drought tolerant, and accepts desert environments of heat and aridity. Fast growing.
- Application:** Perimeter planting to create shadows or within the parking lot.
-
- Name:** *Pinus monophylla*, One-Leaf Pine, Evergreen.
- Dimensions:** 16 to 30 feet high, 15-foot spread, 1-1/2-foot diameter trunk.
- Life Span:** Short lived.
- Description:** Tolerates hot, dry, arid conditions. Slow growing.
- Application:** Along the perimeter in berms for screening purposes.
-
- Name:** *Pinus pinea*, Italian Stone Pine, Evergreen.
- Dimensions:** 30 to 60 feet high, 50-foot spread, 2-foot diameter trunk.
- Life Span:** Long lived.
- Description:** Dark green needles 3 to 7 inches long occurring in pairs. Tree is round topped when young and matures into a broad flat-topped tree. Requires protection from the cold when young. Tolerant of city conditions. Prefers

full sun. Range of use from coastal and inland valleys to high desert.

Becomes tolerant of cold and drought with age.

Application: Within the parking lot and in berms.

Name: *Pinus quadrifolia*, Four-Leaf Pine, Evergreen.

Dimensions: 16 to 30 feet high, 15-foot spread, 1-1/2-foot diameter trunk.

Life Span: Short lived.

Description: Tolerates hot, dry, arid conditions. Slow growing.

Application: Along the perimeter on berms for screening purposes.

Name: *Pistacia chinensis*, Chinese Pistache, Deciduous.

Dimensions: 40 to 60 feet high, 40- to 60-foot spread, 1-1/2-foot diameter trunk.

Life Span: Long lived.

Description: Tolerates drought, smog, aridity, and slightly alkaline soil. Prefers full sun, heat, and deep soils for optimum root development. Leaves turn bright orange, red, and yellow colors in the fall. Casts dense shade. Fully cold hardy. Moderate growth. Pruning required to develop full canopy.

Application: Within the parking lot or along the perimeter.

Name: *Platanus acerifolia*, London Plane Tree ('Yarwood'), Deciduous.

Dimensions: 40 to 70 feet high, 20- to 40-foot spread, 2-foot diameter trunk.

Life Span: Long lived.

Description: Shiny green leaves 5 to 10 inches in size. Round to spreading crown. Fruit one inch in diameter matures in autumn, male and female on the same tree. Moderate growth. Capable of growing in wet or dry, compacted or loose soils. Tolerates alkalinity and moderate salinity. Accepts full sun or partial

shade. Moderate cold tolerance to 18° F. Tolerant of city conditions and is smog and drought tolerant.

Application: Within the parking lot.

Name: *Prosopis alba*, S. American Thornless Mesquite, Nearly Evergreen.

Dimensions: 30 feet high, 30-foot spread, 1-foot diameter trunk.

Life Span: Short lived.

Description: Lush, green foliage. Tolerates heat, aridity, and is fully cold hardy. Prefers deep soil. Lacks thorns common to most mesquite. Creates dense shade. Very fast growing. Pruning required to shape young bushes into trees.

Application: Within the parking lot.

Name: *Quercus douglasii*, Blue Oak, Deciduous.

Dimensions: 40 feet high, 50-foot spread, 1- to 3-foot diameter trunk.

Life Span: Long lived.

Description: Blue-green leaves. One of the most heat and drought resistant species which inhabits the dry perimeter foothills of the San Joaquin Valley. Very slow growing.

Application: Within the parking lot or along the perimeter.

Name: *Quercus agrifolia*, Coast Live Oak, Evergreen.

Dimensions: 40 to 60 feet high, 40- to 80-foot spread, 2- to 3-foot diameter trunk.

Life Span: Long lived.

Description: Shiny dark green leaves above, yellow green beneath. Prefers full sun. Fast growing. Can be planted throughout California's coastal and interior

valleys. Cold hardy. Smog and drought tolerant. Achieves good form and character after 20 years' growth.

Application: Within the parking lot and on the perimeter berms.

Name: *Quercus ilex*, Holly Oak, Evergreen.

Dimensions: 25 to 40 feet high, 20- to 35-foot spread, 1- to 2-foot diameter trunk.

Life Span: Long lived.

Description: Dull green leaves. Introduced species from the Mediterranean. Prefers deep soil and withstands summer watering. Tolerates heat, smog, aridity, drought, and wind. Needs protection from cold when young. Moderate growth.

