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REPORT

PRELIMINARY PEDESTRIAN LEVEL WIND STUDY

221 Sterling Road
Toronto, Ontario

221 Sterling Road Holdings Inc.

REPORT NO. 20631wind **April 21, 2021**

TABLE OF CONTENTS

1. EXECUTIVE SUMMARY

The residential Development proposed by 221 Sterling Road Holdings Inc. for 221 Sterling Road in Toronto, Ontario, has been assessed for environmental standards with regard to pedestrian level wind velocities relative to comfort and safety. The pedestrian level wind and gust velocities measured for the forty-four (44) locations tested were quantitatively assessed and determined well within safety criteria and most are within the comfort criteria described within.

The proposed Development involves a proposal to remove the existing 2 storey building on site and construct three residential towers, 29, 25, and 20 storeys in height. Based upon this analysis, wind conditions on and around the proposed Development are predicted to be mainly suitable for leisurely walking, standing, or better, year-round, under normal to high ambient wind conditions, with a few localised areas in gaps between buildings realising windier conditions, but remaining generally suitable for the intended uses, much of the time.

The property is, for all intents and purposes, surrounded to prevailing windward directions by suburban lands comprised of a mix of mainly low-rise residential and commercial buildings, with a few mid to high-rise buildings to the north and south of the site. These surrounds present a somewhat coarse terrain to approaching winds, limiting the wind's opportunity to accelerate upon approach.

Urban developments provide surface roughness, which induces turbulence that can be wind friendly, while suburban settings similarly, though to a lesser extent, prevent wind from accelerating as the wind's boundary layer profile thins at the pedestrian level. Conversely, open settings afford wind the opportunity to accelerate. Mid to high-rise buildings typically exacerbate wind conditions within their immediate vicinity, to varying degrees, by redirecting wind currents to the ground level and along streets and open areas. Transition zones from open, and/or suburban, to urban settings often prove problematic, as winds exacerbated by relatively more open settings are redirected to flow over, around, down, and between urban buildings.

The proposed Development's towers penetrate winds that formerly flowed over the site. The increased blockage relative to the existing setting causes wind to redirect to flow over the buildings, without consequence, and/or, depending upon the angle of incidence, around, or down the buildings towards the pedestrian level, as downwash. At the pedestrian level, the winds redirect to travel horizontally along the buildings, around the corners and beyond, creating windswept areas at or near the buildings' corners and/or in gaps between. Under high ambient winter wind conditions with winds emanating from specific directions, localised gaps between the proposed Development's towers and neighbouring buildings will be windy from time to time, but remain generally appropriate to the intended purposes much of the time. Ongoing wind appropriate urban intensification of the surroundings will cause the wind's boundary layer profile to thicken, or when considered specific to the site, reduce the propensity for wind to downwash to the pedestrian level.

The Development is punctuated with terraces and features various stepped conditions that discourage downwash associated with prevailing winds, deflecting a portion of said flows around the buildings at elevations well above the pedestrian level. This results in a moderate upset to the impending wind climate realised at the site with inclusion of the proposed Development, relative to the existing setting. Where mitigation was required, it was achieved through the incorporation of the following design features:

- stepped façades
- terraces
- balconies
- podiums
- canopies
- landscaping

and others, that were included in the proposed Development's massing and landscape design. The mitigation features contribute to pedestrian comfort conditions that are suitable to the context. Additional mitigation is required for the Entrances to Towers A and B located in the gap between the buildings in order to achieve conditions that are suitable for the intended uses. Mitigation plans are also recommended for the Public Park and various at-grade and rooftop Outdoor Amenity Spaces in order to achieve conditions that are seasonally appropriate for the uses. Comfort conditions around the proposed Development site are in many cases improved, or similar to the existing setting, and considered acceptable to the suburban context.

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2. INTRODUCTION

221 Sterling Road Holdings Inc. retained Theakston Environmental to study the pedestrian level wind environment for the proposed Development located at 221 Sterling Road, in the City of Toronto as shown on the aerial photo in Figure 2a. The proposed Development involves a proposal to remove the existing 2 storey building on site and construct three residential towers, 29, 25, and 20 storeys in height in a configuration as shown in Figure 2b.

Turner Fleischer Architects provided architectural drawings. The co-operation and interest of the Client and their sponsors in all aspects of this study is gratefully acknowledged.

The specific objective of the study is to determine areas of higher than normal wind velocities induced by the shape and orientation of the proposed buildings and surroundings. The wind velocities are rated in accordance with the safety and comfort of pedestrians, notably at entrances to the buildings, sidewalks, outdoor amenities, as well as other buildings in the immediate vicinity.

In order to obtain an objective analysis of the wind conditions for the property, the wind environment was tested in two configurations. The existing configuration included the 2 storey building currently on site, as well as existing and proposed buildings in the surrounding area. The proposed configuration removed the existing building on site and included the subject Development.

The laboratory techniques used in this study are established procedures that have been developed specifically for analyses of this kind. The methodology, summarized herein, describes criteria used in the determination of pedestrian level wind conditions. The facilities used by Theakston are ideal for observance of the Development at various stages of testing, and the development of wind mitigation measures, if necessary.

3. OBJECTIVES OF THE STUDY

1. To quantitatively assess, by model analyses, the pedestrian level wind environment under existing conditions and future conditions with the proposed Development.

2. To assess mitigative solutions.

3. To publish a Consultant's report documenting the findings and recommendations.

4. METHOD OF STUDY

4.1 General

The Theakston Environmental wind engineering facility was developed for the study of, among other sciences, the pedestrian level wind environment occurring around buildings, with focus on the safety and comfort of pedestrians. To this end, physical scale models of proposed Development sites, and immediate surroundings, are built, instrumented and tested at the facility with resulting wind speeds measured for different wind directions at various locations likely to be frequented by pedestrians. This quantitative analysis provides predictions of wind speeds for various probabilities of occurrence and for various percentages of time that are ultimately weighted relative to a historical range of wind conditions, and provided to the client.

The techniques applied to wind and other studies carried out at the facility, utilise a boundary layer wind tunnel and/or water flume (Figure 1). The testing facility has been developed for these kinds of environmental studies, and has been adapted with equipment, testing procedures and protocols, in order to provide results comparable to full scale. The Boundary Layer Wind Tunnel lends itself well to the simultaneous acquisition of large data streams while the water flume is excellent for flow visualisation.

The purpose of this Pedestrian Level Wind Study is to evaluate the pedestrian level wind speeds for a full range of wind directions. To accomplish this, the wind's mean speed boundary layer profiles are simulated and applied to a site-specific model under test, instrumented with differential pressure probes at locations of interest. During testing, pressure readings are taken over a one-hour model scale period of time, at a full-scale height of approximately 1.8m and correlated to mean and gust wind speeds, expressed as ratios of the gradient wind speed.

The mean and gust wind speeds at forty-four (44) points tested were subsequently combined with the design probability distribution of gradient wind speed and direction, (wind statistics) recorded at Airports in the vicinity, to provide predictions of the full-scale pedestrian level wind environment. Predictions of the full-scale pedestrian level wind environment are presented as the wind speed exceeded 5% of the time, based on annual, and wind for the seasons in Figures 6a – 6e. Criterion employed by Theakston Environmental was developed by others and us and published in the attached references. The methodology has been applied to over 800 projects on this continent and abroad.

4.2 Meteorological Data

The wind climate for the Toronto region that was used in the analysis was based on historical records of wind speed and direction measured at Billy Bishop Airport for the period between 1989 and 2018 and Pearson International Airport for the period between 1980 and 2018. The meteorological data that includes hourly wind records and annual extremes was blended such that wind directions perceived as most representative of areas in the City are selected from the pertinent airport weather station's data. The analysis of the hourly wind records provides information to develop the statistical climate model of wind speed and direction. From this model, predicted wind speeds regardless of wind direction for various return periods can be derived. The record of annual extremes was also used to predict wind speeds at various return periods. Based on the analysis of the hourly records, the predicted hourly-mean wind speed at 10m, corrected for a standard open exposure definition, is 25 m/s for a return period of 50 years.

4.3 Statistical Wind Climate Model

For the analysis of the data, the wind climate model is converted to a reference height of 500*m* using a standard open exposure wind profile. The mean-hourly wind speed at a 500*m* reference height used for this study is 45.6*m/s* for a return period of 50 years. The corresponding 1-year return period wind speed at the 500*m* height is 36*m/s*.

The design probability distribution of mean-hourly wind speed and wind direction at reference height is shown for a blend of data measured at Pearson International Airport & Billy Bishop Airport in Figure 5. Billy Bishop airport, for example, realises a more significant wind climate, in comparison to Pearson, for winds emanating from over the open setting of Lake Ontario, which will afford winds opportunity to accelerate upon approach. Given Billy Bishop is considerably closer to the proposed Development site, data for winds from these directions are considered more representative of winds realised at the site than wind data from Pearson. Conversely, data from winds approaching Pearson from over terrain more representative of that at the site for specific directions was used where pertinent.

From the Wind Roses it is apparent that winds can occur from any direction, however, historical data indicates the directional characteristics of strong winds are from the east as well as west through southwest and said winds are most likely to occur during the winter and fall seasons. In comparison, the Pearson wind climate is dominated by north through west to southwest winds with a far less significant easterly component.

4.4 Wind Simulation

To simulate the correct macroclimate, the upstream flow passes over conditioning features placed upstream of the model, essentially strakes and an appropriately roughened surface, as required to simulate the full-scale mean speed boundary layer approach flow profiles occurring at the site.

4.5 Pedestrian Level Wind Velocity Study

A physical model of the proposed Development and pertinent surroundings, including existing buildings, roadways, pathways, terrain and other features, was constructed to a scale of 1:500. The model is based upon information gathered during a virtual site visit to the proposed Development site, and surrounding area. Turner Fleischer Architects provided architectural drawings. City of Toronto aerial photographs were also used in development of the model to ensure the model reasonably represents conditions at the proposed Development. The model is constructed on a circular base so that, by rotation, any range of wind directions can be assessed. Structures and features that are deemed to have an impact on the wind flows are included upwind of the scale model.

In these studies, the effects of wind were analysed using omni-directional wind velocity probes that are placed on the model and located at the usual positions of pedestrian activity. The probes measure both mean and fluctuating wind speeds at a height of approximately 1.8m. During testing, the model sample period is selected to represent 1hr of sampling time at full scale. The velocities measured by the probes are recorded by a computerized data acquisition system and combined with historical meteorological data via a post-processing program.

4.6 Pedestrian Comfort Criteria

The assignment of pedestrian comfort takes into consideration pedestrian safety and comfort attributable to mean and gust wind speeds. Gusts have a significant bearing on safety, as they can affect a person's balance, while winds flowing at or near mean velocities have a greater influence upon comfort.

Figure 6 presents results for the mean wind speed that is exceeded 5% of the time. These speeds are directly related to the pedestrian comfort at a particular point. The overall comfort rating, for existing and proposed, are depicted in Figure 7. Table 1, below, summarizes the comfort criteria used in the presentation of the results depicted in Figures 6 and 7.

Table 1: Comfort Criteria

ACTIVITY	Mean Wind Speed Exceeded 5% of the Time		Description
COMFORT	***km/h***	***m/s*** (used in Fig. 6)	
Sitting	0-14	0-4	Tree leaves rustle, flags wave slightly. Recommended for outdoor space where people may sit for extended periods.
Standing	0-22	0-6	Small branches move, flags flap and ripple. Suitable for locations where people might sit for short periods or stand in relative comfort.
Leisurely Walking	0-29	0-8	Large branches sway, umbrellas used with difficulty, flags beat and pop. Suitable for activity areas.
Fast Walking	0-36	0-10	Whole trees sway, difficult to walk. This is considered the acceptable upper limit for comfort for the average population.

Uncomfortable	>36	>10	Winds exceed the "Fast Walking" category, can be tolerable for short duration, but will likely be an inconvenience to walking.

The activities are described as suitable for Sitting, Standing, Leisurely Walking or Fast Walking, depending on average wind speed exceeded 5% of the time. For a point to be rated as suitable for Sitting, for example, the wind conditions must not exceed 14*km/h* (4*m/s*), more than 5% of the time. Thus, in the plots (Figure 6), the upper limit of each bar ends within the range described by the comfort category. For sitting, the rating would include conditions ranging from calm up to wind speeds that would rustle tree leaves or wave flags slightly, as presented in the Beaufort Scale included in the Appendices and in Table 1 above. As the name infers, the category is recommended for outdoor space where people might sit for extended periods.

The Standing category is slightly more tolerant of wind, including wind speeds from calm up to 22*km/h* (6*m/s*). In this situation, the wind would rustle tree leaves and, on occasion, move smaller branches while flags flap and ripple. This category would be suitable for locations where people might sit for short periods or stand in relative comfort. The Leisurely Walking category includes wind speeds from calm up to 29*km/h* (8*m/s*). These winds would set tree limbs in motion, lift leaves, litter and dust, and the locations are suitable for activity areas. The Fast Walking category is much more tolerant of wind, including wind speeds up to 36*km/h* (10*m/s*). In this case, whole trees would sway and it would be difficult to walk. This is considered as the acceptable upper limit for comfort for the average population. The Uncomfortable category covers a broad range of wind conditions, including wind speeds above 36*km/h* (10*m/s*).

In Figure 6, the probe locations are listed along the bottom of the chart; beneath the graphical representation of the Mean Wind Speed exceeded 5% of the time. Along the right edge of the plot the comfort categories are shown. The background of the plot is lightly shaded in colours corresponding to the categories shown in Table 1. Each category represents a 2*m/s* (or more) interval. The location is rated as suitable for Sitting, Standing, Leisurely Walking or Fast Walking, if the bar extends into the corresponding interval.

The charts represent the average person's response to wind force annually and for four seasons. Effects such as wind chill and humidex (based on perception) are not considered. Also clothing is not considered, since clothing and perceived comfort varies greatly among the population. There are many variables that contribute to a person's perception of the wind environment beyond the seasonal variations presented. While people are generally more tolerant of wind during the summer months, than during the winter, due to the wind cooling effect, people become acclimatized to a particular wind environment. Persons dwelling near the shore of an ocean, large lake or open field are more tolerant of wind than someone residing in a sheltered wind environment.

4.7 Pedestrian Safety Criteria

Safety criteria are also included in the analysis to ensure that strong winds do not cause a loss of balance to individuals occupying the area. The safety criteria are based on wind speeds exceeded once per year as shown in Table 2.

Both the Comfort and Safety Criteria are based on those developed at the Allan G. Davenport Wind Engineering Group Boundary Layer Wind Tunnel Laboratory, located on the campus of The University of Western Ontario. These criteria were developed for pedestrian wind studies and are used in studies around the world.

Table 2: Safety Criteria

ACTIVITY	**Mean Wind Speed Exceeded once per year**		**Description**
SAFETY	***km/h***	***m/s*** (used in Fig. 8)	
All-Weather Areas	0 - 54	0 - 15	Areas that need to be used in all weather conditions, such as building entrances, sidewalks, etc.
Fair-Weather Areas	0 - 72	0 - 20	Areas that are not used or can be closed in severe weather, such as park benches, lookout points, etc.
Exceeding Fair Weather Areas	>72	>20	Areas that are considered to pose a serious hazard and are undesirable regardless of activity.

4.8 Pedestrian Comfort Criteria – Seasonal Variation

The level of comfort perceived by an individual is highly dependent on seasonal variations of climate. Perceived comfort is also specific to each individual, and depends on the clothing choices. The comfort criterion that is being used averages the results across the general population to remove effects of individuals and clothing choices, however, seasonal effects are important. For instance, a terrace or outdoor amenity space may have limited use during the winter season, but require acceptable comfort during the summer.

The comfort of a site is based on the “annual” results of the study, Figures 6a and 7a and 7b. In cases where seasonal comfort is important, results have been included for the seasons; winter, spring, summer, and fall (see Figures 6b to 6e and Figures 7c to 7j).

When compared to the annual average wind speed, winter winds are about 12.5% higher and summer winds are about 16% lower.

5. RESULTS

5.1 Study Site and Test Conditions

Subject Site

The proposed Development site is located at 221 Sterling Road in the City of Toronto and the subject parcel of land is currently occupied by a 2 storey building that will be removed, as indicated in Figure 2a. The site shares the immediate surrounds with low-rise residential and commercial buildings to most compass points, with a few mid to high-rise buildings to the north and south of the site.

View of the existing conditions at the 221 Sterling Road site looking northeast (Google).

The proposed Development involves redeveloping the site to include three towers that are 29, 25, and 20 storeys in height, as described below.

Tower A is located at the northern end of the site and is 29 storeys in height. The building has a 4 storey podium and a pedestrian bridge extends from the southern façade to connect to Tower B at the 5th level. The main residential lobby to Tower A is accessed via the southern façade of the building. Outdoor Amenity Space is proposed along the eastern and southern façades of the building, at-grade.

Tower B is located central to the site and is 25 storeys in height. The building has a pedestrian bridge extending from the north façade at the 5th level that connects to Tower A, and shares a 7 storey connective podium with Tower C to the south. The main residential lobby to Tower B is accessed via the east and west façades of the connective podium, with a secondary entrance along the northern façade. Outdoor Amenity Space is proposed to the east of the building at-grade, as well as atop the connective podium at the 8th level.

Tower C is located at the southern end of the site and is 20 storeys in height. The building shares a 7 storey connective podium with Tower B to the north. The main residential lobby to Tower C is accessed via the east and west façades of the connective podium. Outdoor Amenity Space is proposed to the east of the building at-grade, as well as atop the connective podium at the 8th level.

A proposed Municipal Road connecting Ruttan Street and Sterling Road to the west of the site will accommodate a private driveway that runs between Towers A and B and provides access to underground parking and a drop-off adjacent to the connective podium between Towers B and C. A Public Park area is proposed along the southwest corner of the site, fronting Sterling Road. The site plan is depicted in Figure 2b.

Surrounding Area

The property is, for all intents and purposes, surrounded to prevailing windward directions by suburban development consisting of low to high-rise residential and commercial buildings, as indicated in Figure 2a. To the immediate north of the site are three 4 storey residential buildings with a 15 storey slab-style apartment building to the immediate northeast of the site. Lands to the north of Bloor Street West are occupied by low-rise residential neighbourhoods and a 9 storey C-shaped residential building to the northeast. Lands to the immediate east of the site accommodate a townhouse block development with rail lands and a mix of low-rise commercial and residential buildings beyond. Immediately south of the site is a 2 storey warehouse-style commercial building. Lands to the south beyond are occupied by the T3 Sterling Road block development with 17, 8, and 6 storey buildings approved at Blocks 4B, 5A, and 3A, respectively, with the other blocks slated for future development. Lands to the southwest through west are occupied by low-rise residential neighbourhoods. An 18 storey building is approved to the northwest of the site, at 1405 Bloor Street West, with a 12 and 4 storey podium that extends along Ruttan Street and the proposed Municipal Road to the immediate west of the site.

In summary, suburban development mainly comprised of low to high-rise residential and commercial buildings occupy lands to all compass points relative to the subject site. The suburban landscape has mitigative effects upon the wind climate to varying degrees, providing surface roughness that reduces the wind's energy at the pedestrian level. Figures 2a and 2b depict the site and its immediate context. The site model, shown in Figure 3, is built to a scale of 1:500.

Macroclimate

For the proposed Development, the upstream wind flow during testing was conditioned to simulate an atmospheric boundary layer passing over urban terrain. The terrain within the site's immediate vicinity was incorporated into the proximity model. Historical meteorological data recorded from Billy Bishop Airport and Pearson International Airport were used in this analysis. For studies in the City of Toronto, the data is split up into four seasons, spring, summer, fall and winter, and the resulting wind roses are presented as mean velocity and percent frequency in Figures 5b-e. The mean velocities presented in the wind roses are measured at an elevation of 10m. Thus, representative ground level velocities at a height of 2m, for an urban macroclimate, are 52% of the mean values indicated on the wind rose, (for suburban and rural macroclimates the values are 63% and 78% respectively). The macroclimate for this area is suburban.

Winter (November 16 to March 31) has the highest mean velocities of the seasons with prevailing winds from the west through southwest, with significant components also from the northwest and east through northeast as indicated in Figure 5b. Spring (April 1 to June 15) has the second highest mean wind velocities with the significant prevailing winds emanating from east through northeast and west through northwest (Figure 5c). Summer (June 16 to September 15) has the lowest mean wind velocities of the seasons with prevailing winds from the east through northeast as well as west through northwest, indicated in Figure 5d. During the Fall, (September 16 to November 15) the possible directions for prevailing winds include the east through northeast as well as the northwest through southwest sector (Figure 5e). The magnitudes of the mean wind velocities are between spring and summer winds. Reported pedestrian comfort conditions generally pertain to annual conditions unless stated otherwise.

5.2 Pedestrian Level Wind Velocity Study

On the site model, forty-four (44) wind velocity measurement probes were located around the proposed Development and other buildings and activity areas to determine conditions related to comfort and safety. Figure 4 depicts probe locations at which pedestrian level wind velocity measurements were taken in the existing and proposed scenarios. For the existing setting, the proposed subject buildings were removed and the "existing" site model retested with the 2 storey building on site.

Measurements of pedestrian level mean and gust wind speeds at the various locations shown were taken over a period of time equivalent to one hour of measurements at full-scale. The mean ground level wind velocity measured is presented as a ratio of gradient wind speed, in the plots of Figure B in the Appendix, for each point in the existing and proposed scenarios. These relative wind speeds are presented as polar plots in which the radial distance for a particular wind direction represents the wind speed at the location for that wind direction, expressed as a ratio of the corresponding wind speed at gradient height. They do not assist in assessing wind comfort conditions until the probability distribution gradient wind speed and direction are applied.

The design probability distribution gradient wind speed and direction, taken from historical meteorological data for the area (see Figures 5a – 5e) was combined with pedestrian level mean and gust wind speeds measured at each point to provide predictions of the percentage of time a point will be comfortable for a given activity. These predictions of mean and maximum or "gust" wind speeds are provided on a seasonal basis in Figures 6a – 6e.

The ratings for a given location are conservative by design; when the existing surroundings and proposed buildings' fine massing details and actual landscaping are taken into consideration, the results tend toward a more comfortable site than quantitative testing alone would indicate.

Venturi action, scour action, downwash and other factors, as discussed in the Appendix on wind flow phenomena, can be associated with large buildings, depending on their orientation and configuration. These serve to increase wind velocities. Open areas within a heavily developed area may also encounter high wind velocities. Consequently, wind force effects are common in heavily built-up areas. The Development site is open to a predominantly suburban setting to prevailing and remaining compass points with winds flowing over and between mature vegetation, low to high-rise buildings and related open spaces. As such, the surroundings can be expected to influence wind at the site to varying degrees. Note: Probes are positioned at points typically subject to windy conditions in a suburban environment in order to determine the worst-case scenario.

Review of Probe Results

The probe results, as follows, were clustered into groups comprised of Public Street Conditions, Neighbouring Site Conditions, Pedestrian Entrance Conditions, Public Park Conditions, and Outdoor Amenity Space Conditions. The measurement locations are depicted in Figure 4 and are listed in Figures 6a – 6e annually and for the seasons for the existing and proposed configurations. The results are also graphically depicted for the existing and proposed configurations annually, and for the seasons in Figures 7a – 7j. The following discusses anticipated wind conditions and suitability for the points' intended use.

5.2.1 Public Street Conditions

Bloor Street West
Probes 1 through 8 were located along Bloor Street West, within the zone of influence of the proposed Development. Their locations are depicted in Figure 4, their comfort ratings are listed annually and for each of the seasons in Figures 6a – 6e and depicted in Figures 7a through 7j. Probes situated on Bloor Street West indicate annually averaged wind conditions in the existing setting that are mainly suitable for standing, with the exception of probes 4 and 6 that are rated for sitting.

The fairly comfortable conditions predicted along the street can be attributed to the surroundings. The surrounding low to high-rise residential and commercial buildings introduce turbulence into a significant portion of the prevailing wind climate, mitigating the winds on approach and resulting in generally comfortable conditions. Note: probes are typically situated in activity areas that are of interest and/or anticipated to realise windy conditions, the latter providing a conservative indication of overall pedestrian comfort conditions.

With inclusion of the proposed Development, very similar pedestrian level wind conditions will be realised along Bloor Street West, however, a realignment of winds was noted, resulting in localised changes to comfort conditions at a few locations. While the changes were subtle, probes 4 and 6 realised sufficient upsets in winds to change the annual comfort ratings from sitting to standing. In the spring months, probe 2 realised increases in winds from northeasterly through easterly directions that changed the spring rating from standing to leisurely walking.

The above noted can be attributed to the proposed Development causing a realignment of winds that reduces apparent wind effects at the pedestrian level for several points for several wind directions, but causes an increase in winds for others, as indicated in the Appendices Figure B, Ground Level Wind Velocity Plots presented as a ratio of gradient wind velocity. Subtle increases in winds can be attributed to the proposed Development redirecting winds to flow along portions of Bloor Street West, while improvements can be attributed to the proposed Development providing blockage to locations along Bloor Street West for winds from specific directions.

The mostly subtle changes to wind conditions are a reasonable expectation understanding Bloor Street West is windward of the proposed Development to much of the prevailing wind climate. While the proposed Development involves a substantial change to the site, it is a minor change to the streetscape and employs an overall wind mitigative design. As such, the probe locations along Bloor Street West, with the above noted exceptions, retained their original annual pedestrian comfort ratings. The street remains suitable for its intended purpose and consideration of existing and proposed building elements that are too fine to incorporate into the model, and landscaping, will result in more comfortable conditions than those reported.

Bloor Street West falls within the pedestrian level wind velocity safety criteria as an All-Weather Area, as described in Section 4.7 and depicted in Figure 9.

Sterling Road

Probes 9 through 12 and 19 were located along Sterling Road, to the west of the proposed Development. The probes were mainly rated as annually suitable for sitting in the existing setting, with probes 12 and 19 realising conditions suitable for standing. The comfortable conditions along Sterling Road can be attributed to the low-rise surroundings that provide a coarse terrain to approaching winds, directing much of the wind climate to flow above the pedestrian level. Probes 12 and 19 are located along more open areas of Sterling Road that are exposed to larger portions of the wind climate, resulting in windier conditions.

With inclusion of the proposed Development, a realignment of winds was noted along portions of Sterling Road, however the changes were subtle and insufficient to change the majority of the annual comfort ratings. The above-noted can be attributed to the proposed development causing a realignment of winds that reduces apparent wind effects for several wind directions, but causes an increase to winds for others.

Probe 19 realised a sufficient increase in winds with inclusion of the proposed Development to change the annual rating from standing to leisurely walking. This can be attributed to easterly and westerly winds that formerly flowed over the low-rise site being redirected by the proposed towers to flow around the Development and ultimately along the façades of the low-rise building to the south.

The remaining points along Sterling Road retained their annual comfort ratings and the street remains comfortable and appropriate to the sidewalk's intended purpose. Consideration of design and landscape elements that were too fine to include in the massing model will result in more comfortable conditions than those reported.

With inclusion of the proposed Development, Sterling Road remains within the pedestrian level wind velocity safety criteria as an All-Weather Area, as described in Section 4.7 and depicted in Figure 9.

Ruttan Street

Probes 13 and 20 were situated along Ruttan Street, to the northwest of the proposed Development site. In the existing setting, probe 13 realises conditions annually suitable for standing, while probe 20 is annually rated for leisurely walking. The windy conditions at probe 20 can be attributed to the area being exposed to dominant winds from the northwest that are directed to flow around the adjacent 18 storey building at 1405 Bloor Street West and over the area.

With inclusion of the proposed Development, Ruttan Street realises an increase in winds from easterly and southwesterly directions, resulting in an upset in comfort conditions. Probe 13 becomes annually suitable for leisurely walking and probe 20 becomes annually suitable for fast walking. Consideration of design and landscape elements that were too fine to include in the massing model will result in more comfortable conditions than those reported.

Ruttan Street remains comfortable and suitable for the intended uses, year-round. In the existing setting, probe 20 falls within safety criteria as a Fair-Weather Area, but with inclusion of the proposed Development, it improves to an All-Weather Area. As such, both probes situated along Ruttan Street fall within the pedestrian level safety criteria as All-Weather Areas.

Proposed Municipal Road

A Municipal Road is proposed extending from Ruttan Street and connecting to Sterling Road to the west of the Development site, as represented by probes 14 to 17 and 21 to 23. In the existing setting, the probes are located within a parking lot and are rated suitable for standing annually.

