WATERLOO STATE SIGNIFICANT PRECINCT STUDY -

WATERLOO METRO QUARTER

PEDESTRIAN WIND ENVIRONMENT STUDY

WD510-02F02(REV6)- WE REPORT

OCTOBER 2, 2018

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June 25, 2018	Combine the Existing Site and Proposed Massing Report utilising the UrbanGrowth structure	1	JG	SWR	JG
July 6, 2018	Minor Changes to Exec. Summary, Section 1, 2, 3, and 6	2	JG	SWR	JG
July 18, 2018	Final	3	JG	SWR	JG
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September 17, 2018	Include Seating Criteria Table and Discussion	5	JG	SWR	BU
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EXECUTIVE SUMMARY

This report presents the results of a detailed investigation into the wind environment conditions for the proposed Waterloo Metro Quarter precinct. The existing site wind conditions were identified via wind tunnel testing, allowing for opportunities and constraints to be explored through the master planning process of the Metro Quarter development, including land use and community needs to support the development. Similarly, a review of the proposed massing model was conducted to identify key wind sensitive ground locations within and around the site which where quantitatively assessed by conducting a wind tunnel test of the massing model.

The existing site conditions and proposed massing of the Waterloo Metro Quarter site were tested and are detailed within this report. Testing was performed using Windtech's boundary layer wind tunnel, which has a 3.0m wide test section and has a fetch length of 14m. Measurements were made in the wind tunnel at selected critical trafficable outdoor locations within and around the development from 16 wind directions at 22.5 degree increments using a 1:400 scale detailed model of the development. The effect of nearby buildings and land topography has been accounted for through the use of a proximity model, which represents an area with a radius of 600m.

Peak gust and mean wind speeds were measured at selected critical outdoor trafficable locations within and around the subject development. Wind velocity coefficients representing the local wind speeds are derived from the wind tunnel and are combined with a statistical model of the regional wind climate (which accounts for the directional strength and frequency of occurrence of the prevailing regional winds) to provide the equivalent full-scale wind speeds at the site. The wind speed measurements are compared with criteria for pedestrian comfort and safety, based on Gust-Equivalent Mean (GEM) and annual maximum gust winds, respectively.

Wind tunnel testing of the existing site wind conditions allowed for a baseline case for the proposed development precinct to be established, taking into account the prevailing wind directions for the area, as well as the local topographical effects of the terrain and the surrounding buildings of the proposed site. An assessment of the wind conditions has been made to identify the wind conditions and patterns, with the information used to coordinate a massing model.

Wind tunnel testing of the proposed Waterloo Metro Quarter development was undertaken, based on the 3D Sketchup massing model received from UrbanGrowth NSW, January 2018. The results indicate only a number of localised ground level areas are subject to wind conditions that do not achieve the desired criteria for pedestrian comfort and safety. Through the incorporation of recommended in-principle treatments these wind conditions are expected to be ameliorated. The recommended in-principle wind ameliorative treatments include impermeable awnings at strategic locations and an investigation of building form changes.

An updated drawing package (For Coordination – 11/5/2018) prepared by Turner architects and received from UrbanGrowth NSW, May 2018 has been reviewed. Upon review of the updated

drawings it was noticed that the building form of Tower D had changed from the initial massing model. The change in building form is not expected to cause a significant impact on the measured ground level wind conditions. Review of the drawing package indicates the incorporation of alternative wind ameliorative devices in wind sensitive areas such as the Pedestrian Link and New Street through site link. These include baffle screens, awnings and densely foliating evergreen tree planting, which are expected to provide similar alleviating wind measures as the recommended in-principle treatments.

The surrounding pedestrian footpath areas and the communal community square indicate the inclusion of landscaping and tree planting located in wind sensitive areas which has the potential to further enhance the wind comfort conditions. The building form of Tower D is noted to have changed from the initial massing model, however the change in building form is not expected to cause a significant impact on the measured ground level wind conditions. Hence, with the inclusion of the abovementioned design changes to the development, it is expected that the wind conditions for all outdoor trafficable areas within and around the proposed development will be acceptable for their intended uses.

A desktop assessment of the private balconies indicates that a majority are exposed to winds on a single aspect and also benefit from a setback design, hence they are expected to be suitable for their intended use. Recommendations have been made to address the balconies exposed to two aspects, through the incorporation of deflective wind elements such as full-height screens to be added along one of the aspects. The elevated communal open spaces are exposed to the prevailing north-easterly, southerly and westerly winds due to their locations. With the recommended incorporation of wind deflective elements and strategic landscaping within these areas the wind conditions are expected to be acceptable for their intended uses.

Further wind tunnel testing of the ground level and elevated areas within the proposed Metro Quarter will be investigated during the design development stage to verify the suitability of the areas for their intended purpose.

CONTENTS

1 INTRODUCTION

The Minister for Planning has determined that parts of Waterloo (the Precinct) are of State planning significance which should be investigated for rezoning through the State Significant Precinct (SSP) process. Study Requirements for such investigations were issued by the Minister on 19 May 2017.

Investigation of the Precinct is being undertaken by UrbanGrowth NSW Development Corporation (UrbanGrowth NSW), in partnership with NSW Land and Housing Corporation (LAHC) and Sydney Metro. The outcome of the State Significant Precinct process will be new planning controls that will enable development applications for renewal of the Precinct.

The Precinct includes two separate, but adjoining and inter-related parts:

- The Waterloo Metro Quarter (the Metro Quarter)
- The Waterloo Estate (the Estate)

While the study requirements for the Precinct were provided as separate requirements for the Metro Quarter and for the Estate, comprehensive baseline investigations have been prepared for the entire Precinct. However, lodgement of a separate SSP study for the Metro Quarter in advance of the SSP Study for the Estate is proposed to allow construction of Over Station Development (OSD) within the Metro Quarter to be delivered concurrently with the Metro Station, as an Integrated Station Development (ISD).

While this report therefore provides comprehensive baseline investigations for the entire Precinct, it only assesses the proposed Planning Framework amendments and Indicative Concept Proposal for the Metro Quarter.

1.1 Overall Precinct objectives

The following are the objectives for renewal of the Precinct:

Housing: A fully integrated urban village of social, private and affordable housing
A place that meets the housing needs of people with different background, ages, incomes, abilities and lifestyles – a place where everyone belongs. New homes for social, affordable and private residents that are not distinguishable and are modern, comfortable, efficient, sustainable and adaptable.
Services and Amenities: New and improved services, facilities and amenities to support a diverse community
A place that provides suitable and essential services and facilities so that all residents have easy access to health, wellbeing, community support, retail and government services.
Culture & Design: A safe and welcoming place to live and visit
A place where there is activity day and night, where people feel safe, at ease and part of a cohesive and proud community. A place that respects the land and Aboriginal people by showcasing and celebrating Waterloo's culture, history and heritage.
Open Space & Environment: High quality public spaces and a sustainable urban environment
A place that promotes a walkable, comfortable and healthy lifestyle with high quality, well designed and sustainable buildings, natural features and safe open spaces for everyone to enjoy, regardless of age, culture or ability.
Transport and Connectivity: A well connected inner city location
Integrate the new metro station and other modes of transport in such a way that anyone who lives, works or visits Waterloo can get around easily, safely and efficiently.

1.2 Waterloo State Significant Precinct

The Precinct is located approximately 3.3km south-south-west of the Sydney CBD in the suburb of Waterloo (refer Figure 1.1). It is located entirely within the City of Sydney local government area (LGA).

It is bordered by Phillip Street to the north, Pitt Street to the east, McEvoy Street to the south and Botany Road to the west. It also includes one block east of Pitt Street bordered by Wellington, Gibson and Kellick Streets. The Precinct has an approximate gross site area of 20.03 hectares (ha) (including road reserves) and comprises two separate but adjoining parts:

1. The Waterloo Estate (the Estate); and
2. The Waterloo Metro Quarter (the Metro Quarter).

A map of the Precinct and relevant boundaries is at Figure 1.2.

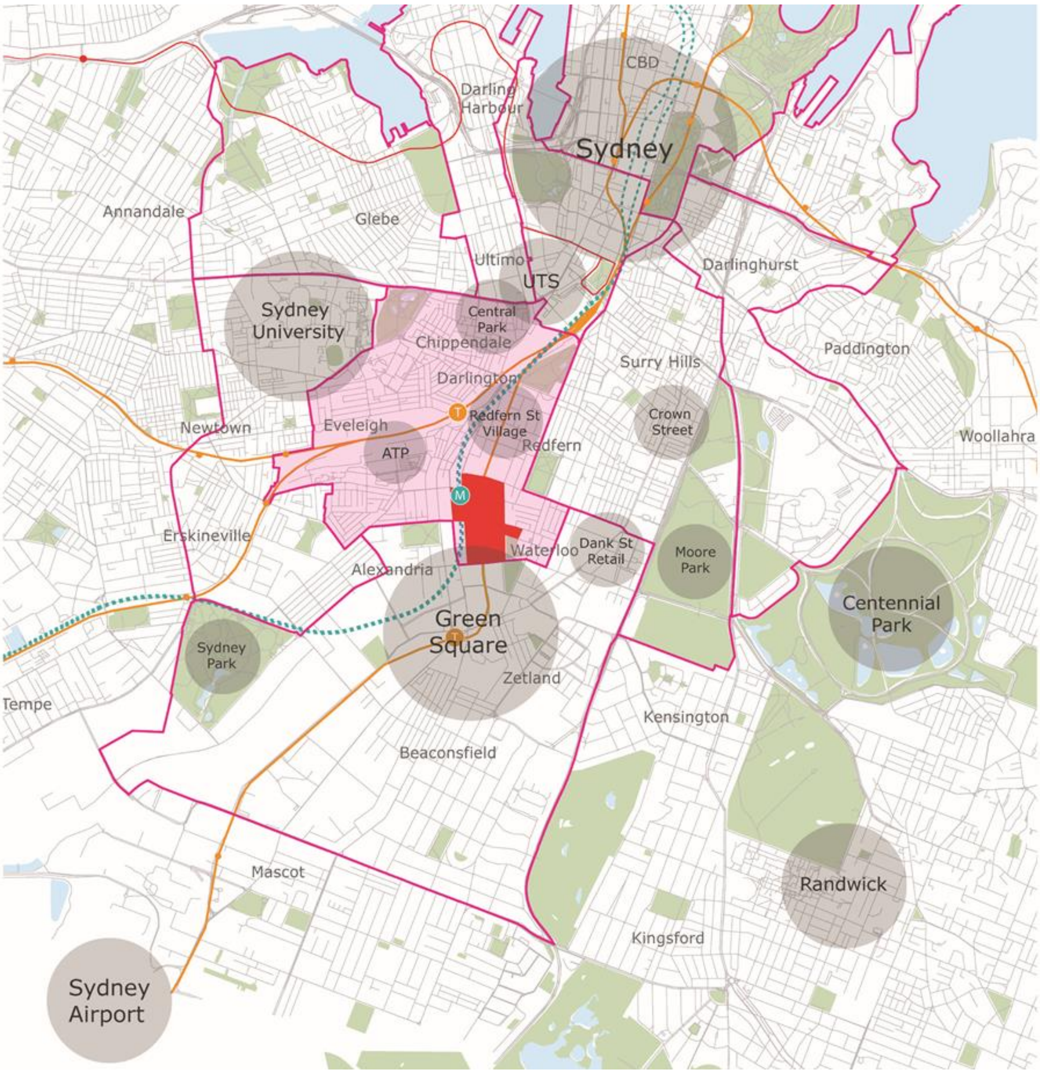

Figure 1.1 Location and site plan of the Precinct (Source: Turners Studio)

Figure 1.2 Aerial photograph (Source: Ethos Urban & Nearmap)

1.3 The Metro Quarter

The Metro Quarter comprises land to the west of Cope Street, east of Botany Road, south of Raglan Street and north of Wellington Street. It has an approximate gross site area of 1.91ha and a developable area of 1.28ha. The heritage listed Waterloo Congregational Church located at 103–105 Botany Road is located within the Precinct. However, there are no proposals for physical works or changes to the planning framework applicable to the church.

Formerly privately owned, all land in the Metro Quarter was purchased by the NSW Government to facilitate construction of the Waterloo Metro Station and associated over station development.

1.3.1 Approved Metro Rail Infrastructure

The Waterloo Metro station will be constructed within the eastern side of the Metro Quarter as part of the Sydney Metro City & Southwest - Chatswood to Sydenham. This section of the Sydney Metro project received planning approval in January 2017 (SSI 15_7400), with construction led by Sydney Metro. While most of the Metro Station will be located beneath finished ground level, two substantial entry/plant structures, with heights equivalent to a 5 storey residential building (up to 20 metres), will protrude above finished ground level; one along the northern end of Cope Street, the other along the southern end of Cope Street.

Demolition of existing buildings has been completed and excavation of the Waterloo Metro Station is underway.

1.4 Purpose

The purpose of this report is to address the relevant Study Requirements detailed below.

2 STUDY REQUIREMENTS

On 19 May 2017 The Minister issued Study Requirements for the nominated Precinct. Of relevance to this study are the following requirements:

19. Wind

19.1. Provide a complete understanding of the existing wind characteristics of the precinct. Consider the wind climate of Sydney, local characteristics such as topography that modify this wind climate for the precinct and the impact of existing buildings, in particular, the tower and slab blocks, on wind conditions.

19.2. Identify significant locations for wind sensitivity within the public domain, including metro station entry, bus stops, public plazas and other public domain areas for the purpose of modelling wind impacts of the proposed development.

19.3. Ensure early consideration of potential wind impacts and amelioration approaches through the layout and arrangement of the public domain and the built form.

19.4. Advise on measures to ensure the suitability of areas for their intended use with regard to the impact of wind on comfort and safety. In particular, this is to focus on the public space areas intended to be used for seating (ie the park, outdoor dining areas on footpaths and public plazas) and standing (ie building entries); and, also for outdoor private recreation areas to be suitable for sitting (eg balconies, decks and outdoor communal private open space). Advise on the placement, orientation, shape and external design of buildings, and relevant wind mitigation devices.

19.5. Any advice on landscaping of public space must accord with the City of Sydney Public Design Manual and the Public Domain design. In general landscaping can only be used for wind mitigation if it is already in place.

19.6. Include areas surrounding the precinct that may be wind affected as a result of the proposal.

19.7. Undertake an assessment to demonstrate that subject to any recommended measures, wind will not have an unacceptable impact on the proposal, and the proposal will not generate unacceptable wind impacts.

19.8. Wind tunnel testing is required.

The above Study Requirements are addressed in the following sections of the report.

Report Section	Study Requirements Addressed
3 Baseline Investigations	19.1, 19.8
4 Implementation Plan & Strategy	19.2, 19.3, 19.4, 19.8
5 Assessment	19.4, 19.5, 19.6, 19.7

3 BASELINE INVESTIGATIONS

This section will address study requirements 19.1 and 19.8 through the analysis of the existing site wind conditions via wind tunnel testing. Testing of the existing site ground level wind conditions was undertaken to identify issues, opportunities and constraints to be explored through the master planning process of the Metro Quarter development, including land use and community needs to support the development.

Wind tunnel testing was performed at Windtech's boundary layer wind tunnel facility. The wind tunnel has a 3.0m wide working section and a fetch length of 14m, and measurements were taken from 16 wind directions at 22.5 degree increments. Testing was carried out using a 1:400 detailed scale model of the development. The effects of nearby buildings and land topography have been accounted for through the use of a proximity model which represents an area with a radius of 600m. The testing procedures were based on the guidelines set out in the Australasian Wind Engineering Society Quality Assurance Manual (AWES-QAM-1-2017), ASCE 7-10 (Chapter C31), and CTBUH (2013).

Peak gust and mean wind speeds were measured at selected critical ground level outdoor trafficable locations within and around the subject development. Wind velocity coefficients representing the local wind speeds are derived from the wind tunnel and are combined with a statistical model of the regional wind climate (which accounts for the directional strength and frequency of occurrence of the prevailing regional winds) to provide the equivalent full-scale wind speeds at the site. The wind speed measurements are compared with criteria for pedestrian comfort and safety, based on Gust-Equivalent Mean (GEM) and annual maximum gust winds, respectively.

Testing of the Metro Quarter development site was undertaken for the existing site conditions, based on the architectural drawing packages received May 2017. The existing site development was tested in the wind tunnel without the effect of any forms of wind ameliorating devices such as screens, balustrades, etc. that are not already shown in the architectural drawings. The effect of vegetation was also excluded from the testing.

The results provide a baseline wind case for the existing site wind conditions for the proposed development site to be established, taking into account the prevailing wind directions for the region, as well as the local topographical effects of the terrain and the surrounding buildings of the proposed site.

3.1 Wind Climate for the Sydney Region

The regional wind model used in this study was determined from an analysis of measured directional mean wind speeds obtained at the meteorological recording station located at Kingsford Smith Airport (Sydney Airport). Data was collected from 1995 to 2016 between 6am to 10pm and corrected so that it represents wind speeds over standard open terrain at a height of 10m above ground for each wind direction. From this analysis, directional probabilities of exceedance and directional wind speeds for the region are determined. The directional wind speeds are summarised in Table 3.1. The directional wind speeds and corresponding directional frequencies of occurrence are presented in Figure 3.1.

The data indicates that the southerly winds are by far the most frequent winds for the Sydney region, and are also the strongest. The westerly winds occur most frequently during the winter season for the Sydney region, and although they are typically not as strong as the southerly winds, they are usually a cold wind and hence can be a cause for discomfort for outdoor areas. North-easterly winds occur most frequently occur during the warmer months of the year for the Sydney region, and hence are usually welcomed within outdoor areas since they are typically not as strong as the southerly or westerly winds.

The recurrence intervals examined in this study are for exceedances of 5% (per 90 degree sector) for the pedestrian comfort criteria using Gust-Equivalent Mean (GEM) wind speeds, and annual maximum wind speeds (per 22.5 degree sector) for the pedestrian safety criterion. Note that the 5% probability wind speeds presented in Table 3.1 are only used for the directional plot presented in Figure 3.1 and are not used for the integration of the probabilities.

Table 3.1: Directional Wind Speeds (m/s)

(hourly means, referenced to 10m above ground in standard open terrain)

Wind Direction	5% Exceedance	Annual Maximum
N	5.9	9.9
NNE	9.9	12.9
NE	9.7	12.3
ENE	7.5	10.0
E	6.3	9.3
ESE	6.2	9.1
SE	7.0	10.1
SSE	8.5	12.2
S	10.3	13.9
SSW	10.0	14.1
SW	6.9	11.9
WSW	9.3	13.6
W	9.8	14.4
WNW	8.8	14.3
NW	6.7	12.6
NNW	5.5	10.7

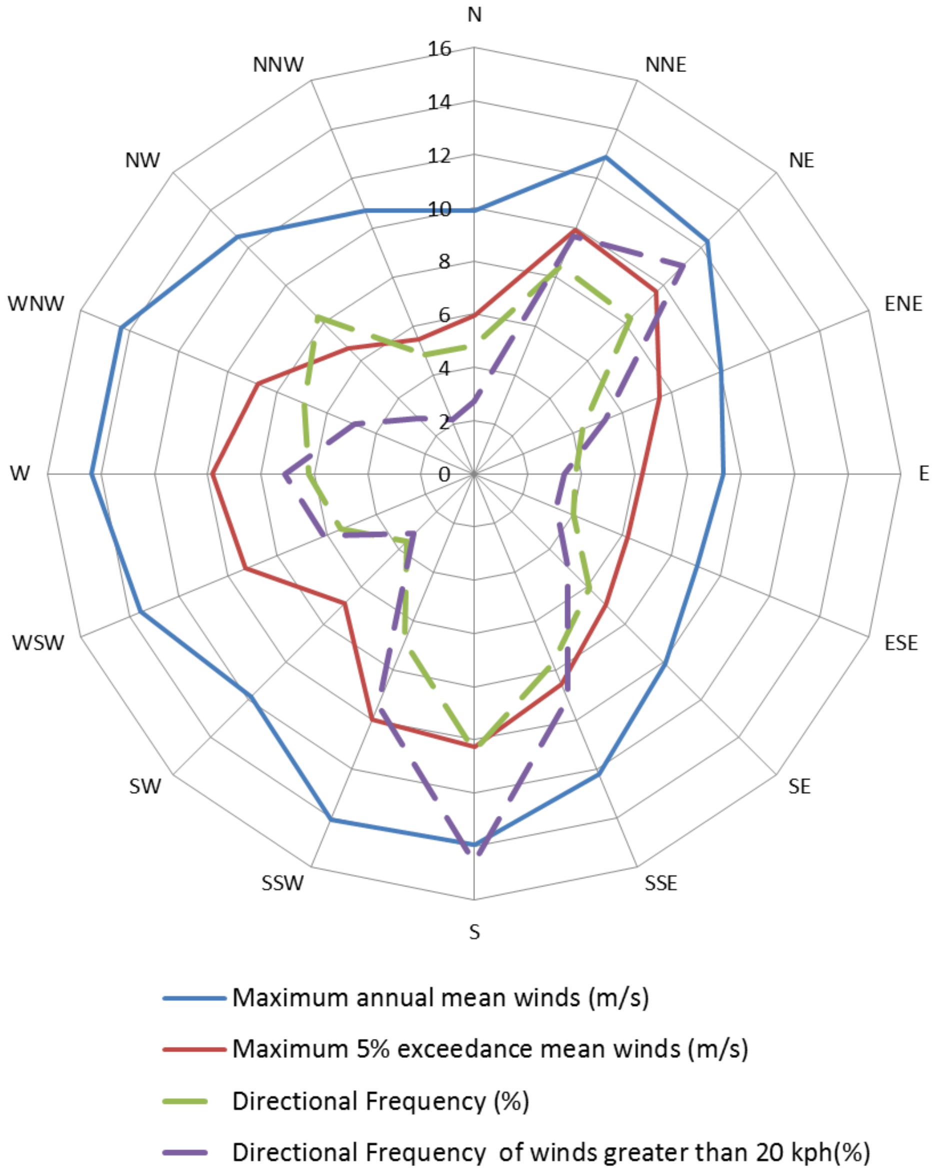

Figure 3.1: Annual and 5% Exceedance Hourly Mean Wind Speeds, and Frequencies of Occurrence, for the Sydney Region (referenced to 10m above ground in standard open terrain)

3.2 The Wind Tunnel Model

Measurements were made in the wind tunnel at selected critical trafficable outdoor locations within and around the development from 16 wind directions at 22.5 degree increments using a 1:400 scale detailed model of the development. The existing site study model incorporates all necessary architectural features on the development to ensure an accurate wind flow is achieved. The effect of nearby buildings and land topography has been accounted for through the use of a proximity model, which represents a radius of approximately 600m. Photographs of the wind tunnel model are presented below for the existing site in Figures 3.2a to 3.2f on the following pages. Figure 3.2g depicts a plan view of the proximity model.

The model of the proposed development was tested in the wind tunnel without the effect of any forms of wind ameliorating devices such as screens, balustrades, awnings, etc., which are not already shown in the architectural drawings.

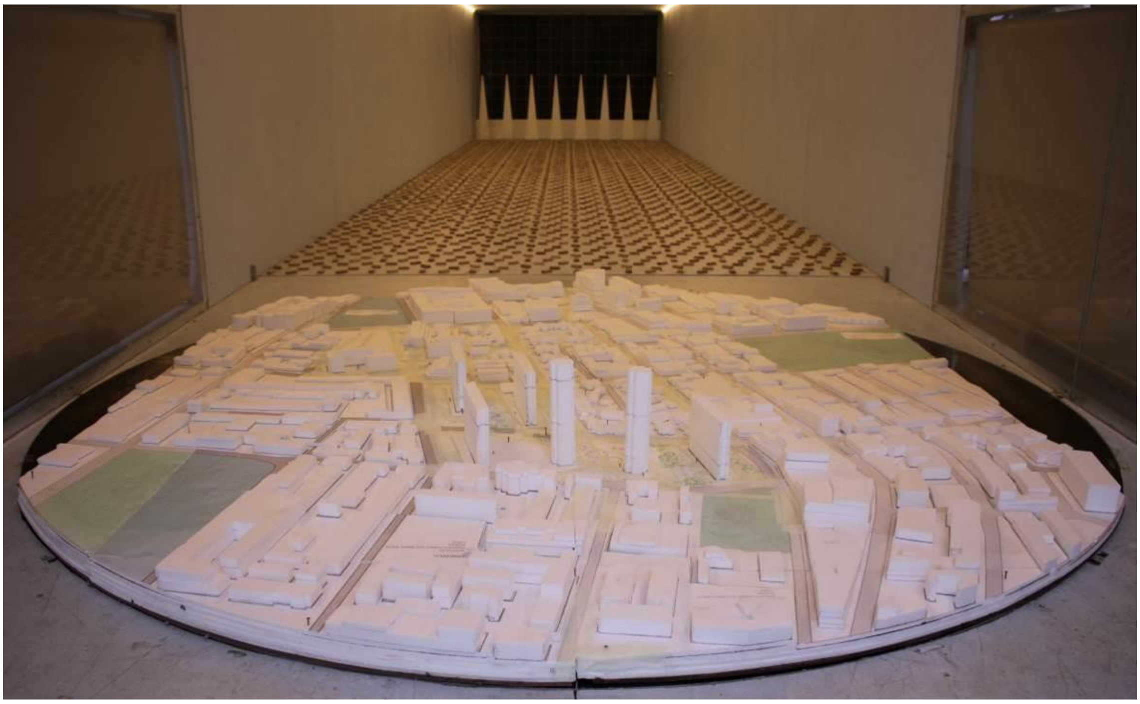

Figure 3.2a: Photograph of the Wind Tunnel Model – (View from the North)

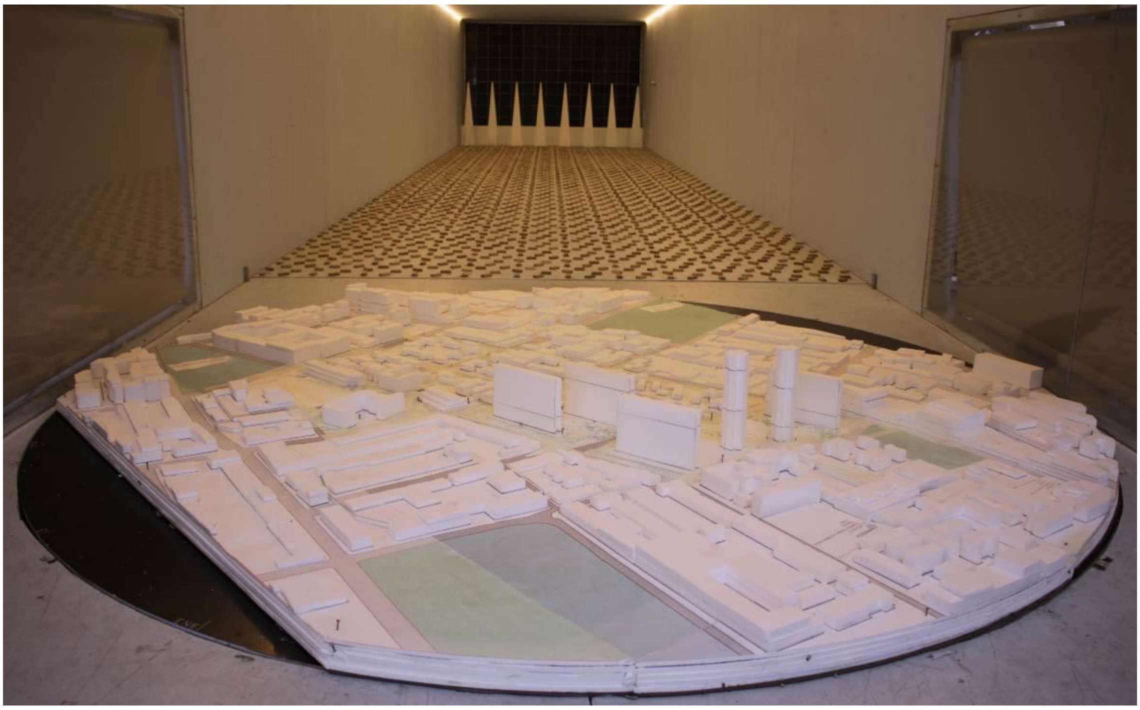

Figure 3.2b: Photograph of the Wind Tunnel Model – (View from the North-East)

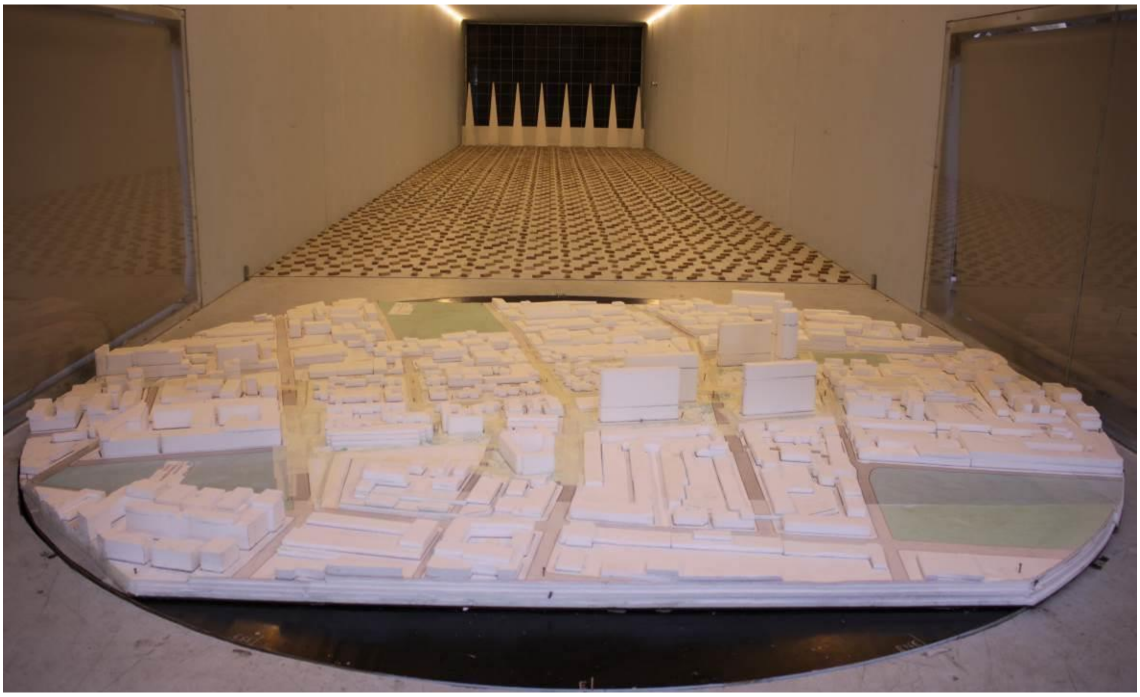

Figure 3.2c: Photograph of the Wind Tunnel Model – (View from the East)

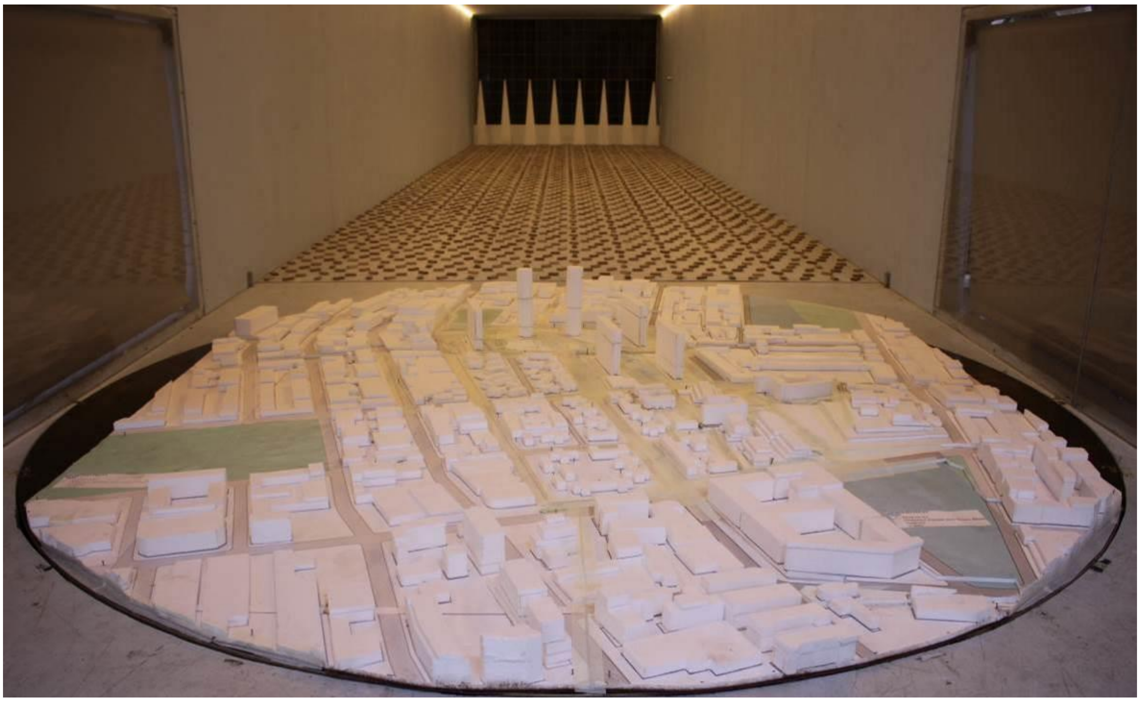

Figure 3.2d: Photograph of the Wind Tunnel Model – (View from the South)

Figure 3.2e: Photograph of the Wind Tunnel Model – (View from the West)

Figure 3.2f: Photograph of the Wind Tunnel Model – (View from the South-East)

Figure 3.2g: Map of Proximity Model

3.3 Boundary Layer Wind Flow Model

Testing was performed using Windtech's boundary layer wind tunnel, which has a 3.0m wide working section and has a fetch length of 14m. The model was placed in the appropriate standard boundary layer wind flow for each of the prevailing wind directions for the wind tunnel testing. The type of wind flow used in a wind tunnel study is determined by a detailed analysis of the surrounding terrain types around the subject site. Details of the analysis of the surrounding terrain for this study are provided in the following pages of this report.