Application: Within the parking lot or along the perimeter.

Name: *Quercus lobata*, Valley Oak, Deciduous.

Dimensions: 60 to 75 feet high, 50- to 80-foot spread, 3- to 4-foot diameter trunk.

Life Span: Long lived.

Description: Deeply growing roots reach ground water in the rich soil of the San Joaquin Valley. Magnificent looking tree. Tolerates heat, aridity, wind, and drought. Moderately fast growing. Construction around this tree may cause its death.

Application: Within the parking lot or along the perimeter.

Name: *Quercus suber*, Cork Oak, Evergreen.

Dimensions: 40 to 60 feet high, 40- to 60-foot spread, 2- to 3-foot diameter trunk.

Life Span: Long lived.

Description: Introduced species from the Mediterranean that adapts well to the warmest and driest locations and low desert environments. Tolerates heat, smog, aridity, wind, and drought. Moderate growth.

Application: Within the parking lot or along the perimeter.

Name: *Quercus virginiana*, Southern Live Oak, Evergreen.

Dimensions: 60 feet high, 70-foot spread, 2- to 3-foot diameter trunk.

Life Span: Long lived.

Description: Dark green leaves cast a dense shade. Resistant to root rot diseases. Fully cold hardy. Tolerates heat, aridity, and drought. Prefers deep soils. Water responsive. Moderate growth.

Application: Within the parking lot or along the perimeter.

Name: *Rhus lancea*, African Sumac, Evergreen.

Dimensions: 25 feet high, 25-foot spread, 8-inch diameter trunk.

Life Span: Short lived - 20 to 40 years.

Description: Glossy, green leaves, with rough red bark. Prefers heat and full sun. Accepts wind, aridity, and drought. Good shade producer. Moderate to fast growing. Pruning to control the shape and litter problems.

Application: Within the parking lot in raised planters, alongside walkways at the parking lot/building interface, on berms for screening purposes.

Name: *Robinia pseudoacacia*, Black Locust, Deciduous.

Dimensions: 40 to 70 feet high, 30- to 40-foot spread, 1- to 2-foot diameter trunk.

Life Span: Short lived.

Description: Deep blue-green leaves with snowy white flowers which are fragrant in May-June. Very aggressive tree which tolerates heat, cold, aridity, drought, smog, and poor soils. Performs well in extremely hot and dry landscapes including interior desert regions. Fast growing. Frequent pruning to control brittle wood and thorn problems which could injure pedestrians or damage cars.

Application: Along the perimeter.

Name: *Schinus molle*, California Pepper, Evergreen.

Dimensions: 20 to 40 feet high, 20- to 50-foot spread, 1-foot diameter trunk.

Life Span: Short lived.

Description: Light green leaves. Tree is highly tolerant of difficult areas with poor soils, wind, dust, heat, aridity, smog, and limited (drought tolerant). Voracious surface roots can crack pavement. Develops heart or root rot if water is applied during the summer. Moderately fast growing. Pruning is required to control shape and aid in removing brittle wood. Substantial leaf and seed leaf litter problems.

Application: Along the perimeter for screening purposes where leaf and seed litter is not a problem.

Name: *Schinus terebinthifolius*, Brazilian Pepper (Male), Evergreen.

Dimensions: 15 to 30 feet high, 15- to 30-foot spread, 1-foot diameter trunk.

Life Span: Short lived.

Description: Dark green, leathery leaves. Grows in most regions of California including low desert. Does not develop the surface root or litter problems of *Schinus*

molle. Tolerant of heat, aridity, smog, and drought. Moderately fast growth. Pruning helps to develop its shape.

Application: Along the perimeter of the parking lot for screening purposes or in selected areas within the lot where litter will not interfere with pedestrians.

Name: *Tamarisk asphylla*, Tamarisk, Athel Tree, Evergreen.

Dimensions: 30 to 60 feet high, 30-foot spread, 2-1/2-foot diameter trunk.

Life Span: Short lived.

Description: Gray-green leaves (scales). Handsome tree which produces dense shade. Thrives in full sun and heat. Drought resistant and tolerant of alkaline and salty soils. Roots grow deep and are invasive in their search for water. Fast growing. Pruning required to shape into a tree and to control heavy branches and weak wood.

Application: Along the perimeter where falling branches will not damage cars or injure pedestrians.