With inclusion of the proposed Development, the probes along the proposed Municipal Road will be located within a narrow gap between the proposed Development and the neighbouring building at 1405 Bloor Street West. As such, the area realises a moderate increase in winds as winds are redirected to flow down and around the proposed buildings and through the gap along the proposed Municipal Road. Probes 15, 16, 17, and 21 realise sufficient upsets in wind conditions to change the annual comfort ratings from standing to leisurely walking. Probe 14 similarly realises increases in winds that change the annual rating to fast walking.

The remaining probes along the proposed Municipal Road, located adjacent to the western façades of the proposed buildings retain annual ratings of standing. Through the summer months, the proposed road realises more comfortable conditions that are suitable for standing, with the exception of probe 14 that is rated for leisurely walking. The proposed Municipal Road realises conditions that remain suitable for the intended use, year-round, and will experience more comfortable conditions with consideration of fine design and landscape elements.

The proposed Municipal Road remains within the safety criteria as an All-Weather Area, with the exception of probe 14 that becomes a Fair-Weather Area in the proposed setting. The rating for probe 14 is near the transition to an All-Weather Area, and with consideration of fine design and landscape elements, is expected to be suitable as such.

Merchant Lane

Probes 28, 31, 33, and 36 were situated along Merchant Lane to the north and east of the proposed Development. In the existing setting, probes 28 and 36 located to the north of the Development site were rated annually suitable for standing, and probes 31 and 33, located to the east of the Development site, were rated annually suitable for sitting.

With inclusion of the proposed Development, winds that formerly flowed over the low-rise site, will be redirected to flow down and around the facades of the proposed buildings, and ultimately over portions of Merchant Lane. The result is moderate changes to the comfort conditions along the northern portion of the street, sufficient to change the annual ratings at probes 28 and 36 from standing to leisurely walking. The areas to the east of the proposed Development realise subtle changes in wind conditions, however they are relatively well sheltered by the adjacent townhouse blocks and as such retain the annual ratings of sitting.

Merchant Lane remains comfortable and suitable for the intended use, and consideration of design and landscape elements that were too fine to include in the massing model will result in more comfortable conditions than those reported. The street remains within the safety criteria as an All-Weather Area.

5.2.2 Neighbouring Site Conditions

Probes 26 and 27 were located within the spaces between the neighbouring 4 storey residential buildings to the immediate north of the Development site. In the existing setting, the area realises conditions suitable for standing year-round, with the exception of probe 27 that is rated suitable for leisurely walking in the winter months. The area is well protected from the surrounding low-rise residential buildings, and as such the proposed setting realises very similar conditions, suitable for standing, year-round. The area remains comfortable and suitable for the intended use.

Probes 29, 30, and 32 were similarly located within spaces between the neighbouring townhouse blocks to the immediate east of the Development site. In the existing setting, the areas realise varied conditions, with annual ratings of sitting and standing at probes 30 and 32, respectively, and windier conditions at probe 29 that are rated for leisurely walking, annually. Probe 29 realises windier conditions as the orientation of the adjacent townhouse blocks leaves the area exposed to easterly and westerly winds that are directed to flow through the gap between the buildings. With inclusion of the proposed Development, the probes realise relatively subtle changes in winds from various directions and as such the probes all become suitable for standing, annually. The improvements can be attributed to the proposed Development providing blockage to winds from specific directions and increases in winds can be attributed to the proposed Development redirecting portions of the wind climate to flow down and around the buildings and over the neighbouring areas. The areas remain comfortable and suitable for the intended use, year-round.

Probes 34 and 35 were situated to the west and east of the neighbouring 15 storey apartment building at 1369 Bloor Street West, respectively. In the existing setting, the probes are well protected from the majority of the wind climate by the surrounds, and as such realise conditions that are rated suitable for standing, annually. With inclusion of the proposed Development, the probes realise subtle changes in wind conditions, however the areas retain the original comfort ratings of standing. The areas remain comfortable and suitable for the intended use, year-round.

The aforementioned neighbouring areas realise relatively similar conditions in the existing and proposed scenarios and remain comfortable and suitable for the intended uses year-round. Consideration of fine design and landscape features will result in more comfortable conditions than reported. The instrumented neighbouring sites remain within the pedestrian level wind velocity safety criteria as All-Weather Areas.

5.2.3 Pedestrian Entrance Conditions

Probe 37 was situated adjacent to the Main Entrance to the Residential Lobby of Tower A, and probe 38 was similarly located adjacent to a secondary entrance to the Residential Lobby of Tower B. The area is well sheltered by the proposed Development to winds emanating from the north, however the entrances are located within a gap between Towers A and B and as such are exposed to large portions of the wind climate that are directed to flow through the gap. This results in exacerbated winds from westerly through southwesterly and easterly directions, causing conditions that are rated suitable for leisurely walking in the summer, fast walking in the shoulder months, and uncomfortable conditions through the winter. The entrances will not be suitable for the intended use, and it is recommended they be removed from the gap between buildings, if possible. As an alternate, the wind conditions at the entrances may be mitigated by recessing the entrances well into the façades of the building, as well as adding significant mitigation to the area, in the form of wind screens, fencing, coniferous trees/shrubs, and others, situated to the east and west of the gap. Consideration of an appropriate mitigation plan for the area will result in conditions at the entrances that are suitable for the intended uses.

Probes 24 and 40 were situated along the western and eastern façades of the connective podium between Towers B and C, adjacent to the Main Entrances to the Residential Lobby. Both entrances are well protected from the majority of the wind climate by the proposed Development and surrounds and as such realise comfortable conditions. The western entrance is rated suitable for sitting year-round, while the eastern entrance is rated for sitting in the summer and standing through the remainder of the year. As such, the entrances will be comfortable and suitable for the intended uses, year-round.

Wind conditions comfortable for standing are preferable at building entrances, while conditions suitable for walking are suitable for walkways. Consideration of existing and proposed surface roughness features too fine to incorporate into the massing model will further improve the comfort ratings at the proposed entrances. The Main Entrances to the Residential Lobby between Towers B and C will be comfortable for the intended uses, however the Entrances to Towers A and B located in the gap between Towers A and B will require mitigation in order to achieve appropriate conditions.

The Main Entrances to the Residential Lobby between Towers B and C fall within the pedestrian level wind velocity safety criteria as All-Weather Areas. The Entrances to Towers A and B that are located in the gap between the buildings are rated as Fair-Weather Areas. Consideration of an appropriate mitigation plan for the areas will result in conditions that are suitable as All-Weather Areas.

5.2.4 Public Park Conditions

A Public Park is proposed in the southwest corner of the site fronting Sterling Road, as represented by probes 18 and 25. The area is well protected from large portions of the wind climate by the proposed Development and surrounds, however it is exposed to portions of the wind climate emanating from westerly and northerly directions. The area is predicted suitable for leisurely walking in the winter and standing through the remainder of the year. If lower activity levels are desired in the Public Park throughout the year, a mitigation plan is recommended for the area. The plan may include fencing, wind screens, berms, coniferous trees/shrubs, raised planters, trellises, and others, situated about the space as practical. Consideration of an appropriate mitigation plan for the space will result in more comfortable conditions that are suitable for sitting or standing throughout the year.

The Public Park falls within the pedestrian level wind velocity safety criteria as an All-Weather Area.

5.2.5 Outdoor Amenity Space Conditions

Outdoor Amenity Spaces are proposed for various areas throughout the site, at-grade. Probes 36 and 37 are located within at-grade Outdoor Amenity Spaces surrounding Tower A, along the east and south façades, respectively. The area along the eastern façade of Tower A is exposed to much of the dominant northerly and westerly wind climate that is directed to flow down and around the proposed and neighbouring buildings to the east and through the gap between. This results in relatively windy conditions in the area, suitable for standing in the summer and leisurely walking through the remainder of the year. In order to achieve more comfortable conditions, it is recommended a mitigation plan be developed for the space, including fencing, wind screens, coniferous trees/shrubs, raised planters, and others, situated along the northern and southern portions of the space, adjacent to building corners. The area along the southern façade of the building is similarly exposed to large portions of the wind climate that are directed to flow through the gap between Tower A and Tower B. A mitigation plan, similar to that recommended for the adjacent building entrance and discussed above, is recommended for the space. This may include wind screens, fencing, coniferous trees/shrubs, and others, situated to the east and west of the gap between buildings. With consideration of appropriate mitigation plans for the spaces, the Outdoor Amenity Areas around Tower A will realise more comfortable conditions that are seasonally suitable for the intended use.

Probe 39 is located within an at-grade Outdoor Amenity Space to the east of Tower B. The area is protected from much of the dominant wind climate, however it is exposed to winds flowing down and around the proposed Development and through the gap between Tower B and the buildings to the east. The area realises conditions suitable for sitting in the summer and standing through the remainder of the year. A mitigation plan, including wind screens, fencing, coniferous trees/shrubs, and others, situated about the space will result in more comfortable conditions that are suitable for sitting throughout the shoulder seasons.

Probe 41 is located adjacent to an at-grade Outdoor Amenity Space to the southeast of Tower C. The area is susceptible to much of the easterly and westerly wind climate that is directed to flow down and around Tower C and through the gap between the proposed Development and the neighbouring building to the south. As such, the area realises windy conditions that are rated for standing in the summer, leisurely walking in the winter and fall, and fast walking in the spring months. In order to achieve more comfortable conditions, it is recommended a mitigation plan be developed for the space, including fencing, wind screens, coniferous trees/shrubs, raised planters, and others, situated about the space as practical, specifically adjacent to building corners. Consideration of an appropriate mitigation plan for the space will result in more comfortable conditions that are seasonally suitable for the intended use.

A Rooftop Amenity Space is proposed atop the connective podium between Towers B and C at the 8^{th} level, as represented by probes 42, 43, and 44. The area is exposed to much of the dominant wind climate emanating from westerly directions that is directed to flow down and around Towers B and C and through the gap between. As such, probe 42 located adjacent to Tower B, realises conditions suitable for fast walking in the summer and uncomfortable conditions in the shoulder seasons. Probe 43 realises leisurely walking conditions in the summer and fast walking conditions in the shoulder seasons, and probe 44 is rated for standing in the summer and shoulder seasons. A mitigation plan is required for the space in order to achieve conditions that are appropriate for the intended use. The plan should be designed with input from the consultant and may include 2.2m high perimeter wind screens, trellises, raised planters with coarse plantings, and others, situated about the space as practical. Consideration of an appropriate mitigation plan for the space will result in more comfortable conditions that are seasonally suitable for the intended use.

The at-grade and Rooftop Amenity Spaces proposed around the site are predicted to realise windy conditions, and mitigation plans are recommended for the areas. With incorporation of appropriate mitigation plans as discussed above, the Outdoor Amenity Spaces are predicted to realise more comfortable conditions that are seasonally suitable for the intended uses.

The at-grade Outdoor Amenity Spaces fall within the pedestrian level wind velocity safety criteria as All-Weather Areas, with the exception of probe 37 which is a Fair-Weather Area. The Rooftop Amenity Space realises windier conditions and probes 42 and 43 are rated as Exceeding Fair-Weather Areas. These ratings are near the transition to Fair-Weather Areas and with consideration of an appropriate mitigation plan for the spaces, as discussed above, the area is expected to be suitable as an All-Weather Area.

5.3 Summary

The observed wind velocity and flow patterns at the proposed Development are largely influenced by approach wind characteristics that are dictated by the suburban surrounding areas. These surroundings moderate wind flow in streamlines near the pedestrian level, resulting in generally comfortable conditions with localised windy conditions proximate to building corners and gaps between significant buildings. Historical weather data recorded at Billy Bishop Airport and Pearson International Airport indicates that strong winds of a mean wind speed greater than 30 km/h occur approximately 16 percent of the time during the winter months and 4 percent of the time during the summer.

Once the subject site is developed, ground level winds at some locations will improve, with localized areas of higher pedestrian level winds, resulting in wind conditions that are predicted as windy at times, but remain mainly comfortable and appropriate to the areas' intended purpose throughout the year. The relationship between surface roughness and wind is discussed in the Appendix and shown graphically in Figure A of the same section.

As such, the site and surrounds are predicted mainly suitable for sitting, standing, or leisurely walking under normal wind conditions annually; however, under high ambient winter wind conditions with winds emanating from specific directions, localised gaps between the proposed Development's towers and neighbouring buildings will be windy from time to time, but remain appropriate to the intended purpose much of the time.

Additional mitigation is required for the Entrances to Towers A and B located in the gap between the buildings in order to achieve conditions that are suitable for the intended uses. Mitigation plans are also recommended for the Public Park and various at-grade and rooftop Outdoor Amenity Spaces in order to achieve conditions that are seasonally appropriate for the uses.

The consideration of proposed surface roughness will result in conditions more comfortable than those reported herein. The site will realise conditions suitable to a typical suburban context.

6. FIGURES:

Figure 1: Laboratory Testing Facility

Figure 2a: Site Aerial Photo

Figure 2b: Site Plan

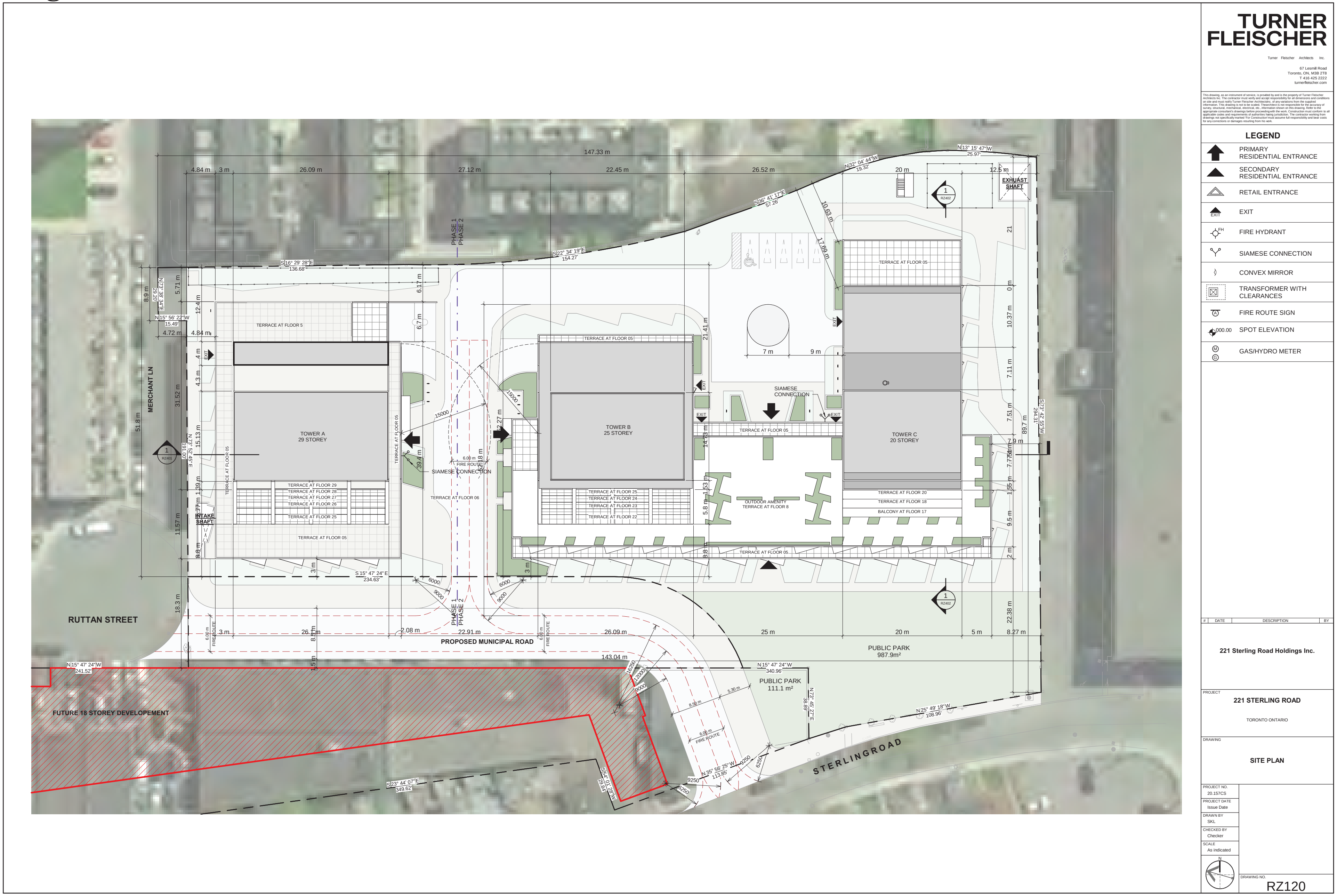
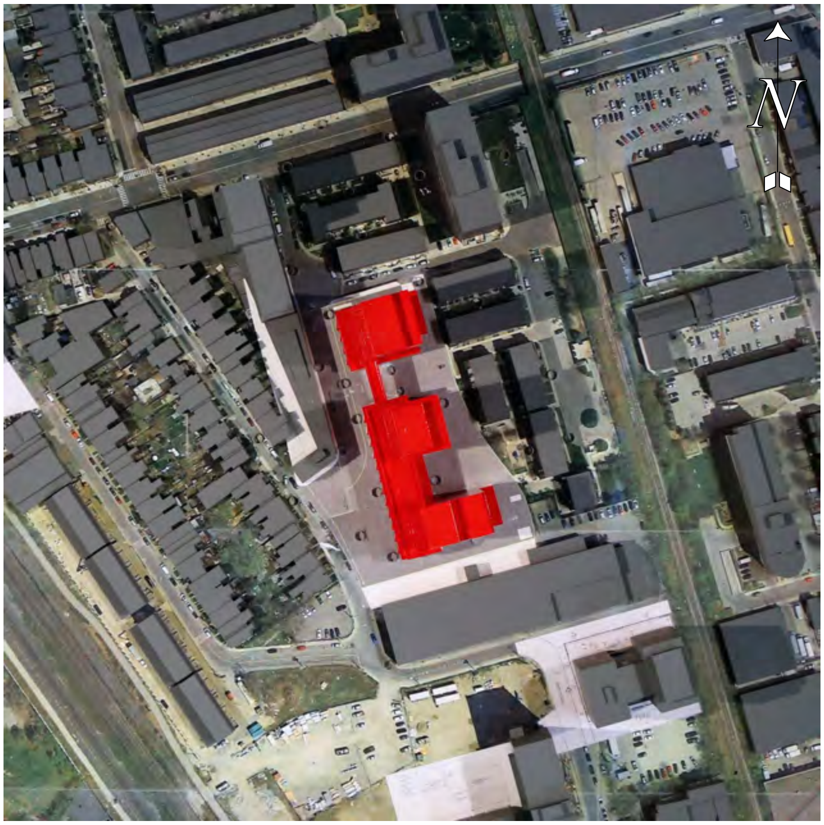
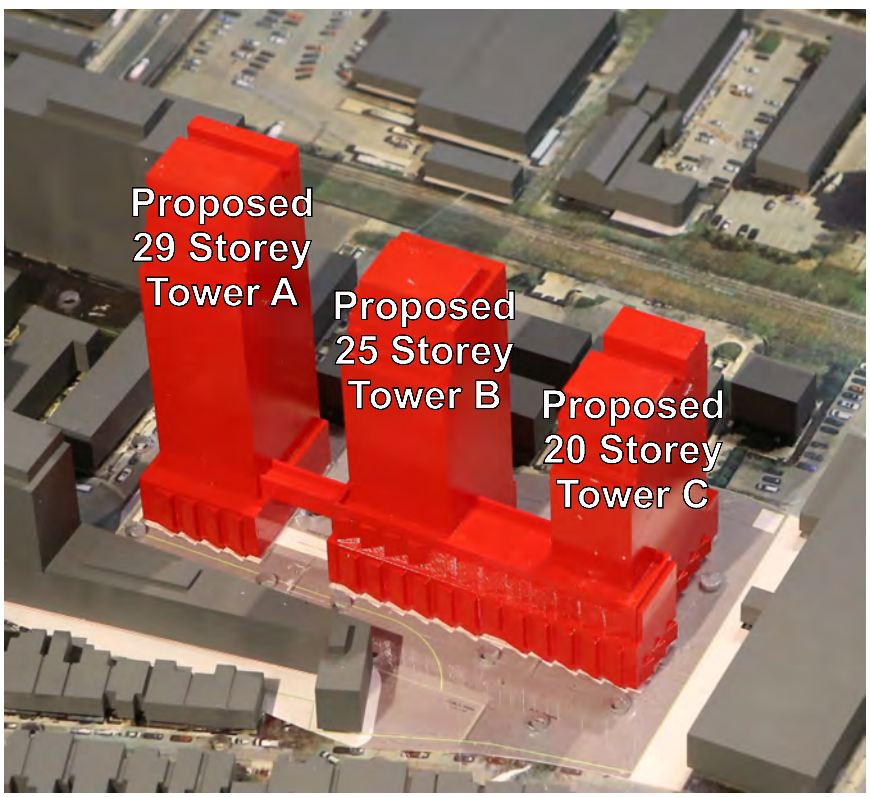


Figure 3: 1:500 Scale model of test site



a) Overall view of model - Proposed Site



b) Close-up view of model - Proposed Site

Figure 4: Location plan for pedestrian level wind velocity measurements.

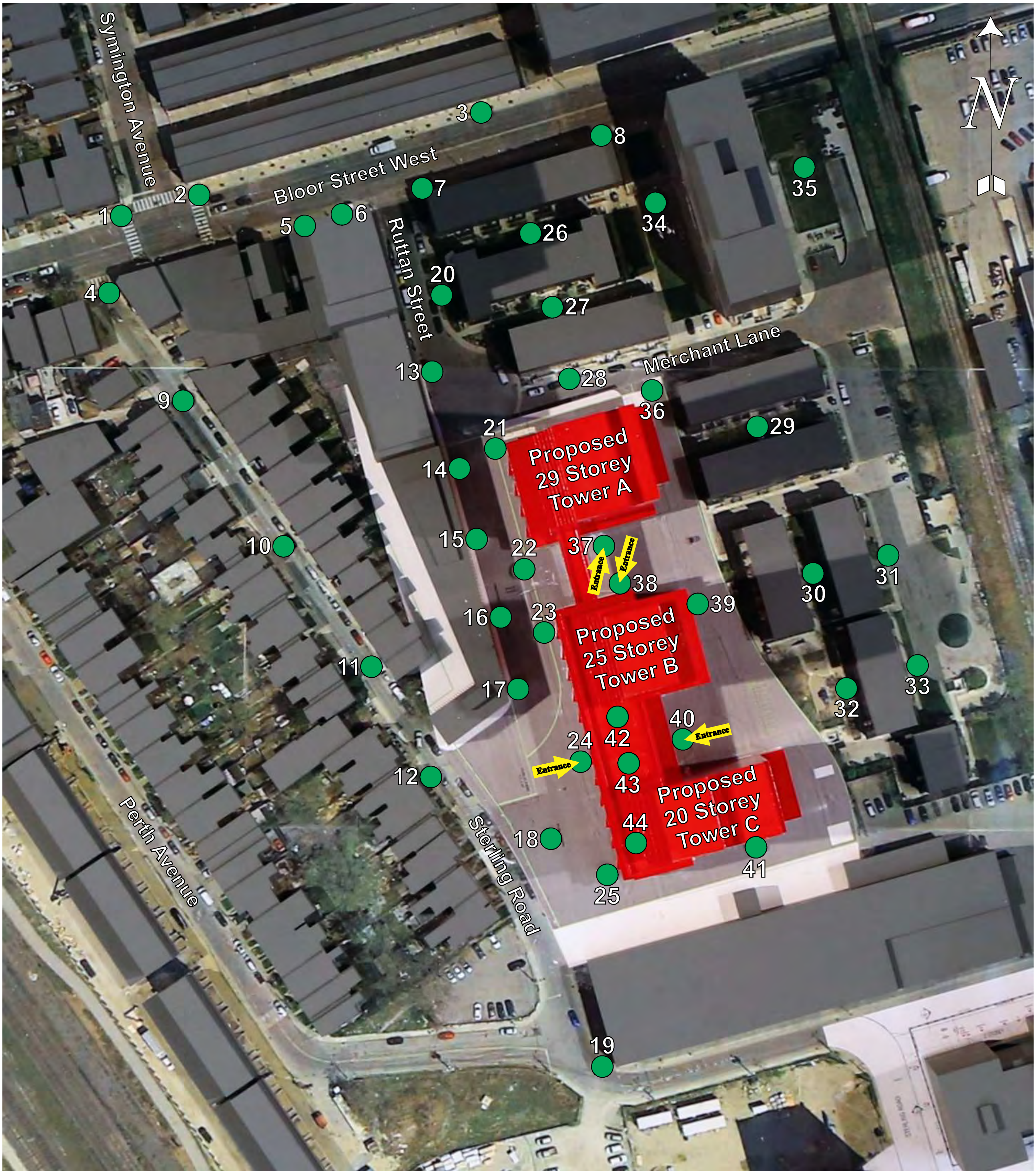
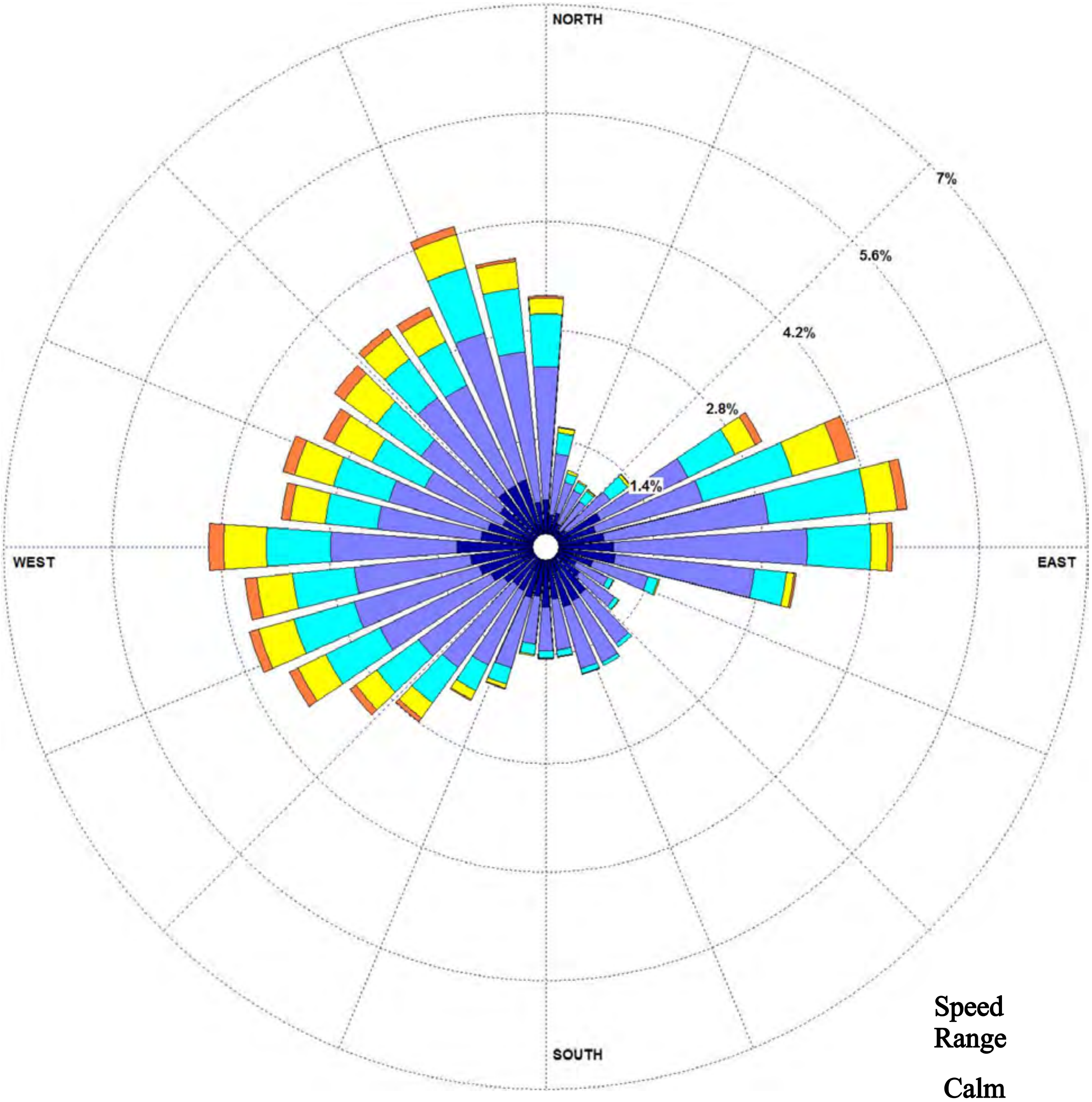


Figure 5a: Annual Wind Rose - Pearson International Airport & Billy Bishop Toronto City Airport - Combined.

