

APPENDIX 10: SCREENING-LEVEL WIND ASSESSMENT

BETTER MARKET STREET

SAN FRANCISCO, CA

SCREENING-LEVEL WIND ASSESSMENT - FINAL

RWDI # 1700387

June 18, 2018

SUBMITTED TO

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1 INTRODUCTION

Rowan Williams Davies & Irwin Inc. (RWDI) was retained by ICF to assess the pedestrian wind conditions along Market Street in San Francisco, CA (Image 1) after the implementation of the Better Market Street Project (proposed project). The proposed project consists of transportation and streetscape improvements along Market Street that would include changes to the roadway configuration and private vehicle access; traffic signals; surface transit, including transit-only lanes, stop spacing and service, stop locations, stop characteristics, and infrastructure; bicycle facilities; pedestrian facilities; streetscapes; commercial and passenger loading; vehicular parking; utilities; and street trees. The wind assessment focuses on the wind hazard conditions as they may be affected by the proposed project, including the removal of all existing street trees on Market Street, the replacement or relocation of some street trees, and the addition of street furniture and public art. The proposed transportation improvements are not expected to alter the wind conditions for the proposed project and are therefore not discussed in this assessment.

Also, discussed in this assessment is the potential wind impact of the proposed project variant. The project variant is a variation of the proposed project within the project limits. The differences between the project variant and the proposed project include changes in regards to roadway configuration, private vehicle access, surface transit, and pedestrian and bicycle facilities in the western segment of the project corridor. The differences between the project variant and the proposed project are not expected to have an impact on wind conditions.

This screening-level assessment is qualitative in nature and based on the following:

- local wind conditions in the San Francisco area;
- the extensive wind studies conducted by RWDI for various developments along Market Street;
- design drawings and information for the proposed project and the project variant received by RWDI on April 20, 2018; and
- RWDI's engineering judgment, experience and expert knowledge of wind flows around buildings and trees¹²³.

As discussed in Section 3, *Meteorological Data*, no wind tunnel tests were conducted solely for the purpose of this assessment; this assessment relies on wind studies conducted by RWDI for other projects along Market Street, as well as our experience and engineering judgment.

¹ C.J. Williams, H. Wu, W.F. Waechter and H.A. Baker (1999), "Experience with Remedial Solutions to Control Pedestrian Wind Problems", 10th International Conference on Wind Engineering, Copenhagen, Denmark.

² H. Wu and F. Kriksic (2012). "Designing for Pedestrian Comfort in Response to Local Climate", Journal of Wind Engineering and Industrial Aerodynamics, vol.104-106, pp.397-407.

³ H. Wu, C.J. Williams, H.A. Baker and W.F. Waechter (2004), "Knowledge-based Desk-Top Analysis of Pedestrian Wind Conditions", ASCE Structure Congress 2004, Nashville, Tennessee.



Image 1: Aerial view of the project corridor and surroundings (not to scale)
(Google™ Earth is the source for this and many other photos in the report.)

2 PROPOSED PROJECT AND PROJECT CORRIDOR INFORMATION

2.1 Proposed Project

The proposed project would redesign and provide various transportation and streetscape improvements to a 2.2-mile-long corridor, generally encompassing Market Street between Steuart Street and Octavia Boulevard, including Charles J. Brenham Place, and Valencia Street between Market and McCoppin streets, (the project corridor) (Image 2). The proposed improvements that could affect the existing wind conditions along the project corridor would include the removal of all existing street trees on Market Street. Trees would be replaced or relocated in areas where sidewalks would be reconfigured to accommodate wider center transit boarding islands and the new sidewalk-level bikeway. Street furniture and public art would be added in certain locations.

The main features of the proposed project that would have the potential to affect the wind conditions are the proposed removal of all existing street trees along Market Street and the proposed replacement and relocation of some of the street trees along Market Street. In the right conditions, with the appropriate species and size, trees



have been proven to be effective in the reduction of wind speeds at the pedestrian level. In an open area exposed to the predominant winds (such as a park or large courtyard space), moving or reducing the number of trees could have a substantial effect on wind conditions at grade level. In a built-up area, such as Market Street, where the main factors affecting the wind conditions are the buildings in the immediate surroundings, the effects of the removal and replacement of trees would be less substantial.