CHAPTER 13

REFERENCES

- Akbari, H. and A. Rosenfeld. 1989. "White Surfaces and Urban Trees for Mitigation of Summer Heat Islands: Setting Up Priorities. (Draft)" Berkeley: Lawrence Berkeley Laboratory.
- Akbari, H., J. Huang, P. Martien, L. Rainer, A. Rosenfeld, and H. Taha. 1989. Saving Energy and Reducing Atmospheric Pollution by Controlling Summer Heat Islands. In Proceedings of the Workshop on Saving Energy and Reducing Atmospheric Pollution by Controlling Summer Heat Islands, Berkeley, California, February 23-24, 1989. Berkeley: Lawrence Berkeley Laboratory.
- American Society of Landscape Architects Foundation. 1977. Landscape Planning for Energy Conservation. Reston, Virginia: Environmental Design Press.
- Arbor Day Magazine. January-February 1990. "Stress." Nebraska City: National Arbor Day Foundation.
- Barbour, Michael G., Jack H. Burk, Wanda D. Pitts. 1987. Terrestrial Plant Ecology. Menlo Park, California: The Benjamin/Cummings Publishing Co.
- Beaudoin, Mark. 1991. Telephone interview by author, 17 September.
- Bowman, Roger K. 1990. Interview by author, 19 February.
- Critchfield, Howard J. 1961. General Climatology. Englewood Cliffs, New Jersey: Prentice-Hall.
- Deering, Robert B. 1952. Technology of the Cooling Effect of Trees and Shrubs. In Proceedings for Housing and Building in Hot-Humid and Hot-Dry Climates, November 18-19. Washington, D.C.: National Research Council National Academy of Sciences.

- Degan, James, Jan Frainie, Alden Kelley, and Al Remyn. 1983. Street Trees Recommended for Southern California. Street Tree Seminar, Inc.
- Elias, Thomas S., and Howard S. Irwin. 1976. Urban Trees. Scientific American 235, no. 5 (November).
- Garbesi, Karina, Hashem Akbari, and Phil Martien, eds. 1989. Controlling Summer Heat Islands: Proceedings of the Workshop on Saving Energy and Reducing Atmospheric Pollution by Controlling Summer Heat Islands, Berkeley, California, February 23-24, 1989. Berkeley: Lawrence Berkeley Laboratory.
- Geiger, Rudolf. 1950. The Climate Near the Ground. Cambridge: Harvard University Press.
- Grey, Gene W., and Frederick J. Dendke. 1986. Urban Forestry. New York: John Wiley & Sons.
- Heisler, Gordon M., Robert E. Schutzki, Robert P. Zisa, Howard G. Halverson, and Bruce A. Hamilton. 1982. Effect of Planting Procedures on Initial Growth of Acer Rubrum L. and Fraxinus Pennsylvanicum L. in a Parking Lot. U.S.D.A. Forest Service Northeast Forest Experiment Station. Washington, D.C.: Government Printing Office.
- Hightshoe, Gary L. 1978. Native Trees for Urban and Rural America: A Planting Design Manual for Environmental Designers. Ames, Iowa: Iowa State University Research Foundation.
- International Union of Forestry Research Organizations. 1976. Trees and Forests for Human Settlements. In Proceedings of P1.05-00 Symposia, Vancouver, British Columbia, June 11-12, 1976. Toronto: Centre for Urban Forestry Studies.
- Krakauer, John. 1990. If You Want to Fight Air Pollution, Go Plant a Tree. Smithsonian (April).

