City of Pacific Grove

Urban Tree Canopy Assessment

2015

CITY OF PACIFIC GROVE, CA.
INC. 1889

DAVEY RESOURCE GROUP
A Division of The Davey Tree Expert Company

City of Pacific Grove

Urban Tree Canopy Assessment

2015

Prepared for:
City of Pacific Grove
300 Forest Avenue
Pacific Grove, CA 93950

Prepared by:
Davey Resource Group
A Division of the Davey Tree Expert Company
6005 Capistrano Ave., Suite A
Atascadero, California 93422
Phone: 805-461-7500
Toll Free: 800-966-2021
Fax: 805-461-8501
www.davey.com/drg

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Executive Summary

Pacific Grove is a coastal community with a unique public tree population including a substantial portion of native species. The City of Pacific Grove is committed to proactive management of their community tree resource (City of Pacific Grove Forestry, 2015). In an effort to comprehensively evaluate the urban forest, Pacific Grove contracted with Davey Resource Group (DRG) in 2015 to conduct a Public Tree Inventory, a Resource Analysis, and an Urban Tree Canopy Assessment. While the inventory and analysis evaluated data collected by field crews about individual public trees, the Urban Tree Canopy Assessment (UTC) provides uses remote image sensing and GIS analysis to develop a birds-eye view of the entire urban forest, including public and private trees. This helps managers understand several factors about the community tree canopy, including:

- Quantity and distribution of existing tree canopy
- Potential impacts of tree planting and removal
- Quantified annual benefits trees provide to the community
- Benchmark canopy percent values over the past 15 years

Canopy distribution was evaluated at several levels, including overall, neighborhoods, and by zoning. Land cover changes from 2005 to 2014 were analyzed and projections for 2024 are based on this history. Functional values, including canopy health and stormwater impact, were mapped and priority planting locations were identified for reducing erosion and soil degradation during storm events.

Land Cover

The City of Pacific Grove encompasses a total area of 1,837 acres. Excluding impervious surfaces (784 acres) and open water (5 acres), Pacific Grove includes 0.82 square miles (523 acres) with the potential to support tree canopy. The following information characterizes land cover within the City of Pacific Grove:

- 28.6% existing canopy, including trees and woody shrubs (525 acres) (Figure 1)
- 57% canopy potential, considering suitable planting sites on areas of existing pervious surface (523 acres) and the existing canopy (525 acres), for a total of 1,048 acres
- 43% impervious surfaces, including roads, parking lots, and structures (784 acres)
- 73% of canopy (377 acres) is in good to excellent condition
- The Government zoning class has the highest canopy percent (50%), followed by Planned Unit Development (42%), and Residential (33%)
- By neighborhood, Country Club Gate/Forest Grove has the highest canopy cover (51%) followed by Pacific Grove Acres (48%) and Del Monte Park (41%)
- 312 acres of potential planting areas, including 9,901 sites
- From 2005 to 2014 tree canopy increased from 25.8% to 28.6%
- By 2024, land cover projections estimate that tree canopy will increase by 41 acres to 31%.

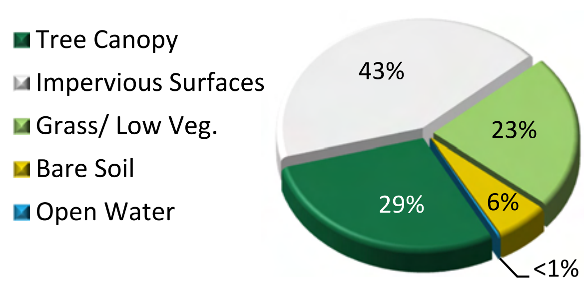


Figure 1. Land Cover in Pacific Grove

Environmental Benefits

Pacific Grove's land cover data was used with i-Tree Canopy (v6.1) (Appendix B) to estimate the environmental benefits from the entire urban forest (public and private). Trees in Pacific Grove are providing air quality and stormwater benefits worth nearly $1.8 million annually (Figure 2) by:

- Removing 19.4 tons of air pollutants, including carbon monoxide (CO), nitrogen dioxide (NO_2), ozone (O_3), sulfur dioxide (SO_2), and particulate matter (PM_{10})
- Reducing stormwater runoff by more than 35.6 million gallons, valued at $356,536

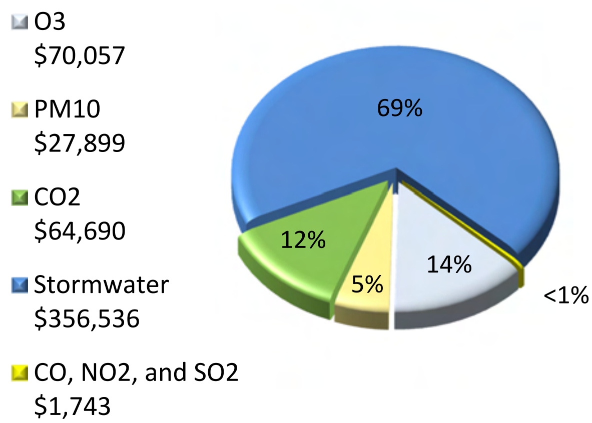


Figure 2. Environmental Benefits in Pacific Grove

- Pacific Grove's urban forest is currently storing 66,044 tons of carbon (CO_2) in its biomass, valued at nearly $1.3 million
- Annually, this resource removes (sequesters) an additional 3,341 tons of CO_2, valued at $64,690

Management Applications

Understanding the location and extent of tree canopy is key to developing and implementing sound management strategies that promote the sustainability of Pacific Grove's urban forest resource and the benefits it provides. The data, combined with existing and emerging urban forestry research, enables managers to strike a balance between urban growth and tree preservation and aid in identifying and assessing urban forestry opportunities. Spatial understanding of the past, present, and potential for tree canopy is a valuable tool to help managers align urban forestry management with the community's vision for the urban forest in Pacific Grove.

Pacific Grove has set a canopy goal of 33% canopy by 2037. Considering that tree canopy is projected to increase to 31% by 2024, the City is on track to achieve this goal. Recommendations for maintaining canopy growth include:

- Remove and replace failing trees identified in the public tree inventory collected in 2015.
- Use stormwater priority planting site analysis to identify new tree planting locations to reduce erosion and soil degradation (Figure 3).
- Use GIS canopy and land cover mapping to explore under-treed neighborhoods and zoning locations to identify potential planting sites.
- Incentivize tree planting on private property.

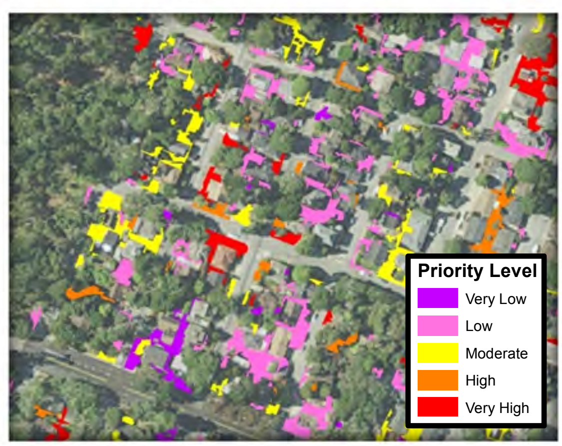


Figure 3. Stormwater Planting Priority

Introduction

The Urban Tree Canopy (UTC) Assessment used high-resolution, infrared aerial imagery and remote sensing software (See Appendix C for Methodology). The assessment resulted in a GIS map layer detailing the location and extent of existing tree canopy (public and private) along with other primary land cover classifications, including impervious and pervious surfaces, bare soils, and water.

Urban Tree Canopy and Geographic Information Systems (GIS)

Urban tree canopy is the layer of leaves, branches, and stems of trees that cover the ground when viewed from above. The UTC assessment does not distinguish between publicly-owned and privately-owned trees. Since trees provide benefits to the community that extend beyond property lines, the assessment includes all tree canopy within the borders of the community. To place tree canopy in context and better understand its relationship within the community, the assessment included other primary landcover classifications, including impervious surfaces, pervious surfaces, bare soils, and water.

As more communities focus attention on environmental sustainability, community forest management has become increasingly dependent on geographic information systems (GIS) for urban tree canopy mapping and analysis. Understanding the extent and location of existing canopy is key to identifying various types of community forest management opportunities, including:

- Future planting plans
- Stormwater management
- Water resource and quality management
- Impact and management of invasive species based on tree condition
- Preservation of benefit stream and sustainability
- Outreach and education

High-resolution aerial imagery and infrared technology was used to remotely map tree canopy and land cover (Figure 4). The results of the study provide a clear picture of the extent and distribution of tree canopy within Pacific Grove. The data developed during the assessment becomes an important part of the City's GIS database and provides a foundation for developing community goals and urban forest policies. The primary purpose of the assessment was to establish benchmark values at 5-year increments for the past 15 years. These values will enable managers to understand recent changes in the urban forest and measure the success of long-term management objectives over time.

With this data, managers can determine:

- Pacific Grove's progress towards local and regional canopy goals
- Changes in tree canopy over time and in relation to growth and development
- The location and extent of canopy at virtually any level, including neighborhood, land use, zoning, parking lots and parcels
- The location of available planting space and develop strategies to increase canopy in underserved areas

In addition to quantifying existing UTC, the assessment illustrates the potential for increasing tree canopy across Pacific Grove. The data, combined with existing and emerging urban forestry research and applications, can provide additional guidance for determining a balance between growth and preservation and aid in identifying and assessing urban forestry opportunities.

Figure 4. High-resolution aerial imagery (left) is used to remotely identify existing land cover. Infrared technology delineates living vegetation including tree canopy (middle). Remote sensing software identifies and maps tree canopy and other land cover (right).

Benefits of Urban Tree Canopy

Urban forests continuously mitigate the effects of urbanization and development and protect and enhance lives within the community in the following ways:

Air Quality

Urban trees improve air quality in five fundamental ways:

- Reducing particulate matter (dust)
- Absorbing gaseous pollutants
- Shade and transpiration
- Reducing power plant emissions
- Increasing oxygen levels

Urban trees protect and improve air quality by intercepting particulate matter (PM_{10}), including dust, ash, pollen, and smoke. The particulates are filtered and held in the tree canopy where they are eventually washed harmlessly to the ground. Trees and forests absorb harmful gaseous pollutants like ozone (O_3), nitrogen dioxide (NO_2), and sulfur dioxide (SO_2). Shade and transpiration reduces the formation of O_3, which is created during higher temperatures. In fact, scientists are now finding that some trees may absorb more volatile organic compounds (VOC's) than previously thought (Karl, T. et al; Science NOW, 2010). VOC's are a class of carbon-based particles emitted from automobile exhaust, lawnmowers, and other human activities. By reducing energy needs, trees also reduce emissions from the generation of power. And, through photosynthesis, trees and forests increase oxygen levels.

Annually, in Pacific Grove, trees remove 19.4 tons of air pollutants for a total value of $99,557, including carbon monoxide (CO 860 lbs, $571), nitrogen dioxide ($NO_2$, 2,540 lbs, $1,030), ozone ($O_3$, 25,740, $70,057), sulfur dioxide (SO_2), and particulate matter (PM_{10}, 8,940 lbs, $27,899).

Carbon Reduction

Trees and forests reduce atmospheric carbon dioxide (CO_2) in two ways:

- Directly, through growth and carbon sequestration
- Indirectly, by lowering the demand for energy

Trees and forests directly reduce CO_2 in the atmosphere through growth and sequestration of CO_2 as woody and foliar biomass. Indirectly, trees and forests reduce CO_2 by lowering the demand for energy and reducing the CO_2 emissions from the consumption of natural gas and the generation of electric power.

As environmental awareness continues to increase, governments and individuals are paying particular attention to climate change and the effects of greenhouse gas emissions. Two national policy options are currently making headlines; the establishment of a carbon tax and a greenhouse gas cap-and-trade system, aimed at reducing atmospheric CO_2 and other greenhouse gases. A carbon tax places a tax burden on each unit of greenhouse gas emissions and would require regulated entities to pay for their level of emissions. Alternatively, in a cap-and-trade system, an upper limit (or cap) is placed on global (federal, regional, or other jurisdiction) levels of greenhouse gas emissions and the regulated entities are required to either reduce emissions to required limits or purchase emissions allowances in order to meet the cap (Williams et al, 2007).

In 2006, California adopted the Global Warming Solutions Act (AB32) which commits California to reduce its greenhouse gas emissions to 1990 levels by 2020. Beginning in 2013, a statewide cap on greenhouse gases places a mandatory limit on large businesses that emit more than 25,000 metric tons of CO_2. The limit is set to decline 2-3% each year and to expand the scope of businesses and industries that are regulated. Companies that are regulated must obtain an allowance (or permit) for each ton of carbon they emit. These allowances have value and can be traded on the open market.