As part of the proposed project, the majority of the sidewalks along Market Street between Van Ness Avenue and Steuart Street would include 10-foot-wide zones with furnishings, referred to as “Streetlife Zones” (Image 3). Streetlife Zones would be defined by street trees and streetlight poles and would be located between the pedestrian through-zone and the sidewalk-level bikeway. The Streetlife Zones would allow for the installation of features such as street furniture, benches, moveable tables and chairs, sidewalk planting areas, small retail stands (e.g., flower sellers, food carts), public restrooms, advertising kiosks, news racks, bicycle share facilities, and bicycle racks on the sidewalk. The placement of the larger proposed features, such as the kiosks and retail stands, may reduce some wind speeds to the immediate east of the features. The smaller proposed features (i.e., the features that would be less than six feet tall) would not be expected to affect the wind conditions. At this time, the dimensions of the proposed street furniture and public art have not been determined.

The conclusions in Section 5, *Pedestrian Wind Conditions*, of this assessment take all the above factors into account when assessing the impact on the conditions for each segment of the project corridor.

2.2 Project Variant

The project variant would redesign and provide various transportation and streetscape improvements within the approximately 0.6-mile portion of Market Street between Octavia Boulevard and approximately 300 feet east of the Hayes and Market Street intersection. As with the proposed project, the project variant would include the removal of all existing street trees on Market Street. Similar to the proposed project, trees would be replaced or relocated in areas where sidewalks would be reconfigured and street furniture and public art would be added in certain Streetlife Zones. Thus, the features of the proposed project that could affect the wind conditions are also proposed under the project variant and the project variant is not expected to have any additional impact on the wind conditions in the project corridor.

2.3 Project Corridor

Pedestrian areas within the project corridor include sidewalks, crosswalks, transit stops and platforms, bicycle facilities, and outdoor seating areas. For most of the project corridor, a single row of street trees are included within the existing sidewalks on either side of the street.

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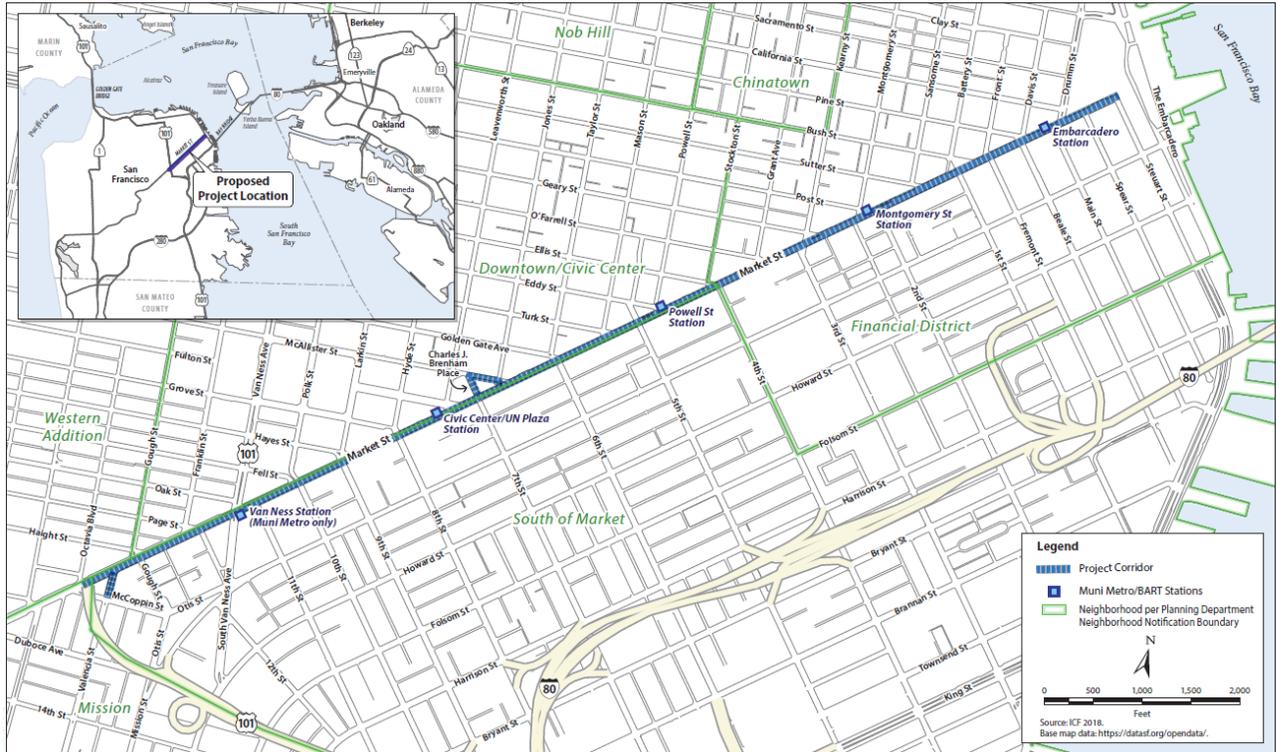


