



Pasadena Windstorm Tree Failure Analysis

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Prepared for:

City of Pasadena

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Executive Summary

The City of Pasadena maintains nearly 57,500 street trees distributed over 64,500 sites throughout the City. With over 200 distinct species and more than 30 different genera, the City's urban forest provides a diverse and unique setting for the residents and visitors of Pasadena. The maintenance of this large tree population follows the most current International Society of Arboriculture (ISA) Best Management Practices. Most trees are routinely pruned on a 5-year cycle with some of the trees being pruned more frequently. The recently updated tree inventory completed in March of 2012 found that over 90% of Pasadena's trees were in fair or better condition.

Between November 30 and December 1, 2011, strong sustained winds swept through the area causing significant damage to the City's infrastructure, including the urban forest. Official wind speeds of over 60 miles per hour recorded throughout the region with documented wind speeds of over 100 miles per hour within the City of Pasadena. Hundreds of buildings and light poles were damaged. The City's urban forest endured severe losses with approximately 9% of the trees suffering damage in the high winds. Overall, the City costs are projected to be in the tens of millions of dollars.

In February 2012, the City of Pasadena contracted with Davey Resource Group (DRG) to analyze the tree failure data following the historic windstorm. Information gathered by City staff on nearly 5,500 damaged trees, data from the most recent inventory, and historical weather data used to analyze the impact of the windstorm on the urban forest. Tree species, condition, location, pruning practices, failure types, and site condition were several of the contributing factors analyzed as part of this report. In addition, field observations at over 50 locations were also performed.

The results of this analysis revealed that over 56% of the damage to the urban forest was branch failure and more than 30% identified as whole tree failure. Other findings included:

- Live oak, Chinese elm, southern magnolia, camphor, Queensland pittosporum and holly oak were the top six species with the most damage.
- Queensland pittosporum was the poorest performing species with over 50% of its population suffering damage.
- Tree condition was a minor contributing factor to the extent of damage as most affected trees were in fair or better condition at the time of the storm.
- Wind speed and direction was determined to be the major contributing factor. The extent of the damage to the trees from the wind was based on the tree's location within the canopy or within a street segment.
- Current and past pruning practices did not contribute to the extent of damage based on observed tree condition.
- Tree form (growth habit) contributed to damage type; broad canopy trees had more failure types than columnar trees.
- Whole tree failures were dominated by soil failure rather than root failure, indicating tree root structure and health was good.
- Trees adjacent to taller structures or otherwise protected fared better than some exposed trees in the downtown area.
- Site conditions such as planting space size or the presence of irrigation were not contributing factors to tree failure in this analysis.



- Although widespread throughout the City, storm damage was greater in certain portions of the City such as the Eaton Wash area.

Historical weather data clearly indicated that the windstorm of 2011 was a severe and unique event for the region and an extremely rare occurrence for Pasadena. The high intensity and direction of the winds was the primary cause of the unpreventable wide variety of damage to the urban forest structure. The current tree management program, including proper pruning practices and frequent maintenance cycle, most certainly prevented even more significant damage from occurring. The City of Pasadena should continue to eliminate low performing species that suffered damage in the windstorm from the Master Street Tree Plan, removing trees in poor condition, and maintaining the current level of tree care to promote good health.

Introduction

Between November 30, 2011 and December 1, 2011, a severe and unique weather event occurred throughout the Los Angeles metropolitan basin. High, sustained winds with exceptionally strong gusts were widespread and caused damage throughout the region. Isolated pockets of extremely strong winds were also recorded, especially along the foothills and canyons of the San Gabriel Mountains. The City of Pasadena suffered significant damage, particularly to Pasadena's urban forest.

The City of Pasadena contracted with Davey Resource Group (DRG) in February 2012, to analyze tree failure data following the historic windstorm. Utilizing tree failure data provided by the City, staff interviews, recently collected inventory information, and field visits, DRG performed multiple analyses and field observations to review the storm event and look for potential contributing factors to the nearly 5,500 tree failures that occurred in the City. Past and current pruning practices, species failures, and types of tree damage were reviewed along with examining wind speed and direction data. This report provides the findings of that analysis.

Limits of Analysis

The findings and conclusions presented in this report were limited by several factors. No soil tests, aerial or root inspections, or tissue analysis were conducted, nor were technologies, such as a Resistograph[®], used on the failed trees. Cleanup was well underway and little evidence was still on the ground by the time Davey Resource Group arrived on site for inspections on February 16, 2012. Information regarding wind speeds and direction was obtained from verifiable and documented sources and interviews from City staff. Geocoding of sites did not always result in an accompanying tree species for the site and, therefore, may alter some species quantities without altering the analysis.

Background

The City of Pasadena maintains approximately 57,500 street trees throughout the City's 64,500 street tree planting sites and recently completed a citywide tree inventory update. The tree population includes over 200 distinct species with over 30 genera, providing a diverse and unique urban forest.

Pasadena maintains its trees on a 5-year cyclical basis. Davey Resource Group has worked with many cities in California, and across the nation, and Pasadena maintains one of the most complete and aggressive urban forest management programs we have observed. The pruning cycle is well below average in length when compared to cities with similar tree population size.



Typically, winds in the area generated by air moving from a high-pressure dome over Nevada, Utah, and Arizona to a low-pressure zone generally centered off the coast of Southern California. This weather pattern generates winds that blow from a southwest direction. In the fall, “Santa Ana” winds can be common to the area and normally create hot, dry winds that blow from a more northeast direction. These types of winds generated from high pressure over the Great Basin interacting with a low-pressure zone centered inland over the desert areas, which pushes the warm winds towards the coastal areas.

The Windstorm of 2011

On November 30, to December 1, 2011 the City of Pasadena experienced a unique and severe wind event. Damage from this storm to the City of Pasadena was extensive. Downed trees and power lines reported throughout the entire 26 square miles of the City. City Manager, Michael Beck, described Pasadena as being the “epicenter of the storm”. Beck further stated the “no one can remember when something so severe and encompassing has occurred” in the City of Pasadena (Quinones, 2011). Pasadena experienced damage to 200 buildings. Of those buildings, damage to 75 was so severe, public access was denied.

From a historical perspective, this wind event was unique in both wind speed and direction (see Figure 1 below). A contributing factor to the strength of the winds was a high-pressure system in Northern California and a low-pressure system over Arizona that squeezed fast-moving cold air into Southern California, particularly in the Pasadena and Alta Dena foothills. Additionally, the direction of the winds during this particular storm came from the north, rather than the more typical northeast direction of Santa Ana winds (Patzert, 2011). This intensified the force of the winds for this event (Duginski, 2011).

Weather station KCAPASAD11, located in Pasadena at Hill Avenue and the I-210 freeway, confirms wind gusts in excess of 60 mph as well as winds coming from the North during the storm event (weatherunderground.com, 2011). Official quality controlled reports from the National Oceanic and Atmospheric Administration (NOAA) for the weather station located 10 miles away at the Burbank Airport supports this data, reporting wind gusts up to 55 mph coming from the North (weathersource.com, 2011). This is the nearest official NOAA station and is situated in a geographically different area than Pasadena.