The roughness of the earth's surface has the effect of slowing down the prevailing wind near the ground. This effect is observed up to what is known as the *boundary layer height*, which can range between 500m to 3km above the earth's surface depending on the roughness of the surface (i.e. oceans, open farmland, dense urban cities, etc.). Within this range, the prevailing wind forms what is known as a *boundary layer wind profile*.

Various wind codes and standards classify various types of boundary layer wind flows depending on the surface roughness. However, it should be noted that the wind profile does not change instantly due to changes in the terrain roughness. It can take many kilometres (at least 100km) of a constant surface roughness for the boundary layer profile to achieve a state of equilibrium. Descriptions of the standard boundary layer profiles for various terrain types are summarised as follows (in accordance with AS/NZS1170.2.2011):

- **Terrain Category 1.0:** Extremely flat terrain. Examples include enclosed water bodies such as lakes, dams, rivers, bays, etc.
- **Terrain Category 1.5:** Relatively flat terrain. Examples include the open ocean, deserts and very flat open plains.
- **Terrain Category 2.0:** Open terrain. Examples include grassy fields and plains and open farmland (without buildings or trees).
- **Terrain Category 2.5:** Relatively open terrain. Examples include farmland with scattered trees and buildings and very low-density suburban areas.
- **Terrain Category 3.0:** Suburban and forest terrain. Examples include suburban areas of towns and areas with dense vegetation such as forests, bushland, etc.
- **Terrain Category 3.5:** Relatively dense suburban terrain. Examples include centres of small cities, industrial parks, etc.
- **Terrain Category 4.0:** Dense urban terrain. Examples include CBD's of large cities with many high-rise towers, and areas with many closely-spaced mid-rise buildings.

For this study, the shape of the boundary layer wind flows over standard terrain types is defined in accordance with Deaves & Harris (1978). These are summarised in Table 3.2, referenced to the study reference height of 56m above ground. The Suburban Terrain Category 3.0 profile has been used in the wind tunnel testing of the subject development.

Table 3.2: Terrain and Height Multipliers, Turbulence Intensities, and Corresponding Roughness Lengths, for the Standard Boundary Layer Profiles (referenced to the study reference height)

Terrain Category	Terrain and Height Multipliers			Turbulence Intensity I_v	Terrain Roughness Length (m) $z_{0,r}$
	$k_{tr,T=3600s}$ (hourly)	$k_{tr,T=600s}$ (10-minute)	$k_{tr,T=3s}$ (3-second)		
1.0	0.97	1.00	1.29	0.109	0.003
1.5	0.91	0.95	1.26	0.125	0.01
2.0	0.86	0.89	1.23	0.144	0.03
2.5	0.78	0.82	1.18	0.171	0.1
3.0	0.70	0.74	1.13	0.204	0.3
3.5	0.60	0.64	1.07	0.260	1
4.0	0.48	0.53	0.98	0.346	3

An analysis of the effect of changes in the upwind terrain roughness was carried out for each of the wind directions studied. This has been undertaken based on the method given in AS/NZS1170.2:2011, which uses a "fetch" length of 40 times the study reference height. However, it should be noted that this "fetch" commences *beyond* a "lag distance" area, which has a length of 20 times the study reference height (in accordance with AS/NZS1170.2:2011), so the actual "fetch" of terrain analysed is the area between 20 and 60 times the study reference height away from the site. An aerial image showing the surrounding terrain is presented in Figure 3.3 for a radius of 3.4km from the edge of the wind tunnel proximity model. The resulting mean and gust terrain and height multipliers at the site location are presented in Table 3.3, referenced to the study reference height.

For each of the 16 wind directions tested in this study, the approaching boundary layer wind profiles modelled in the wind tunnel matched the model scale and the overall surrounding terrain characteristics beyond the extent of the proximity model. Plots of the wind tunnel boundary layer wind profiles are presented in Appendix B of this report.

Table 3.3: Directional Mean and Gust Terrain and Height Multipliers at the Site (at the study reference height)

Wind Sector (degrees)	$k_{tr,T=3600s}$ (hourly mean)	$k_{tr,T=600s}$ (10-minute mean)	$k_{tr,T=3s}$ (3-second gust)
0	0.60	0.65	1.07
30	0.60	0.64	1.07
60	0.74	0.78	1.16
90	0.78	0.82	1.18
120	0.74	0.78	1.16
150	0.78	0.81	1.18
180	0.70	0.74	1.13
210	0.60	0.64	1.07
240	0.70	0.74	1.13
270	0.70	0.74	1.13
300	0.68	0.72	1.12
330	0.79	0.82	1.18

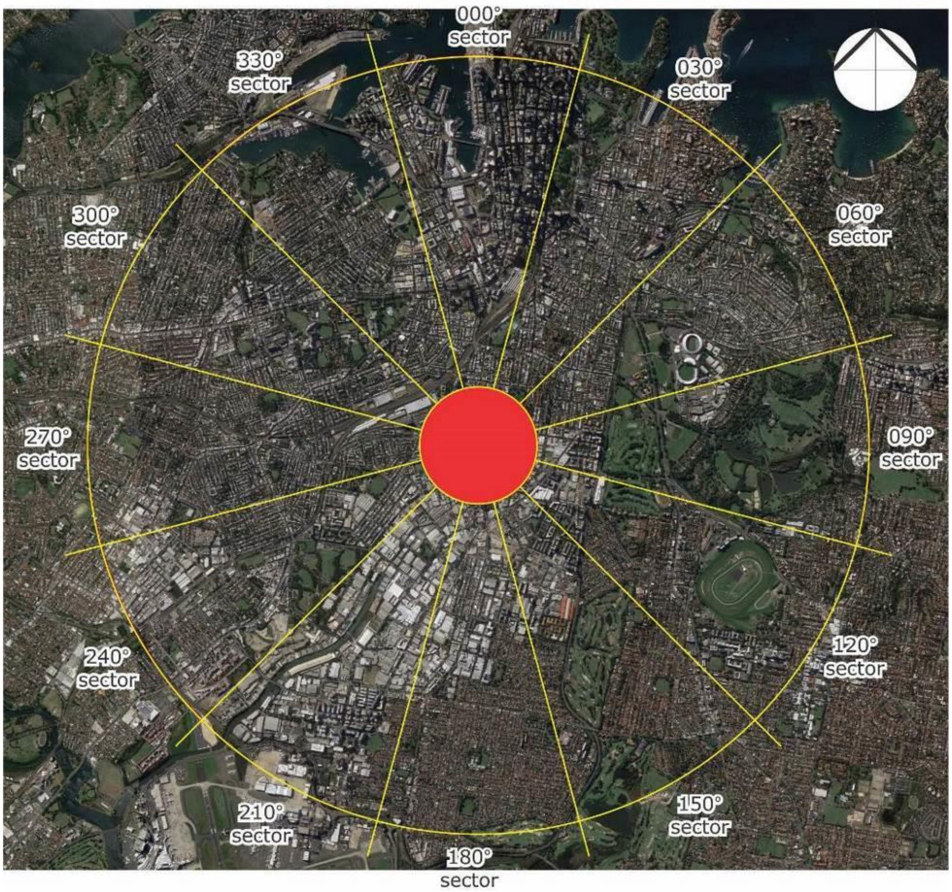

Figure 3.3: Aerial Image of the Surrounding Terrain (radius of 3.4km from the edge of the proximity model, which is coloured red)

3.4 Pedestrian Wind Comfort and Safety

The acceptability of wind conditions of an area is determined by comparing the measured wind speeds against an appropriate criteria. This section outlines how the measured wind speeds were obtained, the criteria considered for the development, as well as the critical trafficable areas that were assessed and their corresponding criteria designation.

3.4.1 Measured Wind Speeds

Wind speeds were measured using Dantec hot-wire probe anemometers, positioned to monitor wind conditions at critical outdoor trafficable areas of the development. The reference mean free-stream wind speed measured in the wind tunnel, which is at a full-scale height of 200m and measured 3m upstream of the study model.

Measurements were acquired for 16 wind directions at 22.5 degree increments using a sample rate of 1,024Hz. The full methodology of determining the wind speed measurements at the site from the Dantec Hot-wire probe anemometers is provided in Appendix D. Based on the results of the analysis of the boundary layer wind profiles at the site (see Section 3.3), and incorporating the regional wind model (see Section3.1), the data sampling length of the wind tunnel test for each wind direction corresponds to a full-scale sample length ranging between 30 minutes and 1 hour. Research by A.W. Rofail and K.C.S. Kwok (1991) has shown that, in addition to the mean and standard deviation of the wind being stable for sample lengths of 15 minutes or more (full-scale), the peak value determined using the upcrossing method is stable for sample lengths of 30 minutes or more.

3.4.2 Wind Speed Criteria Used for This Study

For this study, the measured wind conditions for the various critical outdoor trafficable areas around the subject development are compared against the criteria presented in the Draft Sydney Development Control Plan 2012 - Central Sydney Planning Review Amendment, which supersedes the criteria detailed in the City of Sydney Development Control Plan 2012 (SDCP2012).

For pedestrian comfort, the Draft Sydney DCP 2012 requires that the hourly mean wind speed, or Gust-Equivalent Mean (GEM) wind speed (whichever is greater for each wind direction), must not exceed 8m/s for walking, 6m/s for standing, and 4m/s for sitting. These are based on a 5% probability of exceedance.

For pedestrian safety, the Draft Sydney DCP 2012 defines a safety limit criterion of 24m/s, based on an annual maximum 0.5 second gust wind speed, which applies to all areas.

Furthermore, in accordance with the provisions of the Draft Sydney DCP 2012, the existing conditions for the pedestrian footpaths around the site are also analysed as part of this study to determine the impact of the subject development. If it is found that the existing conditions exceed the relevant criteria, then the target wind speed for that area with the inclusion of the proposed development is to at least match the existing site conditions.

In accordance with the provisions of the Draft Sydney DCP 2012, the wind speed assessment is undertaken for winds occurring between 6am and 10pm (AEST).

A more detailed comparison of published criteria for pedestrian wind comfort and safety is provided in Appendix C

For this study the measured wind conditions of the selected critical outdoor trafficable areas are compared against two sets of criteria; one for pedestrian safety, and one for pedestrian comfort. The safety criterion is applied to the annual maximum gust winds, and the comfort criteria is applied to Gust Equivalent Mean (GEM) winds. In accordance with ASCE (2003), the GEM wind speed is defined as follows:

$$GEM = max\left(\bar{V}, \frac{\hat{V}}{1.85}\right) \tag{3.1}$$

Where:

$\bar{V}$ is the mean wind speed.

$\hat{V}$ is the gust wind speed.

The criteria considered in this study are summarised in Tables 3.4 and 3.5 for pedestrian comfort and safety, respectively. The results of the wind tunnel study are presented in the form of directional plots attached in Appendix A of this report. For each study point there is a plot of the GEM wind speeds using the comfort criteria, and a plot for the annual maximum gust wind speeds using the safety criterion.

Table 3.4: Pedestrian Comfort Criteria (Draft Sydney DCP 2012)

Classification	Description	Maximum 5% Exceedance GEM Wind Speed (m/s)
Sitting	Outdoor areas that involve seating such as parks, dining areas in restaurants, amphitheatres, etc.	4
Standing	Short duration stationary activities (generally less than 1 hour), including window shopping, waiting areas, etc.	6
Walking	For pedestrian thoroughfares, private swimming pools, most communal areas, private balconies and terraces, etc.	8

Table 3.5: Pedestrian Safety Criterion (Draft Sydney DCP 2012)

Classification	Description	Annual Maximum Gust Wind Speed (m/s)
Safety	Safety criterion applies to all trafficable areas.	24

3.4.3 Layout of Study Points, and Relevant Wind Speed Criteria

For this study a total of 10 ground level study points have been selected for analysis in the wind tunnel located within and around various locations of the proposed development site.

The locations of the various study points tested are presented in Figure 3.4 in the form of a marked-up plan drawing. The target wind speed criteria for the outdoor trafficable areas within and around the development is also indicated in these figure which are based on the intended use (length of stay).

The most critical outdoor locations of the development have been selected for analysis which will help with the masterplan design input. The significant areas of concern are the corner areas of the proposed development site due to the alignment of the city street grid coinciding with two of the prevailing winds for the Sydney region, which are the southerly and westerly winds. These areas may be subject to adverse wind effects due to a combination of direct winds and corner accelerations. The wind tunnel results are explained in Section 3.6.

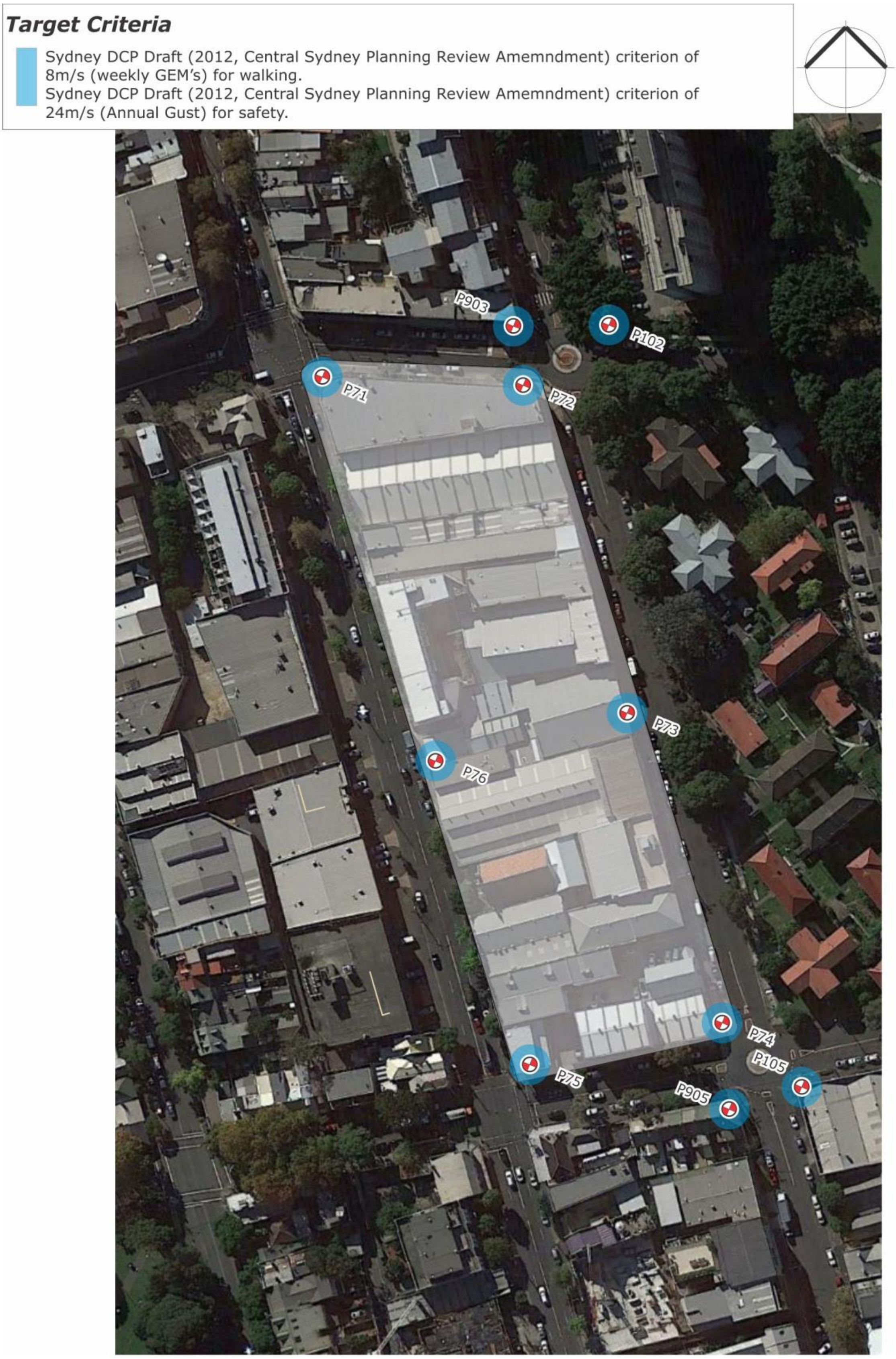

Figure 3.4: Study Point Locations and Target Criteria – Ground Level - Existing Site of Proposed Waterloo Metro Block

3.5 Results

The results for the existing site point locations are presented in the form of directional plots in Appendix A, summarised in Table 3.6, and shown on marked-up plans in Figure 3.6 below. The wind speed criteria that the wind conditions should achieve are also listed in Table 3.6 for each study point location, as well as shown in Figure 3.4.

The baseline conditions established from the pedestrian wind environment testing will then be compared against the results of the wind tunnel testing of the proposed masterplan development stage of this project, at which point it is expected that the future Sydney DCP draft will be in full effect.

Table 3.6: Wind Tunnel Results Summary – Existing Site Conditions (Draft Sydney DCP 2012)

Study Point	Wind Speed Criteria and Overall Rating			
	GEM 5% exceedance (m/s)	Rating	Safety Limit (m/s)	Rating
Point 71	8.0	PASS	24.0	PASS
Point 72	8.0	PASS	240	PASS
Point 73	8.0	PASS	24.0	PASS
Point 74	8.0	PASS	24.0	PASS
Point 75	8.0	PASS	24.0	PASS
Point 76	8.0	PASS	24.0	PASS
Point 102	8.0	PASS	24.0	PASS
Point 105	8.0	PASS	24.0	PASS
Point 903	8.0	PASS	24.0	PASS
Point 905	8.0	PASS	24.0	PASS

Note that when classifying a "Pass" or "Fail" for the weekly GEM wind speeds, the desired criterion is exceeded if the probability of exceedance is greater than 5% and hence awarded a "Fail".

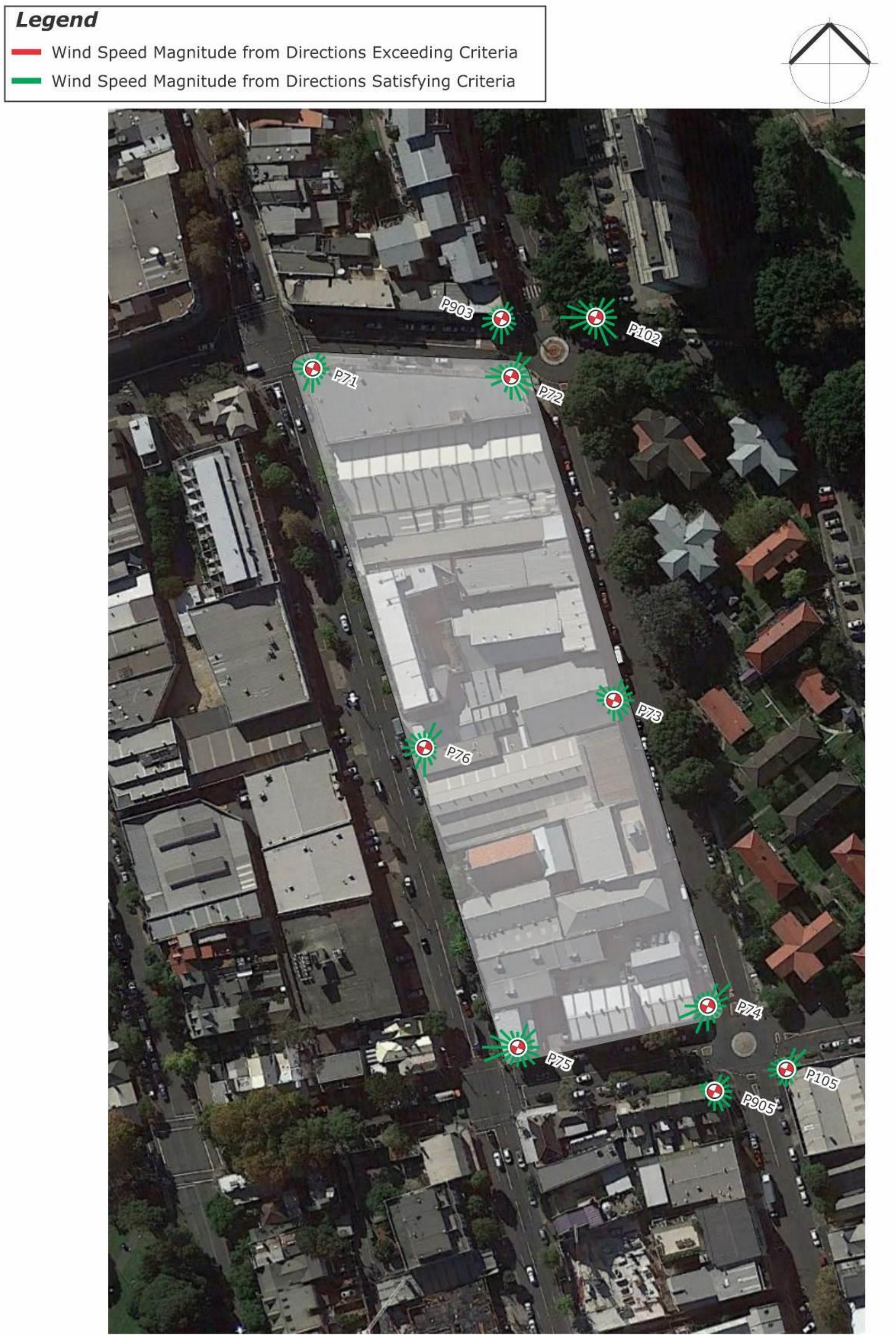

Figure 3.5: Wind Directionality Plots – Ground Level - Existing Site of Proposed Waterloo Metro Block

3.6 Discussion of Results

Wind tunnel testing was performed to determine the existing site wind conditions at the proposed development site. The prevailing wind directions for the region, as well as the local topographical effects of the terrain and the surrounding buildings of the proposed site were considered. The results allow for design guidance and comparison with the wind tunnel testing results of the proposed concept design stage of the development.

Due to the relatively low-rise and scattered nature of the existing buildings within and around the study site, the wind conditions from the wind tunnel test generally indicate the exposed nature of the site to the predominant north-easterly, westerly and southerly winds for the region, with localised wind effects detected. More specifically, the majority of wind effects detected from the wind tunnel testing were observed to be direct wind effects due to limited shielding.

The predominant north-easterly, westerly and southerly winds are seen to impact the various study point locations located around the Waterloo Metro Quarter site. The noted wind effects will be important for the consideration of the layout and openings for the Metro Station and nearby outdoor areas, including proposed outdoor areas/laneways through the site. The westerly winds also predominantly occur during the winter months hence will have a significantly adverse impact on thermal comfort due to “wind chill” effects.

The orientation and location of the various streetscapes around the site were observed to play a role in the amount of exposure the regions experienced to the predominant wind directions. For example, the streets orientated east/west were heavily impacted by the westerly winds, namely Henderson Road, Raglan Street and Wellington Street. The north/south orientation of Botany Road and Cope Street were noted to make the pedestrian footpath areas susceptible to the predominant north-easterly and southerly winds. This is a direct result of the exposed nature of the development site, as the incoming predominant winds are able to flow freely throughout these streetscapes, hence being the main contributor to the wind effects within these regions. This is an important point to consider during the conceptual masterplan/massing stage of the development, in order to ensure that these predominant winds are not further accentuated by the future built forms. Furthermore, these wind effects were noted for the existing relatively low-rise built form of the site and the inclusion of future taller built forms within the site have the potential to further exacerbate these effects, which will be investigated in Section 4.

3.7 Proposal

This report relates to:

- An SSP Study to create a new suite of planning controls; and
- an Indicative Concept Proposal

for the Waterloo Metro Quarter ISD.

3.7.1 Proposed Planning Framework

The existing and proposed planning controls for the Metro Quarter are:

	Existing	Proposed
Zoning	B4 Mixed Use	B4 Mixed Use
Height of Buildings	Part 12, Part 15 metres	- Part RL 116.9 (AHD) - North - Part RL 104.2 (AHD) - Central - Part RL 96.9 (AHD) - South
Floor Space Ratio	1.75:1	6.1:1 (including Metro Station)

3.7.2 Indicative Concept Proposal

The Indicative Concept Proposal for the Metro Quarter ISD comprises:

- Approximately 69,000 sqm of gross floor area (GFA), comprising:
    - Approximately 56,500 sqm GFA of residential accommodation, providing for approximately 700 dwellings, including 5 to 10% affordable housing and 70 social housing dwellings;
    - Approximately 4,000 sqm of GFA for retail premises and entertainment facilities.
    - Approximately 8,500 sqm GFA for business and commercial premises and community, health and recreation facilities (indoor).
- Publicly accessible plazas fronting Cope Street (approximately 1,400 sqm) and Raglan Street (580sqm).
- A three storey mixed-use, non-residential podium, including a free standing building within the Cope Street Plaza.
- Three taller residential buildings of 23, 25 and 29 storeys, and four mid-rise buildings of four to ten storeys above the podium and/or the approved metro station infrastructure.
- Parking for approximately 65 cars, 700 residential bicycles and 520 public bicycles.

- Two east-west, through-block pedestrian connections.

Approval has already been separately granted for a Sydney Metro station on the site, which will comprise approximately 8,415 sqm of GFA. The total GFA for the ISD, including the metro station GFA is approximately 77,500 sqm. Transport interchange facilities including bus stops on Botany Road and kiss and ride facilities on Cope Street will be provided under the existing CSSI Approval.

The above figures are deliberately approximate to accommodate detailed design resolution.

While the existing heritage listed Waterloo Congregational Church is within the SSP Study Area, there are no proposals for physical works or changes to the planning framework applicable to the church.

Three dimensional drawings of the Concept Proposal are included at Figure 3.6 and 3.7.

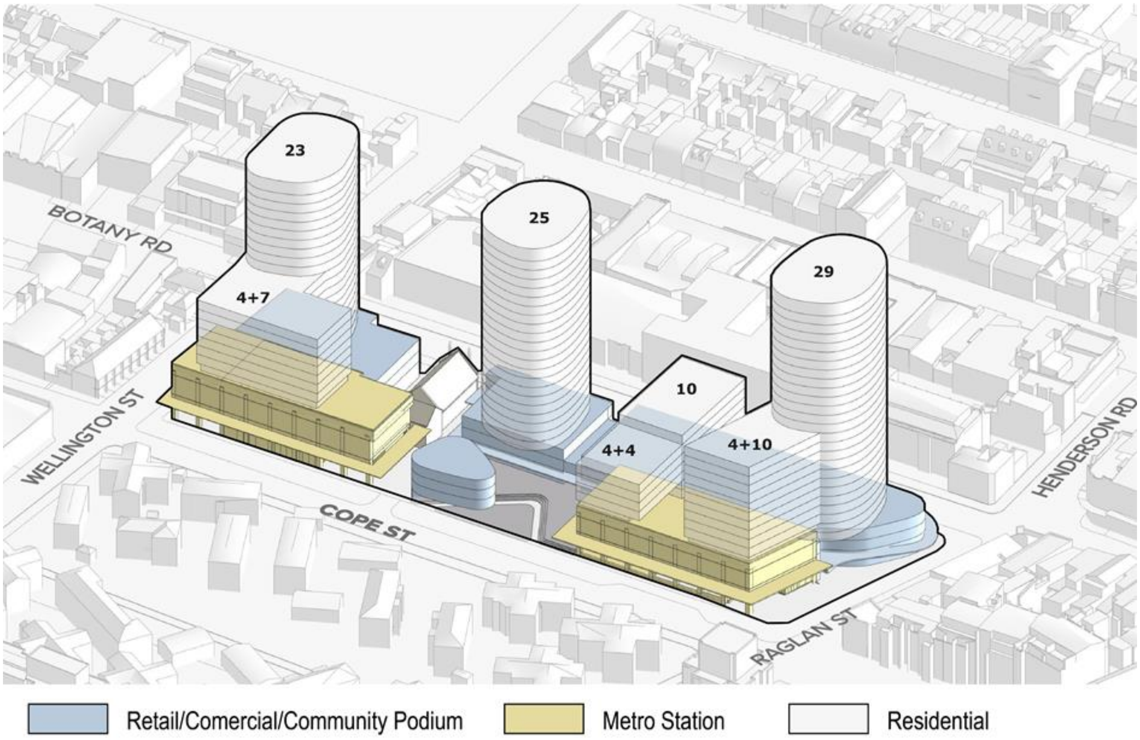

Figure 3.6 – Three-dimensional drawing of the Indicative Concept Proposal, viewed from the East

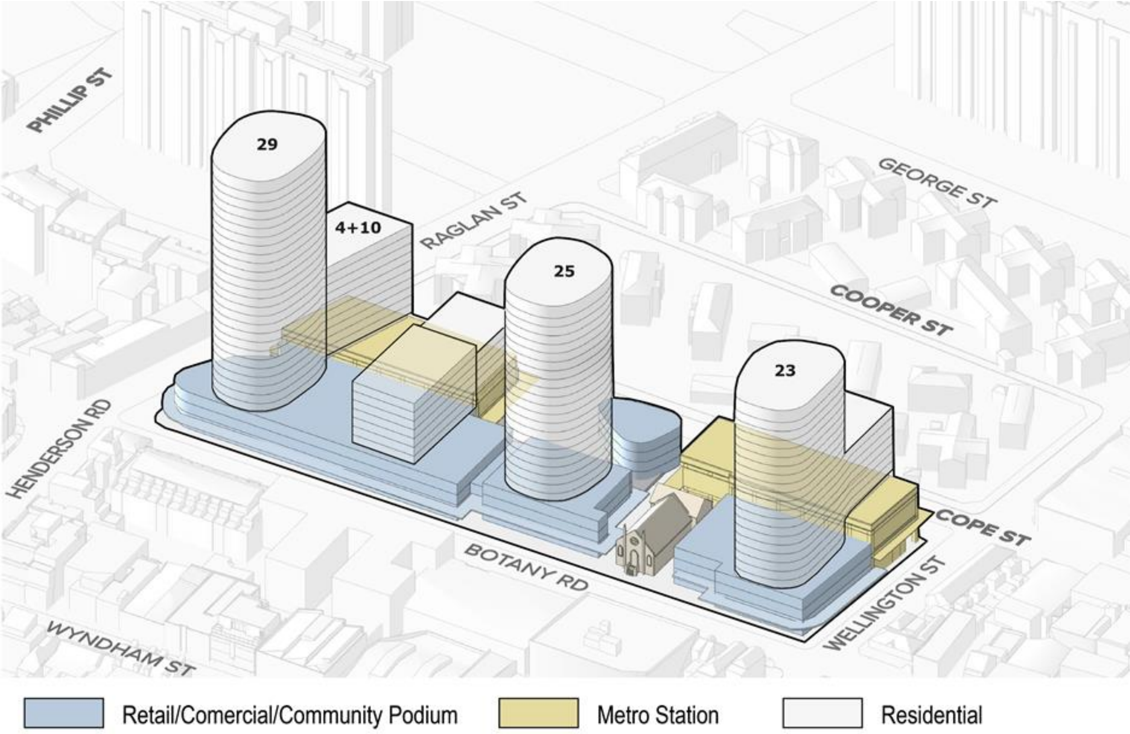

Figure 3.7 – Three-dimensional drawing of the Indicative Concept Proposal, viewed from the West

4 IMPLEMENTATION PLAN & STRATEGY

This section will address study requirements 19.2, 19.3, 19.4 and 19.8 through a review of the proposed massing model to identify key wind sensitive ground locations within and around the site which will be quantitatively assessed by conducting a wind tunnel test of the massing model.

In analysing the initial wind conditions of the existing site for the Waterloo Metro Quarter development, a baseline scenario has been established, which has provided design guidance for the massing model. The wind conditions as outlined above in Section 3 have been considered and a proposed massing model has been developed by the design team within the design parameters and principals presented during the concept stage. Given the baseline wind conditions, the design team have prepared a massing model, which requires further investigation of wind conditions to be undertaken to determine the suitability of areas for pedestrian comfort and safety.

The results of a detailed investigation into the ground level wind environment conditions for the proposed massing model of the Waterloo Metro Quarter development has been undertaken. Wind tunnel testing of the proposed Waterloo Metro Quarter development was undertaken, based on the 3D Sketchup massing model received from UrbanGrowth NSW, January 2018. The wind conditions were assessed at critical outdoor ground level locations including retail and residential entrances, pedestrian footpath areas and through site links, public/communal open space locations, the Metro Station entries and bus stop areas. Elevated pedestrian accessible areas were not tested and will be further investigated during the detailed design stage. If the results of the study indicate that any ground level area is exposed to strong winds, in-principle treatments have been recommended to assist the design team during the design stage.

The testing was performed using one of the boundary layer wind tunnels located at Windtech's Boundary Layer Wind Tunnel Testing Facility in Sydney, which have a 3.0m wide test section and a fetch length of 14m. The testing procedures were based on the guidelines set out in the Australasian Wind Engineering Society Quality Assurance Manual (AWES-QAM-1-2017), ASCE 7-10 (Chapter C31), and CTBUH (2013). Measurements were made in the wind tunnel at selected critical trafficable outdoor ground locations within and around the development from 16 wind directions at 22.5 degree increments using a detailed 1:400 scale model of the development. The effect of nearby buildings and land topography has been accounted for through the use of a proximity model, which represents an area with a radius of 600m. The massing model of the proposed development was initially tested in the wind tunnel without the effect of any forms of wind ameliorating devices such as screens, balustrades, etc. that are not already shown in the architectural drawing package. The effect of vegetation was also excluded from the testing.

Peak gust and mean wind speeds were measured at selected critical outdoor trafficable locations within and around the subject development. Wind velocity coefficients representing the local wind speeds are derived from the wind tunnel and are combined with a statistical model of the regional wind climate (which accounts for the directional strength and frequency of occurrence of the prevailing regional winds) to provide the equivalent full-scale wind speeds at the site. These wind speed measurements are compared with criteria for pedestrian comfort and safety, based on gust wind speeds and Gust-Equivalent Mean (GEM) wind speeds.

If the results of the massing model study indicate that any ground level area is exposed to strong winds, in-principle treatments have been recommended and discussed in Section 6. These treatments could be in the form of wind deflective elements such as screens, awnings, etc or vegetation that is already proposed for the site, and/or additional trees, shrubs, etc.

