REPORT

FINAL PEDESTRIAN LEVEL WIND STUDY

THE PROMENADE

ROBIE STREET & COLLEGE STREET
HALIFAX, NOVA SCOTIA

3088962 NOVA SCOTIA LIMITED

REPORT NO. 20668wind **October 9, 2020**

TABLE OF CONTENTS

1 EXECUTIVE SUMMARY

The Promenade Development proposed by 3088962 Nova Scotia Limited for Robie Street and College Street in Halifax, Nova Scotia 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 are within the safety criteria and most are within the comfort criteria described within the following report.

The proposed Development is located in the City of Halifax and occupies a portion of the block of lands bound by College Street to the south, Robie Street to the west, Spring Garden Road to the north, and Carlton Street to the east. The site is currently occupied by multiple low-rise residential buildings that will be removed. The Development involves a proposal to construct two phases. Phase 1 includes four low-rise, multi-unit dwellings, occupying the eastern portion of the site. Phase 2 includes a 29 storey tower and a 28 storey tower, denoted Towers 1 and 2, with a 3 storey connective podium, occupying the western portion of the site. Based upon this analysis, wind conditions on and around the proposed Development are predicted to be mainly suitable for standing, or better, year-round, under normal to high ambient wind conditions, with a few localised areas proximate to corners and gaps between buildings realising windier conditions, suitable for leisurely walking during the winter.

Suburban lands supporting mainly low-rise residential, commercial, and institutional buildings surround the property, with a few high-rise buildings to the east of the site along College Street. The Halifax Harbour is approximately 1.5km to the east of the site.

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 buildings 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, however the areas will remain generally suitable for the intended uses.

The towers of the proposed Development are punctuated with steps, overhangs, balconies, notches, and other features 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
- irregular facades
- overhangs
- balconies
- canopies
- notches
- 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 not required for the Courtyard area, however if more comfortable conditions are desired through the winter months, a mitigation plan may be applied to the space. Comfort conditions expected at the proposed Development site are in many cases improved, or similar to the existing setting, and considered acceptable to the suburban context.

Respectfully submitted,

Nicole Murrell, M.Eng.

Paul Kankainen, M.A.Sc.

Stephen Pollock, P. Eng.

2 INTRODUCTION

Theakston Environmental, Consulting Engineers, Fergus, Ontario, were retained by 3088962 Nova Scotia Limited to study the pedestrian level wind environment for their proposed The Promenade Development at Robie Street and College Street. The proposed Development will be located in the City of Halifax, the site as depicted on the Aerial Photo in Figure 2a. The Development involves a proposal to construct two phases, with Phase 1 consisting of four low-rise, multi-unit dwellings, occupying the eastern portion of the site and Phase 2 consisting of a 29 and a 28 storey tower with a 3 storey connective podium, occupying the western portion of the site, in the configuration shown in Figure 2b.

Zwicker Zareski Architecture + Planning prepared drawings for the proposed Development. 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, courtyards on the property, 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 current study site as well as existing and proposed buildings in the surrounding area. The proposed configuration included the Development's subject buildings. The ultimate configuration was assessed with selected mitigation strategies during these tests to determine their impact on the various wind conditions.

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 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 respects methodology described by Halifax for predictions of pedestrian comfort for various probabilities of occurrence and percentages of time that are weighted relative to the historical range of wind conditions.

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 visualization of the complex wind flow patterns often realised in an urban environment.

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 the forty-four (44) points tested were subsequently combined with the design probability distribution of gradient wind speed and direction, (wind statistics) recorded at Halifax Shearwater Airport, 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 20% of the time, based on annual, winter, and summer seasons in Figures 6a – 6c. 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 Halifax region that was used in the analysis was based on historical records of wind speed and direction measured at Halifax Shearwater Airport for the period between 1988 and 2018. The meteorological data includes hourly wind records and annual extremes. 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.

4.3 Statistical Wind Climate Model

The design probability distribution of mean-hourly wind speed and wind direction at reference height is shown for Halifax Shearwater Airport in Figure 5. Annual, winter, and summer seasonal distributions are shown. From this it is apparent that winds can occur from any direction, however, historical data indicates the directional characteristics of strong winds are mainly northwest during the winter months and south through southwest during the summer.

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. Zwicker Zareski Architecture + Planning provided architectural drawings. City of Halifax 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 20% 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	**Gust Equivalent Mean Wind Speed Exceeded 20% of the Time***		**Description**
COMFORT	***km/hr***	***m/s*** (used in Fig. 6)	
Sitting	0-10	0-2.78	Calm or light breezes for outdoor restaurants and seating areas where one can read a paper without having it blown away.
Standing	0-14	0-3.89	Gentle breezes suitable for main building entrances and bus stops.
Leisurely Walk	0-17	0-4.72	Moderate winds that would be appropriate for window shopping and strolling along a downtown street, plaza, or park.
Fast Walking	0-20	0-5.56	Relatively high speeds that can be tolerated if one's objective is to walk, run, or cycle without lingering.
Uncomfortable	>20	>5.56	Strong winds of this magnitude are considered a nuisance for most activities, and wind mitigation measures are recommended.

*Note: The Gust Equivalent Mean wind speed = maximum (mean wind, gust speed/1.85)

The activities are described as suitable for Sitting, Standing, Leisurely Walking or Fast Walking, depending on average wind speed exceeded 20% of the time. For a point to be rated as suitable for Sitting, for example, the wind conditions must not exceed 10*km/hr* (2.78*m/s*), more than 20% 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 14*km/hr* (3.89*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 17*km/hr* (4.72*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 20*km/hr* (5.56*m/s*). In this case, whole trees would sway and it would be more 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 20*km/hr* (5.56*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 20% 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 3*km/h* (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 the winter and summer 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 nine times 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. These criteria were developed for pedestrian wind studies and are used in studies around the world.

Table 2: Safety Criteria

ACTIVITY	Gust Equivalent Mean Wind Speed Exceeded nine times per year		Description
SAFETY	***km/hr***	***m/s*** (used in Fig. 8)	
All-Weather Areas	0-90	0-25	Areas that need to be used in all weather conditions, such as building entrances, sidewalks, etc.
Exceeding All-Weather Areas	>90	>25	Excessive gusts that can adversely affect a pedestrian's balance and footing. Wind mitigation is required.

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 & b. In cases where seasonal comfort is important, results have been included for the winter and summer seasons (see Figures 6b and 6c and Figures 7c to 7f).

5 RESULTS

5.1 Study Site and Test Conditions

<u>Proposed Development</u>

The proposed Development is located in the City of Halifax, and occupies a portion of the block of lands bound by College Street to the south, Robie Street to the west, Spring Garden Road to the north, and Carlton Street to the east. The site is currently occupied by multiple low-rise residential buildings that will be removed.

The Development involves a proposal to construct two phases. Phase 1 includes four low-rise, multi-unit dwellings, occupying the eastern portion of the site. Various entrances to the buildings are located along College Street and Carlton Street.

Phase 2 includes a 29 storey tower and a 28 storey tower, denoted Towers 1 and 2, with a 3 storey connective podium, occupying the western portion of the site. A driveway from Robie Street, along the northern site boundary, provides access to the internal courtyard and drop-off area. Various retail and residential entrances are located along Robie Street, College Street, and the internal courtyard.

Surrounding Area

Suburban lands supporting mainly low-rise residential, commercial, and institutional buildings surround the property to all compass points. The only high-rise buildings in the surrounds are located to the east of the Development site, along College Street. To the immediate east of the site are low-rise residential buildings with a 21 storey apartment building at 1470 Summer Street beyond. To the southeast of the site is the 15 storey Sir Charles Tupper Medical building of Dalhousie University. Further to the southeast through south to southwest are low to mid-rise institutional buildings associated with Dalhousie University. To the southwest through northwest of the Development site is St. Andrew's United Church and surrounding low-rise residential neighbourhoods. To the immediate north of the site are low-rise commercial buildings, with mid-rise commercial and residential buildings on the north side of Spring Garden Road. Open lands and mature vegetation associated with Camp Hill Cemetery are to the north beyond, with similar open lands and mature vegetation associated with the Halifax Public Gardens to the northeast.

The Halifax Harbour is approximately 1.5km to the east of the site. Figures 2a and 2b depict the site and its immediate context and the site model, shown in Figure 3, is built to a scale of 1:500.

View of the Proposed Development Site Looking Northeast from Robie Street

Macroclimate

For the proposed Development, the upstream wind flow during testing was conditioned to simulate an atmospheric boundary layer passing over suburban terrain. Historical meteorological data recorded from the Halifax Shearwater Airport was used in this analysis. For studies in the City of Halifax, the historical weather data is depicted on an annual and seasonal basis and the resulting wind roses are presented as mean velocity and percent frequency in Figures 5a-c. The mean velocities presented in the wind roses are measured at an elevation of 10*m*. Thus, representative ground level velocities at a height of 2*m*, 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 dependent upon wind direction and varies with direction but is predominantly suburban.

Winter (November to April) has the highest mean velocities with prevailing winds from the northwesterly quadrant, with significant components from the southwest quadrant as well, as indicated in Figure 5b. Summer (May to October) has the lowest mean wind velocities with prevailing winds from the south through southwest with components from northwest as well, as indicated in Figure 5c. Reported pedestrian comfort conditions generally pertain to the Annual conditions, which are depicted in Figure 5a.

5.2 Pedestrian Level Wind Velocity Study

On the site model forty-four (44) wind velocity measurement probes were located on and around the proposed Development as well as 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 proposed scenario. For the existing setting, the subject building was removed and the "existing" site model retested with the existing buildings.

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 of the Appendices, 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 is applied.

The design probability distribution gradient wind speed and direction, taken from historical meteorological data for the area (see Figures 5a – 5c) 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 annually and for the winter and summer seasons in Figures 6a – 6c.

The ratings for a given location are conservative by design. Those ratings that are close to a transition between ratings will likely assume the more comfortable rating when the existing surroundings and proposed buildings' fine massing details and actual landscaping are taken into consideration. As such the actual 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 exposed to a suburban setting to prevailing and remaining compass points with winds flowing over low to mid-rise buildings that assist in mitigating the approaching wind climate. As such, the surroundings can be expected to influence wind at the site to varying degrees.

It should be noted that the probes are positioned at points typically subject to windy conditions in an urban environment in order to determine the worst-case scenario.

5.3 Review of Probe Results

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

5.3.1 Public Street Conditions

Robie Street
Probes 1 through 11 and 27 through 30 were located along Robie Street, within the zone of influence of the proposed Development, as indicated in Figure 4. The probes indicate conditions in the existing setting that are suitable for sitting on an annual basis, with the exception of probes 8 and 9 that are situated at the intersection with Spring Garden Road, and realised windier conditions, suitable for standing. In the winter months, the street realises slightly windier conditions with more points rated as suitable for standing. The relatively comfortable conditions realised along the street are a reasonable expectation, given the low to mid-rise buildings flanking the street direct a significant portion of the wind climate to flow up and over the area.

With inclusion of the proposed Development a realignment of winds was noted along Robie Street, resulting in localised changes to comfort conditions at a few locations. Probes located proximate to the proposed Development realised an increase in winds emanating from the north and west that were redirected to flow over portions of Robie Street. The changes were sufficient to alter the annual ratings at probes 4, 5, 10, 27, 28, 29, and 30 to suitable for standing annually. In the winter months, probes 4 and 30 realised a sufficient upset to change from suitable for sitting to leisurely walking. In the summer months the street realises more comfortable conditions, suitable for sitting or standing.

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. The subtle increases in winds can be attributed to the proposed Development redirecting winds to flow down and around the proposed buildings and along portions of Robie Street, while improvements can be attributed to the proposed Development providing blockage to locations along the street for winds from specific directions.

As such, with inclusion of the proposed Development, many probe locations along Robie Street, with the above noted exceptions, retained their original annual pedestrian comfort ratings. The street remains comfortable and suitable for the intended use year-round. Consideration of existing and proposed building elements that were too fine to incorporate into the model, and landscaping, will result in more comfortable conditions than those reported.

Robie Street remains within the pedestrian level wind velocity safety criteria as All-Weather Areas, as described in Section 4.7 and depicted in Figure 9.

Spring Garden Road

Probes 12 through 18 were situated along Spring Garden Road, to the north of the proposed Development. In the existing setting, the street realises annual conditions mainly suitable for standing, with the exception of probes 16 and 14 that were rated for sitting, and probe 18 that was rated for leisurely walking.

With inclusion of the proposed Development, the street realises relatively similar conditions, with a few areas noting improvements that were sufficient to change the annual comfort ratings. Probes 12 and 18 realised a realignment of winds sufficient to improve the annual ratings from standing to sitting and leisurely walking to standing, respectively. The improvements can be attributed to the proposed Development blocking winds from specific directions and redirecting winds to flow in different patterns along the adjacent roads.

In the winter months, similar conditions were noted along Spring Garden Road, with probe 18 rated suitable for leisurely walking in the existing and proposed settings. Probe 13 realises a sufficient increase in southwesterly winds to change the winter rating from standing to leisurely walking.

Spring Garden Road remains comfortable and suitable to the area's intended purpose with inclusion of the proposed Development and the reported pedestrian comfort conditions do not pose a concern to pedestrian safety as indicated in Figure 9; the points are rated as All-Weather Areas.

Carlton Street

Probes 19, 38, and 39 were placed along Carlton Street to the east of the proposed Development. In the existing setting, the street is well protected from the majority of the wind climate by the flanking low-rise buildings, resulting in conditions that are predicted suitable for sitting year-round. In the proposed setting, Carlton Street realises subtle changes in winds, insufficient to change the ratings throughout the year. This is a reasonable expectation given the adjacent low-rise Phase 1 buildings are not a substantial change in massing compared to the existing setting, and the high-rise Phase 2 buildings are sufficiently removed from Carlton Street and do not pose a significant influence on winds along the street. Carlton Street will remain comfortable and suitable for the intended purpose and within the pedestrian level wind velocity safety criteria as an All-Weather Area, as depicted in Figure 9.

College Street

Probes 21 through 25, and 31 through 37 were situated along College Street within the zone of influence of the proposed Development. These locations indicate relatively comfortable conditions along College Street, mainly suitable for sitting, annually. Windier conditions, rated suitable for standing, are realised proximate to the intersection with Carlton Street and adjacent to the 15 storey Sir Charles Tupper Medical building of Dalhousie University, at probes 23 through 25 and 35 through 37. The western portion of the street will realise generally more comfortable conditions as it is sheltered by the flanking low to mid-rise buildings, as represented by the annual sitting ratings. Similar conditions were noted through the winter, however probe 25 realises windier conditions, rated for leisurely walking.

With inclusion of the proposed Development a realignment of winds along College Street was noted, improving winds from specific directions and exacerbating others, as indicated in the ground level wind velocity plots of Appendix Figure B. Probes located proximate to the site realised a general increase in winds, sufficient to change the annual ratings at probes 33 and 34, located along the southern façade of Tower 2, from sitting to standing annually and to leisurely walking in the winter. Probes 21 and 37 similarly realised an increase in winds, sufficient to change the annual and winter ratings to suitable for leisurely walking. These changes in winds can mainly be attributed to the Phase 2 towers redirecting winds from the north and west to flow down and around the towers and ultimately accelerating along portions of College Street.

Conversely, probes more removed from the Development site realised slight improvements in wind conditions due to the proposed Development providing blockage to dominant winds emanating from westerly directions. These improvements were sufficient to change the annual ratings for probes 23 and 24 from standing to sitting. Remaining probes along College Street retained their annual comfort ratings.

The analysis indicates College Street will remain comfortable and realise conditions that are suitable to the intended purpose. The predicted conditions will improve upon consideration of massing and landscape details too fine to incorporate into the model. College Street will remain within the safety criteria as an All-Weather Area.

5.3.2 Neighbouring Site Conditions

Probe 20 was situated adjacent to the main entrance to the neighbouring Forrest Building on Dalhousie campus, to the southeast of the proposed Development. In the existing setting, the entrance is well protected from much of the dominant wind climate and as such is predicted suitable for standing annually. In the summer months, the entrance realises more comfortable conditions, suitable for sitting. With inclusion of the proposed Development, the area realises a slight realignment of winds, insufficient to change the annual or seasonal ratings. The neighbouring entrance remains suitable for the intended use and within safety criteria as an All-Weather Area.

Probe 4 was situated along Robie Street adjacent to the main entrance to the neighbouring St. Andrews United Church, to the west of the proposed Development. In the existing setting, the area was rated suitable for sitting year-round. With inclusion of the proposed Development, the probe adjacent to the main entrance realises windier conditions, rated suitable for standing in the summer and leisurely walking through the winter months. The entrance is set back from the street and as such is predicted to realise more comfortable conditions than the street beyond. The winter rating is at the transition to standing and with consideration of fine design and landscape features, will realise more comfortable conditions than reported, suitable for standing year-round. Probe 26 was situated adjacent to a secondary entrance to St. Andrews United Church and was rated suitable for sitting year-round in both the existing and proposed settings. The entrances to St. Andrews United Church will be comfortable and suitable for the intended use, and fall within the safety criteria as All-Weather Areas.

5.3.3 Pedestrian Entrance Conditions

Phase 1 Entrances
Probes 35 and 36 were located along College Street, proximate to private residential entrances to the Phase 1 buildings. The entrances are exposed to winds emanating from the northwest and southwest that are redirected by the proposed buildings to flow along College Street, however the area remains suitable for standing, annually. Probes 38 and 39 were located along Carlton Street, proximate to private residential entrances to the Phase 1 buildings. The entrances are protected from the majority of the wind climate by the proposed Development and surrounds and as such are rated suitable for sitting year-round.