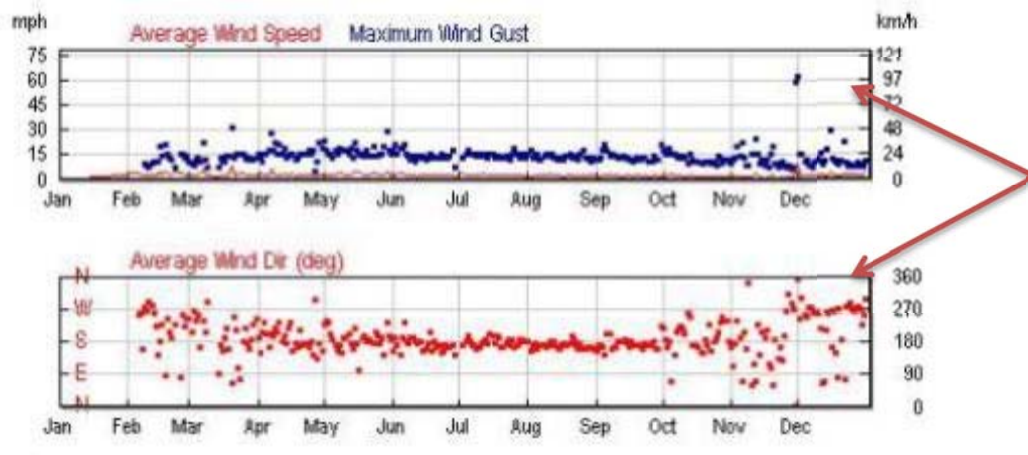


Figure 1. Annual Wind Data for Pasadena – 2011

While official wind speeds were in the 50 to 60 mph range, unofficial reports of winds topping 80 to 90 mph observed in the region during this storm (Patzert, 2011). Other nearby readings included a wind



monitoring station at San Rafael Hills above the City that clocked sustained (over 2 minutes in duration) wind speeds of 72 to 82 mph (E. Boldt, National Weather Service). In addition, Henninger Flats, approximately 7 miles east of the City registered gusts of 167 mph before the monitor stopped recording. (worldweatherpost.com).

Supporting the unofficial reports of 80 to 90 mph wind gusts, is the fact that Pasadena experienced damage or destruction to multiple streetlights that designed to withstand wind gusts of 80 to 100 mph, based on pole height and wind duration. This included 375 streetlights that required repair. Additionally, 50 traffic signals incurred damaged, Caltrans maintain eight of the 50 signals damaged.

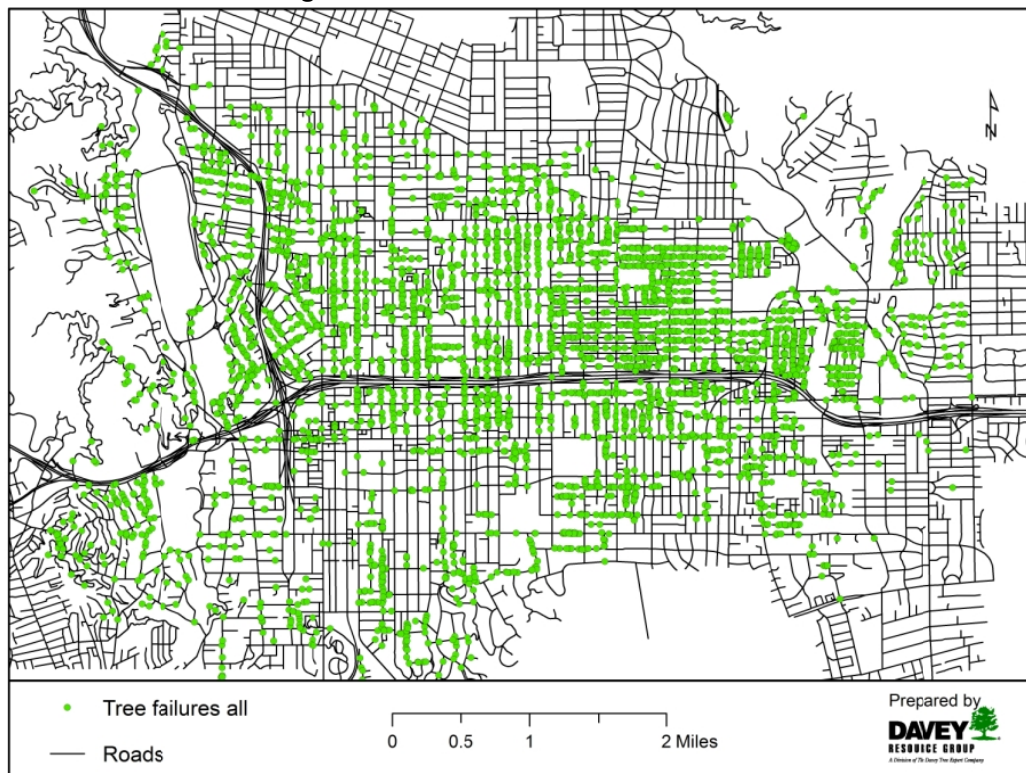
Tree Failures

Almost 5,500 tree related failures were reported after the November 30, 2011 to December 1, 2011 windstorm. More than 500 hundred of these reports were determined to be non-City tree related which includes private trees, tree debris, or not related to a specific City tree. Of the reported tree failures, approximately 2,000 were total failures that resulted in complete removal. City and contractor crews worked around the clock in two 12-hour shifts for two weeks to mitigate the major tree damage. The Parks and Natural Resources Division spent 3.2 million dollars on the cleanup, and the annual budget for the division is just under 11 million dollars.

Tree Failure Locations

Based on location data received from the City, DRG mapped locations of all reported tree failures that occurred during the windstorm. The figure below demonstrates the widespread damage that occurred to the City's urban forest.

Figure 2. Street Tree Failure Overview





Findings and Analysis

Methodology

Following the windstorm, the City developed a spreadsheet to track tree failure locations. The failure data provided to Davey Resource Group for analysis is used as part of this report. This data from the City typically tracked location and failure type, but did not include species identification of the associated tree.

Address locations were geocoded for comparisons to the City’s existing tree inventory and to map of failure locations. Where the species was not identified by the City data, Davey Resource Group cross-checked the information against the tree inventory database to match the location and tree species that was the most closely associated to the site using GIS. This assumption can alter some species quantities, but does not result in significant variation in the final analysis.

Davey Resource Group also performed field inspections in February of 2012. Over 50 locations from staff’s tracking spreadsheet selected for inspection and additional information collected at each site used in the analysis. The locations selected based on staff recommendations as well as areas with higher concentration of damage. These included the fig trees in the downtown area along Green Street between Orange Grove and Hill. In addition, locations selected based on street direction and tree placement within a street segment. Information on wind exposure, adjacent private tree damage, size of the failed tree part, and type of whole tree failure collected. Specific observations and comments made on site considerations and patterns of failure within the street segment.

In the tracking spreadsheet, the City utilized approximately 40 unique codes to identify the type of damage incurred. To allow for analysis, those 40 codes categorized into four failure types. The codes utilized by the City and the corresponding failure types and definitions listed below in Table 1.

Table 1. Failure Class Categorizations

Failure Class	Failure Type	Definition
Branch Failure	Broken Branches/Stubs	Smaller broken branches (<4”) that includes remaining broken end portion still attached to tree
	Hanger	Broken branch still hanging in canopy
	Hanger/Stub	Broken branch still in canopy with broken end still attached to tree
	Hangers and debris	Hanger with excessive debris on ground
	Hangers, safety prune	Hangers creating a safety hazard
	Hangers, Stubs, Removals	Combination
	Stub	Remainder of broken branch still attached needing repair
Other	Broken Branches	Branches in tree or on ground
	Debris	Litter/branches on ground
Major Limb Failure	Power Line Conflict	Branch, limb or tree on utilities
	Large Limbs	Large structural limbs failed
	Large Broken Branches	>4” limbs
	Limb Down	Large limb on ground
	Split Scaffold	Major limb or scaffold crack



Failure Class	Failure Type	Definition
	Split Section	Large portion of tree split
Whole Tree Failure	Blocking	Broken limb impeding access
	Blocking driveway	Broken limb blocking driveway
	Blocking sidewalk	Broken limb blocking sidewalk
	Blocking street	Broken limb blocking street
	Large Split Section	Large portion of whole tree split
	Removal	Failed tree needing removal
	Split Tree	Completely split tree
	Stump	Remaining stump to be removed
	Tree down	Whole tree on ground
	Tree leaning	Excessive lean or tree lifting
	Tree on car	Whole tree on car
	Tree on house	Whole tree on house
	Tree split	Whole tree split and collapsed
	Uprooted	Soil lifted and roots exposed

Figure 3. Tree Failure Types



Other



Branch



Major



Whole Tree



The data was reviewed for trends including species and type of failure. In addition, data from the International Tree Failure Database also utilized to compare failures resulting from the windstorm, to existing trends by species.

