Central Wharf Plaza – Boston, MA
Methodology for Landscape Performance Benefits
Prepared by:

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Environmental

Reduces the average ground-level temperature of the plaza by 10.4°F with tree canopy cover that shades 94% of the site.

Urban heat islands, especially in the evenings, may be as much as 22°F warmer than air in less developed, nearby areas. Urban heat island problems include hotter daytime temperatures, higher air pollution levels, and reduced cooling after sunset. Heat islands also create greater risk for populations particularly sensitive to excessive heat events. Trees reduce surface and air temperatures by providing shade and through the process of evapotranspiration. Cooler temperatures can improve comfort levels and a substantial tree canopy can reduce exposure to harmful UV rays.

To determine the cooling effect of the 25 oak trees on the site, the temperature of the plaza was compared to the temperature of an adjacent park with a similar surface, but no vegetative cover. Temperature readings were taken for both the plaza and for a paved area of the Rose Fitzgerald Kennedy Greenway directly across Atlantic Avenue to the west, between 2:00 – 3:30pm on July 30th, 2012. Weather conditions were sunny with air temperatures in the range of 75 – 80°F. An ambient thermometer with an accuracy of ±2°F was used to take readings approximately 12 inches above each surface in multiple locations. The average plaza temperature was 10.4°F cooler than the average temperature of a paved area of the Greenway.

To determine the amount of shade provided by the 25 trees, approximate site measurements were taken to get an estimated average tree canopy radius of 14 ft. Using this information, the following calculations were completed:

Area = πr^2
Canopy area per tree = $\pi \times$ (canopy radius)^2
615.4 ft^2 = 3.14 $\times$ (14)^2
Total area of shade = Canopy area per tree $\times$ # of trees $\times$ 80% (to account for ~20% overlap)
12,308 ft^2 = 615.4 $\times$ 25 $\times$ 0.8
Percentage of site that is shaded = Total area of shade/Total area of site
94% = 12,308 ft^2/13,124 ft^2

Source
Information on urban heat islands obtained from:
U.S. Environmental Protection Agency. *Heat Island Impacts*
http://www.epa.gov/hiri/impacts/index.htm

Prevents 369,000 gallons of annual stormwater runoff from entering the city's combined sewer system by infiltrating all runoff for up to a 25-year, 24-hour storm event.

Stormwater infiltrates through the permeable joints between the dry-laid granite pavers or directly through the permeable soil of the planted areas, entering the continuous sand-based structural soil layer below the surface. Additionally, the interior area of the site contains 12 slot drains that convey any excess runoff directly to the root zones of 13 of the site's 25 large oak trees. The stormwater infiltrating through the paver joints or collected by the slot drains is either taken up by tree roots or continues to percolate down through the structural soil into the subsoil. This irrigation of the trees by stormwater reduces the amount of mechanical irrigation needed, and thus the use of potable water. A rain sensor automatically adjusts the amount of mechanical irrigation depending on precipitation levels and moisture sensors were also installed on select trees. Although the moisture sensors are not connected to the irrigation system, they do allow maintenance staff to periodically adjust irrigation based on soil moisture readings. The trees are mechanically irrigated through a flood bubbler, an efficient deep root watering system.

To determine the total depth of stormwater that is able to infiltrate the site, the following calculations were completed:

Area of site $\times$ Depth of soil = Volume of sand-based structural soil below plaza
13,124 $ft^2 \times$ 3' = 39,372 cubic feet of structural soil
20% water storage capacity (conservative estimate for sand-based soil)
39,372 $ft^3 \times$ 0.2 = 7,874 ft^3 water storage
Volume of water storage/Total site area = Depth of water storage below plaza
7,874 ft^3/13,124 ft^2 = 0.6' = 7.2" water storage
Infiltration rate of pervious pavers = ~3.2 inches/hour minimum
Infiltration rate of sand-based structural soil ~ 3 inches/hour (conservative estimate)
25-year storm event for Boston: 60 min. = 2.08" and 24-hour = 6.19"
50-year storm event for Boston: 60 min. = 2.48" and 24-hour = 7.40"

The water storage capacity of the structural soil below the plaza is 7.2 inches and the infiltration rates of the pavers and soil are approximately 3 inches per hour. This depth is greater than 6.19 inches and the infiltration rates exceed 2.08 inches per hour, indicating that all of the stormwater from a 25-year 24-hour storm event can be infiltrated on the site. The storage capacity of 7.2 inches is not enough to contain the 7.4 inches of a 50-year 24-hour storm event.