4.1 Wind Climate for the Sydney Region

The regional wind model used in this study was determined from an analysis of measured directional mean wind speeds obtained at the meteorological recording station located at Kingsford Smith Airport (Sydney Airport). Data was collected from 1995 to 2016 between 6am to 10pm and corrected so that it represents wind speeds over standard open terrain at a height of 10m above ground for each wind direction. From this analysis, directional probabilities of exceedance and directional wind speeds for the region are determined. The directional wind speeds are summarised in Table 4.1. The directional wind speeds and corresponding directional frequencies of occurrence are presented in Figure 4.1.

The data indicates that the southerly winds are by far the most frequent winds for the Sydney region, and are also the strongest. The westerly winds occur most frequently during the winter season for the Sydney region, and although they are typically not as strong as the southerly winds, they are usually a cold wind and hence can be a cause for discomfort for outdoor areas. North-easterly winds occur most frequently occur during the warmer months of the year for the Sydney region, and hence are usually welcomed within outdoor areas since they are typically not as strong as the southerly or westerly winds.

The recurrence intervals examined in this study are for exceedances of 5% (per 90 degree sector) for the pedestrian comfort criteria using Gust-Equivalent Mean (GEM) wind speeds, and annual maximum wind speeds (per 22.5 degree sector) for the pedestrian safety criterion. Note that the 5% probability wind speeds presented in Table 4.1 are only used for the directional plot presented in Figure 4.1 and are not used for the integration of the probabilities.

Table 4.1: Directional Mean and Gust Wind Speeds for the Sydney Region (referenced to 10m height above ground in standard open terrain)

Wind Direction	5% Exceedance	Annual Maximum
N	5.9	9.9
NNE	9.9	12.9
NE	9.7	12.3
ENE	7.5	10.0
E	6.3	9.3
ESE	6.2	9.1
SE	7.0	10.1
SSE	8.5	12.2
S	10.3	13.9
SSW	10.0	14.1
SW	6.9	11.9
WSW	9.3	13.6
W	9.8	14.4
WNW	8.8	14.3
NW	6.7	12.6
NNW	5.5	10.7

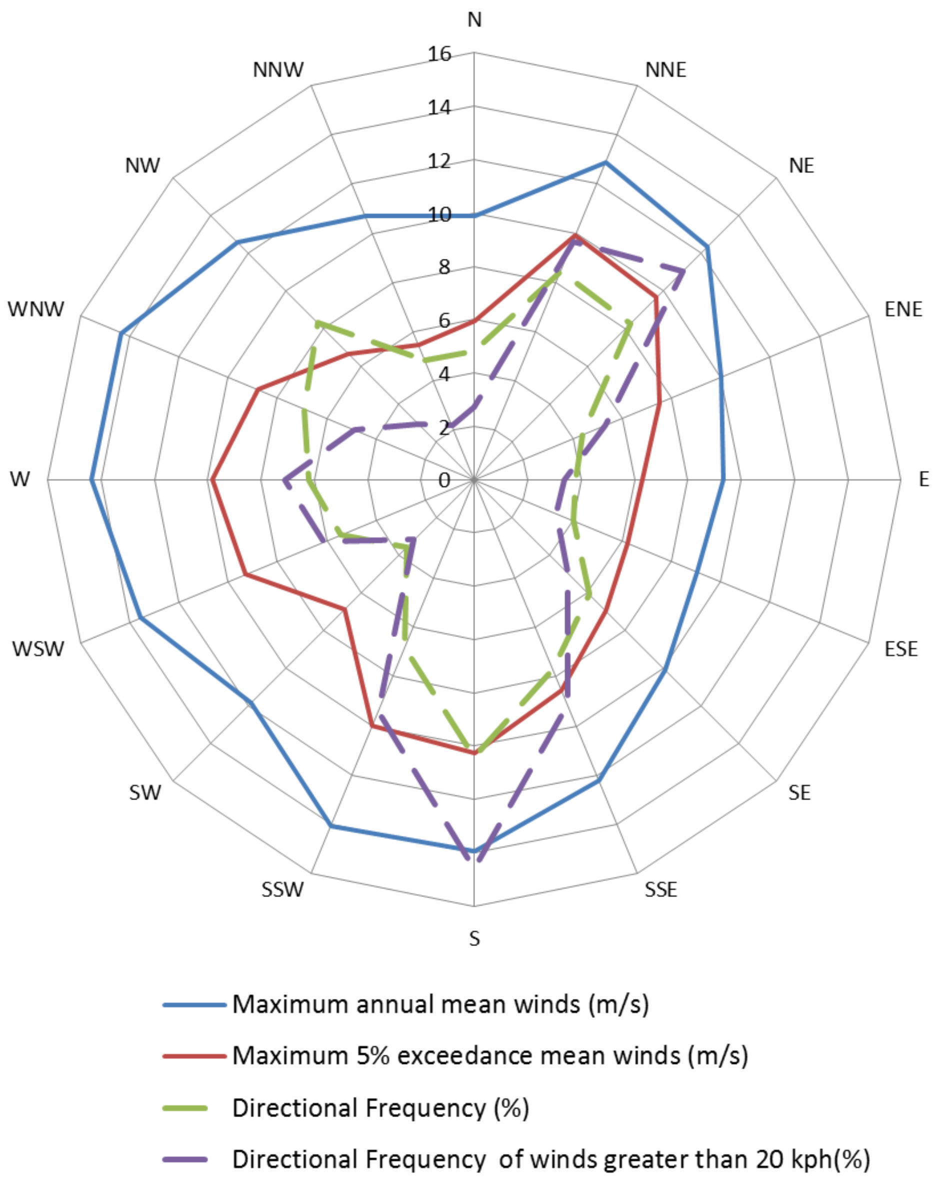

Figure 4.1: Annual and 5% Exceedance Hourly Mean Wind Speeds, and Frequencies of Occurrence, for the Sydney Region (referenced to 10m above ground in standard open terrain)

4.2 The Wind Tunnel Model

Measurements were made in the wind tunnel at selected critical trafficable outdoor locations within and around the development from 16 wind directions at 22.5 degree increments using a 1:400 scale detailed model of the development. The massing study model incorporates all necessary architectural features on the development to ensure an accurate wind flow is achieved. Testing of the proposed Waterloo Metro Quarter development was undertaken, based on the 3D Sketchup massing model received from UrbanGrowth NSW, January 2018. The effect of nearby buildings and land topography has been accounted for through the use of a proximity model, which represents a radius of approximately 600m. Photographs of the wind tunnel model are presented below for the existing site conditions in Figures 4.2a to 4.2g on the following pages. Figure 2h depicts a plan view of the proximity model.

The model of the proposed development was tested in the wind tunnel without the effect of any forms of wind ameliorating devices such as screens, balustrades, awnings, etc., which are not already shown in the architectural drawings.

Figure 4.2a: Photograph of the Wind Tunnel Model – (View from the North-West)

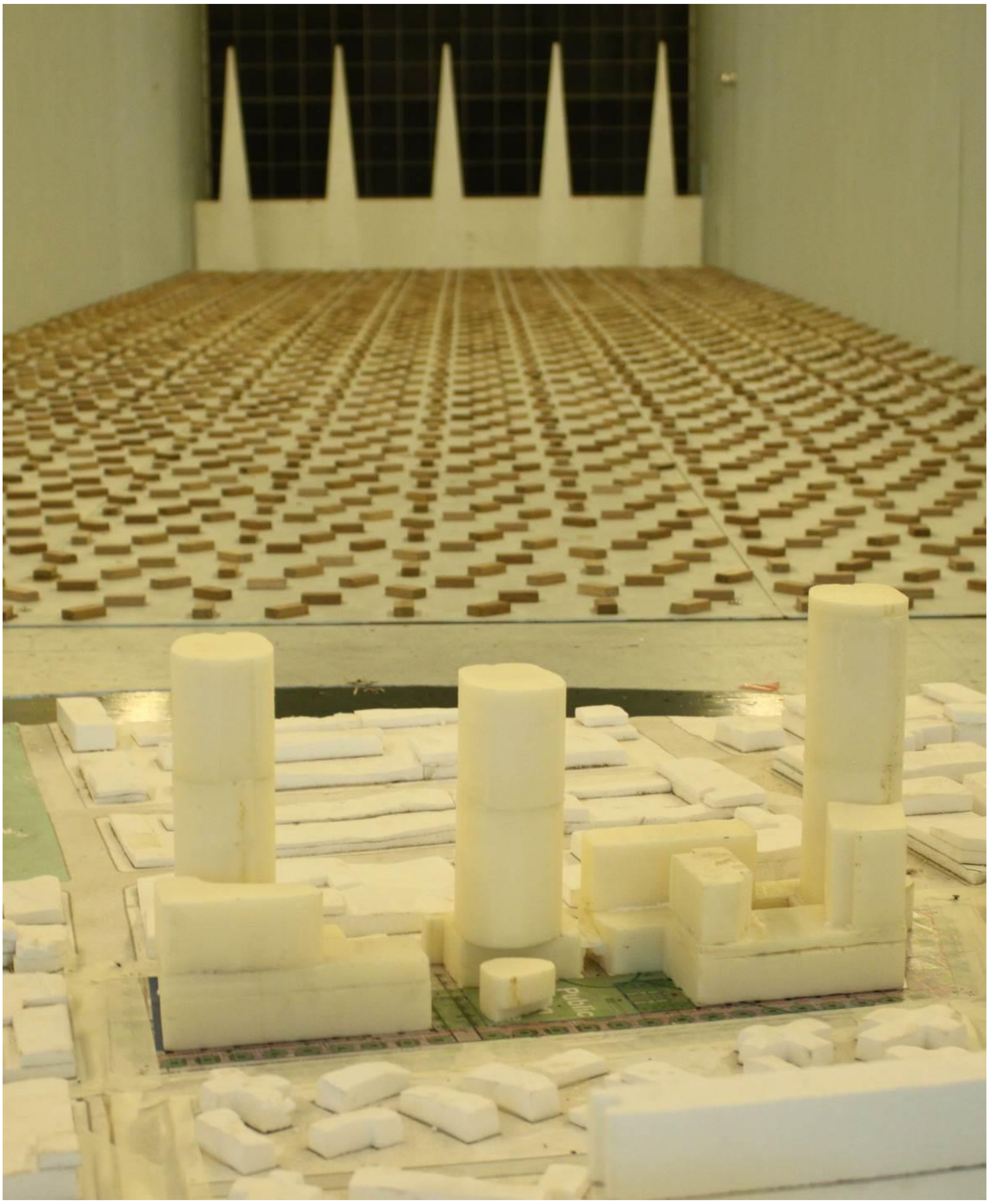

Figure 4.2b: Photograph of the Wind Tunnel Model – (View from the South-East)

Figure 4.2c: Photograph of the Wind Tunnel Model – (View from the North-West)

Figure 4.2d: Photograph of the Wind Tunnel Model – (View from the North)

Figure 4.2e: Photograph of the Wind Tunnel Model – (View from the East)

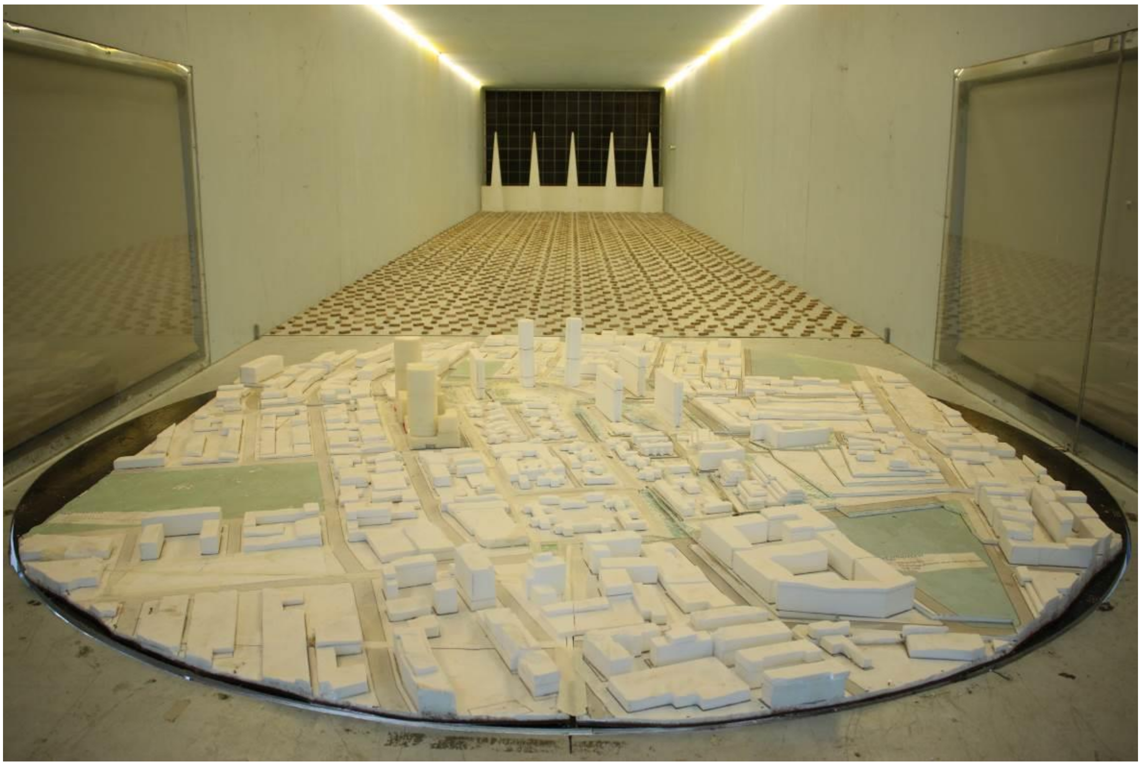

Figure 4.2f: Photograph of the Wind Tunnel Model – (View from the South)

Figure 4.2g: Photograph of the Wind Tunnel Model – (View from the West)

Figure 4.2h: Map of Proximity Model

4.3 Boundary Layer Wind Flow Model

Testing was performed using Windtech's boundary layer wind tunnel, which has a 3.0m wide working section and has a fetch length of 14m. The model was placed in the appropriate standard boundary layer wind flow for each of the prevailing wind directions for the wind tunnel testing. The type of wind flow used in a wind tunnel study is determined by a detailed analysis of the surrounding terrain types around the subject site. Details of the analysis of the surrounding terrain for this study are provided in the following pages of this report.

The roughness of the earth's surface has the effect of slowing down the prevailing wind near the ground. This effect is observed up to what is known as the *boundary layer height*, which can range between 500m to 3km above the earth's surface depending on the roughness of the surface (i.e. oceans, open farmland, dense urban cities, etc.). Within this range, the prevailing wind forms what is known as a *boundary layer wind profile*.

Various wind codes and standards classify various types of boundary layer wind flows depending on the surface roughness. However, it should be noted that the wind profile does not change instantly due to changes in the terrain roughness. It can take many kilometres (at least 100km) of a constant surface roughness for the boundary layer profile to achieve a state of equilibrium. Descriptions of the standard boundary layer profiles for various terrain types are summarised as follows (in accordance with AS/NZS1170.2.2011):

- **Terrain Category 1.0:** Extremely flat terrain. Examples include enclosed water bodies such as lakes, dams, rivers, bays, etc.
- **Terrain Category 1.5:** Relatively flat terrain. Examples include the open ocean, deserts and very flat open plains.
- **Terrain Category 2.0:** Open terrain. Examples include grassy fields and plains and open farmland (without buildings or trees).
- **Terrain Category 2.5:** Relatively open terrain. Examples include farmland with scattered trees and buildings and very low-density suburban areas.
- **Terrain Category 3.0:** Suburban and forest terrain. Examples include suburban areas of towns and areas with dense vegetation such as forests, bushland, etc.
- **Terrain Category 3.5:** Relatively dense suburban terrain. Examples include centres of small cities, industrial parks, etc.
- **Terrain Category 4.0:** Dense urban terrain. Examples include CBD's of large cities with many high-rise towers, and areas with many closely-spaced mid-rise buildings.

For this study, the shape of the boundary layer wind flows over standard terrain types is defined in accordance with Deaves & Harris (1978). These are summarised in Table 4.2, referenced to the study reference height of 56m above ground. The Suburban Terrain Category 3.0 profile has been used in the wind tunnel testing of the subject development.

Table 4.2: Terrain and Height Multipliers, Turbulence Intensities, and Corresponding Roughness Lengths, for the Standard Boundary Layer Profiles

Terrain Category	Terrain and Height Multipliers			Turbulence Intensity I_v	Terrain Roughness Length (m) $z_{0,r}$
	$k_{tr,T=3600s}$ (hourly)	$k_{tr,T=600s}$ (10-minute)	$k_{tr,T=3s}$ (3-second)		
1.0	0.97	1.00	1.29	0.109	0.003
1.5	0.91	0.95	1.26	0.125	0.01
2.0	0.86	0.89	1.23	0.144	0.03
2.5	0.78	0.82	1.18	0.171	0.1
3.0	0.70	0.74	1.13	0.204	0.3
3.5	0.60	0.64	1.07	0.260	1
4.0	0.48	0.53	0.98	0.346	3

An analysis of the effect of changes in the upwind terrain roughness was carried out for each of the wind directions studied. This has been undertaken based on the method given in AS/NZS1170.2:2011, which uses a "fetch" length of 40 times the study reference height. However, it should be noted that this "fetch" commences *beyond* a "lag distance" area, which has a length of 20 times the study reference height (in accordance with AS/NZS1170.2:2011), so the actual "fetch" of terrain analysed is the area between 20 and 60 times the study reference height away from the site. An aerial image showing the surrounding terrain is presented in Figure 4.3 for a radius of 3.4km from the edge of the wind tunnel proximity model. The resulting mean and gust terrain and height multipliers at the site location are presented in Table 4.3, referenced to the study reference height.

For each of the 16 wind directions tested in this study, the approaching boundary layer wind profiles modelled in the wind tunnel matched the model scale and the overall surrounding terrain characteristics beyond the extent of the proximity model. Plots of the wind tunnel boundary layer wind profiles are presented in Appendix b of this report.

Table 4.3: Directional Mean and Gust Terrain and Height Multipliers at the Site (at the study reference height)

Wind Sector (degrees)	$k_{tr,T=3600s}$ (hourly mean)	$k_{tr,T=600s}$ (10-minute mean)	$k_{tr,T=3s}$ (3-second gust)
0	0.60	0.65	1.07
30	0.60	0.64	1.07
60	0.74	0.78	1.16
90	0.78	0.82	1.18
120	0.74	0.78	1.16
150	0.78	0.81	1.18
180	0.70	0.74	1.13
210	0.60	0.64	1.07
240	0.70	0.74	1.13
270	0.70	0.74	1.13
300	0.68	0.72	1.12
330	0.79	0.82	1.18

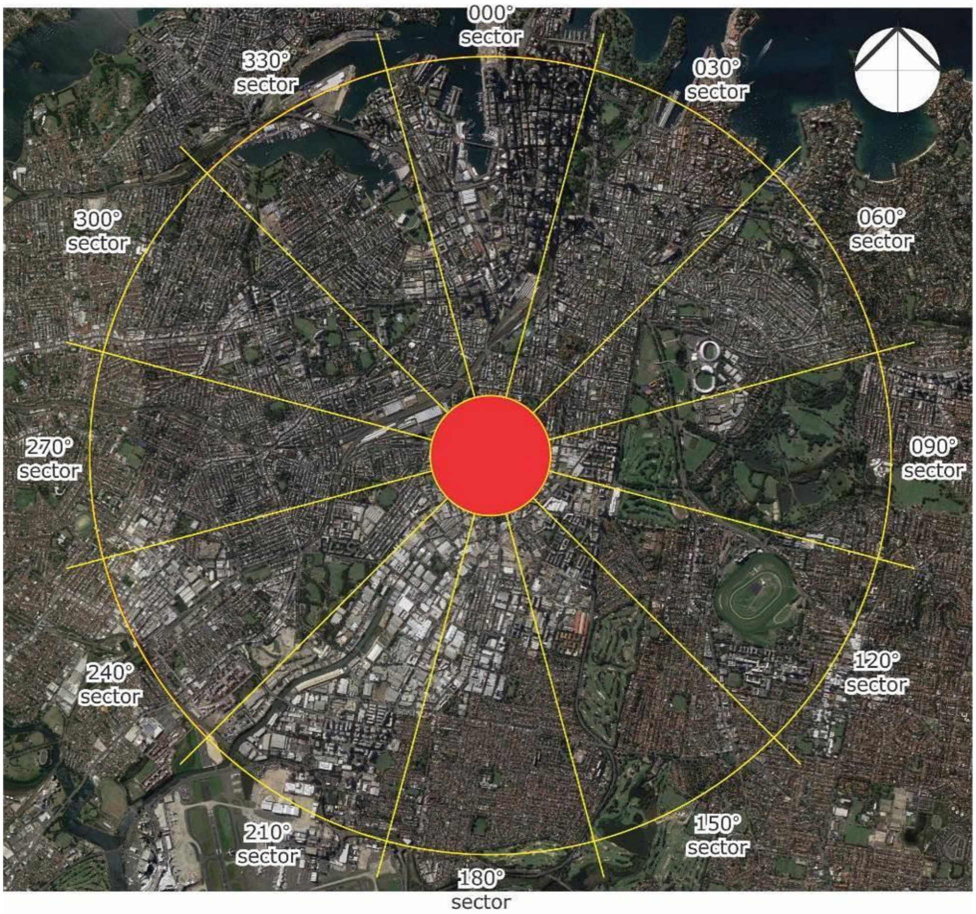

Figure 4.3: Aerial Image of the Surrounding Terrain (radius of 3.4km from the edge of the proximity model, which is coloured red)

4.4 Pedestrian Wind Comfort and Safety

The acceptability of wind conditions of an area is determined by comparing the measured wind speeds against an appropriate criteria. This section outlines how the measured wind speeds were obtained, the criteria considered for the development, as well as the critical trafficable areas that were assessed and their corresponding criteria designation.

4.4.1 Measured Wind Speeds

Wind speeds were measured using Dantec hot-wire probe anemometers, positioned to monitor wind conditions at critical outdoor trafficable areas of the development. The reference mean free-stream wind speed measured in the wind tunnel, which is at a full-scale height of 200m and measured 3m upstream of the study model.

Measurements were acquired for 16 wind directions at 22.5 degree increments using a sample rate of 1,024Hz. The full methodology of determining the wind speed measurements at the site from the Dantec Hot-wire probe anemometers is provided in Appendix D. Based on the results of the analysis of the boundary layer wind profiles at the site (see Section 4.3) and incorporating the regional wind model (see Section 4.1), the data sampling length of the wind tunnel test for each wind direction corresponds to a full-scale sample length ranging between 30 minutes and 1 hour. Research by A.W. Rofail and K.C.S. Kwok (1991) has shown that, in addition to the mean and standard deviation of the wind being stable for sample lengths of 15 minutes or more (full-scale), the peak value determined using the upcrossing method is stable for sample lengths of 30 minutes or more.

4.4.2 Wind Speed Criteria Used for This Study

For this study, the measured wind conditions for the various critical outdoor trafficable areas around the subject development are compared against the criteria presented in the Draft Sydney Development Control Plan 2012 - Central Sydney Planning Review Amendment, which supersedes the criteria detailed in the City of Sydney Development Control Plan 2012 (SDCP2012).

For pedestrian comfort, the Draft Sydney DCP 2012 requires that the hourly mean wind speed, or Gust-Equivalent Mean (GEM) wind speed (whichever is greater for each wind direction), must not exceed 8m/s for walking, 6m/s for standing, and 4m/s for sitting. These are based on a 5% probability of exceedance.

For pedestrian safety, the Draft Sydney DCP 2012 defines a safety limit criterion of 24m/s, based on an annual maximum 0.5 second gust wind speed, which applies to all areas.

Furthermore, in accordance with the provisions of the Draft Sydney DCP 2012, the existing conditions for the pedestrian footpaths around the site are also analysed as part of this study to determine the impact of the subject development. If it is found that the existing conditions exceed the relevant criteria, then the target wind speed for that area with the inclusion of the proposed development is to at least match the existing site conditions.

In accordance with the provisions of the Draft Sydney DCP 2012, the wind speed assessment is undertaken for winds occurring between 6am and 10pm (AEST).

A more detailed comparison of published criteria for pedestrian wind comfort and safety is provided in Appendix C.

For this study the measured wind conditions of the selected critical outdoor trafficable areas are compared against two sets of criteria; one for pedestrian safety, and one for pedestrian comfort. The safety criterion is applied to the annual maximum gust winds, and the comfort criteria is applied to Gust Equivalent Mean (GEM) winds. In accordance with ASCE (2003), the GEM wind speed is defined as follows:

$$GEM = max\left(\bar{V}, \frac{\hat{V}}{1.85}\right) \tag{4.1}$$

Where:

$\bar{V}$ is the mean wind speed.

$\hat{V}$ is the gust wind speed.

The criteria considered in this study are summarised in Tables 4.4 and 4.5 for pedestrian comfort and safety, respectively. The results of the wind tunnel study are presented in the form of directional plots attached in Appendix A of this report. For each study point there is a plot of the GEM wind speeds using the comfort criteria, and a plot for the annual maximum gust wind speeds using the safety criterion.

Table 4.4: Pedestrian Comfort Criteria (Draft Sydney DCP 2012)

Classification	Description	Maximum 5% Exceedance GEM Wind Speed (m/s)
Sitting	Outdoor areas that involve seating such as parks, dining areas in restaurants, amphitheatres, etc.	4
Standing	Short duration stationary activities (generally less than 1 hour), including window shopping, waiting areas, etc.	6
Walking	For pedestrian thoroughfares, private swimming pools, most communal areas, private balconies and terraces, etc.	8

Table 4.5: Pedestrian Safety Criterion (Draft Sydney DCP 2012)

Classification	Description	Annual Maximum Gust Wind Speed (m/s)
Safety	Safety criterion applies to all trafficable areas.	24

4.4.3 Layout of Study Points, and Relevant Wind Speed Criteria

For this study a total of 51 ground level study points have been selected for analysis in the wind tunnel located within and around various locations of the proposed development site.

The locations of the study points tested for this study are presented in Figures 4.5a and 4.5b in the form of marked-up plan drawings. The target wind speed criteria for the outdoor trafficable areas within and around the development is also indicated in these figure which are based on the intended use (length of stay).

The ground level plan includes retail and residential entrances, pedestrian footpath areas and through site links, public/communal open space locations, the Metro Station entries and bus stop areas. For the purpose of this study the selected pedestrian comfort criteria applied to the site is both the standing and walking comfort, as described in Table 4.4. All areas have been assessed against the safety criteria.

A discussion of the results for the areas within the Public Plaza and along Raglan Street compared against the seating comfort criteria is provided in Section 5.3.

It should also be noted that only the most critical outdoor locations of the development have been selected for analysis which will help with the masterplan design input. Elevated pedestrian accessible areas were not tested and will be investigated at a later design stage.

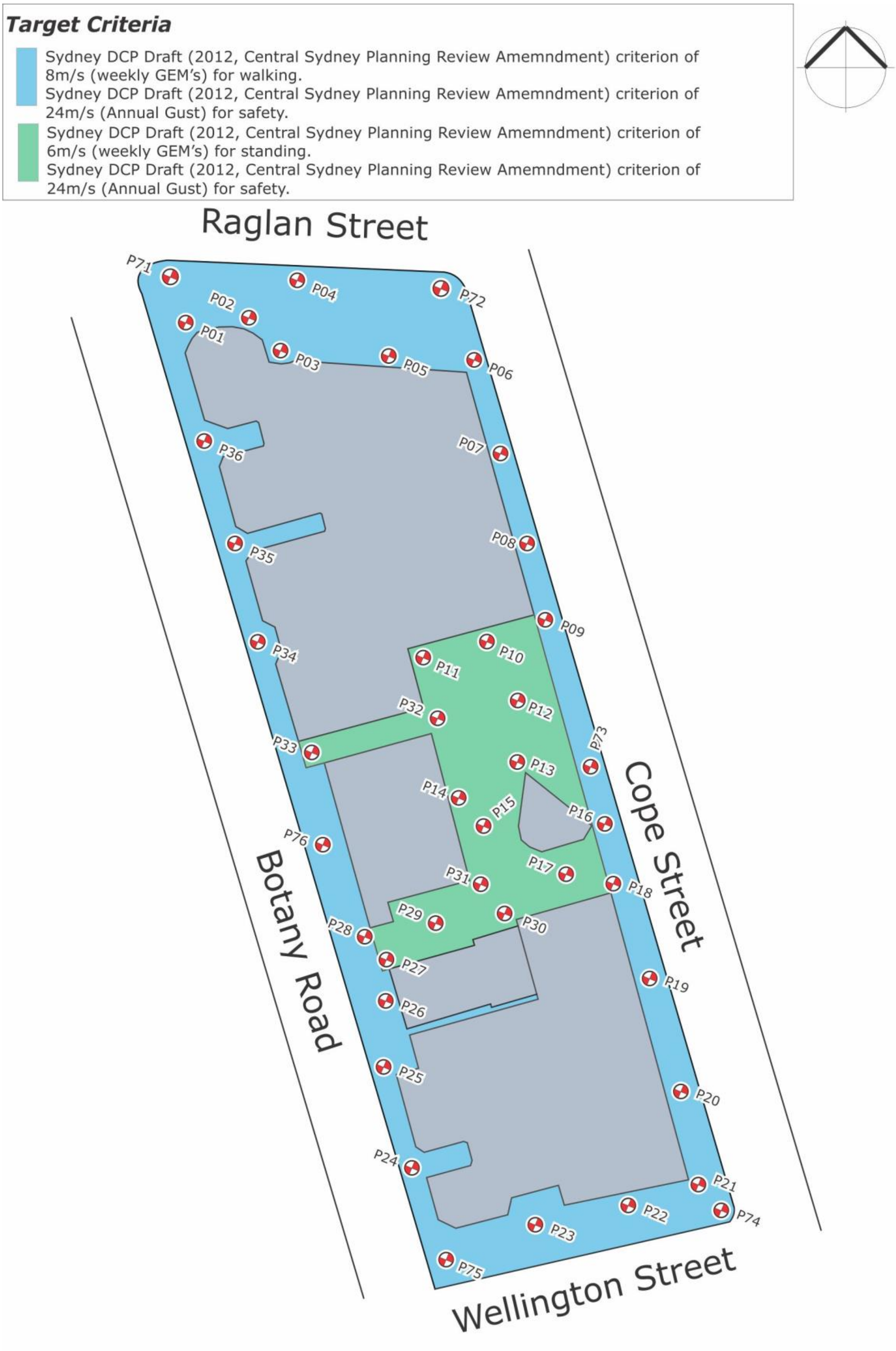

Figure 4.5a: Study Point Locations and Target Criteria – Ground Level

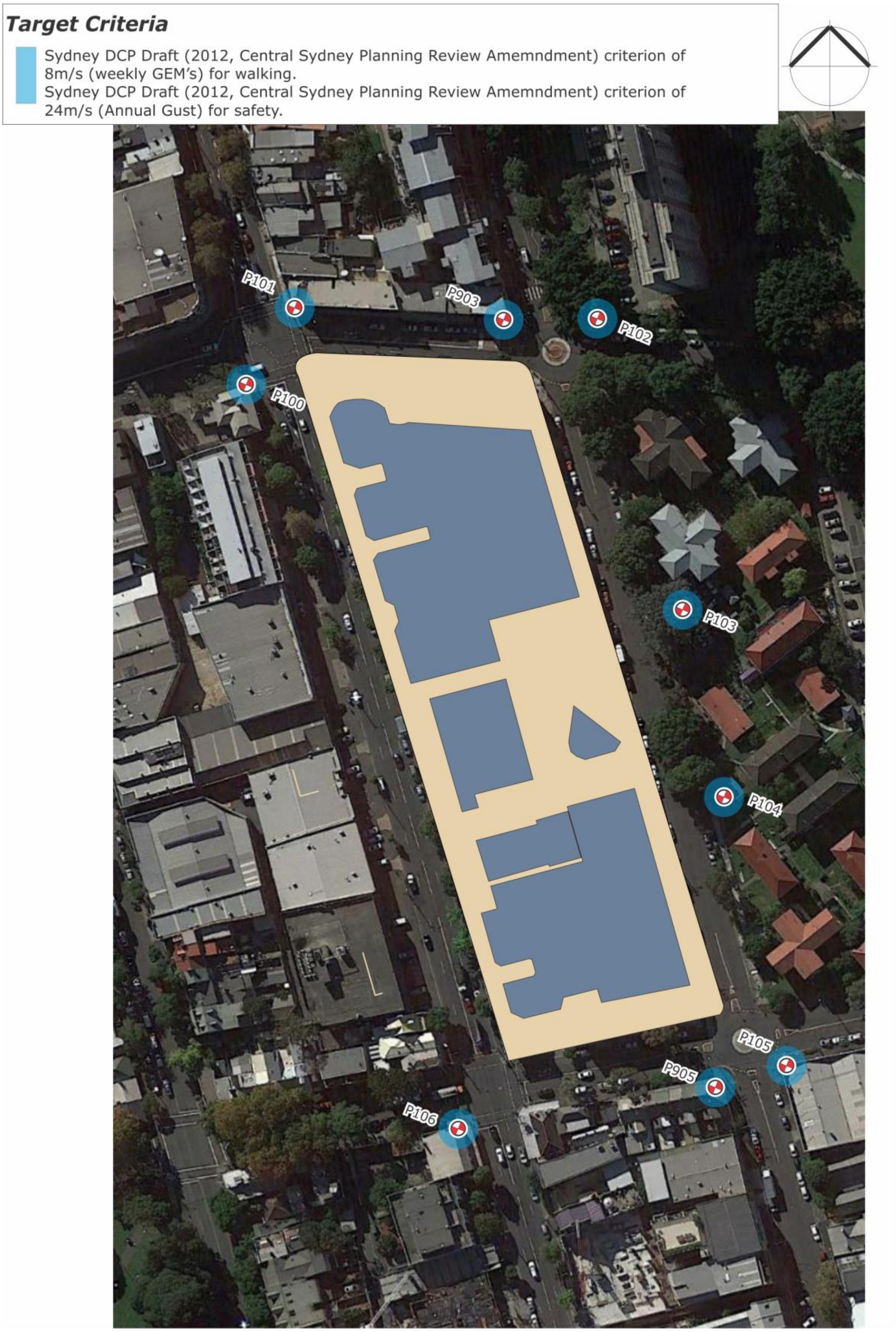

Figure 4.5b: Study Point Locations and Target Criteria – Surrounding Study Points

4.5 Discussion

This section addressed study requirements 19.2, 19.3, 19.4 and 19.8 by conducting a detailed wind environment test of the massing model to identify the key wind sensitive areas within and around the development site. The results allow for the opportunity to design and develop the site to enhance the wind conditions within and around the public, pedestrian and communal areas.