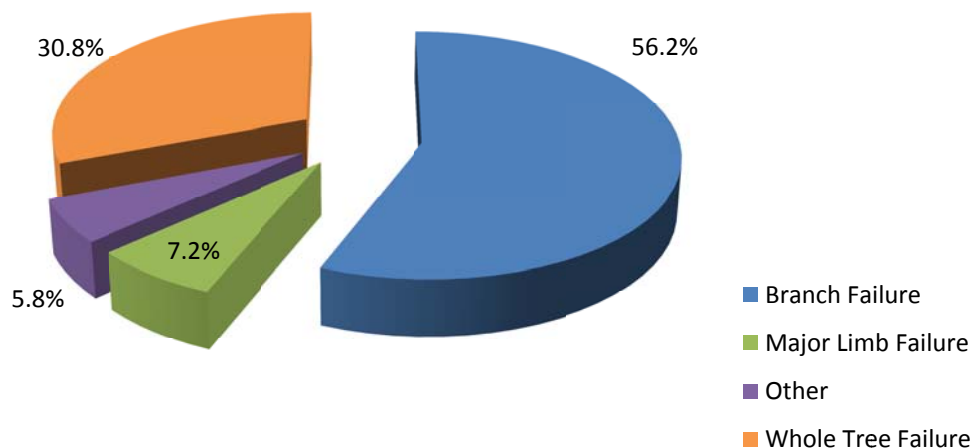
Data from Pasadena's newly completed inventory update of approximately 57,500 street trees sites was also utilized to examine tree failures as a relative percentage of their overall representation in the City and to determine if any trends were apparent, as well as tree condition and failure types. Other contributing factors to tree failures also considered. These included growth habit, type of whole tree failure (if occurred), pruning history, and site considerations.

Failure Types

As incidents recorded and crews sent to respond, the tree inventory data was supplemented with emergency and damage comments. The comments summarize to provide a categorical view of the types of tree failures across the City as seen in Chart 1. In addition to examining the total percentage of tree failures, the percentage of failure type by species was also reviewed as illustrated in Appendix 1.

Chart 1. Types of Tree Failures by Occurrence

Failure Classification Summary





Relative Percent of Tree Failures

The relative performance (failure rate) of each species as a percentage of the population was also analyzed. Data from Pasadena's newly completed street tree inventory update of approximately 57,500 street tree sites was reviewed to determine the total number of trees for each species in the population. From that information, the performance of species representing greater than 1% of the total storm failure trees was examined. For example, while live oak accounted for over 13% of the failures during the windstorm, they also represent a significant percentage of the overall tree population in the City of Pasadena (10.12%). By far, Queensland pittosporum had the lowest performance, with over 50% of trees of that species failing during the storm. While only representing less than 5% of total tree failures, the fact that those trees performed poorly relative to their total population indicates this species should be removed from the City's planting palette. Other species of concern are Chinese elm, Indian laurel fig, carrotwood, Western sycamore, and jacaranda. All of those species had greater than 10% of their representative population incur a specific failure during the windstorm.

Table 2 below summarizes species failure percentages during the windstorm.

Table 2. Species Failure Percentages

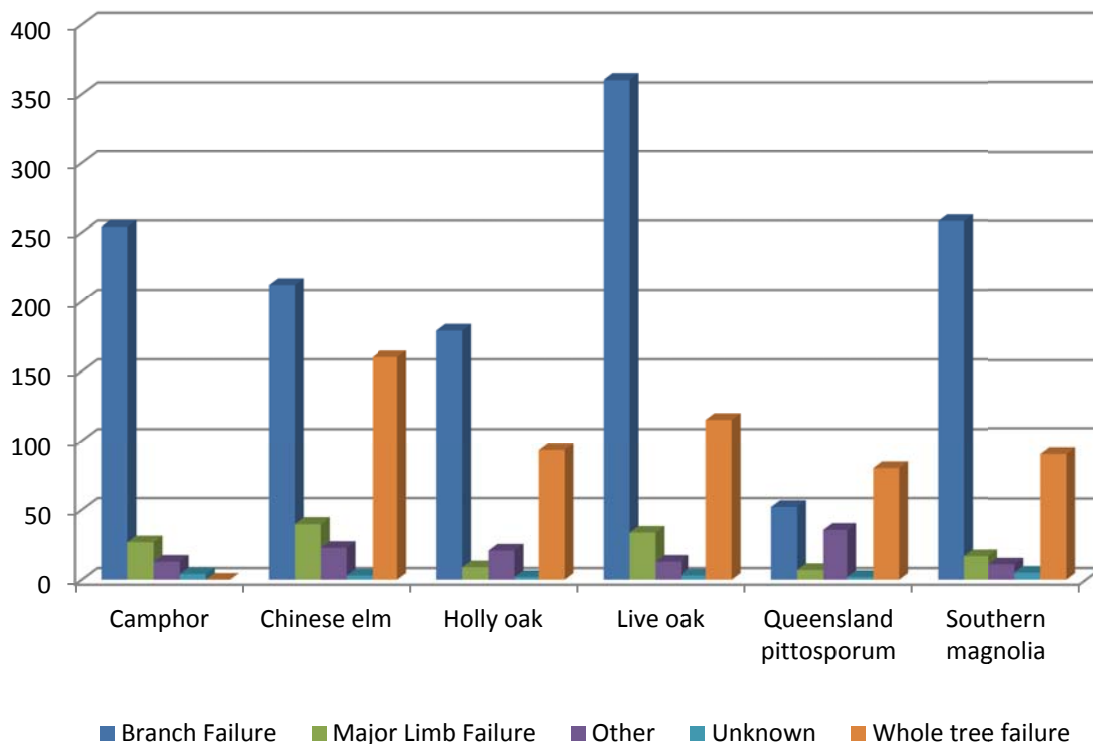
Species	Failure Count	Percent of Whole Tree Failure	Percent of Species Failures	Percent of Total Overall Population
Queensland pittosporum	174	4.37%	50.73%	0.59%
Chinese elm	445	11.19%	13.65%	5.64%
Indian laurel fig	65	1.63%	13.16%	0.85%
Carrotwood	126	3.17%	11.39%	1.92%
Western sycamore	46	1.16%	10.90%	0.75%
Jacaranda	166	4.17%	10.74%	2.76%
Live oak	523	13.15%	9.25%	10.12%
Carob	90	2.26%	9.09%	1.64%
Brisbane box	113	2.84%	8.94%	2.22%
Holly oak	303	7.62%	8.19%	6.34%
Bottle tree	79	1.99%	8.18%	1.67%
Southern magnolia	379	9.53%	7.30%	8.95%
Italian cypress	46	1.16%	6.53%	1.22%
Canary island date palm	56	1.41%	6.21%	1.56%
American sweetgum	73	1.84%	6.12%	2.12%
Camphor tree	295	7.42%	5.61%	9.19%
Crape myrtle	65	1.63%	3.28%	3.54%
Mexican fan palm	110	2.77%	2.43%	7.88%



When the most commonly failed species are queried by type of failure, trends are found for certain species. The most common failure type for most species was branch failure. Queensland pittosporum was unique of the top species in having more whole tree failures than any of the other failure categories. Chinese elm should also be noted as having a high percentage of whole tree failure when compared with the other failure categories.