Previously an asphalt parking area with all runoff flowing into the city storm sewers, the Central Wharf Plaza now captures 100% of the stormwater that falls on the site, except in the case of extreme precipitation events. If a storm event occurred that exceeded the infiltration ability of the site, some stormwater would overflow into the city's combined sewer system. However, due to the storage capacity of the structural soil layer and the amount of time it would take to fill, peak flows would be greatly reduced and delayed. This helps decrease the volume of discharge from combined sewer overflows, reducing the amount of pollution entering the harbor and other bodies of water.

To estimate the annual volume of stormwater infiltrated on the site, and therefore prevented from entering the city storm sewers, the following calculations were completed:

State of Massachusetts average annual precipitation = 45.12" = 3.76'
Area of site $\times$ Depth of annual precipitation = Volume of annual stormwater
13,124 $ft^2 \times$ 3.76' = 49,346 ft^3
Convert cubic feet to gallons (1 ft^3 = 7.48 gallons)
49,346 ft^3 = 369,108 gallons

<u>Sources</u>

Information on stormwater infiltration, irrigation system and soil volume provided by Eric Kramer & Ryan Wampler, Reed Hilderbrand LLC

Storm data for Boston obtained from: Interactive Web Tool for Extreme Precipitation Analysis http://precip.eas.cornell.edu/
Permeable paver surface infiltration rate obtained from: NWQEP Notes. November 2005. *NC State University Permeable Pavement Research* (p.6)
http://www.bae.ncsu.edu/stormwater/PublicationFiles/NWQEPnotes2005.pdf
Sand-based soil infiltration rate obtained from: Ohio Department of Natural Resources. *Post Construction Stormwater Management Practices* (p.97)
http://www.dnr.state.oh.us/portals/12/water/rainwater/8_30_2012RLDFiles/8_30_12RLD_Ch2.pdf
Information on permeable paver systems obtained from:
Massachusetts Low Impact Development Toolkit. *Fact Sheet #6 Permeable Paving* (p.2)
http://www.mapc.org/sites/default/files/LID_Fact_Sheet_-_Permeable_Paving.pdf
State precipitation data obtained from: Massachusetts Department of Conservation and Recreation http://www.mass.gov/dcr/watersupply/rainfall/

Sequesters over 3,600 lbs of carbon annually in the 25 oak trees.

Average tree size = 10” DBH (Trunk diameter at breast height – 4.5’ above ground)
25 trees = 10 Red oaks + 15 Pin oaks
Red oak sequesters 122 pounds of CO^2/year
Pin oak sequesters 159 pounds CO^2/year
Total annual carbon sequestered = Sum of (pounds of CO^2/year $\times$ # of trees)
3,605 pounds = (122 $\times$ 10) + (159 $\times$ 15)

Sources
DBH data obtained from 2011 field measurements provided by Jim Urban, Urban Trees + Soils
Carbon sequestration amounts obtained from: National Tree Benefit Calculator
http://www.treebenefits.com/calculator/