The concept of purchasing emission allowances (offsets) has led to the acceptance of carbon credits as a commodity that can be exchanged for financial gain. As a result, some communities are exploring the concept of planting trees to develop a carbon offset (or credit). The Center for Urban Forest Research Pacific Southwest Research Station and USDA Forest Service recently led the development of Urban Forest Greenhouse Gas Reporting Protocol (McPherson et al, 2008/2010). The protocol incorporates methods of the Kyoto Protocol and Voluntary Carbon Standard and establishes methods for calculating reductions, provides guidance for accounting and reporting, and guides urban forest managers in developing tree planting and stewardship projects that could be registered for greenhouse gas reduction credits. The protocol can be applied to urban tree planting projects within municipalities, educational campuses, and utility service areas anywhere in the U.S. or its territories.

Pacific Grove's urban forest is currently storing 66,044 tons of carbon (CO_2) in its biomass, valued at nearly $1.3 million. Furthermore, annually, Pacific Grove's trees sequester 3,341 lbs of carbon valued at $64,690.

Stormwater

Trees and forests improve and protect the quality of surface waters, such as creeks, rivers, and lakes, by reducing the impacts of stormwater runoff through:

- Interception
- Increasing soil capacity and rate of infiltration
- Reducing soil erosion

Trees intercept rainfall in their canopy, which act as a mini-reservoir (Xiao et al, 1998). During storm events, this interception reduces and slows runoff. In addition to catching stormwater, canopy interception lessens the impact of raindrops on bare soil. Root growth and decomposition increase the capacity and rate of soil infiltration by rainfall and snowmelt (McPherson et al, 2002). Each of these processes greatly reduce the flow and volume of stormwater runoff, avoiding erosion and preventing sediments and other pollutants from entering local waterways and the ocean.

Annually, Pacific Grove's urban forest reduces stormwater runoff by more than 35.6 million gallons, valued at $356,536. This constitutes 69% of the environmental benefits. The role of trees in stormwater management is discussed in further detail in the Canopy & Stormwater Management Section (Pg. 19).

Energy Savings

Urban trees and forests modify climate and conserve energy in three principal ways:

- Shading dwellings and hardscape
- Transpiration
- Wind reduction

Shade from trees reduces the amount of radiant energy absorbed and stored by hardscapes and other impervious surfaces, thereby reducing the heat island effect, a term that describes the increase in urban temperatures in relation to surrounding locations. Transpiration releases water vapor from tree canopies, which cools the surrounding area. Through shade and transpiration, trees and other vegetation within an urban setting modify the environment and reduce heat island effects. Temperature differences of more than 9°F (5°C) have been observed between city centers without adequate canopy cover and more vegetated suburban areas (Akbari et al, 1997).

Trees reduce wind speeds relative to their canopy size and height by up to 50% and influence the movement of warm air and pollutants along streets and out of urban canyons. By reducing air movement into buildings and against conductive surfaces (e.g., glass and metal siding), trees reduce conductive heat loss from buildings, translating into potential annual heating savings of 25% (Heisler, 1986). Reducing energy needs has the added bonus of reducing carbon dioxide (CO_2) emissions from fossil fuel power plants.

Aesthetics and Socioeconomics

While perhaps the most difficult to quantify, the aesthetic and socioeconomic benefits from trees may be among their greatest contributions, including:

- Beautification, comfort, and aesthetics
- Shade and privacy
- Wildlife habitat
- Opportunities for recreation and passive recreation
- Creation of a sense of place and history
- Human health

Many of these benefits are captured as a percentage of property values, through higher sales prices where individual trees and forests are located.

Calculating Tree Benefits

Pacific Grove has conducted a Resource Analysis (2015) to calculate tree benefits for the subset of the urban tree canopy including just the public trees, based on the 2014 complete inventory. This analysis was completed using the USDA Forest Service i-Tree software tools. This state-of-the-art, peer-reviewed software suite considers regional environmental data and costs to quantify the ecosystem services unique to a given urban forest resource. Individuals can calculate the benefits of trees to their property by using the National Tree Benefit Calculator or with i-Tree Design. (www.itreetools.org/design)

i-Tree Design

Calculate My Tree Benefits

Land Cover in Pacific Grove

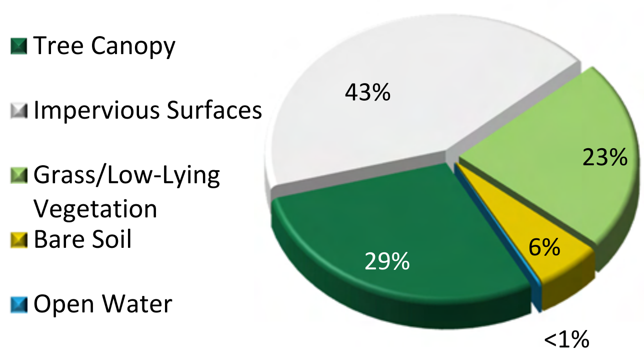
Existing Overall Land Cover

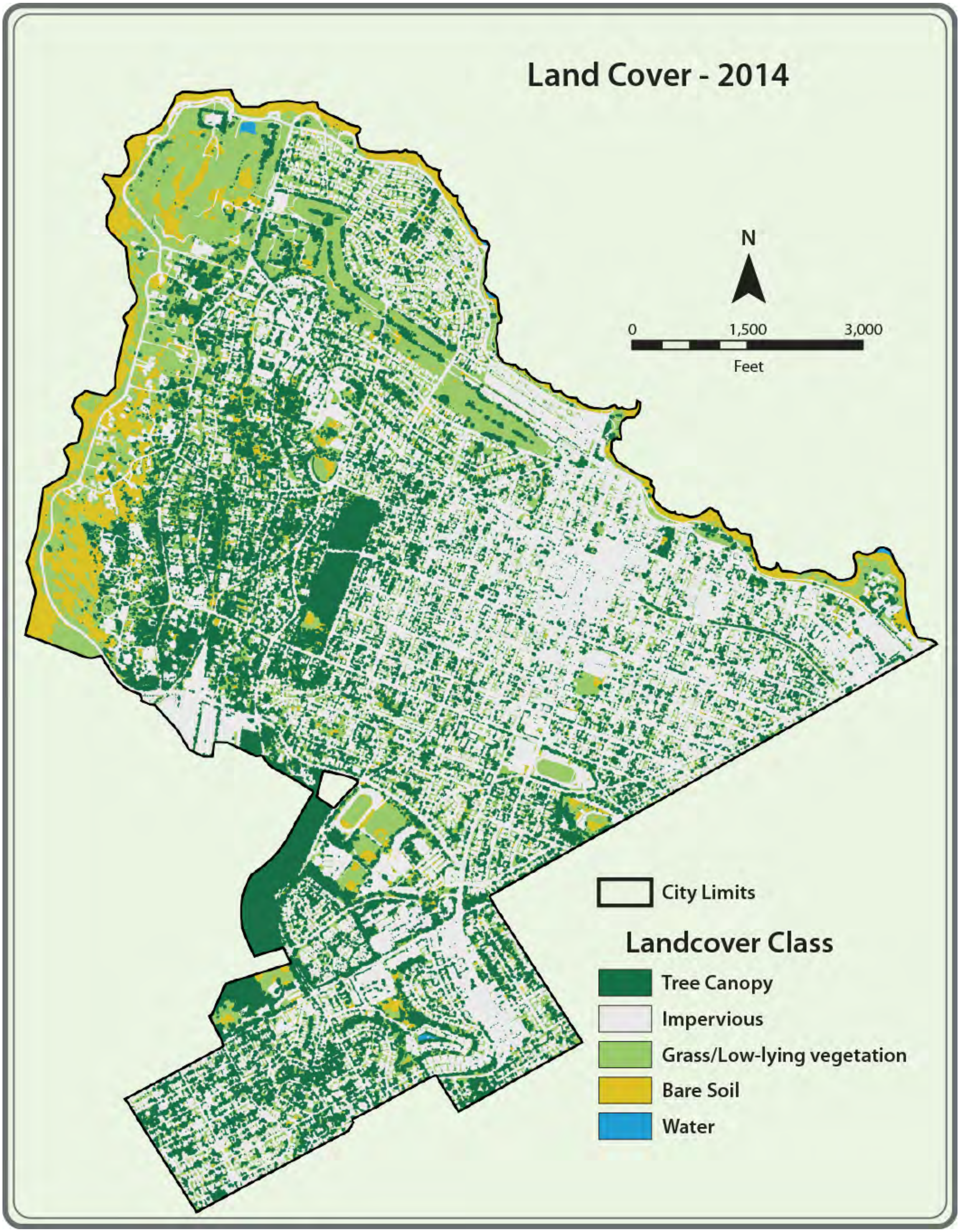
The City of Pacific Grove encompasses a total area of 2.9 square miles. Land cover classification within the city limits includes almost 29% tree canopy, 23% grass and low vegetation, and 43% impervious surfaces, including roads and buildings (Table 1, Figure 5, and Map 1). Bare soil, grass, and low vegetation are considered plantable areas, which cover 523 acres, 28% of the community. Considering the existing tree canopy and possible tree canopy over impervious areas, the canopy potential of Pacific Grove is 57%, although the actual potential may be higher where tree canopy can shade impervious surfaces such as roads, parking lots, and buildings.

Table 1. Land Cover Classes

Land Cover Class	Acres	%
Tree Canopy	525.46	28.60
Buildings	326.56	17.78
Roads	244.03	13.28
Other Impervious	213.56	11.63
Grass/Low-Veg.	413.33	22.50
Bare Soil	109.44	5.96
Open Water	5.02	0.27
Total	**1,837.40**	**100%**

Figure 5. Land Cover Classes





Map 1. Land Cover Classes in Pacific Grove

Tree Canopy Health

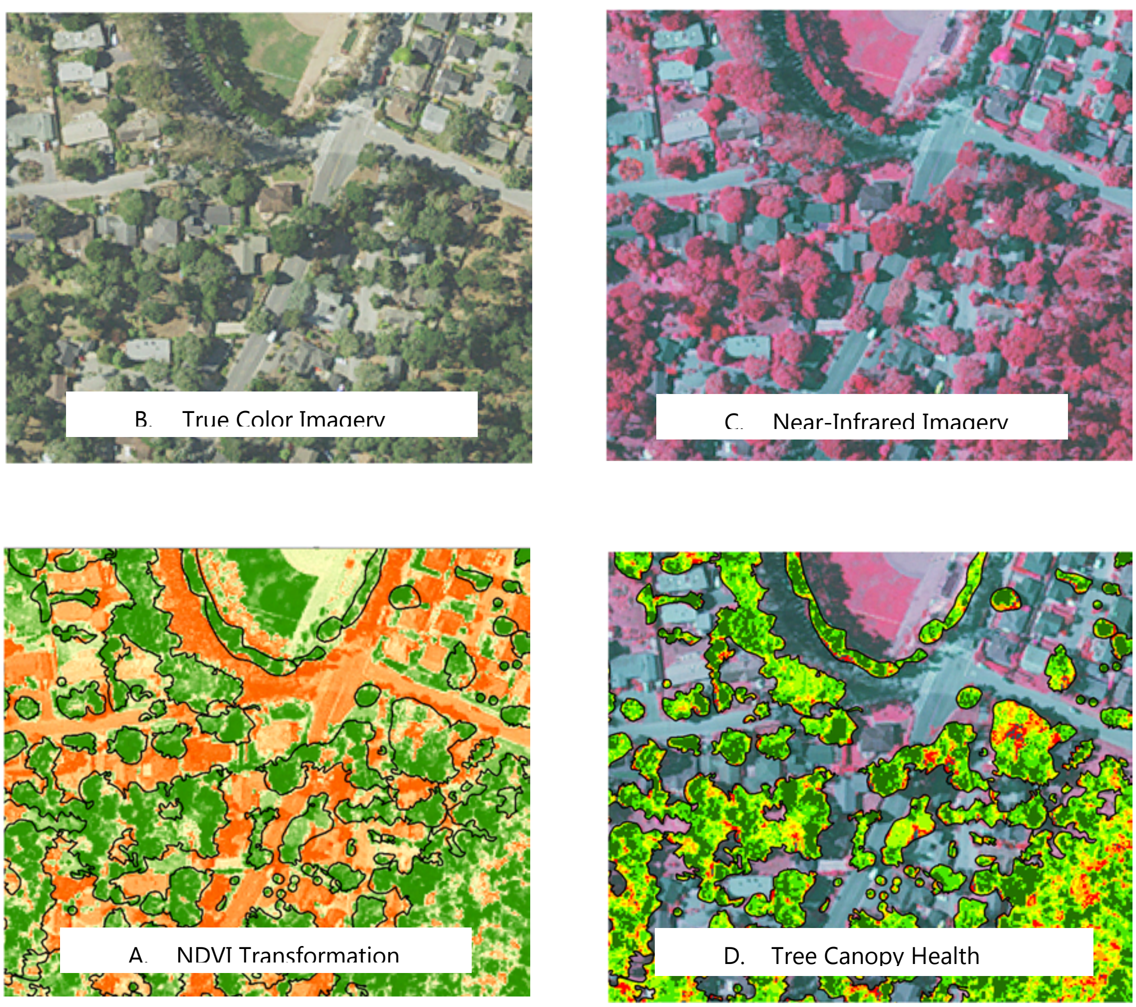
Canopy health was determined using near –infrared imagery and NDVI transformation (Figure 6 and Appendix C). In Pacific Grove, 73% of the canopy (377 acres) is in good to excellent condition. Healthy trees are vigorous, often producing more leaf surface area each year. The amount and distribution of leaf surface area is the driving force behind the urban forest's ability to produce benefits for the community (Clark et al, 1997). As canopy cover increases, so do the benefits contributed by leaf area. These benefits, which include energy savings, air quality, water quality, stormwater interception, aesthetic and other socio-economic benefits are quantified for their value to the community in the following section.