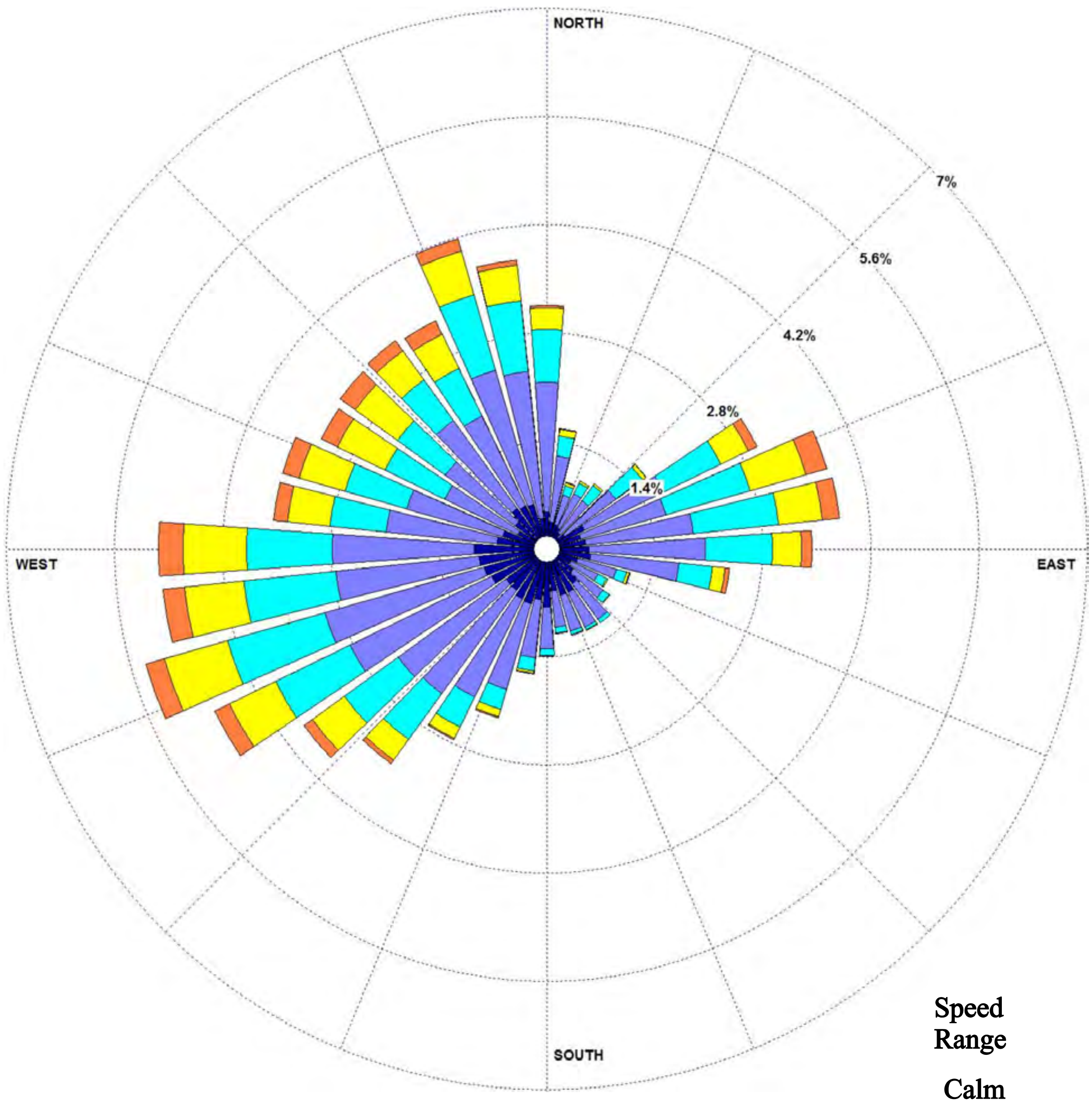
Historical Directional Distribution of Winds (@ 10*m* height)
(1980 - 2018)



Speed Range	Probability (%)
Calm	4%
1 - 10*km/h*	25%
11 - 20*km/h*	43%
21 - 30*km/h*	18%
31 - 40*km/h*	8%
> 40*km/h*	2%

Figure 5b: Winter Wind Rose - Pearson International Airport & Billy Bishop Toronto City Airport - Combined.

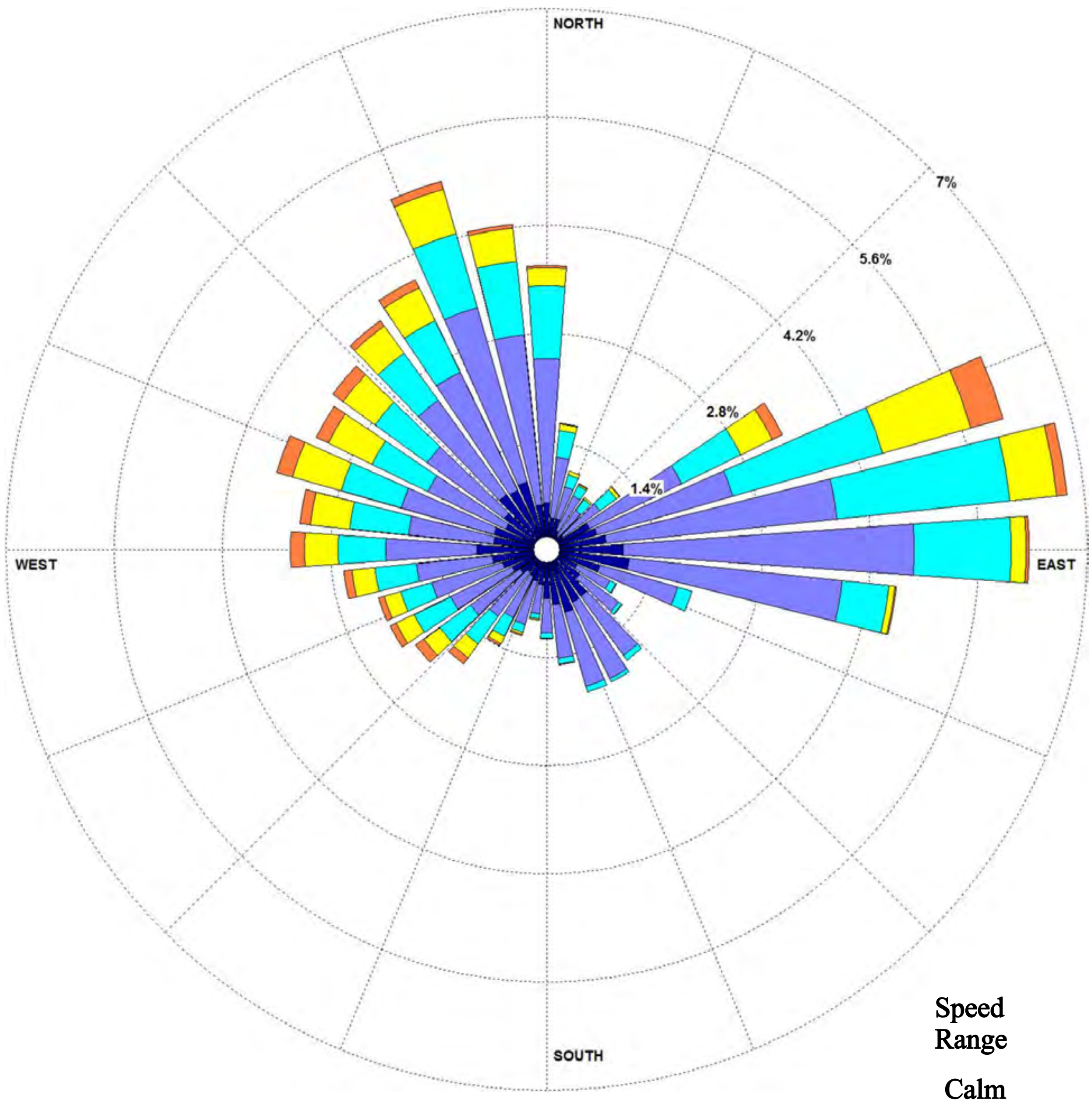
Historical Directional Distribution of Winds (@ 10*m* height)
November 16 through March 31 (1980 - 2018)



Speed Range	Probability (%)
Calm	3%
1 - 10*km/h*	20%
11 - 20*km/h*	41%
21 - 30*km/h*	20%
31 - 40*km/h*	12%
> 40*km/h*	4%

Figure 5c: Spring Wind Rose - Pearson International Airport & Billy Bishop Toronto City Airport - Combined.

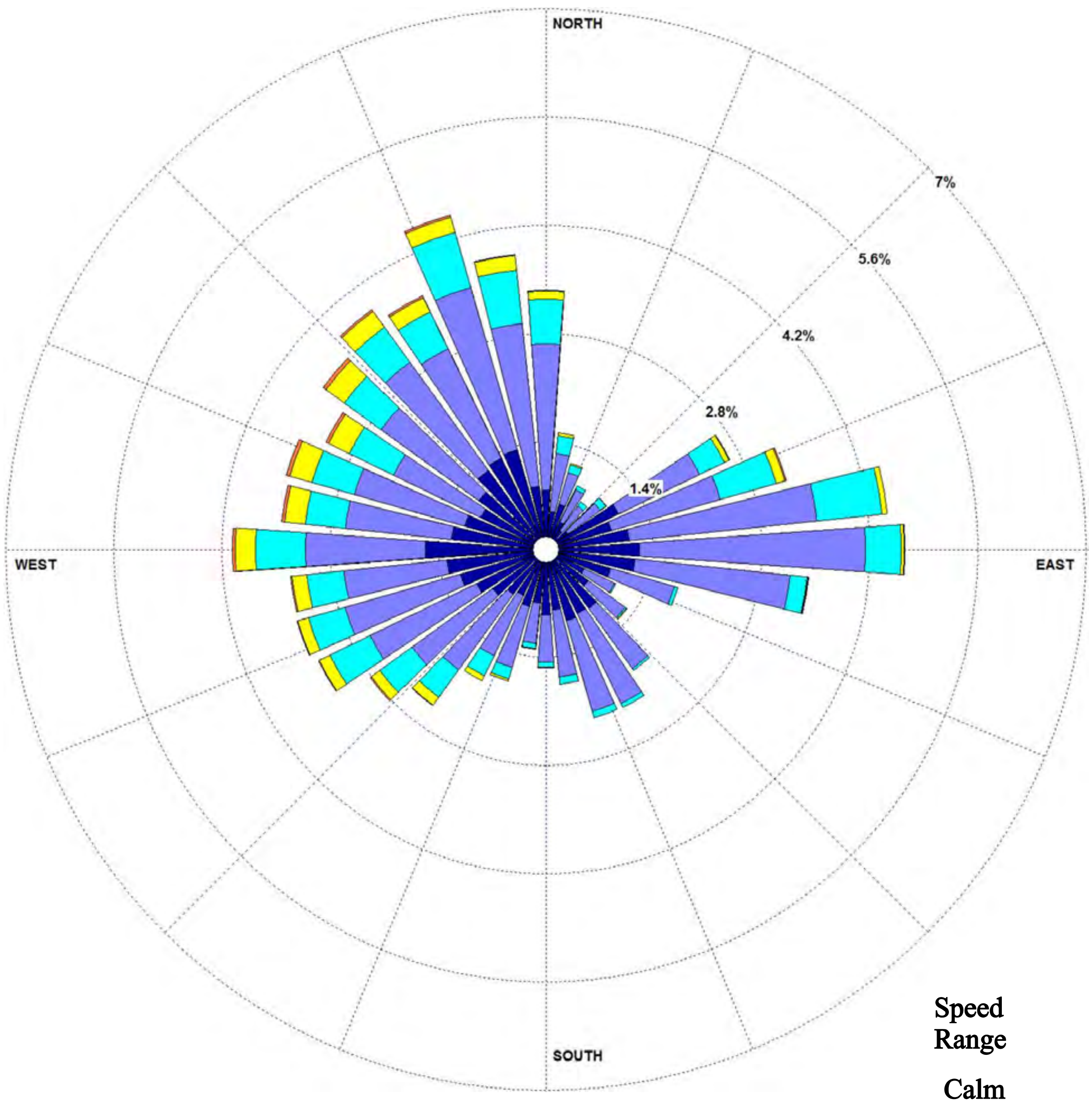
Historical Directional Distribution of Winds (@ 10*m* height)
April 1 through June 15 (1980 - 2018)



Speed Range	Probability (%)
Calm	3%
1 - 10*km/h*	22%
11 - 20*km/h*	43%
21 - 30*km/h*	20%
31 - 40*km/h*	9%
> 40*km/h*	3%

Figure 5d: Summer Wind Rose - Pearson International Airport & Billy Bishop Toronto City Airport - Combined.

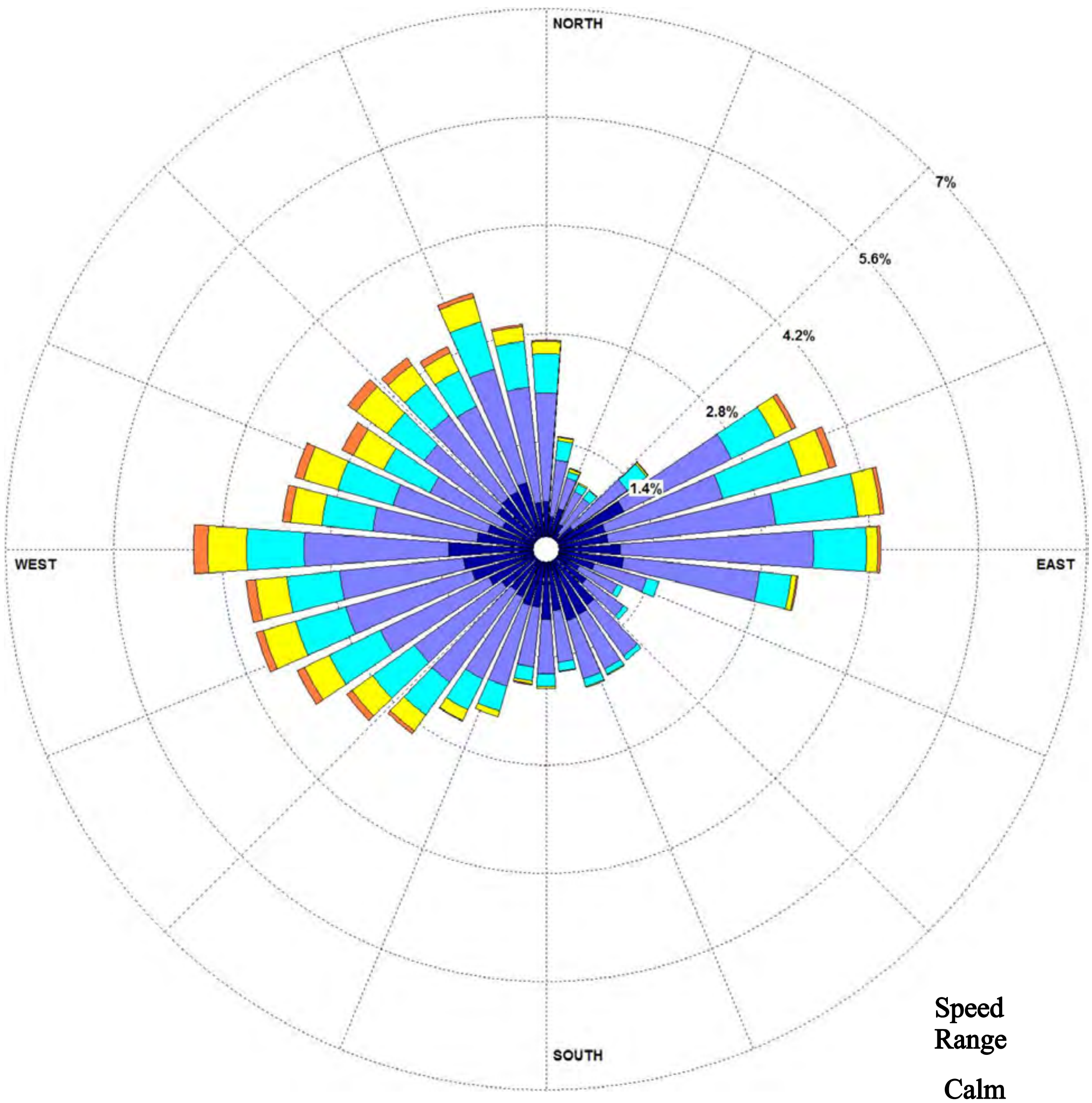
Historical Directional Distribution of Winds (@ 10*m* height)
June 16 through September 15 (1980 - 2018)



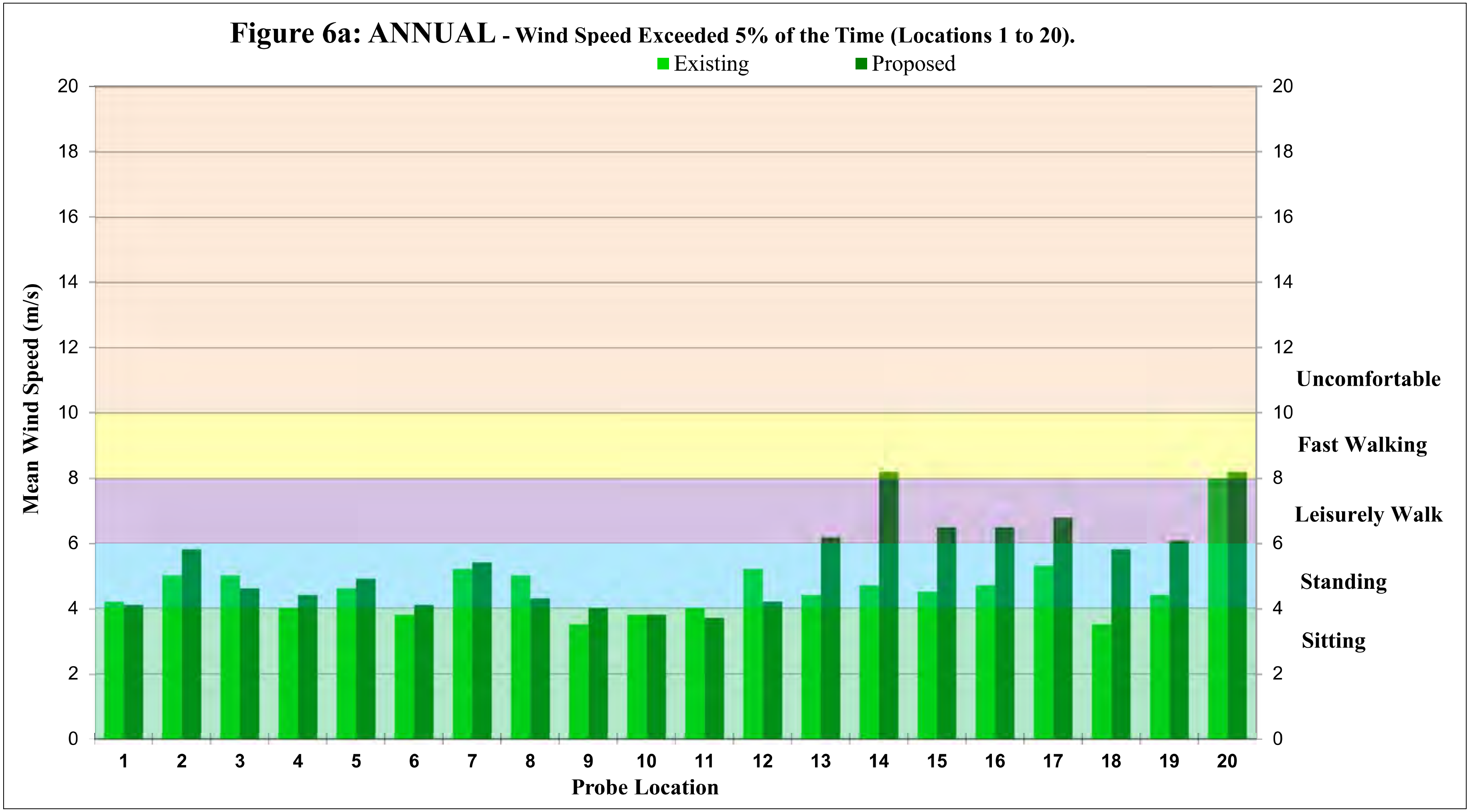
Speed Range	Probability (%)
Calm	5%
1 - 10*km/h*	33%
11 - 20*km/h*	45%
21 - 30*km/h*	13%
31 - 40*km/h*	4%
> 40*km/h*	<1%

Figure 5e: Fall Wind Rose - Pearson International Airport & Billy Bishop Toronto City Airport - Combined.

Historical Directional Distribution of Winds (@ 10*m* height)
September 16 through November 15 (1980 - 2018)



Speed Range	Probability (%)
Calm	5%
1 - 10*km/h*	28%
11 - 20*km/h*	42%
21 - 30*km/h*	16%
31 - 40*km/h*	7%
> 40*km/h*	2%



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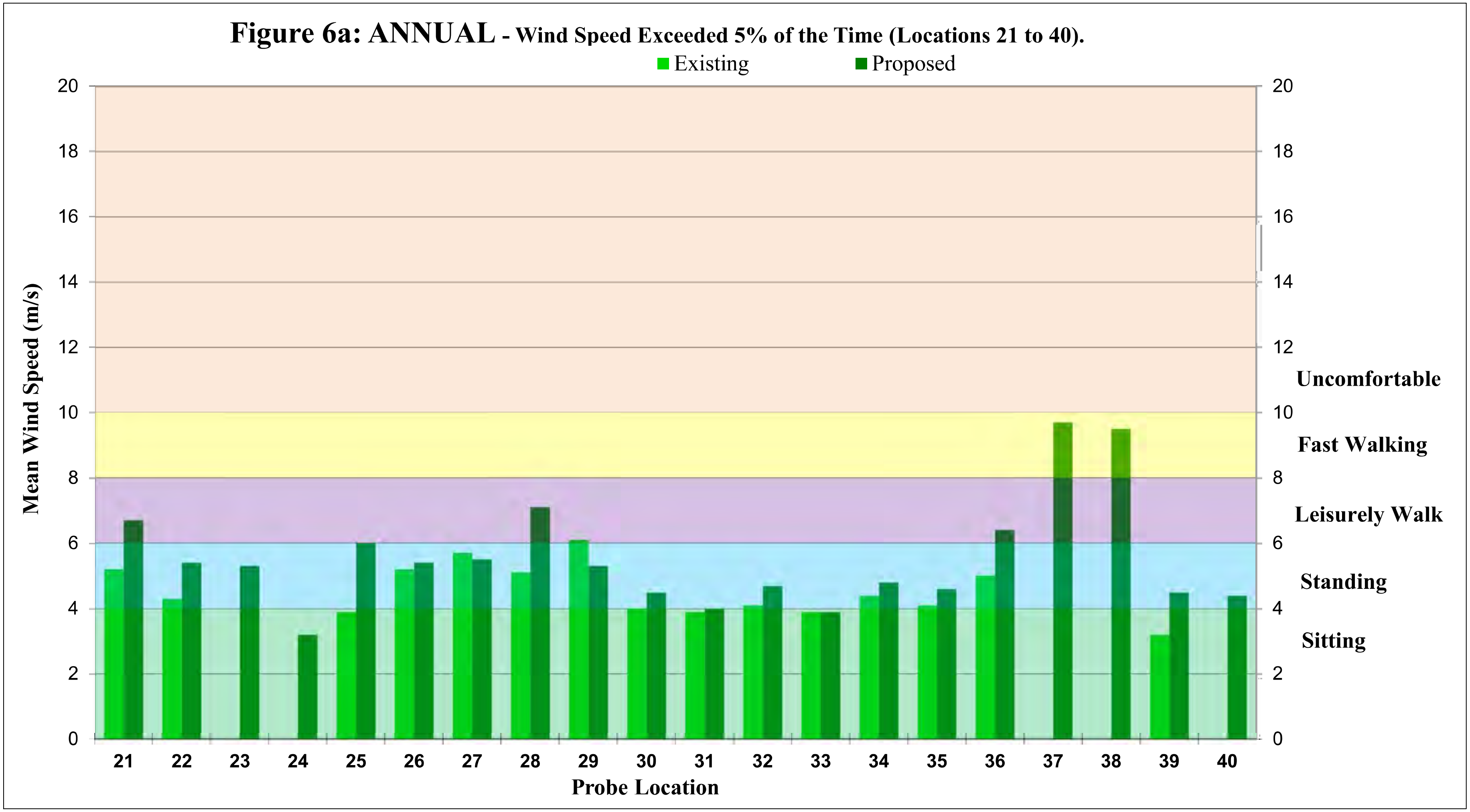


Figure 6a: ANNUAL - Wind Speed Exceeded 5% of the Time (Locations 21 to 40).
Existing
Proposed
Mean Wind Speed (m/s)
Probe Location
Uncomfortable
Fast Walking
Leisurely Walk
Standing
Sitting