Image 2: Proposed project corridor

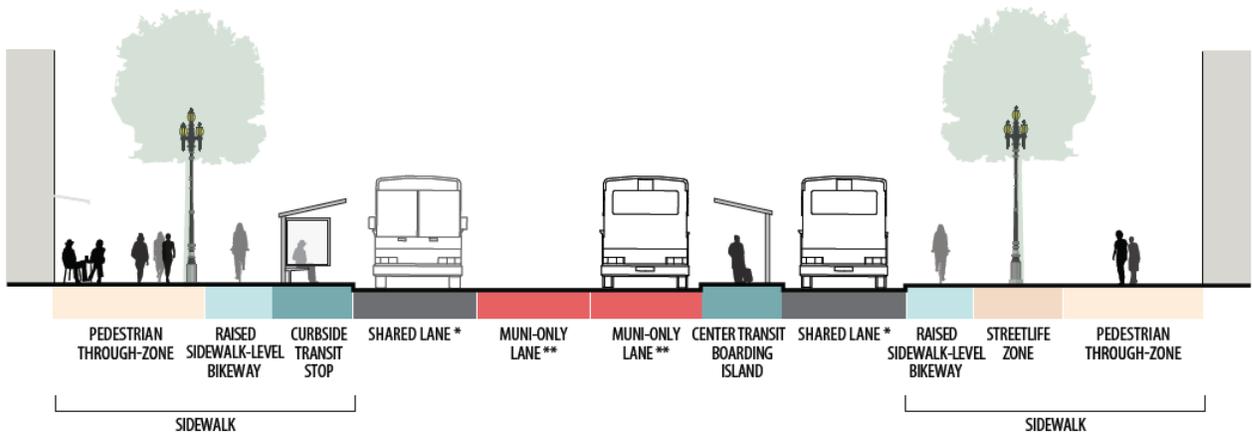


Image 3: Typical mid-block cross section

3 METEOROLOGICAL DATA

Long-term wind data recorded at a height of 33 feet at San Francisco International Airport between 1948 and 2017 are used as a reference for this wind assessment. They are presented as an annual wind rose in Image 4a. Of the primary wind directions, four have the greatest frequencies of occurrence and make up the majority of the strong



winds that occur as shown in Image 4a. These wind directions are west-northwest, west, northwest and west-southwest.

Another set of wind data is often used in San Francisco for projects that are subject to the San Francisco planning code requirements. It was gathered at the old San Francisco Federal Building at 50 United Nations Plaza (Weather Service Office) at a height of 132 feet above grade during the period of 1945 to 1950. Image 4b shows a similar distribution of wind speeds and directions as those in Image 4a.

This qualitative assessment primarily considers the above wind data for winds from the dominant directions (west, west-northwest and west-southwest) as they interact with the project corridor. However, winds from other directions are also considered in this assessment. Although wind direction is not directly referenced at every location, information derived from our knowledge of how winds behave, the directionalities, and previous wind studies conducted by RWDI in the area, that support the conclusions provided in Section 5, *Pedestrian Wind Conditions*.

As this assessment focuses on the effect of the removal of all existing street trees on Market Street, the replacement or relocation of some street trees, and the addition of street furniture and public art, some of the previous wind tunnel studies carried out within the project corridor were used to inform the wind conditions expected with no landscaping or street furniture in place. This is a conservative assessment of conditions within the project corridor because landscaping and other porous elements along the street are considered positive wind control measures and are often used to reduce wind speeds in areas that are less comfortable than required. With this knowledge, and the comparison to other projects in the corridor that were tested with and without landscaping in place, RWDI assessed how much the proposed project would change existing wind conditions.

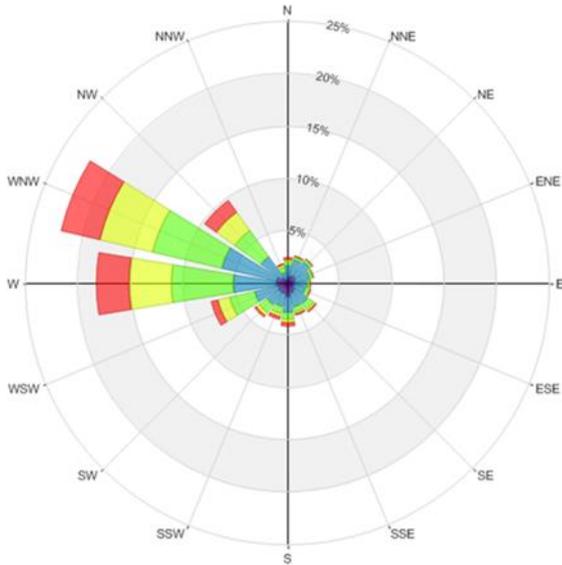


Image 4a: Annual distribution of winds approaching San Francisco International Airport (1948 to 2017)