The results of a detailed investigation into the ground level wind environment conditions for the proposed massing model of the Waterloo Metro Quarter development has been undertaken. Wind tunnel testing of the proposed Waterloo Metro Quarter development was undertaken, based on the 3D Sketchup massing model received from UrbanGrowth NSW, January 2018.

The wind conditions were assessed at critical outdoor ground level locations including retail and residential entrances, pedestrian footpath areas, through site links, public/communal open space locations, the Metro Station entries and bus stop areas. For the purpose of the study the ground level areas have been assessed against the pedestrian walking and standing comfort criteria, given the usage of the site, as described in Table 4.4. Should the usage of an area require the stricter seating criteria to be assessed, further treatment investigation would be required, which could be further investigated during the detailed design stage. All areas have been assessed against the safety criteria.

If the results of the study indicate that any ground level area is exposed to strong winds, in-principle treatments have been recommended to assist the design team during the design stage. Elevated pedestrian accessible areas were not tested and will be further investigated during the detailed design stage.

Review of the proposed massing model as provided by UrbanGrowth NSW indicates that the built form of the towers and podiums incorporate setbacks along certain aspects, which assist in reducing downwash winds. The building form setback along Raglan Street frontage and the proposed incorporation of awnings has the potential to improve wind conditions. However, the east/west orientation of the through site links is noted to have the potential to result in adverse wind conditions due to the funnelling of the predominant north-easterly and westerly winds. Review of the design layout indicates that the location of the public plaza space should provide protection to the prevailing southerly and westerly winds.

The results of the wind tunnel test for the massing model ground level areas are detailed and discussed in Section 5, and if any areas are exposed to adverse wind conditions, in-principle treatments have been recommended.The treatments could be in the form of wind deflective elements such as screens, awnings, etc or vegetation that is already proposed for the site, and/or additional trees, shrubs, or wind ameliorative elements such as screens, awnings, etc. Treatment strategies can be dealt with initially during the detailed design and built form development application and can then be verified at a later stage by performing additional wind tunnel testing for the built form development application.

5 ASSESSMENT

This section will address study requirements 19.4, 19.5, 19.6 and 19.7 by providing a detailed review of the wind tunnel conditions as obtained from the wind tunnel test of the massing model, as outlined in Section 4. If the results of the massing model study indicate that any key ground level area within and around the site is exposed to strong winds, in-principle treatments have been recommended. These treatments could be in the form of wind deflective elements such as screens, awnings, etc or vegetation that is already proposed for the site, and/or additional trees, shrubs, etc to be placed in a strategic manner.

5.1 Ground Level Results

The results of the study are summarised in Table 5.1. The wind speed criteria that the wind conditions should achieve at each study point location are also listed in Table 5.1 and shown on marked-up plans in Figures 4.5a and 4.5b. The results for all study points locations can be seen in the form of directional wind speed plots presented in Figures 5.1a and 5.1b and in the plots in Appendix A.

Table 5.1: Wind Tunnel Results Summary

Study Point	Desired Criterion (m/s)		Equivalent to or Better than Existing Site Wind Conditions?	Treatment Necessary to Pass?	Description of Suggested Treatment/ Notes
	Weekly GEM	Annual Peak			
P01	8.0	24.0		YES	Refer to Figure 5.2
P02	8.0	24.0		NO	
P03	8.0	24.0		NO	
P04	8.0	24.0		NO	
P05	8.0	24.0		NO	
P06	8.0	24.0		YES	Refer to Figure 5.2
P07	8.0	24.0		NO	
P08	8.0	24.0		NO	
P09	8.0	24.0		NO	
P10	6.0	24.0		NO	
P11	6.0	24.0		NO	
P12	6.0	24.0		NO	
P13	6.0	24.0	-	NO	
P14	6.0	24.0	-	NO	
P15	6.0	24.0	-	NO	
P16	8.0	24.0	-	NO	
P17	6.0	24.0	-	NO	

Study Point	Desired Criterion (m/s)		Equivalent to or Better than Existing Site Wind Conditions?	Treatment Necessary to Pass?	Description of Suggested Treatment/ Notes
	Weekly GEM	Annual Peak			
P18	8.0	24.0	-	NO	
P19	8.0	24.0	-	NO	
P20	8.0	24.0	-	NO	
P21	8.0	24.0	-	YES	Refer to Figure 5.2
P22	8.0	24.0	-	NO	
P23	8.0	24.0	-	NO	
P24	8.0	24.0	-	NO	
P25	8.0	24.0	-	NO	
P26	8.0	24.0	-	NO	
P27	6.0	24.0	-	YES	Refer to Figure 5.2
P28	6.0	24.0	-	YES	Refer to Figure 5.2
P29	6.0	24.0	-	YES	Refer to Figure 5.2
P30	6.0	24.0	-	YES	Refer to Figure 5.2
P31	6.0	24.0	-	YES	Refer to Figure 5.2
P32	6.0	24.0	-	YES	Refer to Figure 5.2
P33	6.0	24.0	-	YES	Refer to Figure 5.2
P34	8.0	24.0	-	NO	
P35	8.0	24.0	-	NO	
P36	8.0	24.0	-	NO	
P71	8.0	24.0	NO	NO	
P72	8.0	24.0	NO	YES	Refer to Figure 5.2
P73	8.0	24.0	YES	NO	
P74	8.0	24.0	NO	NO	
P75	8.0	24.0	NO	YES	Refer to Figure 5.2
P76	8.0	24.0	NO	NO	
P100	8.0	24.0	-	NO	
P101	8.0	24.0	-	NO	
P102	8.0	24.0	YES	NO	
P103	8.0	24.0	-	NO	
P104	8.0	24.0	-	NO	
P105	8.0	24.0	YES	NO	
P106	8.0	24.0	-	NO	
P903	8.0	24.0	NO	NO	
P905	8.0	24.0	NO	NO	

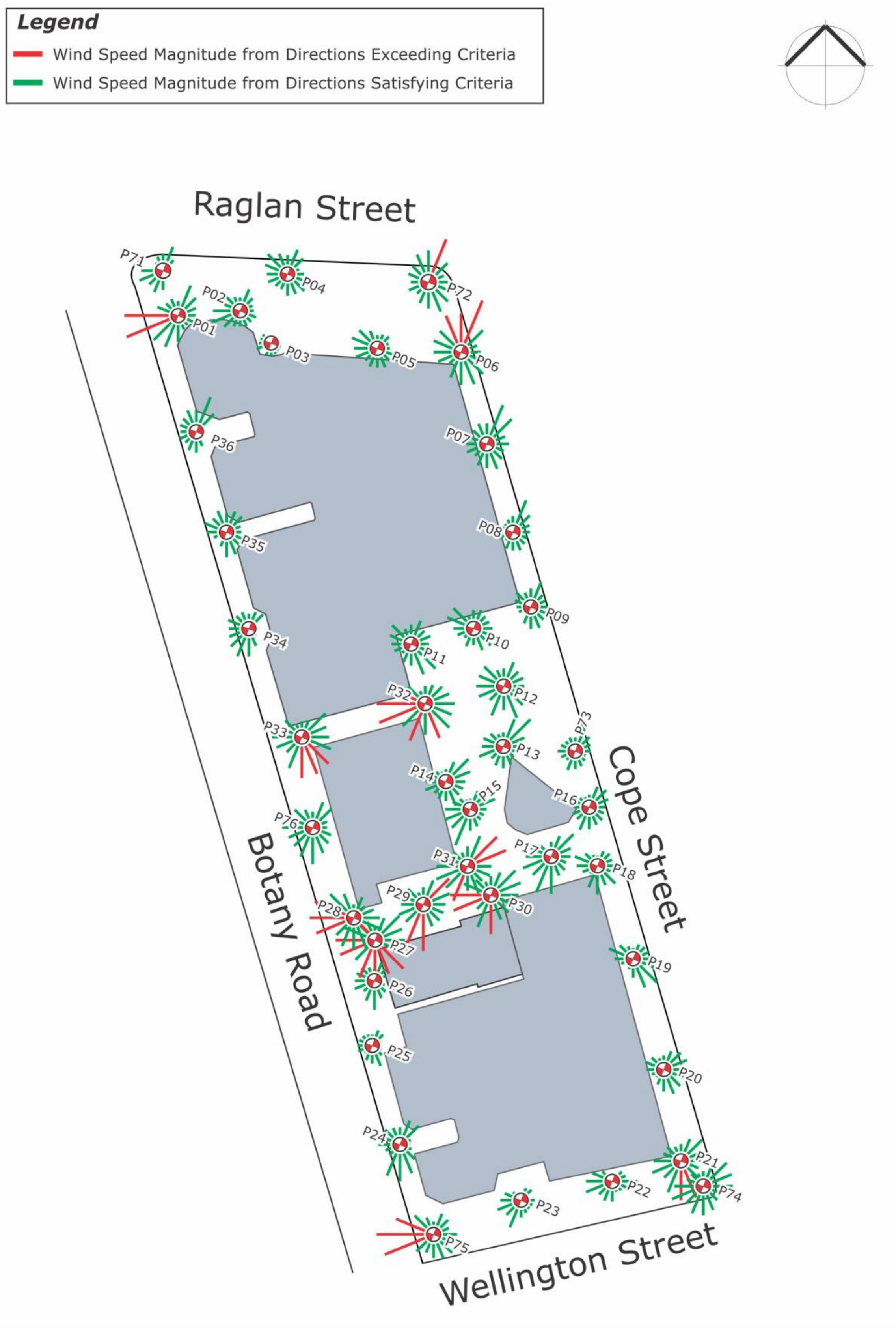

Figure 5.1a: Wind Directionality Plots – Ground Level

Figure 5.1b: Wind Directionality Plots – Surrounding Study Points

Due to the mid to low-rise nature of the development site and surrounding areas, the site is exposed to the predominant north-easterly, southerly and westerly winds due to limited shiedling. The north-west corner of the development site (Point P01) is exposed to localised effects due to the direct westerly winds which travel along Henderson Road wrapping around the corner. Furthermore, the westerly winds are seen to downwash off the western aspect of the north-west tower (Tower A) and onto the ground floor areas. Similarly, the north-east corner of the development site (Points P06 and P72) is prone to localised adverse wind conditions due to the prevailing north-easterly winds. These winds are seen to downwash off of the northern aspect of the northern tower and its corresponding podium, impacting the north-eastern corner of the ground floor of the development. It is recommended to include impermeable awnings along these corners of the development to assist with the downwash winds.

The pedestrian footpath areas at the south-west and south-east corners of the development are prone to adverse wind conditions. The prevailing westerly winds are seen to downwash off of the south-westerm aspect of the southern tower (Tower F) and impact the ground level at the south-west corner (Point P75). This area is also impacted by the direct westerly winds which travel along Buckland Street. The south-east corner of the development (Point P21) is prone to adverse wind conditions due to the downwashing of the southerly winds onto the ground floor. This area is also impacted by the direct southerly winds interacting with the building form and wrapping around the south-east corner.

Due to the orientation of the throughsite links (Pedstrian Link and New Street) the areas are exposed to the prevailing north-easterly, southerly and westerly winds. The Pedestrian Link (Points P32 and P33) is prone to adverse wind conditions due to the southerly winds being captured and interacting with the northern podium, and funneling through the space. Due to limited shielding the westerly winds are seen to funnel through this space.

The New Street located between the church and the central podium (Points P27, P28, P29, P30 and P31) is prone to adverse wind conditions due to the downwashing of the southerly winds off of the central tower (Tower E) onto this area. The downwash winds are seen to circulate within this laneway. Furthermore, the direct westerly and north-easterly winds funnel through the laneway worsening conditions in the area. It is recommended to include impermeable awnings over these areas of the development to assist with the downwash winds and investigate building form changes. Results indicate that a majority of the areas within the public plaza are exposed to wind conditions which meet the comfort criteria. The public plaza located on the eastern aspect appears to be generally shielded from the prevailing winds by the built form. Addressing the through site link funnelling effects will further enhance the conditions within the public plaza.

All other ground level areas within and around the development site including the surrounding off-site points are exposed to suitable wind conditions.

The results of the study indicate that treatments are required for particular locations to achieve the desired criteria for pedestrian comfort and safety. The recommended in-principle treatments are detailed in the marked-up plan presented in Figure 5.2. These treatments are summarised as follows:

- The inclusion of an impermeable awning along the four corners of the development as well as along the western aspect of the central building podiums (Tower D and E).
- Recommended change in building form for some of the areas on the central building podiums (Tower D and E).
- The inclusion of an impermeable awning or pergola structure over the southern through site link (New Street) between Tower E and the Church.

It should be noted that with the inclusion of strategically located densely foliating evergreen tree planting/shrubs within and around the development site boundary it is expected to further enhance the comfort conditions.

With the inclusion of these treatments to the design, it is expected that the ground level wind conditions for the areas within and around the site will be suitable for their intended uses.

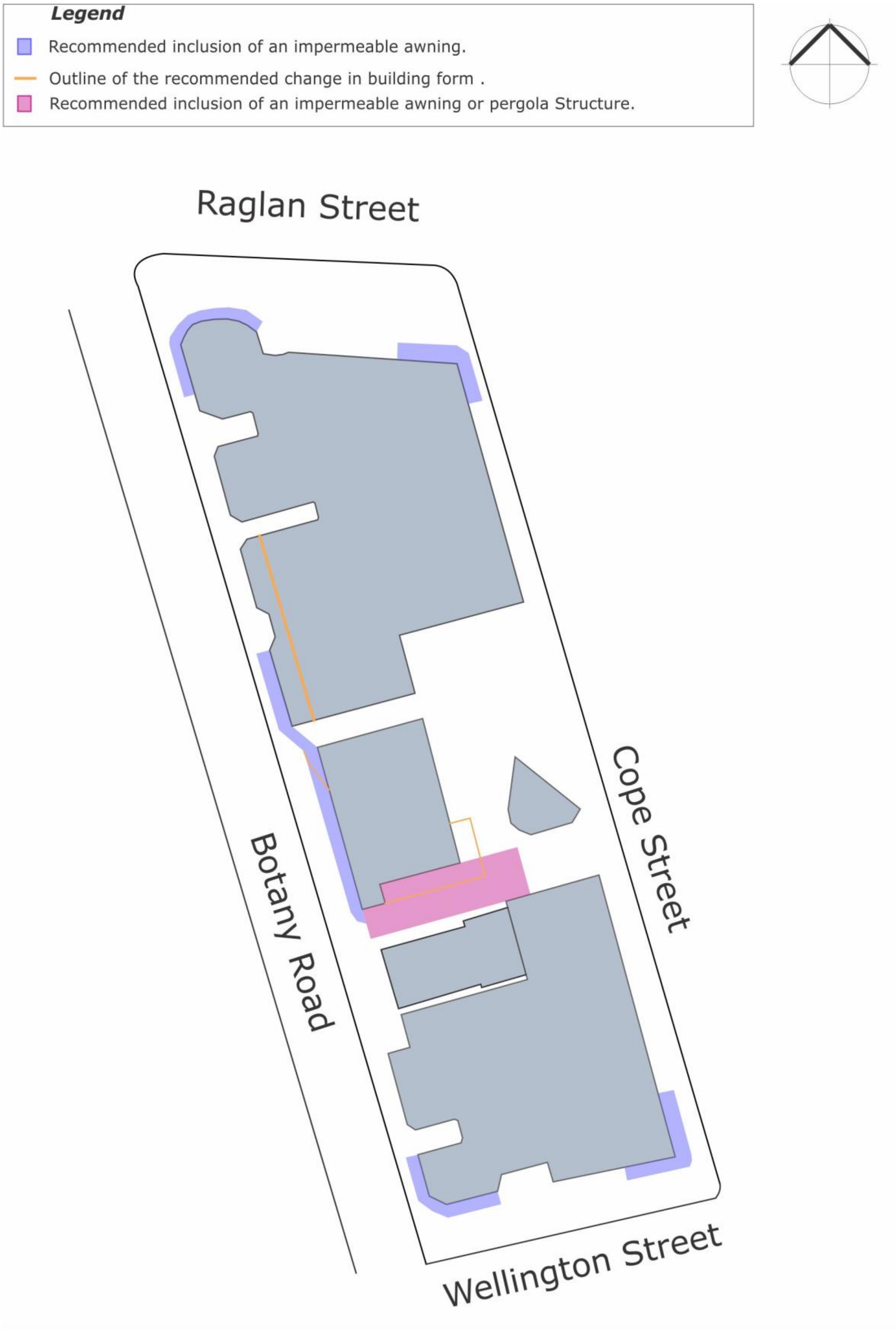

Figure 5.2: Suggested Treatments – Ground Level

5.2 Discussion of Updated Drawing Package and Treatments

The information provided from the wind tunnel analysis has been incorporated by the design team to further consolidate the proposed design. An updated drawing package (For Coordination – 11/5/2018) prepared by Turner architects and received from UrbanGrowth NSW, May 2018 has been reviewed.

Upon review of the updated drawings it was noticed that the building form of Tower D had changed from the design presented for the initial massing model. The change in building form is not expected to cause a significant impact on the measured ground level wind conditions.

Review of the drawing package indicates the inclusion of baffle screens at the eastern and western entries to the Pedestrian Link. The inclusion of these elements will assist in mitigating the predominant southerly winds being captured by the protruding building form along Botany Road, which are observed to be funneling through this space. The inclusion of the impermeable awning along Botany Road and the retention of the baffle screens is expected to provide similar alleviating wind measures as the building form change (recommended in-principle and indicated in Figure 5.2) and hence is suitable.

The New Street through site link is noted to include tree planting along the through site link and at the entry along Botany Road. It is noted that the awning does not fully extend across the space as recommended in-principle in Figure 5.2. However, the inclusion of this proposed awning in combination with the tree planting will assist in mitigating the wind conditions within this area and has the potential to provide similar ameliorative impacts as the recommended awning and building form change (recommended in-principle and indicated in Figure 5.2). The tree planting is recommended to be of a dense evergreen species, capable of growing to a height of 4-6 metres.

As an appraisal, the results of the analysis indicate that all study point locations along the Pedestrian Link and New Street, when compared against the comfort criteria for walking meet the criteria without the inclusion of ameliorative treatments. The safety criteria is satisfied along these areas.

Review of the updated drawings indicate that the recommended awnings over the pedestrian footpath areas around the development have been incorporated. The surrounding pedestrian footpath areas and the community square indicate the inclusion of landscaping and tree planting located in wind sensitive areas, which have the potential to further enhance the wind comfort conditions.

Hence, with the inclusion of the abovementioned design changes to the design of the development, it is expected that the wind conditions for all outdoor trafficable areas within and around the development will be suitable for their intended uses.

5.3 Public Plaza and Raglan Street Seating Criteria Comparison

The wind condition results for the areas within the Public Plaza and along Raglan Street were compared against the seating comfort criteria and are summarised in Table 5.2. These results were obtained by comparing the initial wind tunnel results obtained from the massing model study as described in Section 4. Testing of the proposed Waterloo Metro Quarter development was undertaken, based on the 3D Sketchup massing model received from UrbanGrowth NSW, January 2018. The model of the proposed development was tested in the wind tunnel without the effect of any forms of wind ameliorating devices such as screens, balustrades, awnings, etc., which are not already shown in the architectural drawings.

Table 5.2: Wind Tunnel Results Summary compared against Seating Criteria

Study Point	GEM (5% exceedance)			Annual Gust			Final Result
	Criterion (m/s)	Results (%)	Grade	Criterion (m/s)	Results (m/s)	Grade	
Point 01	4.0	40%	Fail	24	31	Fail	Fail
Point 02	4.0	24%	Fail	24	20	Pass	Fail
Point 03	4.0	1%	Pass	24	10	Pass	Pass
Point 04	4.0	36%	Fail	24	22	Pass	Fail
Point 05	4.0	25%	Fail	24	21	Pass	Fail
Point 06	4.0	54%	Fail	24	26	Fail	Fail
Point 71	4.0	21%	Fail	24	14	Pass	Fail
Existing		18%	Fail		14	Pass	Fail
Point 72	4.0	46%	Fail	24	22	Pass	Fail
Existing		38%	Fail		15	Pass	Fail
Point 10	4.0	10%	Fail	24	18	Pass	Fail
Point 11	4.0	18%	Fail	24	17	Pass	Fail
Point 12	4.0	25%	Fail	24	17	Pass	Fail
Point 13	4.0	17%	Fail	24	16	Pass	Fail
Point 14	4.0	14%	Fail	24	13	Pass	Fail
Point 15	4.0	18%	Fail	24	16	Pass	Fail

Review of the initial testing results indicate that a majority of areas do not achieve the seating comfort criteria. As discussed in section 3.6 the existing site wind conditions indicate the areas along Raglan Street are exposed to the predominant north-easterly and westerly winds. The existing site results, when compared against the seating comfort criteria, indicate that wind conditions will exceed this criteria. Points 1 and 6 indicate strong wind conditions due to the predominant north-easterly and southerly winds accelerating around the building massing corners. Points 02 and 05 are observed to be impacted by the predominant north-easterly and westerly winds. The area represented by Point 3 indicates wind conditions that does satisfy the seating comfort criteria.

The wind conditions within the Public Plaza do not satisfy the seating comfort criteria. These locations are observed to be impacted by the predominant north-easterly and southerly winds.

Note that these results are obtained from the testing undertaken based on the initial massing model, hence no treatments have been applied to these results. With the inclusion of the impermeable awnings as indicated in the latest drawing package (discussed in Section 5.2) and the inclusion of the landscaping, it is expected that wind conditions would improve.

It is recommended that further investigation of the wind conditions for the ground level areas along Raglan Street and within the Public Plaza be undertaken at a later stage, during the design development, if the uses of the proposed areas are intended for activities that are required to satisfy seating comfort criteria.

5.4 Various Private Balconies and Podia Communal Spaces

The effect of wind activity is examined for the three predominant wind directions for the Sydney region. A desktop analysis of the wind effects relating to the elevated balcony areas has been carried out in the context of the local wind climate, building morphology and land topography.

The conclusions in this section of the report are drawn from our extensive experience in this field and are based on an examination of the architectural drawings received June, 2018. No wind tunnel tests have been undertaken for these areas of the subject development, and hence this only addresses the general wind effects and any localised effects that are identifiable by visual inspection. Any recommendations in this report are made only in-principle and are based on our extensive experience in the study of wind environment effects. Wind tunnel testing can be performed to quantitatively assess the wind effects to ensure pedestrian comfort and safety at a more detailed design stage.

The wind conditions for the various private balconies are heavily dependent on their location and design. The majority of the private balconies are only exposed to winds on a single aspect and hence are expected to be suitable for their intended use. The balconies will also benefit from the setback design. However, it is noted that there are several balconies exposed to two aspects on Building B, C, and G which may cause prevailing winds to accelerate though these areas as these winds move around the building. Generally, the wind speeds at the corners of the building form are expected to be the highest due to the winds accelerating around the corner of the building. Provisions should be made to limit the exposure of these balconies to a single aspect by considering a wind deflective element such as a full-height screen to be added along one of the aspects. This can be in the form of glazing, louvres, etc. (which can be operable) which are expect to mitigate this effect. It is recommended to incorporate impermeable balustrades for all balconies.

The buildings themselves can shield the balconies from the prevailing winds. For example, the southern aspect balconies on Building E have the potential to be shielded from the direct southerly winds from Building F.

The elevated communal outdoor areas are located at various locations and heights within the development. The northern communal open space (Building B) is exposed to the prevailing north-easterly, southerly and westerly winds. The wind impacts that are expected to affect this space are the direct north-easterly and southerly winds, and the potential for the westerly winds to side stream along the curved façade of Building A. Winds impacting the façade can also upwash and cause adverse winds on the communal open space.

The communal open spaces (Building C, G and F) are exposed to the prevailing north-easterly, southerly and westerly winds. The wind impacts that are expected to affect these spaces are the north-easterly and westerly winds, especially the communal open spaces that are potentially exposed to the funnelling of winds between Building B and C and Building E and F. The southerly winds are expected to affect these spaces due to limited shielding, with the potential for the southerly winds to side stream along the curved façade of Building F and impact the adjacent communal spaces. Winds impacting the façade can also upwash and cause adverse winds on the communal open space.

Within these communal open spaces, landscaping is recommended to reduce the effect of the adverse winds. In order to be effective as a wind mitigation measure, the recommended planting should be densely foliating with interlocking canopies, rather than planted in isolation. Due to its exposure to the prevailing westerly winter winds, the planting should be of an evergreen variety to ensure its effectiveness throughout the year. The perimeter of the terraces should incorporate wind screening to redirect the winds above the trafficable space. For the abovementioned corner accelerations, wind screens connected to the façade are expected to be required to be implemented to mitigate this effect. These screens can be supplemented with additional planting in these areas to further improve conditions.

The use of loose glass-tops, lightweight sheets or covers (including loose BBQ lids) and other lightweight furniture is not recommended on the upper level outdoor terraces and balconies unless it is securely attached to the balcony or terrace floor slab.

6 CONCLUSION

This report presents the results of a detailed investigation into the wind environment conditions for the proposed Waterloo Metro Quarter development site. The wind conditions for the existing site and proposed massing model of the Waterloo Metro Quarter site were tested at critical ground level locations within and around the site.

Wind tunnel testing was performed at Windtech's boundary layer wind tunnel facility. The wind tunnel has a 3.0m wide working section and a fetch length of 14m, and measurements were taken from 16 wind directions at 22.5 degree increments. Testing was carried out using a 1:400 detailed scale model of the development. The effects of nearby buildings and land topography have been accounted for through the use of a proximity model which represents an area with a radius of 600m. The testing procedures were based on the guidelines set out in the Australasian Wind Engineering Society Quality Assurance Manual (AWES-QAM-1-2017), ASCE 7-10 (Chapter C31), and CTBUH (2013).

Peak gust and mean wind speeds were measured at selected critical ground level outdoor trafficable locations within and around the subject development. Wind velocity coefficients representing the local wind speeds are derived from the wind tunnel and are combined with a statistical model of the regional wind climate (which accounts for the directional strength and frequency of occurrence of the prevailing regional winds) to provide the equivalent full-scale wind speeds at the site. The wind speed measurements are compared with criteria for pedestrian comfort and safety, based on Gust-Equivalent Mean (GEM) and annual maximum gust winds, respectively.

The existing site wind conditions were measured with the incorporation of the existing site developments. Wind tunnel testing allowed for a baseline wind case for the existing site conditions of the proposed development precinct to be established, taking into account the prevailing wind directions for the area, as well as the local topographical effects of the terrain and the surrounding buildings of the proposed site. An assessment of the wind conditions was made and the information used by the design team to coordinate a massing model.

Wind tunnel testing of the proposed Waterloo Metro Quarter development was undertaken, based on the 3D Sketchup massing model received from UrbanGrowth NSW, January 2018. Results indicated that a number of localised areas are subject to wind conditions that do not achieve the desired criteria for pedestrian comfort and safety. In-principle treatments have been recommended to address the adverse wind conditions. The recommended in-principle wind ameliorative treatments include impermeable awnings at strategic locations and an investigation of a building form change. The inclusion of strategically located densely foliating evergreen tree planting/shrubs within and around the development is expected to further enhance wind comfort conditions.

The information provided from the analysis has been incorporated by the design team to further consolidate the proposed design. An updated drawing package (For Coordination –

11/5/2018) prepared by Turner architects and received from UrbanGrowth NSW, May 2018 has been reviewed. Upon review of the updated drawings it was noticed that the building form of Tower D had changed from the initial massing model. The change in building form is not expected to cause a significant impact on the measured ground level wind conditions. Review of the drawing package indicates the incorporation of alternative wind ameliorative devices in wind sensitive areas such as the Pedestrian Link and New Street through site link. These include baffle screens, awnings and densely foliating evergreen tree planting, which are expected to provide similar alleviating wind measures as the recommended in-principle treatments.

The surrounding pedestrian footpath areas and the communal community square indicate the inclusion of landscaping and tree planting located in wind sensitive areas which has the potential to further enhance the wind comfort conditions. Hence, with the inclusion of the abovementioned design changes to the design of the development, it is expected that the wind conditions for all outdoor trafficable areas within and around the development will be suitable for their intended uses.

The majority of the private balconies are only exposed to winds on a single aspect and also benefit from the setback design, hence are expected to be suitable for their intended use. Recommendations have been made to address the balconies exposed to two aspects, through the recommended incorporation of deflective elements such as full-height screens to be added along one of the aspects. The elevated communal open spaces are exposed to the prevailing north-easterly, southerly and westerly winds due to their locations. With the recommended incorporation of wind deflective elements and strategic landscaping within these areas the wind conditions are expected to be acceptable for their intended uses.

It is recommended that further investigation of the wind conditions for the ground level and elevated areas within and around the development be undertaken at a later stage during the design development to verify the suitability of the areas.

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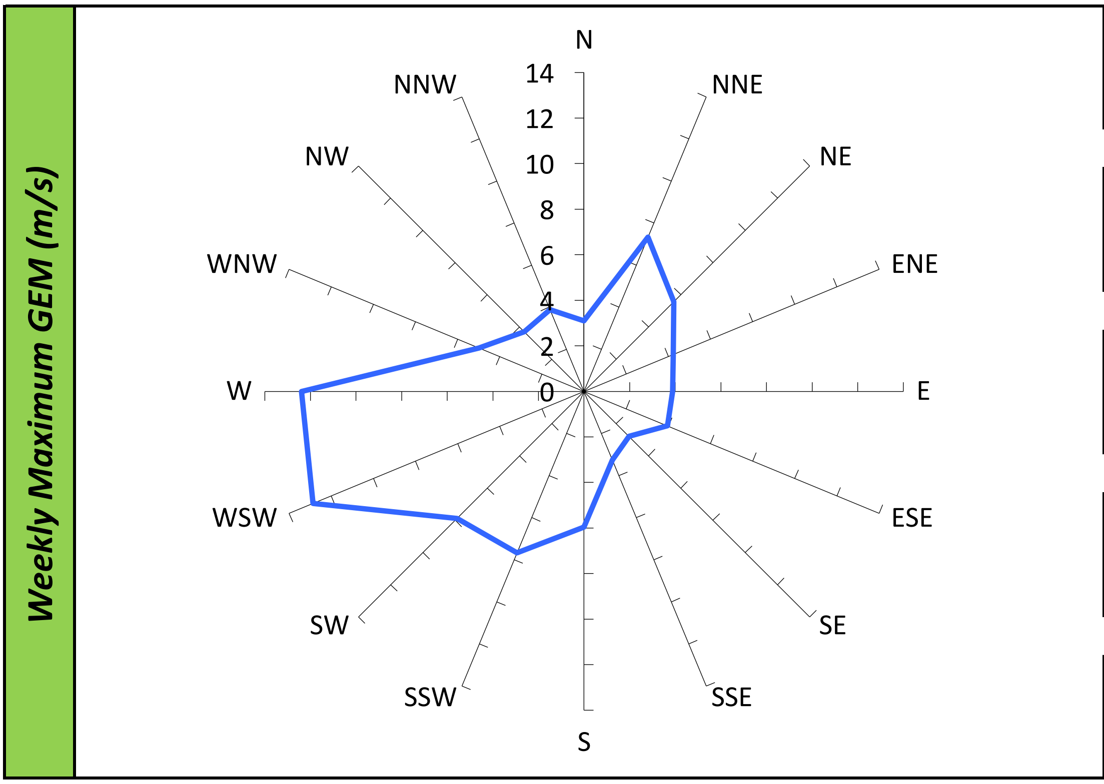
APPENDIX A - DIRECTIONAL PLOTS OF THE WIND TUNNEL RESULTS

Measured Wind Speeds at P01



Desired Criterion
8m/s

Prob. of Criterion Exceedence (existing site conditions)
N/A

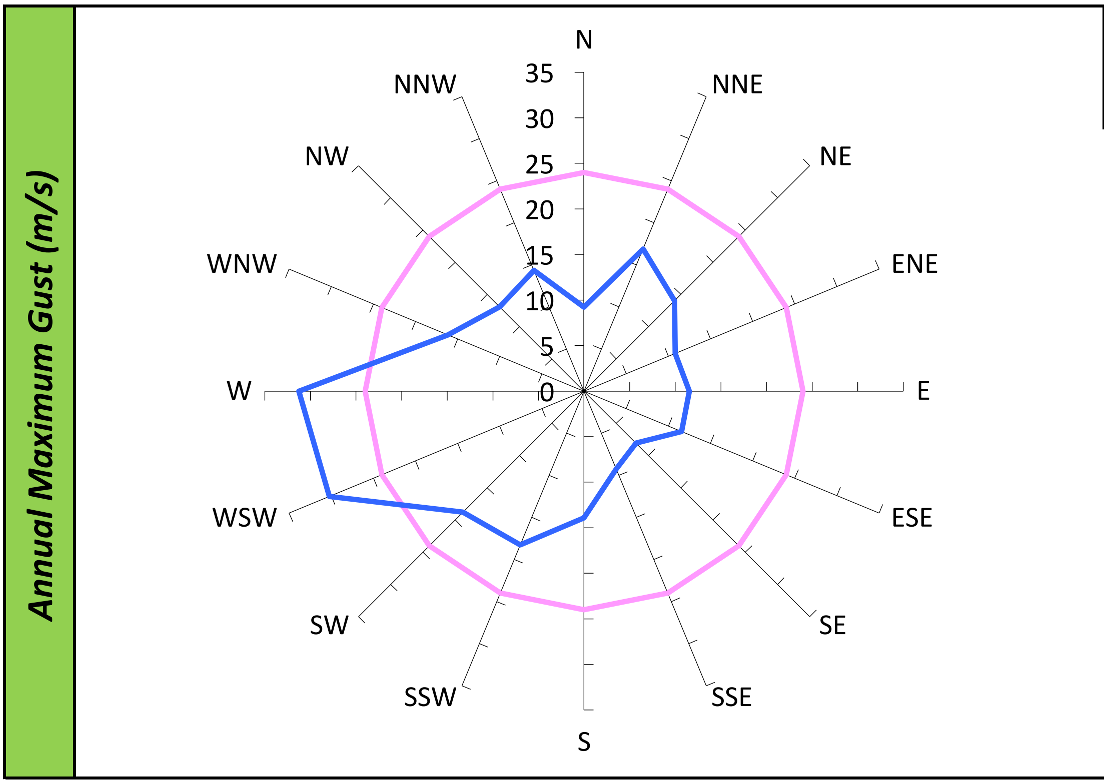
Probability of Criterion Exceedence (initial test)
13%

Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

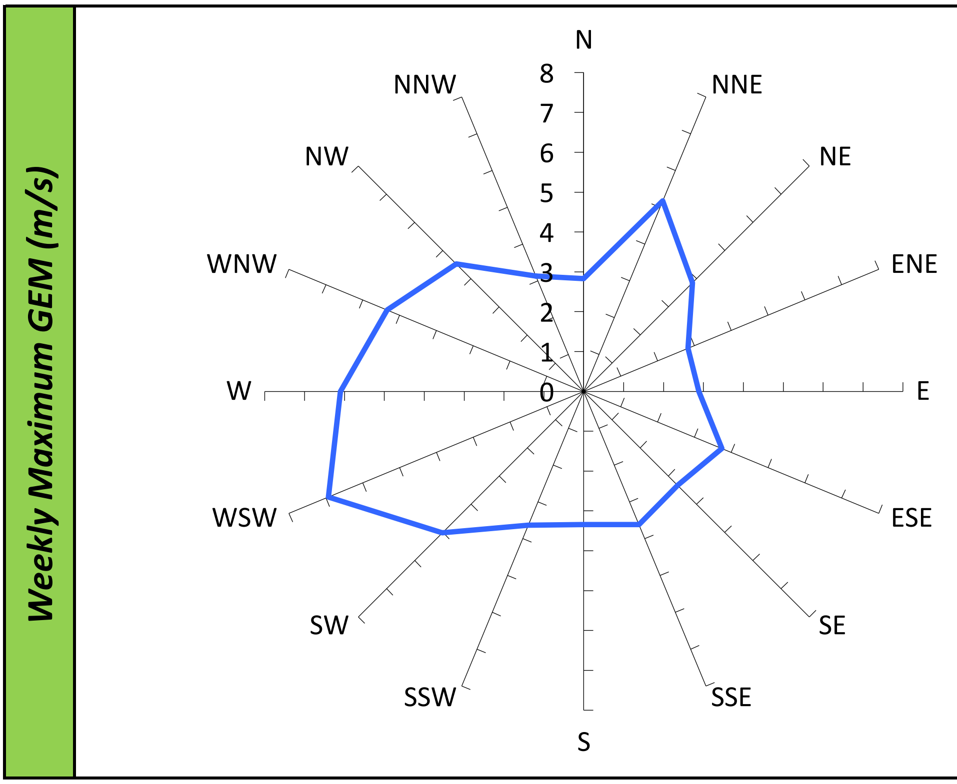
Criterion.