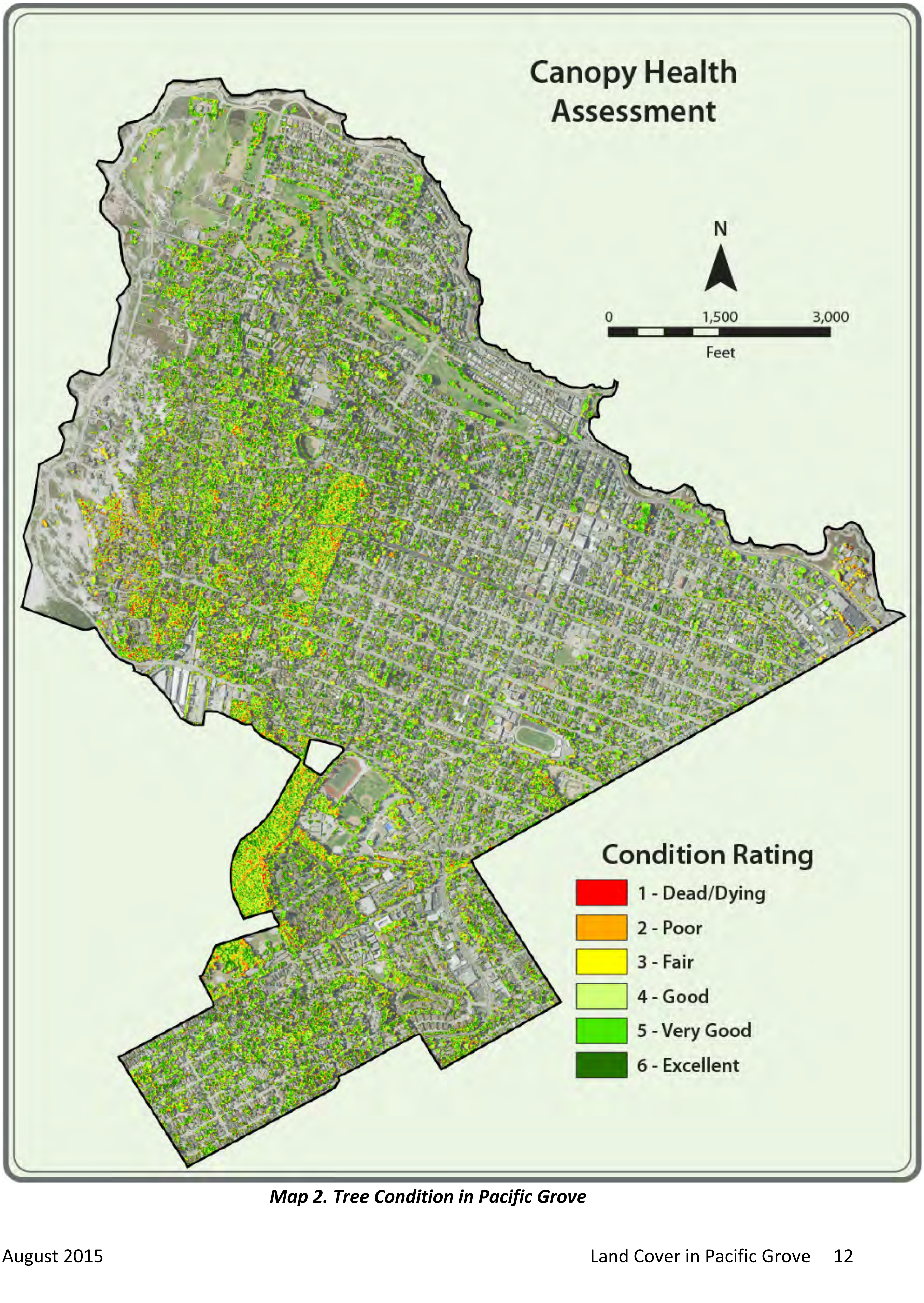
Table 2. Tree Condition

Health Condition	Acres	Percent
1 - Dead/Dying	28.00	5.44%
2 - Poor	44.59	8.67%
3 - Fair	65.36	12.70%
4 - Good	97.48	18.95%
5 - Very Good	140.38	27.28%
6 - Excellent	138.73	26.96%

The population of 7,394 inventoried public trees is a subset of the overall urban tree canopy. The Pacific Grove Resource Analysis (2015) found 43% of public trees in good to excellent condition. However, the inventory used a ground-based inspection procedure, which differs from the methodology used in the aerial canopy condition assessment.

Figure 6. Tree Canopy Health Workflow





Map 2. Tree Condition in Pacific Grove

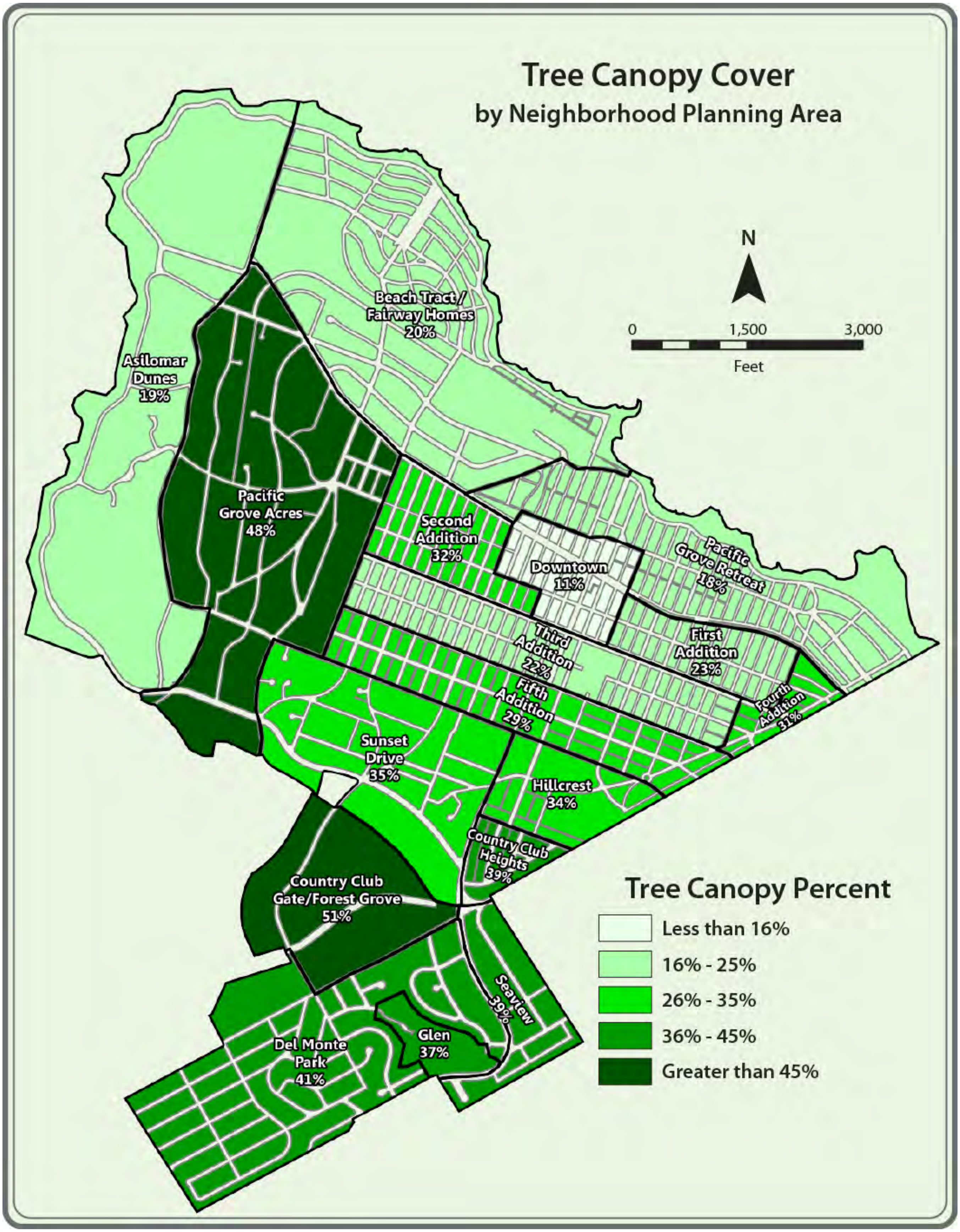
Tree Canopy by Neighborhood

In Pacific Grove, neighborhood boundaries encompass 1,438 acres of the city's 1,837 total acres. The remaining acres fall within the City's right-of-way. Neighborhood boundaries are often used to understand tree canopy, as they tend to reflect geographies that are well understood by community members and elected officials. Exploring canopy distribution and socio-economic indicators at this level can help facilitate outreach and education activities as well as develop a deeper understanding of tree canopy at a meaningful scale.

Pacific Grove is divided into 17 neighborhoods (Map 3). Overall, each neighborhood has a percent canopy cover greater than 18%, with the exception of downtown (11%), which generally has higher impervious surfaces. Country Club Gate/Forest Grove (42 acres) has the highest canopy cover of 51% followed by Pacific Grove Acres (48%) and Del Monte Park (41%). By area, Pacific Grove Acres has the greatest area of canopy (106 acres).

Table 3. Tree Canopy and Impervious Surface by Neighborhood Association

Neighborhood	Acres	Canopy Acres	% Canopy	Impervious Acres	% Impervious
Asilomar Dunes	254.05	47.51	18.70	31.46	12.38
Beach Tract / Fairway Homes	208.19	42.57	20.45	68.27	32.79
Country Club Gate/Forest Grove	83.64	42.86	51.24	28.44	34.00
Country Club Heights	13.56	5.27	38.91	5.16	38.10
Del Monte Park	148.28	60.08	40.52	60.70	40.94
Downtown	26.88	3.08	11.47	21.89	81.42
Fifth Addition	57.11	16.30	28.55	28.31	49.57
First Addition	27.22	6.23	22.90	15.32	56.30
Fourth Addition	12.27	3.77	30.77	5.34	43.57
Glen	18.19	6.68	36.72	7.03	38.64
Hillcrest	36.88	12.46	33.80	13.53	36.70
Pacific Grove Acres	219.99	105.57	47.99	67.43	30.65
Pacific Grove Retreat	105.06	19.14	18.22	52.12	49.61
Seaview	34.05	13.14	38.58	13.78	40.48
Second Addition	31.80	10.07	31.66	15.95	50.16
Sunset Drive	106.29	36.94	34.75	41.04	38.61
Third Addition	55.42	12.14	21.90	30.85	55.65
All Neighborhoods	**1,438.87**	**443.83**	**31.01%**	**506.62**	**42.92%**



Map 3. Tree Canopy by Neighborhood in Pacific Grove

Tree Canopy by Zone

In Pacific Grove, zoning class boundaries encompass 1,444 acres of the city's 1,837 total acres. Zoning class is a reflection of development patterns and the community's plan for growth in specific areas. In general, open spaces and residential areas typically have less impervious surface and are able to support a greater percentage of tree canopy. Commercial and Industrial areas tend to have a higher proportion of impervious surface and lower canopy cover.