Wind conditions comfortable for standing are preferable at building entrances, while conditions suitable for walking are suitable for walkways. The private residential entrances to the Phase 1 buildings are set back from the above-mentioned streets and as such will realise more comfortable conditions than the probes beyond. The Phase 1 entrances remain comfortable and suitable for the intended use year-round and fall within the safety criteria as All-Weather Areas.

Phase 2 Entrances

Probes 29 and 30 were situated adjacent to Retail Entrances to Tower 1 along Robie Street. Probe 29 realises conditions suitable for standing in the winter and sitting through the summer, however the retail entrance is set back into a notch in the façade of the building and will realise more comfortable conditions than the sidewalk beyond. Probe 30 is located at the corner of Robie Street and College Street and as such is exposed to dominant winds from westerly directions that are directed to accelerate around the corner of the building, creating windswept conditions. This results in conditions suitable for leisurely walking through the winter and standing through the summer. The winter rating is at the transition to standing and with consideration of fine design details and landscaping, will realise more comfortable conditions than those reported. As such, the entrance is predicted to realise comfortable conditions, suitable for standing much of the time, and appropriate for the intended use.

Probes 32 and 40 were situated adjacent to the Main Residential Entrances to Towers 1 and 2, accessed to the south and north of the connective podium. The entrance along College Street, represented by probe 32, is set back into the façade of the building and as such is protected from large portions of the wind climate. The entrance is rated suitable for sitting in the summer and standing through the winter months, and appropriate for the intended use. The entrance within the courtyard area, represented by probe 40, is similarly protected from large portions of the wind climate by the proposed Development, and as such is rated suitable for sitting in the summer and standing through the winter, and appropriate for the intended use as well.

Probes 33 and 34 were located adjacent to private residential entrances to Tower 2, along College Street. The area is susceptible to dominant winds from the west that are directed by the proposed Development to flow down College Street, and as such realise relatively windy conditions, suitable for leisurely walking in the winter and standing through the summer. The entrances are set back from the sidewalk, in notches in the façade of the building, and as such will be protected from portions of the wind climate, resulting in more comfortable conditions than the sidewalk beyond. Consideration of this, as well as fine design and landscape features, will result in comfortable conditions at the private entrances along College Street, suitable for standing much of the time.

Probes 42, 43, and 44 were located adjacent to private residential entrances to Tower 2, along the northern and eastern façades of the building. The area is well protected by the proposed buildings and surrounds to much of the wind climate and as such the entrances realise comfortable conditions, suitable for standing year-round, with the exception of probe 42 that is suitable for sitting through the summer months.

Wind conditions comfortable for standing are preferable at building entrances, while conditions suitable for walking are suitable for walkways. The walkways adjacent to the various entrances to Phase 2 of the proposed Development will realise conditions suitable for the intended use of walking. The adjacent entrances are set back into the façades of the buildings and will realise more comfortable conditions than the sidewalks beyond, appropriate for the intended uses much of the time. Consideration of existing and proposed surface roughness features too fine to incorporate into the massing model as well as landscape features will likely translate into comfort ratings better than those described above.

The Residential and Retail Entrances to Phase 2 of the proposed Development are rated as All-Weather Areas.

5.3.4 Outdoor Amenity Courtyard Space

An Outdoor Amenity Courtyard area is proposed to the north of the connective podium between Towers 1 and 2, represented by probes 40 and 41. The area is well protected by the proposed Development from the majority of the wind climate and as such is predicted comfortable for sitting through the summer months. Through the winter months, the courtyard will realise slightly windier conditions, suitable for standing, mainly due to dominant winds emanating from the west, flowing around the northern façade of Tower 1 and over the area. The space is expected to be subject to seasonal use, however if more comfortable conditions are desired through the winter months, application of a mitigation plan will improve the conditions in the area. The mitigation plan may include coniferous trees, coarse plantings in raised planters, wind screens, trellises, or others, situated as practical about the space.

Comfort conditions generally suitable for sitting are preferred for amenity spaces during the summer months and extending well into the shoulder seasons. The Courtyard is predicted to be comfortable and suitable for the intended purpose through the summer and much of the shoulder months. If more comfortable conditions are desired through the winter months, a mitigation plan, as described above, may be applied to the space. The Outdoor Amenity Courtyard falls within the safety criteria as an All-Weather Area.

5.3.5 Summary

The observed wind velocity and flow patterns at the Development are largely influenced by approach wind characteristics that are dictated by the surrounding areas to prevailing wind directions. These surroundings moderate wind flow in streamlines near the pedestrian level, resulting in generally comfortable conditions with localised windy conditions proximate to open areas within gaps between significant buildings. Historical weather data measured at Halifax Shearwater Airport indicates the mean annual wind speed is 13 km/h with wind speeds greater than 30 km/h occurring approximately 10 percent of the time during the winter, and 2 percent of the time during the summer.

Once the subject site is developed, ground level winds at several locations will improve from specific directions, with occasional localized areas of higher pedestrian level winds, resulting in wind conditions that are predicted as windy at times, but remain 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 or standing under normal wind conditions annually; however, under high ambient winter wind conditions with winds emanating from specific directions, localised areas along the adjacent public streets will be slightly windy from time to time, but remain appropriate to the intended purpose. Additional mitigation is not required for the Courtyard area, however if more comfortable conditions are desired through the winter months, a mitigation plan may be applied to the space. 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

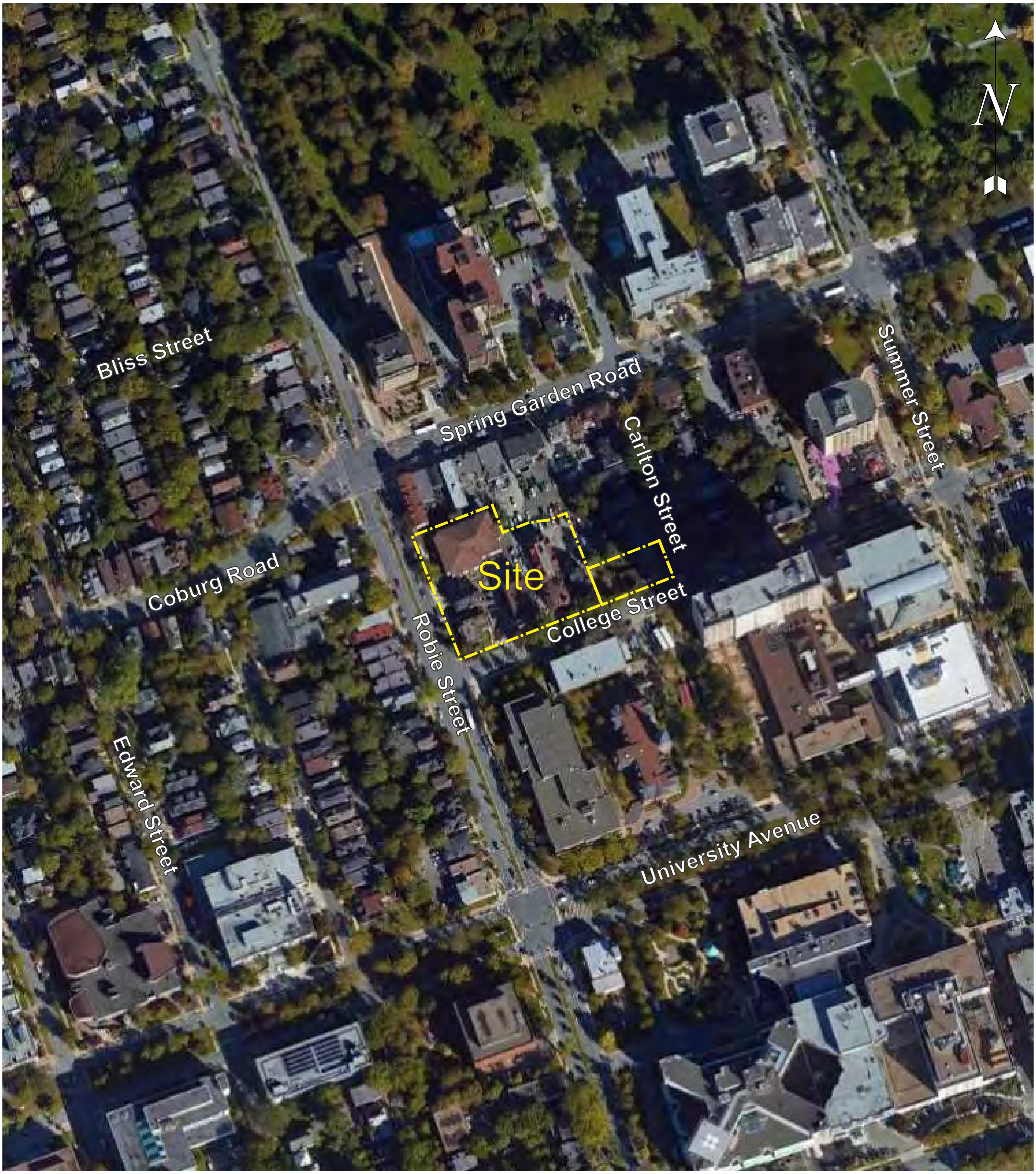


Figure 2b: Site Plan

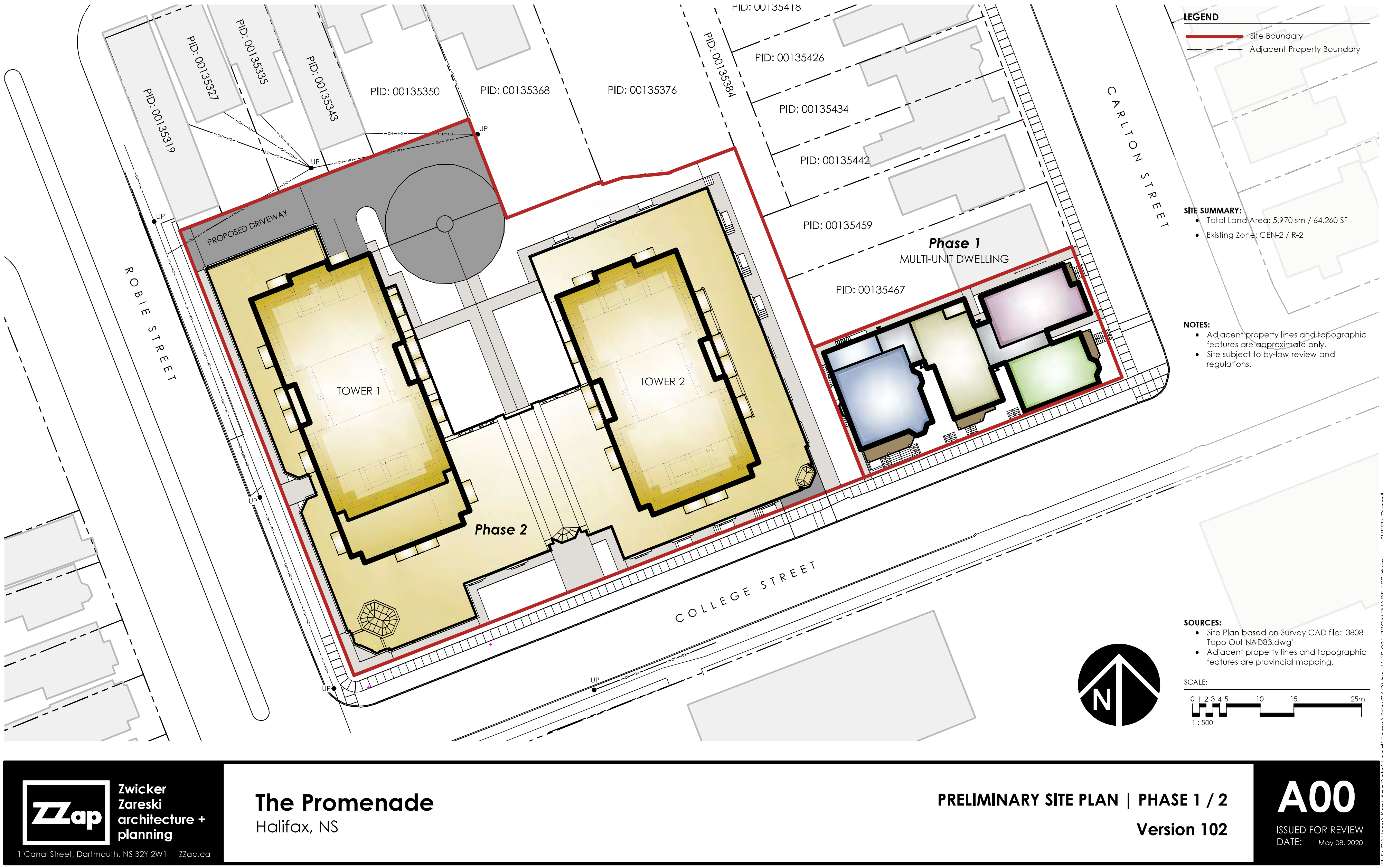


Figure 3: 1:500 Scale model of test site

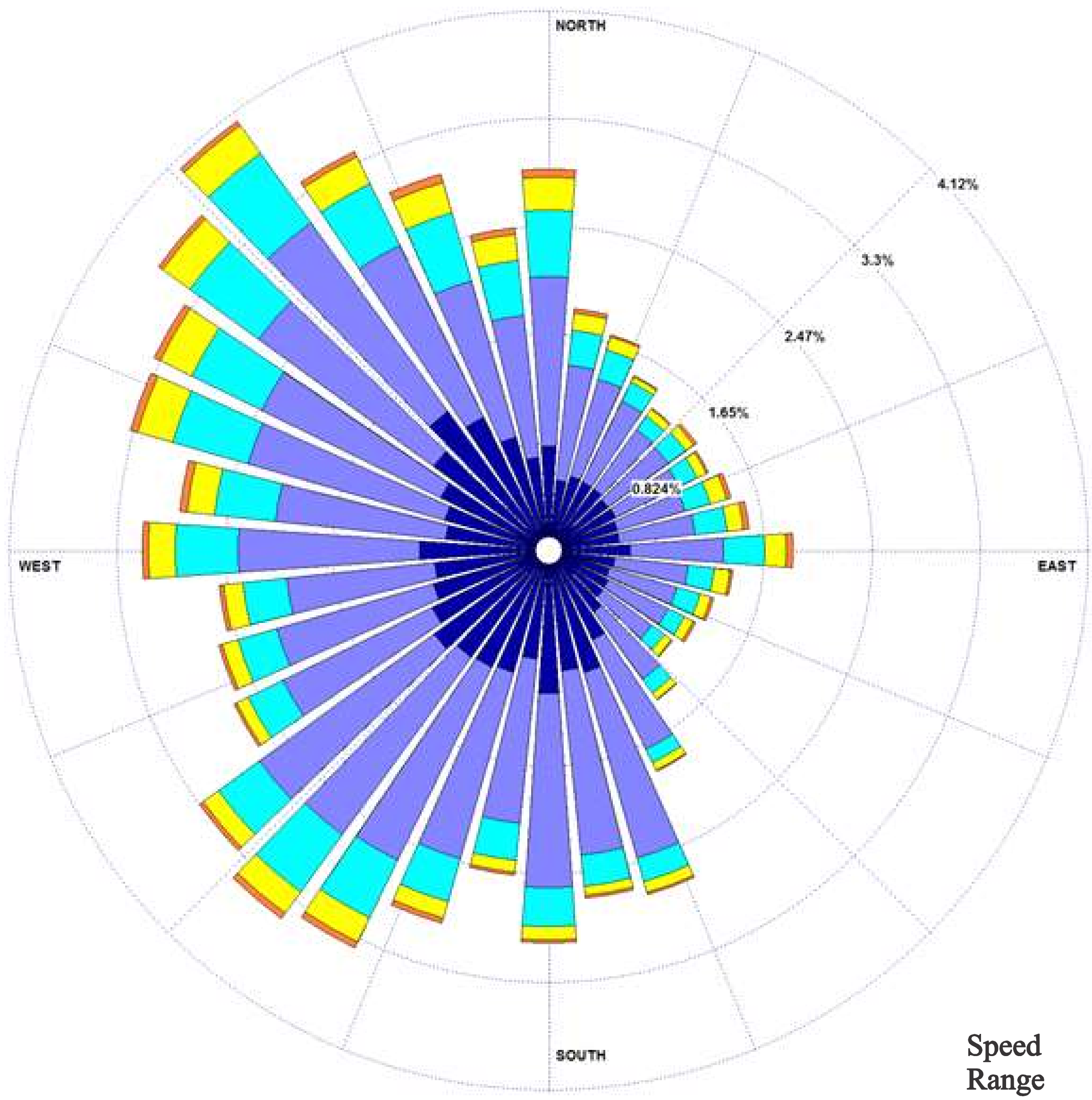
a) Overall view of model - Proposed Site

b) Close-up view of model - Proposed Site

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

Figure 5a: Annual Wind Rose - Halifax Shearwater Airport.