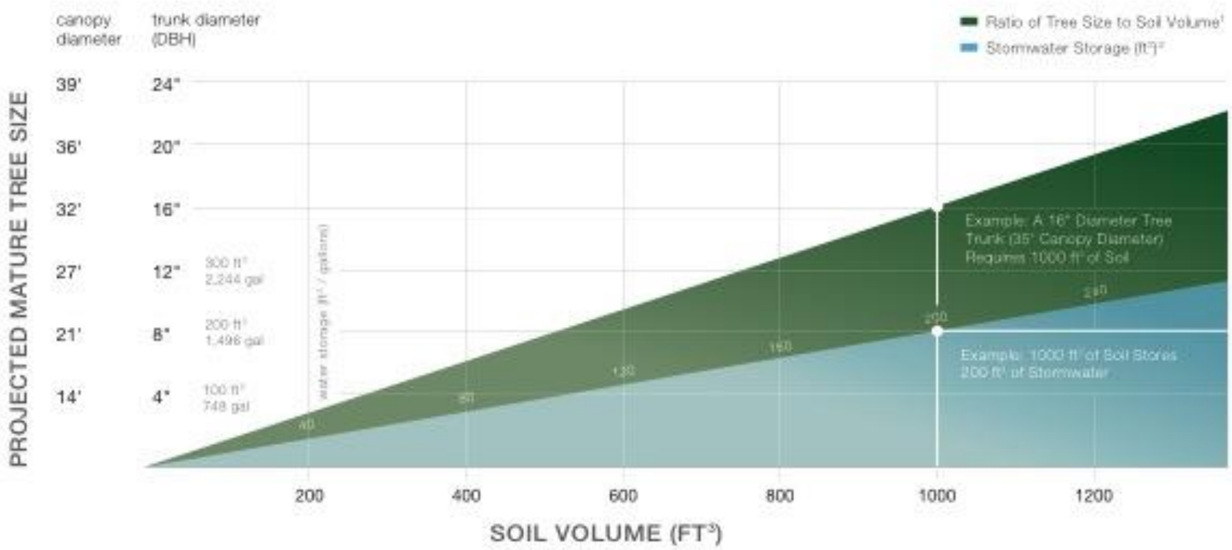
Increases the tree growth rate by 57% when compared to a typical urban oak by providing over 1,500 cubic feet of soil per tree. When the trees reach their projected mature size in about 33 years, they will sequester over 13,000 lbs of carbon and intercept almost 87,000 gallons of rainwater annually.

One of the most important elements for the survival and growth rates of urban trees is soil availability. Adequate soil volume sustains healthy root development, allowing trees to live longer and grow larger. Evidence supports the general guideline that trees need approximately 1 ft^3 to 2 ft^3 of soil for each square foot of mature tree canopy and may gain additional benefits from sharing soil volumes. The site provides a high volume of sand-based structural soil in a continuous layer below the surface. This provides the trees with a shared continuous root zone and allows for integrated aeration and irrigation lines, all of which contribute to the health and growth of the oak trees.

See Method for Landscape Performance Benefit #2 for calculation of total volume of soil below the plaza. To determine the amount of soil available on the site per tree, the following calculation was completed:

Total volume of structural soil/# of trees = Volume of soil per tree
39,372 ft^3/25 trees = 1,575 ft^3 of soil per tree

Using the graph below (which is based on the guideline of 1 ft^3 to 2 ft^3 of soil per 1 ft^2 tree canopy) and the amount of soil available per tree, the oak trees are projected to reach a mature size of about 24” DBH.



To determine the average growth rate of the trees and how long it will take them to reach their projected mature size, the following calculations were completed:

Average 2011 caliper - Average 2007 caliper (@ installation) = Average 4 year growth rate
(Trunk caliper – diameter 12" above ground, Trunk DBH – diameter 4.5' above ground)
13.7" – 12" = 1.7"
Average 4 year growth rate/4 years = Average annual growth rate for oak trees on site
1.7"/4 years = 0.425" per year
Average annual growth rate of typical urban oak trees = 0.69 cm/year = 0.27 inches/year
[(Site growth rate – Typical growth rate)/Typical growth rate] × 100 = % faster than typical
[(0.425" – 0.27")/0.27"] × 100 = 57.4%
Average DBH of trees on site = 10"
(Projected mature DBH – Current DBH)/Site growth rate = Years to projected mature size
(24" – 10")/0.425" per year = 32.9 years

To estimate the amount of projected annual carbon sequestered and rainwater intercepted once the trees reach their mature size, the following calculations were completed:

Projected mature tree size = 24" DBH
25 trees = 10 Red oaks + 15 Pin oaks
Red oak sequesters 436 pounds of CO^2/year & intercepts 3,599 gallons of rainwater/year
Pin oak sequesters 594 pounds CO^2/year & intercepts 3,384 gallons of rainwater/year
Total projected annual carbon sequestered = Sum of (pounds of CO^2/year × # of trees)
13,270 pounds = (436 × 10) + (594 × 15)
Total projected annual rainwater intercepted = Sum of (gallons/year × # of trees)
86,750 gallons = (3,599 × 10) + (3,384 × 15)