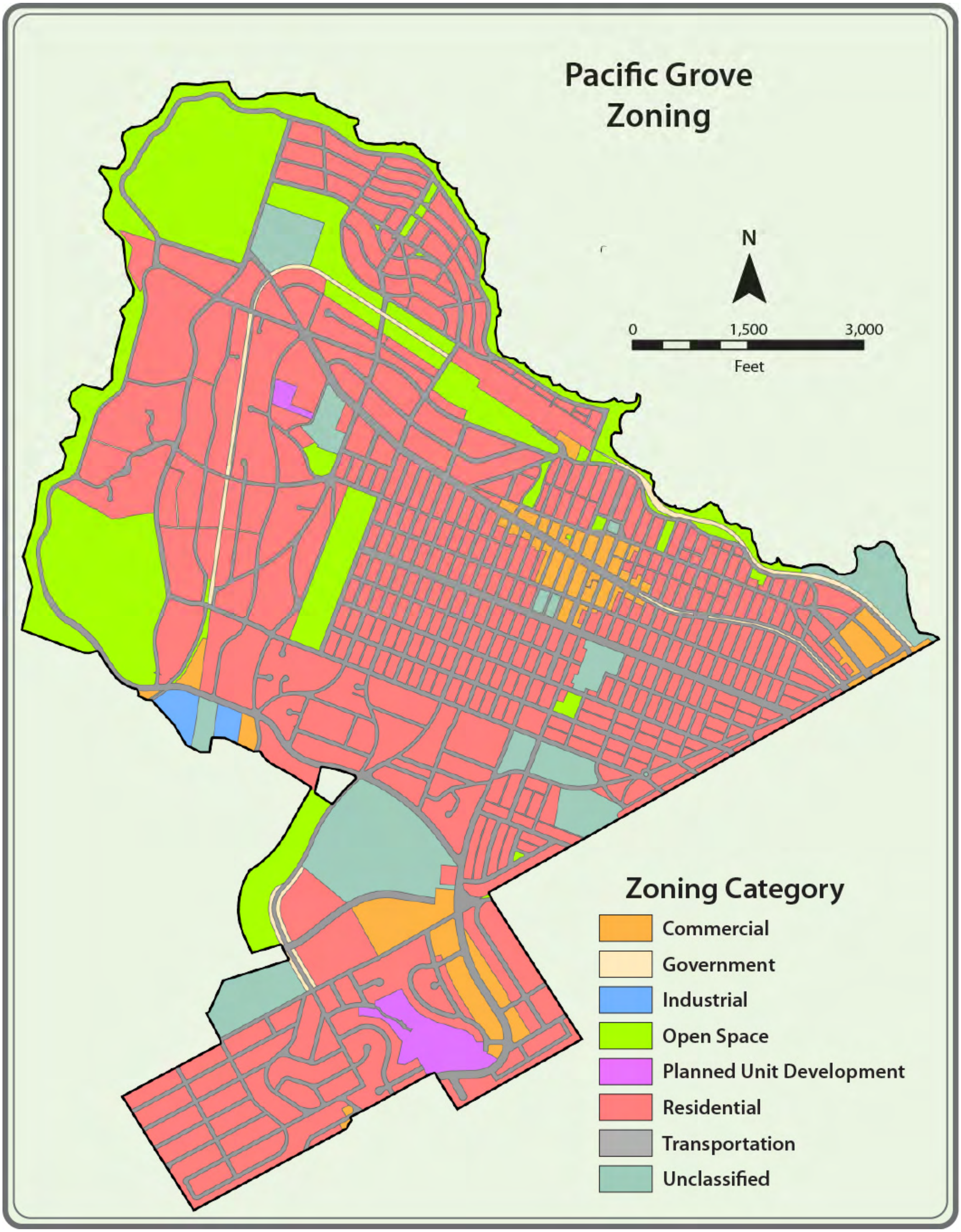
Government zoned parcels have the highest canopy cover (50%); this zoning class encompasses all parks that are maintained by the Parks and Recreation Department. Government zoned parcels have the potential to increase canopy cover by 22 percentage points (4.4 acres) to nearly 72%. Planned Unit Development (PUD) has the second highest canopy cover (42%). These parcels generally contain multi-use areas, where parks and other green spaces are commonly found. This class, along with Residential zoning, each have the potential to increase their canopy cover to nearly 60%. Residential zoned parcels have 220 acres of plantable area and PUD has nearly 4 acres of plantable area. Industrial zoned parcels have the lowest canopy cover at 9%. This is typical, as a result of site uses and generally high impervious surfaces (89%) (Table 5).

On average, Pacific Grove's zoning classes have close to 30% canopy cover with the potential to increase that cover to nearly 43%.

Table 4. Acreage and Percent Canopy Cover and Preferred Plantable Space by Zoning Class

Zoning Class	% Canopy	% Impervious	% Pervious	% Preferred Plantable	Maximum UTC
Commercial	18.22	76.58	4.71	4.91	23.13
Government	49.87	17.39	23.18	22.10	71.97
Industrial	8.65	88.83	2.17	2.45	11.10
Open Space	26.30	8.48	40.16	10.32	36.62
Planned Unit Development	41.86	35.23	16.22	17.94	59.80
Residential	33.41	41.12	23.16	24.40	57.81
Unclassified	27.78	32.20	30.19	12.07	39.85
Total	**29.44%**	**42.84%**	**19.97%**	**13.46%**	**42.90%**

Zoning Class	Acres	Canopy Acres	Impervious Acres	Pervious Acres	Preferred Plantable Acres	Maximum UTC
Commercial	67.09	12.22	51.55	3.19	3.29	22.40
Government	19.69	9.82	3.43	4.56	4.35	73.97
Industrial	9.00	0.78	7.99	0.20	0.22	11.10
Open Space	298.04	78.40	25.27	119.68	30.75	46.79
Planned Unit Development	21.28	8.91	7.50	3.45	3.82	59.80
Residential	899.99	300.68	370.09	208.46	219.60	59.80
Unclassified	128.62	35.73	41.42	38.82	15.53	46.06
Total	**1,443.69**	**446.54**	**507.07**	**378.34**	**277.56**	**42.90**



Map 4. Pacific Grove Zoning

Canopy & Stormwater Management

Federal Clean Water Act regulations, require municipalities to obtain a permit for managing their stormwater discharges into water bodies. Each city's program must identify the best management practices it will implement to reduce its pollutant discharge. Nationwide, non-point source pollution is one of the biggest contributors to poor water quality. Non-point source pollution occurs when stormwater carries surface contaminants into surface or ground water. Preventing non-point source pollution and reducing stormwater runoff is becoming a serious environmental concern for many communities.

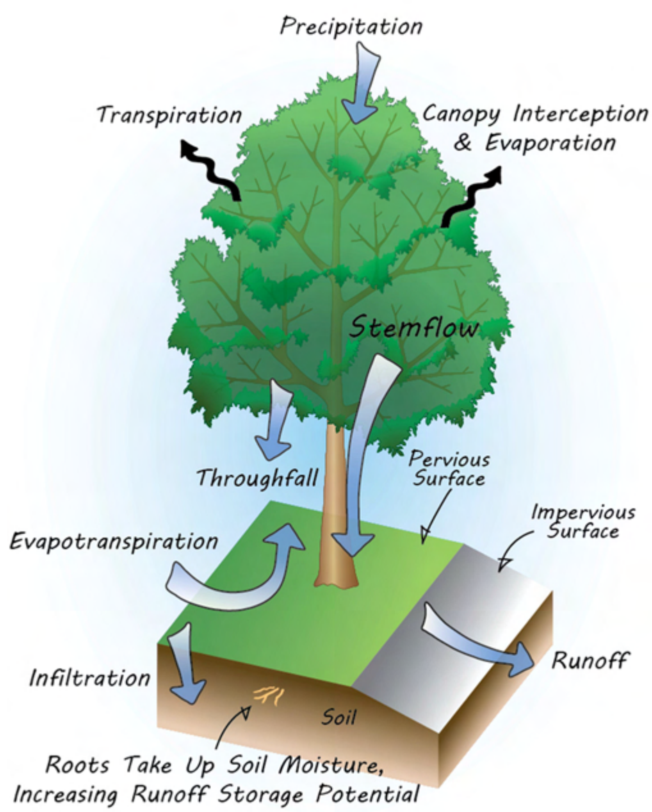


Figure 7. Role of trees in reducing stormwater runoff

Trees and forests are a natural, cost-efficient, and highly effective part of a stormwater management program (Figure 7). Many communities are turning to trees to help solve their stormwater issues in a more holistic manner. Engineered and natural stormwater systems that incorporate and take advantage of the natural benefits provided by trees and forests are proving to be more cost-effective and sustainable than traditional detention and treatment methods. While there are many methods and construction designs available for integrating urban trees into stormwater management infrastructure, including pervious pavement systems, suspended sidewalks, structural soils, bioswales, and stormwater tree pits, some of these designs can be costly to implement. Preserving natural or engineered forest stands and existing trees before, during, and after development reduces runoff from urban and suburban properties and effectively solves many stormwater issues before they become costly and/or detrimental to the surrounding environment.

Trees intercept rainfall in their canopy, which act as a mini-reservoir (Xiao et al, 1998). During storm events, this interception reduces and slows runoff. Furthermore, root growth and decomposition increase the capacity and rate of soil infiltration by rainfall (McPherson et al, 2002) Combined, this reduces and prolongs storm events so that water is less likely to overwhelm stormwater infrastructure. These benefits reduce the city's costs associated with maintaining and increasing the capacity of aging stormwater infrastructure. These costs are modeled based on typical costs of stormwater management in the Northern California Coast Region (i-tree Canopy v 6.1).

In Pacific Grove, the community tree canopy reduces stormwater runoff by more than 35.6 million gallons, valued at $356,536. This accounts for 69% of the total environmental benefits provided by this resource.

Assessing Stormwater Risk Potential

The impact of trees on stormwater systems is variable across the urban landscape. In Pacific Grove, tree planting at certain planting sites will produce greater stormwater benefits compared to other sites.

Identifying possible planting sites begins by mapping all grass, low-lying vegetation, and bare soil. However, not all of these areas are suitable planting sites because of site uses, including golf courses, cemeteries, sports fields, and other conflicts. Furthermore, some impervious areas can realistically be covered in tree canopy. Potential realistic plantable areas are determined by excluding those pervious areas that are unsuitable for planting and including impervious areas where trees could realistically be added, such as in parking lot islands, along sidewalks and near road edges. This UTC analysis included consideration of site design and environmental factors to prioritize planting sites on both public and private property with the greatest potential for return on investment, as young trees mature to provide maximum stormwater benefits.

Prioritized Planting Sites

To identify areas where additional trees would provide the greatest benefits to stormwater management and reducing runoff and erosion, Pacific Grove's existing landcover data was analyzed along with impervious surface and environmental factors (Table 5). Each of the datasets was classified based on the value of "risk" from 0-4, with 4 representing the greatest risk of contributing to stormwater runoff. Variables were weighted to produce a results grid. The grid was summarized using zonal statistics by each feature layer and each was assigned an average risk score. Areas and locations with the greatest risk score were classified as higher priority.

Table 5. Environmental Factors Used to Prioritize Tree Planting Sites

Dataset	Weight	Source
Impervious Distance	0.35	Urban Tree Canopy Assessment
Slope	0.25	National Elevation Dataset
Soils	0.20	Natural Resource Conservation Service
K-Factor	0.10	Natural Resource Conservation Service
Canopy Distance	0.10	Urban Tree Canopy Assessment

The Stormwater Priority Planting Map illustrates planting priority sites based on runoff risk (Figure 8 and Map 5). Increasing the number of trees and canopy in areas with the highest priority (red) will provide the greatest benefits to stormwater management by increasing capture rates, reducing runoff, and providing greater soil stability.

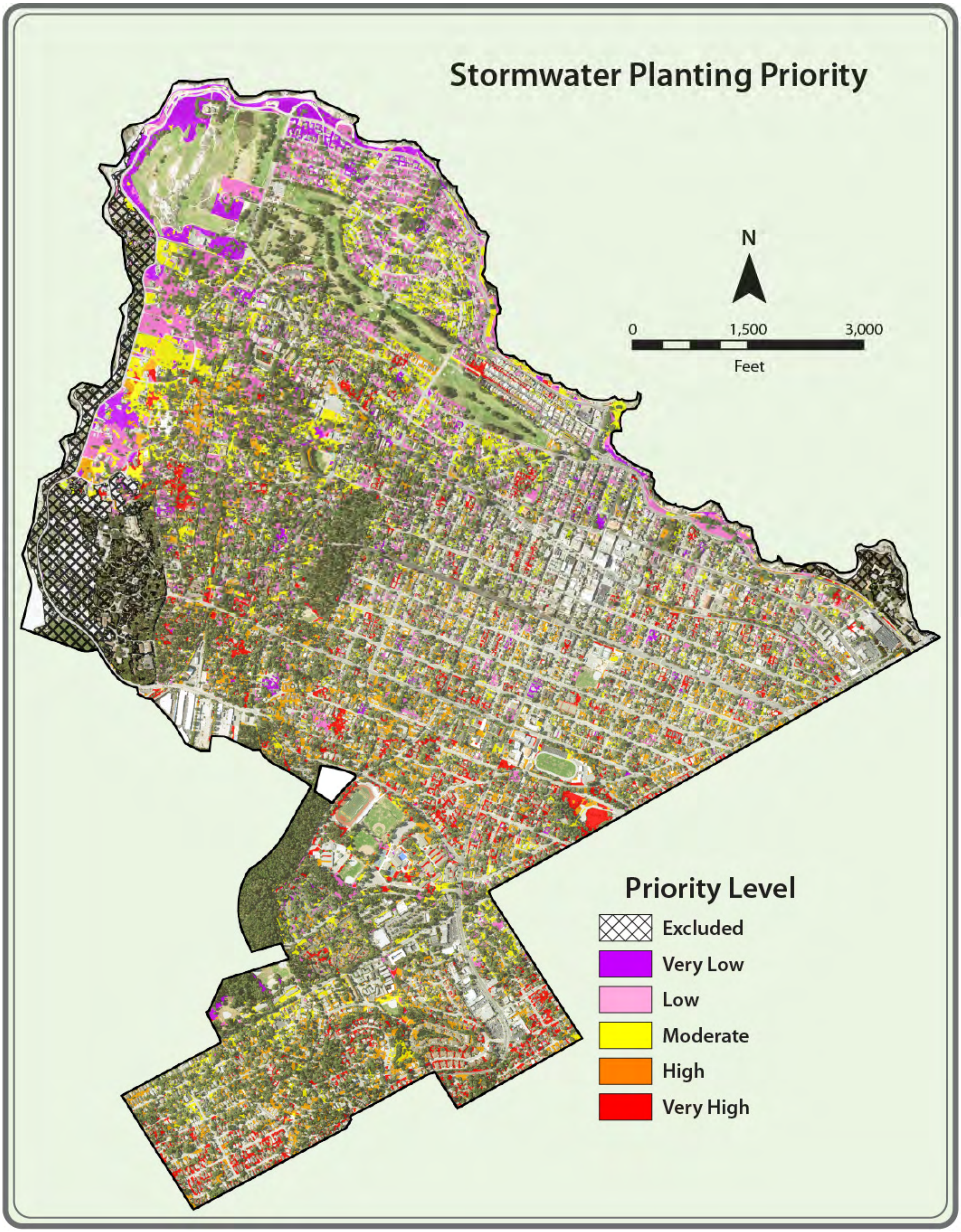
Based on stormwater runoff potential, the analysis identified 312 acres for priority planting and 9,901 potential planting areas or sites (Table 6).