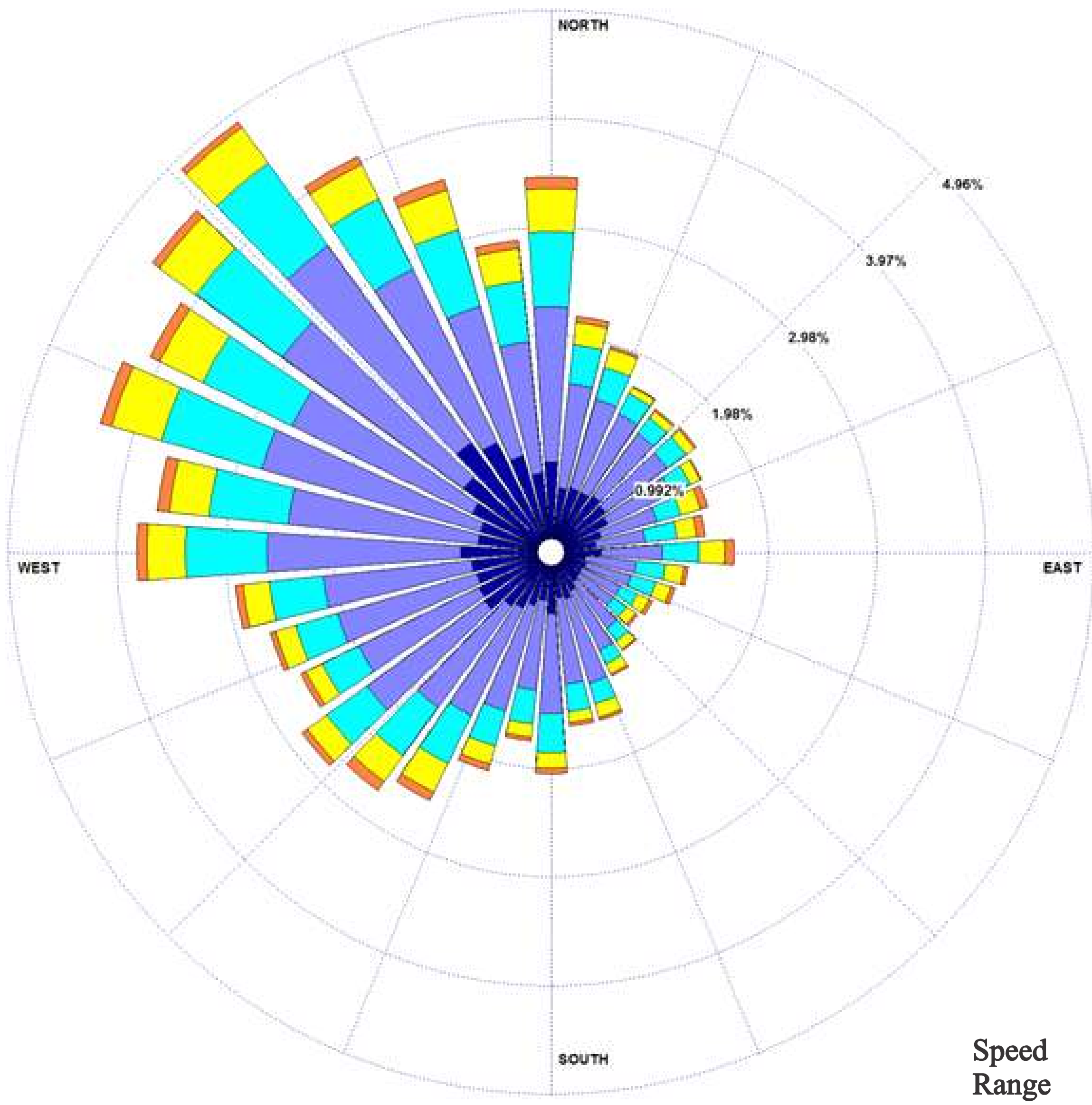
Historical Directional Distribution of Winds (@ 10*m* height)
(1988 - 2018)



Speed Range	Probability (%)
Calm	14%
1 - 10*km/h*	29%
11 - 20*km/h*	39%
21 - 30*km/h*	12%
31 - 40*km/h*	5%
> 40*km/h*	1%

Figure 5b: Winter Wind Rose - Halifax Shearwater Airport.

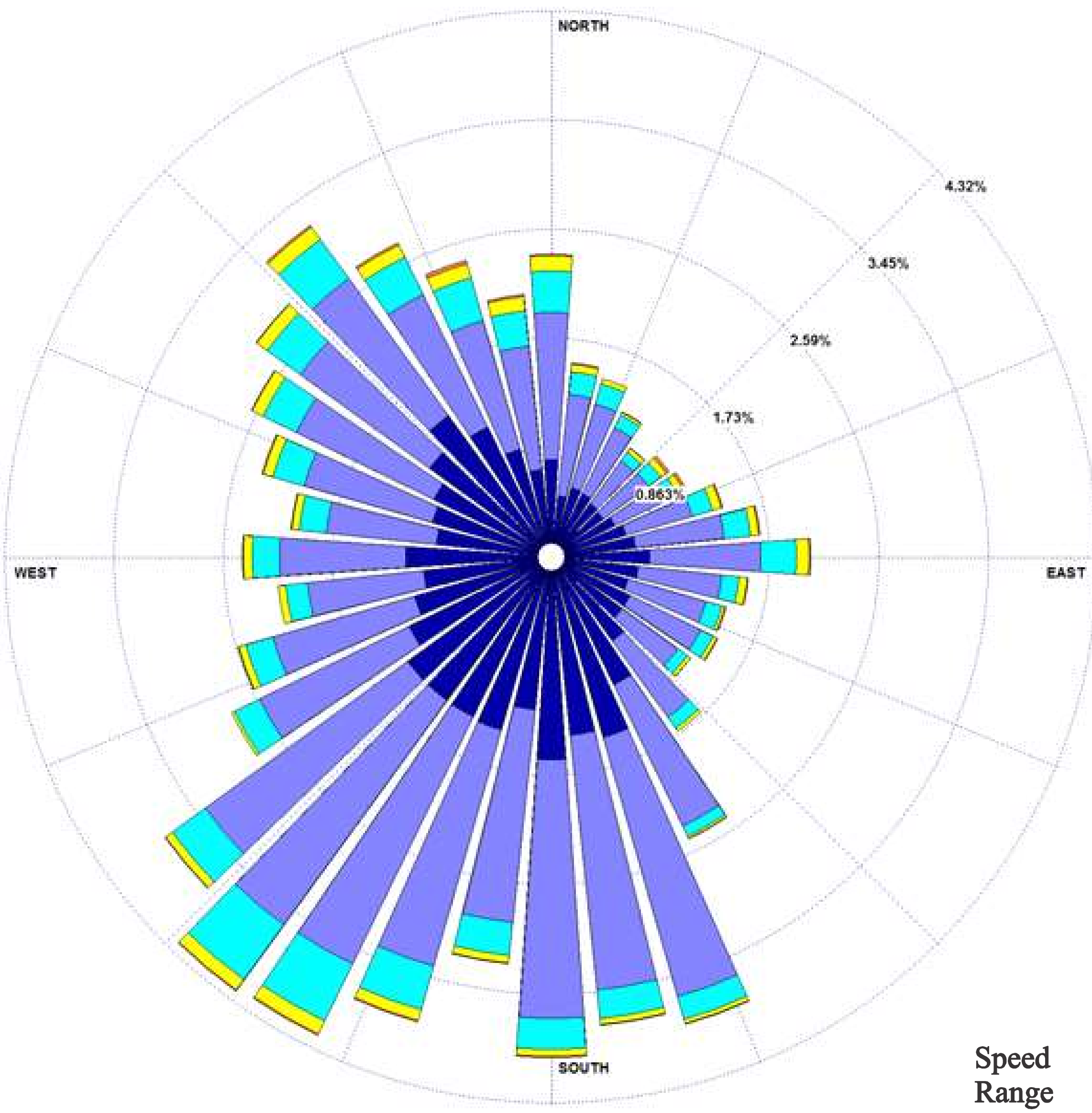
Historical Directional Distribution of Winds (@ 10*m* height)
November through April (1988 - 2018)



Speed Range	Probability (%)
Calm	14%
1 - 10*km/h*	22%
11 - 20*km/h*	38%
21 - 30*km/h*	16%
31 - 40*km/h*	8%
> 40*km/h*	2%

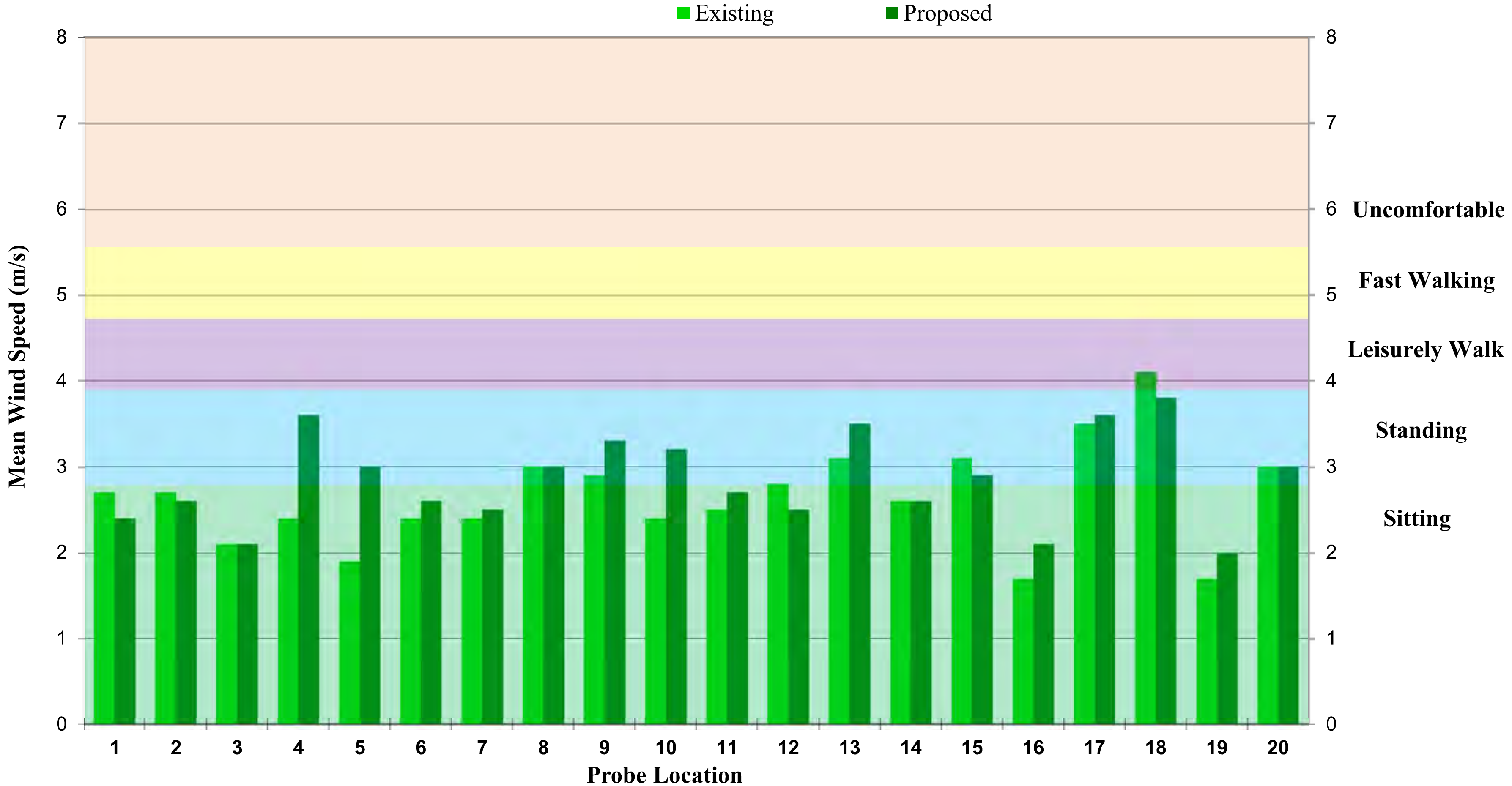
Figure 5c: Summer Wind Rose - Halifax Shearwater Airport.

Historical Directional Distribution of Winds (@ 10*m* height)
May through October (1988 - 2018)



Speed Range	Probability (%)
Calm	14%
1 - 10*km/h*	35%
11 - 20*km/h*	41%
21 - 30*km/h*	8%
31 - 40*km/h*	2%
> 40*km/h*	<1%

Figure 6a: ANNUAL - Wind Speed Exceeded 20% of the Time (Locations 1 to 20).



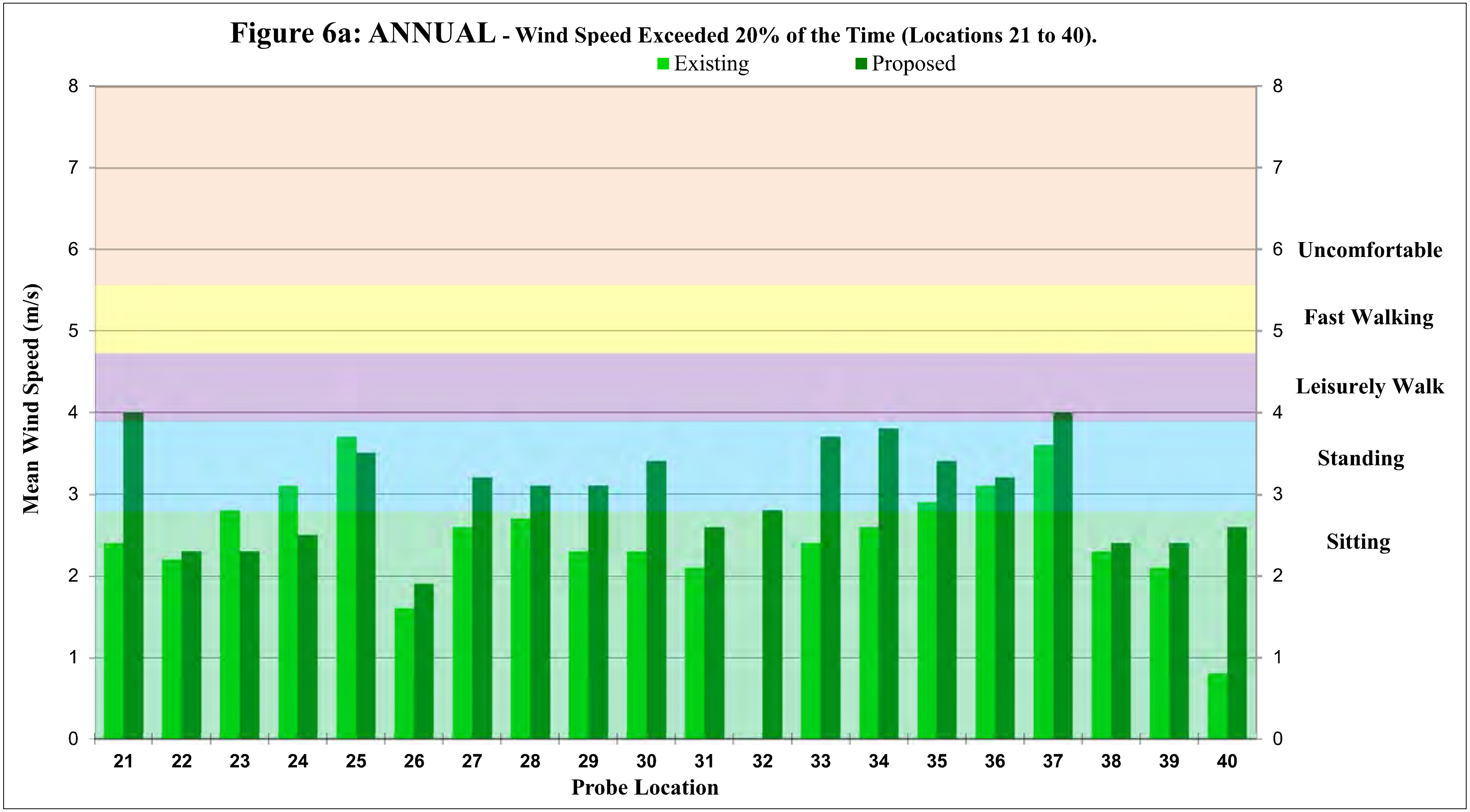
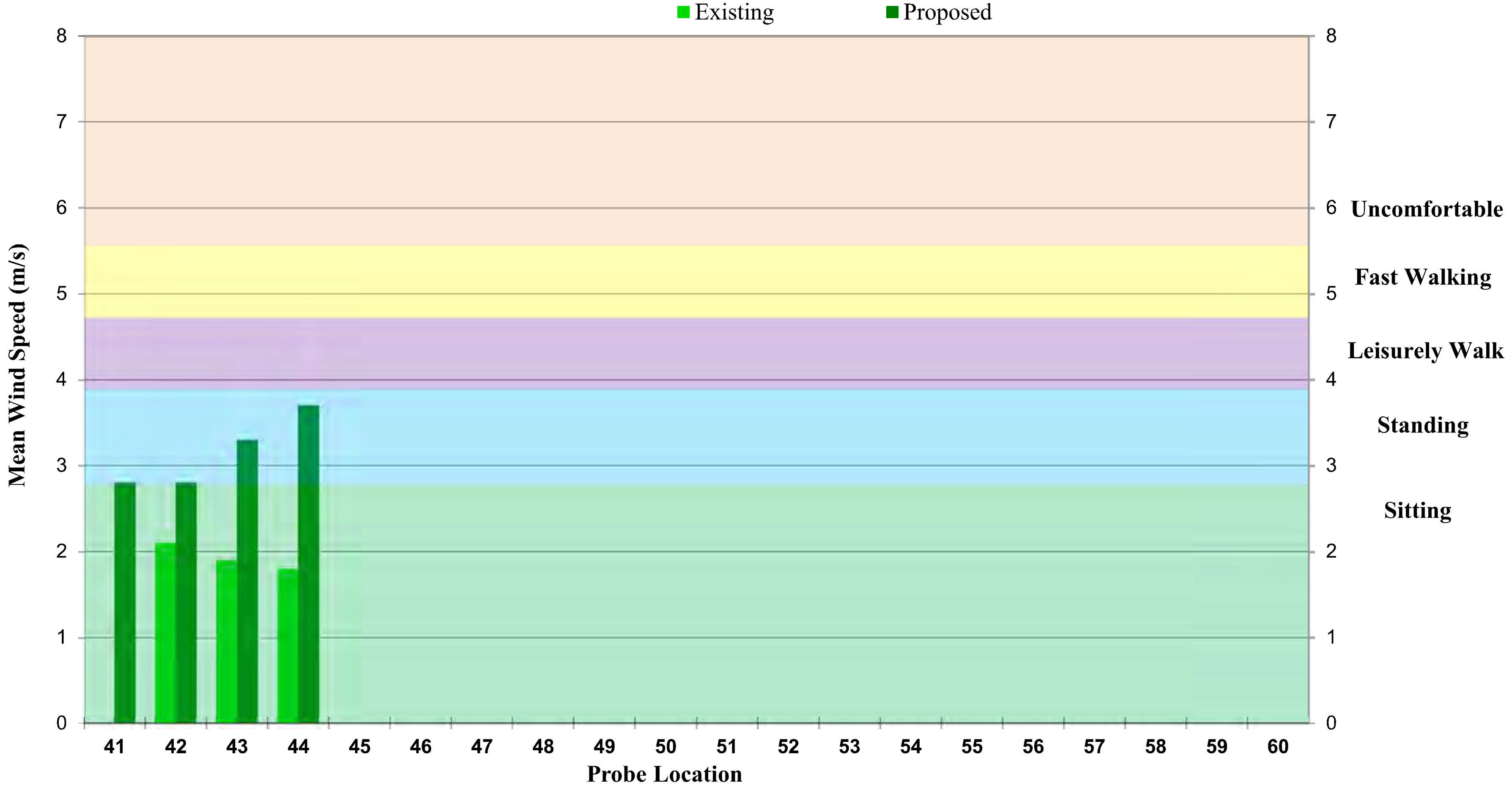


Figure 6a: ANNUAL - Wind Speed Exceeded 20% of the Time (Locations 21 to 40).
Existing
Proposed
Mean Wind Speed (m/s)
Probe Location
Uncomfortable
Fast Walking
Leisurely Walk
Standing
Sitting
0
1
2
3
4
5
6
7
8
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40

Figure 6a: ANNUAL - Wind Speed Exceeded 20% of the Time (Locations 41 to 44).