<u>Sources</u>

Information on soil volume provided by Eric Kramer & Ryan Wampler, Reed Hilderbrand LLC
Caliper & DBH data obtained from 2011 field measurements provided by Jim Urban, Urban Trees + Soils
Average annual growth rate of typical urban oak trees obtained from:
Buhler, O., P. Kristoffersen & S. U. Larsen. 2007. Growth of Street Trees in Copenhagen With Emphasis on the Effect of Different Establishment Concepts. *Arboriculture & Urban Forestry* 33, 5: 330-337. (p.333)
Information on the health benefits of adequate soil volume and soil sharing for urban trees:
Kent, D., S. Shultz, T. Wyatt & D. Halcrow. 2006. Soil Volume and Tree Condition in Walt Disney World Parking Lots. *Landscape Journal* 25, 1-06: 94-107.

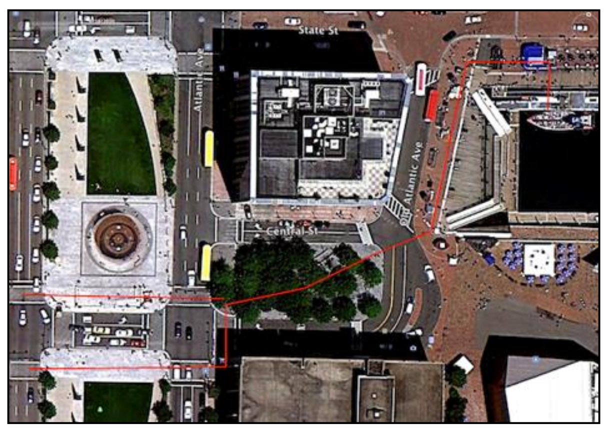
http://www.urbanforestryinstitute.com/uploads/healthy/Soil%20Volume%20and%20Tree%20Condition%20in%20Walt%20Disney%20Parking%20%20Lots.pdf
Carbon sequestration and rainwater interception amounts obtained from:
National Tree Benefit Calculator
http://www.treebenefits.com/calculator/
Graph of relationship between soil volume and tree size (credit: James Urban) obtained from:
http://www.deeproot.com/blog/blog-entries/how-much-soil-do-you-need-to-grow-a-big-tree
Information on the relationship between soil volume and tree size obtained from:
Casey Trees. 2008. *Tree Space Design: Growing the Tree out of the Box* (p.2-3)
http://caseytrees.org/wp-content/uploads/2012/02/tree-space-design-report-2008-tsd.pdf

Social

Provides a pleasant connection between the Rose Fitzgerald Kennedy Greenway and the Inner Harbor waterfront with over 1,550 pedestrians observed passing through the site in 5.5 hours (~280 pedestrians per hour).

The plaza is located in a busy pedestrian intersection between popular tourist and commuter destinations. Central Wharf Plaza is bordered directly on the west by the Rose Fitzgerald Kennedy Greenway, beyond which is Boston's Financial District and Faneuil Hall Marketplace (including Quincy Market). Directly to the east of the plaza, is Central Wharf, which houses the New England Aquarium and serves as a primary connection to the Massachusetts Bay Transportation Authority (T) Inner Harbor Ferry. More than 1.3 million tourists visit the Aquarium annually and on an average weekday, approximately 1,000 commuters ride the ferry. As seen in the left image below, the site was previously a makeshift parking area in the center of wide streets, providing no sidewalks or safe pedestrian route across, forcing users to take a circuitous route to make the connection. Now, as seen in the right image below, the pedestrian only plaza connects the Greenway with the Central Wharf.

Site prior to construction



Site after construction

Five and a half hours were spent observing plaza users over a consecutive Sunday and Monday. Observations took place between 11:50am – 1:50pm and 4:50 – 6:20pm on July 29th, 2012 and between 11:30am – 1:30pm on July 30th. Weather conditions were cloudy on the first day with air temperatures in the range of 65 – 70°F and sunny on the following day with temperatures in the range of 75 – 80°F. Users moving through the site were counted, excluding those who utilized only the west sidewalk to travel along the street since they were not considered to have entered the plaza. A total of 1,552 individuals were recorded passing through the site over the observation periods. Additional observations during different seasons, days or hours should be conducted to obtain a more comprehensive result.