Chart 2. Failure Type of Top Six Species

Failure Type of Top Six Species

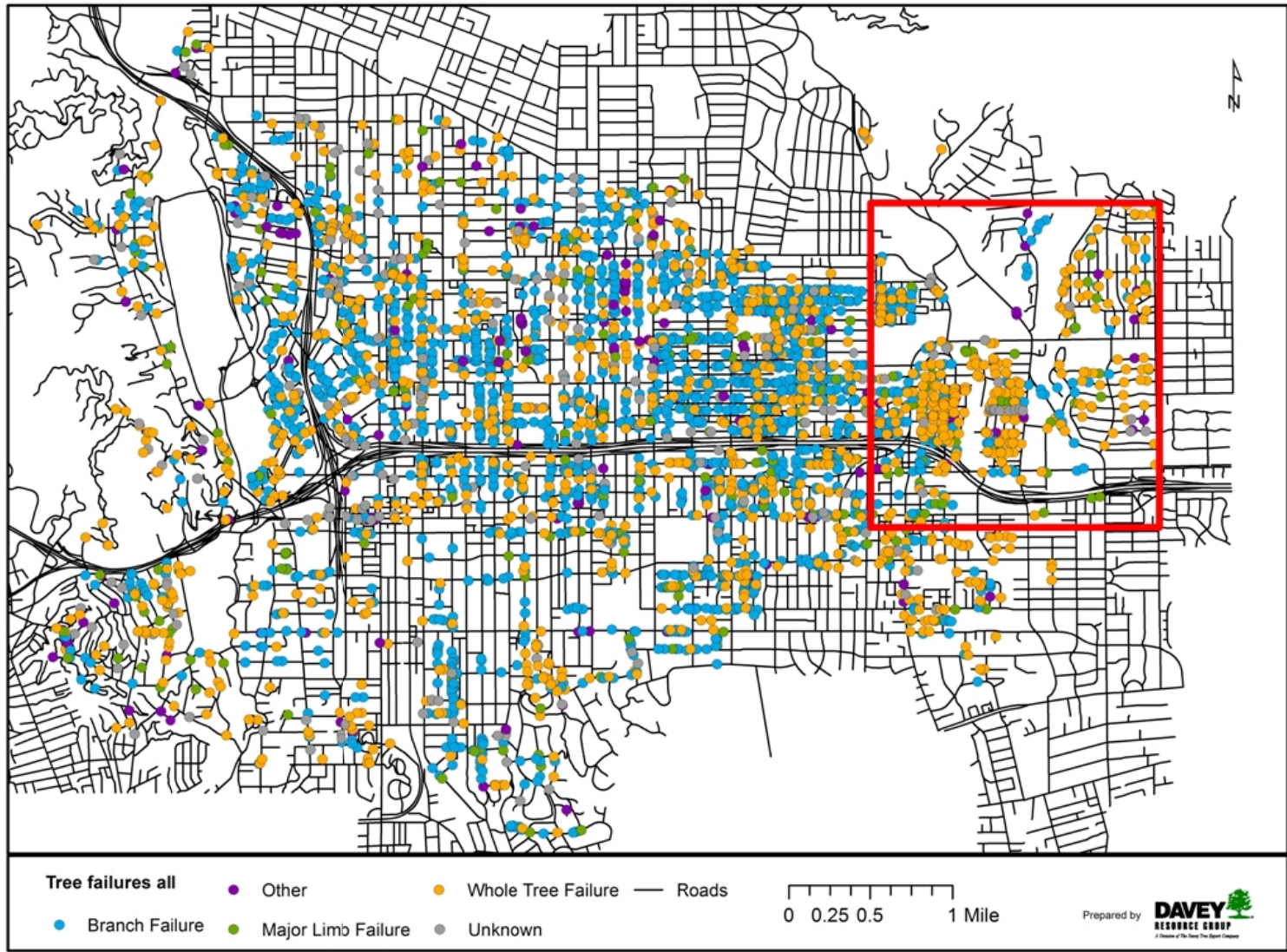


Concentration of Whole Tree Failures

From the mapping data presented earlier, it is clear that the tree damage was widespread throughout the City. There also appears to be a concentration of damage occurring north of the I-210 Freeway between North Hill Avenue and South Michillinda Avenue. When the map is delineated according to tree failures as shown below in Figure 4, it is evident that the area on the East side of the City, North of the I-210 Freeway near South Michillinda and Sierra Madre Boulevard experienced a higher concentration of whole tree failures than did the rest of the City.



Figure 4. Tree Failure Types





While there were five species in the area of concentration that experienced 100% whole tree failures, they were underrepresented in terms of the number of failures in that area. For example, Aleppo pine and Japanese black pine each had 100% failure rates in the area, but that failure rate was due to the fact that only one tree for each species failed. More attention should be paid to species such as Chinese elm, which had nearly 60% of the failures in the area represented as total tree failures, with a much larger number of failures in general.

Total failure within the area of concentration increased as compared to failure types citywide. For instance, American sweetgum and Western sycamore, while having a significant amount (40% or greater) of failures in the concentrated area categorized as total tree failures, fared much better citywide. Table 3 below illustrates total failures by species in the area of concentration compared to other failure types for the species.

Table 3. Number of failures and relative percent of total failures in “Concentrated Area of Whole Tree Failure”

Species	Total Species Failures	Whole Tree Failures	% of Species Total
Aleppo pine	1	1	100.00%
Chinese rain tree	1	1	100.00%
Japanese black pine	1	1	100.00%
Lemon	1	1	100.00%
Purple-leaf plum	4	4	100.00%
Chinese elm	160	93	58.13%
Canary island pine	17	9	52.94%
Incense cedar	11	5	45.45%
Siberian elm	7	3	42.86%
American sweetgum	25	10	40.00%
Western sycamore	20	8	40.00%
Southern live oak	3	1	33.33%
Weeping bottle brush	3	1	33.33%
Southern magnolia	90	24	26.67%
Jacaranda	38	10	26.32%
Bottlebrush	4	1	25.00%
Cajeput tree	8	2	25.00%
California fan palm	4	1	25.00%
Cork oak	4	1	25.00%
Fern pine	4	1	25.00%
Maidenhair tree	4	1	25.00%
Guadalupe palm	5	1	20.00%
Sawtooth zelkova	5	1	20.00%
Yew pine	11	2	18.18%
Crape myrtle	29	5	17.24%
Brisbane box	25	3	12.00%
Shamel ash	9	1	11.11%
Carrotwood	37	4	10.81%
Carob	29	3	10.34%
Mesa oak	13	1	7.69%
Indian laurel fig	14	1	7.14%
Holly oak	93	6	6.45%
Live oak	115	6	5.22%
Queensland pittosporum	80	1	1.25%



Tree Failure Comparison with the International Tree Failure Database

The International Tree Failure Database (ITFD) compiles data on tree failures based on failure types. Since 2003, over 6,800 reports have been compiled (primarily in North America) that include tree species, location, failure type, and various environmental conditions. Species and other information can be adjusted for specific areas for comparison. Chart 2 (page 9) previously illustrated the top six species in Pasadena that experienced some type of failure as defined by staff failure types. The data comparing ITFD and Pasadena data for the same top six failed species is in Table 4 below.