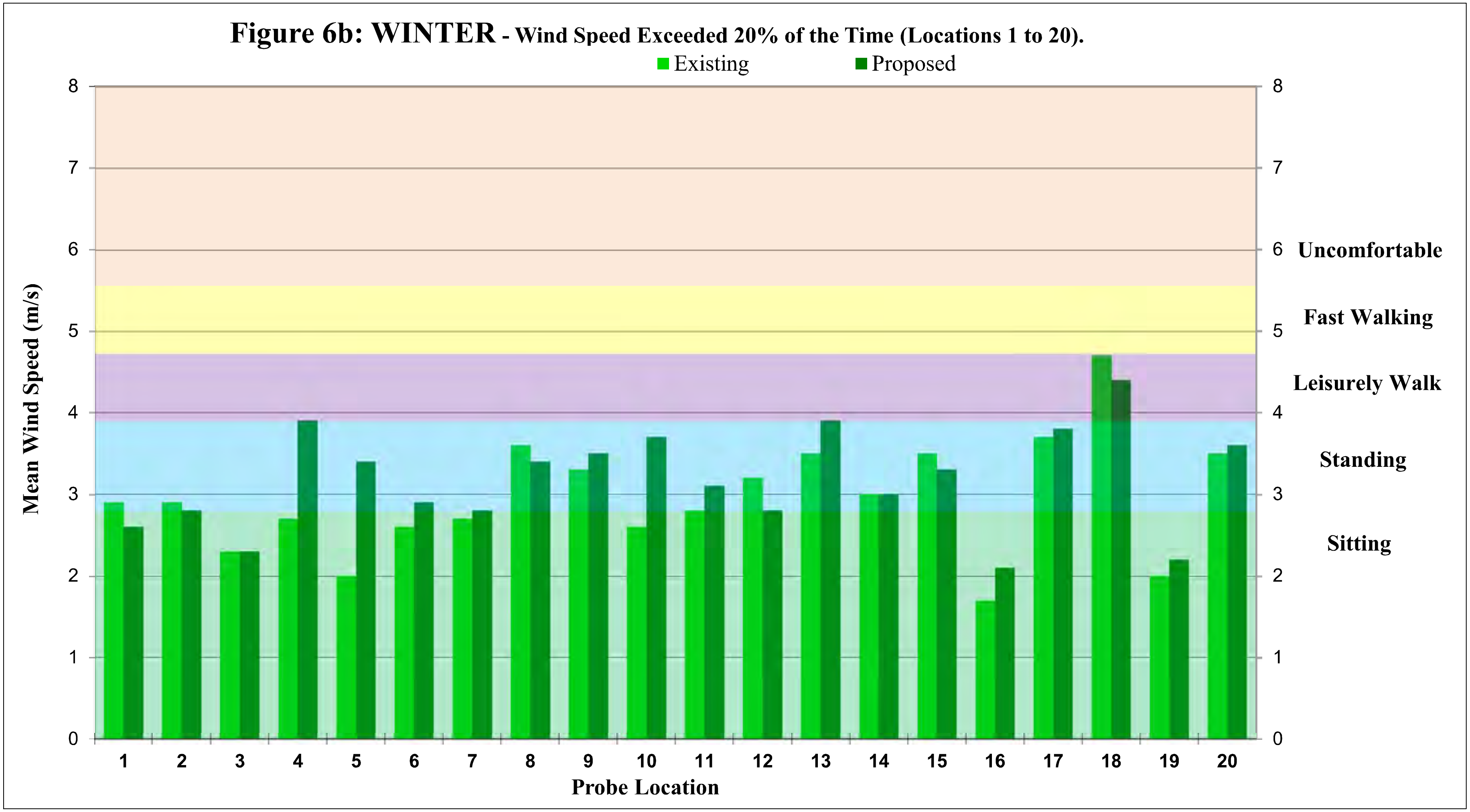


Figure 6b: WINTER - Wind Speed Exceeded 20% of the Time (Locations 1 to 20).
Existing
Proposed
Mean Wind Speed (m/s)
Probe Location
Uncomfortable
Fast Walking
Leisurely Walk
Standing
Sitting

Figure 6b: WINTER - Wind Speed Exceeded 20% of the Time (Locations 21 to 40).

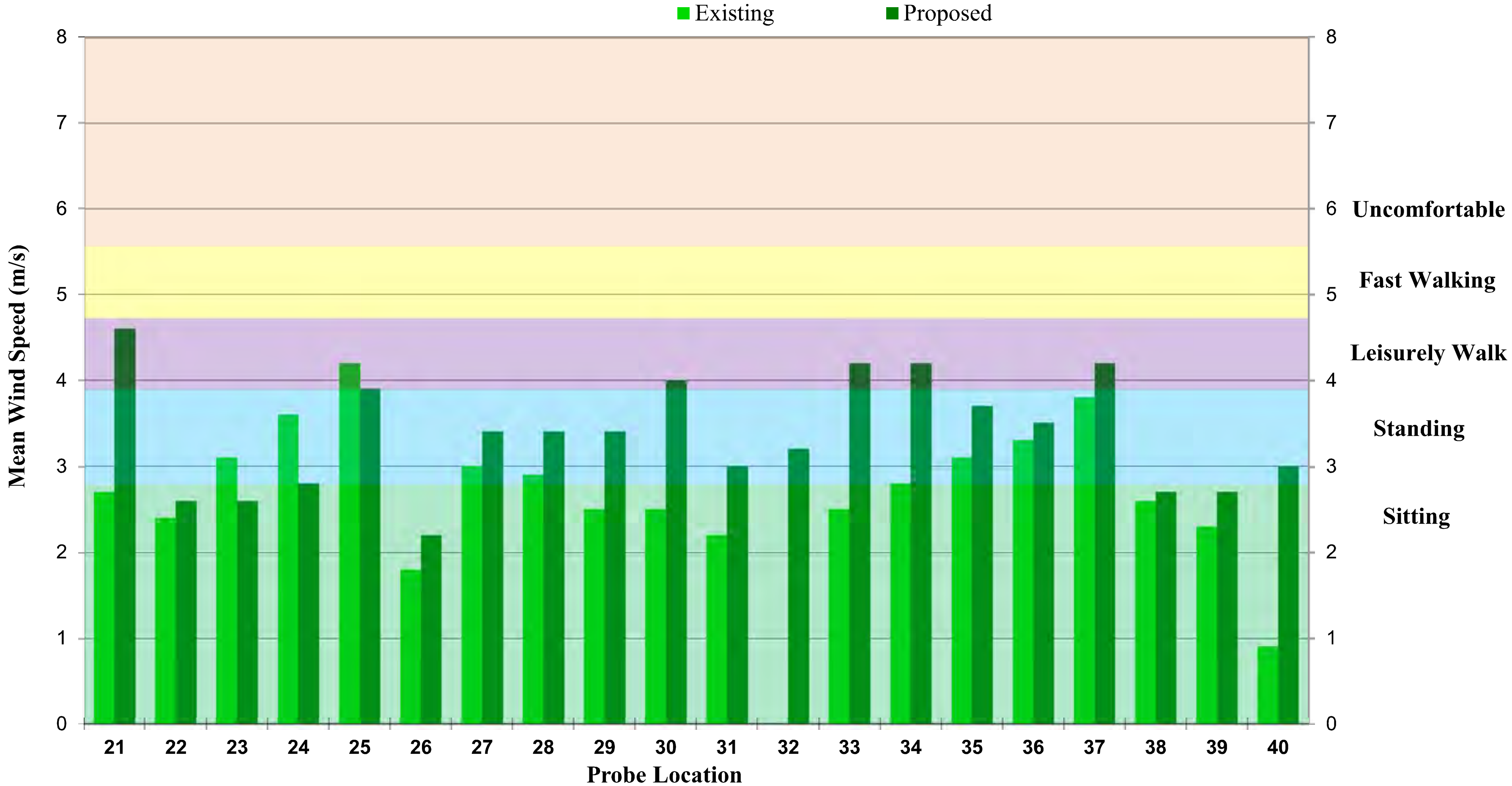
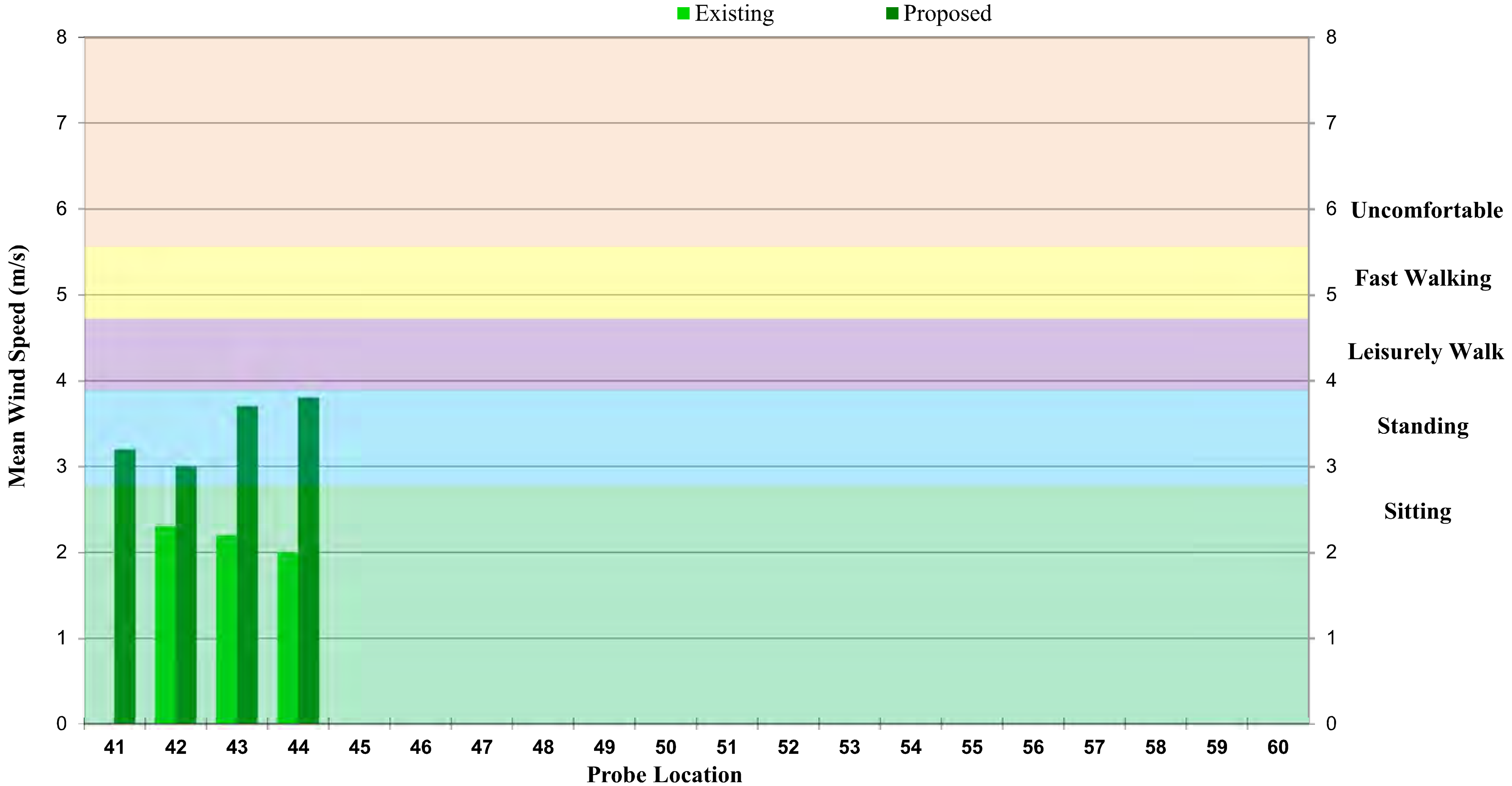


Figure 6b: WINTER - Wind Speed Exceeded 20% of the Time (Locations 41 to 44).



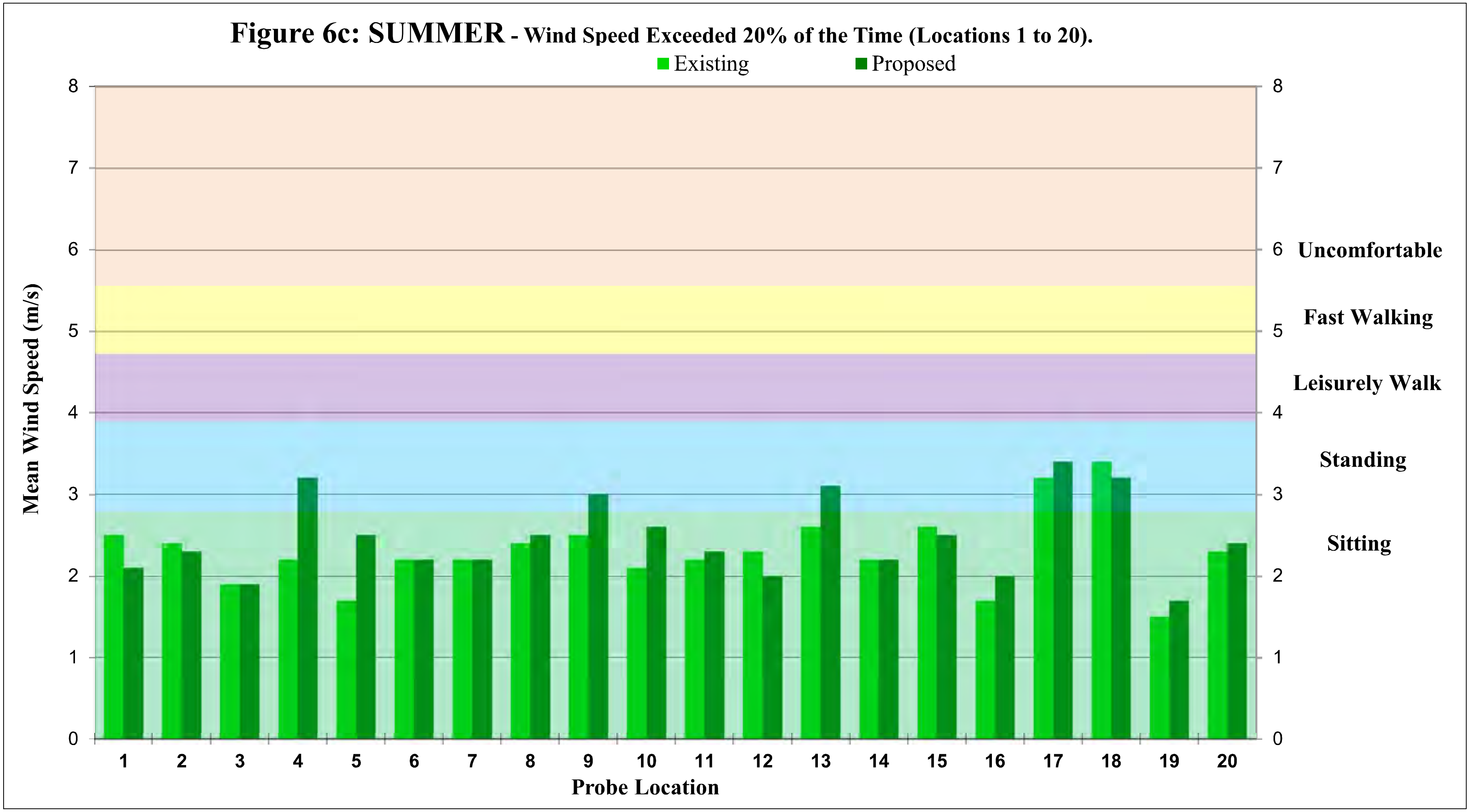


Figure 6c: SUMMER - Wind Speed Exceeded 20% of the Time (Locations 1 to 20).
Existing
Proposed
Mean Wind Speed (m/s)
Probe Location
Uncomfortable
Fast Walking
Leisurely Walk
Standing
Sitting