Table 6. Acres of Planting Priority Sites

Priority Level	Planting Areas	Acres
Very High	2,217	57.6
High	2683	65.2
Moderate	2,596	83.6
Low	1932	71.7
Very Low	473	33.6
Excluded	418	70.7
	9,901	**311.7**

A final determination on priority planting sites should be made through site inspections with additional consideration for community values and further prioritized by zone, neighborhood, and parcel to determine the most optimal planting priorities. In addition, the 2015 public tree inventory revealed that, in public areas alone, 16% of tree sites will be available within the next five years due to vacant sites and recommended removals. Beyond those public sites, many planting opportunities exist on private property as well.

Figure 8. Planting Priorities Based on Site Uses and Environmental Factors



Map 5. Planting Priority

Historic Land Cover Change

Net Change

Over time, land cover shifts with development, tree planting, growth and removal, and with changes in land use. While Pacific Grove's population increased from 14,831 to 15,601 (5%) between 2005 and 2014, impervious surface remained nearly constant (42.8% to 42.7%) and tree canopy increased 51 acres (25.8% to 28.6%) (Figure 9 and Table 7). Grass and low-lying vegetation fluctuated between 23% and 25%, but resulted in little net change. Bare soils were reduced by 37 acres to 6%. Open water fluctuated as well, but this is to be expected in a coastal community and is a result of fluctuating tide levels in conjunction with the acquisition of aerial imagery.

Figure 9. Net Land Cover Change by Year

Table 7. Net Land Cover Change 2005 - 2014

	2005		2009		2014	
Land Cover Class	**Acres**	**%**	**Acres**	**%**	**Acres**	**%**
Tree Canopy	474	25.8	457	24.9	525	28.6
Buildings	321	17.5	328	17.8	327	17.8
Roads	247	13.4	247	13.5	244	13.3
Other Impervious	219	11.9	224	12.2	214	11.6
Grass/Low-Veg.	416	22.7	461	25.1	413	22.5
Bare Soil	146	8.0	111	6.1	109	6.0
Open Water	14	0.7	9	0.5	5	0.3
Citywide	**1,837**	**100%**	**1,837**	**100%**	**1,837**	**100%**

Land Cover Gains and Losses (2005-2014)

In addition to net change, an understanding of the dynamic fluctuations of land cover and in relation to geography can provide additional useful information. Tree Canopy and Grass and Low-lying Vegetation gained and lost the most acreage between 2005 and 2014 (Figure 10). This illustrates how dynamic and highly susceptible to change these land cover classes can be.

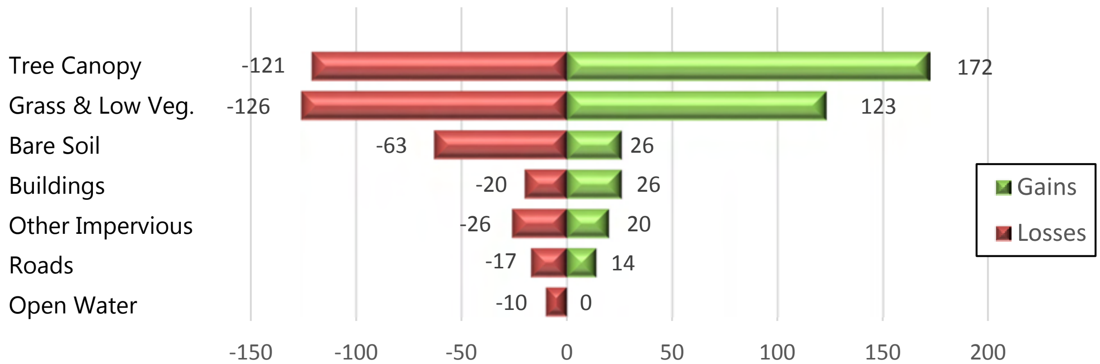


Figure 10. Gains and Losses (2005 – 2014)

Between 2005 and 2014, Tree Canopy gained 172 acres and lost 121 acres. Grass and low-lying vegetation on the other hand gained 123 acres and lost 126 acres. Bare soils gained 26 acres and lost 63 acres.

Buildings, Roads, and Other Impervious Surfaces gained 60 acres and lost 63 acres. However, it is most likely that any losses in impervious surface can be attributed to the overgrowth of tree canopy. Further illustrating that tree canopy has a great potential to share space with impervious surface. Purposeful design and planning can facilitate this relationship.

Figure 11 illustrates the spatial trend from All Land Cover Classes to Tree Canopy between 2005 and 2014. This is a best fit, third-order polynomial trend map of the pattern of tree canopy transitions from other land cover classes. The locations of the highest values (red) give an indication of where the greatest change most likely occurred. The area of greatest change is concentrated within the western segment of the city extending southwards; the area bordered by the Pacific Grove Golf Links, Asilomar State Beach, Hayward Park, Rip Van Winkle Open Space Park and George Washington Park area. The centroid of this hot spot is around the George Washington Park. This is where the greatest fluctuation between tree canopy and other land cover classes occurred. This variability highlights the fact that management for urban forest canopy must anticipate both gains and losses in order to ultimately promote strategies that result in net canopy growth.

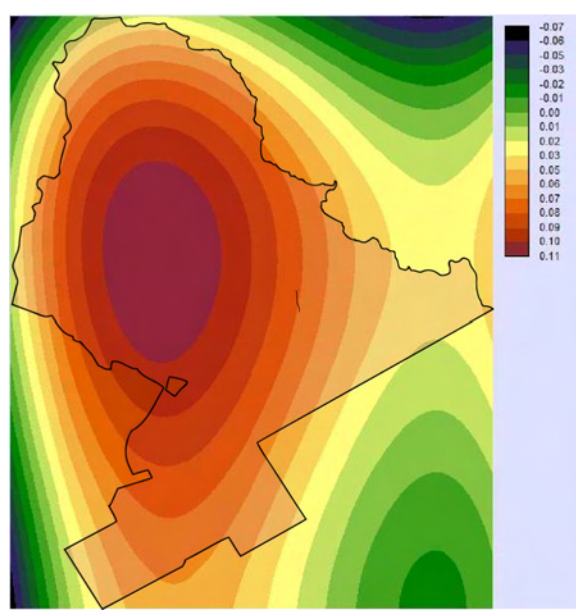
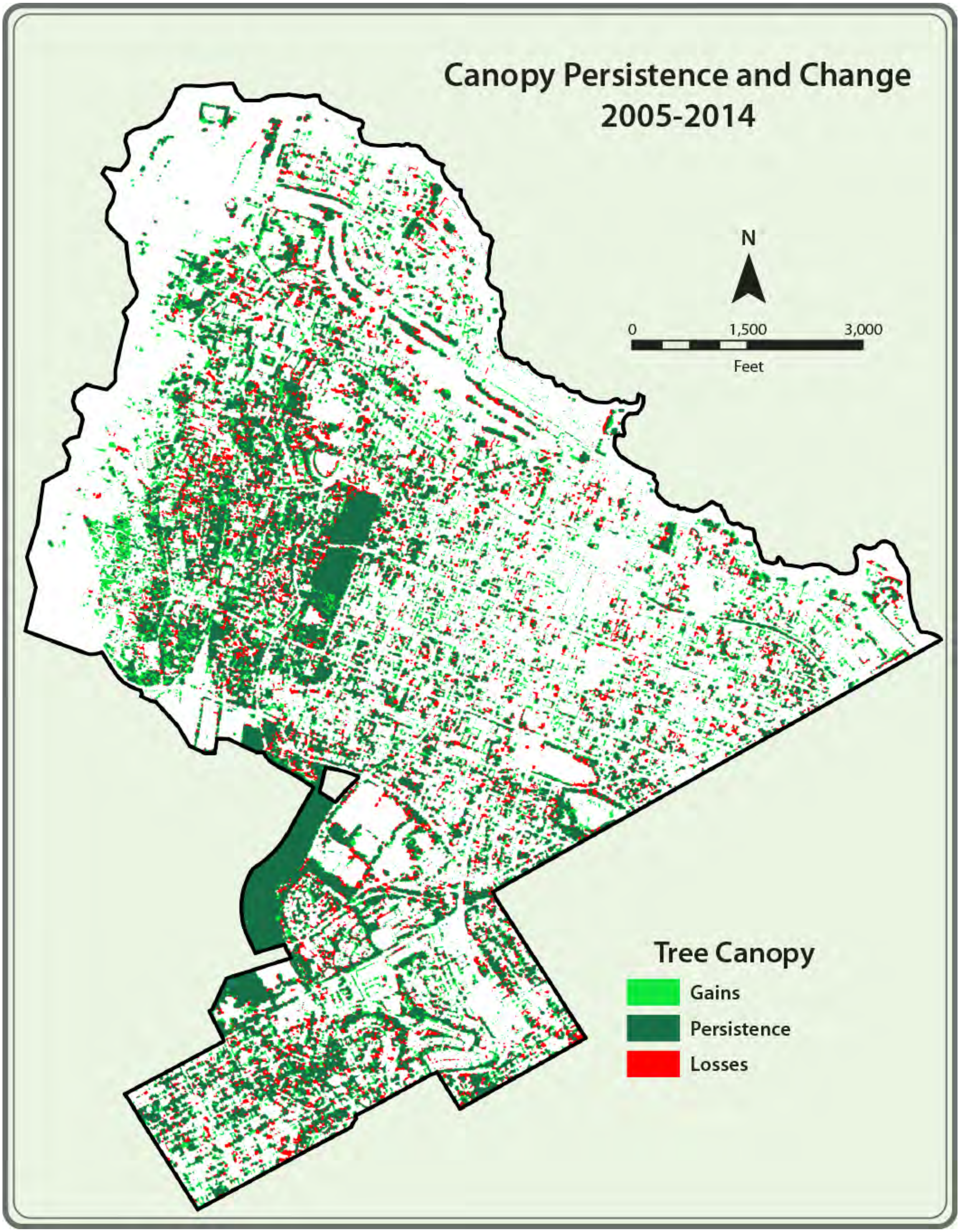


Figure 11. Hot Spot of Land Cover Changing to Tree Canopy

Map 6 illustrates areas of persistence and change in tree canopy from 2005 through 2014.



Map 6. Canopy Persistence and Change (2005-2014)

Net Change in Tree Canopy by Zone

In Pacific Grove, zoning class boundaries encompass 1,444 acres of the city's 1,837 total acres, and the remaining land is in the right-of-way. In the land use zones, from 2005 to 2014, canopy cover increased from 26% to 29%. The highest increases were seen in Government (44% to 50%) and PUD (37% to 42%) zoning classes. Residential had the highest canopy loss (from 30% to 28%) from 2005 to 2009, but gained 5% from 2009 to 2014 resulting in a total of 33% (Table 6). Based on these trends, with proactive management and ongoing strategic tree planting Pacific Grove will continue to enjoy the benefits of their current and future tree canopy.

Table 8. Percent Canopy Cover Change by Zoning Class from 2005 to 2014.

Zoning Class	2005 % Canopy	2009 % Canopy	2014 % Canopy
Commercial	15.20	15.94	18.22
Government	44.16	45.04	49.87
Industrial	4.57	6.14	8.65
Open Space	22.79	23.38	26.30
Planned Unit Development	37.18	40.20	41.86
Residential	30.44	28.47	33.41
Unclassified	27.61	26.63	27.78
Zoning Class Total	**25.99%**	**26.54%**	**29.44%**

Net Change in Tree Canopy by Neighborhood

In Pacific Grove, neighborhood boundaries encompass 1,438 acres of the city's 1,837 total acres. The overall canopy cover in neighborhoods is 443 acres (31%). In previous years, canopy cover has fluctuated. Asilomar has increased canopy cover from 12% to 19% since 2005. In contrast, Seaview neighborhood has lost canopy cover, from 40.4% in 2005 to 28.6% in 20014. Forth Addition neighborhood lost canopy cover from 2005 (30%) to 2009 (21%), but regained that lost cover by 2014 (31%). While the canopy cover has varied in the last decade, overall, the City increased canopy cover from 28.5% to 31% within all neighborhoods.