Table 4. ITFD Data on Pasadena's Top Six Failure Species

Species	ITFD	Pasadena	ITFD	Pasadena
	Branch %	Branch %	Trunk %	Trunk %
Camphor	100.0%	100.0%	0.0%	0.0%
Chinese elm	61.3%	62.2%	19.2%	37.8%
Holly oak	0.0%	70.0%	0.0%	30.0%
Live oak	22.8%	78.6%	53.7%	21.4%
Queensland pittosporum*	N/A	55.2%	N/A	44.8%
Southern magnolia	69.2%	75.7%	44.4%	24.3%

* No ITFD data available for Queensland pittosporum

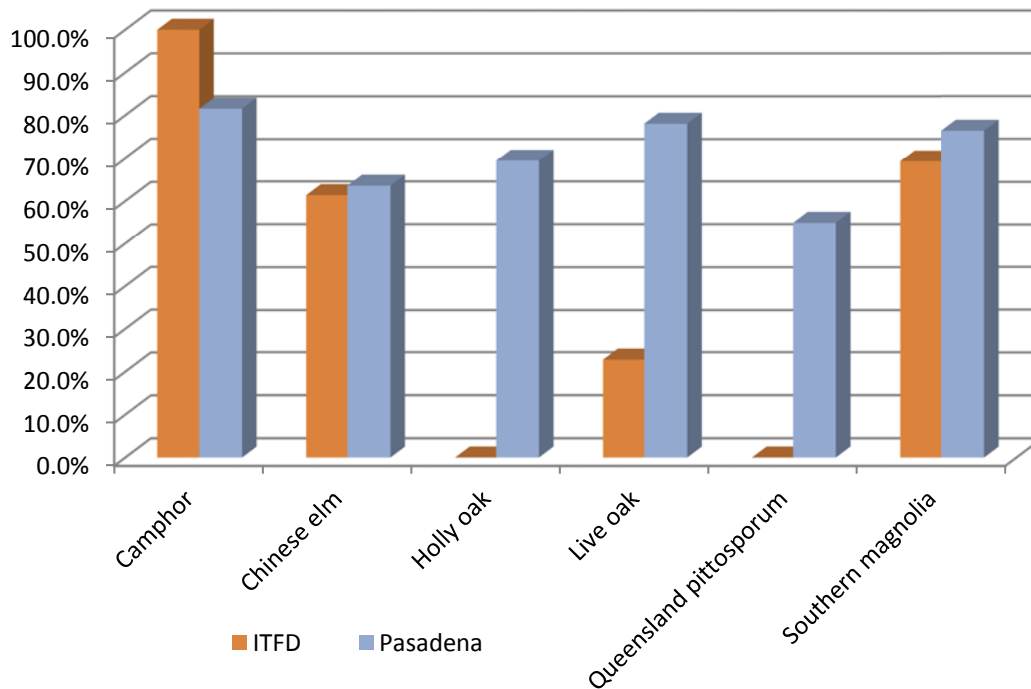
Because the data was collected in a different format, adjustments needed to be made for a valid comparison of ITFD data with Pasadena's data. The local failure classes "Branch Failure," "Major Limb Failure," and "Other," were combined as the ITFD "Branch" failure class. Similarly, the ITFD classes "Root" and "Trunk" were merged to compare with the "Whole Tree Failure" Pasadena class.

Comparing failure trends between the ITFD and Pasadena's windstorm yields mixed results. Camphor, Chinese elm, and southern magnolia all experienced similar percentage of branch failure patterns in Pasadena when compared to data from the ITFD. Holly oak, live oak, and Queensland pittosporum all experienced a much greater percentage of branch failure in Pasadena than represented in the overall ITFD data.



Chart 3. Branch Failure Percentage by Species, ITFD versus Pasadena

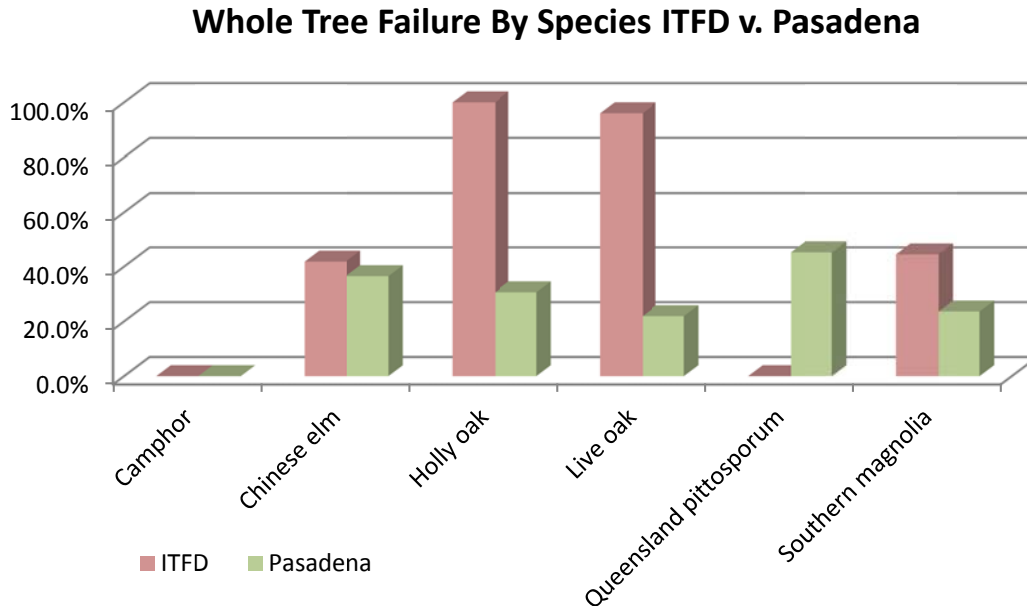
Branch Failure By Species ITFD v. Pasadena



Whole tree failure comparisons demonstrated less consistency. Only Chinese elm failures in Pasadena closely mirrored ITFD statistics. Holly oak, live oak and Southern magnolia all experienced a much lower percentage of whole tree failures in Pasadena than represented in data from the ITFD. Camphor and Queensland pittosporum all experienced a higher degree of whole tree failure in Pasadena than in the ITFD. These discrepancies might be related to the single, historic wind event that occurred in Pasadena versus the year-round data collection as gathered by the ITFD during a variety of conditions independent of specific weather events.



Chart 4. Whole Tree Failure Percentage by Species, ITFD versus Pasadena



Other Contributing Factors

Tree Health and Failure Type

In most cases, trees in good health are able to withstand stress better than those trees that are in poor condition. Stress can include pressure from pests, drought, and tolerance to normal weather events. Using the existing tree inventory data, tree condition was compared to tree failure types as compiled by staff. Trees in poor or worse condition suffered more damage as a percentage of failure type than those in fair or better condition. Table 5 below breaks down tree failure type as compared to the condition rating given during the citywide street tree inventory.

Table 5. Tree Condition and Failure Type

Condition Class	Failure Class	Count	Percent of Condition Class	Percent of Total Population
Very Good	Branch Failure	1	0.83%	0.00%
Very Good	Whole Tree Failure	1	0.83%	0.00%
Good	Branch Failure	890	3.80%	1.59%
Good	Major Limb Failure	111	0.47%	0.20%
Good	Other	126	0.54%	0.22%
Good	Whole Tree Failure	500	2.14%	0.89%
Fair	Branch Failure	975	4.49%	1.74%
Fair	Major Limb Failure	126	0.58%	0.22%
Fair	Other	73	0.34%	0.13%
Fair	Whole Tree Failure	493	2.27%	0.88%



Condition Class	Failure Class	Count	Percent of Condition Class	Percent of Total Population
Poor	Branch Failure	127	5.02%	0.23%
Poor	Major Limb Failure	14	0.55%	0.02%
Poor	Other	6	0.24%	0.01%
Poor	Whole Tree Failure	56	2.21%	0.10%
Critical	Branch Failure	4	4.71%	0.01%
Critical	Whole Tree Failure	2	2.35%	0.00%
Dead	Branch Failure	6	2.23%	0.01%
Dead	Other	1	0.37%	0.00%
Dead	Whole Tree Failure	6	2.23%	0.01%