- Lenz, Lee W., and John Dourley. 1981. California Native Trees and Shrubs for Garden and Environmental Use in Southern California and Adjacent Areas. Claremont, Calif.: Rancho Santa Ana Botanic Garden.
- McCaleb, Charles S. 1981. Tracks, Tires and Wires. Glendale, Calif.: Interurban Press.
- McPherson, Greg. 1990. Letter from the University of Arizona, to author, 3 January.
- McPherson, E. Gregory. 1989. Vegetation to Conserve Water and Mitigate Urban Heat Islands. In Proceedings of the Workshop on Saving Energy and Reducing Atmospheric Pollution by Controlling Summer Heat Islands, Berkeley, California, February 23-24, 1989. Berkeley: Lawrence Berkeley Laboratory.
- Miller, Robert W. 1988. Urban Forestry Planning and Managing Urban Greenspaces. Englewood Cliffs, New Jersey: Prentice-Hall.
- National Stone Association. 1985. Design Guide for Parking Areas. Washington, D.C.: National Stone Association.
- Parker, John H. 1989. The Impact of Vegetation on Air Conditioning Consumption. In Proceedings of the Workshop on Saving Energy and Reducing Atmospheric Pollution by Controlling Summer Heat Islands, Berkeley, California, February 23-24, 1989. Berkeley: Lawrence Berkeley Laboratory.
- Perry, Robert C. 1981. Trees and Shrubs for Dry California Landscapes. San Dimas, California: Land Design Publishing.
- Pinchot Institute of Environmental Forestry Research. 1977. Air Pollution and Metropolitan Woody Vegetation. New Haven, Conn.: Yale University Printing Services.
- Purchasing Magazine. 19 April 1990. Newton, MA: Cahners Publishing Co.
- Robinette, Gary O. 1976. Parking Lot Landscape Development. Reston, Virginia: Environmental Design Press.
- Rugg, John W., Jr., 1989. Letter to author, 21 September.

- Santamour, Frank S., Jr., Henry D. Gerhold, and Silas Little, eds. 1975. Better Trees for Metropolitan Landscapes. In Proceedings of the U.S. Department of Agriculture Symposium, November 4-6, 1975, Washington, D.C. Washington, D.C.: Government Printing Office.
- Saratoga Horticultural Foundation. 1979. California Native Plants with Commercial Sources. Saratoga, California: Saratoga Horticultural Foundation.
- Smith, David R. 1981. Green Parking Lot. An Experimental Installation of Grass Pavement: Maintenance Evaluation. Dayton, Ohio: The Heritage Conservation and Recreation Service.
- Spirm, Anne Whiston. 1984. The Granite Garden. New York: Basic Books.
- Stone, Edward D., Jr. 1987. Architectural Landscaping. The Parking Professional (May) Fredericksburg, Virginia: Institutional and Municipal Parking Congress.
- Thurrow, Charles. 1983. Improving Street Climate Through Urban Design. Chicago: The American Planning Association.
- Tree People. 1983. A Planters Guide to the Urban Forest. Beverly Hills: Tree People.
- Urban, Jim, Ralph Sievert, and Jim Patterson. 1988. Trees and Space: A Blueprint for Tomorrow. American Forests (July-August). Washington, D.C.: The American Forestry Association.
- U.S. Department of Agriculture. 1975. The Conference on Metropolitan Physical Environment. In U.S.D.A. Forest Service General Technical Report N.E. 25, Syracuse, New York, August 25-29, 1974. Washington, D.C.: Government Printing Office.
- U.S. Department of Agriculture. 1988. Forestry A Community Tradition. Washington, D.C.: National Association of State Foresters.

- U.S. Environmental Protection Agency. March 1990. Cooling Our Communities: The Guidebook on Tree Planting and Light-Colored Surfacing. Washington, D.C.: U.S. Environmental Protection Agency Office of Policy, Planning, and Evaluation.
- Watson, Gary W., and Gary Hennen. 1989. Journey to the Bottom of a Tree. American Forests (September-October). Washington, D.C.: The American Forestry Association.
- Weiner, Michael. 1975. Plant a Tree: A Working Guide to Regreening America. New York: MacMillan Publishing Co.

APPENDIX A
ROOT MEASUREMENTS TO AID IN DETERMINING
PLANTING WELL SIZE

The following measurements were taken by the author of trees size compared to surface root development in areas with differing application of water. All data was collected using a tape measure, and heights are approximate.

1. Abandoned home area south of San Jose International Airport bounded by Highway 17/880, Coleman Avenue, Hedding and Ruff Drive.

Trees in this area obtain water from rainfall and whatever subterranean water supplies may exist.

Ailanthus altissima - growing in the field where houses were located:

Two (single trunk) 16-inch Dbh by 30-foot-plus height, measurable roots to 4-foot distance from the trunk.

One (single trunk) 32-inch Dbh by 35- to 40-foot height, measurable roots to 5-foot distance from the trunk.

One (trunk bifurcated 5 feet above the ground) 18-inch Dbh by 35-foot-plus height, measurable roots to 3-foot distance from the trunk.

Sycamore - planted in the area bordered by the sidewalk and street:

One (single trunk) 22-inch Dbh by 35-foot height, measurable roots to 3-foot distance from the trunk.