Table 9. Percent Canopy Cover Change From 2005-2014

Neighborhood	% Canopy 2005	% Canopy 2009	% Canopy 2014
Asilomar Dunes	12.4	13.6	18.7
Beach Tract / Fairway Homes	17.8	16.4	20.5
Country Club Gate/Forest Grove	52.0	51.6	51.2
Country Club Heights	37.0	34.7	38.9
Del Monte Park	37.7	38.8	40.5
Downtown	7.4	6.9	11.5
Fifth Addition	24.2	22.0	28.6
First Addition	18.8	15.4	22.9
Fourth Addition	30.1	20.9	30.8
Glen	33.5	37.8	36.7
Hillcrest	33.8	32.8	33.8
Pacific Grove Acres	46.4	43.3	48.0
Pacific Grove Retreat	15.3	13.4	18.2
Seaview	40.4	36.0	38.6
Second Addition	27.3	27.7	31.7
Sunset Drive	33.8	31.6	34.8
Third Addition	16.6	15.0	21.9
All Neighborhoods	**28.5%**	**26.9%**	**31.0%**

Projected Land Cover

Using IDRISI® Selva Edition 17.0 Land Change Modeler (LCM) software, DRG projected a net change in land cover for Pacific Grove by 2024 (Figure 12 and Map 7). The analysis was generated based on the gains and losses, net change, contributions and exchanges between land cover classes and the persistence and spatial trends of land cover classes that occurred between 2005 and 2014. It must be noted that the projections are based purely on the above without consideration for urban planning interventions and/or drastic modifications to the urban landscape.

Projection modeling estimates that of all land cover, tree canopy will experience the greatest increase, gaining 39 additional acres by 2024. As a result, tree canopy cover in 2024 is anticipated to reach 31%. This growth will most likely correspond with losses in Grass and Low-lying Vegetation and Other Impervious Surfaces.

The western segment of the city extending southwards; the area bordered by the Pacific Grove Golf Links, El Carmelo Cemetery, Asilomar State Beach, Hayward Park, Rip Van Winkle Open Space Park and George Washington Park area and surrounding areas will continue to provide the most conducive environment for Tree Canopy gain and to be the hotbed for most land cover changes.

Buildings are expected to increase 8.3 acres to 18.2%, with the majority of growth occurring around the area east of CA-68 in the northern segment of the city and west of CA-68 south of the intersection with Sunset Drive.

From an aerial viewpoint, Roads are projected to decline by less than an acre as the result of canopy growth along tree lined streets.

Other Impervious Surfaces will have the greatest decline, losing 4.5 acres and accounting for 11.3% of the city by 2024. Most significant losses are projected to be within the western section of the city and the area south-west of the intersection between CA-68 and Sunset Drive.

As mentioned previously, a decline in impervious surface is generally not a loss of impervious surface, but rather a result of shared space between tree canopy and impervious surface as canopy growth expands to provide shade for buildings, roads, sidewalks, and parking areas. This process and the longevity and health of trees in areas with a high percentage of impervious surface can be facilitated and improved with purposeful planning and design, including structural soils, suspended pavements, and pervious pavements that improve and increase uncompacted soil volume below grade.

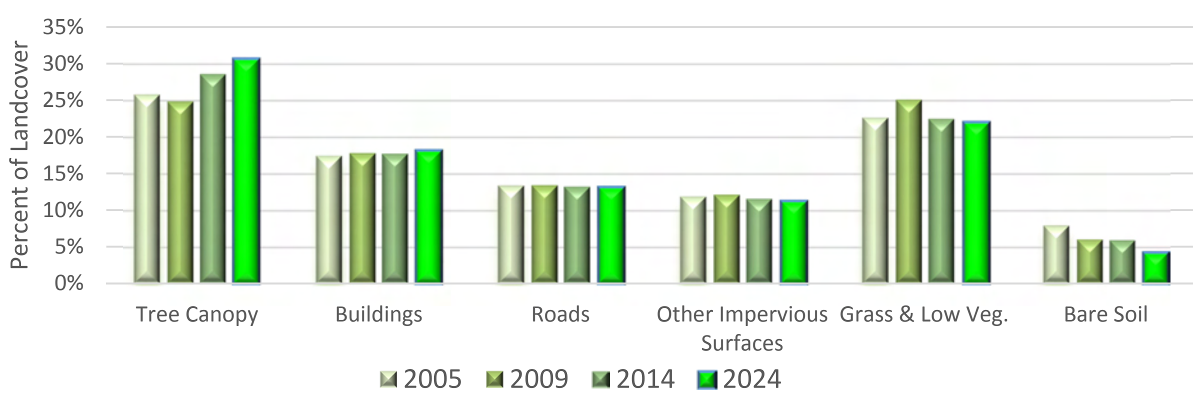
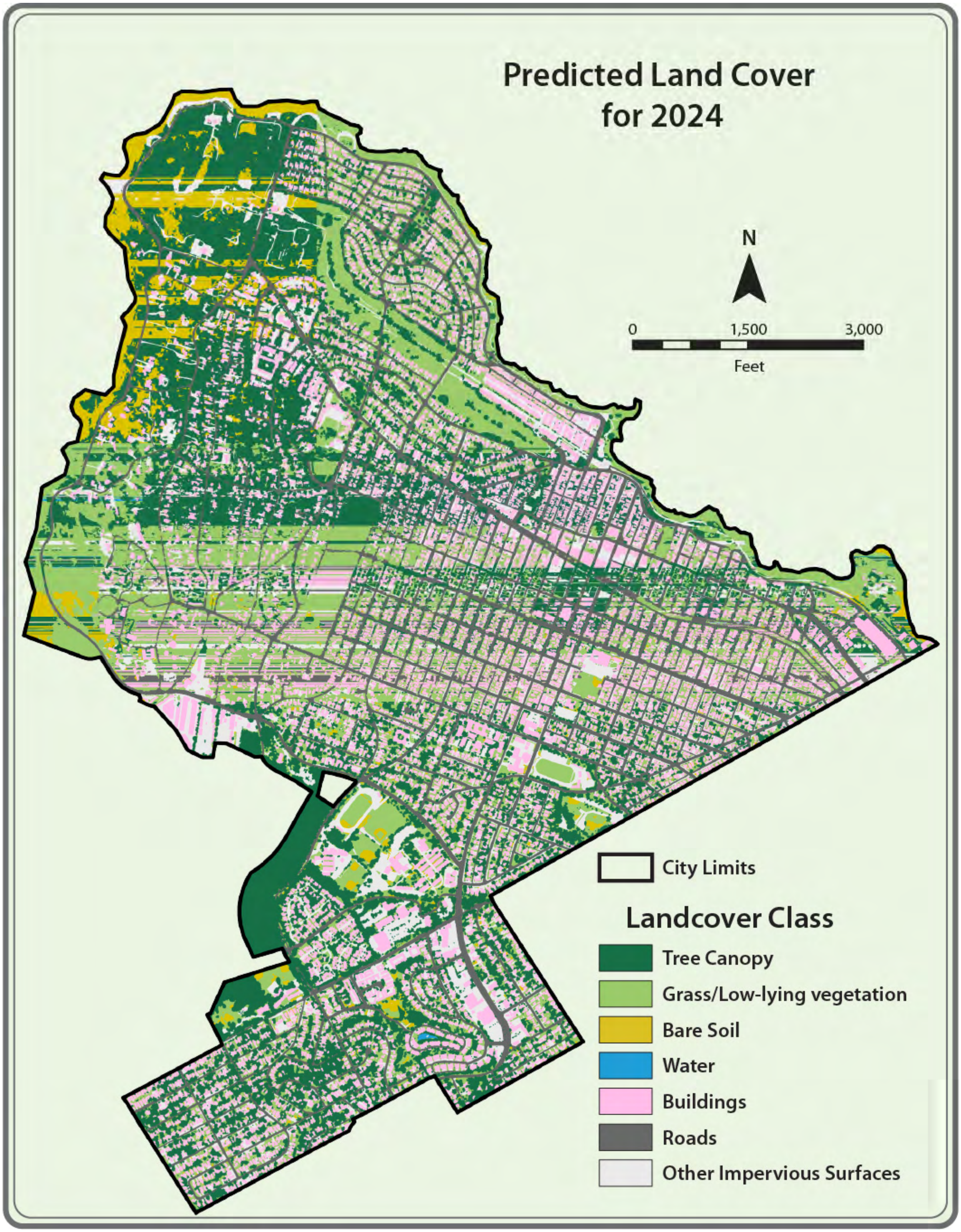


Figure 12. Historic and Predicted Change in Land Cover



Map 7. Land Cover Predicted by 2024

Tree Canopy Potential

The potential for tree canopy can be estimated by adding the area of existing canopy to the area of low-lying vegetation and impervious surface that appears, from aerial imagery and other GIS datasets, to provide potential for trees. This typically excludes sports fields, golf courses, cemeteries, and coastal dunes. Based on this methodology, the potential tree canopy for Pacific Grove is 57% (1,048 acres).

Tree Canopy Goals

Understanding canopy potential is helpful information when setting tree canopy goals. However, it is just as important to balance this information with what is economically, ecologically, and politically feasible for the community. This often requires input and support from multiple stakeholders, including residents, local leaders, and urban forest managers. Canopy goals should reflect local values, local environmental and quality of life goals, compliance with federal and local clean air and water regulations, and economic development plans. These goals can vary based on land use and jurisdiction.

In 2012, Pacific Grove established a canopy goal of an overall 33% tree canopy by 2037. Based on historical growth between 2005 (25.8%) and 2014 (28.6%), and predicted tree canopy in 2024 (31%), the community is on track for achieving this goal (Figure 13). Success will rely partly on increasing trees on private property, where City code has specific tree canopy requirements. Pacific Grove Municipal Code (PGMC) provides guidelines for tree planting on residential properties based on the available landscaped area, specifying 1-4 trees depending on residential lot size. Guidelines for Commercial and Governmental properties specify one tree per 30′ frontage, and a minimum of two trees per property if space is available. Parks and Parking Lots have standard canopy goals of 33%. The GIS information developed as a result of the UTC assessment provides benchmarks for canopy distribution over the previous 10 years, which can provide a valuable tool for measuring the success of the these goals and for making future urban forest management decisions.