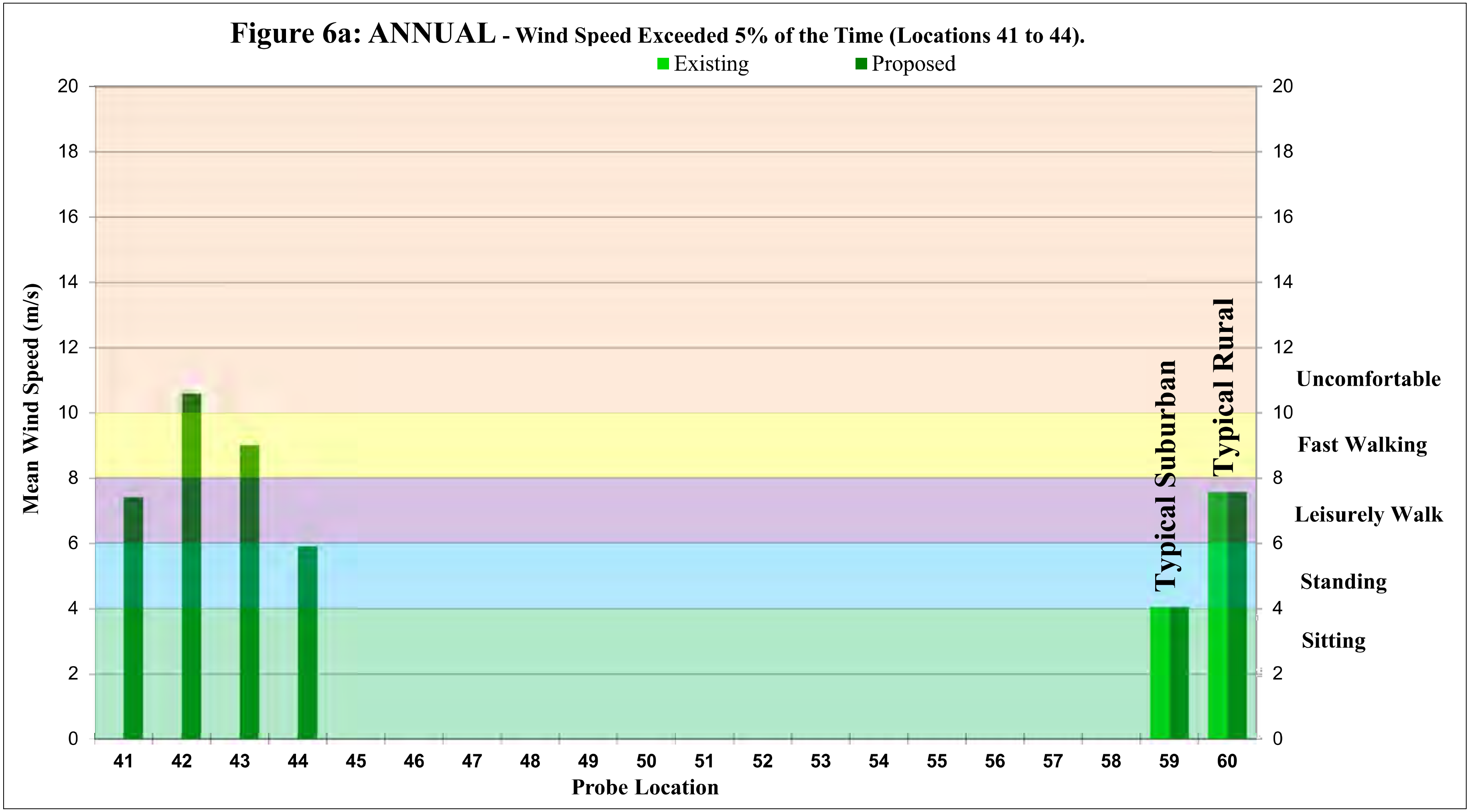
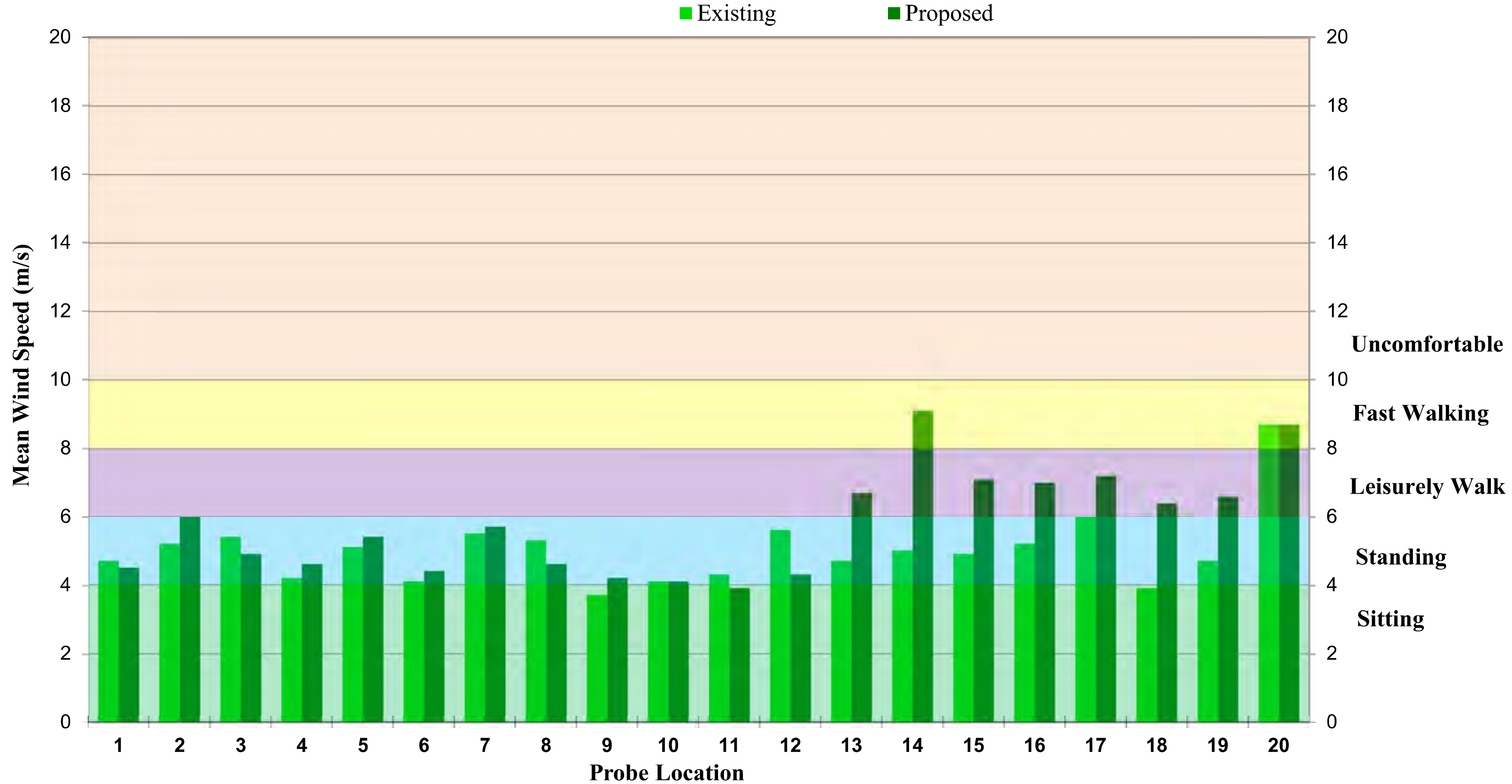


Figure 6a: ANNUAL - Wind Speed Exceeded 5% of the Time (Locations 41 to 44).
Existing
Proposed
Mean Wind Speed (m/s)
Probe Location
Typical Suburban
Typical Rural
Uncomfortable
Fast Walking
Leisurely Walk
Standing
Sitting

Figure 6b: WINTER - Wind Speed Exceeded 5% of the Time (Locations 1 to 20).



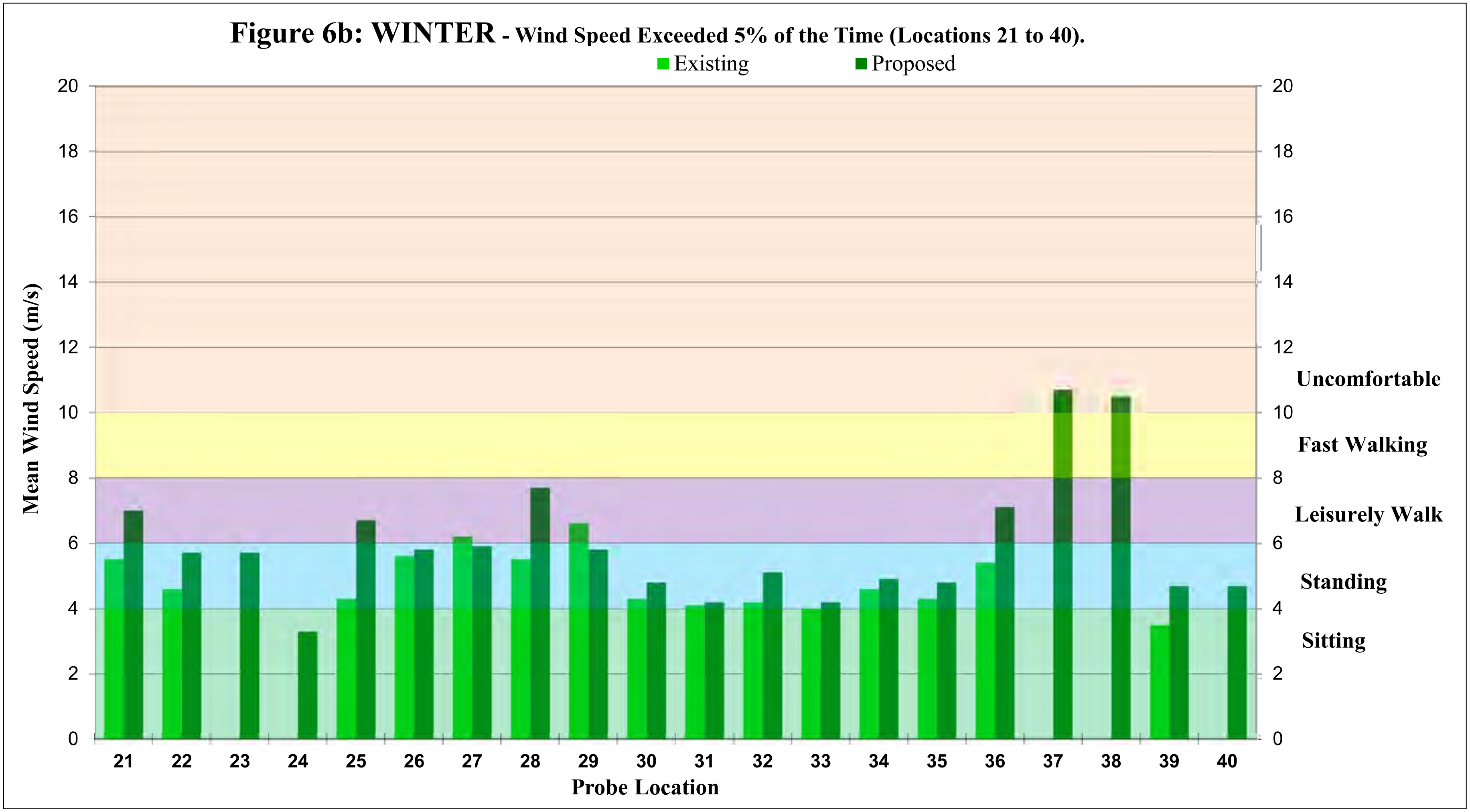


Figure 6b: WINTER - Wind Speed Exceeded 5% of the Time (Locations 21 to 40).
Existing
Proposed
Mean Wind Speed (m/s)
Probe Location
Uncomfortable
Fast Walking
Leisurely Walk
Standing
Sitting
0
2
4
6
8
10
12
14
16
18
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40

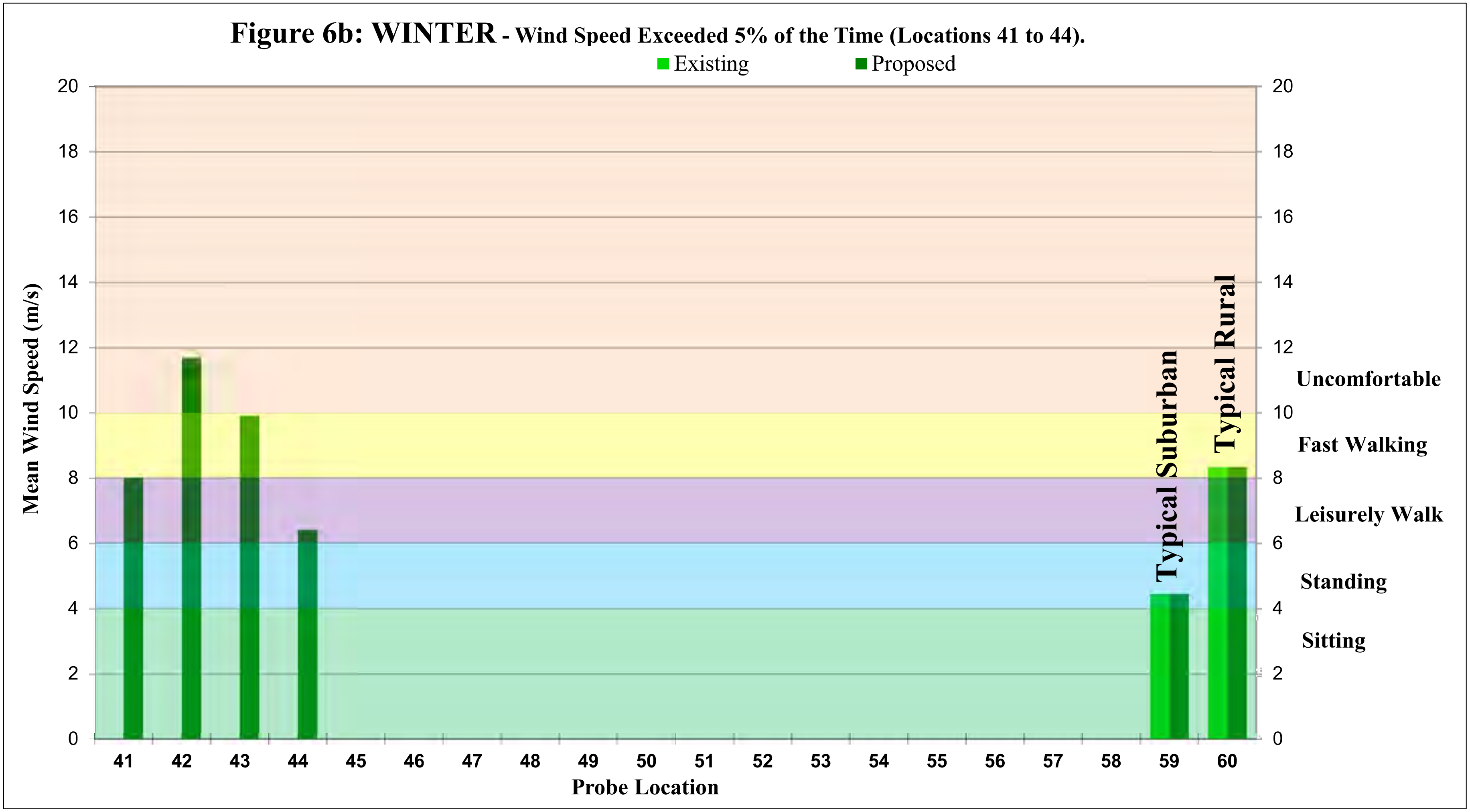


Figure 6b: WINTER - Wind Speed Exceeded 5% of the Time (Locations 41 to 44).
Existing
Proposed
Mean Wind Speed (m/s)
Probe Location
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
0
2
4
6
8
10
12
14
16
18
20
Typical Suburban
Typical Rural
Uncomfortable
Fast Walking
Leisurely Walk
Standing
Sitting

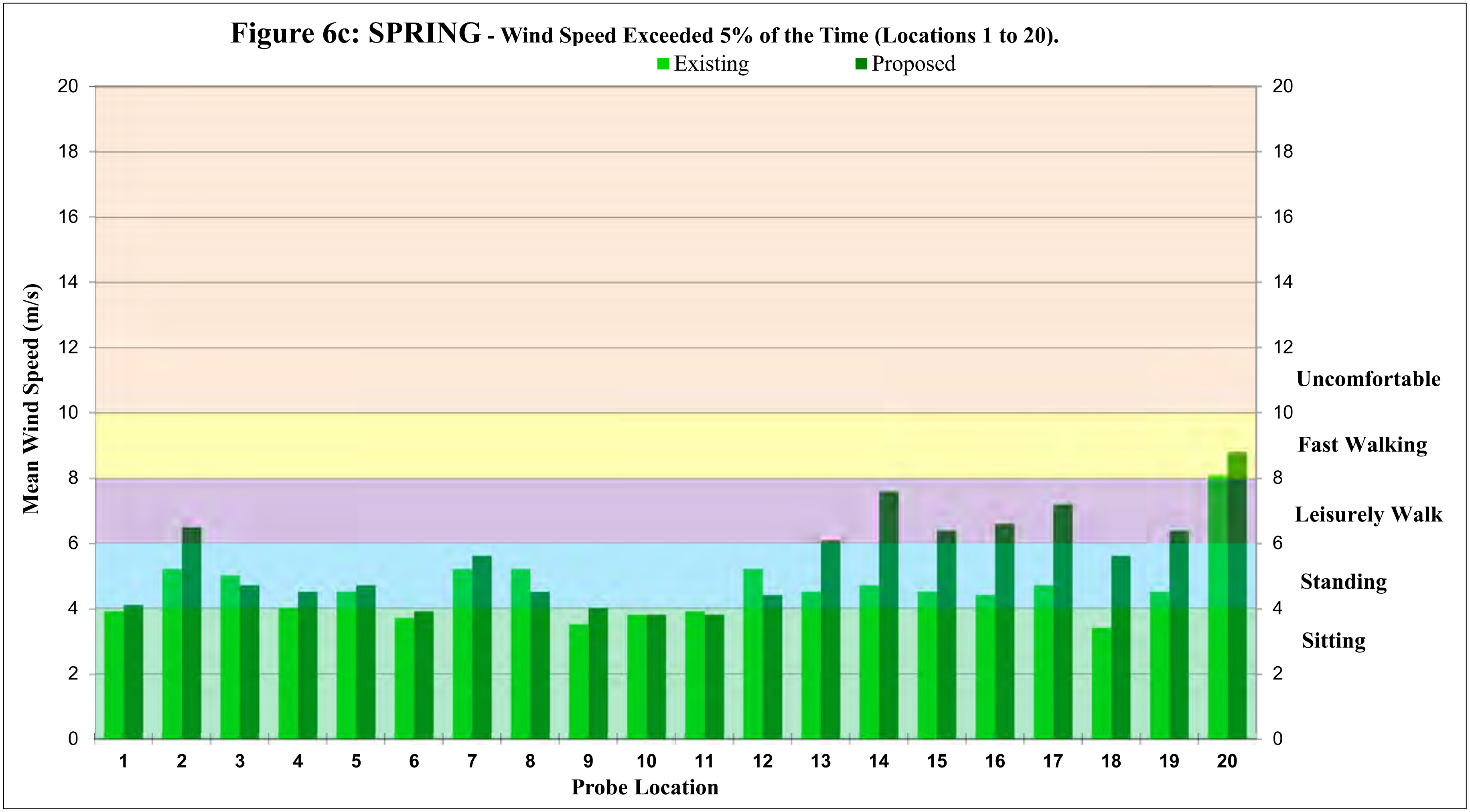


Figure 6c: SPRING - Wind Speed Exceeded 5% of the Time (Locations 1 to 20).
Existing
Proposed
Mean Wind Speed (m/s)
Probe Location
Uncomfortable
Fast Walking
Leisurely Walk
Standing
Sitting
0
2
4
6
8
10
12
14
16
18
20
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20

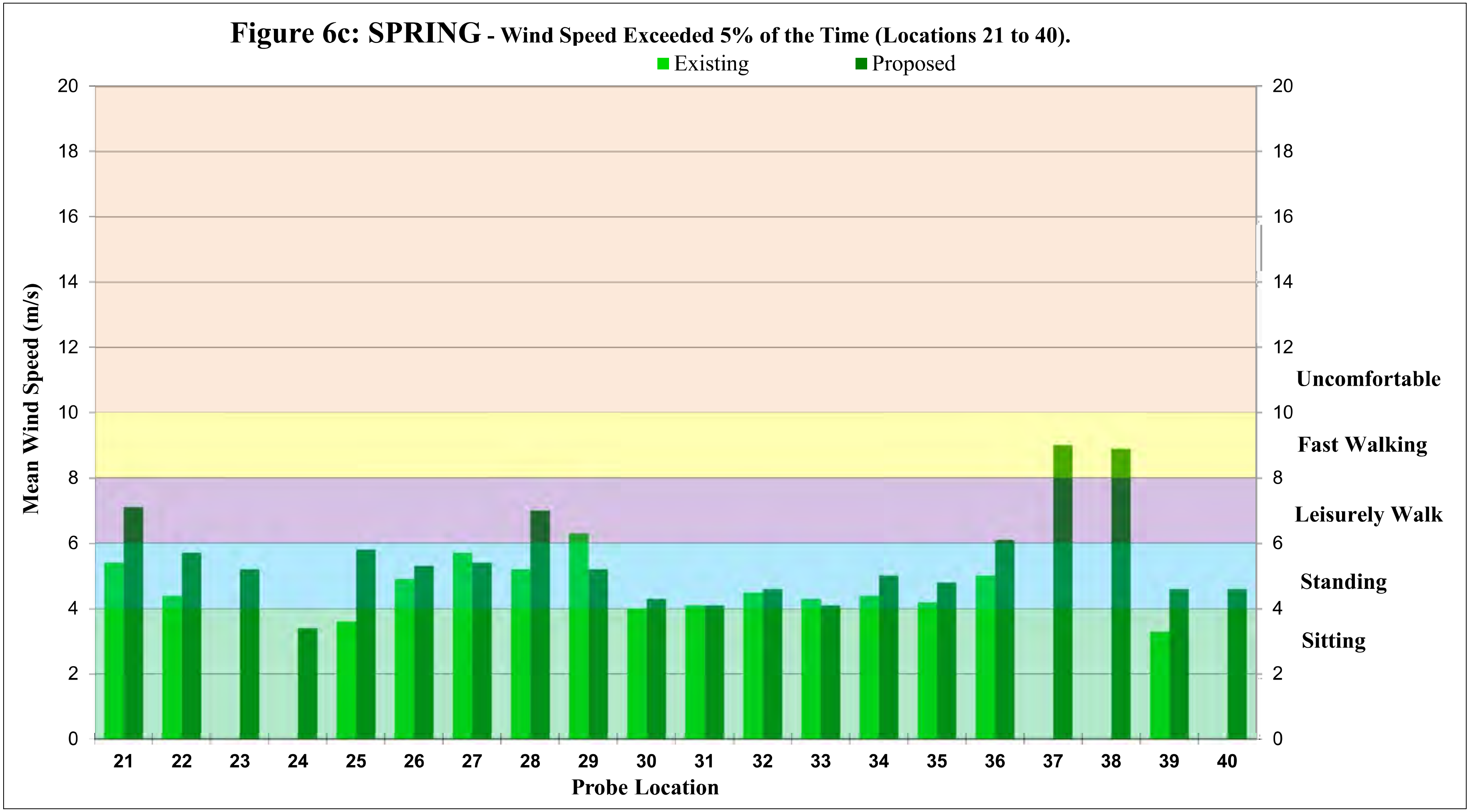


Figure 6c: SPRING - Wind Speed Exceeded 5% of the Time (Locations 21 to 40).
Existing
Proposed
Mean Wind Speed (m/s)
Probe Location
Uncomfortable
Fast Walking
Leisurely Walk
Standing
Sitting
0
2
4
6
8
10
12
14
16
18
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40

Figure 6c: SPRING - Wind Speed Exceeded 5% of the Time (Locations 41 to 44).

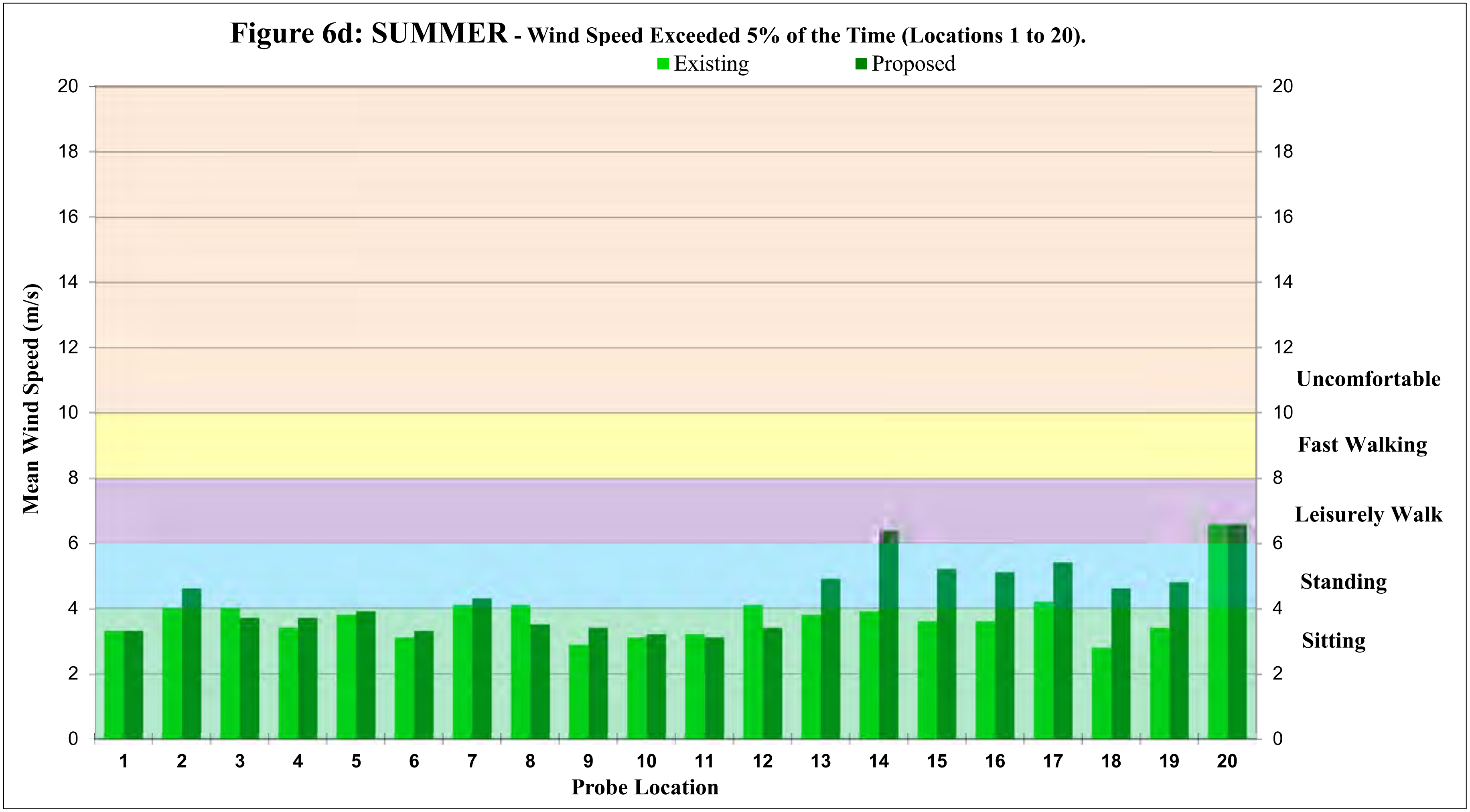


Figure 6d: SUMMER - Wind Speed Exceeded 5% of the Time (Locations 1 to 20).
Existing
Proposed
Mean Wind Speed (m/s)
Probe Location
Uncomfortable
Fast Walking
Leisurely Walk
Standing
Sitting
0
2
4
6
8
10
12
14
16
18
20
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20

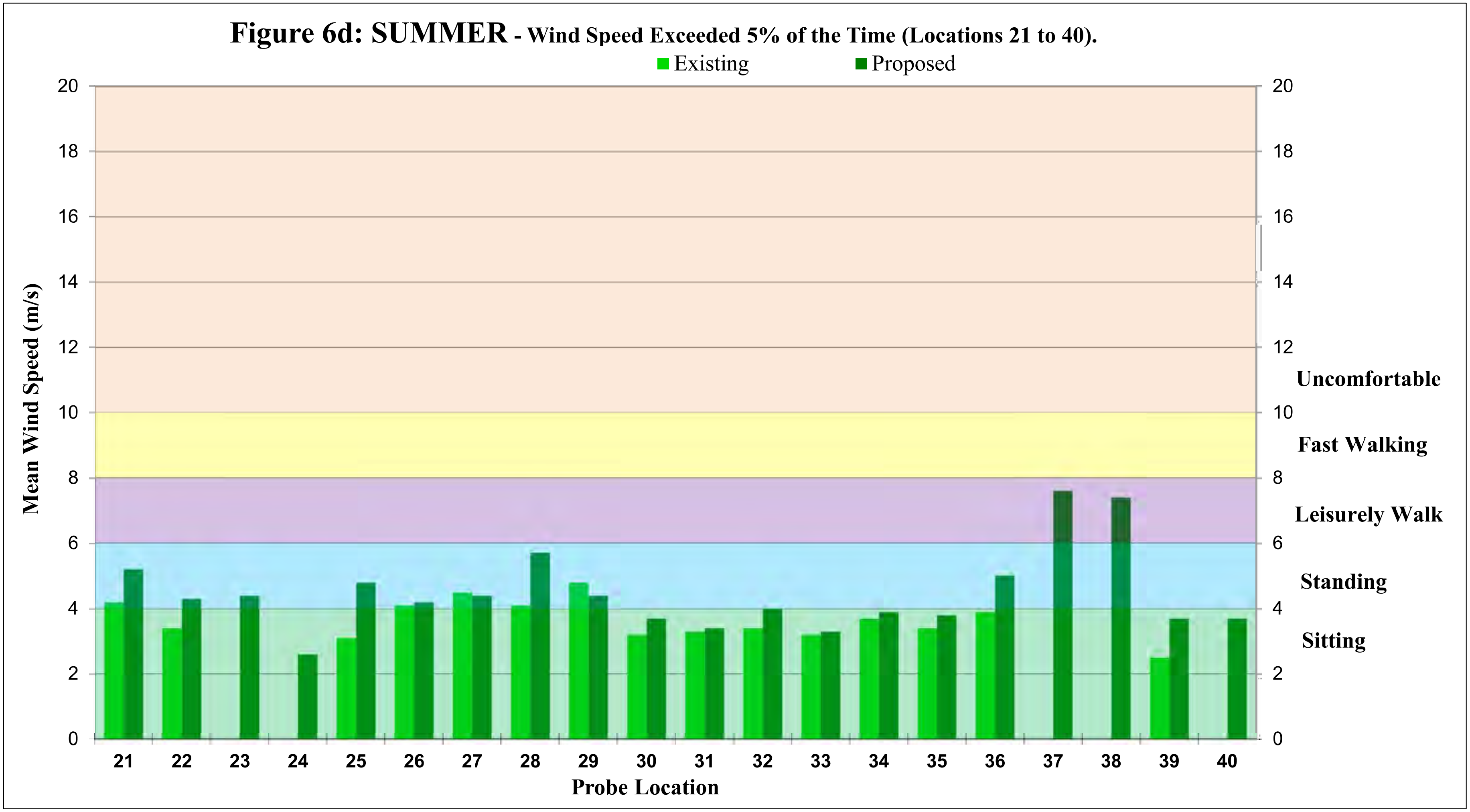


Figure 6d: SUMMER - Wind Speed Exceeded 5% of the Time (Locations 21 to 40).
Existing
Proposed
Mean Wind Speed (m/s)
0
2
4
6
8
10
12
14
16
18
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
Probe Location
Uncomfortable
Fast Walking
Leisurely Walk
Standing
Sitting