With the Waterloo Metro development as proposed. No vegetation or other treatments.



Desired Criterion
24m/s

Measured Wind Speeds at P02



Desired Criterion
8m/s

Prob. of Criterion Exceedence (existing site conditions)
N/A

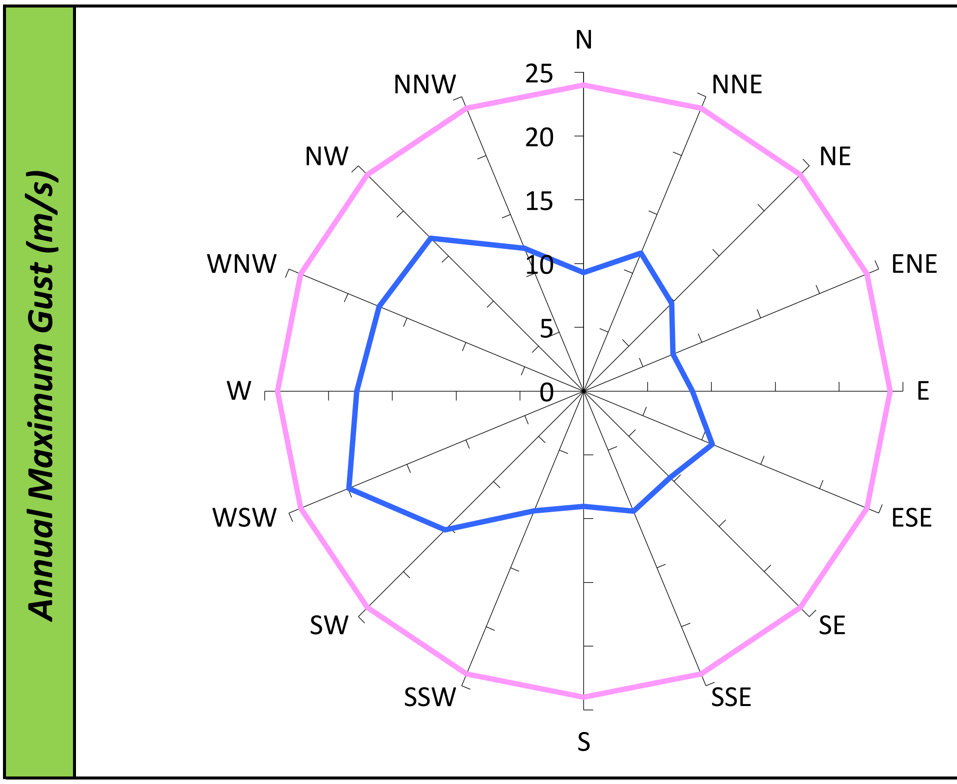
Probability of Criterion Exceedence (initial test)
1%

Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.

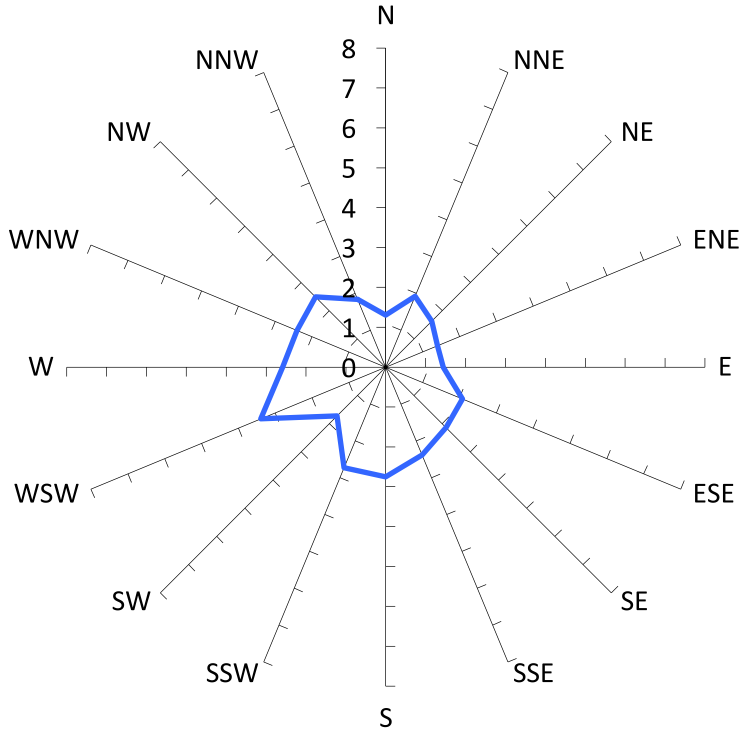
With the Waterloo Metro development as proposed. No vegetation or other treatments.



Desired Criterion
24m/s

Measured Wind Speeds at P03

Weekly Maximum GEM (m/s)



Desired Criterion
8m/s

Prob. of Criterion Exceedence (existing site conditions)
N/A

Probability of Criterion Exceedence (initial test)
0%

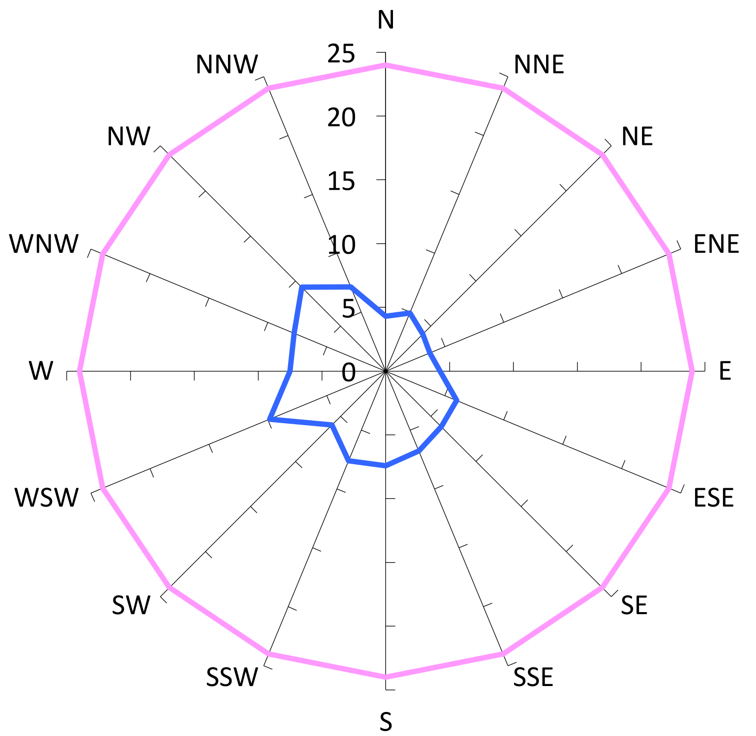
Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.

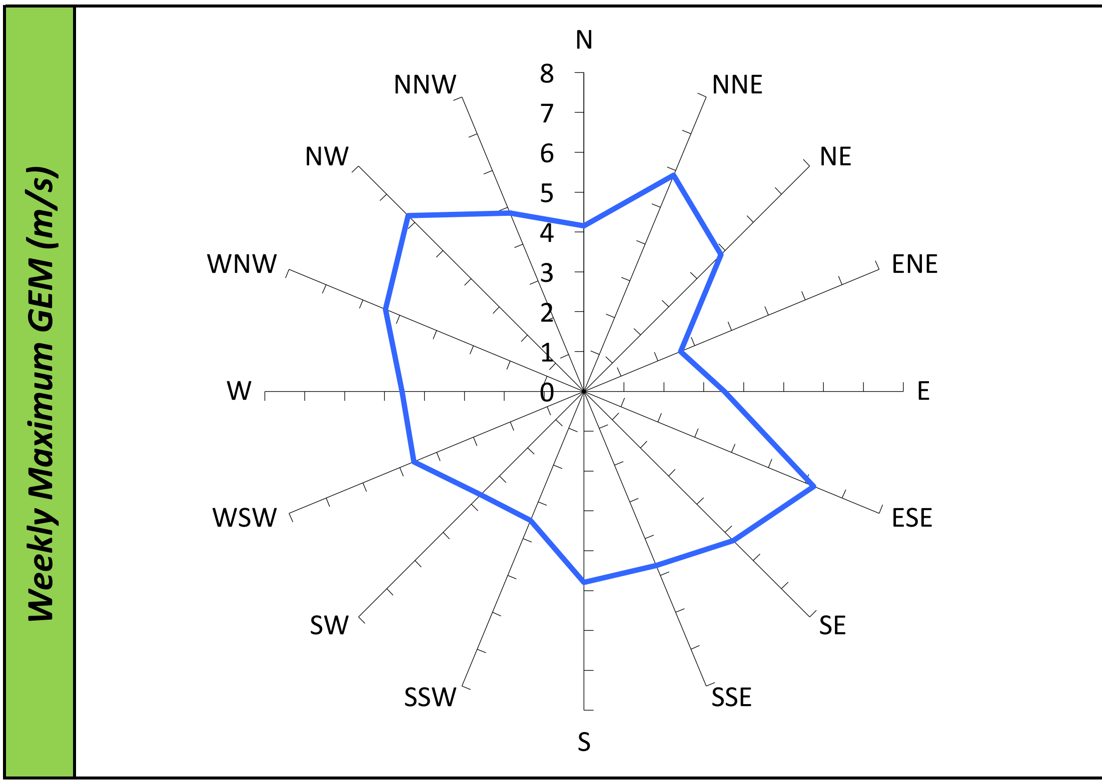
With the Waterloo Metro development as proposed. No vegetation or other treatments.

Annual Maximum Gust (m/s)



Desired Criterion
24m/s

Measured Wind Speeds at P04



Desired Criterion
8m/s

Prob. of Criterion Exceedence (existing site conditions)
N/A

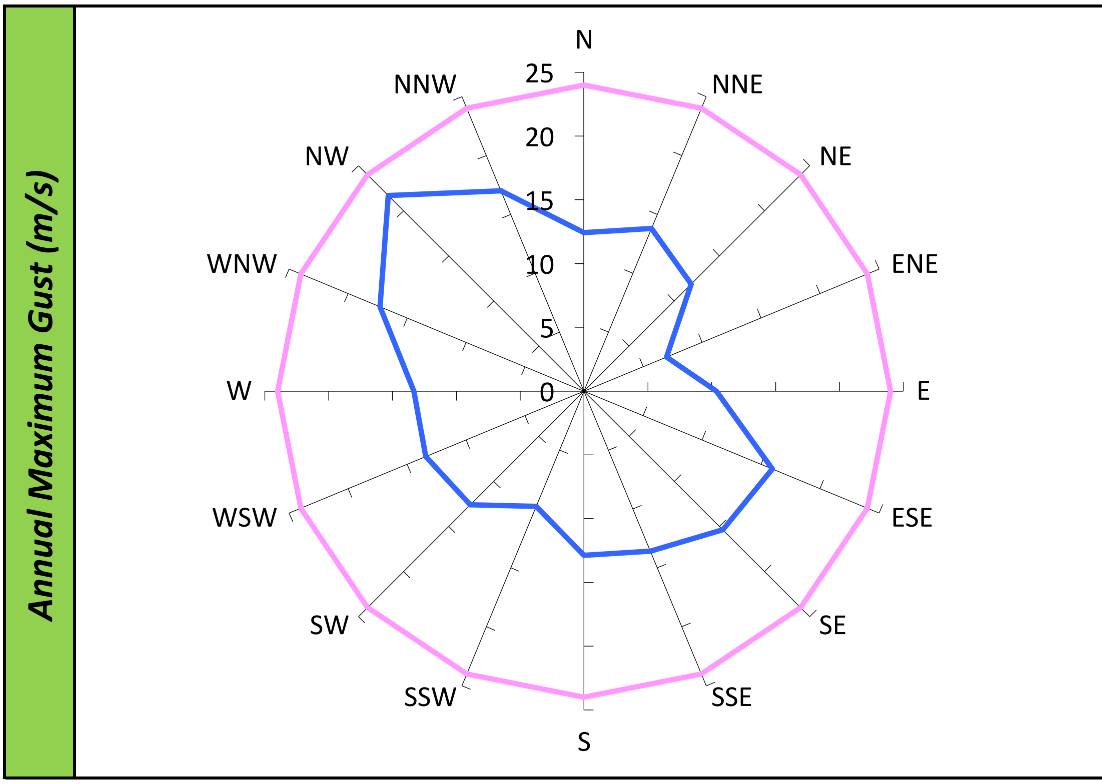
Probability of Criterion Exceedence (initial test)
2%

Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.

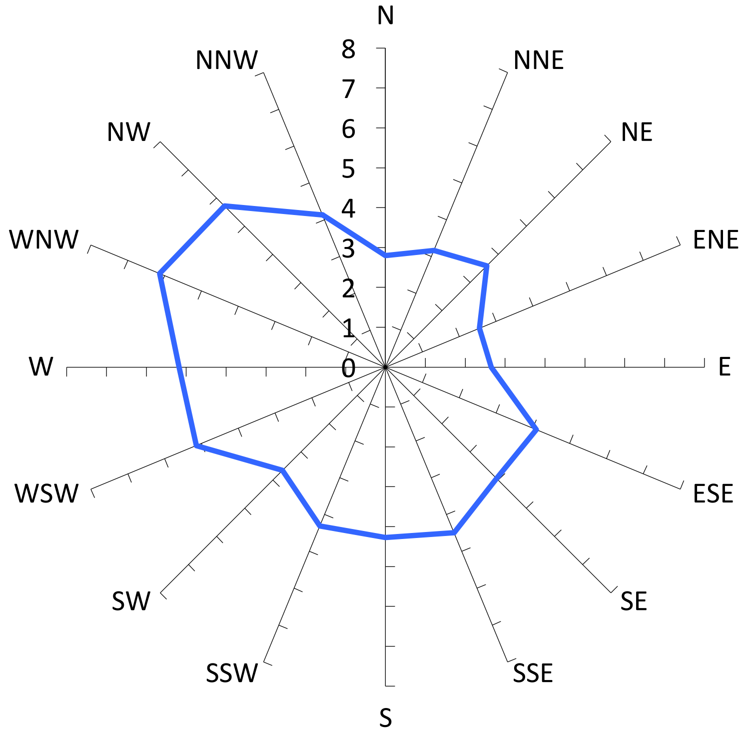
With the Waterloo Metro development as proposed. No vegetation or other treatments.



Desired Criterion
24m/s

Measured Wind Speeds at P05

Weekly Maximum GEM (m/s)



Desired Criterion
8m/s

Prob. of Criterion Exceedence (existing site conditions)
N/A

Probability of Criterion Exceedence (initial test)
1%

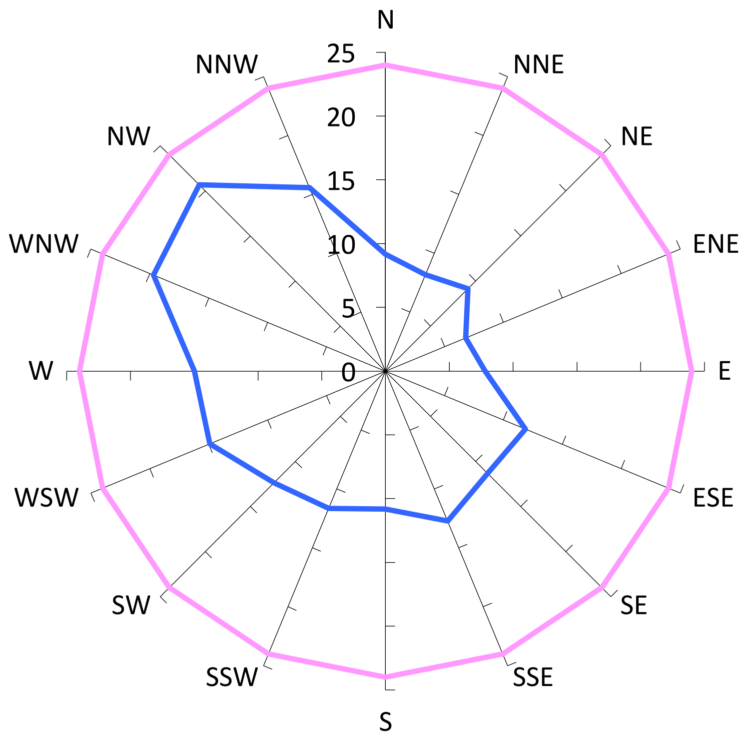
Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.

With the Waterloo Metro development as proposed. No vegetation or other treatments.

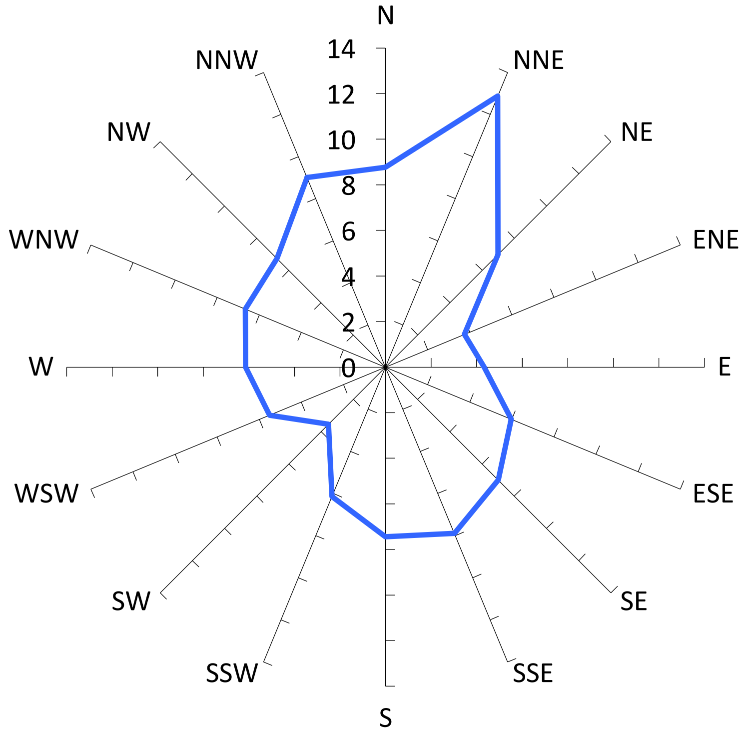
Annual Maximum Gust (m/s)



Desired Criterion
24m/s

Measured Wind Speeds at P06

Weekly Maximum GEM (m/s)



Desired Criterion
8m/s

Prob. of Criterion Exceedence (existing site conditions)
N/A

Probability of Criterion Exceedence (initial test)
14%

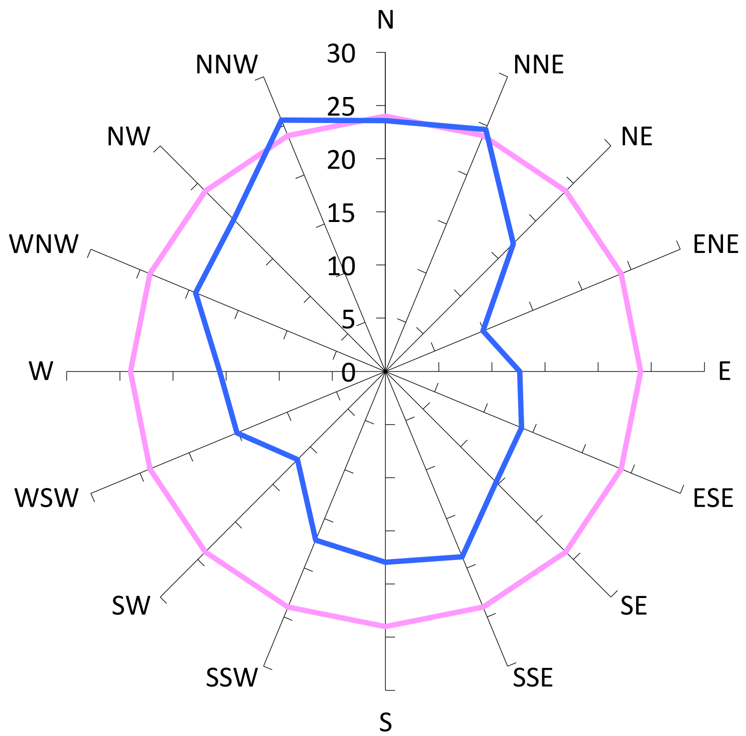
Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.

With the Waterloo Metro development as proposed. No vegetation or other treatments.

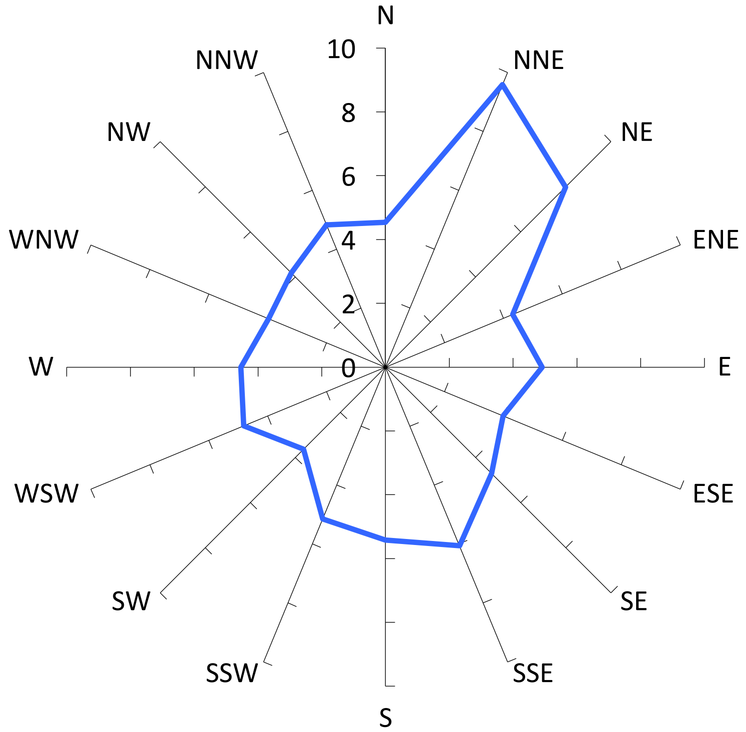
Annual Maximum Gust (m/s)



Desired Criterion
24m/s

Measured Wind Speeds at P07

Weekly Maximum GEM (m/s)



Desired Criterion
8m/s

Prob. of Criterion Exceedence (existing site conditions)
N/A

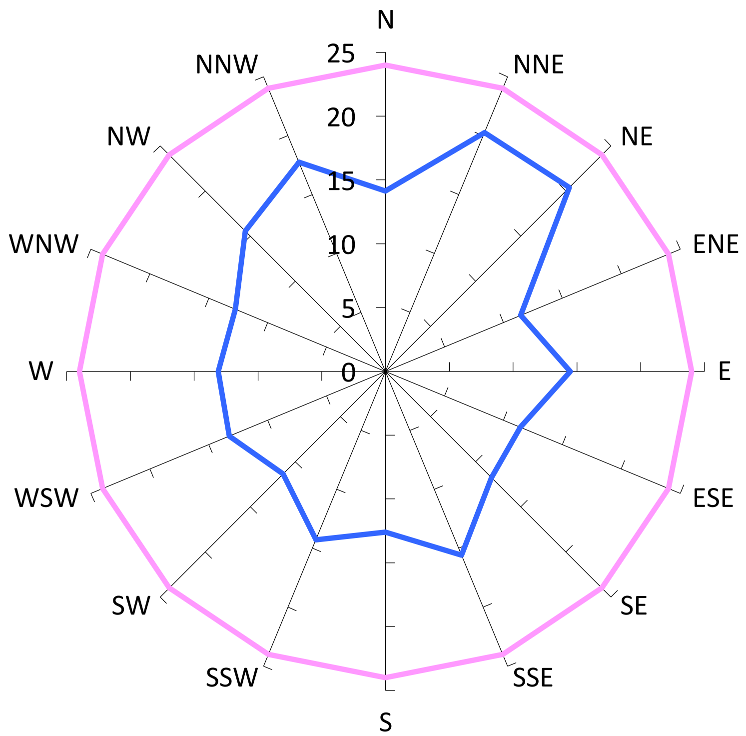
Probability of Criterion Exceedence (initial test)
5%

Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

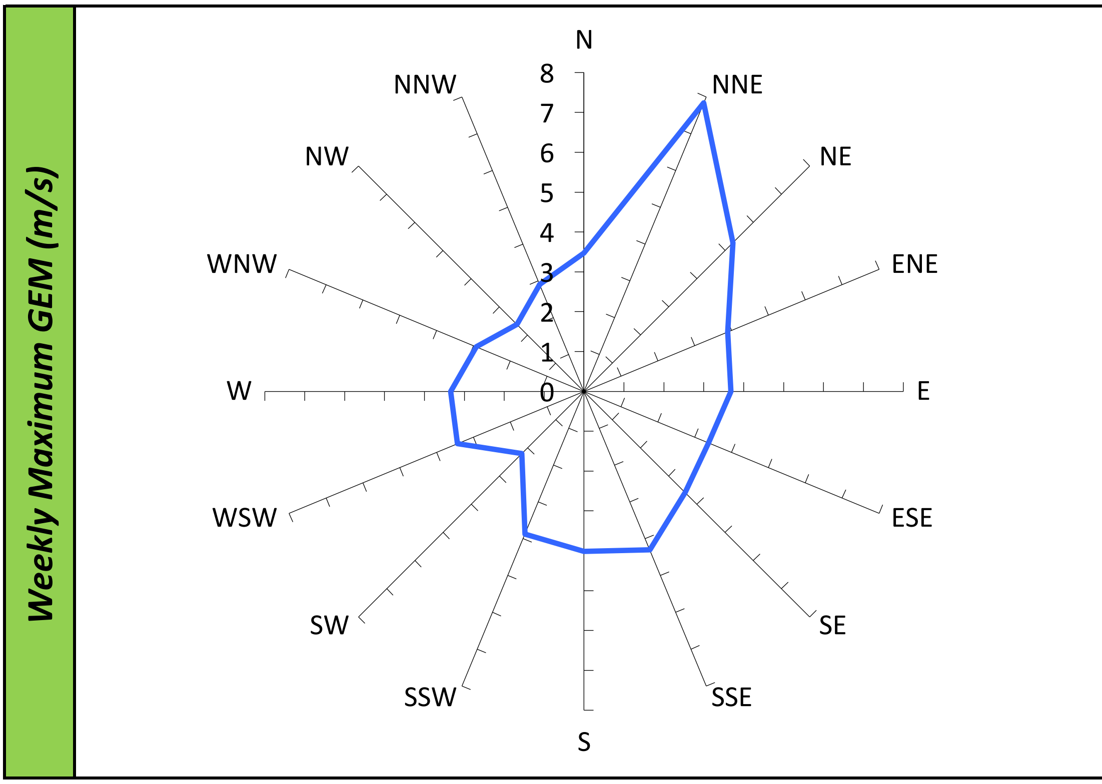
Criterion.
With the Waterloo Metro development as proposed. No vegetation or other treatments.

Annual Maximum Gust (m/s)



Desired Criterion
24m/s

Measured Wind Speeds at P08



Desired Criterion
8m/s

Prob. of Criterion Exceedence (existing site conditions)
N/A

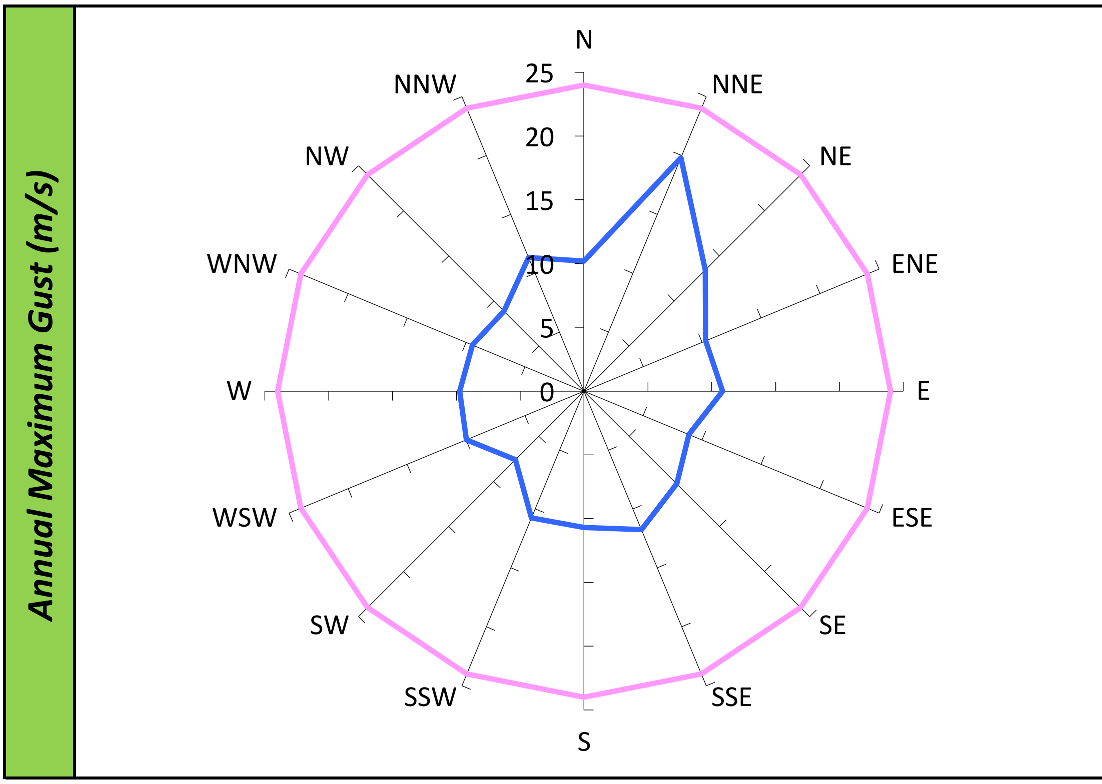
Probability of Criterion Exceedence (initial test)
1%

Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.

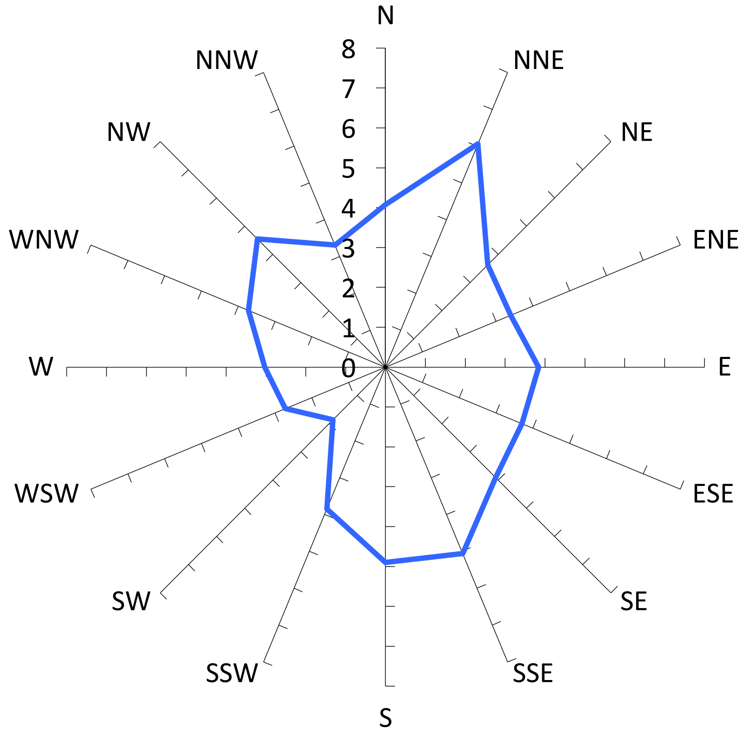
With the Waterloo Metro development as proposed. No vegetation or other treatments.