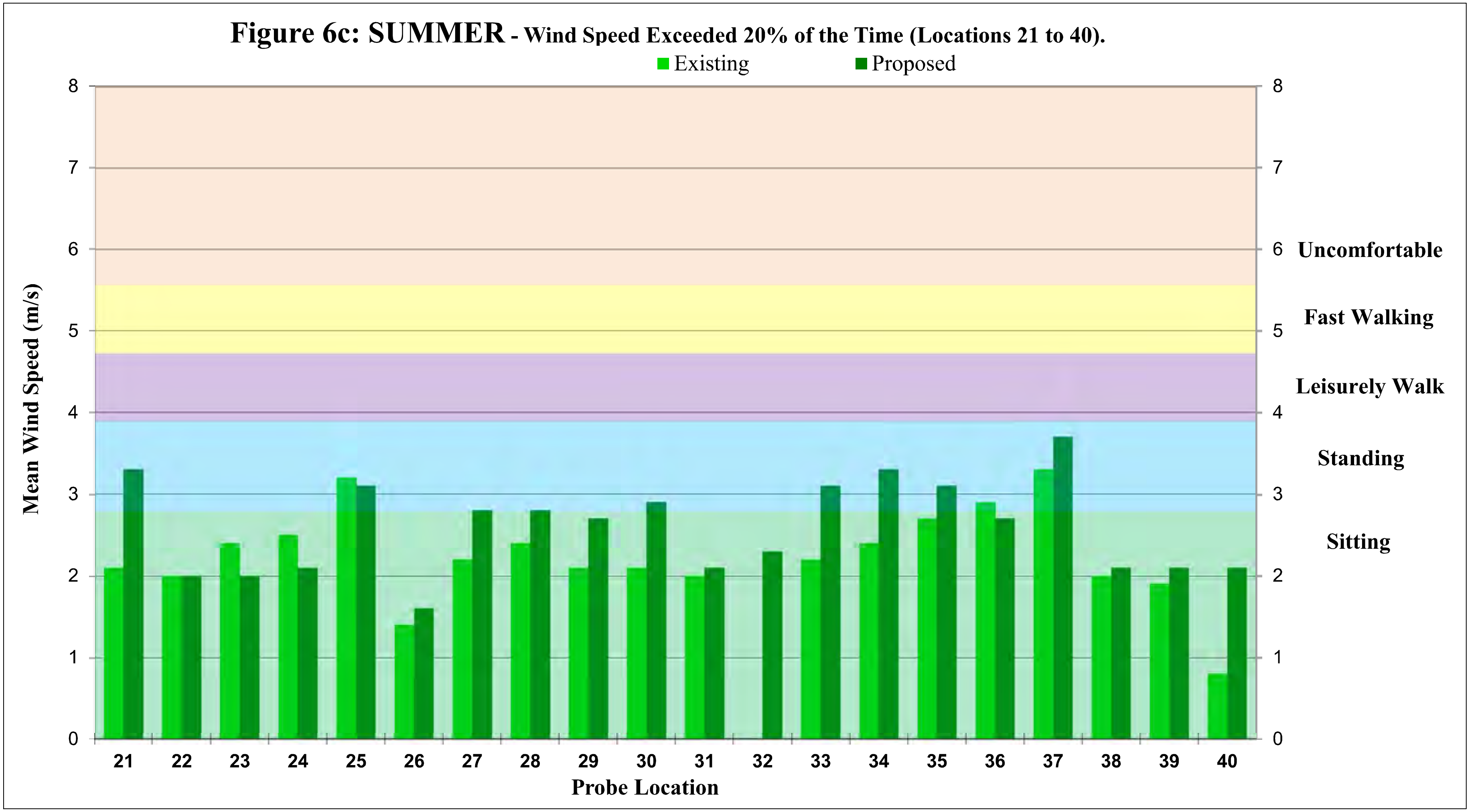


Figure 6c: SUMMER - Wind Speed Exceeded 20% of the Time (Locations 21 to 40).
Existing
Proposed
Mean Wind Speed (m/s)
8
7
6
5
4
3
2
1
0
Uncomfortable
Fast Walking
Leisurely Walk
Standing
Sitting
21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40
Probe Location

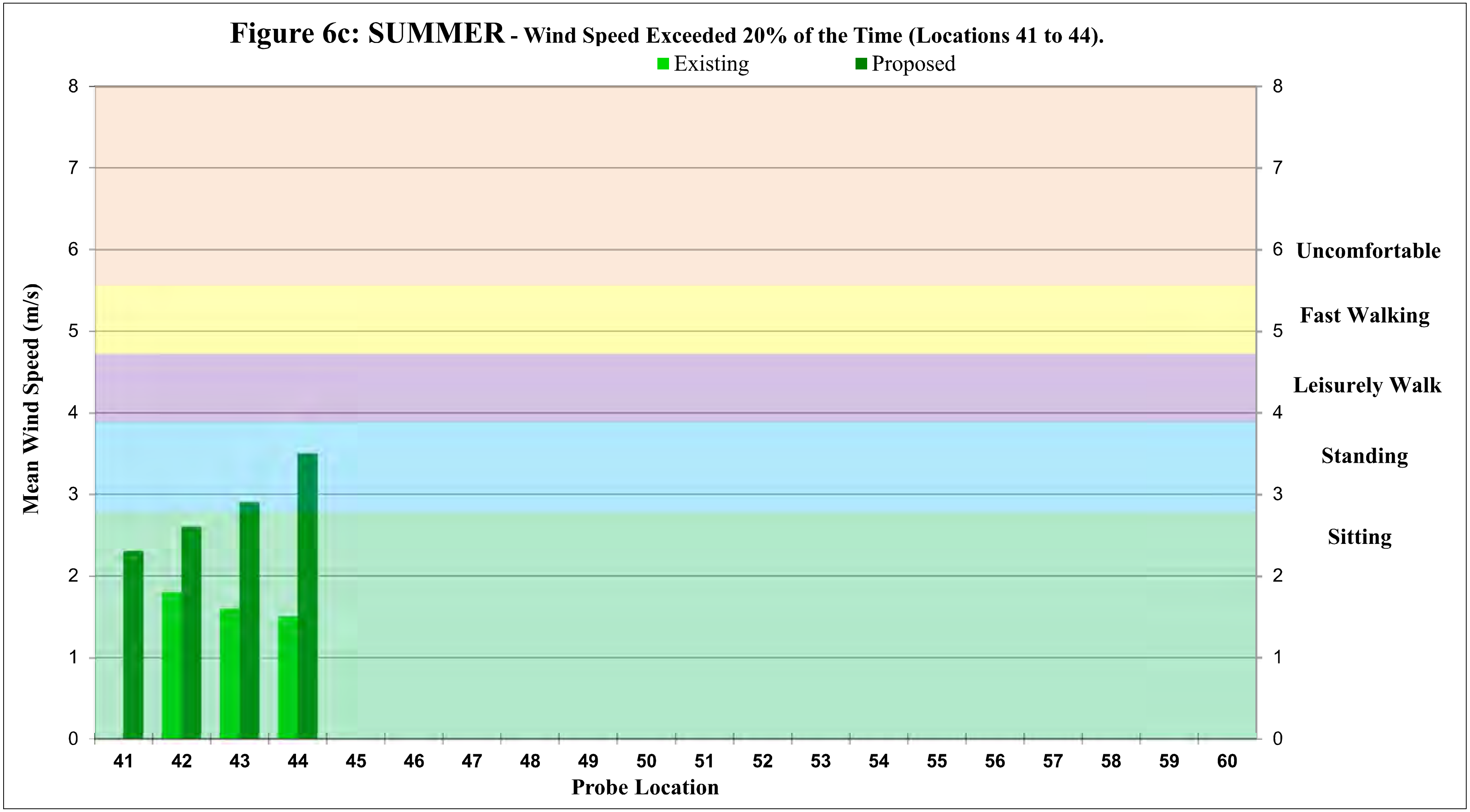


Figure 6c: SUMMER - Wind Speed Exceeded 20% of the Time (Locations 41 to 44).
Existing
Proposed
Mean Wind Speed (m/s)
Probe Location
Uncomfortable
Fast Walking
Leisurely Walk
Standing
Sitting
0 1 2 3 4 5 6 7 8
41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60

Figure 7a: Pedestrian level wind velocity comfort categories.

Figure 7b: Pedestrian level wind velocity comfort categories.

Comfort Categories - Annual - Proposed

Sitting Standing Leisurely Walking Fast Walking Uncomfortable

Theakston Environmental

Figure 7c: Pedestrian level wind velocity comfort categories.

Comfort Categories - Winter - Existing

Sitting Standing Leisurely Walking Fast Walking Uncomfortable

Figure 7d: Pedestrian level wind velocity comfort categories.

Comfort Categories - Winter - Proposed

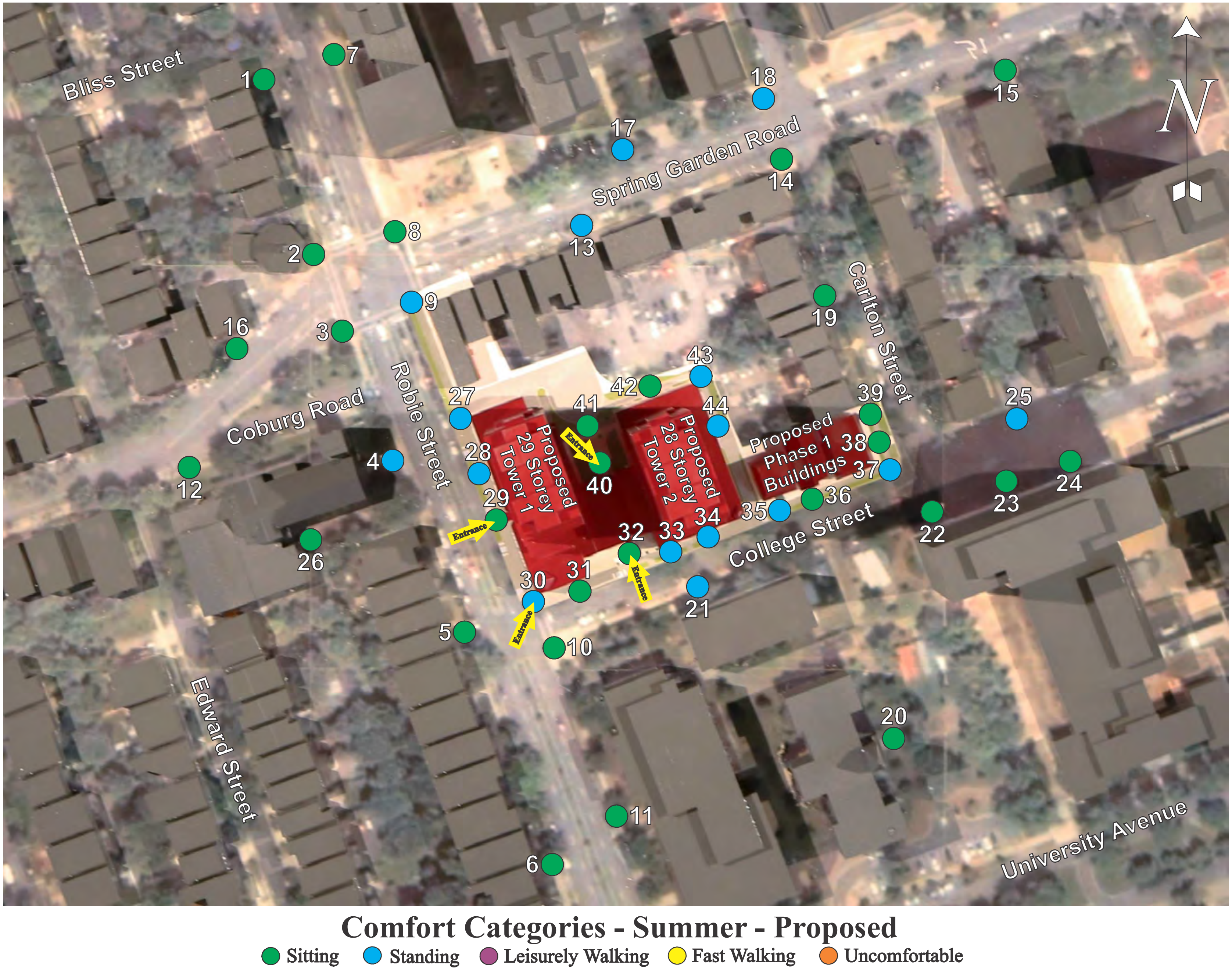
Sitting Standing Leisurely Walking Fast Walking Uncomfortable

Figure 7e: Pedestrian level wind velocity comfort categories.

Comfort Categories - Summer - Existing

Sitting Standing Leisurely Walking Fast Walking Uncomfortable

Figure 7f: Pedestrian level wind velocity comfort categories.



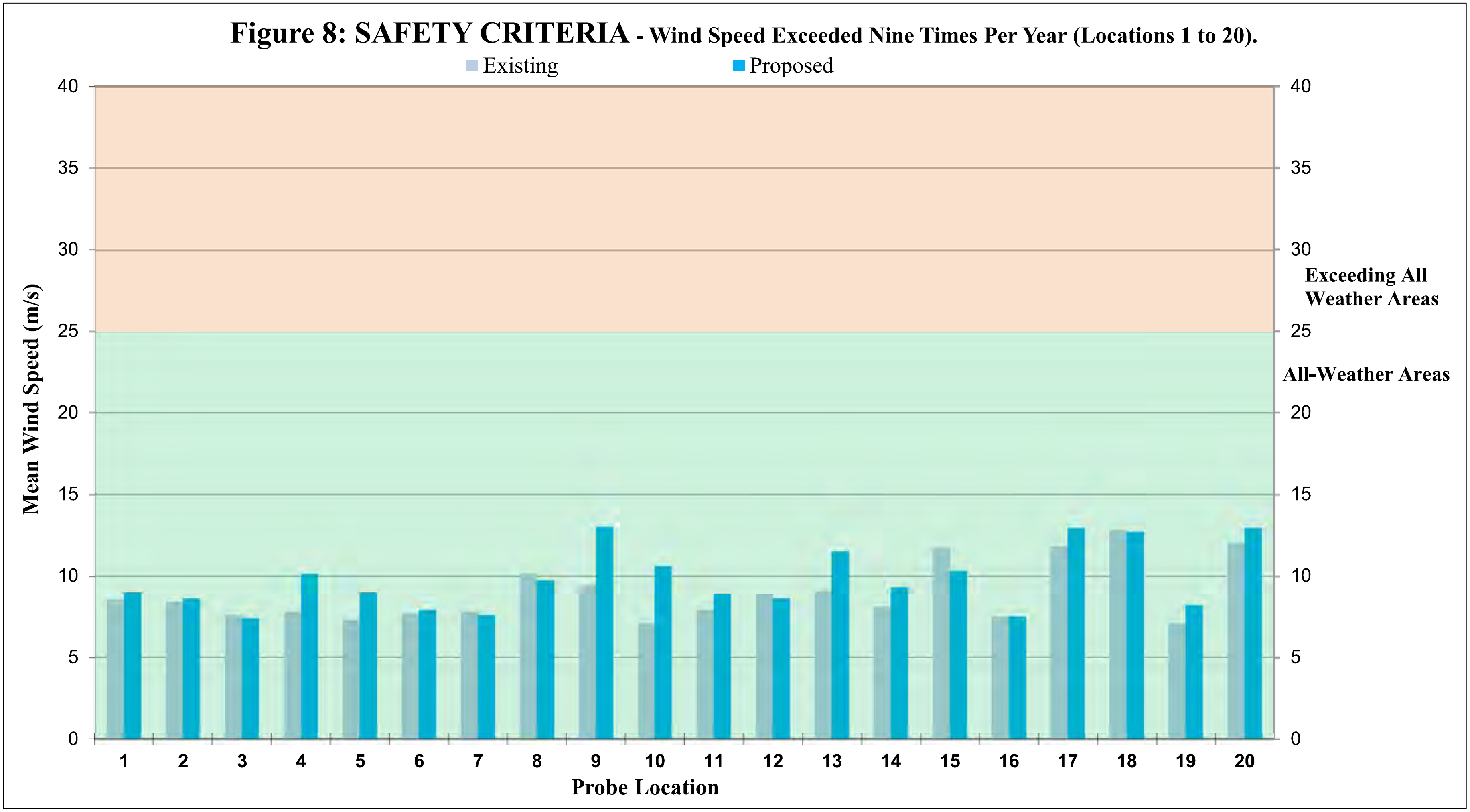


Figure 8: SAFETY CRITERIA - Wind Speed Exceeded Nine Times Per Year (Locations 1 to 20).
Existing
Proposed
Mean Wind Speed (m/s)
Exceeding All Weather Areas
All-Weather Areas
Probe Location
0
5
10
15
20
25
30
35
40
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20