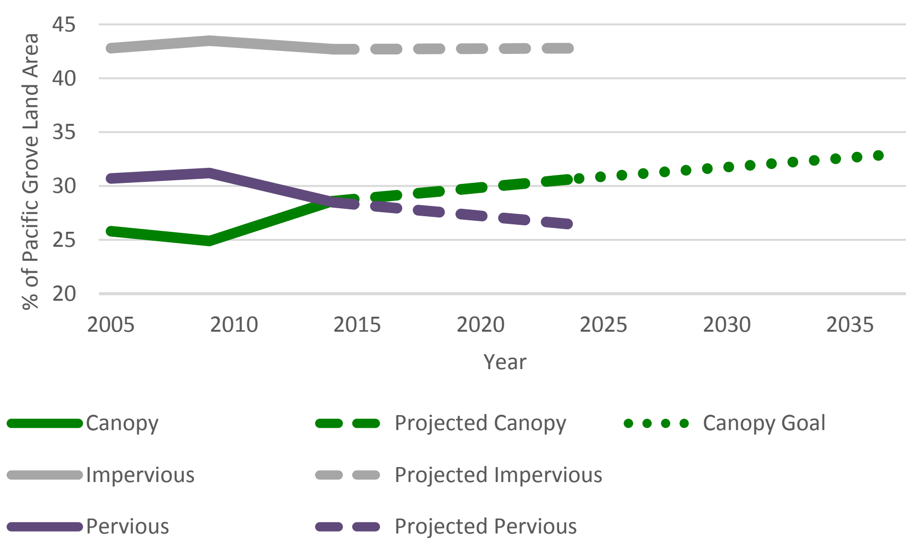


Figure 13. Land Use Trends, Projections, and Goal

Conclusion

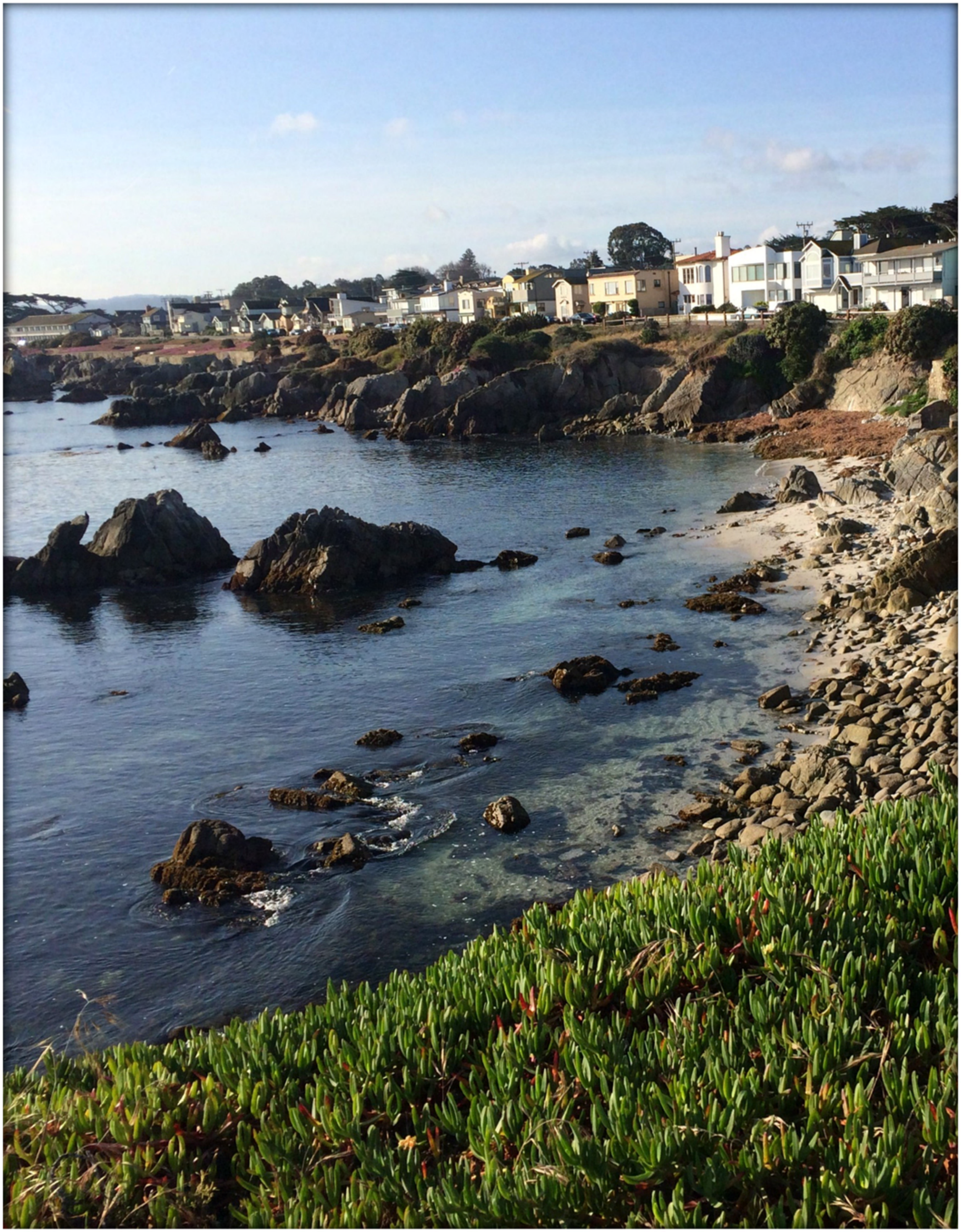
Pacific Grove's existing tree canopy is substantial, covering 29% of the city, and the preservation and protection of this resource is essential to maintaining a healthy and sustainable community. Based on both historical (2005-2014) and projected growth, the community is on track for reaching the established goal of 33% tree canopy by 2037. Proactive preservation and mitigation policies and ongoing tree replacement can ensure that canopy cover continues to grow over time.

The Urban Tree Canopy Assessment establishes a GIS data layer that can be used in conjunction with other infrastructure layers to prioritize planting sites and increase canopy cover strategically by zone, neighborhood or parcel. This assessment establishes a baseline for developing urban forest management strategies and measuring the success of those strategies over time.

Based on this assessment, Pacific Grove has the following opportunities:

- Considering that nearly 43% of the community is covered by impervious surfaces, including roads, parking lots, and structures, and based on possible planting sites near those impervious areas, Pacific Grove has the potential to support 57% overall canopy cover.
- Prioritized maps provide a basis for a strategically focused planting plan to increase trees and canopy that will support stormwater management, preserve soil, and complement the existing urban infrastructure for the greatest impact and return on investment.
- New tree planting can include strategies for increasing canopy cover on both public and private property.
- This report provides an overview of the existing tree canopy and an important outreach tool for engaging public interest and support. However, the accompanying GIS layer that maps the location and extent of existing landcover can support a vast range of additional analysis when used in conjunction with other data layers. The data supports analysis from an overall community level down to the parcel level and can provide an important tool for investigating the relationship of tree canopy in correlation with other important issues, including transportation, walkability, human health, and social and economic concerns.

Land Cover Projections through 2024 can help managers envision future tree canopy gains and losses depending development, tree preservation, and strategically locating tree planting. This spatial understanding the past, present and possible tree canopy can is a valuable tool to help managers align urban forestry management with the community's vision for tree canopy in Pacific Grove.



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Appendix B: Environmental Calculations

Air Quality

The i-Tree Canopy v6.1 Model was used to quantify the value of ecosystem services for air quality. i-Tree Canopy was designed to give users the ability to estimate tree canopy and other land cover types within any selected geography. The model uses the estimated canopy percentage and reports air pollutant removal rates and monetary values for carbon monoxide (CO), nitrogen dioxide (NO_2), ozone (O_3), sulfur dioxide (SO_2), and particulate matter (PM) (Hirabayashi 2014).

Within the i-Tree Canopy application, the U.S. EPA's BenMAP Model estimates the incidence of adverse health effects and monetary values resulting from changes in air pollutants (Hirabayashi 2014; US EPA 2012). Different pollutant removal values were used for urban and rural areas. In i-Tree Canopy, the air pollutant amount annually removed by trees and the associated monetary value can be calculated with tree cover in areas of interest using BenMAP multipliers for each county in the United States.

To calculate ecosystem services for the study area, canopy percentage metrics from UTC land cover data performed during the assessment were transferred to i-Tree Canopy. Those canopy percentages were matched by placing random points within the i-Tree Canopy application. Benefit values were reported for each of the five listed air pollutants.

Carbon Storage and Sequestration

The i-Tree Canopy v6.1 Model was used to quantify the value of ecosystem services for carbon storage and sequestration. i-Tree Canopy was designed to give users the ability to estimate tree canopy and other land cover types within any selected geography. The model uses the estimated canopy percentage and reports carbon storage and sequestration rates and monetary values. Methods on deriving storage and sequestration can be found in Nowak et al. 2013.

To calculate ecosystem services for the study area, canopy percentage metrics from UTC land cover data performed during the assessment were transferred to i-Tree Canopy. Those canopy percentages were matched by placing random points within the i-Tree Canopy application. Benefit values were reported for carbon storage and sequestration.

Stormwater

The i-Tree Hydro v5.0 Model was used to quantify the value of ecosystem services for stormwater runoff. i-Tree Hydro was designed for users interested in analysis of vegetation and impervious cover effects on urban hydrology. This most recent version (v5.0) allows users to report hydrologic data on the city level rather than just a watershed scale giving users more flexibility. For more information about the model, please consult the i-Tree Hydro v5.0 manual (http://www.itreetools.org).

To calculate ecosystem services for the study area, land cover percentages derived for Pacific Grove were used as inputs into the model. Precipitation data from 2011 was selected within the model as that year closely represented the average rainfall (16.1in) for the city (NOAA 2015). Model simulations were run under a Base Case as well as an Alternate Case. The Alterative Case increased canopy by 1% and assumed that impervious and vegetation cover would decrease by 0.7 for vegetated cover and 0.3% for impervious cover as plantings would ultimately reduce these land cover types. This process was completed to assess the runoff reduction volume associated with a 1% increase in tree canopy since i-Tree Hydro does not directly report the volume of runoff reduced by tree canopy. The volume (in cubic meters) was converted to gallons and multiplied by the current canopy percentage (28.6%) in Pacific Grove to retrieve the overall volume reduced by the tree canopy.

Through model simulation, it was determined that tree canopy decreases the runoff volume in Pacific Grove by 35.7 million gallons during an average precipitation year. This equates to approximately 67,852 gallons per acre of tree canopy (35.7M gals/525.5 acres).

To place a monetary value on stormwater reduction, the City of Berkeley Municipal Tree Guide Report (Maco et al. 2005) provided the price to treat a gallon of storm water used in several research studies within the area ($0.01 per gallon). Tree canopy was estimated to contribute roughly $356,500 annually to Pacific Grove.

Appendix C: Methods

Land Cover Assessment Methods

Davey Resource Group utilized an object-based image analysis (OBIA) semi-automated feature extraction method to process and analyze current high-resolution color infrared (CIR) aerial imagery and remotely-sensed data to identify tree canopy cover and land cover classifications. The use of imagery analysis is cost-effective and provides a highly accurate approach to assessing your community's existing tree canopy coverage. This supports responsible tree management, facilitates community forestry goal-setting, and improves urban resource planning for healthier and more sustainable urban environments.

Advanced image analysis methods were used to classify, or separate, the land cover layers from the overall imagery. The semi-automated extraction process was completed using Feature Analyst, an extension of ArcGIS®. Feature Analyst uses an object-oriented approach to cluster together objects with similar spectral (i.e., color) and spatial/contextual (e.g., texture, size, shape, pattern, and spatial association) characteristics. The land cover results of the extraction process was post-processed and clipped to each project boundary prior to the manual editing process in order to create smaller, manageable, and more efficient file sizes. Secondary source data, high-resolution aerial imagery provided by each UTC city, and custom ArcGIS® tools were used to aid in the final manual editing, quality checking, and quality assurance processes (QA/QC). The manual QA/QC process was implemented to identify, define, and correct any misclassifications or omission errors in the final land cover layer.

Classification Workflow

1) Prepare imagery for feature extraction (resampling, rectification, etc.), if needed.
2) Gather training set data for all desired land cover classes (canopy, impervious, grass, bare soil, shadows). Water samples are not always needed since hydrologic data are available for most areas. Training data for impervious features were not collected because the City maintained a completed impervious layer.
3) Extract canopy layer only; this decreases the amount of shadow removal from large tree canopy shadows. Fill small holes and smooth to remove rigid edges.
4) Edit and finalize canopy layer at 1:2000 scale. A point file is created to digitize-in small individual trees that will be missed during the extraction. These points are buffered to represent the tree canopy. This process is done to speed up editing time and improve accuracy by including smaller individual trees.
5) Extract remaining land cover classes using the canopy layer as a mask; this keeps canopy shadows that occur within groups of canopy while decreasing the amount of shadow along edges.
6) Edit the impervious layer to reflect actual impervious features, such as roads, buildings, parking lots, etc. to update features.
7) Using canopy and actual impervious surfaces as a mask; input the bare soils training data and extract them from the imagery. Quickly edit the layer to remove or add any features. Davey

Resource Group tries to delete dry vegetation areas that are associated with lawns, grass/meadows, and agricultural fields.

8) Assemble any hydrological datasets, if provided. Add or remove any water features to create the hydrology class. Perform a feature extraction if no water feature datasets exist.
9) Use geoprocessing tools to clean, repair, and clip all edited land cover layers to remove any self-intersections or topology errors that sometimes occur during editing.
10) Input canopy, impervious, bare soil, and hydrology layers into Davey Resource Group's Five-Class Land Cover Model to complete the classification. This model generates the pervious (grass/low-lying vegetation) class by taking all other areas not previously classified and combining them.
11) Thoroughly inspect final land cover dataset for any classification errors and correct as needed.
12) Perform accuracy assessment. Repeat Step 11, if needed.

Automated Feature Extraction Files

The automated feature extraction (AFE) files allow other users to run the extraction process by replicating the methodology. Since Feature Analyst does not contain all geoprocessing operations that Davey Resource Group utilizes, the AFE only accounts for part of the extraction process. Using Feature Analyst, Davey Resource Group created the training set data, ran the extraction, and then smoothed the features to alleviate the blocky appearance. To complete the actual extraction process, Davey Resource Group uses additional geoprocessing tools within ArcGIS®. From the AFE file results, the following steps are taken to prepare the extracted data for manual editing.

1) Davey Resource Group fills all holes in the canopy that are less than 30 square meters. This eliminates small gaps that were created during the extraction process while still allowing for natural canopy gaps.
2) Davey Resource Group deletes all features that are less than 9 square meters for canopy (50 square meters for impervious surfaces). This process reduces the amount of small features that could result in incorrect classifications and also helps computer performance.
3) The Repair Geometry, Dissolve, and Multipart to Singlepart (in that order) geoprocessing tools are run to complete the extraction process.
4) The Multipart to Singlepart shapefile is given to GIS personnel for manual editing to add, remove, or reshape features.

Accuracy Assessment Protocol

Determining the accuracy of spatial data is of high importance to Davey Resource Group and our clients. To achieve to best possible result, Davey Resource Group manually edits and conducts thorough QA/QC checks on all urban tree canopy and land cover layers. A QA/QC process will be completed using ArcGIS® to identify, clean, and correct any misclassification or topology errors in the final land cover dataset. The initial land cover layer extractions will be edited at a 1:2000 quality control scale in the urban areas and at a 1:2500 scale for rural areas utilizing the most current high-resolution aerial imagery to aid in the quality control process.

To test for accuracy, random plot locations are generated throughout the city area of interest and verified to ensure that the data meet the client standards. Each point will be compared with the most current NAIP high-resolution imagery (reference image) to determine the accuracy of the final land cover layer. Points will be classified as either correct or incorrect and recorded in a classification matrix. Accuracy will be assessed using four metrics: overall accuracy, kappa, quantity disagreement, and allocation disagreement. These metrics are calculated using a custom Excel® spreadsheet.

Land Cover Accuracy

The following describes Davey Resource Group's accuracy assessment techniques and outlines procedural steps used to conduct the assessment.