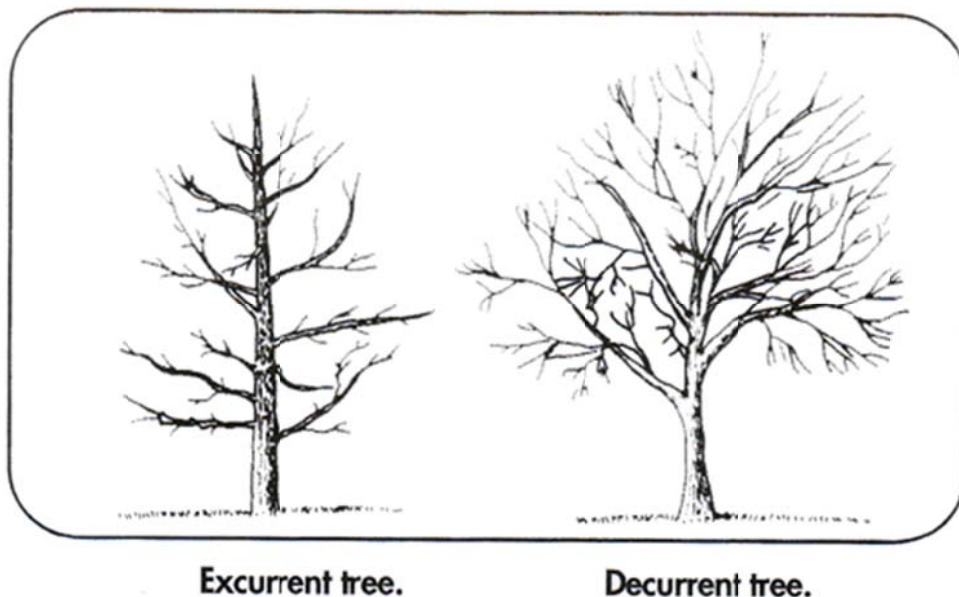
*No associated tree species/condition with location

Tree Growth Habit and Failure Type

Tree growth habit generally falls into two basic structure types: *Excurrent* and *Decurrent*. Trees with a more upright growth habit (excurrent) have a central leader with defined taper in the trunk. Broader canopy trees (decurrent) lack a central leader and have more scaffolding limbs that support many smaller branches (Figure 5). These broader canopies have the potential to be exposed to more wind, which can transfer more stress to the major scaffold limbs and trunk. The excurrent trees will have less wind exposure and a well-tapered trunk is much stronger. Although there are exceptions, most excurrent trees are cone-bearing, such as many pines and cedars, while decurrent trees tend to be broadleaf trees like oaks and elms.

No data was specifically collected by City staff or in the tree inventory on growth habit versus failure types, but general observations were made during the field inspections and cursory analysis was made using Appendix 1 in this report. Analyzed damage reports indicated that excurrent trees experienced branch failures or whole tree failures while decurrent trees experienced somewhat more branch and major limb failures rather than whole tree failures.

Figure 5. Tree Growth Types





Root Versus Soil Failure

When complete failure of a tree occurs (the entire tree falls over), two basic types of failures can normally be identified visually: root failure and soil failure. Evidence of root failures include the base of the trunk (root plate) broken off with few roots lifted out of the ground. When roots fail, it may indicate decay in the root plate with weakly attached roots to the base of the trunk (Figure 6). Soil failures typically result in the majority of the root ball being lifted out of the ground, lifting sidewalks and turf along with it. This type of failure indicates a weak structural topsoil, saturated soil, or shallow soil. Roots are normally healthy but were unable to “hang on” to the soil when faced with above ground stress.

Figure 6. Root and Soil Failures



Root Failure



Soil Failure

During field inspections by Davey Resource Group, 11 sites presented evidence of whole tree failures. Of these, ten clearly indicated soil failures, while only one site displayed evidence of root failure. While most whole tree failures were in irrigated sites, the root failure observed was in a heavily irrigated turf parkway. There is no information on resident irrigation frequency or duration for any tree failure sites, but soil moisture plays a role in soil stability and the potential for root decay as discussed in the next section.

Site Conditions

Multiple factors were considered when site conditions were evaluated. Planting space size, observable irrigation issues, canopy wind exposure (height and density), protection from surrounding structures, and street direction in relation to wind direction were factors considered as part of this analysis.

Although planting spaces were smaller in downtown and commercial areas, there was no data to support any correlation between planting site size and failure rates. As indicated previously, soil moisture can play a role in tree stability and many soil failures can be associated with irrigated planting sites such as turf parkways and front lawns. Based on the variety of planting sites where whole tree failures occurred, there is no direct correlation between planting space size and irrigation to that of whole failure type.

A tree's position within the forest canopy (height), protection from buildings, protection from surrounding trees (density), and its location within the forest or on a street in relation to wind direction (fringe tree) are critical site considerations. Tree height and growth habit was previously discussed, but it can be mentioned here that growth habit determines whether the tree is above the canopy or below the canopy. Since many of the City's urban forest trees are decurrent, they tend to have broader canopies that have more wind exposure within the canopy than excurrent tree types.



Trees growing on the edge of a canopy are considered “fringe” trees and withstand the brunt of wind and storms. These fringe trees also help protect other trees within the canopy. Root structure and branch form adapt to weather conditions, including prevailing wind direction. If the fringe trees are removed or wind direction and intensity changes, the once protected trees can become new fringe trees. Since these new fringe trees have not had the time to adapt to their new position in the canopy, they are now vulnerable to damage from the wind or storm.

Based on field observations and analysis of Figure 4 on page 10, whole tree failures and, to some extent, branch failures were more prevalent in the area of concentrated winds. In addition, trees on streets that are oriented east to west also had a higher quantity of failures than north to south oriented streets. This pattern lessened as the wind spread out to other areas of the City.

A similar pattern was observed in downtown areas or other areas with taller buildings that served as protection from the northern winds. It was observed in the field that trees next to one-story buildings or open areas like parking lots were provided little protection from the high winds. This was especially true for Indian laurel figs in the downtown area, which had excessive thinning of the lower canopies as discussed in the next section.

Past and Current Pruning Practices

Prior to the late 1980s, Pasadena’s trees were routinely topped as a method to control their size.

Topping results in large stubs that do not heal properly and can promote decay of the limbs. New growth that forms around those old topping cuts are weakly attached and become prone to failure as they grow in size and weight. Since topping is no longer a common practice, trees need to be restructured to regain their natural shape. Trees that were decades or hundreds of years old had been topped and required rehabilitation to correct the topping. Pasadena has been applying structural pruning to these trees to assist in developing a healthier urban forest for more than 25 years.



A single story building provided little protection for this fig tree.

Without tissue analysis of failed limbs, it is not possible to determine if decay from old topping cuts contributed to the failure. However, field observations indicated that previous pruning practices did not have an impact on 2011’s windstorm damage. Pruning of downtown or building frontage trees should avoid excess thinning of the lower canopy for sign and building clearance. Field observations indicated that the City’s pruning practice of building and signage clearance, while balancing the tree did not contribute to overall tree failure.



Summary Discussions and Conclusions

Based on historical data and weather station readings, it is apparent that the City of Pasadena experienced a severe and unique weather event. It is also conclusive that wind direction combined with intensity was the major contributing factor to the extensive damage suffered by the City's urban forest. The historical data showed that wind direction from the north was unusual and the official sustained winds of 60 mph and unofficial strong gusts of well over 100 mph were exceptional.

With nearly 60% of tree damage being branch failure, the analysis conducted by Davey Resource Group showed that this level and type of damage is consistent with the overall species composition in the City. This is evidenced by the fact that the top six poorest performing species make up a combined 33% of the total tree population. When combined with other low performing species (carrotwood, jacaranda, carob, and American sweetgum), over 40% of the City's tree population is represented with only nine species. It would follow that these species would suffer more damage than other species based on their larger numbers in the urban forest population. Widely accepted urban forestry guidelines recommend that a city tree population not exceed 10% of any one species or 20% of any one genus (Clark, 1997).

It is also important to note that the species most affected by the storm also have very similar growth habits. It was determined that decurrent trees suffered more damage overall than excurrent trees and many of these trees also can be considered soft wooded. Trees such as magnolia, carrotwood and jacaranda can easily suffer broken branches because of their softer wood. Unfortunately, when major limbs fail on these decurrent trees, the overall structure of the tree is often permanently altered and may require subsequent tree removal.