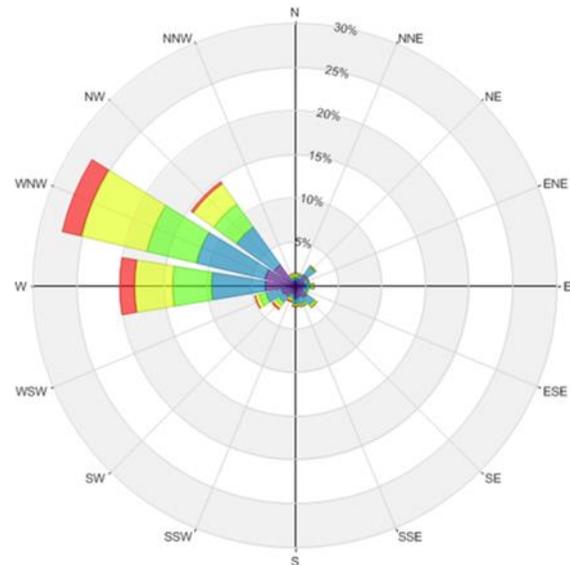


Image 4b: Annual distribution of winds approaching San Francisco Downtown Station (6:00 to 20:00, 1945 to 1950)

Wind Speed (mph)



- Calm
- 1-5
- 6-10
- 11-15
- 16-20
- >20

4 PLANNING CODE REQUIREMENTS

Wind comfort and hazard criteria are specified in San Francisco Planning Code section 148: Reduction of Ground-level Wind Currents in Downtown Commercial (C-3) Districts. Section 148 requires that buildings and additions to existing buildings shall be shaped, or other wind-baffling measures shall be adopted, so that the developments will not cause ground-level wind currents to exceed, more than 10 percent of the time year-round, between 7:00 a.m. and 6:00 p.m., the comfort level of 11 m.p.h. equivalent wind speed in areas of substantial pedestrian use and seven m.p.h. equivalent wind speed in public seating areas. The Planning Code comfort criteria are defined in terms of equivalent wind speed, which is an average wind speed (mean velocity), adjusted to include the level of gustiness and turbulence. Under procedures developed to implement section 148, equivalent wind speed is defined as the mean wind velocity, multiplied by the quantity (one plus three times the turbulence intensity) divided by 1.45. This calculation magnifies the reported wind speed when turbulence intensity is greater than 15 percent. The text in this assessment simply refers to the data as wind speeds.

The modifications proposed for the streets and sidewalks within the project corridor would occur within the existing operational public right-of-way, would not involve the construction of or alterations to buildings along Market Street, and would therefore not be subject to Planning Code section 148. Nonetheless, the project corridor runs

through a C-3 District and these criteria can be and have been applied to the project corridor as a guideline for environmental review of the wind hazard criterion.

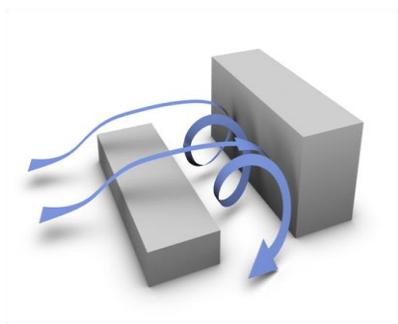
5 PEDESTRIAN WIND CONDITIONS

5.1 Background

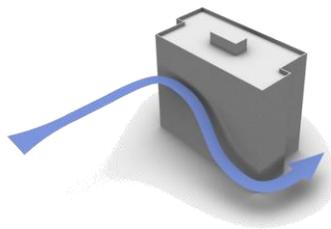
Predicting wind speeds and frequencies of occurrence involves the assessment of building geometry, orientation, position and height of surrounding buildings, upwind terrain and the local wind climate as well as landscaping. RWDI has conducted thousands of wind tunnel model studies on pedestrian wind conditions around buildings, yielding a broad knowledge base. This knowledge has been incorporated into RWDI's proprietary software that allows, in many situations, for a screening-level qualitative estimation of pedestrian wind conditions without wind tunnel testing.

In the following discussion of anticipated wind conditions, reference is made to the following generalized wind flows. Tall buildings tend to intercept the stronger winds at higher elevations and redirect them to the ground level (Image 5a). Such a downwashing flow is often the main cause for wind accelerations around tall buildings at the pedestrian level. These winds can be relatively strong and turbulent, especially around the exposed building corners (Image 5b). These downwashed winds may subsequently channel along street canyons between buildings and make these areas windy (Image 5c).