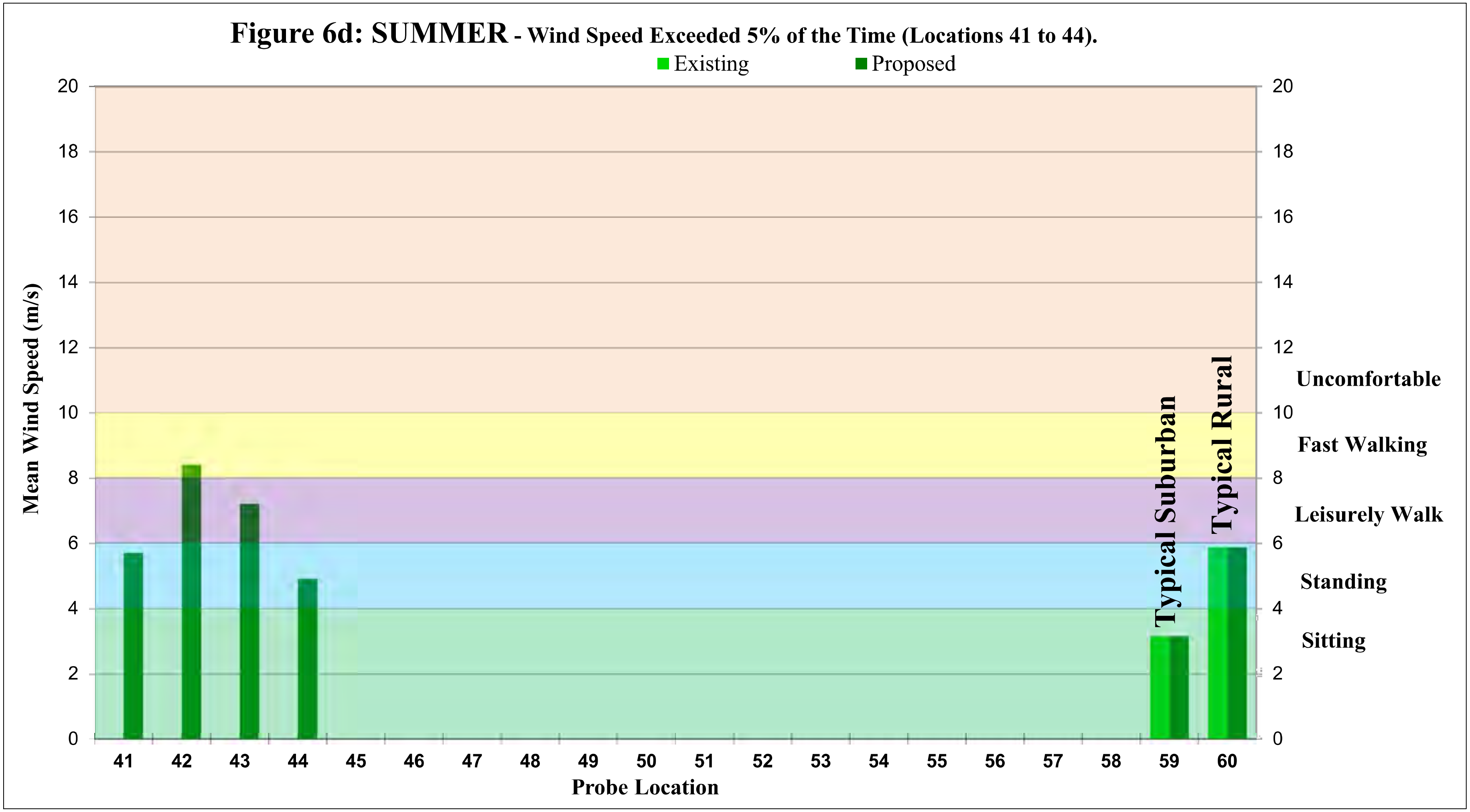
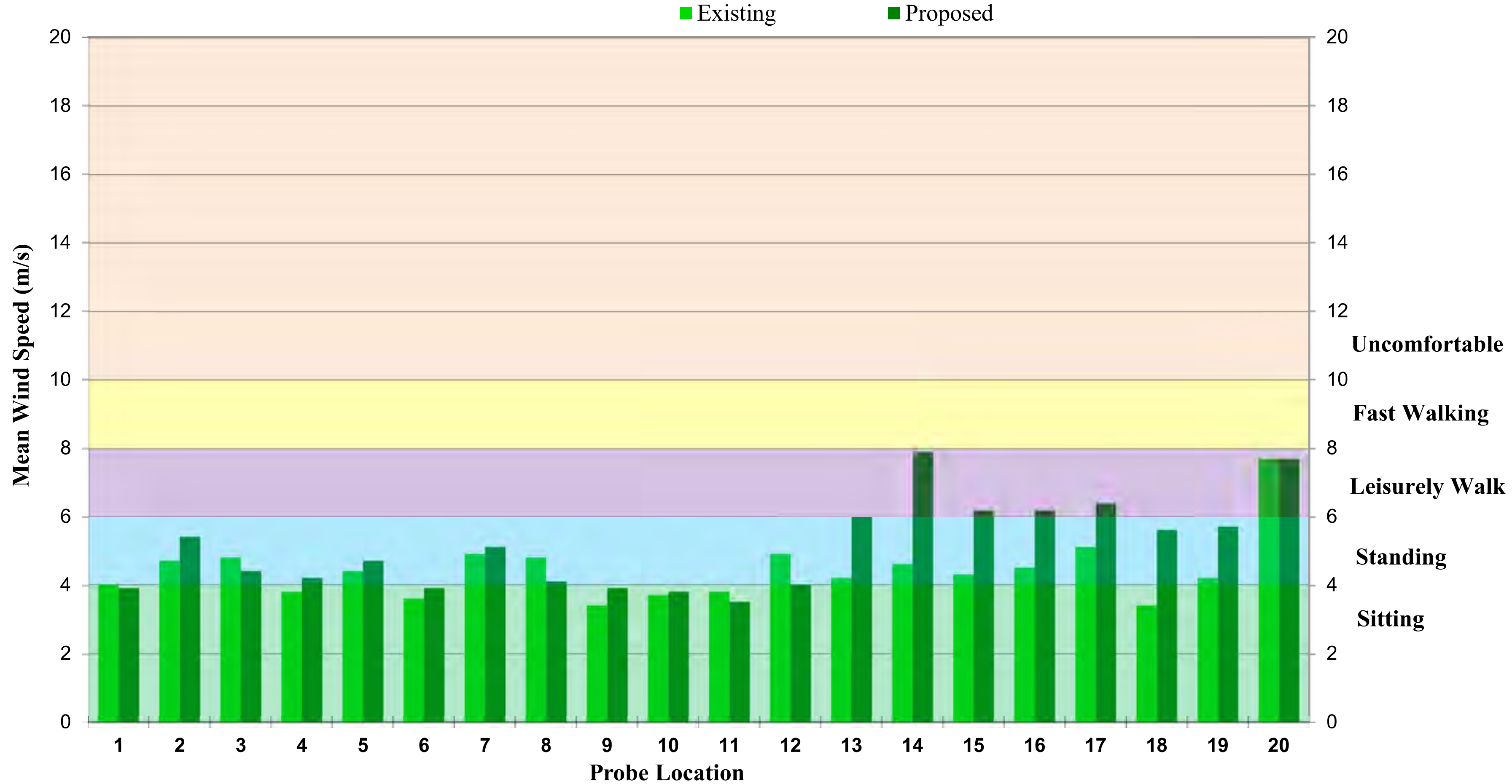


Figure 6d: SUMMER - Wind Speed Exceeded 5% of the Time (Locations 41 to 44).
Existing
Proposed
Mean Wind Speed (m/s)
20
18
16
14
12
10
8
6
4
2
0
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
Probe Location
Typical Suburban
Typical Rural
Uncomfortable
Fast Walking
Leisurely Walk
Standing
Sitting

Figure 6e: FALL - Wind Speed Exceeded 5% of the Time (Locations 1 to 20).



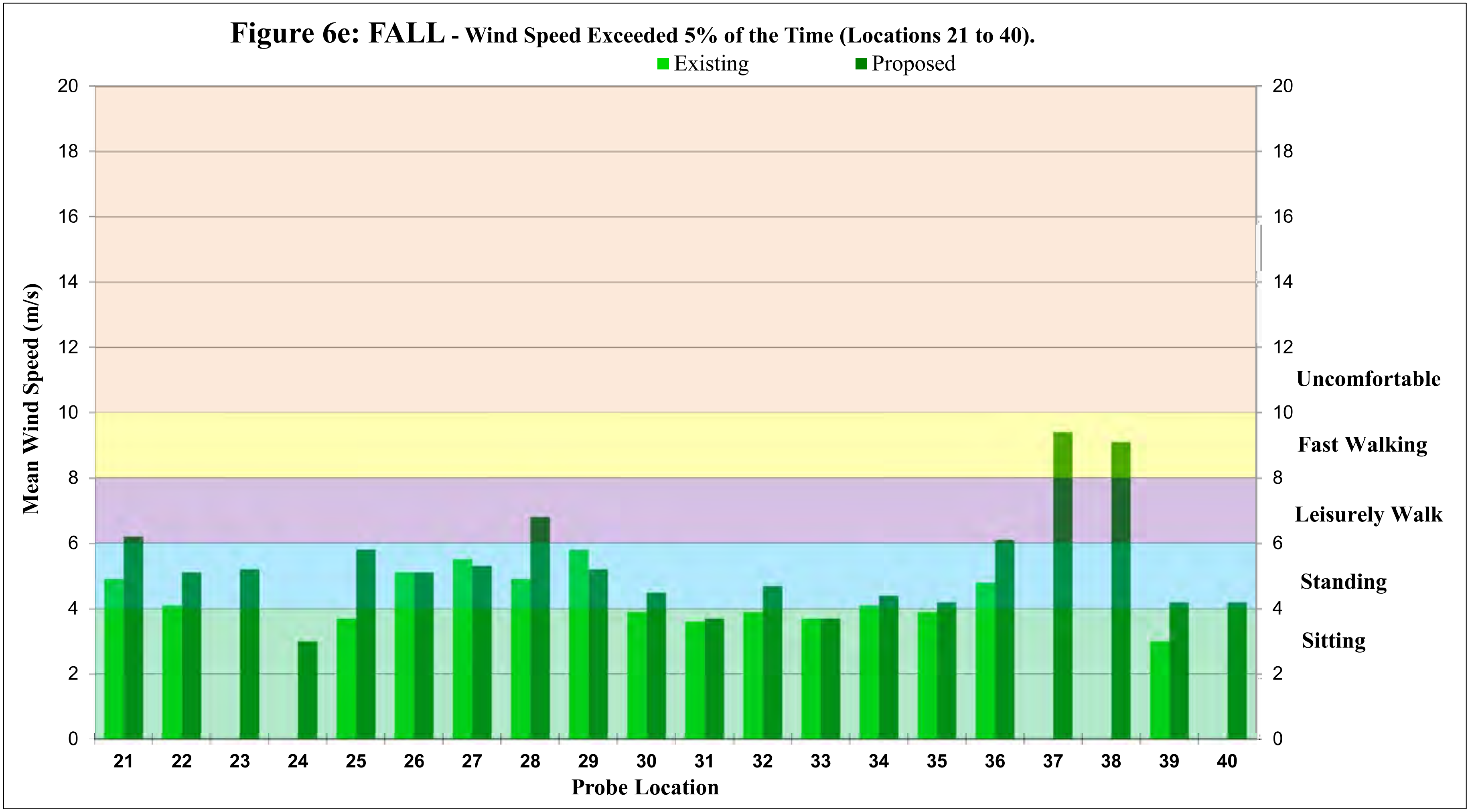


Figure 6e: FALL - Wind Speed Exceeded 5% of the Time (Locations 21 to 40).
Existing
Proposed
Mean Wind Speed (m/s)
0
2
4
6
8
10
12
14
16
18
20
Uncomfortable
Fast Walking
Leisurely Walk
Standing
Sitting
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
Probe Location

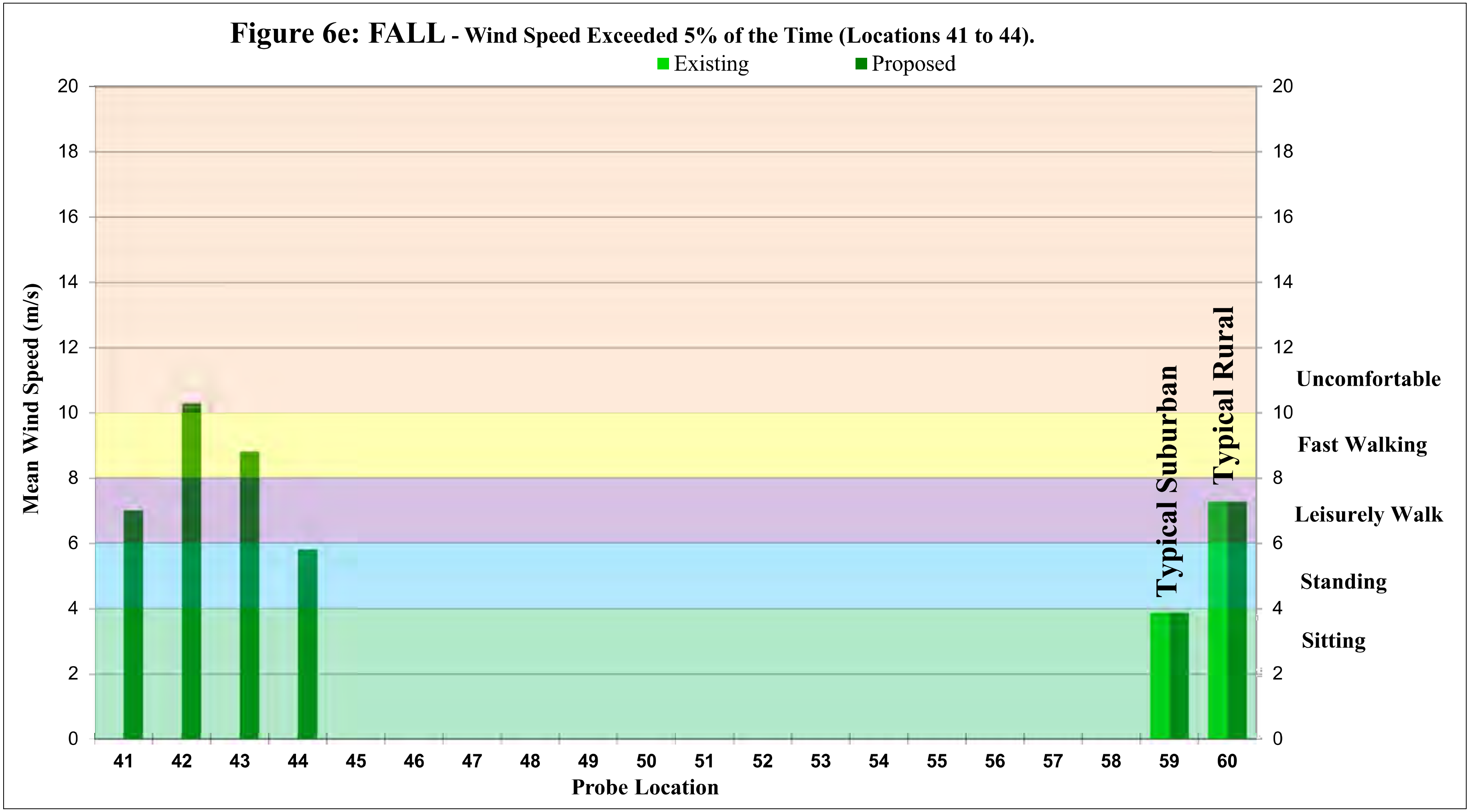


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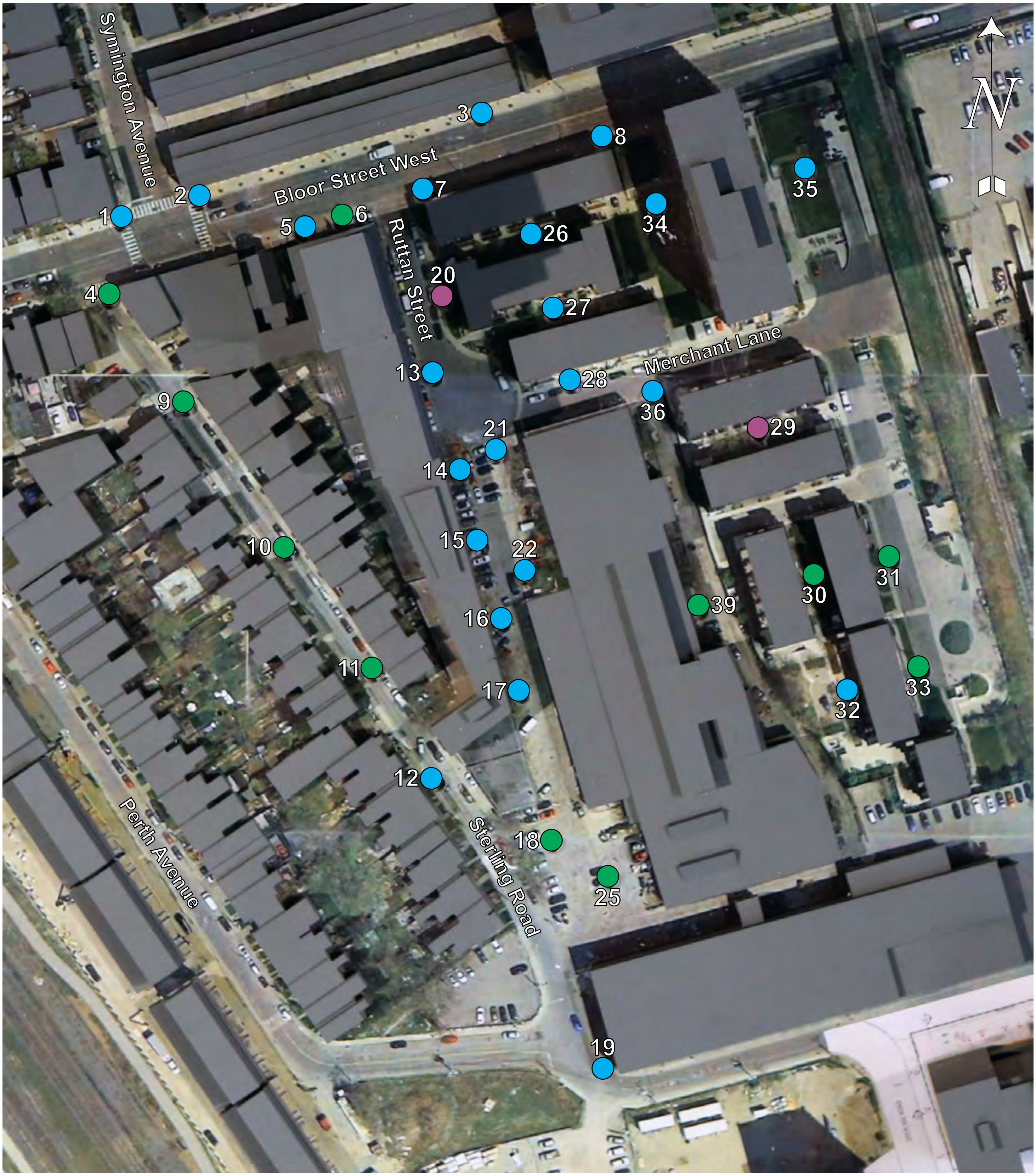
Figure 7a: Pedestrian level wind velocity comfort categories.



Comfort Categories - Annual - Existing

Sitting · Standing · Leisurely Walking · Fast Walking · Uncomfortable

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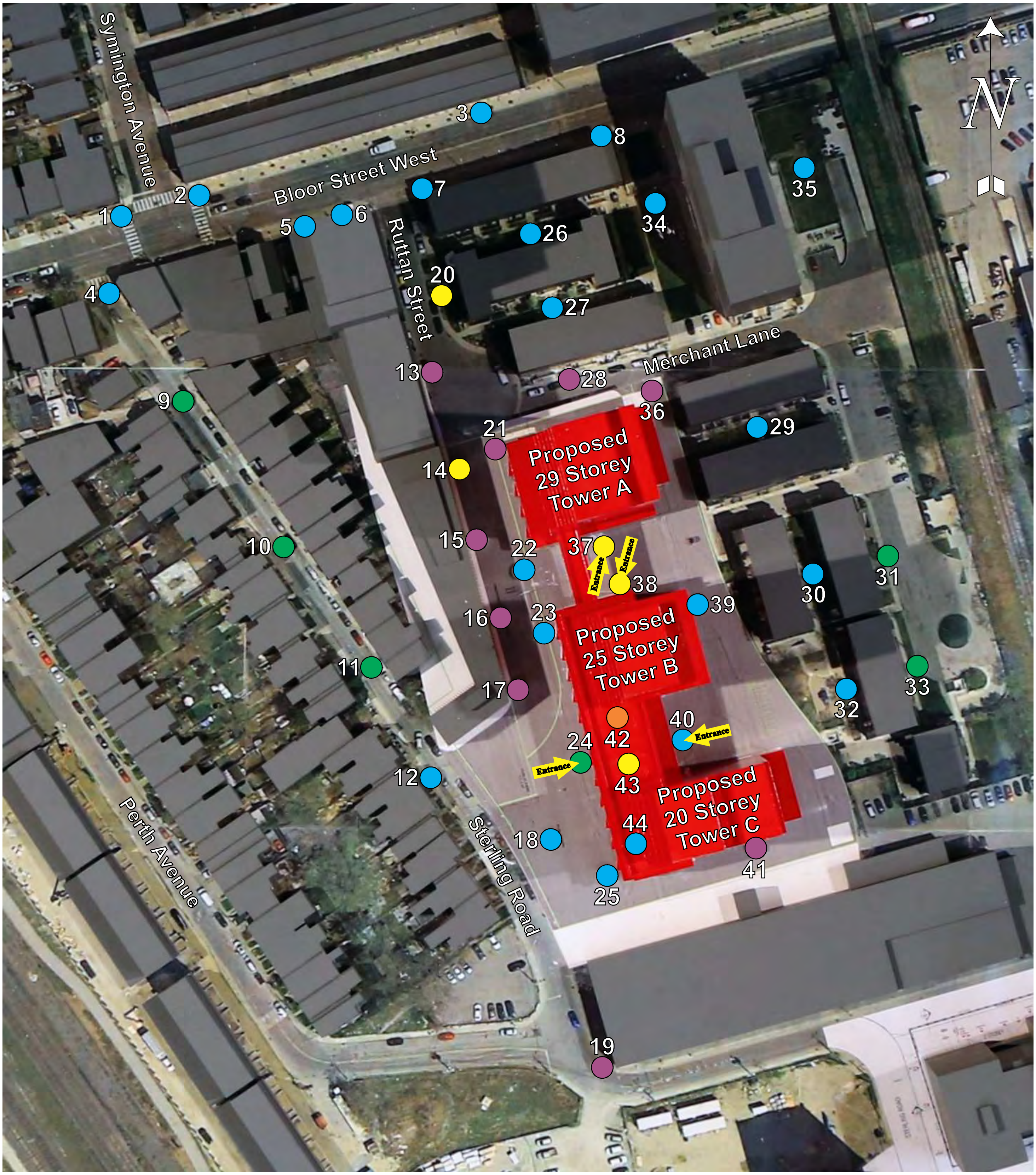
Figure 7b: Pedestrian level wind velocity comfort categories.

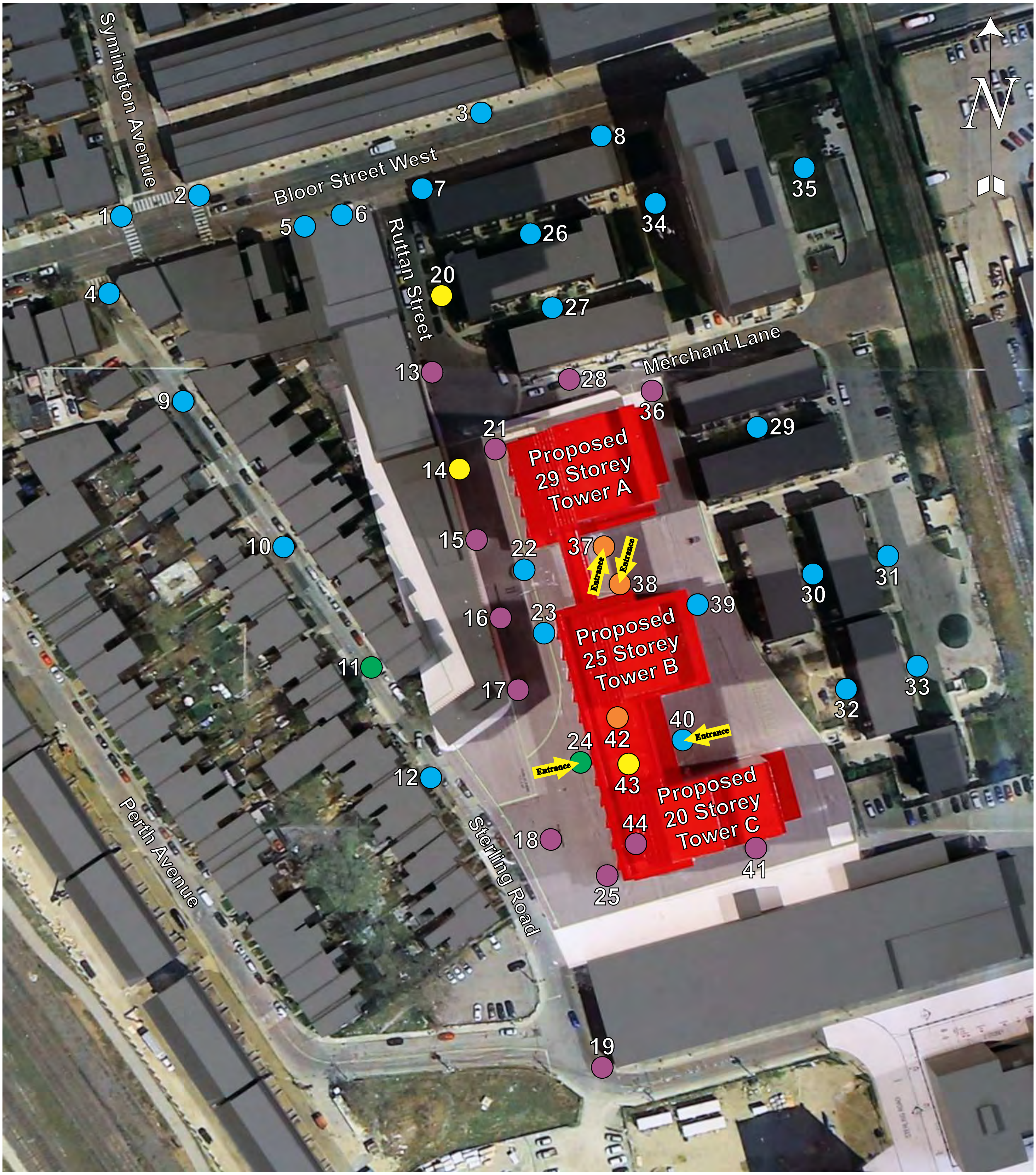


Comfort Categories - Annual - Proposed

Sitting Standing Leisurely Walking Fast Walking Uncomfortable

Figure 7c: Pedestrian level wind velocity comfort categories.