Whole tree failures were highest in the area of concentration (northeast portion of the City), however, complete failures revealed some consistency citywide. Based on field observations, the majority of complete failures were a result of soil failure rather than root failure. This indicates the root systems of the trees were in good condition and did not contribute to the failure. In fact, over 90% of the entire tree population was in fair condition or better and the analysis showed the tree failure types were completely unrelated to tree health or maintenance practices. It is also noteworthy that the International Tree Failure Database closely mirrored or even exceeded the failure types of the City, which supports the findings in this report.

Field observations and analysis showed that, when combined with wind speed and direction, certain site conditions contributed significantly to the tree failure types. Primarily, the location of the tree within the forest canopy and the directional orientation of the street were important site characteristics. Because of the normal prevailing wind direction of east to west, trees that were normally protected from strong winds became fringe trees to the strong northern winds during the storm. These trees had not developed the root or branch structure to adapt to the high winds and suffered multiple tree failure types during the windstorm. In some cases taller buildings served as a buffer, playing a role similar to fringe trees to in protecting trees from the strong winds. This was especially true in downtown areas.

All the evidence showed that it would have been impossible to "prepare" for such a unique and devastating wind event. In fact, the damage suffered to the City of Pasadena could have easily been worse had the City not had such an aggressive and effective tree maintenance program. Valuable information can be gleaned from low performing tree species and site conditions that are less tolerant of strong winds. This may include removing the top six species that had the most damage from the future planting plans or considering wind protection afforded by planting sites. However, this information will serve to improve the City's sustainable urban forest rather than prevent damage should a similar rare weather event occur in the future.



Works Cited

(2011, 2). Retrieved from weathersource.com.

(2011, 2). Retrieved from weatherunderground.com.

Clark JR, Matheny NP, Cross G, Wake V. 1997. A model of urban forest sustainability. *J Arbor* 23(1):17-30.

Duginiski, P. (2011, December 2). What Causes Santa Ana Winds. *The Los Angeles Times*.

Ospina, O. (2011, 12 10). Gov Brown Declares Wind Damage a State of Emergency. *KTLA*.

Patzert, D. B. (2011, 12 3). Dr. Bill Patzert. Scientist Answers 6 Questions on Windstorm. (D. Abendschein, Interviewer) *South Pasadena Patch*.

Quinones, S. (2011, 12 1). Pasadena the 'epicenter' of windstorm, City manager says. *The Los Angeles Times*.

Staff, P. C. (2012, 2-3, 2-15). (V. Mikulanic, M. Bova, Interviews)



Appendix 1

Table 6. Failure Types of All Species

Species	Total Failures	Branch Failure		Major Limb Failure		Other		Whole Tree Failure	
		Count	% of Failures	Count	% of Failures	Count	% of Failures	Count	% of Failures
Aleppo pine	6	3	50.0%	1	16.7%	1	16.7%	1	16.7%
American sweetgum	73	35	47.9%	11	15.1%	1	1.4%	26	35.6%
Apricot	1	0	0.0%	0	0.0%	0	0.0%	1	100.0%
Arizona ash	6	5	83.3%	0	0.0%	0	0.0%	1	16.7%
Arizona cypress	2	0	0.0%	0	0.0%	0	0.0%	2	100.0%
Atlas cedar	5	3	60.0%	0	0.0%	0	0.0%	2	40.0%
Australian flame tree	2	2	100.0%	0	0.0%	0	0.0%	0	0.0%
Australian willow	8	4	50.0%	0	0.0%	0	0.0%	4	50.0%
Bear oak	1	0	0.0%	0	0.0%	0	0.0%	1	100.0%
Black acacia	13	6	46.2%	0	0.0%	0	0.0%	7	53.8%
Blue gum	3	1	33.3%	0	0.0%	0	0.0%	2	66.7%
Bottle tree	79	45	57.0%	7	8.9%	5	6.3%	22	27.8%
Bottlebrush	4	0	0.0%	0	0.0%	0	0.0%	4	100.0%
Brisbane box	113	69	61.1%	7	6.2%	12	10.6%	25	22.1%
Bronze loquat	1	1	100.0%	0	0.0%	0	0.0%	0	0.0%
Brush cherry	30	17	56.7%	4	13.3%	3	10.0%	6	20.0%
Cajeput tree	22	10	45.5%	4	18.2%	0	0.0%	8	36.4%
California box	1	1	100.0%	0	0.0%	0	0.0%	0	0.0%
California fan palm	11	6	54.5%	1	9.1%	0	0.0%	4	36.4%
California pepper	8	2	25.0%	0	0.0%	0	0.0%	6	75.0%
Camphor tree	295	251	85.1%	30	10.2%	14	4.7%	0	0.0%
Canary island date palm	56	37	66.1%	2	3.6%	6	10.7%	11	19.6%
Canary island pine	26	7	26.9%	2	7.7%	1	3.8%	16	61.5%
Cape chestnut	2	2	100.0%	0	0.0%	0	0.0%	0	0.0%
Carob	90	56	62.2%	5	5.6%	1	1.1%	28	31.1%



Species	Total Failures	Branch Failure		Major Limb Failure		Other		Whole Tree Failure	
		Count	% of Failures	Count	% of Failures	Count	% of Failures	Count	% of Failures
Carolina laurel cherry	8	4	50.0%	1	12.5%	2	25.0%	1	12.5%
Carrotwood	126	79	62.7%	7	5.6%	6	4.8%	34	27.0%
Chinaberry	2	1	50.0%	0	0.0%	0	0.0%	1	50.0%
Chinese elm	445	204	45.8%	49	11.0%	24	5.4%	168	37.8%
Chinese flame tree	14	7	50.0%	3	21.4%	0	0.0%	4	28.6%
Chinese hackberry	1	1	100.0%	0	0.0%	0	0.0%	0	0.0%
Chinese juniper	2	1	50.0%	0	0.0%	0	0.0%	1	50.0%
Chinese magnolia	2	2	100.0%	0	0.0%	0	0.0%	0	0.0%
Chinese pistache	11	7	63.6%	0	0.0%	2	18.2%	2	18.2%
Chinese tallow tree	2	0	0.0%	0	0.0%	0	0.0%	2	100.0%
Chitalpa	1	0	0.0%	0	0.0%	0	0.0%	1	100.0%
Coast redwood	1	0	0.0%	0	0.0%	0	0.0%	1	100.0%
Cork oak	7	3	42.9%	0	0.0%	0	0.0%	4	57.1%
Crape myrtle	65	28	43.1%	3	4.6%	5	7.7%	29	44.6%
Date palm	4	1	25.0%	0	0.0%	0	0.0%	3	75.0%
Deodar cedar	38	26	68.4%	2	5.3%	1	2.6%	9	23.7%
Desert willow	5	2	40.0%	0	0.0%	0	0.0%	3	60.0%
Edible fig	1	1	100.0%	0	0.0%	0	0.0%	0	0.0%
Edible loquat	3	0	0.0%	0	0.0%	0	0.0%	3	100.0%
Evergreen pear	1	1	100.0%	0	0.0%	0	0.0%	0	0.0%
Fern pine	9	4	44.4%	1	11.1%	0	0.0%	4	44.4%
Flamegold	1	0	0.0%	0	0.0%	0	0.0%	1	100.0%
Glossy privet	4	2	50.0%	0	0.0%	0	0.0%	2	50.0%
Golden trumpet tree	4	1	25.0%	0	0.0%	1	25.0%	2	50.0%
Guadalupe palm	12	5	41.7%	0	0.0%	1	8.3%	6	50.0%
Guava	1	0	0.0%	0	0.0%	0	0.0%	1	100.0%
Gum myrtle	3	3	100.0%	0	0.0%	0	0.0%	0	0.0%
Holly oak	303	177	58.4%	13	4.3%	22	7.3%	91	30.0%
Hollywood juniper	2	1	50.0%	0	0.0%	0	0.0%	1	50.0%