If these building/wind combinations occur for prevailing directions, there is a greater potential for increased wind activity and uncomfortable or even hazardous conditions.



(a) Downwashing Flow



(b) Corner Acceleration

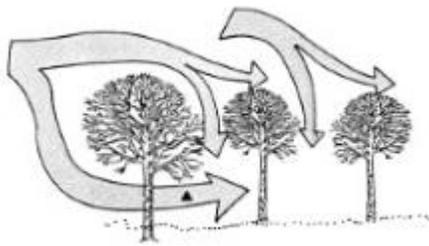


(c) Channeling Effect

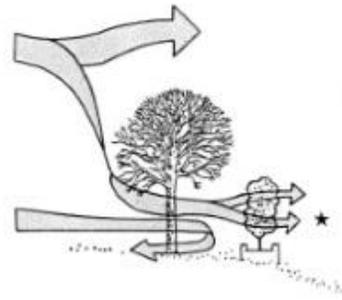
Images 5a-c: General wind flow phenomena around buildings

5.2 Streetscape Features and Wind Control

As discussed below, there are various types of streetscape features used for wind control (e.g., trees, landscaping, hardscaping, and street art). Tree leaves and branches form three-dimensional obstacles that reduce downwashing winds off nearby buildings (Image 6a). Horizontal wind flows above the pedestrian level can also be reduced by canopy-type trees; however, local wind acceleration may occur under tree canopies, as shown in Image 6a. For trees to be effective in controlling winds at the pedestrian level, under-planting or the placement of other features is typically required. These may include low bushes and shrubs (Image 6b) and benches with high backs (Image 6c). In addition, trees should be dense (or mature) and able to keep their foliage reasonably well through the winter months (Image 6d) to be effective in controlling winds at the pedestrian level. Trees are considered effective as wind control measures due to the porosity of the foliage. Similarly, porous windscreens and street art are considered effective as wind control measures. When wind travels through a porous object (e.g., trees, porous windscreens, and porous street art), the wind speed is reduced as the energy of the wind is separated from one strong stream to several weaker streams of wind.



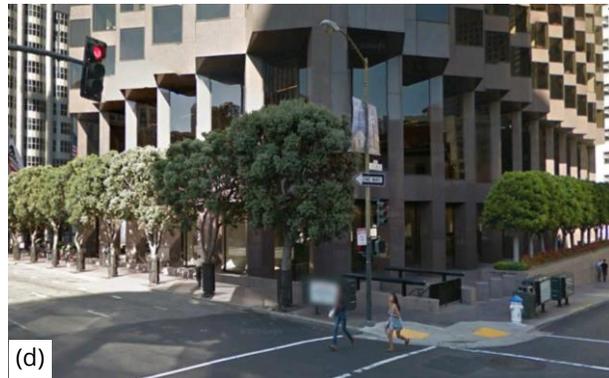
(a)



(b)



(c)



(d)

Images 6a-d: Wind control by trees and other streetscape features



5.3 Existing Wind Conditions

RWDI has conducted various wind studies in the City of San Francisco, including many along Market Street. Wind tunnel studies that have been carried out by RWDI and have been referenced to inform the conclusions made in this assessment are listed below and are marked by yellow pins in Image 7:

- The Hub Plan (2018)
- 22 Franklin Street (2015)
- 1554 Market Street (2014)
- Market and Van Ness/ One Oak (2013)
- 30 Van Ness (2018)
- 1500 Mission (2015)
- 10th and Market (2003)
- 1125 Market Street (2015)
- 1075 Market Street (2015)
- 1028 Market Street (2015)
- 1066 Market Street (2015)
- 57 Taylor Street (2015)
- 950-954 Market Street (2015)
- Mason & Turk Street (2013)
- 120 Stockton Street (2018)
- 706 Mission Street (2012)
- The Place Condo (2008)
- First and Mission (2011)
- 350 Mission Street (2010)

Photos of wind tunnel models of select projects along Market Street are shown in Image 8 to provide context of the area and buildings around the proposed project. These wind tunnel models informed the description of existing conditions provided in this assessment.

Wind conditions along Market Street generally do not exceed the wind hazard criterion for the most of the west (Octavia Boulevard to Franklin Street) and mid portions (9th to 4th streets) between relatively low buildings, and for the entire east portion (2nd Street to The Embarcadero) due to dense surroundings in the downtown. However, higher wind activity that may exceed the wind hazard criterion were previously detected at three areas along Market Street (marked by red circles in Image 7):

- between Van Ness Avenue and Polk Street/10th Street due to the existing and future tall buildings;
- at the north end of Yerba Buena Lane on the west side of an existing hotel tower; and
- around the intersection with 3rd Street/Kearny Street, which is an “entrance” for the prevailing west and west-northwest winds into the downtown core of dense tall buildings.