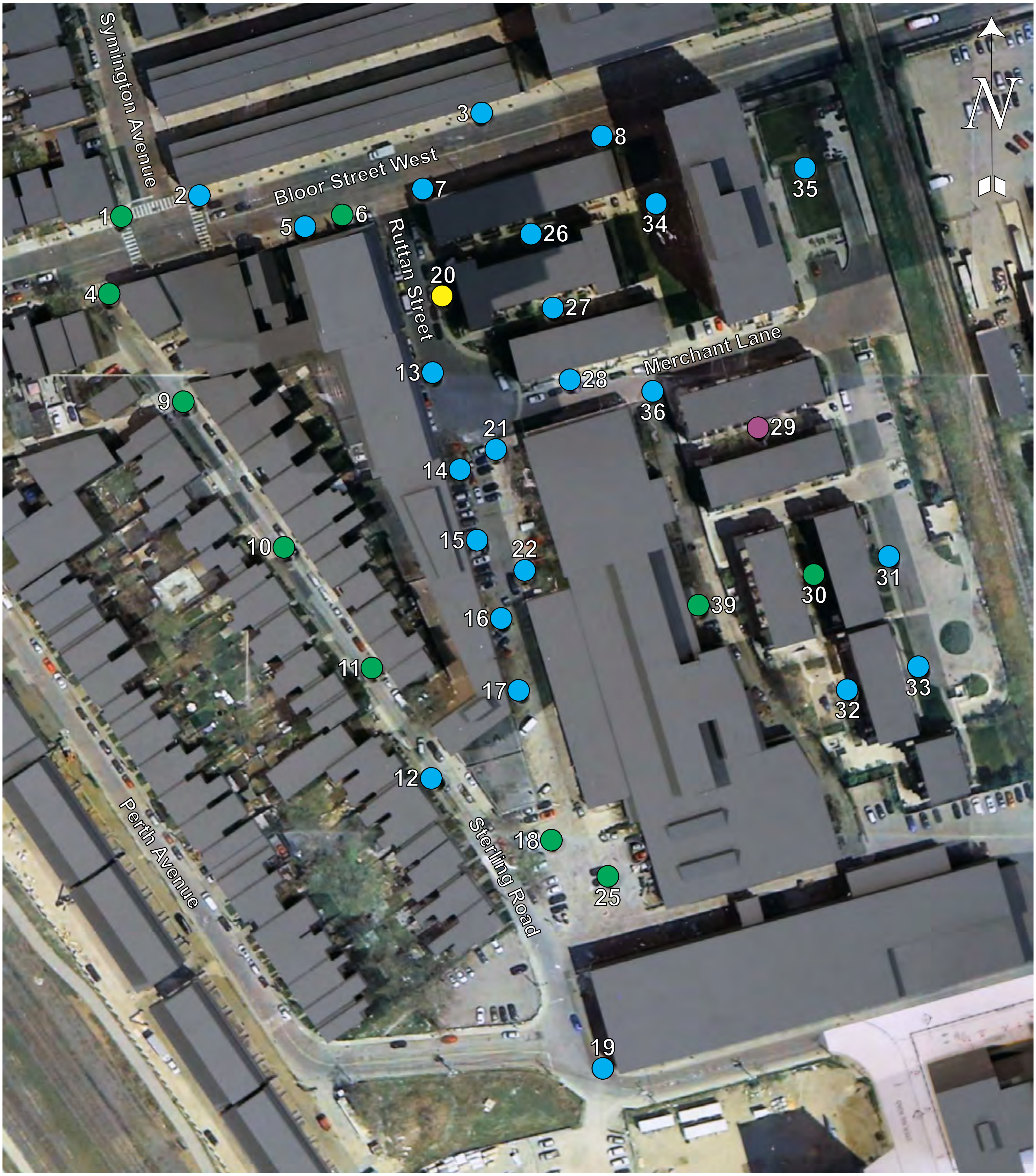
Figure 7d: Pedestrian level wind velocity comfort categories.



Comfort Categories - Winter - Proposed

Sitting · Standing · Leisurely Walking · Fast Walking · Uncomfortable

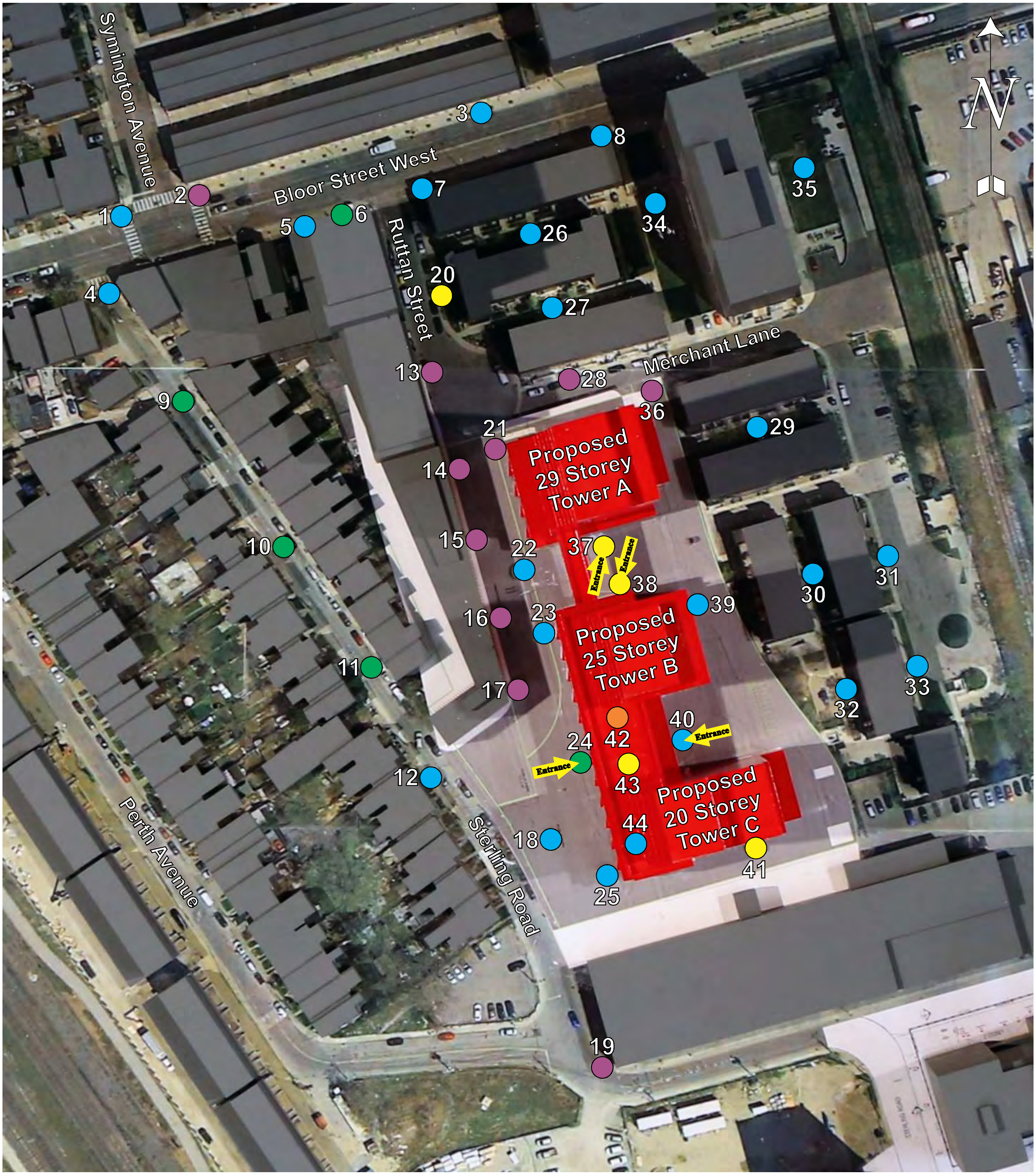
Figure 7e: Pedestrian level wind velocity comfort categories.



Comfort Categories - Spring - Existing

Sitting Standing Leisurely Walking Fast Walking Uncomfortable

Figure 7f: Pedestrian level wind velocity comfort categories.

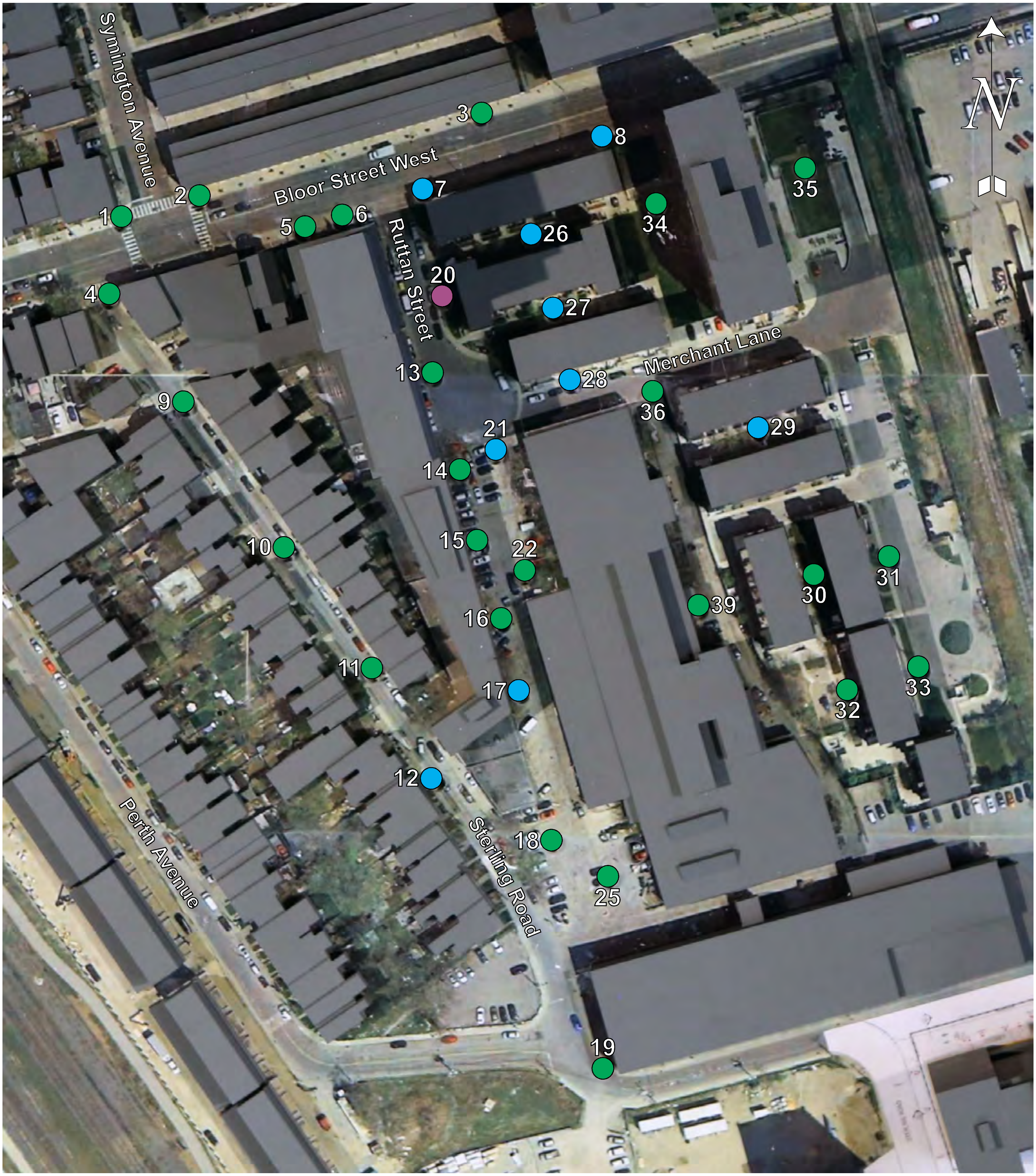


Comfort Categories - Spring - Proposed

Sitting Standing Leisurely Walking Fast Walking Uncomfortable

Theakston
Environmental

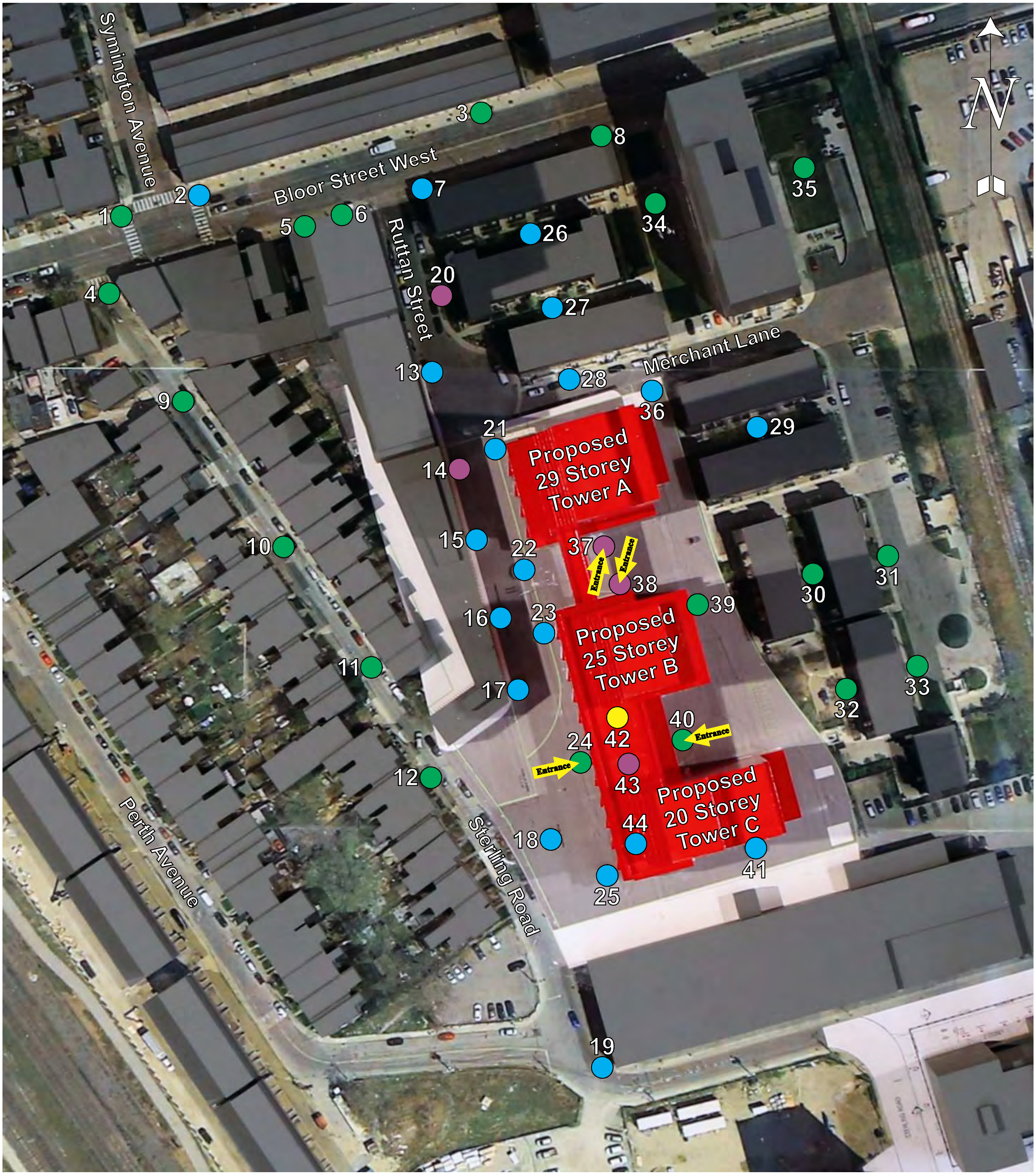
Figure 7g: Pedestrian level wind velocity comfort categories.



Comfort Categories - Summer - Existing

Sitting · Standing · Leisurely Walking · Fast Walking · Uncomfortable

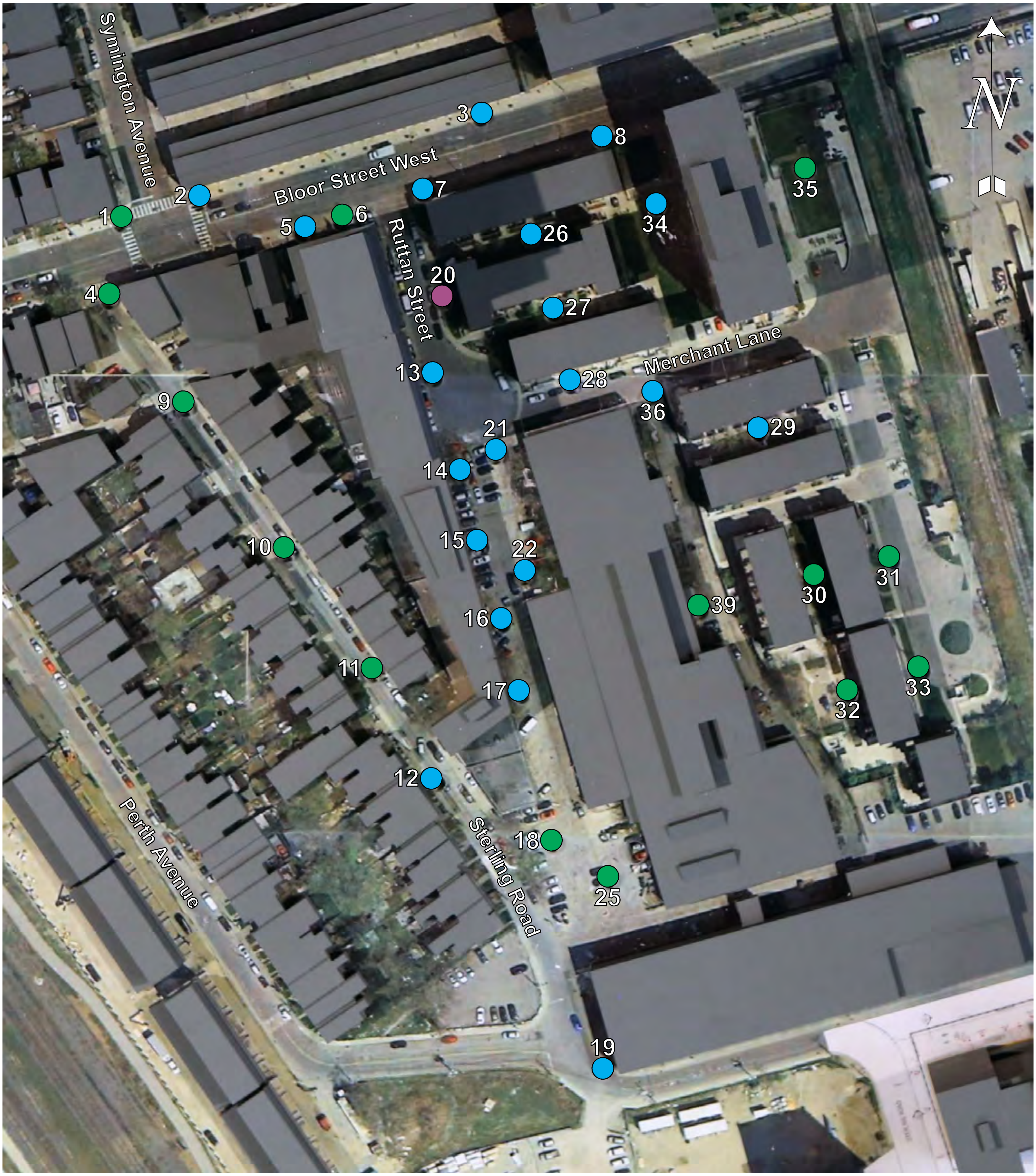
Figure 7h: Pedestrian level wind velocity comfort categories.



Comfort Categories - Summer - Proposed

Sitting · Standing · Leisurely Walking · Fast Walking · Uncomfortable

Figure 7i: Pedestrian level wind velocity comfort categories.

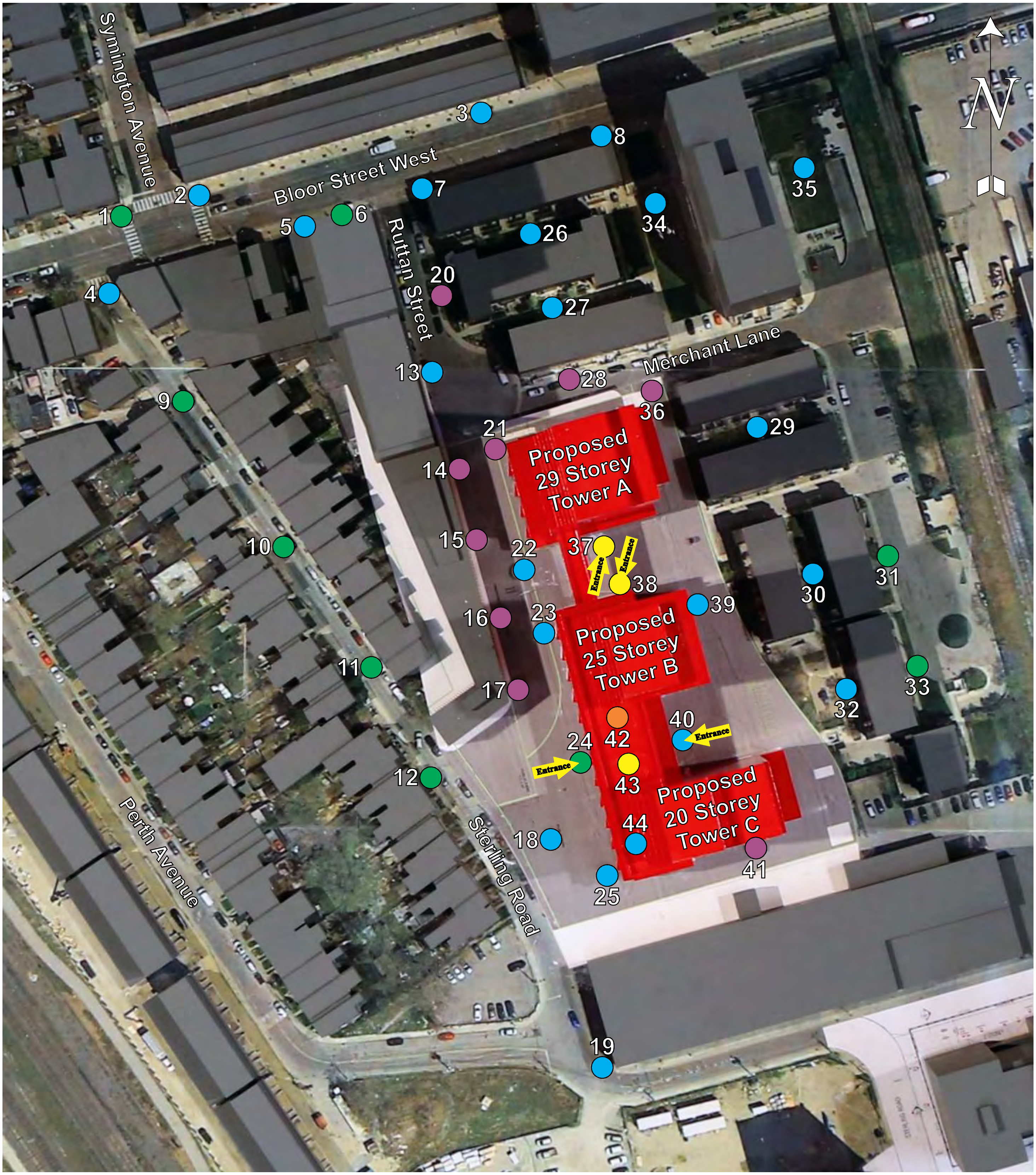


Comfort Categories - Fall - Existing

Sitting Standing Leisurely Walking Fast Walking Uncomfortable

Theakston Environmental

Figure 7j: Pedestrian level wind velocity comfort categories.



Comfort Categories - Fall - Proposed

Sitting · Standing · Leisurely Walking · Fast Walking · Uncomfortable

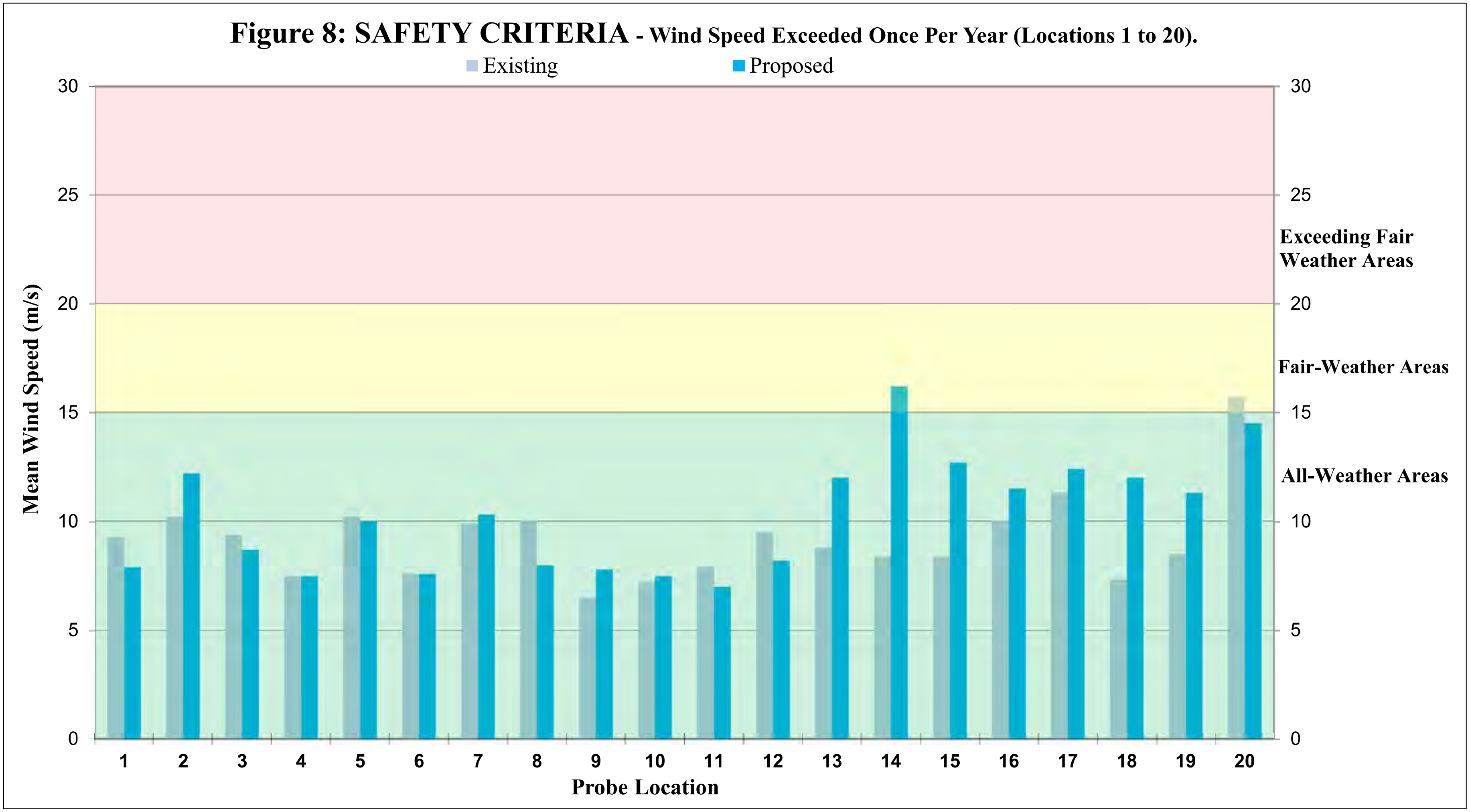


Figure 8: SAFETY CRITERIA - Wind Speed Exceeded Once Per Year (Locations 1 to 20).
Existing
Proposed
Mean Wind Speed (m/s)
Probe Location
Exceeding Fair Weather Areas
Fair-Weather Areas
All-Weather Areas
0
5
10
15
20
25
30
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20