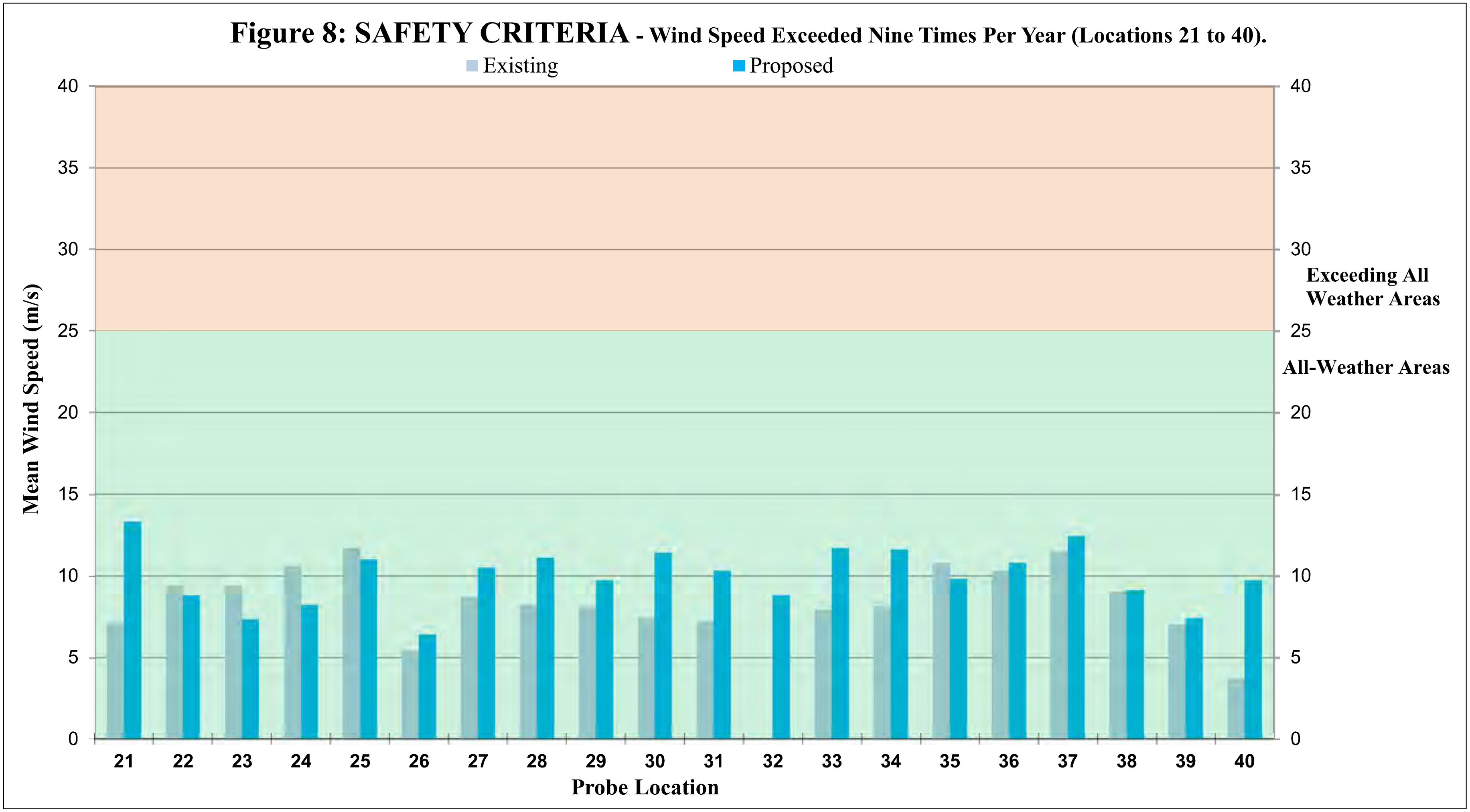


Figure 8: SAFETY CRITERIA - Wind Speed Exceeded Nine Times Per Year (Locations 21 to 40).
Existing
Proposed
Mean Wind Speed (m/s)
Exceeding All Weather Areas
All-Weather Areas
Probe Location
0
5
10
15
20
25
30
35
40
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40

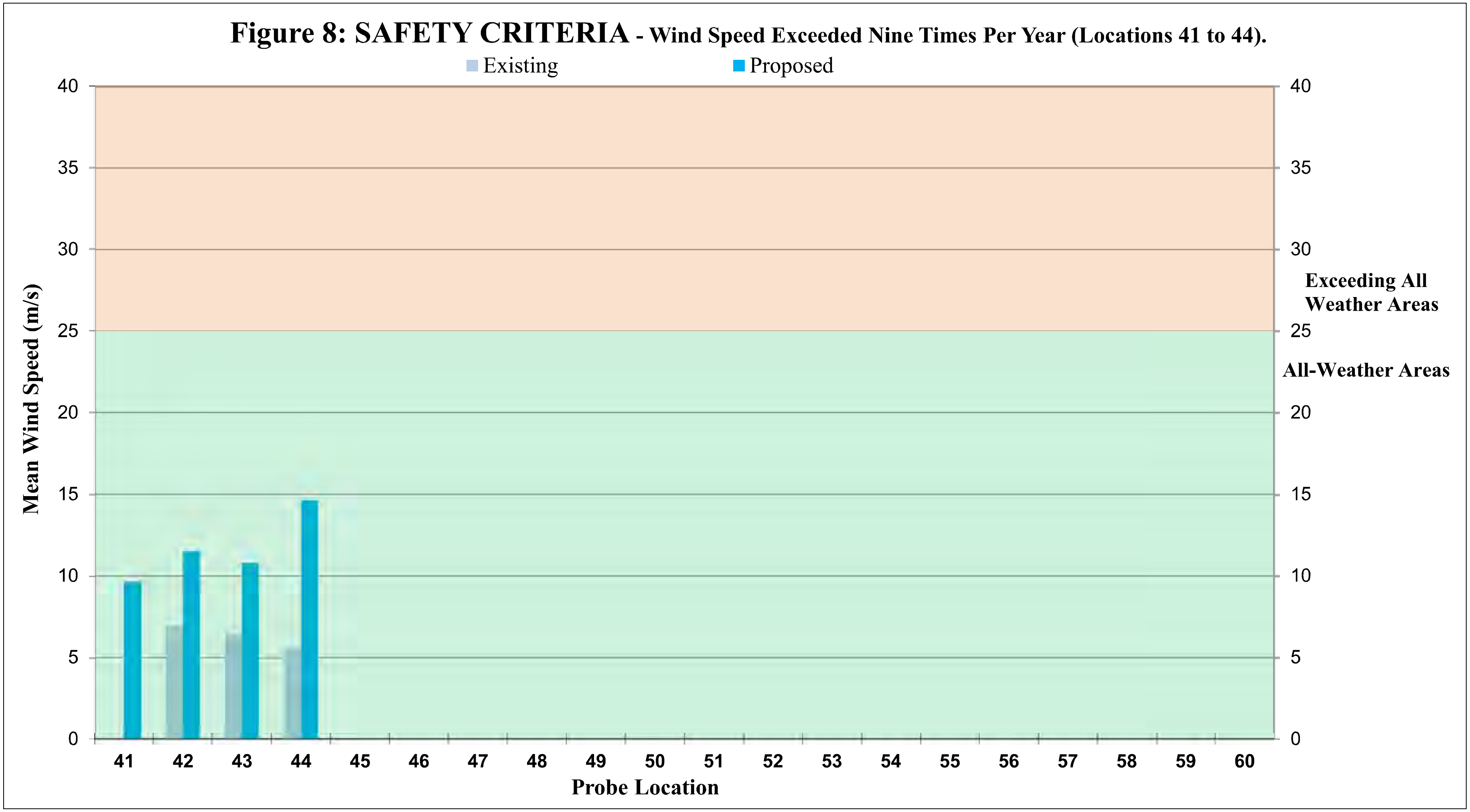
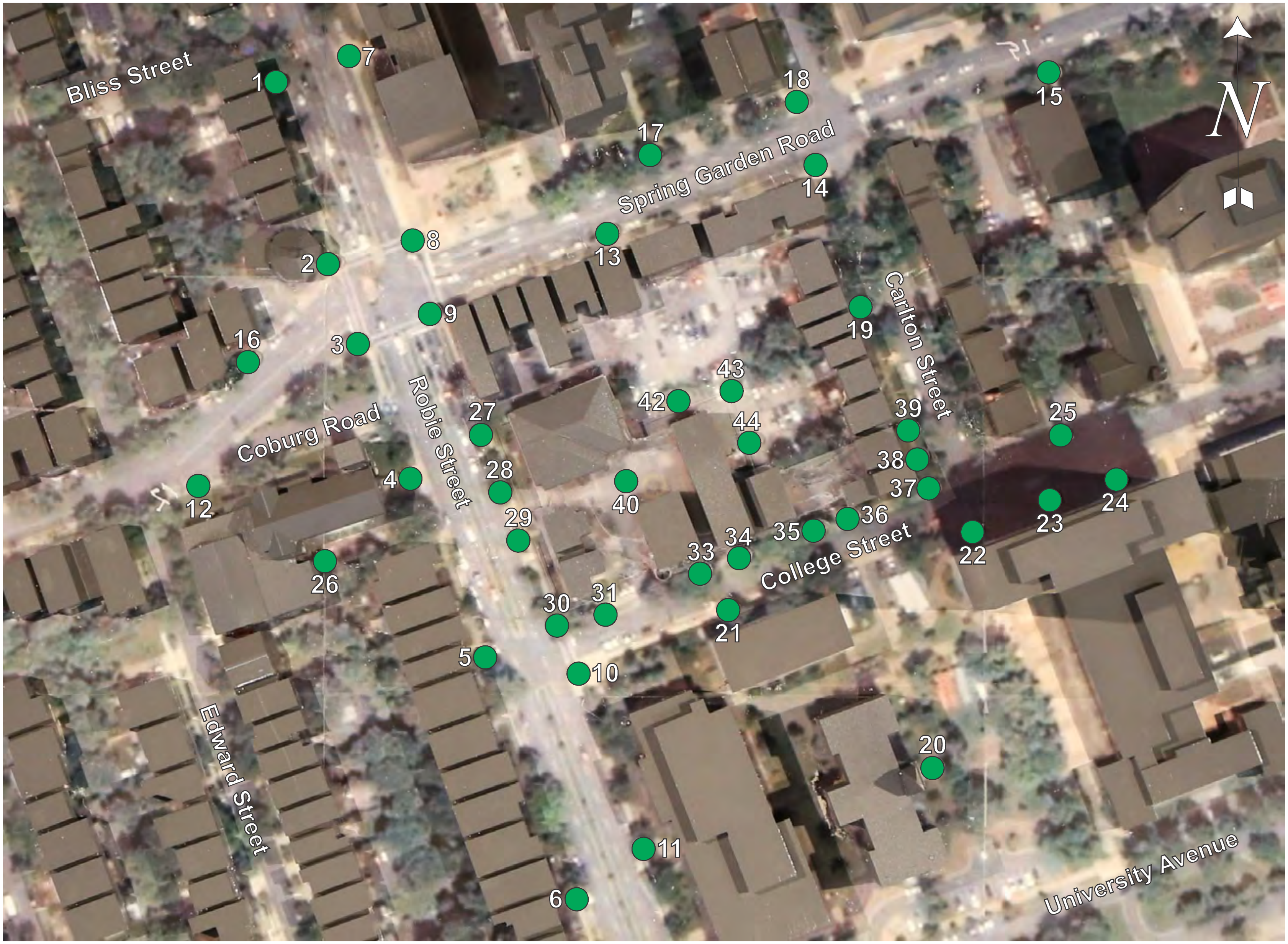


Figure 8: SAFETY CRITERIA - Wind Speed Exceeded Nine Times Per Year (Locations 41 to 44).
Existing
Proposed
Mean Wind Speed (m/s)
0
5
10
15
20
25
30
35
40
Exceeding All Weather Areas
All-Weather Areas
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
Probe Location

Figure 9a: Pedestrian level wind velocity safety criteria.

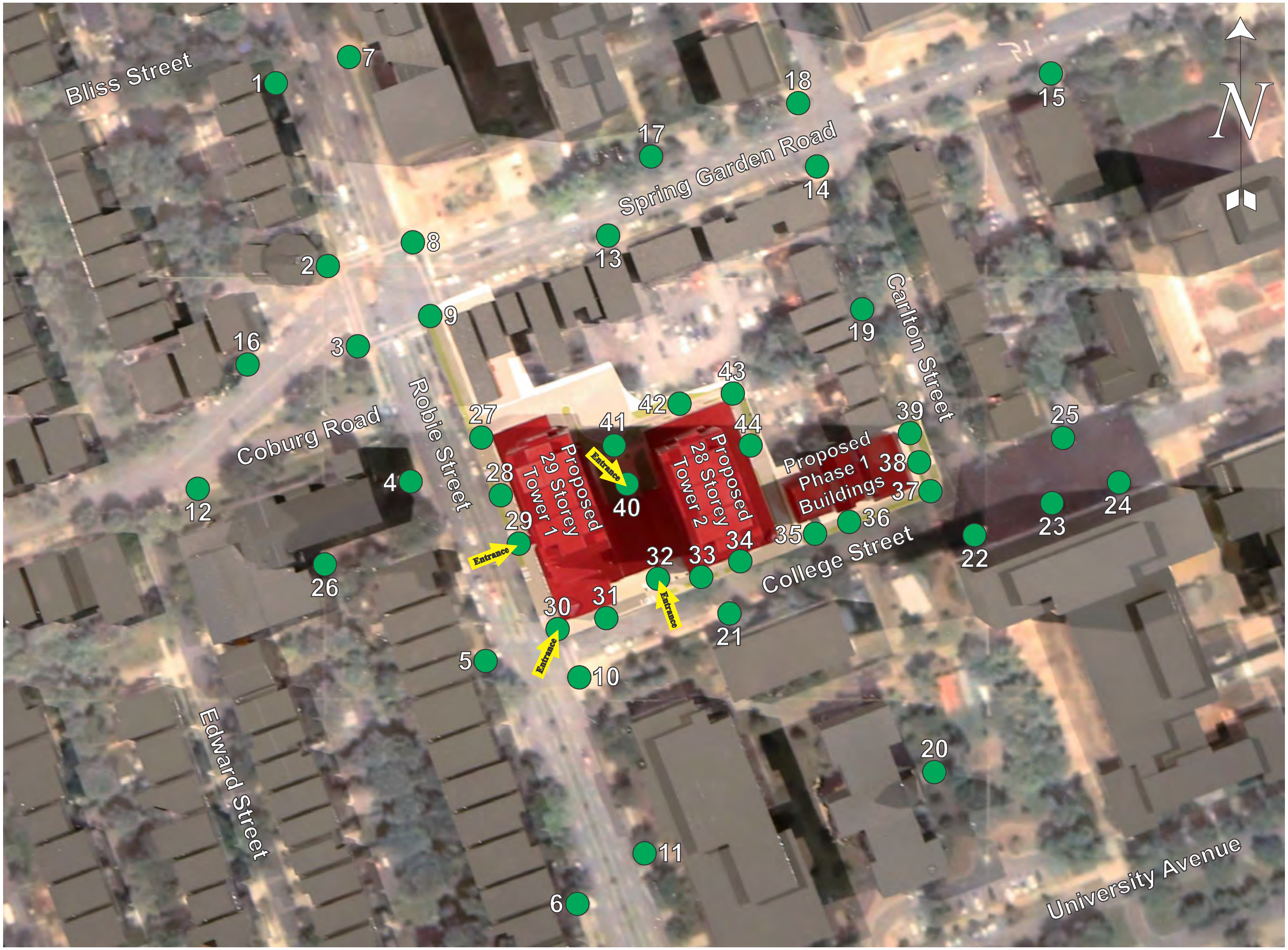


Safety Criteria - Existing

All-Weather Areas   Exceeding All-Weather Areas

Theakston Environmental

Figure 9b: Pedestrian level wind velocity safety criteria.



Safety Criteria - Proposed

All-Weather Areas   Exceeding All-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:

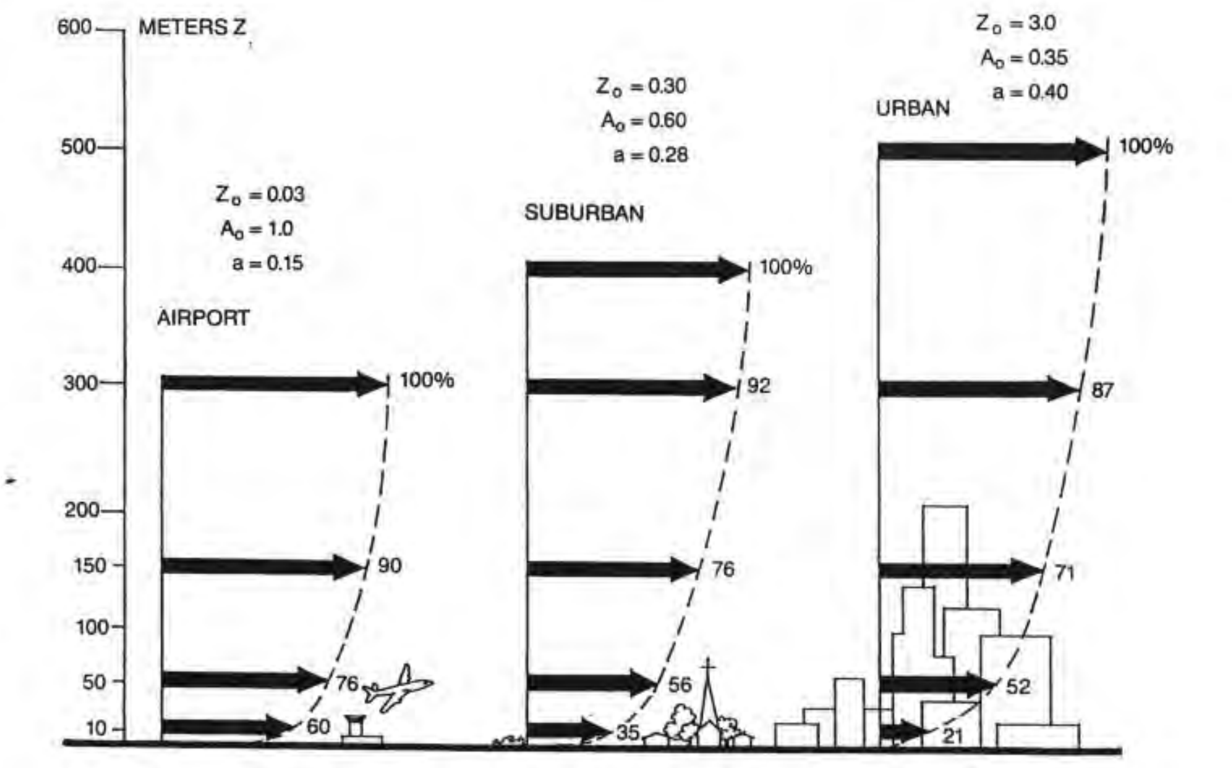


Figure A: Mean wind speed profiles for various terrain (from ASHRAE 1989).