Sources
Images provided by Eric Kramer & Ryan Wampler, Reed Hilderbrand LLC

Aquarium visitor data obtained from: New England Aquarium. *2011 Annual report* (p.1)
http://www.neaq.org/about_us/financial_information/documents/NEAq_AReport_2011.pdf
Ferry Ridership data obtained from:
Massachusetts Bay Transportation Authority. 2010. *Ridership and Service Statistics* (p.5A: 3-4)
http://www.mbta.com/uploadedfiles/documents/Bluebook%202010.pdf

Provides a place of respite and relaxation for 22% of plaza visitors who were observed spending an average of 12 minutes in the space.

See Method for previous benefit for information on site context, and dates, times and weather conditions of observations. Of the 1,992 individuals observed in the site over 5 ½ hours, 440 (22%) of them stopped to spend time there. The following attributes were recorded for these users – grouping, adult or child and an arrival and departure time if possible. Children were classified as any individual estimated to be less than 10 years old by the observer. For 339 out of the 440 observed plaza visitors, an arrival and departure time was used to calculate the total amount of time spent in the space. Visits ranged anywhere from a minute or two, to over an hour, with an average of 12 minutes spent in the plaza. Out of the 440 users, 62 (14%) were classified as children.

In order to compare Central Wharf Plaza visitors to users of the nearby Rose Fitzgerald Kennedy Greenway, additional observations were completed at the Greenway's Rings Fountain. The fountain, located directly to the west of the plaza, contains jets of water shooting up from the paved surface and is surrounded by seating and several open lawn areas. At the fountain, a series of counts were taken at different times on the same days as the plaza observations to determine the percentage of children using the space. Seven counts were completed at the Greenway fountain area on July 29th and six on July 30th with an average of 28% of users classified as children. Due to the fountain, this area of the Greenway seems to be used for more active play and attracts a higher percentage of children. Comparatively, the Central Wharf Plaza seems to provide a quieter area more suited to passive activities such as reading or eating lunch and a lower percentage of children were observed there. Additional observations during different seasons, days or hours should be conducted to obtain a more comprehensive result.

Improved safety with the number of traffic accidents in streets surrounding the site falling from 6 reported in the years before construction to 1 after the new plaza was complete.

See Method for Landscape Performance Benefit #5 for images showing the changes in the traffic circulation before and after construction of the site, and dates and times of observations. As seen in the image, prior to construction, buses and other vehicles pulled over on the road or pulled into parking areas, creating congestion in the streets. The new drop-off area separates vehicles from the street, allowing them to pull through when leaving instead of having to back up into the flow of traffic, improving the efficiency and safety of vehicular circulation. In addition, all streets surrounding the site were narrowed, slowing the speed of traffic and further increasing safety.

Several 30-minute counts were conducted at different times on the same days as the plaza observations to determine the volume of traffic utilizing the new drop-off area. Two counts were completed on July 29th and three on July 30th with an average of 20 vehicles, including buses, taxis and cars, using the area every 30 minutes.

To determine the number of traffic accidents reported in the streets surrounding the site before and after construction in 2007, crash data for the city of Boston was requested for the years 2004 -2006 and 2008 – 2010. The data was searched to find any accidents that were reported in the immediate block around the site. Four accidents were reported in 2004, two in 2005, one in 2009 and none in the remaining years. Almost all accidents reported occurred at the intersection of Atlantic Avenue and Milk Street, at the southwest corner of the site. Other factors aside from the new plaza may also have affected the reduction in accidents reported, including changes to the streets because of the Big Dig project and a change in reporting procedures.