Species	Total Failures	Branch Failure		Major Limb Failure		Other		Whole Tree Failure	
		Count	% of Failures	Count	% of Failures	Count	% of Failures	Count	% of Failures
Horse chestnut	1	0	0.0%	0	0.0%	0	0.0%	1	100.0%
Horsetail tree	4	2	50.0%	1	25.0%	0	0.0%	1	25.0%
Incense cedar	14	1	7.1%	0	0.0%	1	7.1%	12	85.7%
Indian laurel fig	65	39	60.0%	9	13.8%	3	4.6%	14	21.5%
Italian cypress	46	12	26.1%	5	10.9%	1	2.2%	28	60.9%
Italian stone pine	6	3	50.0%	1	16.7%	0	0.0%	2	33.3%
Jacaranda	166	118	71.1%	7	4.2%	3	1.8%	38	22.9%
Japanese black pine	2	1	50.0%	0	0.0%	0	0.0%	1	50.0%
Japanese flowering cherry	4	0	0.0%	0	0.0%	4	100.0%	0	0.0%
Japanese maple	2	0	0.0%	0	0.0%	0	0.0%	2	100.0%
Judas tree	1	0	0.0%	0	0.0%	0	0.0%	1	100.0%
Kaffirboom coral tree	1	0	0.0%	0	0.0%	0	0.0%	1	100.0%
Kurrajong	1	1	100.0%	0	0.0%	0	0.0%	0	0.0%
Lavender bloom	17	3	17.6%	0	0.0%	2	11.8%	12	70.6%
Lemon	1	0	0.0%	0	0.0%	0	0.0%	1	100.0%
Livistonia palm	1	0	0.0%	0	0.0%	0	0.0%	1	100.0%
Live oak	523	360	68.8%	38	7.3%	13	2.5%	112	21.4%
London plane	12	6	50.0%	1	8.3%	1	8.3%	4	33.3%
Maidenhair tree	14	3	21.4%	1	7.1%	5	35.7%	5	35.7%
Maul oak	1	0	0.0%	0	0.0%	0	0.0%	1	100.0%
Melaleuca	1	1	100.0%	0	0.0%	0	0.0%	0	0.0%
Mesa oak	32	15	46.9%	3	9.4%	1	3.1%	13	40.6%
Mexican blue fan palm	1	0	0.0%	0	0.0%	1	100.0%	0	0.0%
Mexican fan palm	110	76	69.1%	6	5.5%	20	18.2%	8	7.3%
Mock orange	1	1	100.0%	0	0.0%	0	0.0%	0	0.0%
Modesto ash	13	11	84.6%	2	15.4%	0	0.0%	0	0.0%
Monterey pine	3	0	0.0%	0	0.0%	0	0.0%	3	100.0%
Moringa tree	1	1	100.0%	0	0.0%	0	0.0%	0	0.0%



Species	Total Failures	Branch Failure		Major Limb Failure		Other		Whole Tree Failure	
		Count	% of Failures	Count	% of Failures	Count	% of Failures	Count	% of Failures
Oak species	1	1	100.0%	0	0.0%	0	0.0%	0	0.0%
Oleander	5	3	60.0%	0	0.0%	0	0.0%	2	40.0%
Olive	3	2	66.7%	0	0.0%	0	0.0%	1	33.3%
Orange	1	0	0.0%	0	0.0%	0	0.0%	1	100.0%
Orchid tree	1	1	100.0%	0	0.0%	0	0.0%	0	0.0%
Ornamental pear - Bradford	10	5	50.0%	0	0.0%	1	10.0%	4	40.0%
Other ¹	4	2	50.0%	0	0.0%	0	0.0%	2	50.0%
Palm species	1	0	0.0%	1	100.0%	0	0.0%	0	0.0%
Peach	1	1	100.0%	0	0.0%	0	0.0%	0	0.0%
Peruvian pepper tree	1	1	100.0%	0	0.0%	0	0.0%	0	0.0%
Pindo palm	2	1	50.0%	0	0.0%	0	0.0%	1	50.0%
Pine species	1	0	0.0%	0	0.0%	0	0.0%	1	100.0%
Primrose tree	1	0	0.0%	1	100.0%	0	0.0%	0	0.0%
Purple-leaf plum	9	3	33.3%	0	0.0%	1	11.1%	5	55.6%
Queen palm	11	5	45.5%	0	0.0%	2	18.2%	4	36.4%
Queensland pittosporum	174	50	28.7%	10	5.7%	36	20.7%	78	44.8%
Red flowering gum	4	4	100.0%	0	0.0%	0	0.0%	0	0.0%
Red gum	1	0	0.0%	1	100.0%	0	0.0%	0	0.0%
Red ironbark	1	0	0.0%	0	0.0%	0	0.0%	1	100.0%
Redbud	2	1	50.0%	0	0.0%	0	0.0%	1	50.0%
Rusty-leaf fig	1	0	0.0%	0	0.0%	0	0.0%	1	100.0%
Saucer magnolia	2	0	0.0%	0	0.0%	1	50.0%	1	50.0%
Sawtooth zelkova	21	8	38.1%	3	14.3%	2	9.5%	8	38.1%
Shamel ash	36	25	69.4%	3	8.3%	0	0.0%	8	22.2%

¹ Species name was not assigned



Species	Total Failures	Branch Failure		Major Limb Failure		Other		Whole Tree Failure	
		Count	% of Failures	Count	% of Failures	Count	% of Failures	Count	% of Failures
Siberian elm	15	5	33.3%	2	13.3%	2	13.3%	6	40.0%
Silk oak	7	3	42.9%	0	0.0%	1	14.3%	3	42.9%
Silk-floss tree	1	0	0.0%	0	0.0%	0	0.0%	1	100.0%
Silver dollar gum	11	6	54.5%	0	0.0%	0	0.0%	5	45.5%
Silver maple	3	2	66.7%	0	0.0%	0	0.0%	1	33.3%
Southern live oak	14	9	64.3%	0	0.0%	2	14.3%	3	21.4%
Southern magnolia	379	251	66.2%	24	6.3%	12	3.2%	92	24.3%
Spanish dagger	1	0	0.0%	0	0.0%	0	0.0%	1	100.0%
Swamp gum	1	1	100.0%	0	0.0%	0	0.0%	0	0.0%
Swamp mahogany	3	3	100.0%	0	0.0%	0	0.0%	0	0.0%
Sweetshade	1	1	100.0%	0	0.0%	0	0.0%	0	0.0%
Tomlinson ash	2	2	100.0%	0	0.0%	0	0.0%	0	0.0%
Tree of heaven	1	0	0.0%	0	0.0%	0	0.0%	1	100.0%
Tulip tree	4	1	25.0%	0	0.0%	0	0.0%	3	75.0%
Unknown ²	171	22	12.9%	4	2.3%	1	0.6%	144	84.2%
Victorian box	5	2	40.0%	0	0.0%	1	20.0%	2	40.0%
Weeping bottle brush	4	3	75.0%	0	0.0%	0	0.0%	1	25.0%
Weeping fig	3	2	66.7%	1	33.3%	0	0.0%	0	0.0%
Western sycamore	46	18	39.1%	5	10.9%	5	10.9%	18	39.1%
White birch	1	0	0.0%	0	0.0%	0	0.0%	1	100.0%
White mulberry	1	0	0.0%	1	100.0%	0	0.0%	0	0.0%
Windmill palm	11	8	72.7%	1	9.1%	0	0.0%	2	18.2%
Yew pine	19	6	31.6%	1	5.3%	1	5.3%	11	57.9%
Total³	3,978	2,236	56.2%	285	7.2%	231	5.8%	1,226	30.8%

² Geocoding did not have an associated species close to reported site

³ Does not include non-tree related reports