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 $300m$ 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.

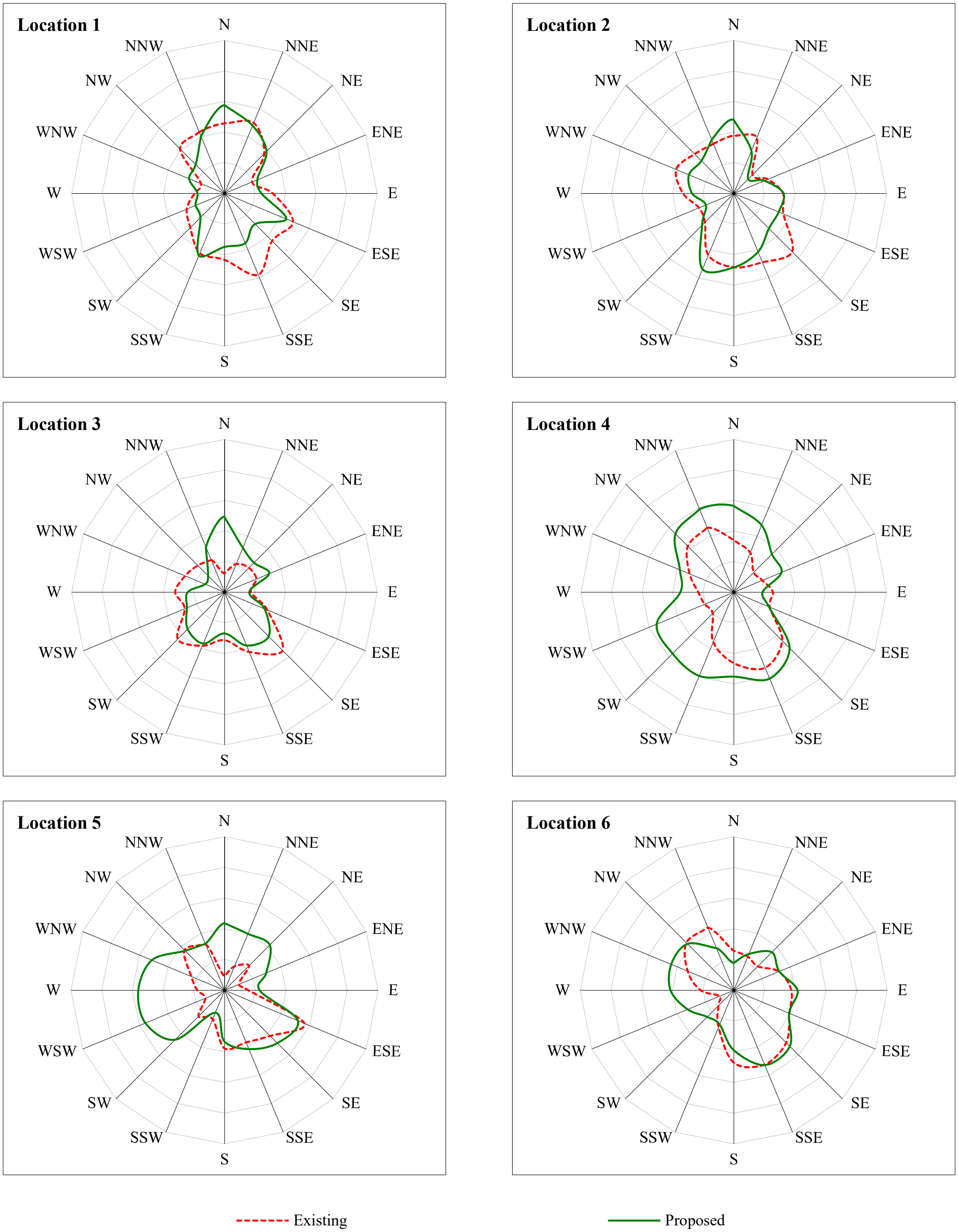


Figure B : Ground level wind velocity as a ratio of gradient wind velocity.

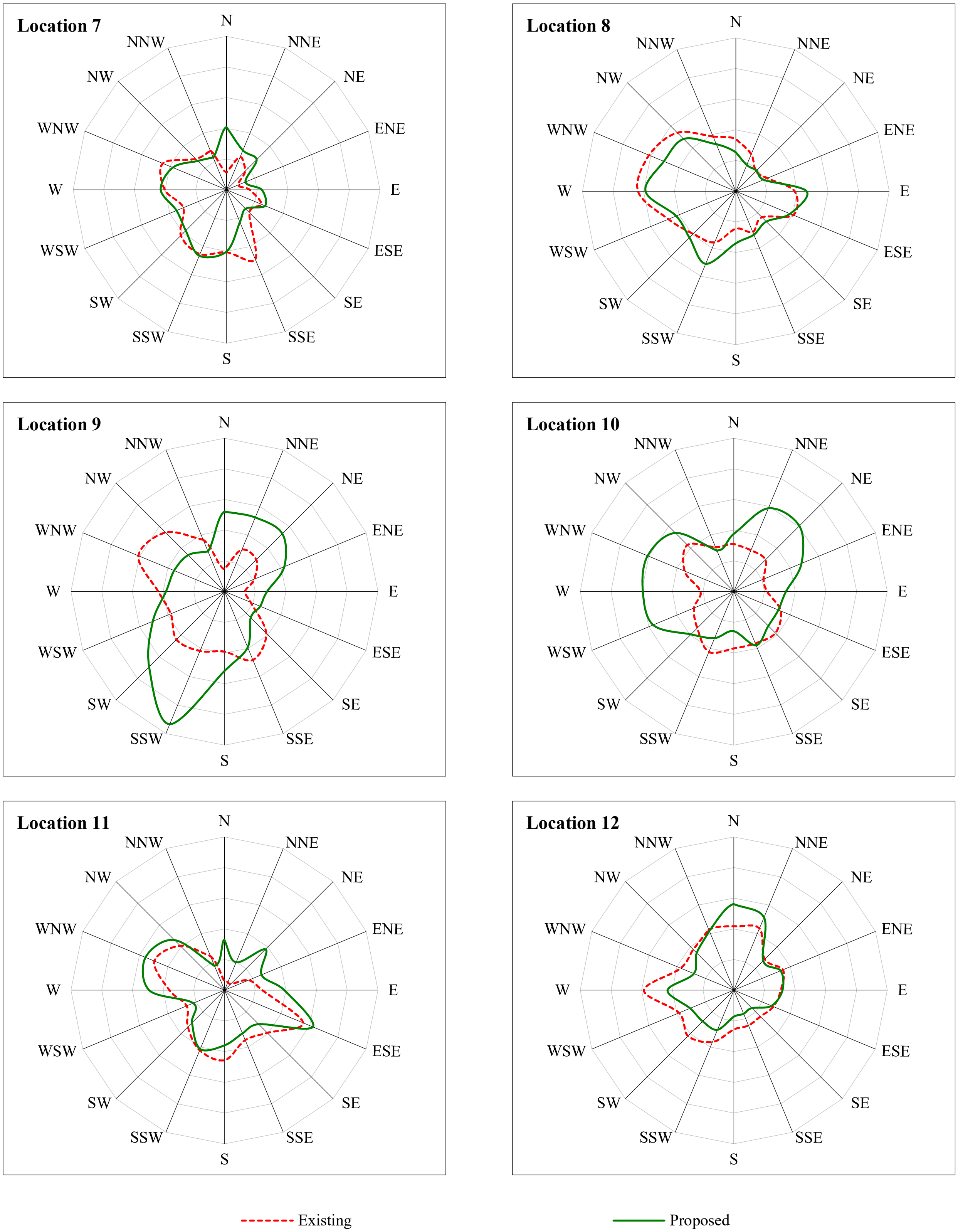


Figure B : Ground level wind velocity as a ratio of gradient wind velocity.

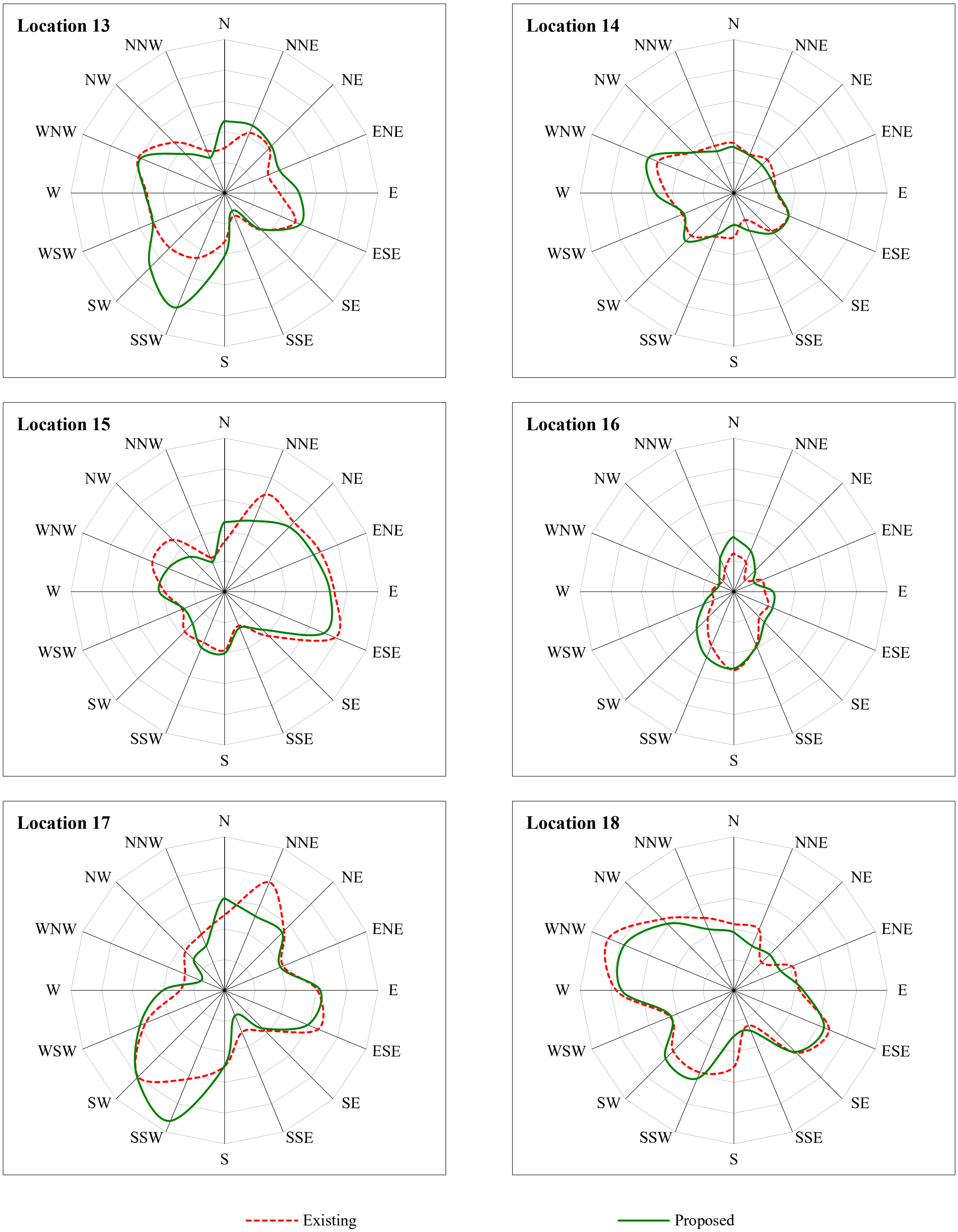


Figure B : Ground level wind velocity as a ratio of gradient wind velocity.

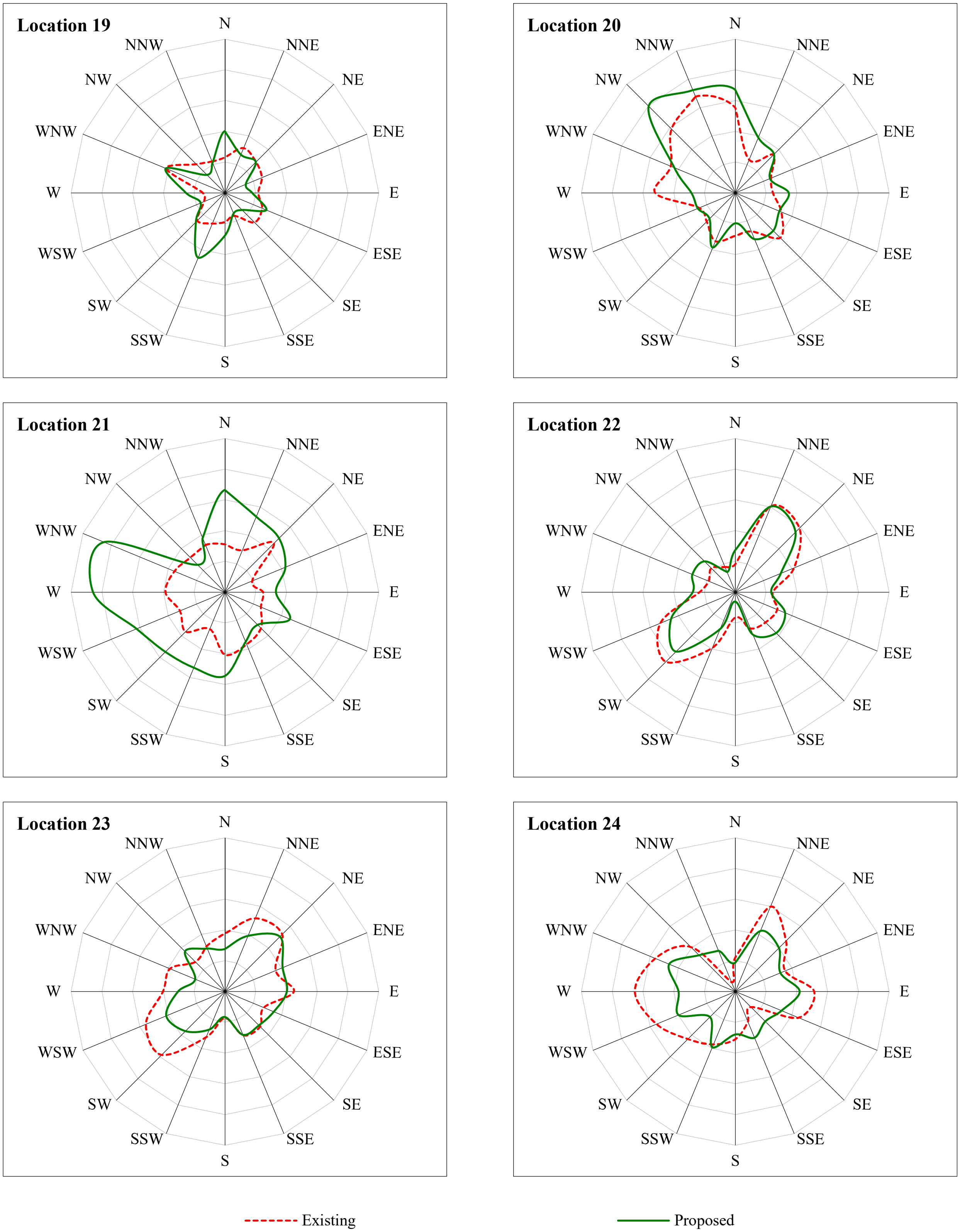


Figure B : Ground level wind velocity as a ratio of gradient wind velocity.