One (single trunk) 18-inch Dbh by 35-foot height, measurable roots to 3-foot distance from the trunk.

One (single trunk) 20-inch Dbh by 35-foot height, measurable roots to 3-foot distance from the trunk.

(Sidewalk and curbs are being buckled and cracked.)

Birch - planted in the area bordered by the sidewalk and street:

One 24-inch Dbh by 20-foot-plus height, no surface root problems.

Camphor - planted in the area bordered by the sidewalk and street next to the traffic court on Ruff Drive:

One (single trunk) 18-inch Dbh by 20-foot height, curbside not broken but the sidewalk was recently replaced and the roots were sawed off 2 feet from the trunk.

One 21 inch Dbh by 20-foot-plus height, curbside not broken but the sidewalk was recently replaced and the roots on this side were sawed off. No other root problems beyond 4 feet from trunk.

APPENDIX A (Continued)

ROOT MEASUREMENTS TO AID IN DETERMINING PLANTING WELL SIZE

2. Sierra Road east of Morrill and on the north side of Sierra Road. Berryessa area of San Jose.

Trees receive water from rainfall and whatever subterranean water supplies may exist.

Eucalyptus (Shaggy Bark) - planted between the sidewalk and street adjacent to the sides of a housing development:

One 17-inch Dbh by 40-foot height, measurable roots to 3-foot distance from the trunk.

One 22-inch Dbh by 40-foot height, measurable roots to 4-foot distance from the trunk.

Similar sized trees along this area exhibited the same pattern of root disturbance.

3. Bell Air Street adjacent to Bascom Avenue and Highway 17/880.

Water is from rainfall, water from lawn watering runoff, direct watering, and whatever subterranean water supplies may exist. Street is 32-feet wide curb to curb and tree branches form a complete canopy.

Oaks - planted between the sidewalk and street in front of homes:

One 34-inch Dbh by 35- to 45-foot height, 6-foot 6-inch by 10-foot opening. Sidewalk is being uplifted.

One 32-inch Dbh by 35- to 45-foot height, 6-foot 6-inch by 10-foot opening. Sidewalk is being uplifted.

One 31-inch Dbh by 35- to 45-foot height, 6-foot 6-inch by 30-foot opening. Sidewalk is being uplifted.

One 21-inch Dbh by 35-foot-plus height, 6-foot 6-inch opening. Sidewalk is being slightly uplifted.

Trees are bifurcated at approximately 7 feet from the ground and form large, dense, foliage canopies.

APPENDIX A (Continued)

ROOT MEASUREMENTS TO AID IN DETERMINING PLANTING WELL SIZE

4. Alum Rock Park, east San Jose foothills, along the creek trail from the back of the main parking lot toward the falls.

Oak:

One 36-inch Dbh by 40-foot height, measurable roots to 3-foot distance from the trunk.

One 17-inch Dbh by 30- to 40-foot height, measurable roots to 2-foot distance from the trunk.

One 31-inch Dbh by 60-foot height, measurable roots to 4-foot distance from the trunk.

One 40-inch Dbh by 60-foot height, measurable roots to 2-foot distance from the trunk.

One 33-inch Dbh by 50-foot height, measurable roots to 2-foot distance from the trunk.

One 31-inch Dbh by 50-foot height, measurable roots to <1-foot distance from the trunk.

One 30-inch Dbh by 50-foot height, measurable roots to <1-foot distance from the trunk.

One 24-inch Dbh by 30- to 40-foot height, measurable roots to <1-foot distance from the trunk.

One 24-inch Dbh by 30- to 40-foot height, in a lawn area, measurable roots to 4-foot distance from the trunk.

One 28-inch Dbh by 30- to 40-foot height, in a lawn area, measurable roots to 4-foot distance from the trunk.

One 28-inch Dbh by 30- to 40-foot height, roots exposed 8 inches below surface level on a hillside, 5° angle from surface level on the top roots, 45° angle from surface level on roots lower down. At a depth 2 feet below surface level, root diameter was 4 to 8 inches. The roots were shaped like an inverted tree canopy. Visible roots were 10 feet out from the trunk at a depth 8 inches below surface level.

Sycamore:

One 21-Dbh by 30-foot height, measurable roots to <4-foot distance from the trunk.

One 30-Dbh by 60-foot height, measurable roots to <1-foot distance from the trunk.

One 18-Dbh by 30-foot height, measurable roots to <1-foot distance from the trunk.