Detailed discussions for these areas are provided in the next section. In addition, see recommendations to lower existing wind speeds in Section 6, *Summary and Recommendations*.



Image 7: Wind studies conducted by RWDI along Market Street (yellow pins), including three segments of higher wind activity (red circles)

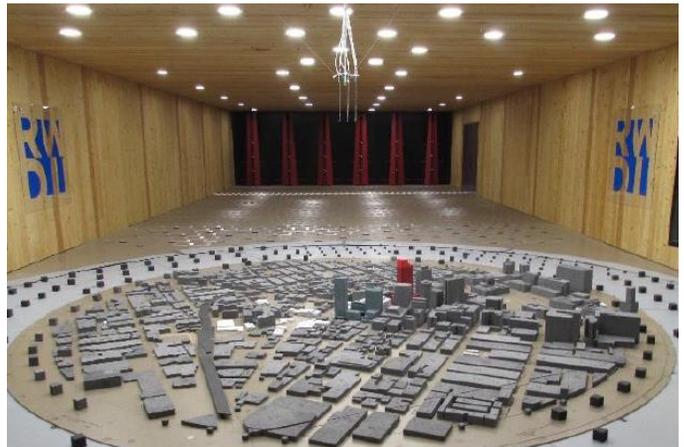
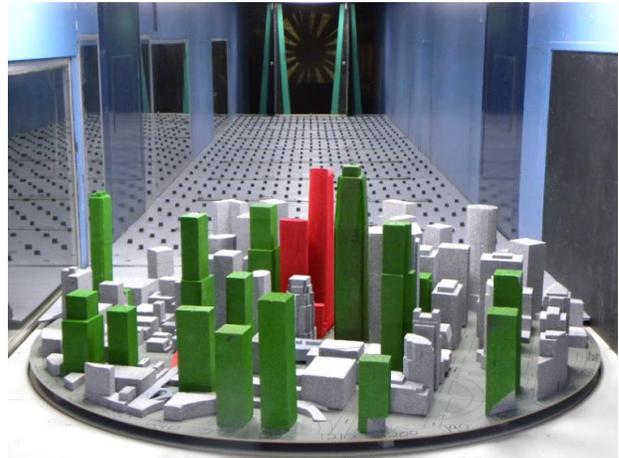


Image 8: Photos of wind tunnel models of select projects along Market Street (1028 Market Street - top left, First and Mission - top right, 120 Stockton Street - bottom left & 30 Van Ness - bottom right)

5.4 Potential Wind Impact: Octavia Boulevard to Fell Street

The west end of the project corridor from Octavia Boulevard to 12th Street includes low buildings on both sides of Market Street (Area A in Image 9a), where wind speeds are typically expected to not exceed the hazard criterion under existing conditions based on previous wind tunnel results.⁴ Wind conditions that would be similar to the existing conditions and would not exceed the hazard criterion are predicted for this segment of Market Street after implementation of the proposed project and the streetscape improvements. This is due to the impact of the surrounding buildings on existing wind conditions compared to the impact of grade-level landscaping, as explained in Section 2, *Proposed Project and Project Corridor Information*.

However, the intersections of Market Street with Fell Street/Polk Street/10th Street (Area B1) and Van Ness/ Oak Street/ 11th Street intersection (Area B2) are currently windy around the existing towers such as 1390 Market Street, 1 Polk Street, 8 10th Street, and 30 Van Ness, with some locations expected to exceed the wind hazard criterion. The wind conditions at these two intersections are caused by downwashing due to the exposure of the taller towers to the northwesterly winds and relatively low buildings to the west. The existing landscaping along this stretch of Market Street is extensive with a single row of trees on either side of the street. The improvements associated with the proposed project, including removal and replacement of trees, are not anticipated to increase wind speeds or exposure to wind hazards in this area as the quantity and size of the trees is expected to be similar to the existing landscaping. The dimensions of the proposed street furniture and public art have not yet been determined. As discussed above, if they are six feet tall or higher then improved wind conditions would result. However, winds exceeding the hazard criterion are still not anticipated to occur if these features are shorter than six feet.



Image 9a: Proposed Improvements: Octavia Boulevard to Fell Street

⁴ Based on previous wind studies prepared for The Hub Plan and projects at 22 Franklin Street and 1554 Market Street.