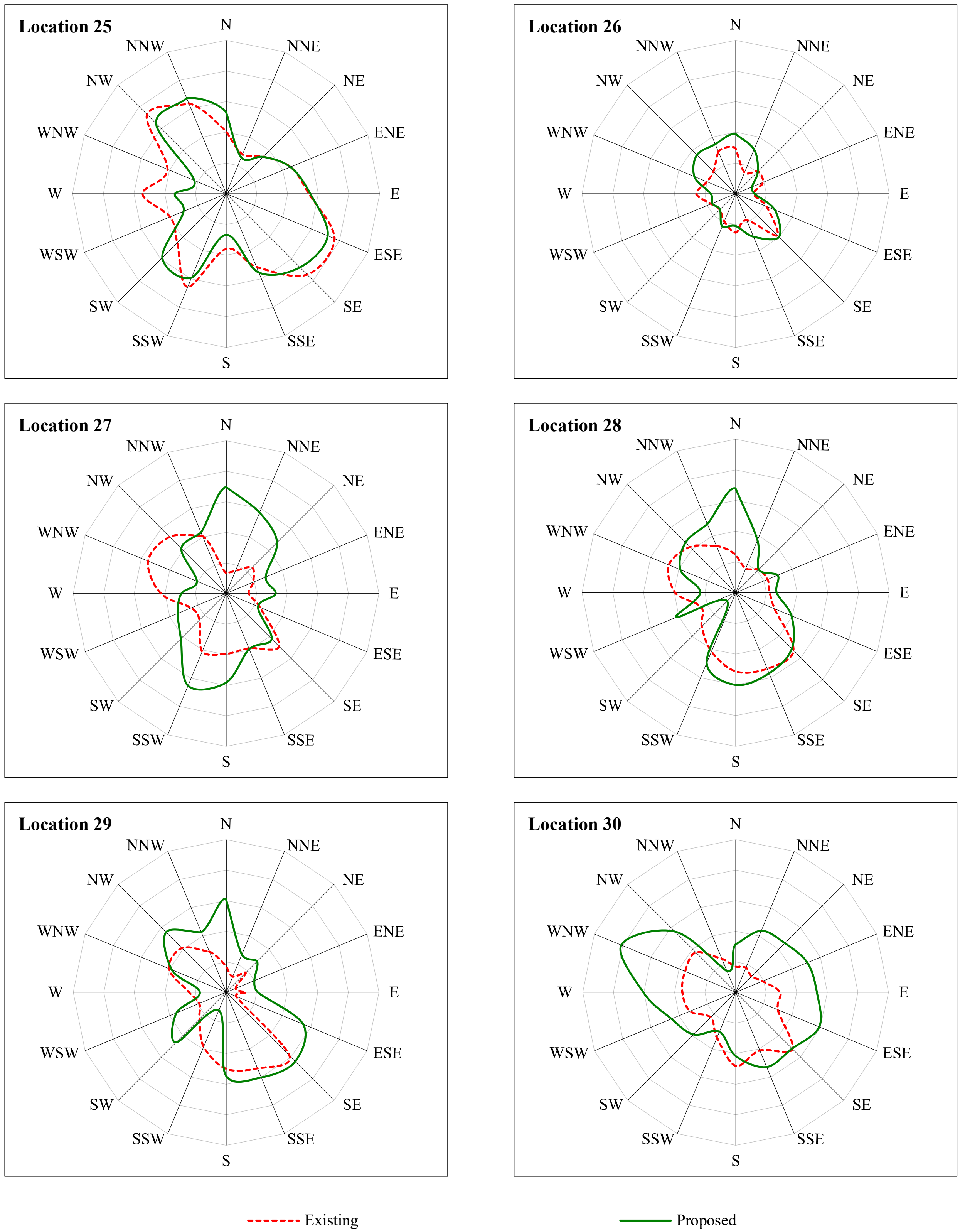


Figure B : Ground level wind velocity as a ratio of gradient wind velocity.

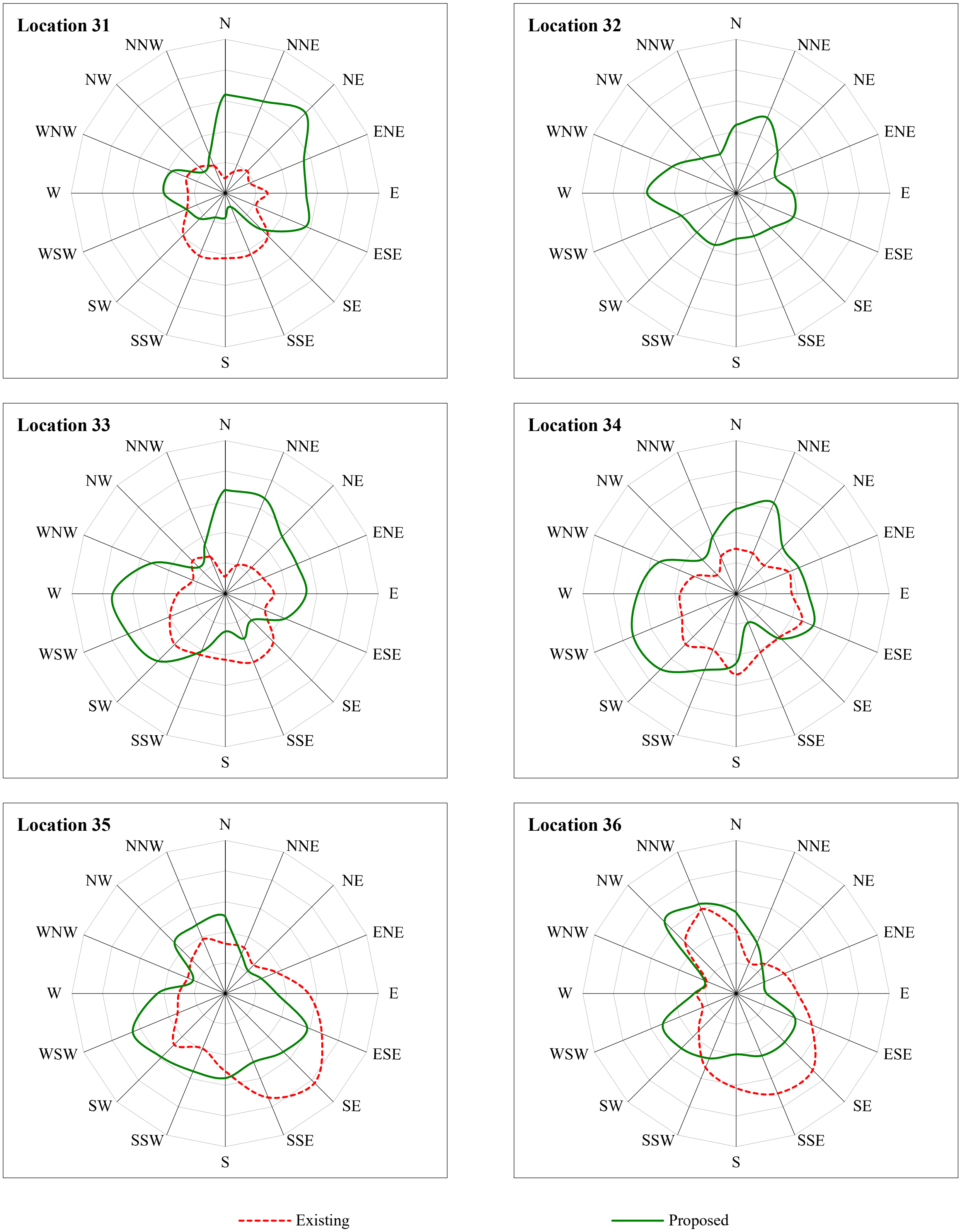


Figure B : Ground level wind velocity as a ratio of gradient wind velocity.

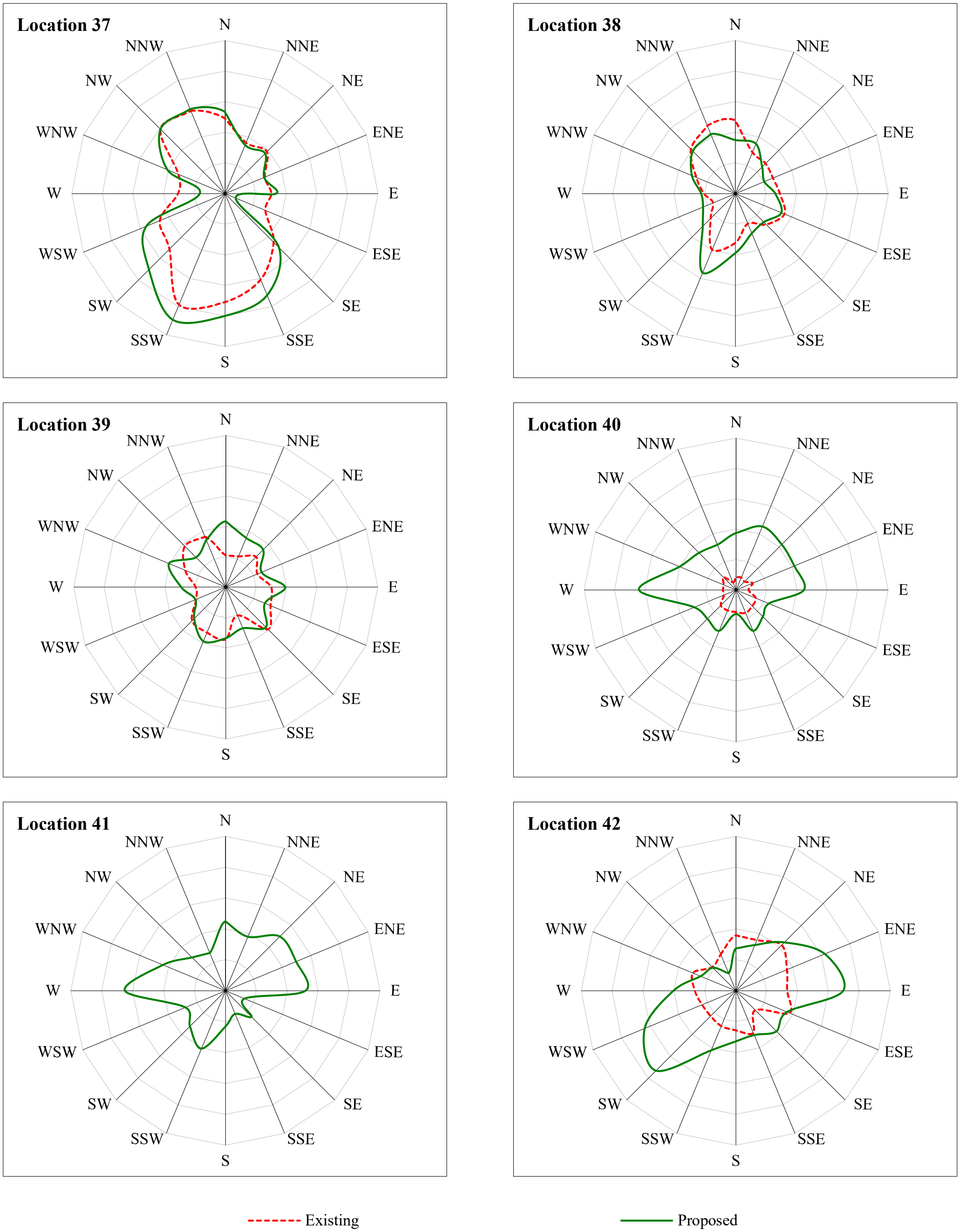
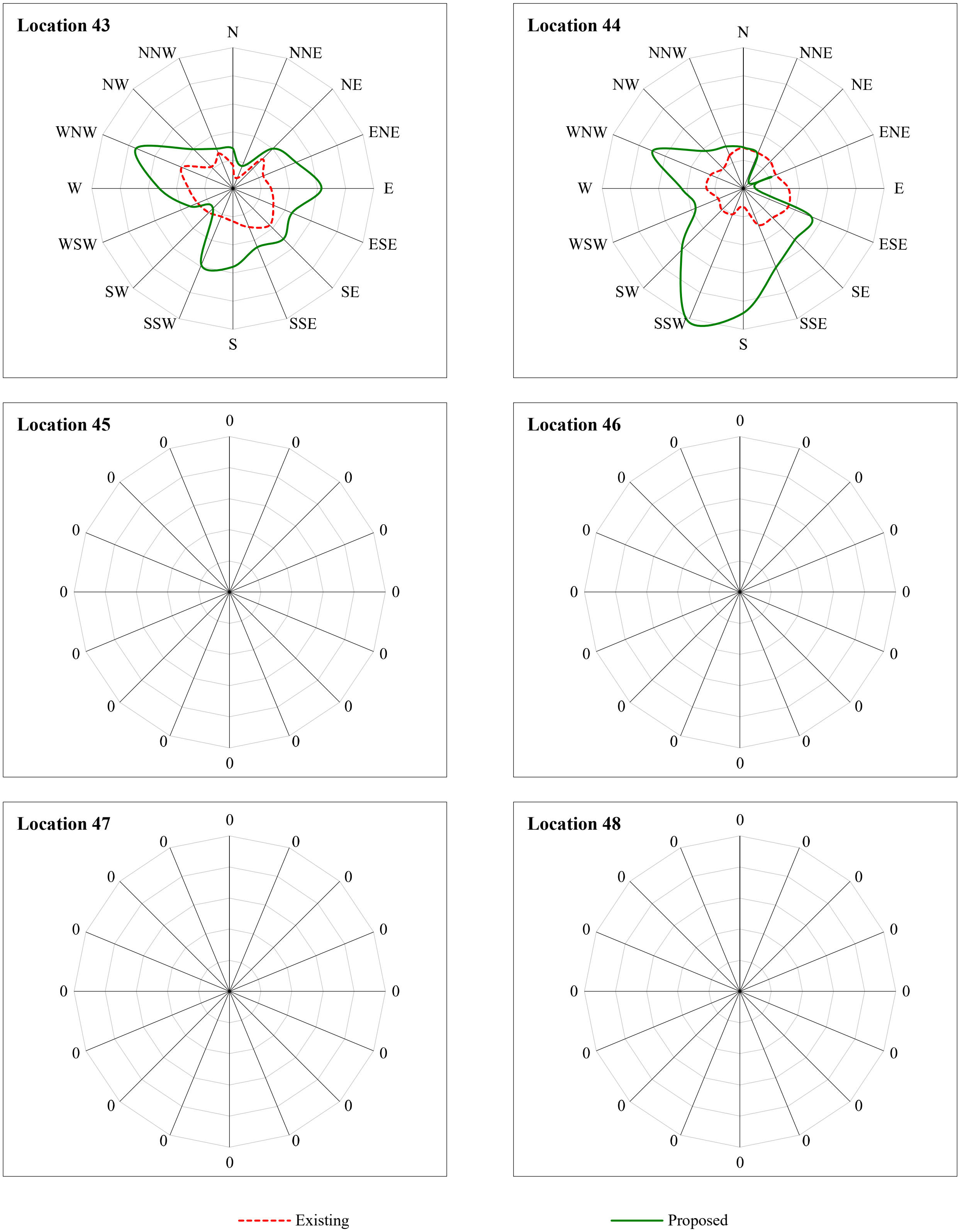


Figure B : Ground level wind velocity as a ratio of gradient wind velocity.



8 REFERENCES

Canadian Climate Program. Canadian Climate Normals, 1961-1990. Documentation for Diskette-Based Version 2.0E (in English) Copyright 1993 by Environment Canada.

Cermak, J.E., "Applications of Fluid Mechanics to Wind Engineering A Freeman Scholar Lecture." Journal of Fluids Engineering, (March 1975), 9-38.

Davenport, A.G."The Dependence of Wind Loads on Meteorological Parameters." International Seminar on Wind Effects on Buildings and Structures, Ottawa, 1967.

-----"An Approach to Human Comfort Criteria for Environmental Wind Conditions." Colloquium on Building Climatology, Stockholm, Sweden, September, 1972.

-----"The Relationship of Wind Structure to Wind Loading." Symposium on Wind Effects on Buildings and Structures, Teddington, 1973.

-----and N. Isyumov. "The Application of the Boundary Layer Wind Tunnel to the Prediction of Wind Loading." Proceedings of International Seminar on Wind Effects on Buildings and Structures, Ottawa, 1967.

-----and N. Isyumov. "The Application of the Boundary Layer Wind Tunnel to the Prediction of Wind Loading." International Research Seminar on Wind Effects on Buildings and Structures, Hamilton: University of Hamilton Press, 1968.

-----and T. Tschanz. "The Response of Tall Buildings to Wind: Effect of Wind Direction and the Direction Measurement of Force." Proceedings of the Fourth U.S.National Conference on Wind Engineering Research, Seattle, Washington, July 1981.

-----Isyumov, N. "Studies of the Pedestrian Level Wind Environment at the Boundary Layer Wind Tunnel Laboratory University of Western Ontario." Journal of Industrial Aerodynamics, (1978), 187-200.

-----and A.G.Davenport. "The Ground Level Wind Environment in Built-up Areas." Proceedings of the Fourth International Conference on Wind Effects on Buildings and Structures, London, England: Cambridge University Press, 1977, 403-422

-----M.Mikitiuk, C.Harding and A.G.Davenport. "A Study of Pedestrian Level Wind Speeds at the Hamilton City Hall, Hamilton,Ontario." London, Ontario: The University of Western Ontario, Paper No.BLWT-SS17-1985, August 1985.

Milles, Irwin and John E. Freund. Probability and Statistics Engineers, Hamilton: Prentice-Hall Canada Ltd., 1965.

National Building Code of Canada, Ottawa: National Research Council of Canada, 1990.

Simiu, Emil, Wind Induced Discomfort In and Around Buildings. New York: John Wiley & Sons, 1978.

Surry, David, Robert B.Kitchen and Alan Davenport, "Design Effectiveness of Wind Tunnel Studies for Buildings of Intermediate Height." Canadian Journal of Civil Engineering 1977, 96-116.

Theakston, F.H., "Windbreaks and Snow Barriers." Morgantown, West Virginia, ASAE Paper No. NA-62-3d, August 1962.

------"Advances in the Use of Models to Predict Behaviour of Snow and Wind", Saskatoon, Saskatchewan: CSAE, June 1967.

Gagge, A.P., Fobelets, A.P., Berglund, L.G., "A Standard Predictive Index of Human Response to the Environment", ASHRAE Transactions, Vol. 92, p709-731, 1986.

Gagge, A.P., Nishi, Y., Nevins, R.G., "The Role of Clothing in Meeting FEA Energy Conservation Guidelines", ASHRAE Transactions, Vol. 82, p234-247, 1976.

Gagge, A.P., Stolwijk, J.A., Nishi, Y., "An Effective Temperature Scale Based on a Simple Model of Human Physiological Regulatory Response", ASHRAE Transactions, Vol. 77, p247-262, 1971.

Berglund, L.G., Cunningham, D.J., "Parameters of Human Discomfort in Warm Environments", ASHRAE Transactions, Vol. 92, p732-746, 1986.

ASHRAE, "Physiological Principles, Comfort, and Health", ASHRAE Handbook - 1981 Fundamentals, Chapter 8, Atlanta, American Society of Heating, Refrigeration and Air-Conditioning Engineers Inc., 1981,

ASHRAE, "Airflow Around Buildings", ASHRAE Handbook - 1989 Fundamentals, Chapter 14, Atlanta, American Society of Heating, Refrigeration and Air-Conditioning Engineers Inc., 1989,