Desired Criterion
24m/s

Measured Wind Speeds at P09

Weekly Maximum GEM (m/s)



Desired Criterion
8m/s

Prob. of Criterion Exceedence (existing site conditions)
N/A

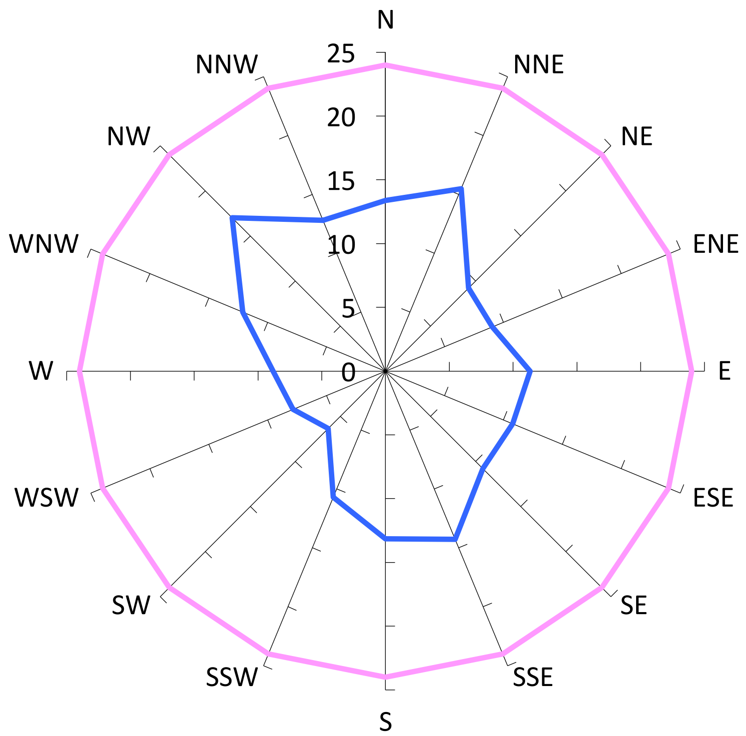
Probability of Criterion Exceedence (initial test)
0%

Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

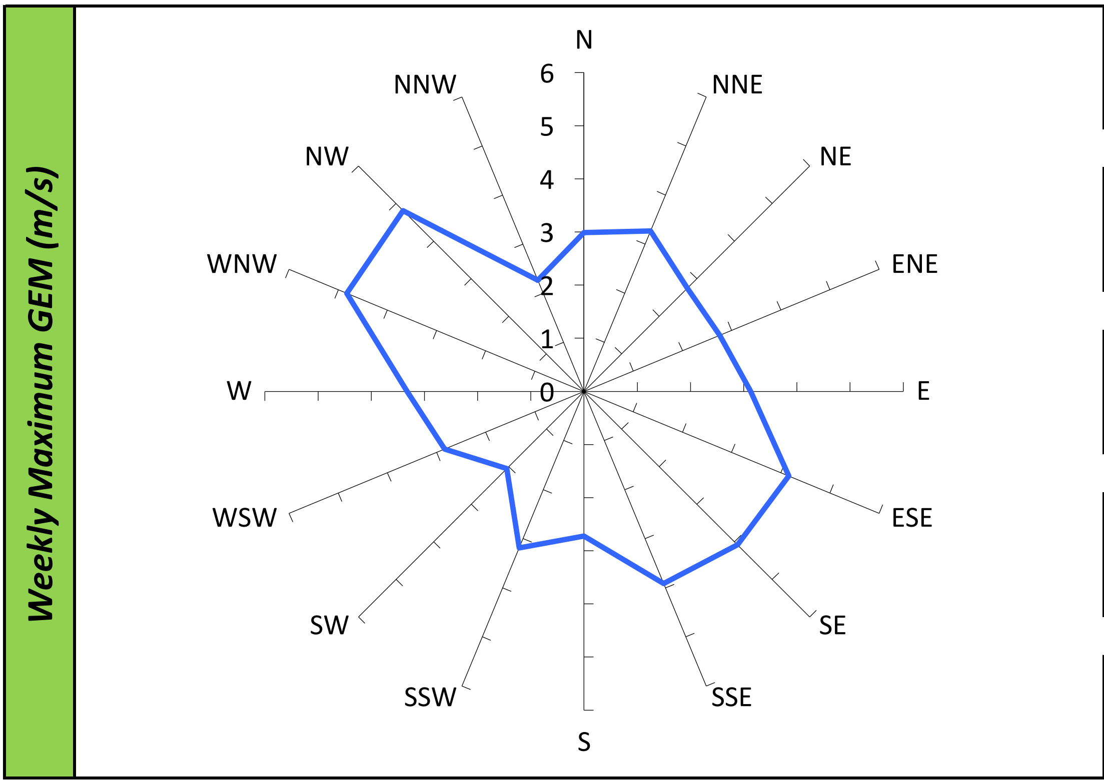
Criterion.
With the Waterloo Metro development as proposed. No vegetation or other treatments.

Annual Maximum Gust (m/s)



Desired Criterion
24m/s

Measured Wind Speeds at P10



Desired Criterion

6m/s

Prob. of Criterion Exceedence (existing site conditions)

N/A

Probability of Criterion Exceedence (initial test)

1%

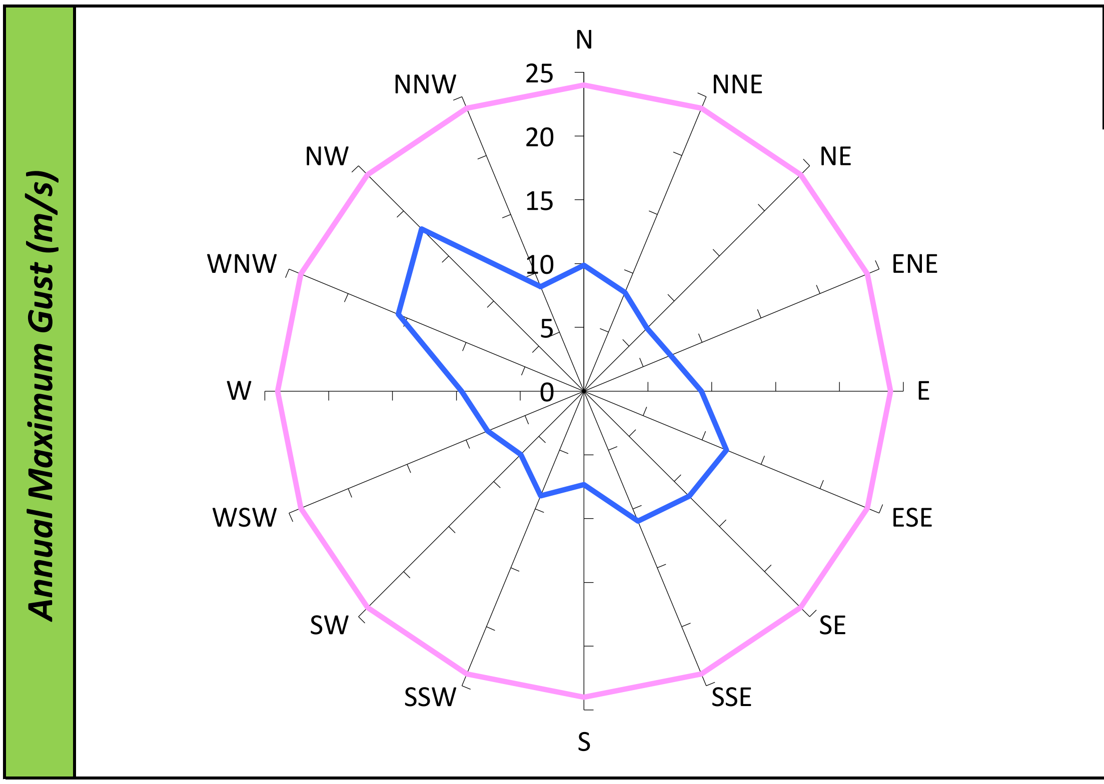
Probability of Criterion Exceedence (final retest)

N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.

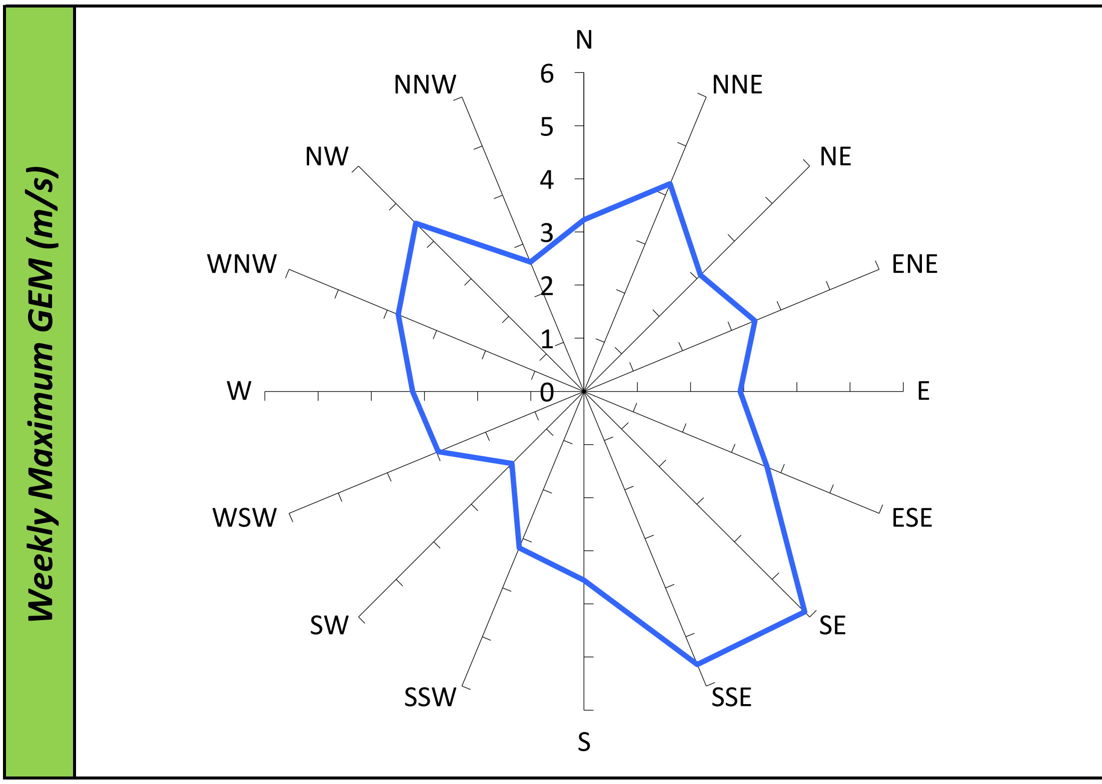
With the Waterloo Metro development as proposed. No vegetation or other treatments.



Desired Criterion

24m/s

Measured Wind Speeds at P11



Desired Criterion
6m/s

Prob. of Criterion Exceedence (existing site conditions)
N/A

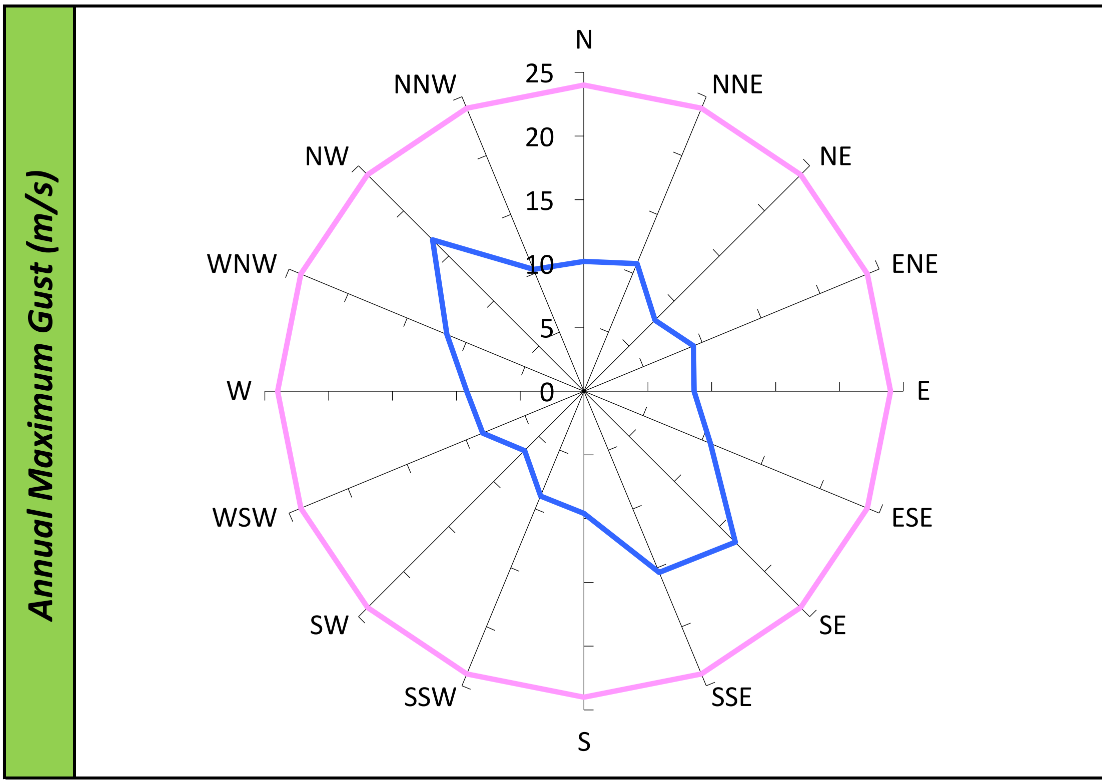
Probability of Criterion Exceedence (initial test)
3%

Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.

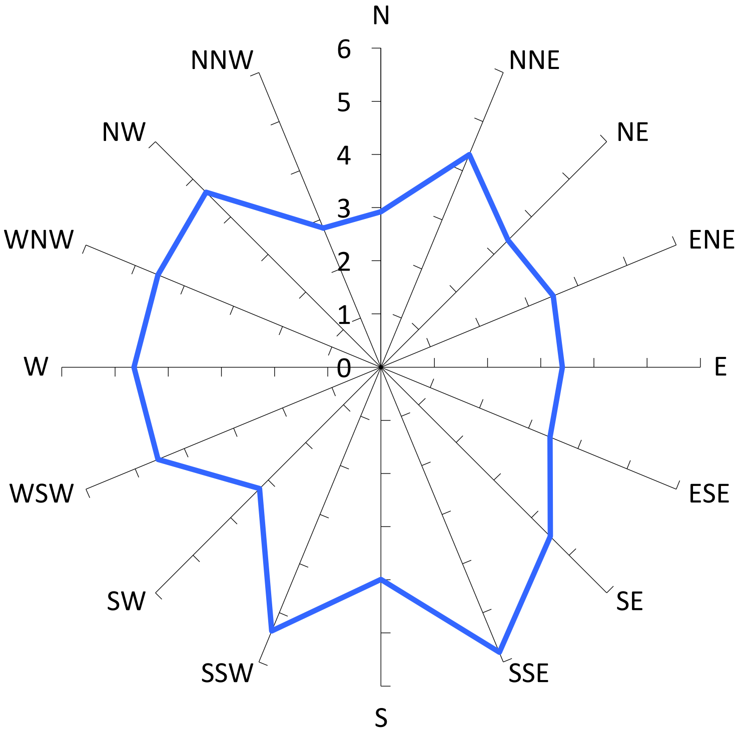
With the Waterloo Metro development as proposed. No vegetation or other treatments.



Desired Criterion
24m/s

Measured Wind Speeds at P12

Weekly Maximum GEM (m/s)



Desired Criterion
6m/s

Prob. of Criterion Exceedence (existing site conditions)
N/A

Probability of Criterion Exceedence (initial test)
4%

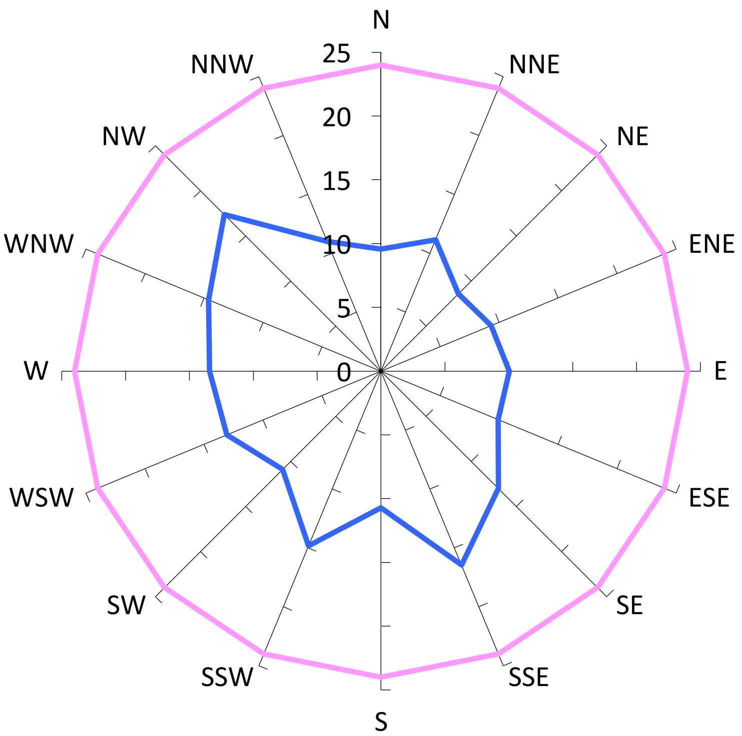
Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.

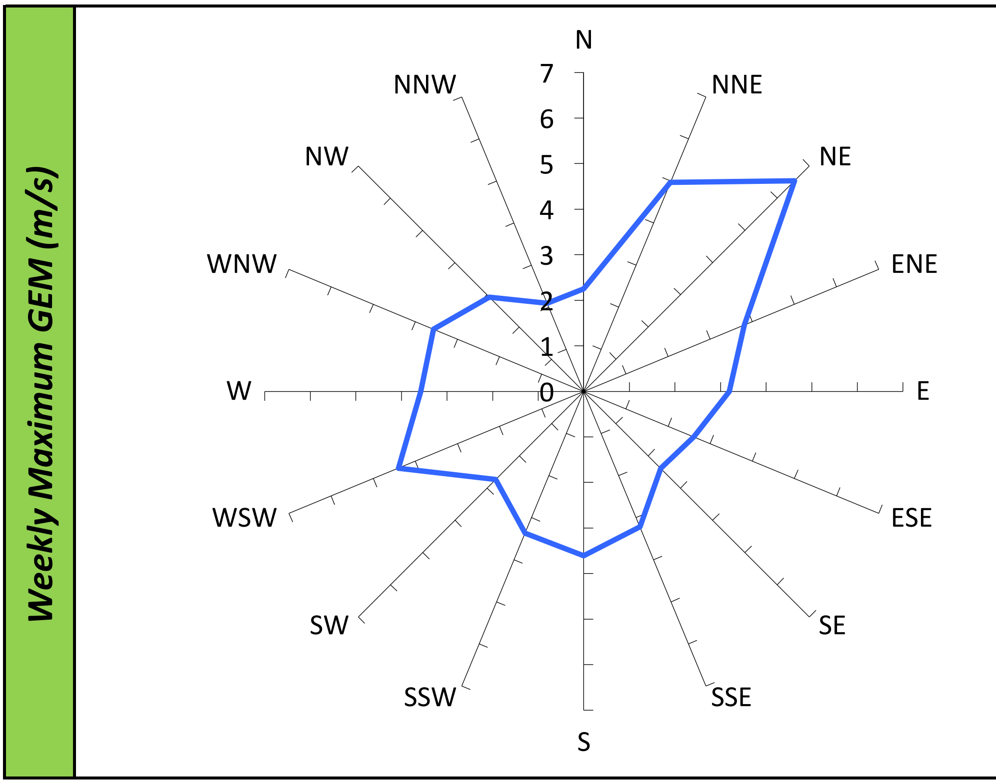
With the Waterloo Metro development as proposed. No vegetation or other treatments.

Annual Maximum Gust (m/s)



Desired Criterion
24m/s

Measured Wind Speeds at P13



Desired Criterion
6m/s

Prob. of Criterion Exceedence (existing site conditions)
N/A

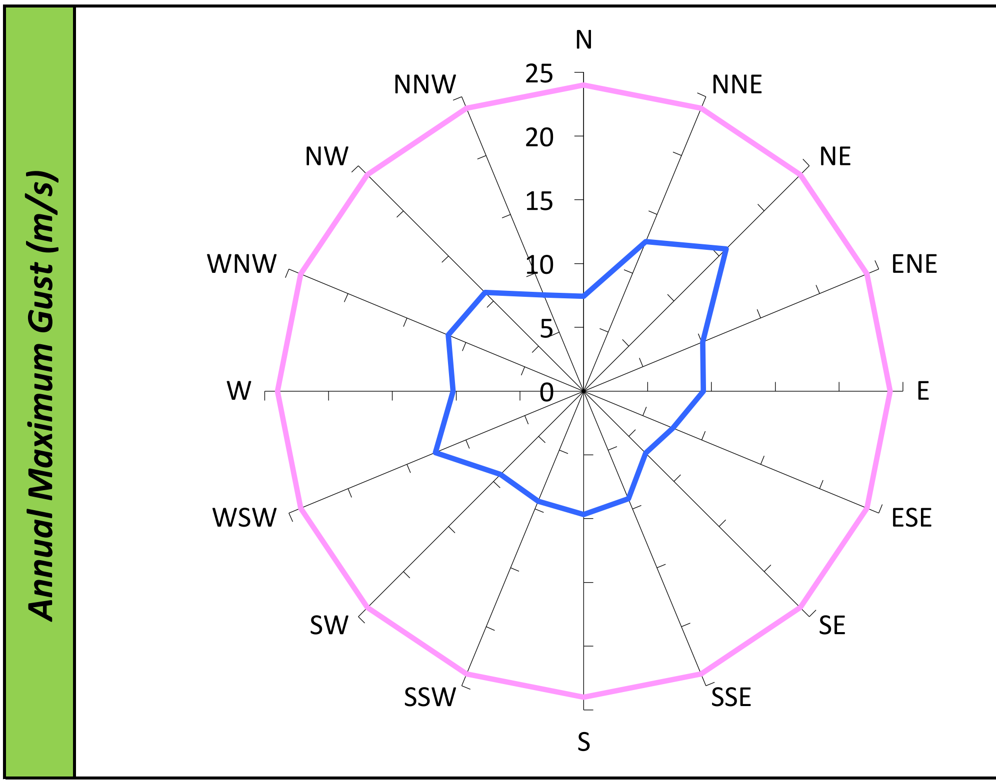
Probability of Criterion Exceedence (initial test)
3%

Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.

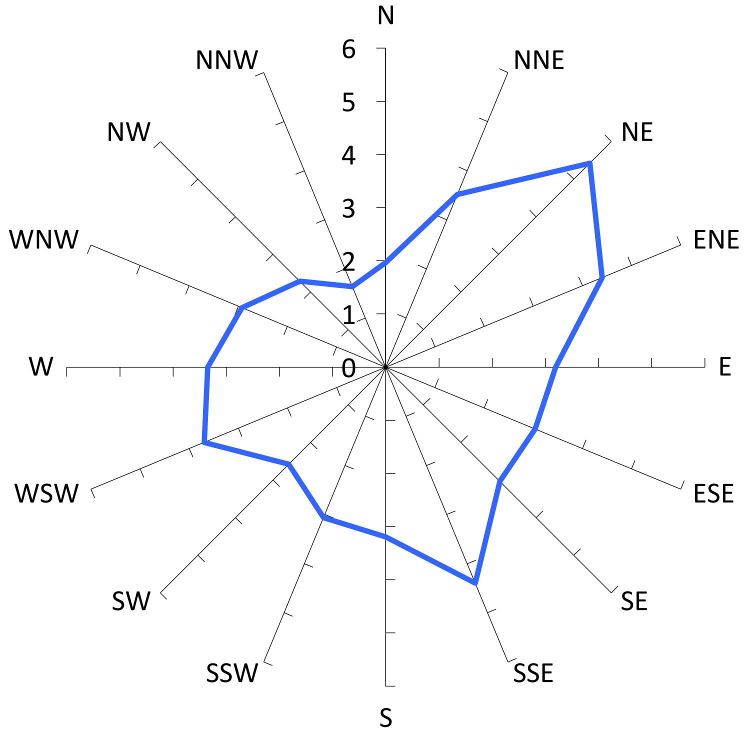
With the Waterloo Metro development as proposed. No vegetation or other treatments.



Desired Criterion
24m/s

Measured Wind Speeds at P14

Weekly Maximum GEM (m/s)



Desired Criterion
6m/s

Prob. of Criterion Exceedence (existing site conditions)
N/A

Probability of Criterion Exceedence (initial test)
1%

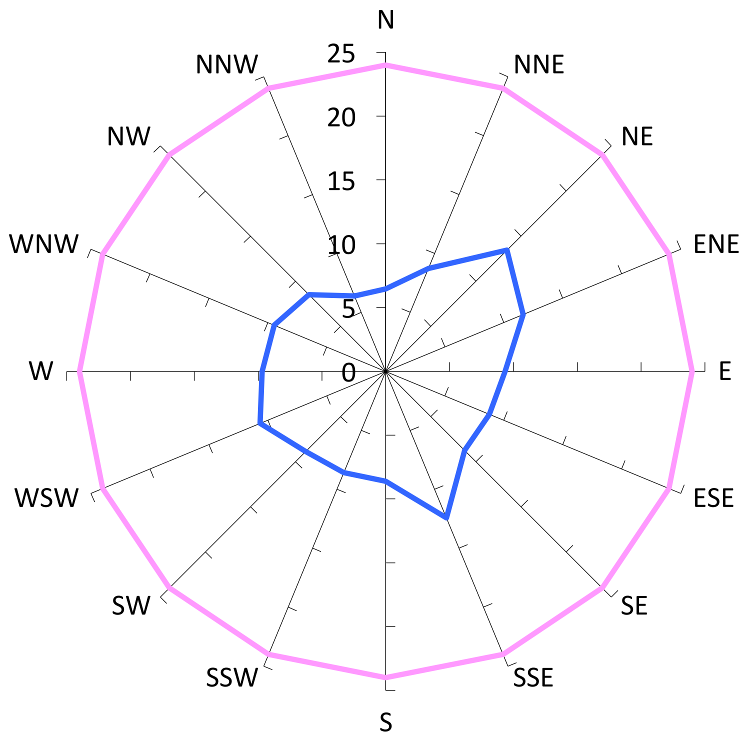
Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.

With the Waterloo Metro development as proposed. No vegetation or other treatments.

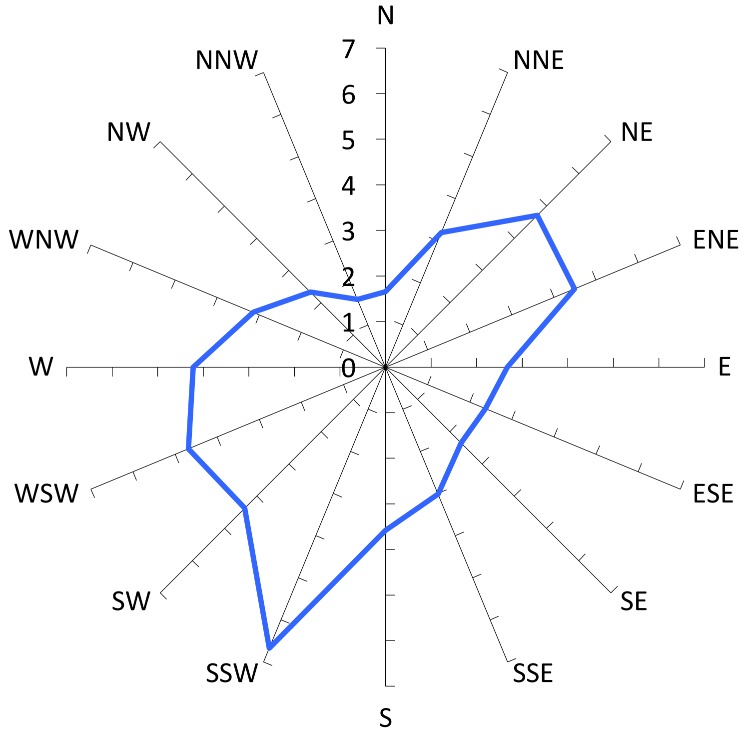
Annual Maximum Gust (m/s)



Desired Criterion
24m/s

Measured Wind Speeds at P15

Weekly Maximum GEM (m/s)



Desired Criterion

6m/s

Prob. of Criterion Exceedence (existing site conditions)

N/A

Probability of Criterion Exceedence (initial test)

3%

Probability of Criterion Exceedence (final retest)

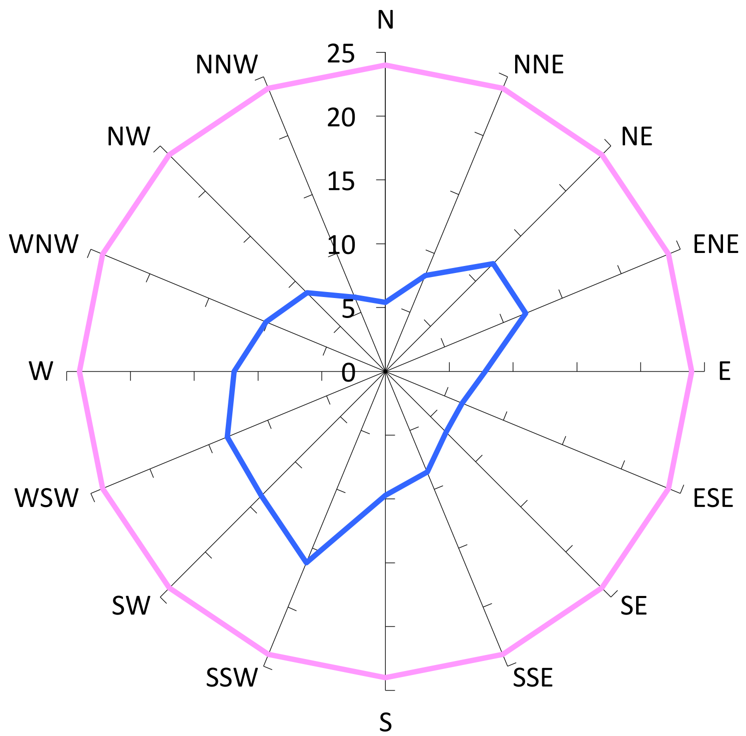
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.

With the Waterloo Metro development as proposed. No vegetation or other treatments.

Annual Maximum Gust (m/s)

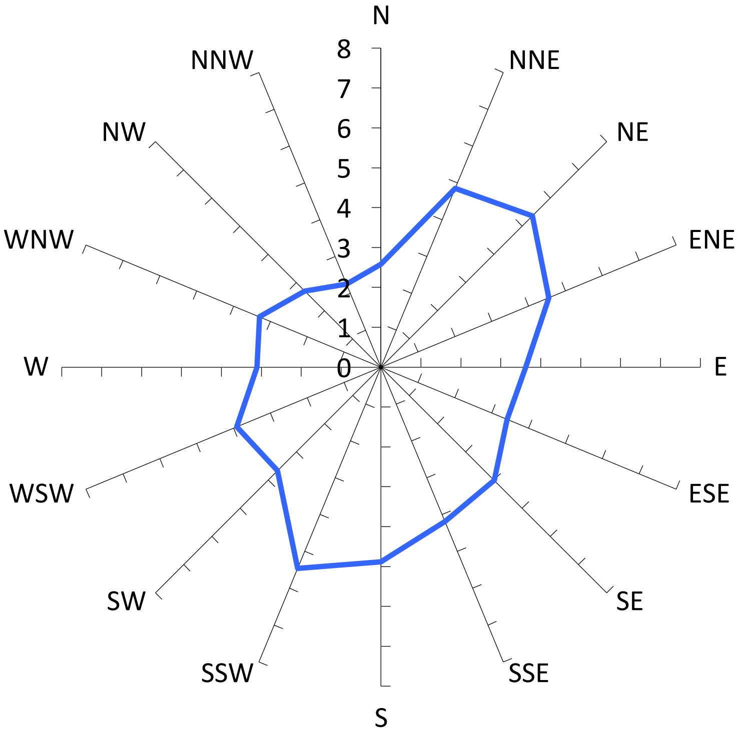


Desired Criterion

24m/s

Measured Wind Speeds at P16

Weekly Maximum GEM (m/s)



Desired Criterion
8m/s

Prob. of Criterion Exceedence (existing site conditions)
N/A

Probability of Criterion Exceedence (initial test)
0%

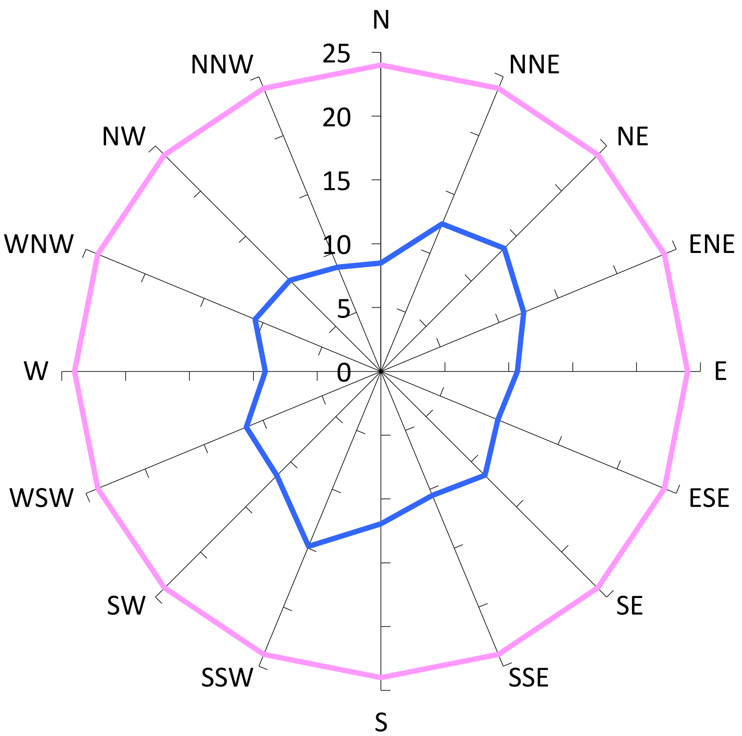
Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.