5.5 Potential Wind Impact: Polk to McAllister streets

Moving east along Market Street between Polk and McAllister streets, wind speeds are expected to not exceed the hazard criterion based on previous wind tunnel results⁵ (Area C in Image 9b). This is due to the relatively dense, medium-rise buildings on the north side of the street and similar buildings on the south. As part of the proposed project, the existing double rows of trees in this area would be completely removed and partially replaced by a single row of trees. Previous wind tunnel studies of the existing conditions were tested without any landscaping. Therefore, changes to the streetscape associated with the proposed project, including removing/replacing trees and re-arrangements of bike paths/cross walks and intersections, would not result in any exceedances of the hazard criterion, or have a substantial effect on existing wind conditions in this segment of Market Street.

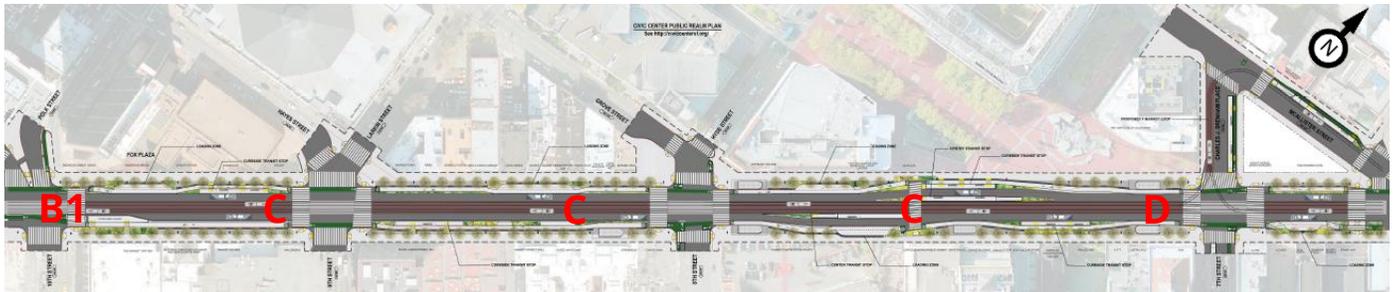


Image 9b: Proposed Improvements: Polk to McAllister streets

5.6 Potential Wind Impact: Jones to Ellis streets

The section of Market Street between Jones and Ellis streets is surrounded by dense buildings on both sides and has no high-rise buildings as shown by the 3-D image (Image 9c). As a result, relatively low wind activity that does not exceed the hazard criterion is expected along this street section (Area E in Image 9c). As part of the proposed project, the existing double rows of trees in this area would be removed and replaced by a single row of trees. Once again, the previous wind tunnel studies carried out along this stretch of Market Street⁶ were without landscaping and showed comfortable wind conditions, therefore wind conditions are not expected to result in any locations where the hazard criterion is exceeded with the proposed changes.

For reasons stated above, it is unlikely that removing and/or replacing trees along sidewalks would result in wind hazard exceedances. However, the comfort conditions in the vicinity of the several outdoor seating areas, such as those close to the Taylor Street intersection (Area F1 in Image 9c), would benefit from street trees of denser foliage and other wind control measures, such as windscreens or street art (Image 6) to the west of the areas.

The sunken station plazas (Area F2 in Image 9c) are currently sheltered from horizontal winds by the walls that surround them. As the proposal for the sidewalks and landscaping in this area are downwind of these plazas, the proposed project is not expected to affect the wind conditions in these areas.

⁵ Based on previous wind studies prepared for projects at 1125 Market Street and 1075 Market Street.

⁶ Based on previous wind studies prepared for projects at 1028 Market Street and 57 Taylor Street.