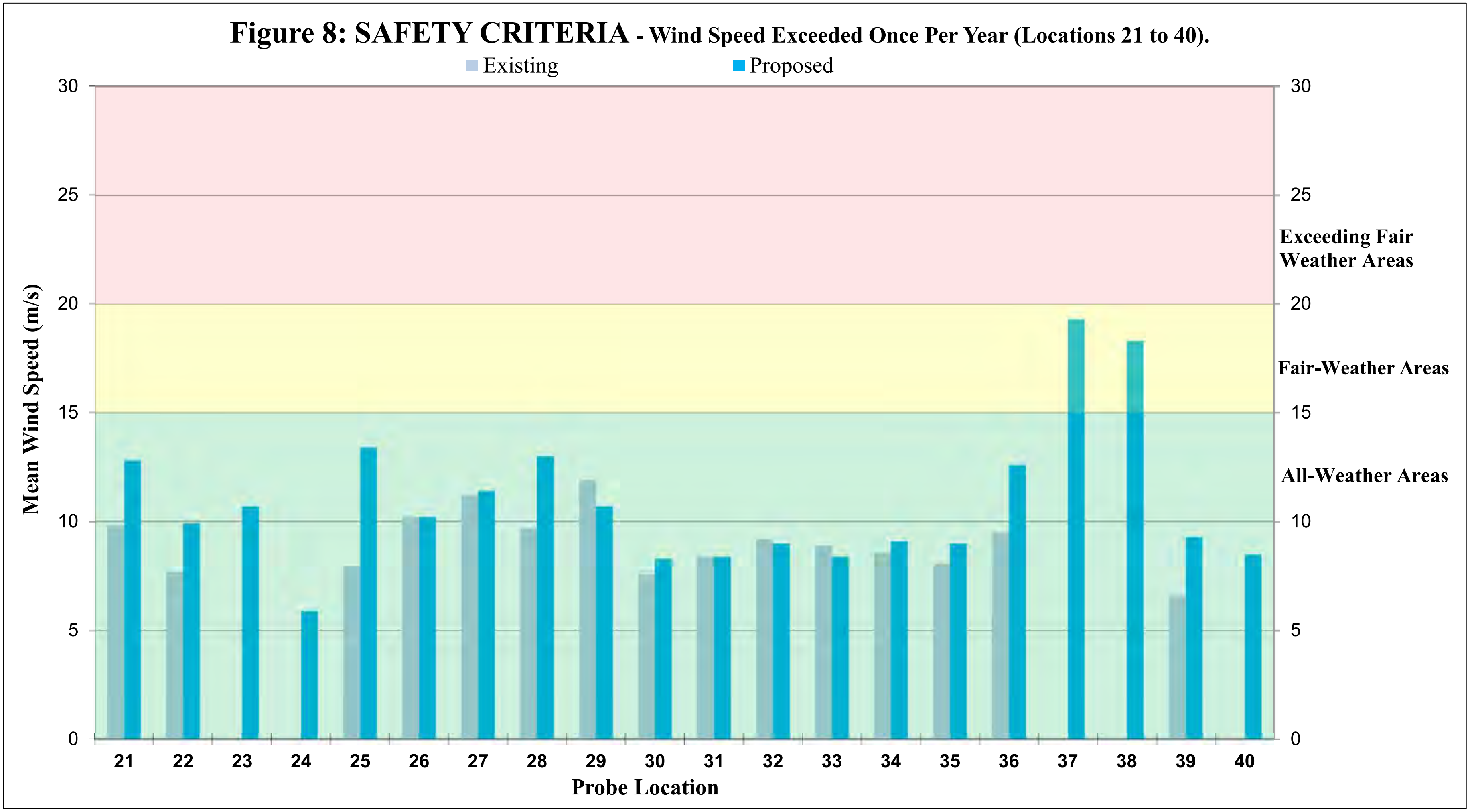


Figure 8: SAFETY CRITERIA - Wind Speed Exceeded Once Per Year (Locations 21 to 40).
Existing
Proposed
Mean Wind Speed (m/s)
Exceeding Fair Weather Areas
Fair-Weather Areas
All-Weather Areas
Probe Location
0
5
10
15
20
25
30
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40

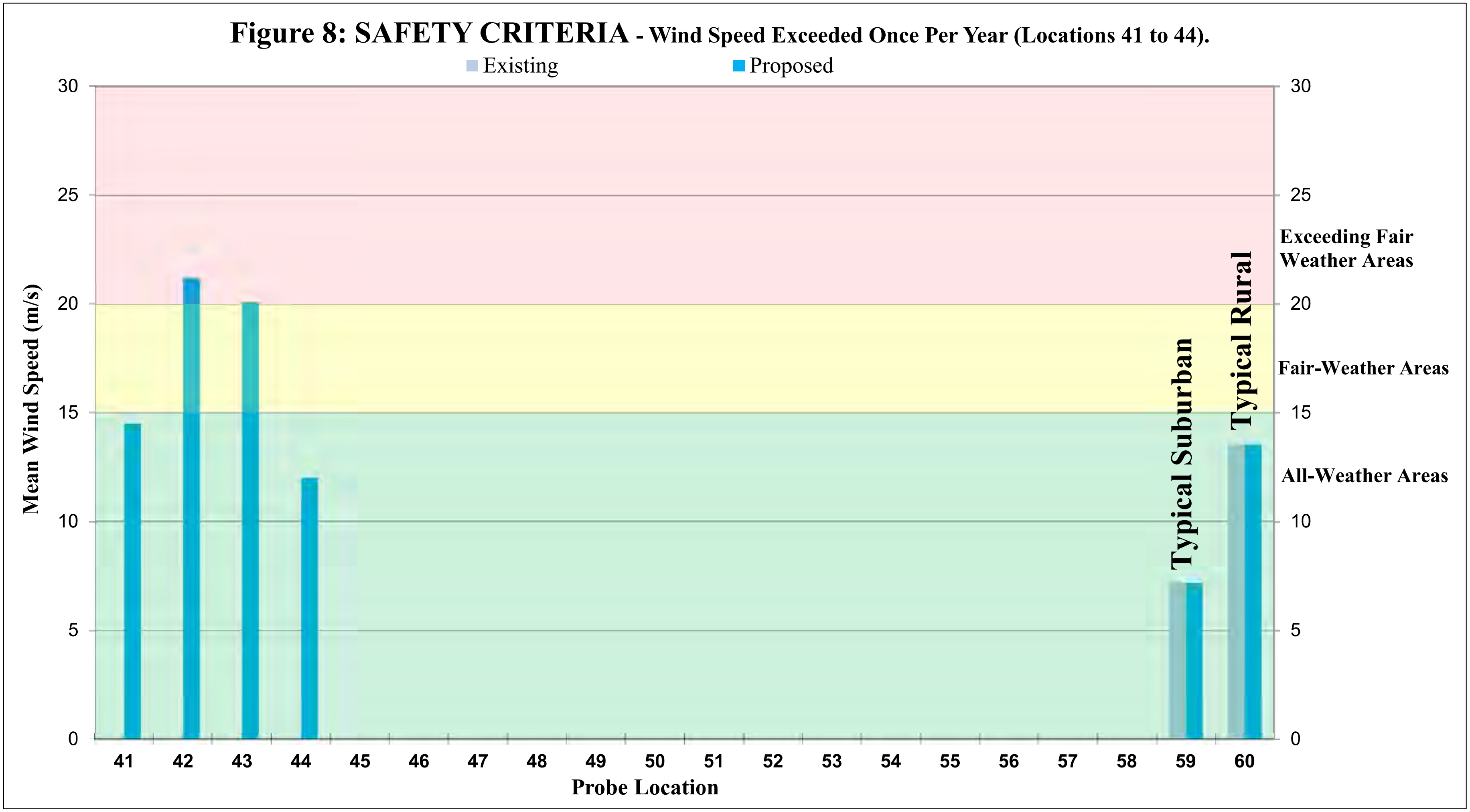
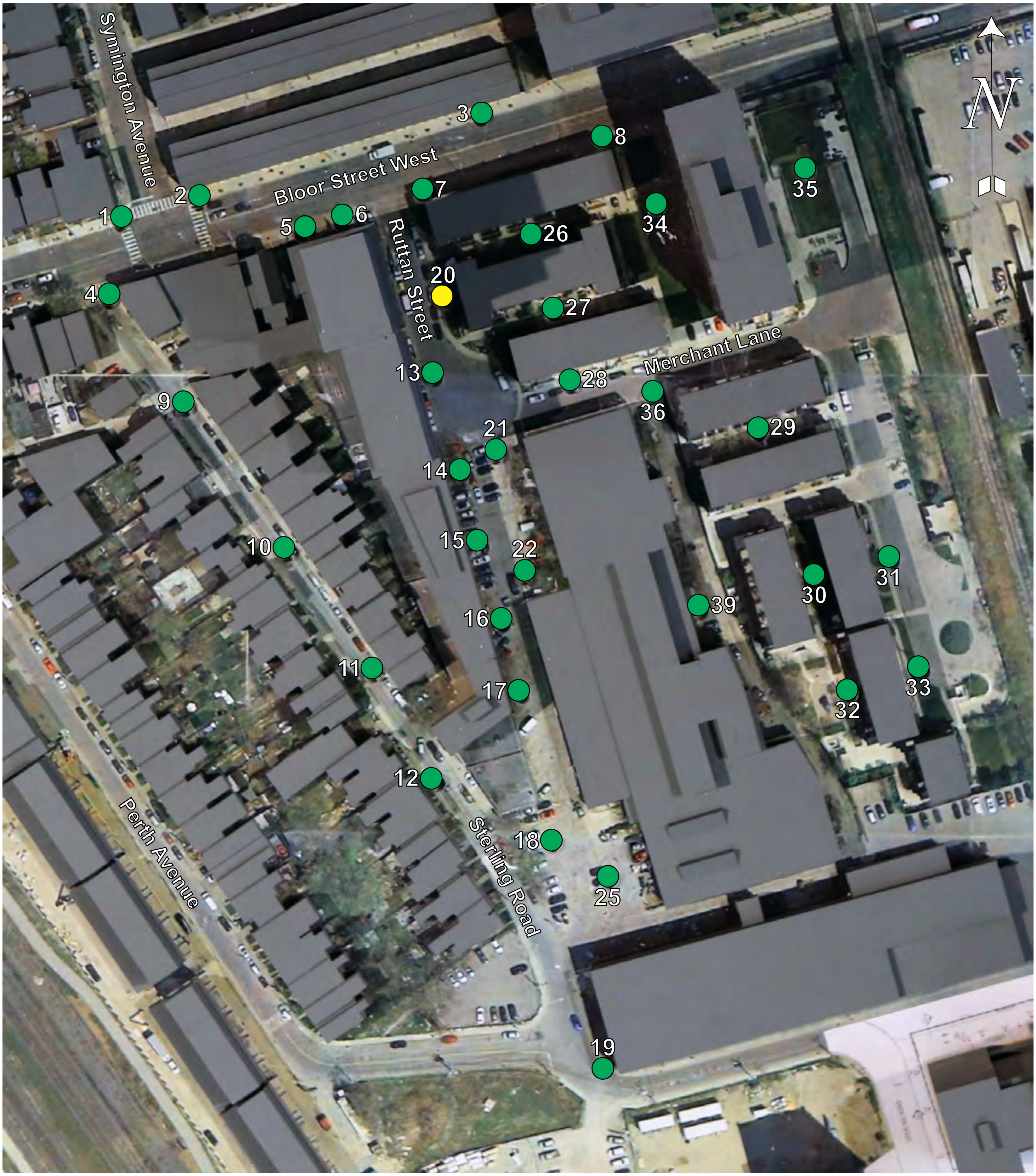


Figure 8: SAFETY CRITERIA - Wind Speed Exceeded Once Per Year (Locations 41 to 44).
Existing
Proposed
Mean Wind Speed (m/s)
30
25
20
15
10
5
0
Exceeding Fair Weather Areas
Fair-Weather Areas
All-Weather Areas
Typical Suburban
Typical Rural
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
Probe Location

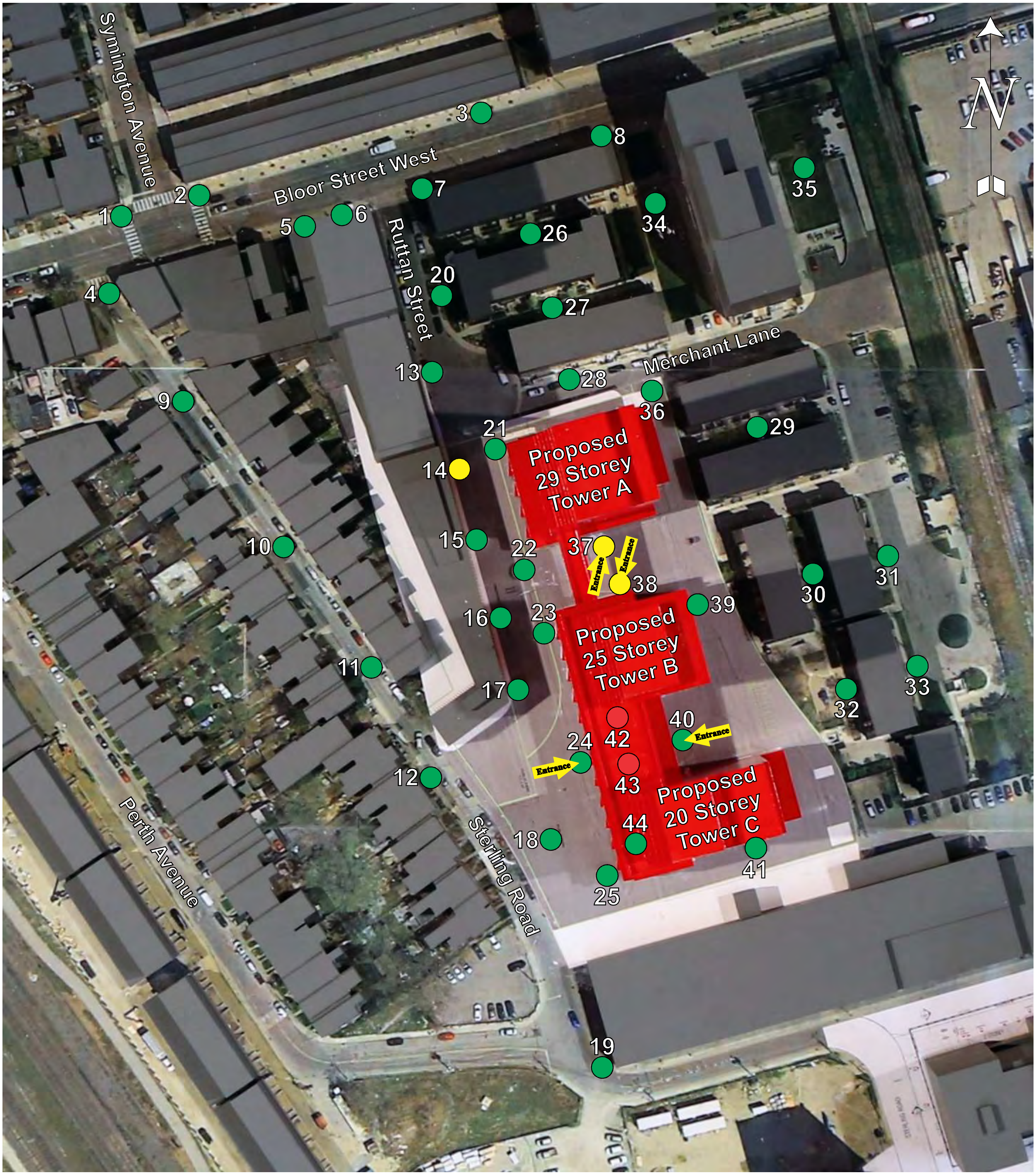
Figure 9a: Pedestrian level wind velocity safety criteria.



Safety Criteria - Existing

All-Weather Areas · Fair-Weather Areas · Exceeding Fair-Weather Areas

Figure 9b: Pedestrian level wind velocity safety criteria.



Safety Criteria - Proposed

All-Weather Areas · Fair-Weather Areas · Exceeding Fair-Weather Areas

7. APPENDIX

BACKGROUND AND THEORY OF WIND MOVEMENT

During the course of a modular analysis of an existing or proposed site, pertinent wind directions must be analysed with regard to the macroclimate and microclimate. In order for the results of the study to be valid, the effects of both climates must be modelled in test procedures.

Macroclimate

Wind velocity, frequency and directions are used in tests with models to establish part of the macroclimate. These variables are determined from meteorological data collected at the closest weather monitoring station. This information is used in the analysis of the site to establish upstream (approach) wind and weather conditions.

When evaluating approach wind velocities and characteristic profiles in the field it is necessary to evaluate certain boundary conditions. At the earth's surface, "no slip" conditions require the wind speed to be zero. At an altitude of approximately one kilometre above the earth's surface, the motion of the wind is governed by pressure distributions associated with large-scale weather systems. Consequently, these winds, known as "geostrophic" or "freestream" winds, are independent of the surface topography. In model simulation, as in the field, the area of concern is the boundary layer between the earth's surface and the geostrophic winds. The term boundary layer is used to describe the velocity profile of wind currents as they increase from zero to the geostrophic velocity.

The approach boundary layer profile is affected by specific surface topography upstream of the test site. Over relatively rough terrain (urban) the boundary layer is thicker and the wind speed increases rather slowly with height. The opposite is true over open terrain (rural). The following power law equation is used to represent the mean velocity profile for any given topographic condition:

$$\frac{U}{U_F} = \left(\frac{z}{z_F}\right)^a$$

where U = wind velocity (m/s) at height z (m)
a = power law exponent
and subscript $_F$ refers to freestream conditions

Typical values for a and z_F are summarized below:

Terrain	a	z_F (m)
Rural	0.14 - 0.17	260 - 300
Suburban	0.20 - 0.28	300 - 420
Urban	0.28 - 0.40	420 - 550

Wind data is recorded at meteorological stations at a height z_{ref} , usually equal to about 10m above grade. This historical mean wind velocity and frequency data is often presented in the form of a wind rose. The mean wind velocity at z_{ref} , along with the appropriate constants based on terrain type, are used to determine the value for U_F , completing the definition of the boundary layer profile specific to the site. The following Figure shows representations of the boundary layer profile for each of the above terrain conditions:

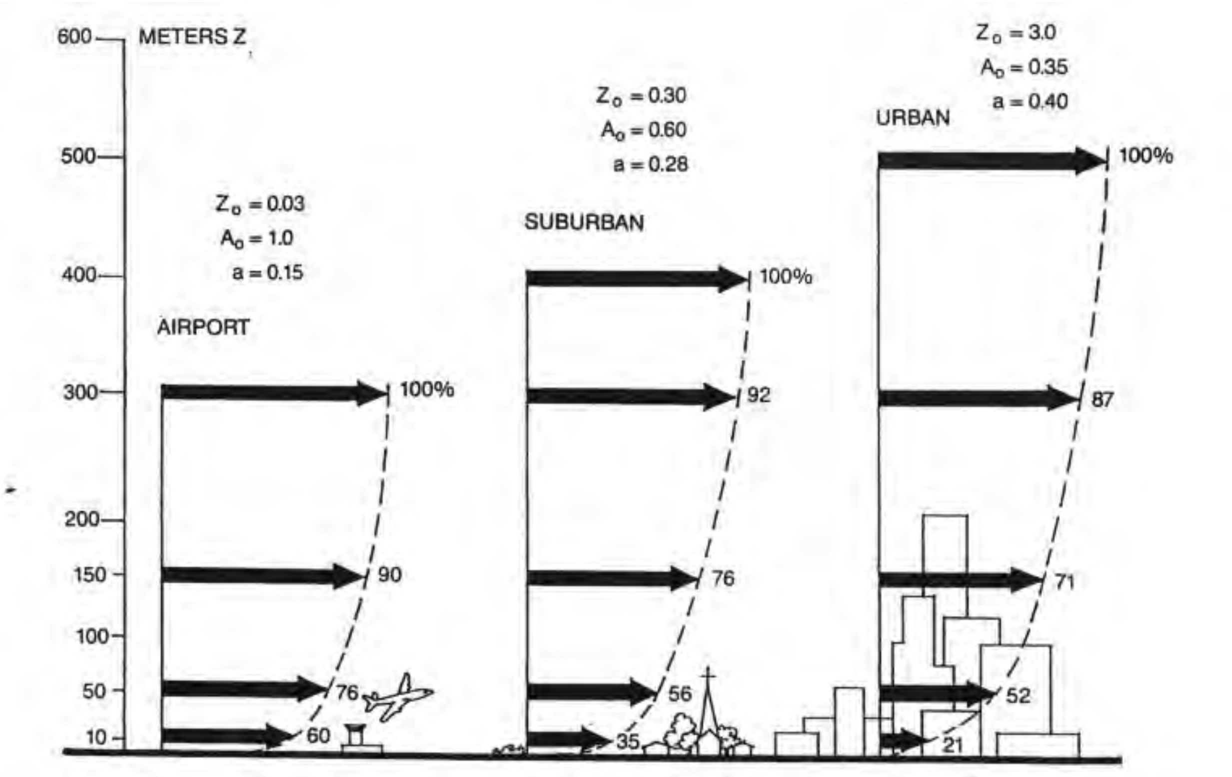


Figure A: Mean wind speed profiles for various terrain (from ASHRAE 1989).

For the above velocity profiles, ground level velocities at a height of $z = 2m$, for an urban macroclimate are approximately 52% of the mean values recorded at the meteorological station at a height equal to $z_{ref} = 10m$. For suburban and rural conditions, the values are 63% and 78% respectively. Thus, for a given wind speed at z_{ref} open terrain or fields (rural) will experience significantly higher ground level wind velocities than suburban or urban areas.

When a boundary layer wind flows over one terrain onto another, the boundary layer profile shape rapidly changes to that dictated by the new terrain. If the preceding wind flow is over rough suburban terrain and an open area is encountered a rapid increase in ground level winds will be realized. A similar effect will occur when large low-density residential areas are demolished to accommodate high-rise developments. The transitional open area will experience significantly higher pedestrian level winds than the previous suburban setting. Once the high-rise development is established, ground level winds will moderate with localized areas of higher pedestrian level winds likely to occur. Pedestrian level wind velocities respond to orientation and shape of the development and if the site is not appropriately engineered or mitigated, pedestrian level wind may be problematic.

Microclimate

The specific wind conditions related to the study site are known as the microclimate, which are dictated mainly by the following factors:

- The orientation and conformation of buildings within the vicinity of the site.
- The surrounding contours and pertinent landscape features.

The microclimate establishes the effect that surrounding buildings or landscape features have on the subject building and the effect the subject building has on the surrounds. For the majority of urban test sites the proper microclimate can be established by modelling an area of 300*m* in radius around the subject building. If extremely tall buildings are present then the study area must be larger, and if the building elevations are on the order of a few floors, smaller areas will suffice to establish the required microclimate.

General Wind Flow Phenomena

Wind flow across undulating terrain contains parallel streamlines with the lowest streamline adjacent to the surface. These conditions continue until the streamlines approach vertical objects. When this occurs there is a general movement of the streamlines upward ("Wind Velocity Gradient") and as they reach the top of the objects turbulence is generated on the lee side. This is one of the reasons for unexpected high wind velocities as this turbulent action moves to the base of the objects on the lee side.

Other fluid action occurs through narrow gaps between buildings (Venturi Action) and at sharp edges of a building or other vertical objects (Scour Action). These conditions are predictable at selected locations but do not conform to a set direction of wind as described by a macroclimate condition. In fact, the orientation and conformation of buildings, streets and landscaping establish a microclimate.

Because of the "Wind Velocity Gradient" phenomena, there is a "downwash" of wind at the face of buildings and this effect is felt at the pedestrian level. It may be experienced as high gusty winds or drifting snow. These effects can be obviated by windbreak devices on the windward side or by canopies over windows and doors on the lee side of the building.

The intersection of two streets or pedestrian walkways have funnelling effects of wind currents from any one of the four directions and is particularly severe at corners if the buildings project to the street line or are close to walkways.

Some high-rise buildings have gust effects as the wind velocities are generated suddenly due to the orientation and conformation of the site. Since wind velocities are the result of energy induced wind currents the solution to most problems is to reduce the wind energy at selected locations by carefully designed windbreak devices, often landscaping, to blend with the surrounds.

The Beaufort Scale is often used as a numerical relationship to wind speed based upon an observation of the effects of wind. Rear-Admiral Sir Francis Beaufort, commander of the Royal Navy, developed the wind force scale in 1805, and by 1838 the Beaufort wind force scale was made mandatory for log entries in ships of the Royal Navy. The original scale was an association of integers from 0 to 12, with a description of the effect of wind on the behaviour of a full-rigged man-of-war. The lower Beaufort numbers described wind in terms of ship speed, mid-range numbers were related to her sail carrying ability and upper numbers were in terms of survival. The Beaufort Scale was adopted in 1874 by the International Meteorological Committee for international use in weather telegraphy and, with the advent of anemometers, the scale was eventually adopted for meteorological purposes. Eventually, a uniform set of equivalents that non-mariners could relate to was developed, and by 1955, wind velocities in knots had replaced Beaufort numbers on weather maps. While the Beaufort Scale lost ground to technology, there remains the need to relate wind speed to observable wind effects and the Beaufort Scale remains a useful tool.

Abbreviated Beaufort Scale

Beaufort Number	Description	Wind Speed			Observations
		km/h	*m/s*	h=2*m* for Urban *m/s*	
2	Slight Breeze	6-11	1.6-3.3	< ~2	Tree leaves rustle; flags wave slightly; vanes show wind direction; small wavelets or scale waves.
3	Gentle Breeze	12-19	3.4-5.4	< ~3	Leaves and twigs in constant motion; small flags extended; long unbreaking waves.
4	Moderate Breeze	20-28	5.5-7.9	< ~4	Small branches move; flags flap; waves with whitecaps.
5	Fresh Breeze	29-38	8.0-10.7	< ~6	Small trees sway; flags flap and ripple; moderate waves with many whitecaps.
6	Strong Breeze	39-49	10.8-13.8	< ~8	Large branches sway; umbrellas used with difficulty; flags beat and pop; larger waves with regular whitecaps.
7	Moderate Gale	50-61	13.9-17.1	< ~10	Sea heaps up, white foam streaks; whole trees sway; difficult to walk; large waves.
8	Fresh Gale	62-74	17.2-20.7	> ~10	Twigs break off trees; moderately high sea with blowing foam.
9	Strong Gale	75-88	20.8-24.4		Branches break off trees; tiles blown from roofs; high crested waves.

Wind speeds indicated above, in *km/h* and *m/s*, are at a reference height of 10 metres, as are the wind speeds indicated on the Figure 5 wind roses. The mean wind speeds at pedestrian level, for an urban climate, would be approximately 56% of these values. The 3rd column for wind speed is shown for reference, at a height of 2*m*, in an urban setting. The approximate Comfort Category Colours are shown above. The relationship between wind speed and height relative to terrain is discussed in the appendices.

Figure B : Ground level wind velocity as a ratio of gradient wind velocity.