With the Waterloo Metro development as proposed. No vegetation or other treatments.

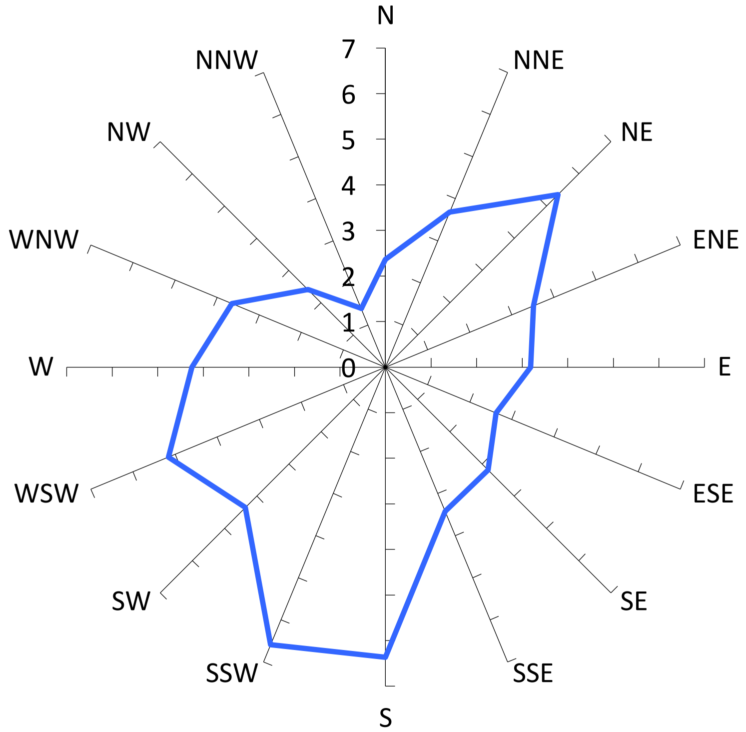
Annual Maximum Gust (m/s)



Desired Criterion
24m/s

Measured Wind Speeds at P17

Weekly Maximum GEM (m/s)



Desired Criterion
6m/s

Prob. of Criterion Exceedence (existing site conditions)
N/A

Probability of Criterion Exceedence (initial test)
5%

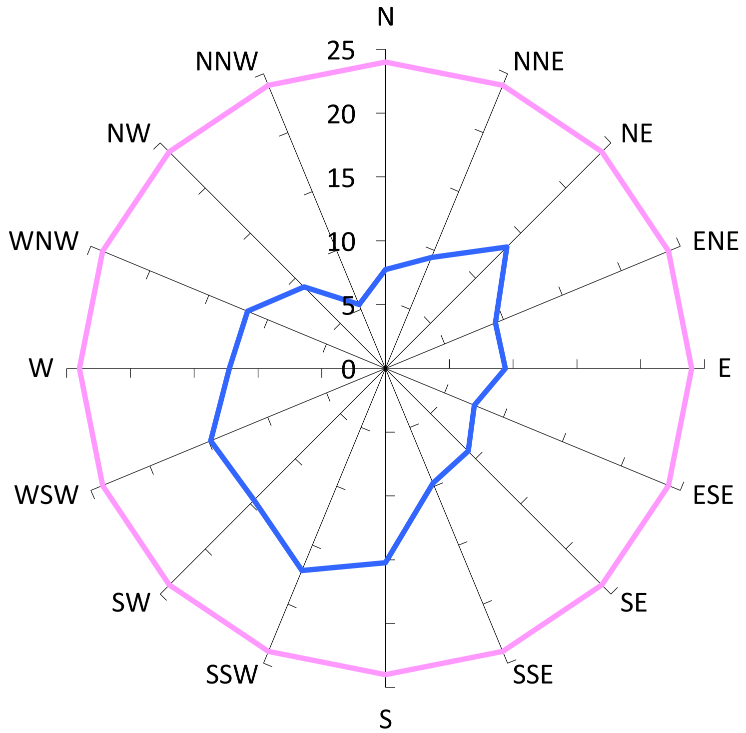
Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.

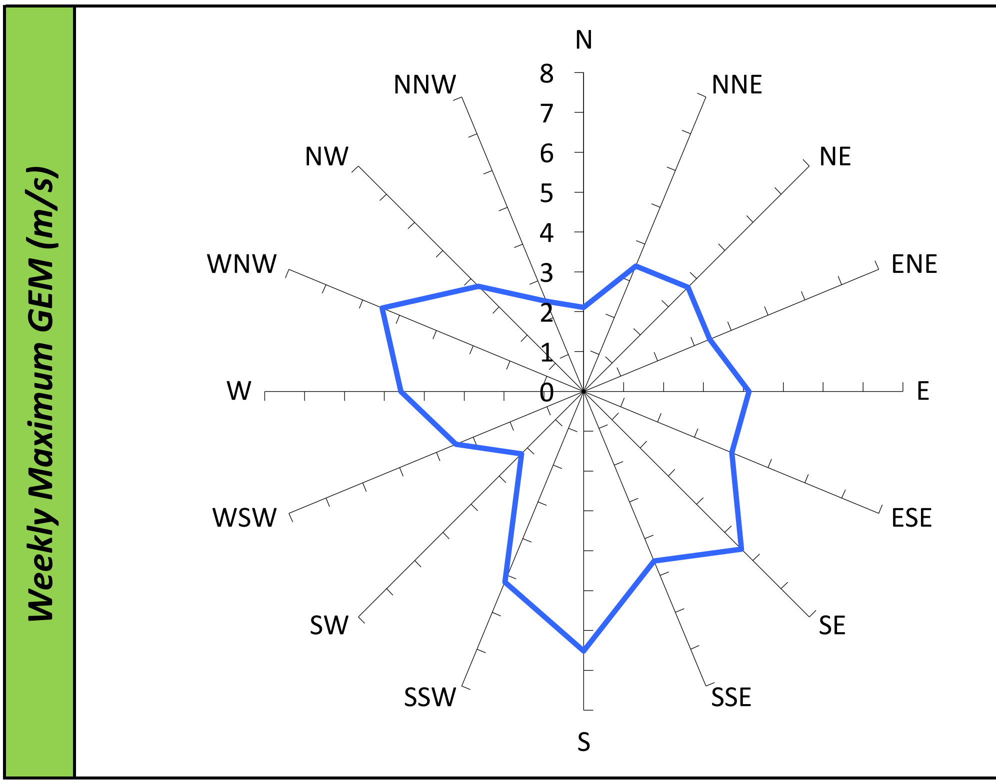
With the Waterloo Metro development as proposed. No vegetation or other treatments.

Annual Maximum Gust (m/s)



Desired Criterion
24m/s

Measured Wind Speeds at P18



Desired Criterion
8m/s

Prob. of Criterion Exceedence (existing site conditions)
N/A

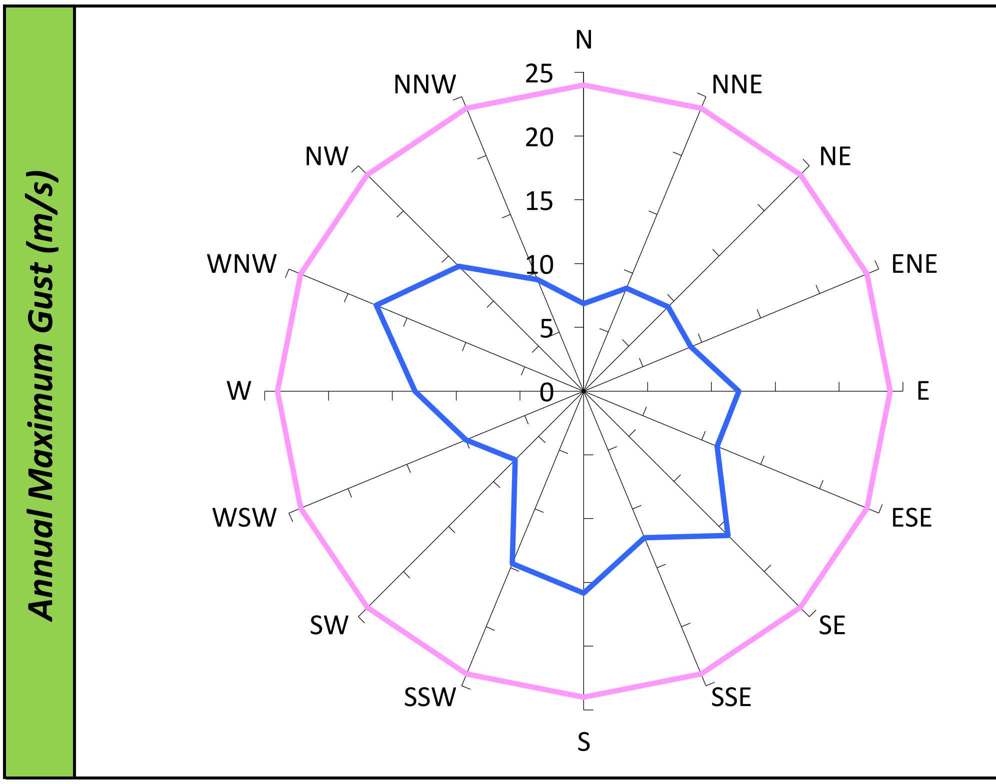
Probability of Criterion Exceedence (initial test)
1%

Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.

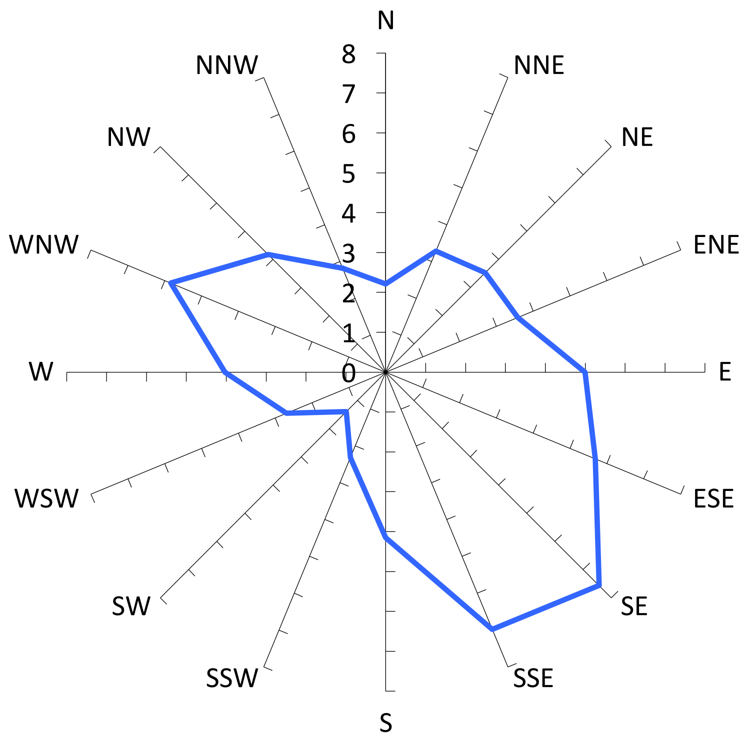
With the Waterloo Metro development as proposed. No vegetation or other treatments.



Desired Criterion
24m/s

Measured Wind Speeds at P19

Weekly Maximum GEM (m/s)



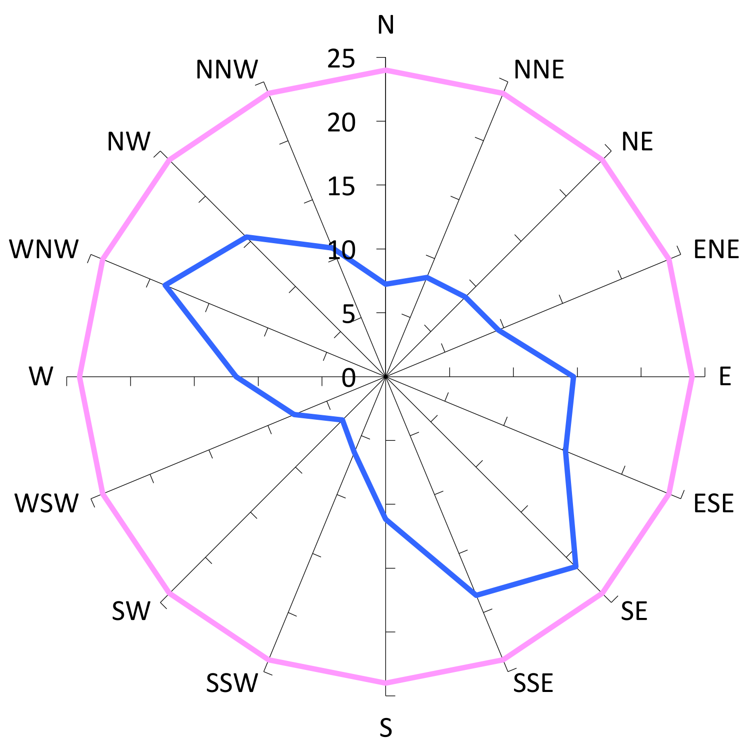
Desired Criterion
8m/s
Prob. of Criterion Exceedence (existing site conditions)
N/A
Probability of Criterion Exceedence (initial test)
2%
Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.

With the Waterloo Metro development as proposed. No vegetation or other treatments.

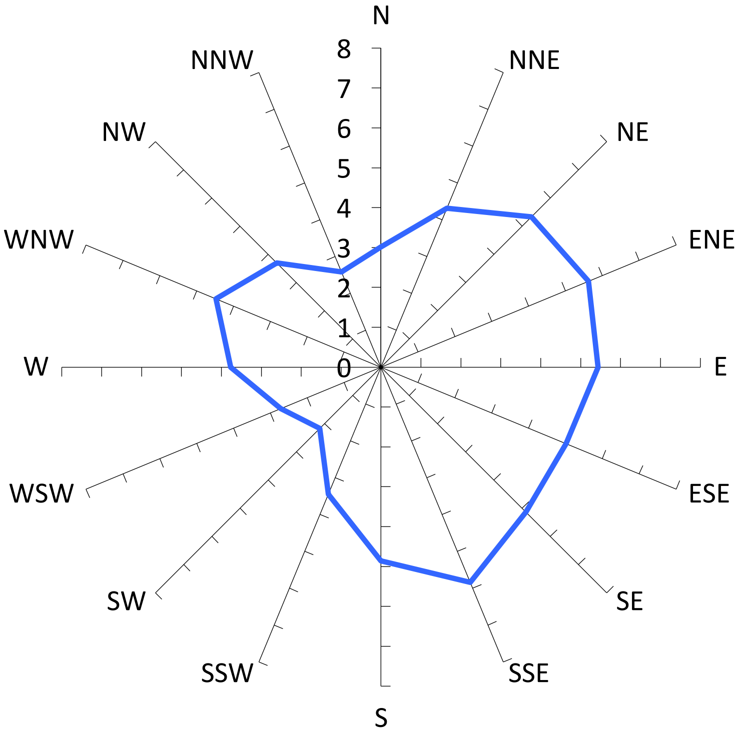
Annual Maximum Gust (m/s)



Desired Criterion
24m/s

Measured Wind Speeds at P20

Weekly Maximum GEM (m/s)



Desired Criterion

8m/s

Prob. of Criterion Exceedence (existing site conditions)

N/A

Probability of Criterion Exceedence (initial test)

1%

Probability of Criterion Exceedence (final retest)

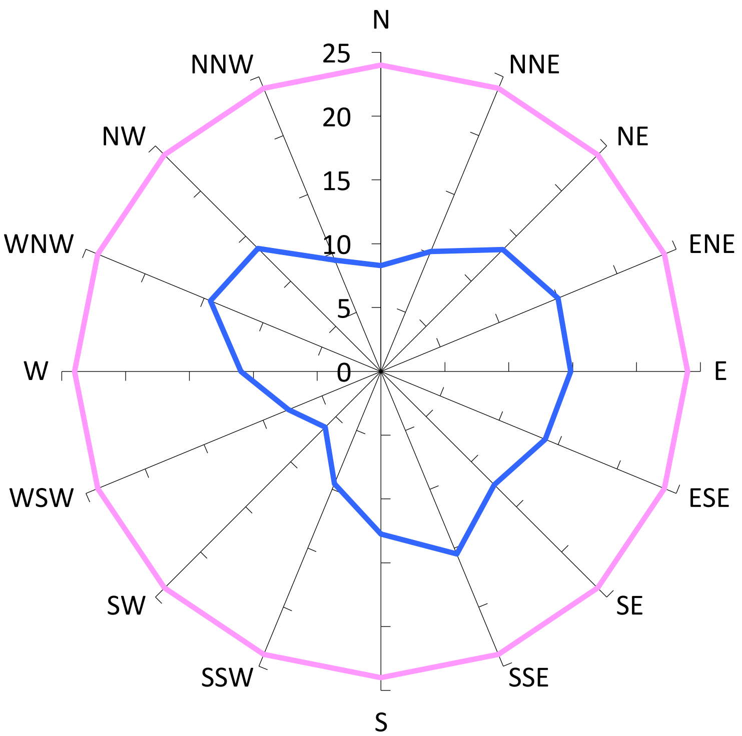
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.

With the Waterloo Metro development as proposed. No vegetation or other treatments.

Annual Maximum Gust (m/s)

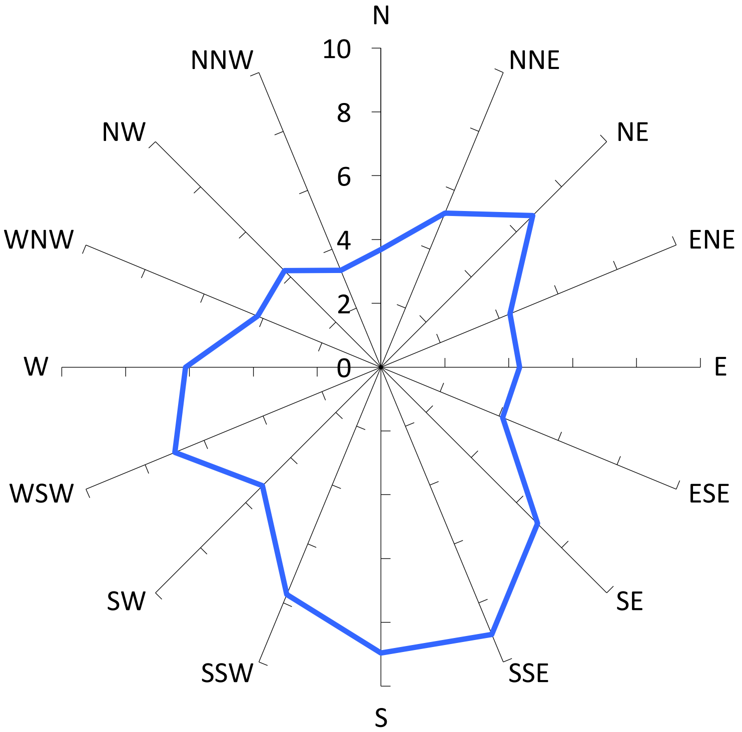


Desired Criterion

24m/s

Measured Wind Speeds at P21

Weekly Maximum GEM (m/s)



Desired Criterion
8m/s

Prob. of Criterion Exceedence (existing site conditions)
N/A

Probability of Criterion Exceedence (initial test)
9%

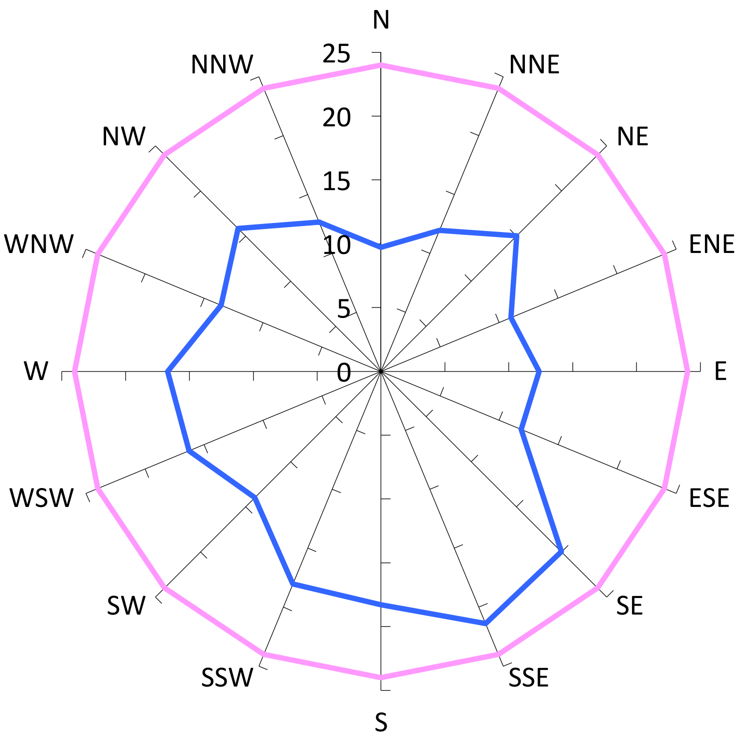
Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.

With the Waterloo Metro development as proposed. No vegetation or other treatments.

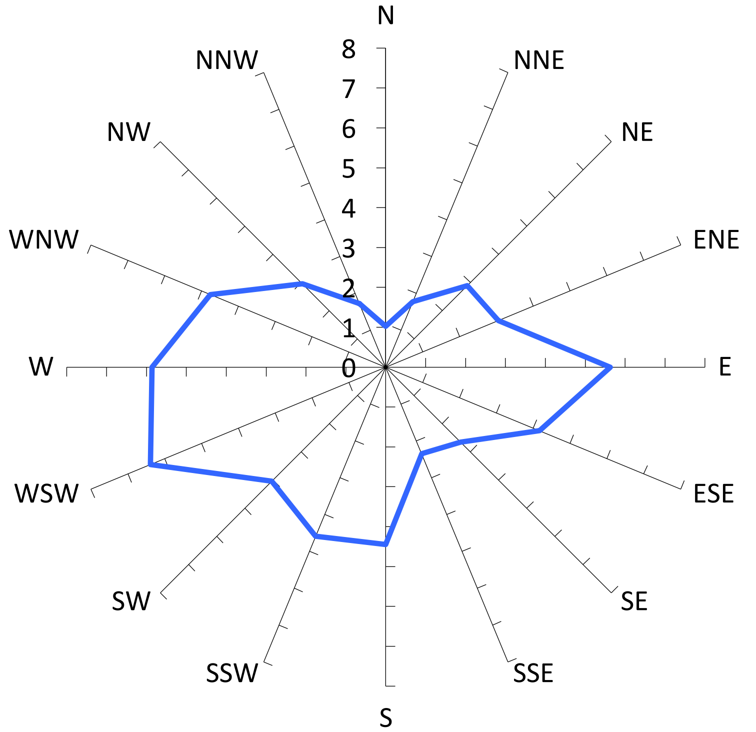
Annual Maximum Gust (m/s)



Desired Criterion
24m/s

Measured Wind Speeds at P22

Weekly Maximum GEM (m/s)



Desired Criterion
8m/s

Prob. of Criterion Exceedence (existing site conditions)
N/A

Probability of Criterion Exceedence (initial test)
1%

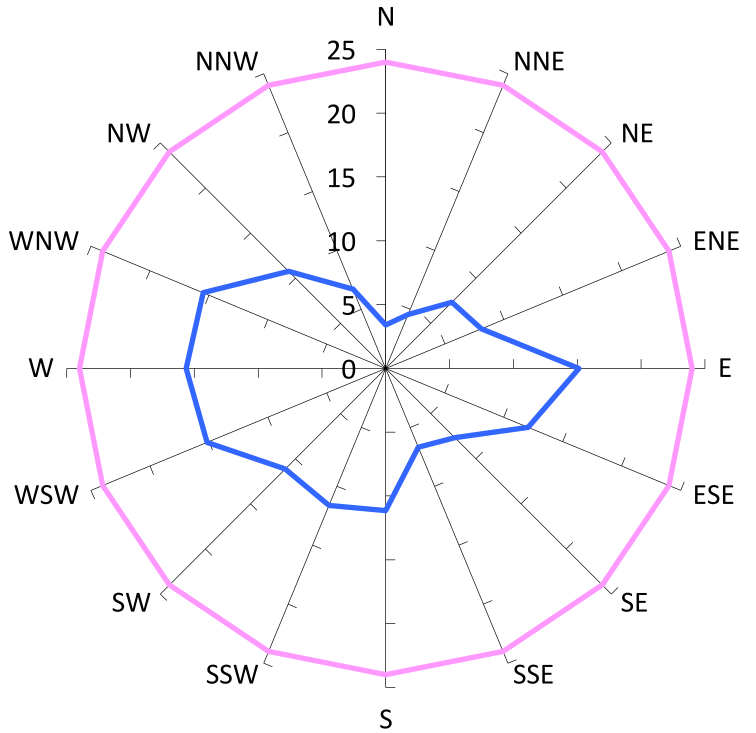
Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.

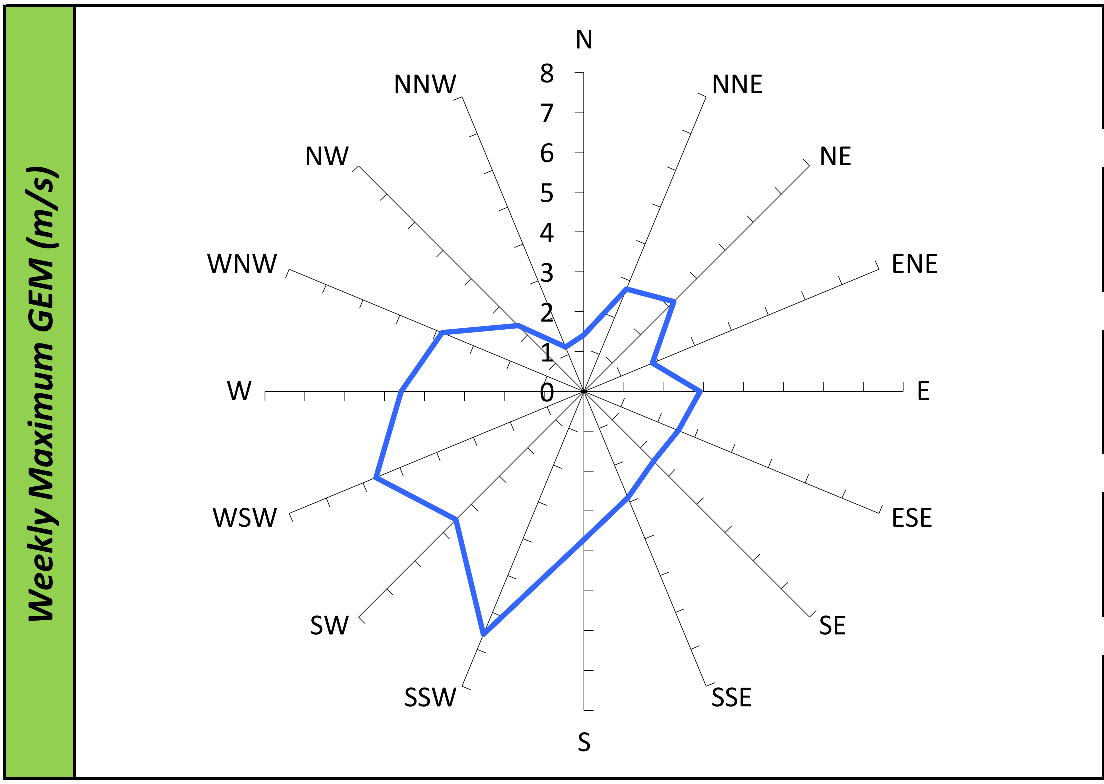
With the Waterloo Metro development as proposed. No vegetation or other treatments.

Annual Maximum Gust (m/s)



Desired Criterion
24m/s

Measured Wind Speeds at P23



Desired Criterion
8m/s

Prob. of Criterion Exceedence (existing site conditions)
N/A

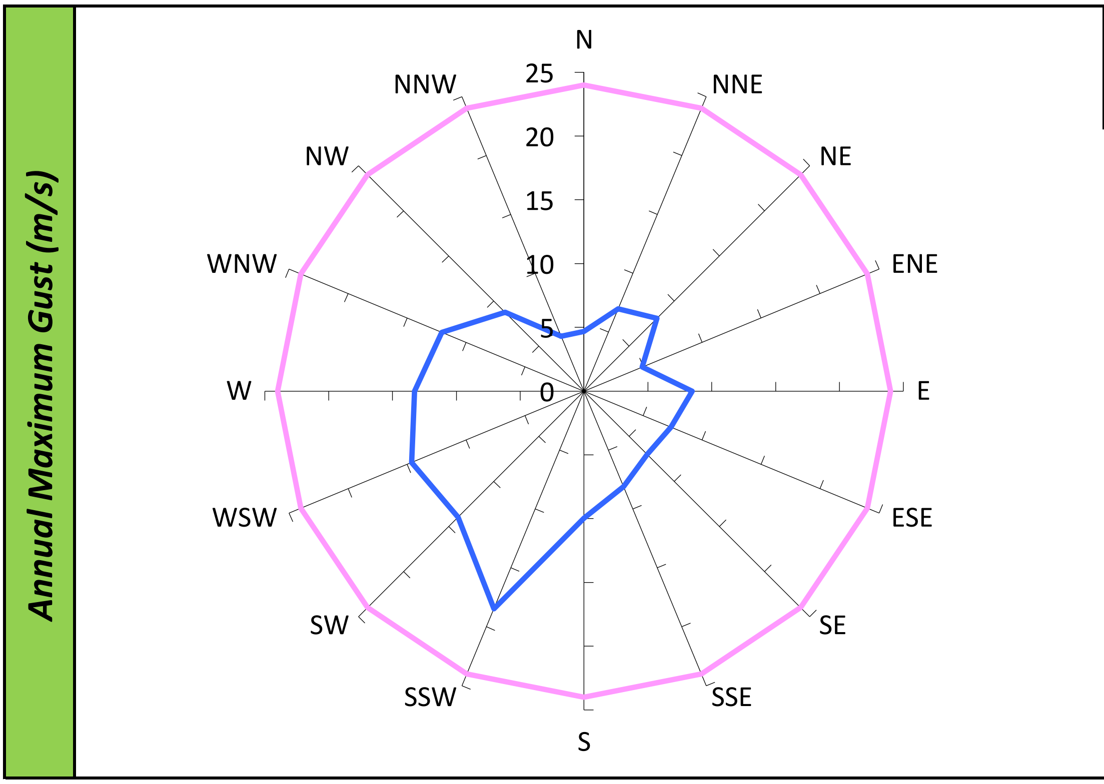
Probability of Criterion Exceedence (initial test)
1%

Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

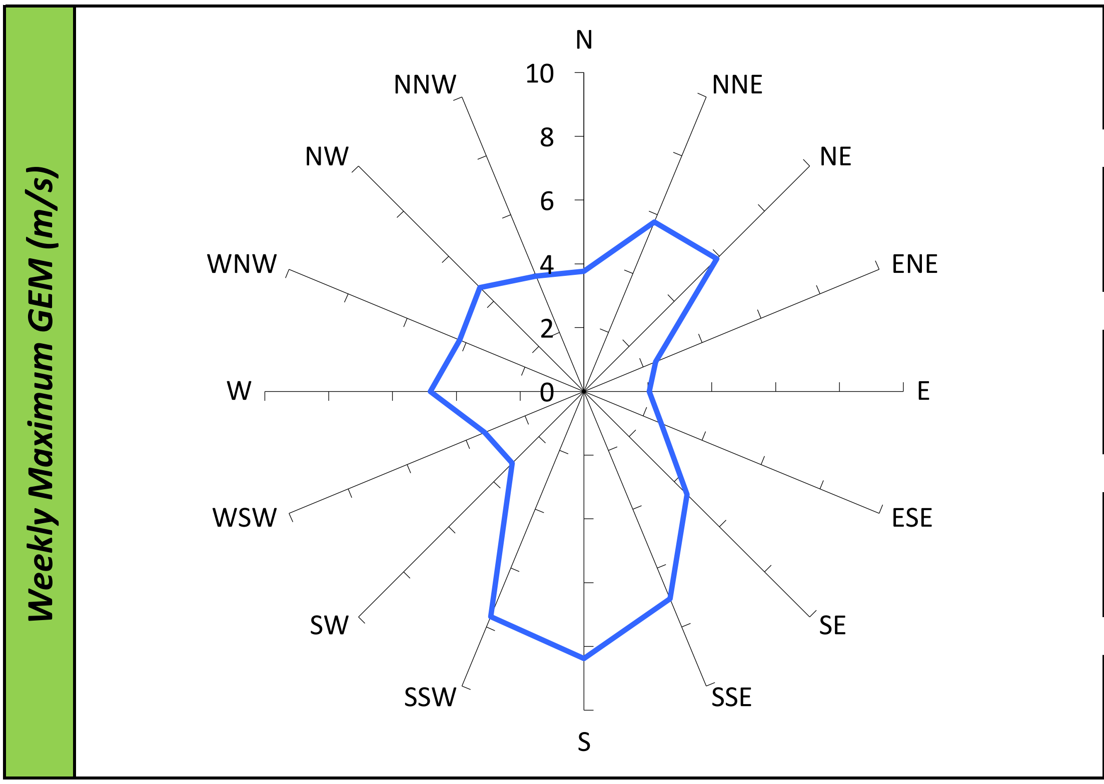
Criterion.