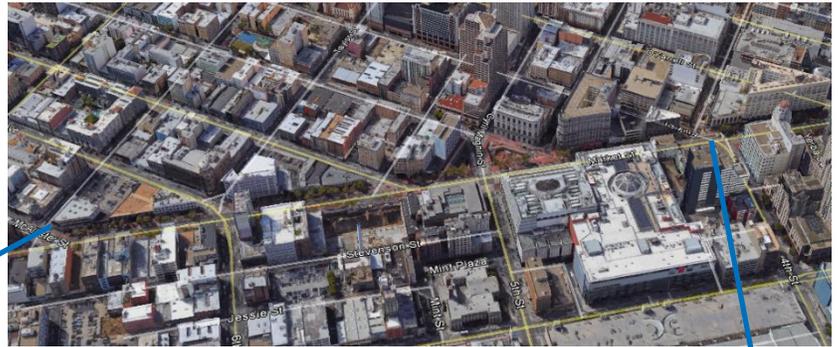


Image 9c: Proposed Improvements: Jones to Ellis streets

5.7 Potential Wind Impact: Stockton to Sutter streets

The section of Market Street between Stockton and Sutter streets contains two known windy areas: one along Yerba Buena Lane on the west side of an existing hotel tower (Area H1 in Image 9d) and the other at the intersection of Market Street with Kearny Street/3rd Street (Area H2 in Image 9d)⁷. Winds along Yerba Buena Lane (Area H1 in Image 9d) are caused by the prevailing winds being deflected down by the existing Four Seasons tower, which is significantly taller than its surroundings to the west. The existing tall buildings on the east side of Kearny Street form a tall wall to deflect the prevailing winds into the open intersection area (Area H2 in Image 9d). Existing wind activity in this area exceeds the wind hazard criterion.

One notable change proposed for this segment of Market Street (Area G in Image 9d) under the proposed project is the complete removal of the existing double rows of trees on both sides of the street, and partial replacement with a single row of trees. Since the existing conditions are a result of downwashing off the tall tower and buildings noted above, and the proposed single line of trees are spaced close together, this change and the other improvements associated with the proposed project are not expected to significantly alter the existing wind conditions along Market Street or create any wind hazard exceedances. In addition, the proposed arrangement of trees under the proposed project is expected to eventually provide a canopy for pedestrians along the sidewalk.

⁷ The Palace Condo and First and Mission



Image 9d: Proposed Improvements: Stockton to Sutter streets

5.8 Potential Wind Impact: Sansome to Steuart streets

The last segment of Market Street east of Sansome Street is heavily sheltered by tall buildings in the downtown core, and existing wind activity in this area does not exceed the wind hazard criterion⁸. Relatively calmer winds are created by the many taller buildings that are sheltering pedestrians at street level. The proposed changes and updates to the grade level landscaping or furniture would have an unsubstantial effect on the existing wind conditions. For this reason, the proposed changes to the street landscaping would not result in winds that exceed the wind hazard criterion.



Image 9e: Proposed Improvements: Sansome to Steuart streets

5.9 Potential Wind Impact: Project Variant

As previously discussed, the features of the proposed project that could affect the wind conditions are also proposed under the project variant and the project variant is not expected to have any additional impact on the wind conditions in the project corridor. Thus, it is anticipated that the potential wind impacts of the project variant would be the same as the impacts discussed above for the proposed project. The project variant is not expected to result in an increase in wind speeds and would not result in an increase in exposure to existing wind hazards.

⁸ Based on previous wind studies prepared for a project at 350 Mission Street.

6 SUMMARY AND RECOMMENDATIONS

6.1 Summary

This screening-level wind assessment was conducted based on the local wind climate, existing and proposed streetscape improvements along Market Street, and previous wind studies conducted by RWDI along the project corridor. The streetscape improvements included under the proposed project, including changes to street trees, pedestrian and bicycle facilities, crosswalks, transit platforms and stops, would not substantially alter the existing wind conditions, nor induce new wind hazard exceedances. Based on previous wind studies, the following three areas experience existing wind speeds that exceed the hazard criterion:

- between Van Ness Avenue and Polk Street/10th Street due to the existing and future tall buildings;
- at the north end of Yerba Buena Lane on the west side of an existing hotel tower; and
- around the intersection with 3rd Street/Kearny Street, which is an “entrance” for the prevailing west and west-northwest winds into the downtown core of dense tall buildings.

The proposed project would not increase wind speeds in these areas, and would not increase the potential for exposure to existing wind hazards. The streetscape improvements proposed under the project variant would be similar to the proposed project, and therefore the project variant would not increase wind speeds and would not result in a potential increase in exposure to existing wind hazards.

6.2 Recommendations

Although additional exceedance of the wind hazard criterion is not expected with implementation of the proposed project or the project variant, RWDI recommends incorporation of the following measures to lower existing wind speeds at the areas identified above that experience existing wind speeds that exceed the hazard criterion:

- street trees to be combined with hardscaping, street art or porous tall furniture such as those shown in Image 6 for the protection of the trees from windy conditions at the intersection of Market Street and Van Ness Avenue;
- street trees be combined with hardscaping, street art and other elements for wind control at the intersection of Market Street with Fell, Polk and 10th streets;
- trees with denser foliage, (Image 6d) be planted at 7th Street;
- enhancements such as those mentioned in Images 6a, 6b and 6d should be made to the existing landscaping in the United Nations Plaza to protect this area from northwest exposure; and
- the street trees should be combined with hardscaping such as windscreens, street art or other elements used for wind control, at the north end of Yerba Buena Lane and the intersection of 3rd and Kearney streets.