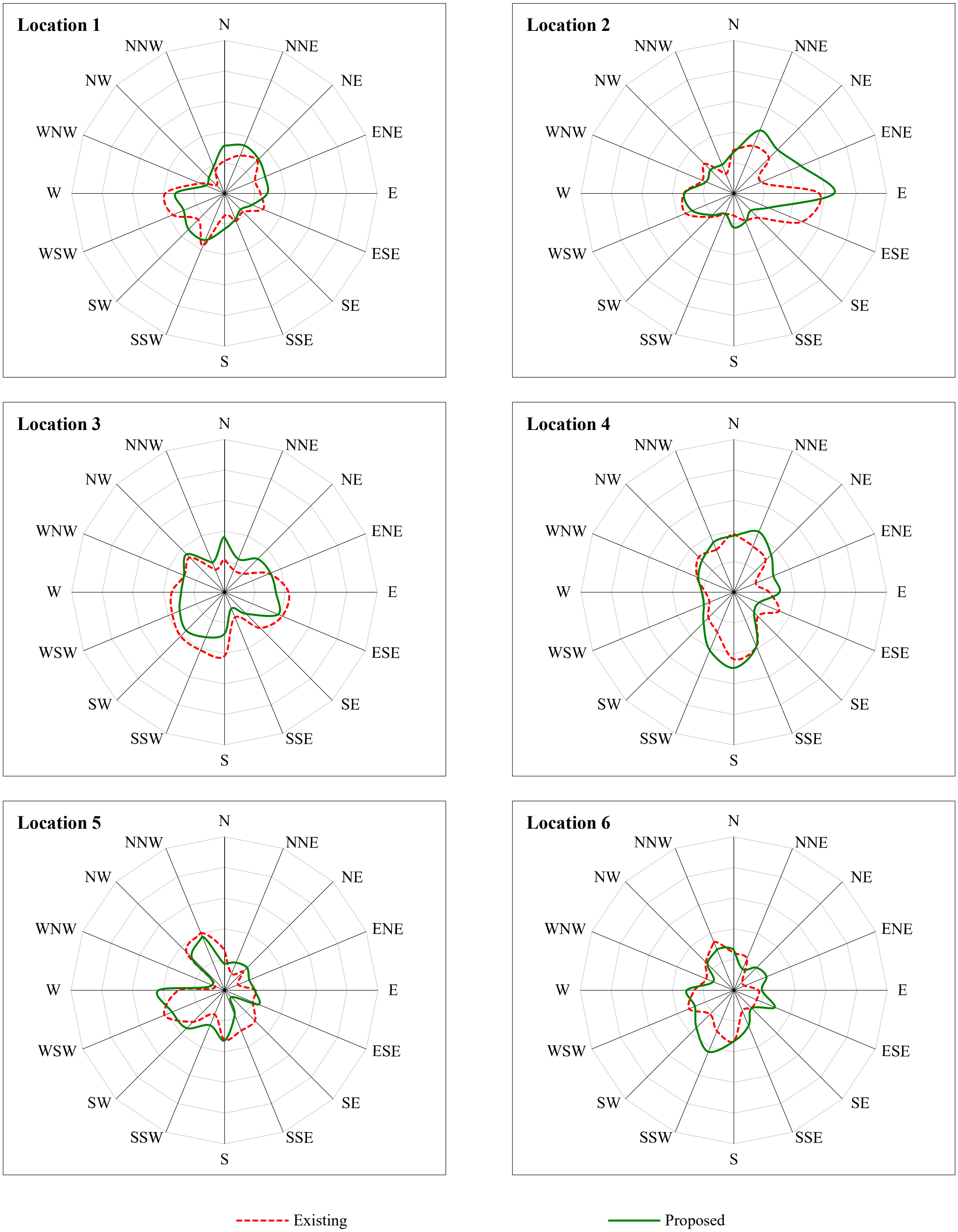


Figure B : Ground level wind velocity as a ratio of gradient wind velocity.

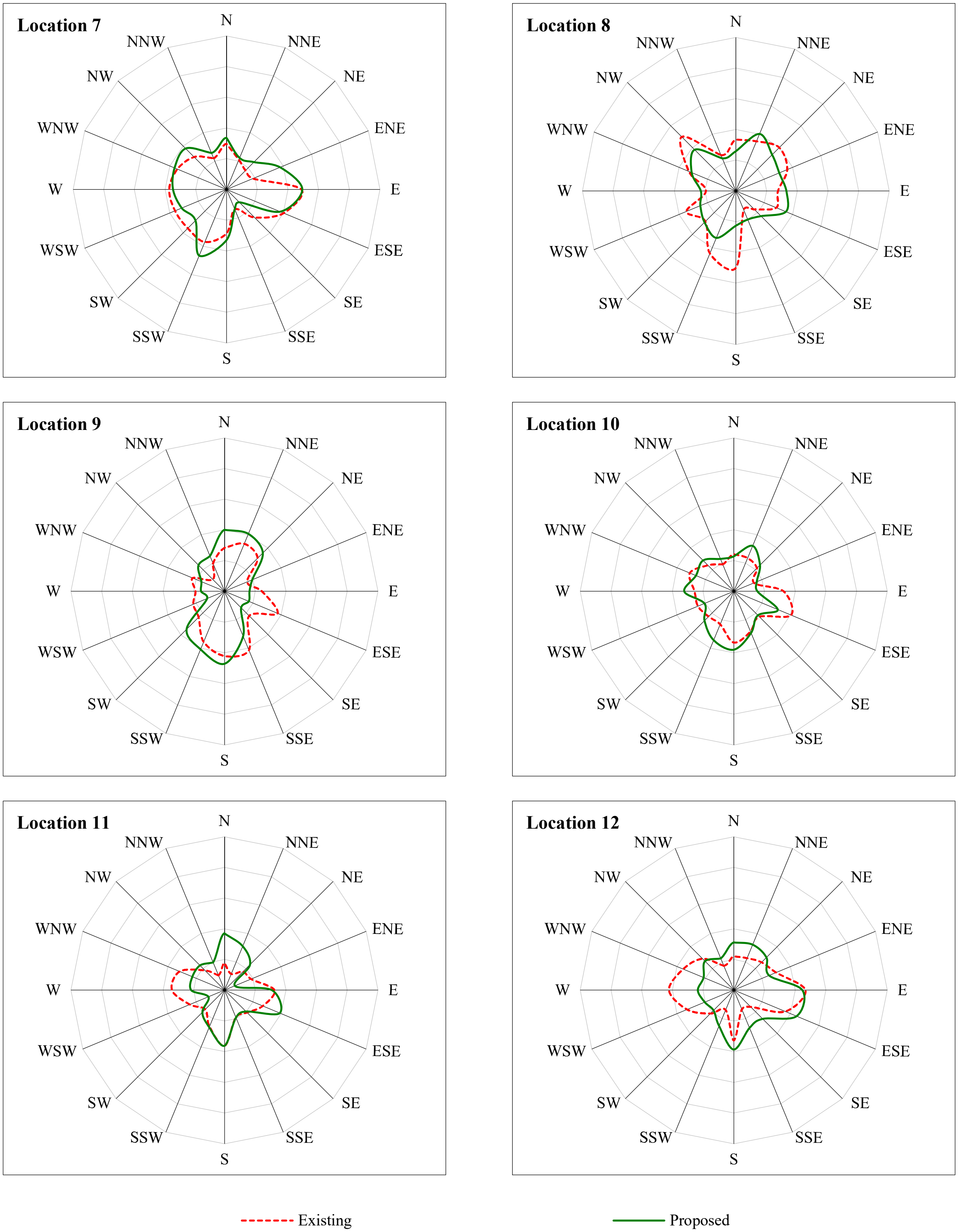
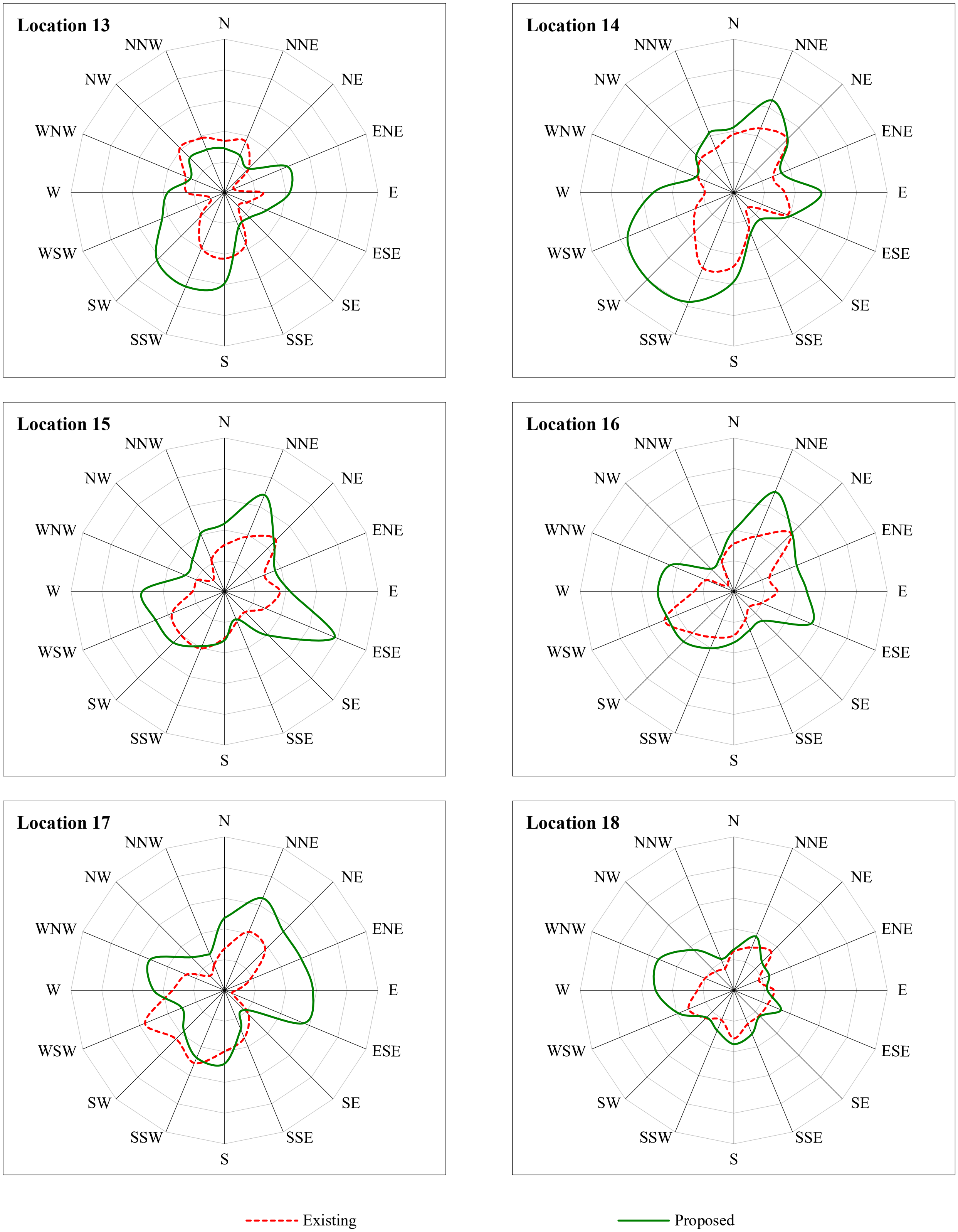


Figure B : Ground level wind velocity as a ratio of gradient wind velocity.



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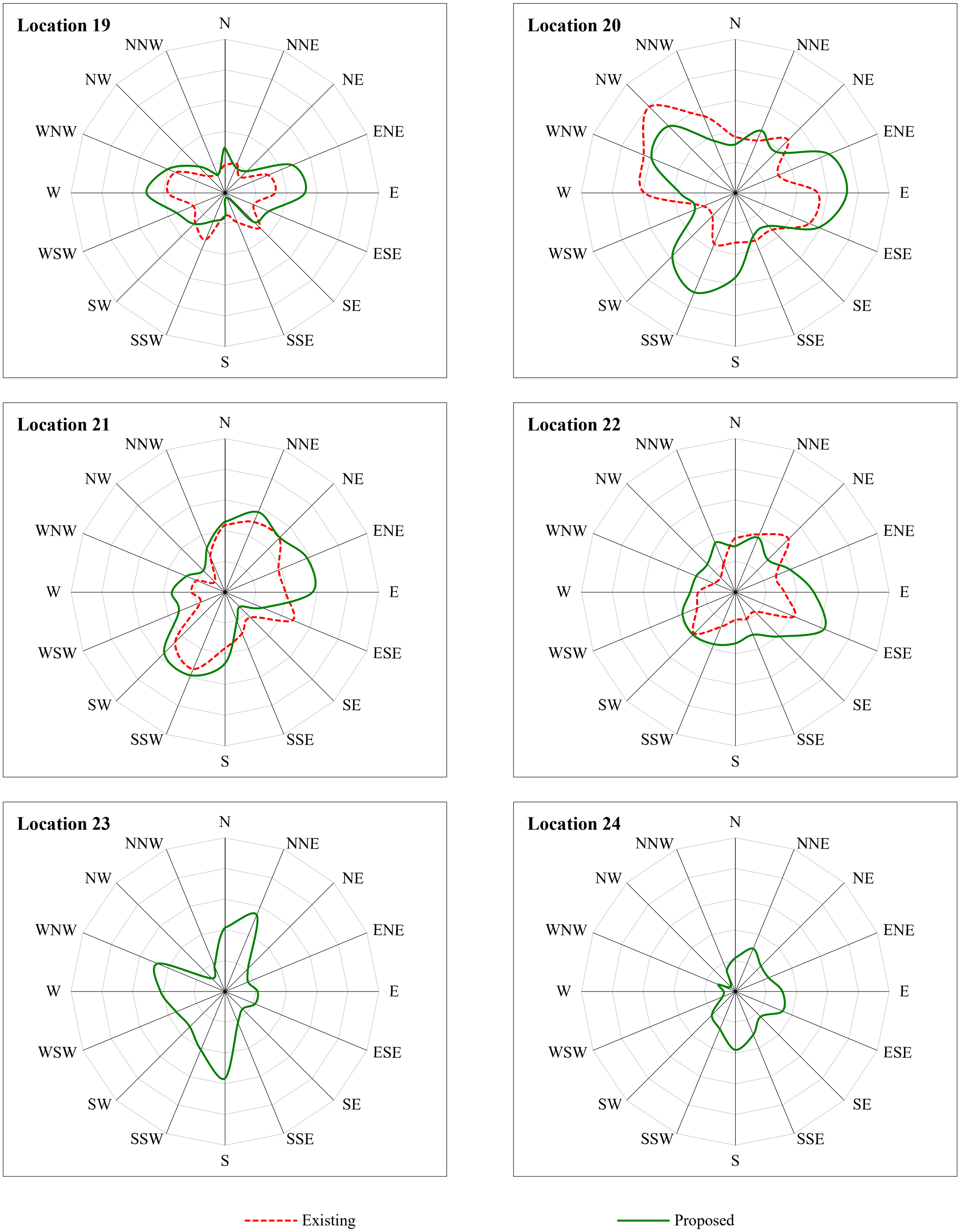

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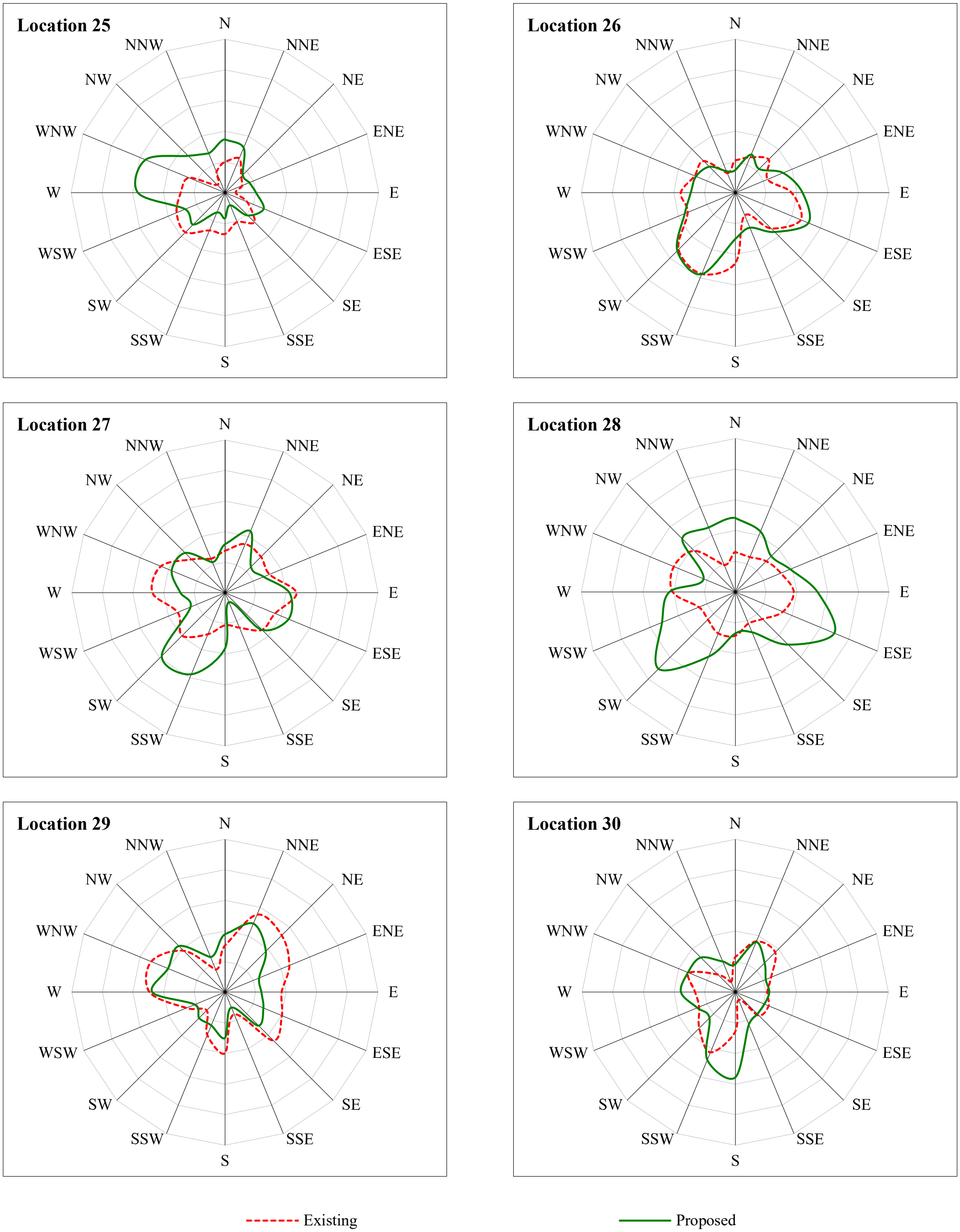

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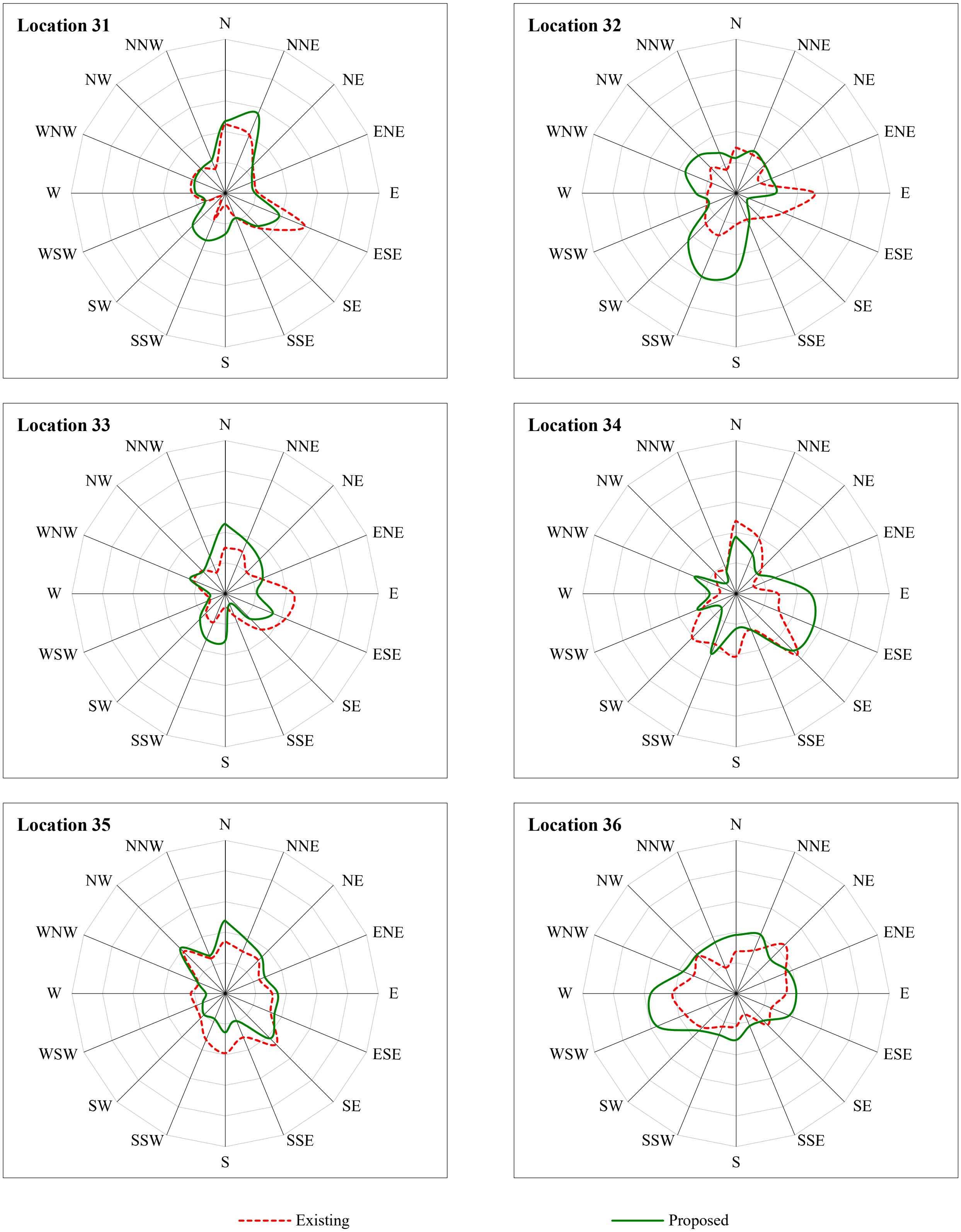

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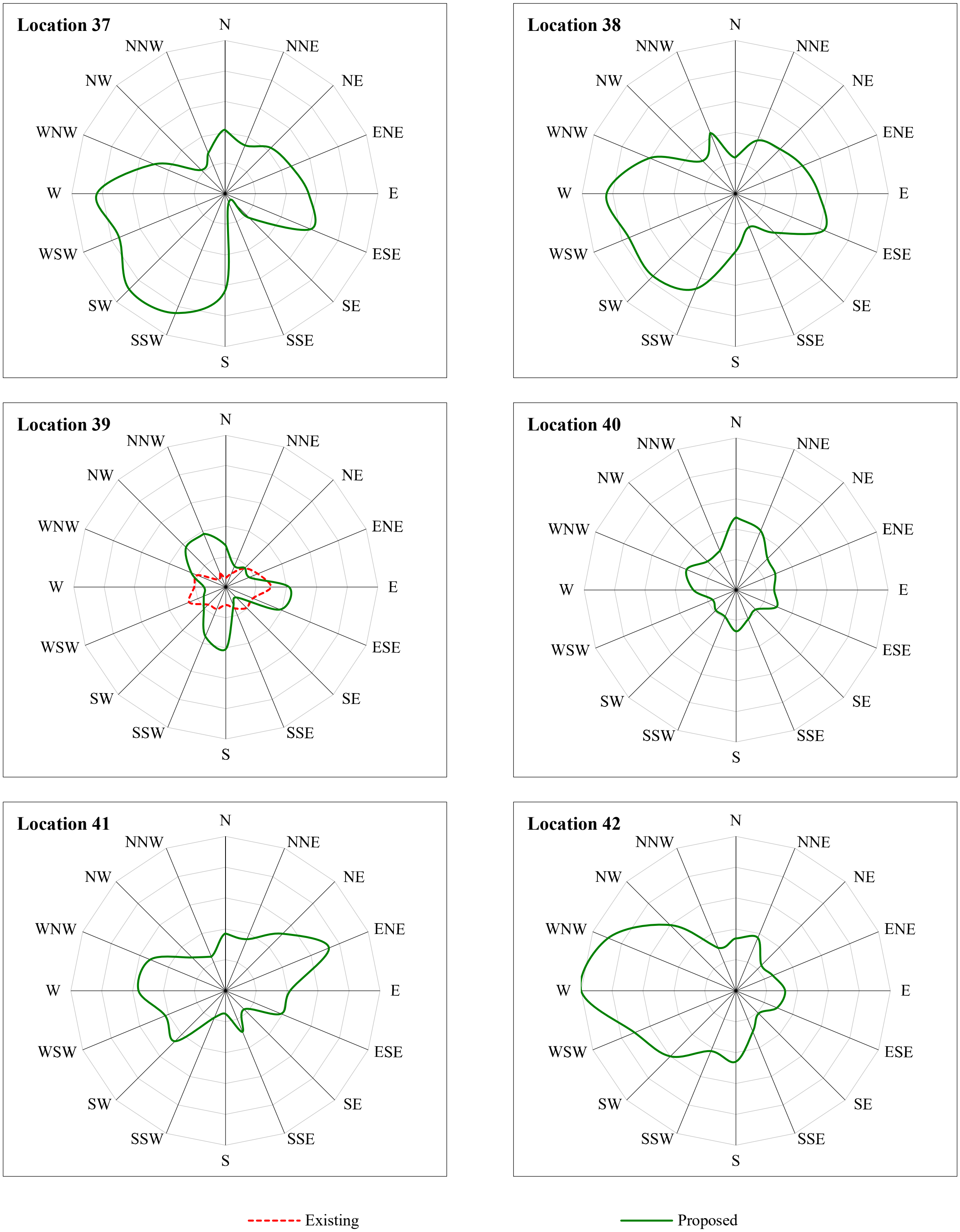

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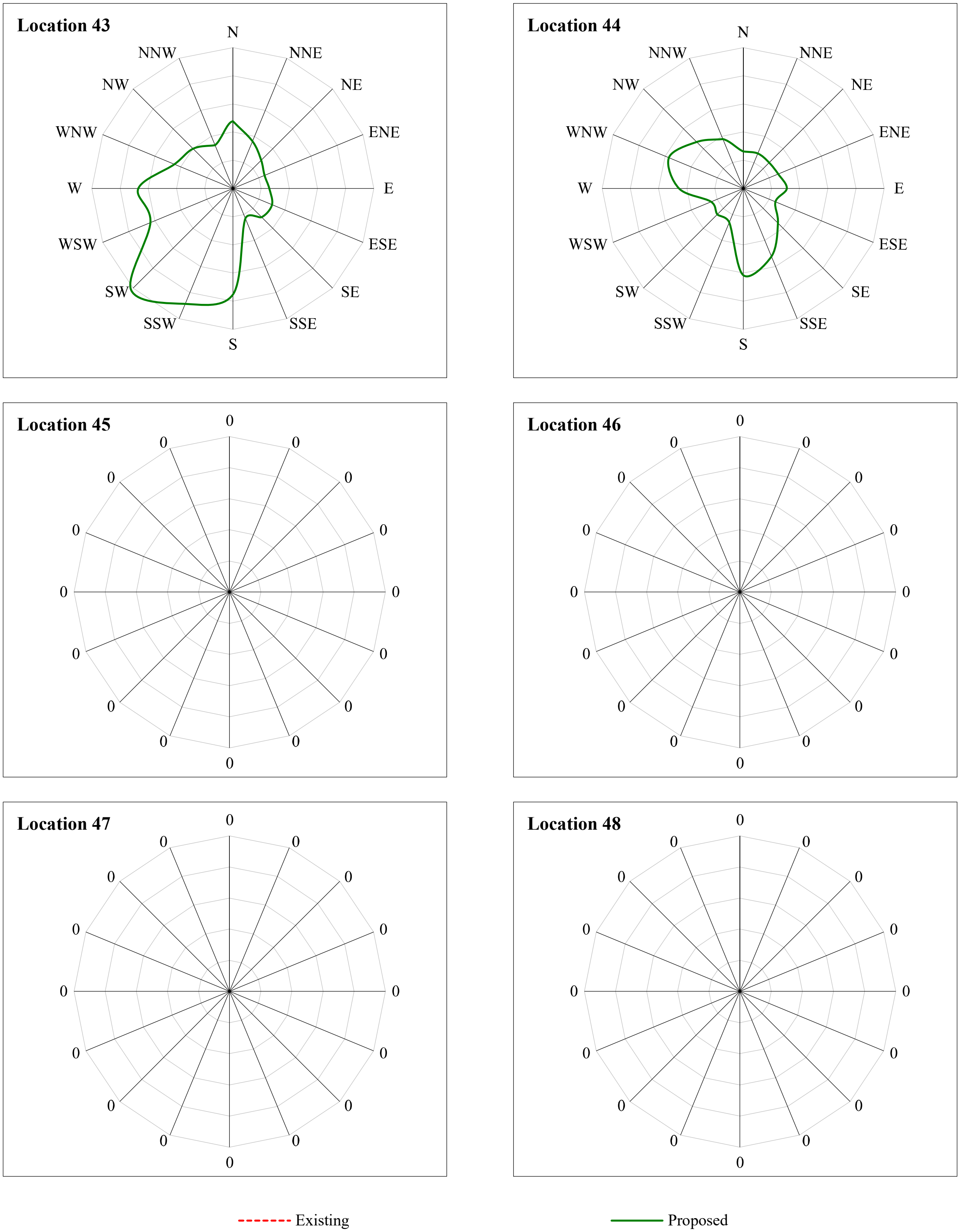

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