Source

Crash data for the city of Boston was obtained from:

Massachusetts Department of Transportation, Highway Division – Crash Portal

http://services.massdot.state.ma.us/crashportal/

Cost Comparison Methods

The integrated planting system on the site contains several elements in its design beyond what is typically found in an urban plaza. These added features improve the conditions for root growth, increasing tree health, size and longevity. Compared to the 4.3% average annual mortality rate of a typical urban street tree, the trees on the site have a current annual mortality rate of only 1.6%. Based on these rates, in a typical urban plaza, all 25 trees would have to be replaced in 23 years, while in this plaza only 9 would have to be replaced over the same time frame, a savings of nearly $50,000.

See Methods for Landscape Performance Benefits #2 and #4 for information on the integrated planting system, which includes pervious surfaces, a continuous sand-based structural soil layer and integrated aeration and irrigation lines. All of these features promote healthy tree development as demonstrated by the generally good current condition of the site's oak trees. Two of the 25 trees have been replaced since installation five years ago, one immediately after being planted and one after the second year. One additional tree on the site failed, however, due to its exposed corner location, it was assumed that no tree would be able to withstand the conditions in that particular spot so it was not replaced. Based on this, tree mortality for the site was assumed to be two trees in five years, out of a total population of 25. A constant annual mortality rate was also assumed because evidence supports the idea that mortality rate will not increase until after trees reach a significant age or size.

To determine the current annual mortality rate and number of trees that would need to be replaced compared to a typical urban plaza, the following calculations were completed:

> [(# of trees replaced/# of years)/Total # of trees] $\times$ 100 = Site annual mortality rate
> [(2 trees replaced/5 years)/25 total trees] $\times$ 100 = 1.6% site mortality rate
> Average annual mortality rate of typical urban street trees = 4.3%
> Total # of trees/(Typical mortality rate $\times$ Total # of trees) = # of years for all typical trees to fail
> 25 total trees/(0.043 typical mortality rate $\times$ 25 total trees) = 23.3 years
> # of years $\times$ (Site mortality rate $\times$ Total # of trees) = # of site trees to be replaced
> 23 years $\times$ (0.016 site mortality rate $\times$ 25 total trees) = 9.2 site trees to be replaced
> Typical trees to be replaced – Site trees to be replaced = # of trees saved from replacing
> 25 typical trees replaced – 9 site trees replaced = 16 trees saved

In order to maintain the design and intent of the plaza, any replacement trees would have to be a substantial size. Since the original trees were installed at 12-inch caliper, replacement trees would most likely need to be 10-inch caliper minimum so they would not obstruct pedestrian circulation and would provide the same canopy as the current large trees. The cost of replacement was difficult to estimate because most methods assume a large caliper tree will be replaced with several smaller caliper trees, which would not work in this case. A rough cost per tree was estimated based on the average nursery prices for the two species (Pin oak & Red oak) at a 10-inch caliper size. This approximate estimate may be a little low because replacement would also require the use of a crane and traffic controls on adjacent streets.

To determine the replacement cost savings compared to a typical urban plaza, the following calculation was completed:

Estimated average cost of 10-inch caliper oaks = $3,000
# of trees saved from replacing × Cost per tree = Cost savings
16 trees saved × $3,000 per tree = $48,000

Sources
Information on tree replacement since installation provided by Eric Kramer & Ryan Wampler, Reed Hilderbrand LLC
Annual mortality rate of typical urban street trees obtained from:
Roman, L. A., & F. N. Scatena. 2011. Street tree survival rates: Meta-analysis of previous studies and application to a field survey in Philadelphia, PA, USA. *Urban Forestry & Urban Greening* 10, 4: 269-274. (p.273)
http://www.fuf.net/drdeath.pdf
Nowak, D. J., M. Kuroda & D. E. Crane. 2004. Tree mortality rates and tree population projections in Baltimore, Maryland, USA. *Urban Forestry & Urban Greening* 2, 3: 139-147. (p.142)
http://www.fs.fed.us/ne/newtown_square/publications/other_publishers/OCR/ne_2004nowak01.pdf
Tree cost estimates for 10-inch caliper Pin & Red oaks obtained from:
Wade and Gatton Nurseries Price Lists – The Oak Family (p.14 & 20)
http://wadeandgattonnurseries.com/wp-content/uploads/2011/03/quercus-oak-desc-2011-retail.pdf
Ruppert Nurseries Catalog & Availability
http://www.ruppertnurseries.com/trees/index.html