1) *Random Point Generation*—Using ArcGIS, 1,000 random assessment points are generated.
2) *Point Determination*—Each point is carefully assessed by the GIS analyst for likeness with the aerial photography. To record findings, two new fields, CODE and TRUTH, are added to the accuracy assessment point shapefile. CODE is a numeric value (1–5) assigned to each land cover class and TRUTH is the actual land cover class as identified according to the reference image. If CODE and TRUTH are the same, then the point is counted as a correct classification. Likewise, if the CODE and TRUTH are not the same, then the point is classified as incorrect. In most cases, distinguishing if a point is correct or incorrect is straightforward. Points will rarely be misclassified by an egregious classification or editing error. Often incorrect points occur where one feature stops and the other begins.
3) *Classification Matrix*—During the accuracy assessment, if a point is considered incorrect, it is given the correct classification in the TRUTH column. Points are first assessed on the NAIP imagery for their correctness using a "blind" assessment—meaning that the analyst does not know the actual classification (the GIS analyst is strictly going off the NAIP imagery to determine cover class). Any incorrect classifications found during the "blind" assessment are scrutinized further using sub-meter imagery provided by the client to determine if the point was incorrectly classified due to the fuzziness of the NAIP imagery or an actual misclassification. After all random points are assessed and recorded; a classification (or confusion) matrix is created. The classification matrix for this project is presented in Table 10. The table allows for assessment of user's/producer's accuracy, overall accuracy, omission/commission errors, kappa statistics, allocation/quantity disagreement, and confidence intervals (Figure 12 and Table 10).

Figure 14. Land Cover Accuracy

Table 10. Classification Matrix

Reference Data	Classification Data									
Classes	**Tree Canopy**	**Buildings**	**Roads**	**Other Impervious**	**Grass & Low Veg.**	**Bare Soils**	**Water**	**Row Total**	**Producer's Accuracy**	**Errors of Omission**
Tree Canopy	**279**	5	10	4	11	0	0	**309**	90.29%	9.71%
Buildings	0	**187**	0	0	2	1	0	**190**	98.42%	1.58%
Roads	0	0	**116**	0	1	0	0	**117**	99.15%	0.85%
Other Impervious	3	1	2	**103**	9	1	0	**119**	86.55%	13.45%
Grass & Low Veg.	11	0	1	4	**178**	2	0	**196**	90.82%	9.18%
Bare Soils	0	0	0	1	6	**57**	0	**64**	89.06%	10.94%
Water	0	0	0	0	0	0	**5**	**5**	100.00%	0.00%
Column Total	**293**	**193**	**129**	**112**	**207**	**61**	**5**	**1,000**		
User's Accuracy	95.22%	96.89%	89.92%	91.96%	85.99%	93.44%	100.00%		Overall Accuracy	92.50%
Errors of Commission	4.78%	3.11%	10.08%	8.04%	14.01%	6.56%	0.00%		Kappa Coefficient	0.9062

Following are descriptions of each statistic as well as the results from some of the accuracy assessment tests.

Overall Accuracy – Percentage of correctly classified pixels; for example, the sum of the diagonals divided by the total points ((279+187+116+103+178+57+5)/1,000 = 92.50%).

User's Accuracy – Probability that a pixel classified on the map actually represents that category on the ground (correct land cover classifications divided by the column total [279/293 = 95.22%]).

Producer's Accuracy – Probability of a reference pixel being correctly classified (correct land cover classifications divided by the row total [279/309 = 90.29%]).

Kappa Coefficient – A statistical metric used to assess the accuracy of classification data. It has been generally accepted as a better determinant of accuracy partly because it accounts for random chance agreement. A value of 0.80 or greater is regarded as "very good" agreement between the land cover classification and reference image.

Errors of Commission – A pixel reports the presence of a feature (such as trees) that, in reality, is absent (no trees are actually present). This is termed as a false positive. In the matrix below, we can determine that 4.78% of the area classified as canopy is most likely not canopy.

Errors of Omission – A pixel reports the absence of a feature (such as trees) when, in reality, they are actually there. In the matrix below, we can conclude that 9.71% of all canopy classified is actually present in the land cover data.

Errors of Omission – A pixel reports the absence of a feature (such as trees) when, in reality, they are actually there. In the matrix below, we can conclude that 10.29% of all canopy classified is actually present in the land cover data.

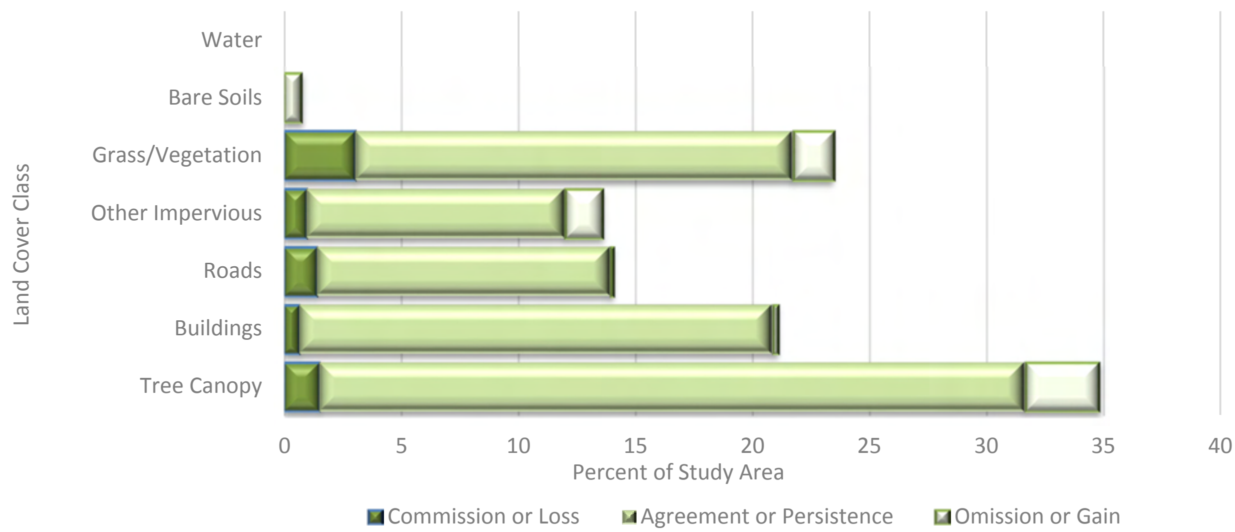

Figure 16. Omission/Commission Errors

Allocation Disagreement – The amount of difference between the reference image and the classified land cover map that is due to less than optimal match in the spatial allocation (or position) of the classes.

Quantity Disagreement – The amount of difference between the reference image and the classified land cover map that is due to less than perfect match in the proportions (or area) of the classes.

Confidence Intervals – A confidence interval is a type of interval estimate of a population parameter and is used to indicate the reliability of an estimate. Confidence intervals consist of a range of values (interval) that act as good estimates of the unknown population parameter based on the observed probability of successes and failures. Since all assessments have innate error, defining a lower and upper bound estimate is essential.

Table 11. Omission/Commission Errors

Class	Acreage	%	Lower Bound	Upper Bound
Tree Canopy	526	28.60%	27.50%	29.70%
Buildings	327	17.80%	16.90%	18.70%
Roads	244	13.30%	12.50%	14.10%
Other Impervious	214	11.60%	10.90%	12.40%
Grass & Low Veg.	413	22.50%	21.50%	23.50%
Bare Soils	109	6.00%	5.40%	6.50%
Open Water	5	0.30%	0.20%	0.40%
Total	**1,837**	**100%**		

Statistical Metrics Summary	
Overall Accuracy =	92.50%
Kappa Coefficient =	90.62%
Allocation Disagreement =	7.00%
Quantity Disagreement =	1.00%

Accuracy Assessment

Class	User's Accuracy	Lower Bound	Upper Bound	Producer's Accuracy	Lower Bound	Upper Bound
Tree Canopy	95.20%	94.00%	96.50%	90.30%	88.60%	92.00%
Buildings	96.90%	95.60%	98.10%	98.40%	97.50%	99.30%
Roads	89.90%	87.30%	92.60%	99.10%	98.30%	100.00%
Other Impervious	92.00%	89.40%	94.50%	86.60%	83.40%	89.70%
Grass & Low Veg.	86.00%	83.60%	88.40%	90.80%	88.80%	92.90%
Bare Soils	93.40%	90.30%	96.60%	89.10%	85.20%	93.00%
Open Water	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

Land Cover Change Assessment

Davey Resource Group utilized IDRISI® Selva Edition 17.0 Land Change Modeler (LCM) software to analyze land cover change and prediction with an assessment of the gains and losses of land cover classes, net change, persistence and specific transitions displayed in a map and graphical form.

Land cover class change analysis was conducted between 2005 and 2014 to identify the transitions from one land cover type to another.

The potentials of the land cover classes to transition over a period of time were modeled based on a driver variable – elevation. Based on an assessment of the rates of change of land cover classes and the corresponding transition potentials, a change prediction analysis was conducted to predict future scenario for 2024 in a map and video format.

Assessment Workflow

1) Convert Land cover layers from ESRI Shapefiles to Rasta data sets and subsequently to American Standard Code for Information Interchange (ASCII) formats in ArcMap 10.2.2 for compatibility and import into IDRISI Selva 17.0 Raster data formats. Ensure the following conditions are met:

   a. The legends in both maps are the same.

   b. The categories in both maps are the same and sequential.

   c. The backgrounds in both maps are the same and have a value of zero.

   d. The spatial dimensions, including resolution and coordinates, are the same.

2) In the Change Analysis Tab, set the Earlier (2005) and Later (2014) Land cover Raster Images within the project parameters Panel.
3) Assess the gains and losses by land cover class category based on the land cover Raster images for 2005 and 2014. All changes were analyzed in acreage and percentage change unless specified.
4) Conduct a net change by category was based on the land cover Raster images.
5) Assess the contributions to net change per land cover category.
6) Create map showing the changes by land cover class.
7) Create a persistence map to depict the land cover class which
8) Create map showing gains and losses in each land cover class.
9) Create maps depicting transitions from specified land cover classes.
10) Create maps depicting exchanges from specified land cover classes
11) Conduct a Spatial Trend Analysis for specified land cover classes using the third order of polynomial within the Spatial Trend of Change panel.
12) Determine all Land cover Transition sub-models and evaluate them accordingly.
13) Assign All Transitions to a specific land cover class to a group and notate them accordingly. All land cover transitions to Tree Canopy are sub-modeled and named 'Tree Canopy' An evaluation of the sub-model 'Tree Canopy' therefore depicts transitions from Impervious Surfaces, Buildings, Roads, Open Water and Bare Soils.

14) Include a variable – Elevation as a Static variable within the Transition sub-model structure.
15) Run the Transition Sub-model using the Multi-Layer perceptron Neural Network.
16) Create a Transition Potential Map for each sub-model: Tree Canopy, Impervious Surfaces, Buildings, Roads, Open Water and Bare Soils.
17) Using the Markov Chain option under the Change Demand Modeling, set the Prediction Date to 2024
18) In the Change Allocation ensure that the set predicted date is correctly reflected and specify the Recalculation stages to 2.
19) Check the create AVI video, specify the Frame Rate (sec) to 0.5 and check the display the intermediate stage images.
20) Run model to create Projected Land cover (2024) map and AVI video.

Tree Canopy Health Assessment

Following the mapping and analysis of tree canopy cover, additional models were completed to evaluate the condition of the tree canopy. Broad band based vegetation indices, based on sensors with broad wavelength region bands, are the most frequently used indicators for monitoring ecosystem dynamics and vegetation health. Many vegetation indices have been developed and applied in vegetation studies since the first vegetation index was introduced. Vegetation indices were created to evaluate cover, chlorophyll content, leaf area, phenology, and absorbed photo-synthetically active radiation. Since live green vegetation and tree canopy absorb solar radiation in the photosynthetically active radiation (PAR) spectral region, they scatter solar radiation in the near-infrared spectral region. When the two spectral regions are assessed in ratio-based indices, they contrast with cover that absorbs or reflects light similarly in both regions.

Normalized Difference Vegetation Index

The Normalized Difference Vegetation Index (NDVI) is a numerical indicator that uses the visible and near-infrared bands of the electromagnetic spectrum, and is adopted to analyze remote sensing measurements and assess whether the target being observed contains live green vegetation or not. NDVI is a ratio (using red and near-infrared bands) ranging from -1 to 1 with vegetation being a positive value – normally greater than 0.3. Increasing positive values indicates healthier vegetation communities. Generally, healthy vegetation will absorb most of the visible light that falls on it, and reflects a large portion of the near-infrared light; thus, healthy vegetation will be more pronounced than dead or dying vegetation because of the amount of chlorophyll within the leaves to absorb visible light.

Determining Tree Canopy Health

To assess canopy health and to identify areas with dead or dying trees, Davey Resource Group utilized NDVI to extract ratio values from the 2014 NAIP imagery using the red and near-infrared bands. The NDVI values were normalized on a scale from 0 – 1 to highlight canopy communities and the overall condition of the trees. Results of this analysis include a breakdown of tree canopy health into six classes: Excellent, Very Good, Good, Fair, Poor, and Dead/Dying. The number of acres for each canopy health class was tabulated and shown below. The results of this analysis can be used by Pacific Grove to further inspect the poor condition canopy to find out the real cause of poor health (i.e. drought, disease, fire, dying trees, etc.).