With the Waterloo Metro development as proposed. No vegetation or other treatments.



Desired Criterion
24m/s

Measured Wind Speeds at P24



Desired Criterion
8m/s

Prob. of Criterion Exceedence (existing site conditions)
N/A

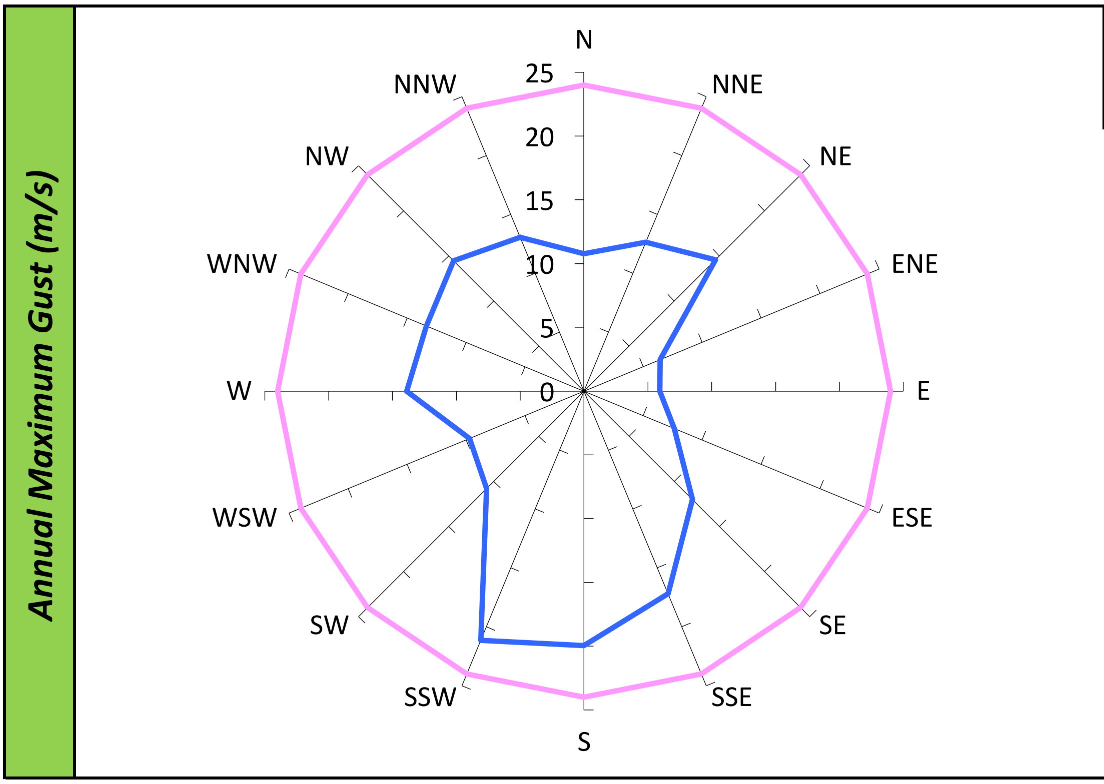
Probability of Criterion Exceedence (initial test)
3%

Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.

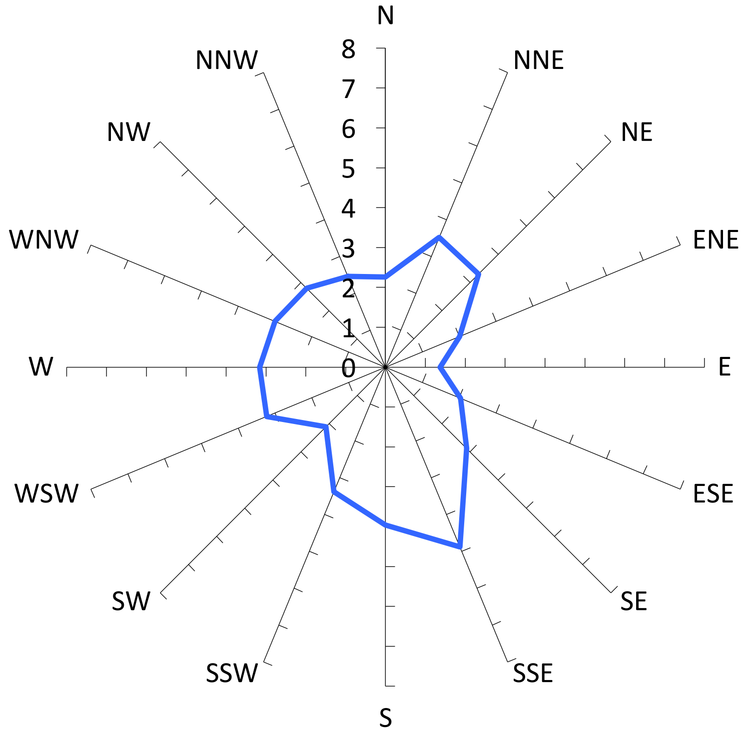
With the Waterloo Metro development as proposed. No vegetation or other treatments.



Desired Criterion
24m/s

Measured Wind Speeds at P25

Weekly Maximum GEM (m/s)



Desired Criterion
8m/s

Prob. of Criterion Exceedence (existing site conditions)
N/A

Probability of Criterion Exceedence (initial test)
0%

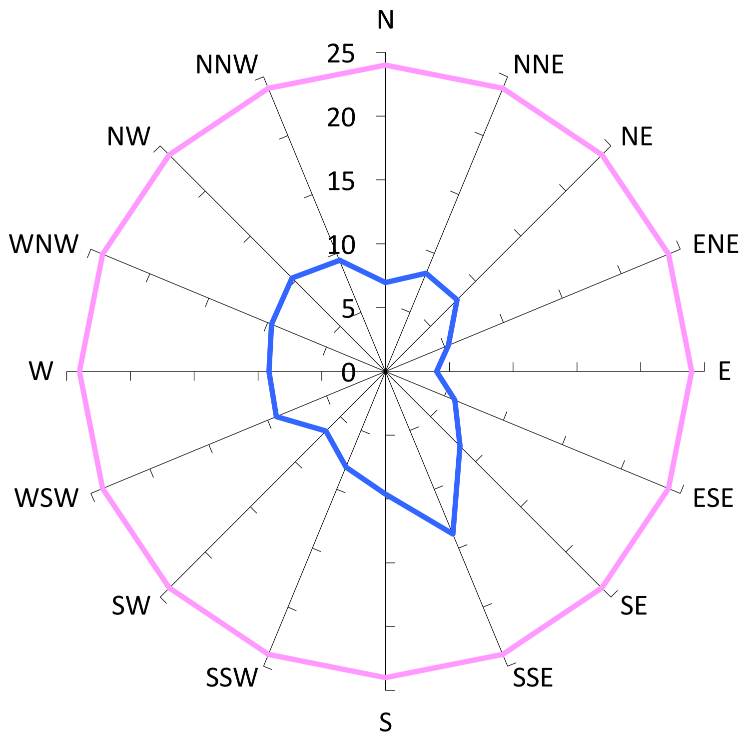
Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.

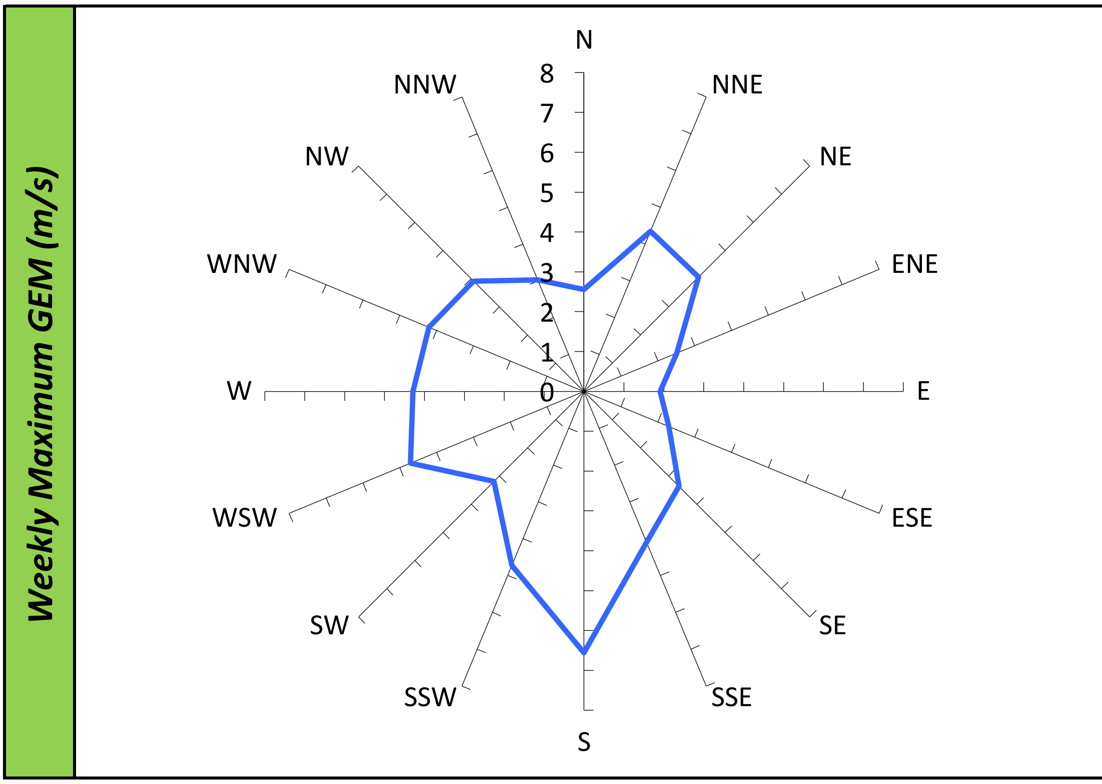
With the Waterloo Metro development as proposed. No vegetation or other treatments.

Annual Maximum Gust (m/s)



Desired Criterion
24m/s

Measured Wind Speeds at P26



Desired Criterion
8m/s

Prob. of Criterion Exceedence (existing site conditions)
N/A

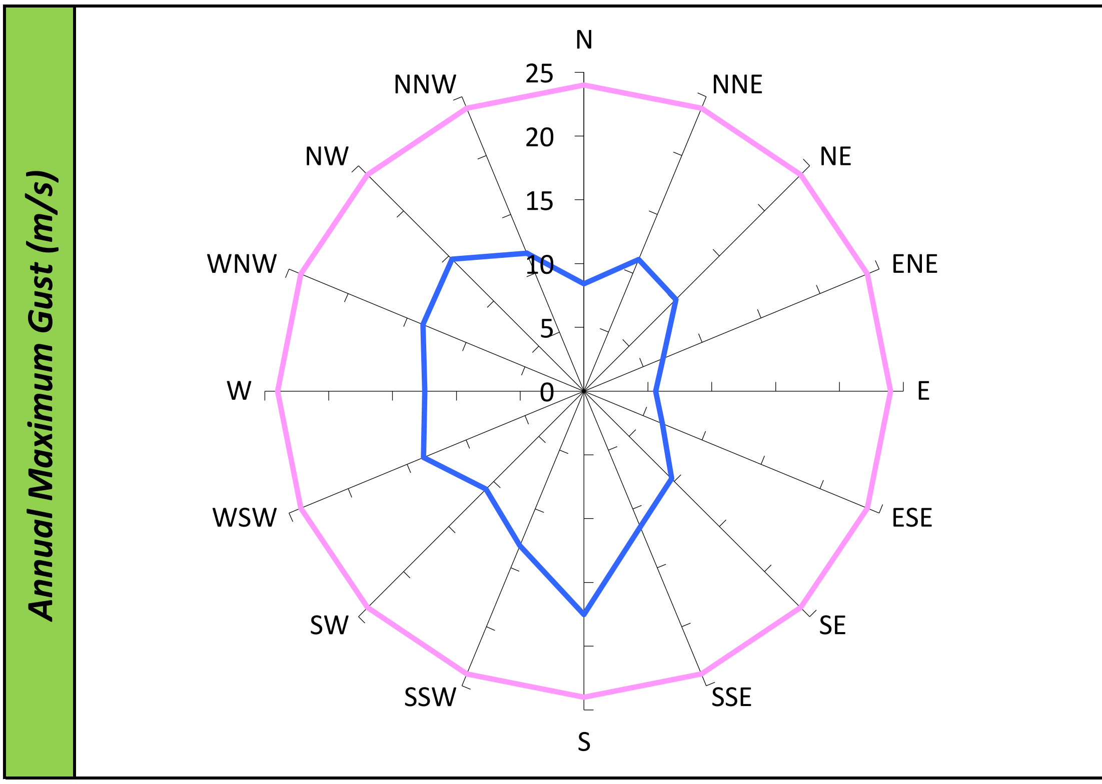
Probability of Criterion Exceedence (initial test)
0%

Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.

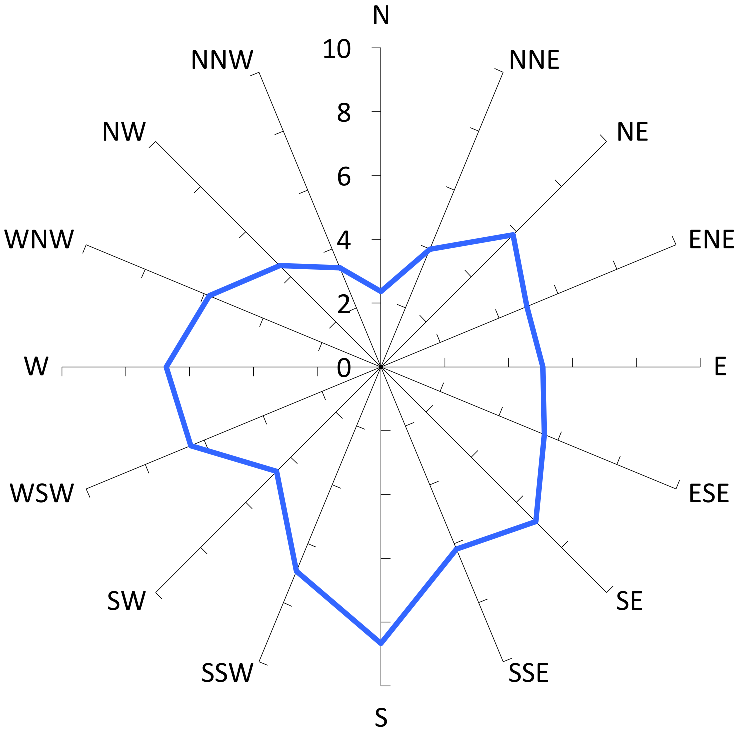
With the Waterloo Metro development as proposed. No vegetation or other treatments.



Desired Criterion
24m/s

Measured Wind Speeds at P27

Weekly Maximum GEM (m/s)



Desired Criterion
6m/s

Prob. of Criterion Exceedence (existing site conditions)
N/A

Probability of Criterion Exceedence (initial test)
21%

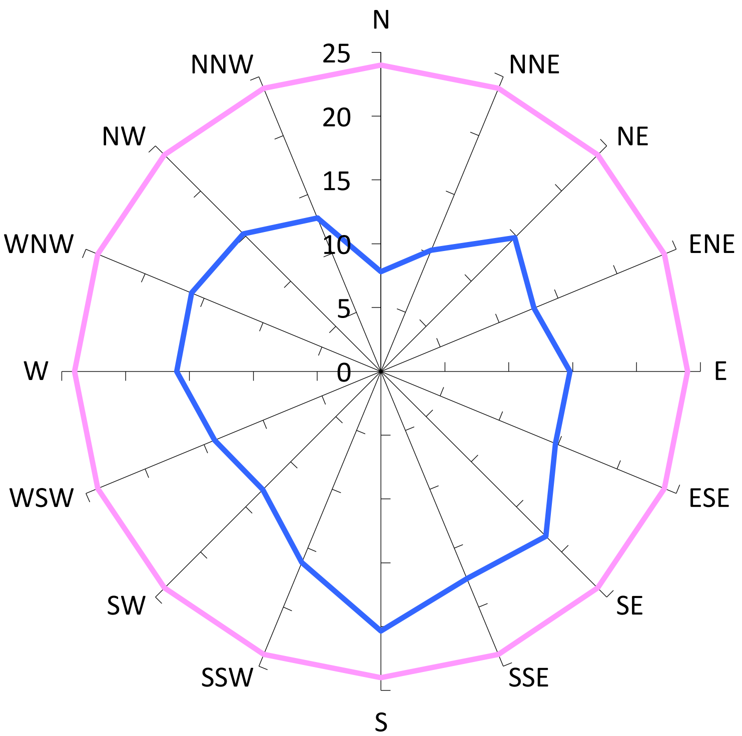
Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.

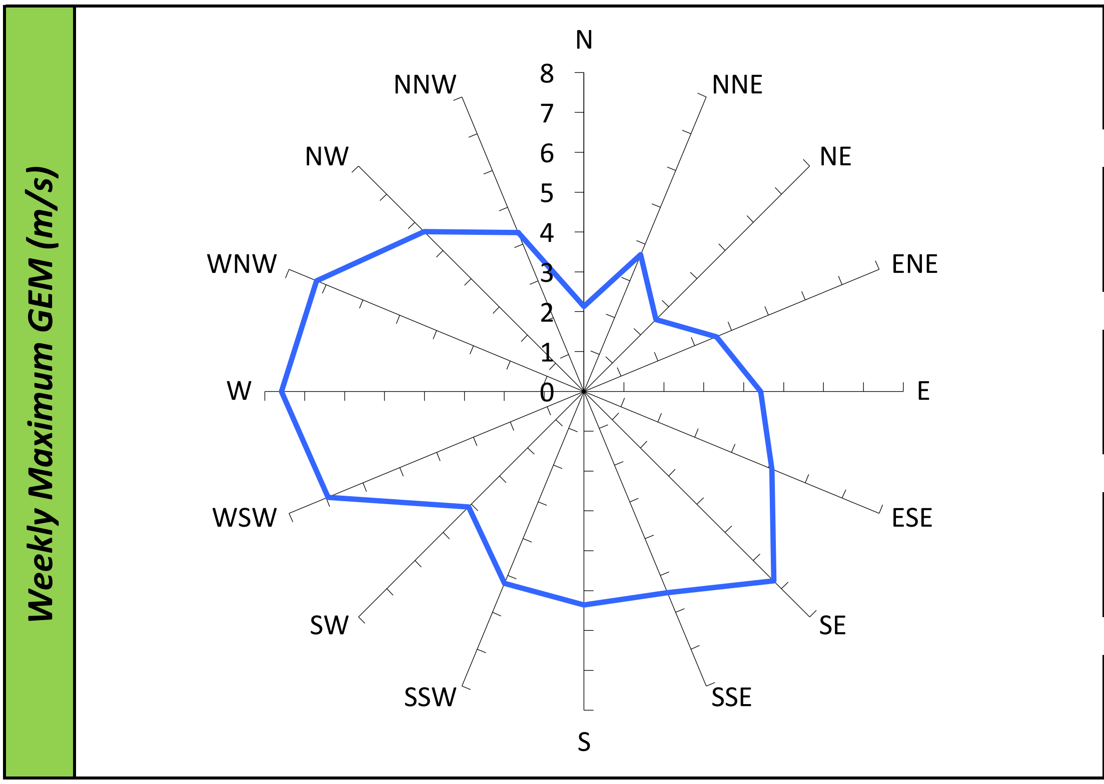
With the Waterloo Metro development as proposed. No vegetation or other treatments.

Annual Maximum Gust (m/s)



Desired Criterion
24m/s

Measured Wind Speeds at P28



Desired Criterion
6m/s

Prob. of Criterion Exceedence (existing site conditions)
N/A

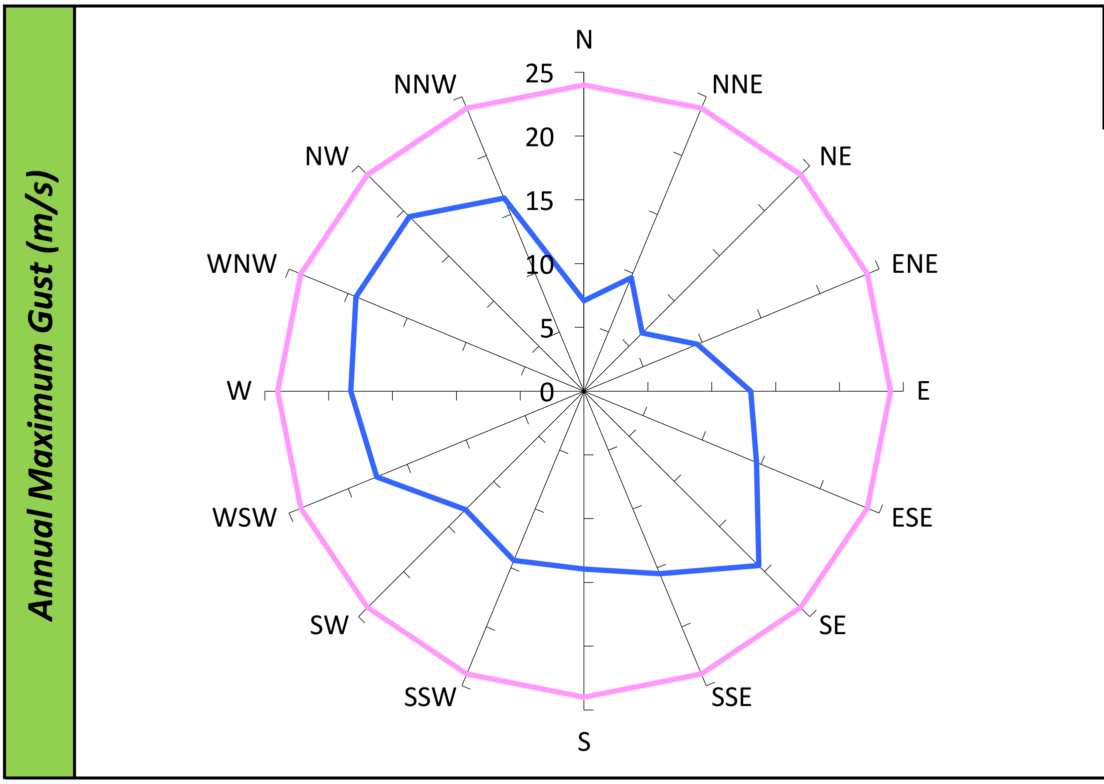
Probability of Criterion Exceedence (initial test)
14%

Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.

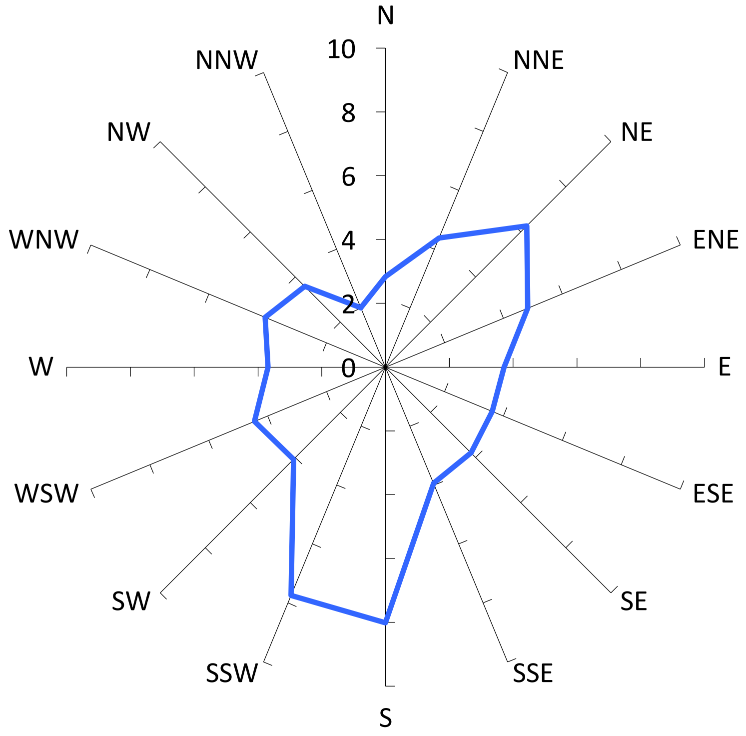
With the Waterloo Metro development as proposed. No vegetation or other treatments.



Desired Criterion
24m/s

Measured Wind Speeds at P29

Weekly Maximum GEM (m/s)



Desired Criterion
6m/s

Prob. of Criterion Exceedence (existing site conditions)
N/A

Probability of Criterion Exceedence (initial test)
13%

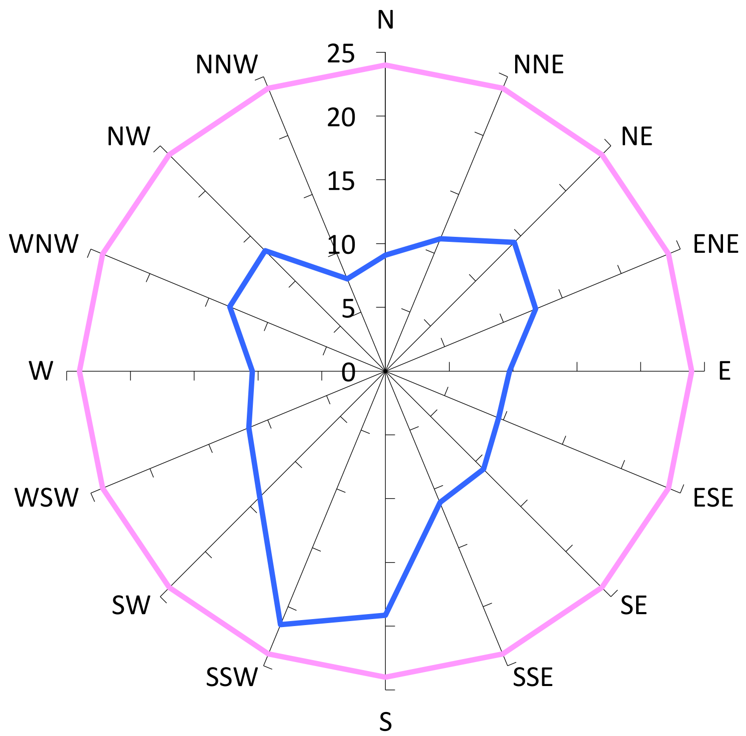
Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.

With the Waterloo Metro development as proposed. No vegetation or other treatments.

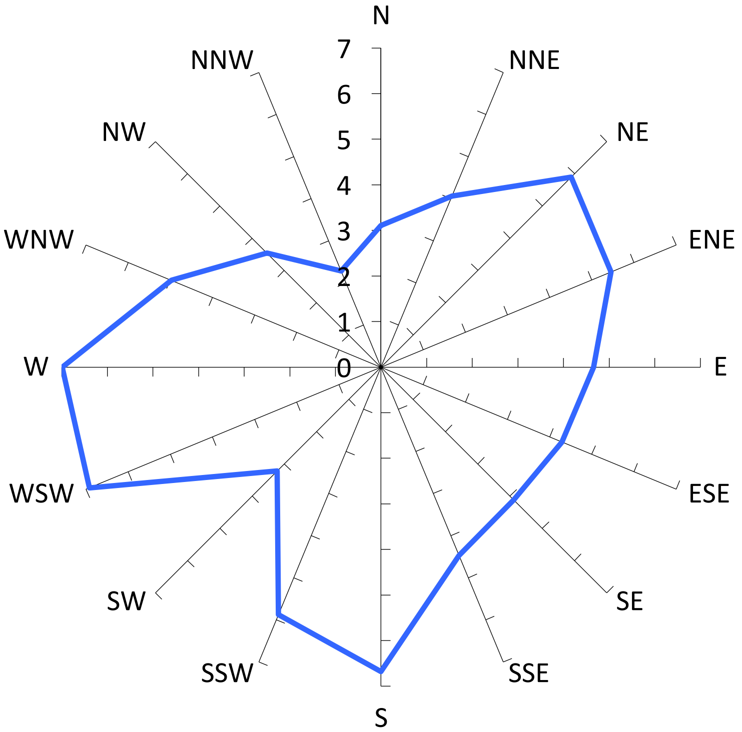
Annual Maximum Gust (m/s)



Desired Criterion
24m/s

Measured Wind Speeds at P30

Weekly Maximum GEM (m/s)



Desired Criterion
6m/s

Prob. of Criterion Exceedence (existing site conditions)
N/A

Probability of Criterion Exceedence (initial test)
10%

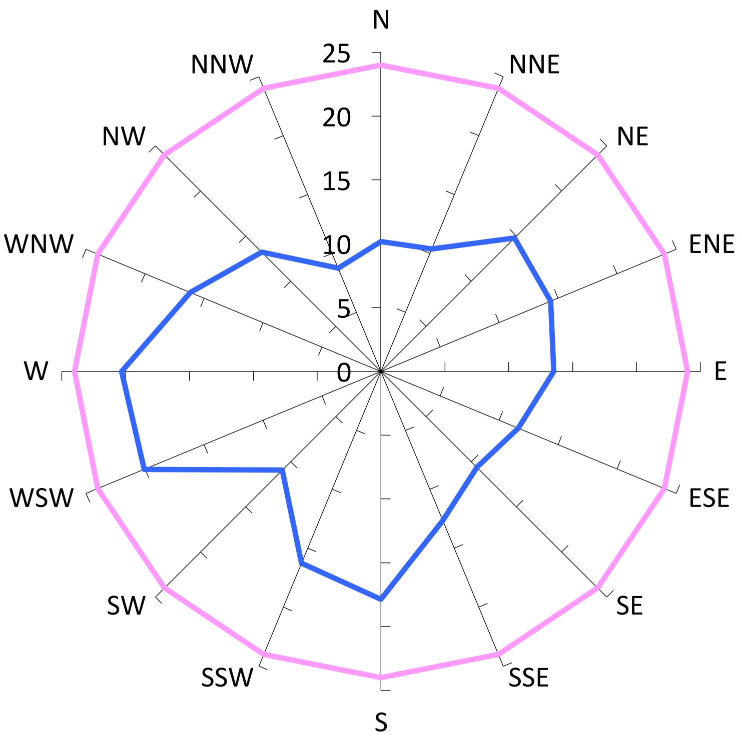
Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.

With the Waterloo Metro development as proposed. No vegetation or other treatments.

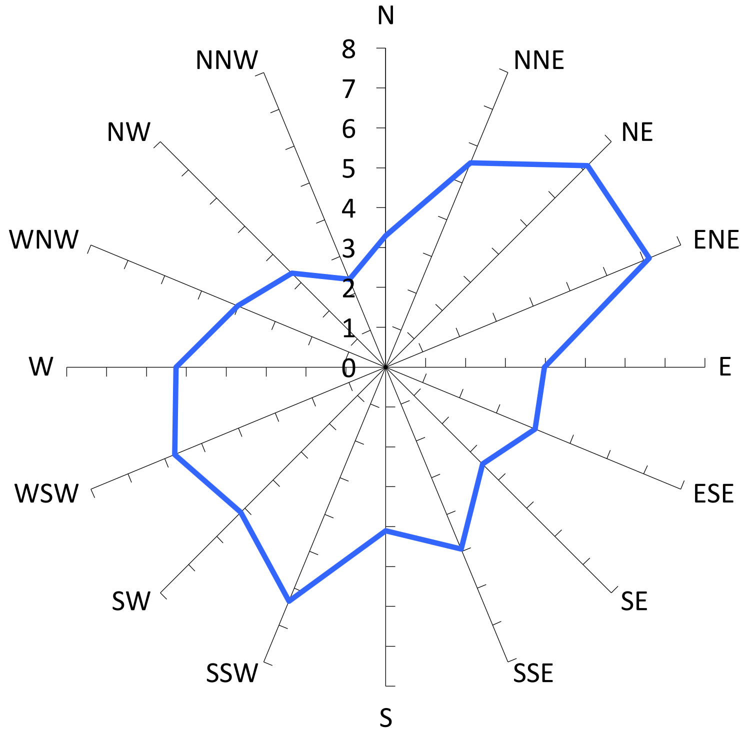
Annual Maximum Gust (m/s)



Desired Criterion
24m/s

Measured Wind Speeds at P31

Weekly Maximum GEM (m/s)



Desired Criterion
6m/s

Prob. of Criterion Exceedence (existing site conditions)
N/A

Probability of Criterion Exceedence (initial test)
12%

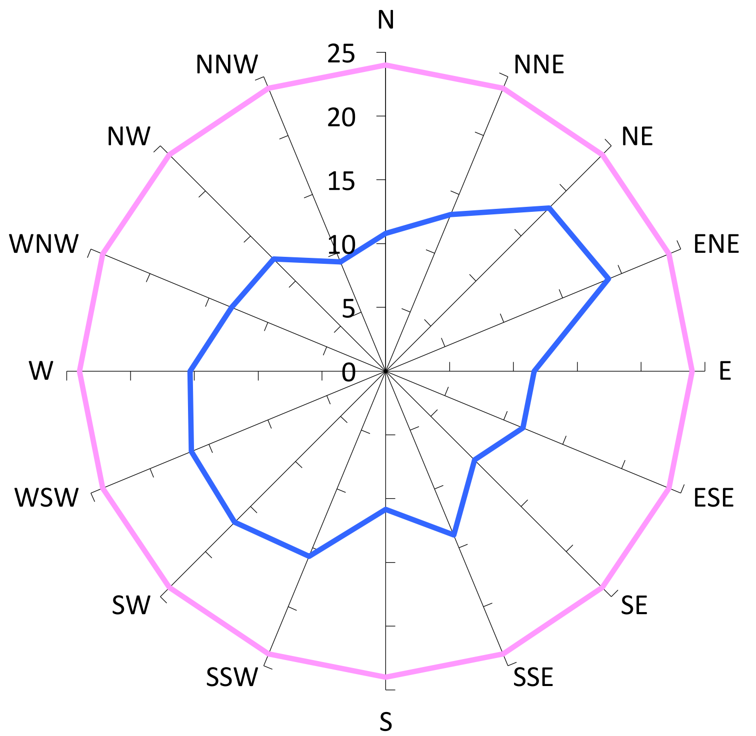
Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.

With the Waterloo Metro development as proposed. No vegetation or other treatments.

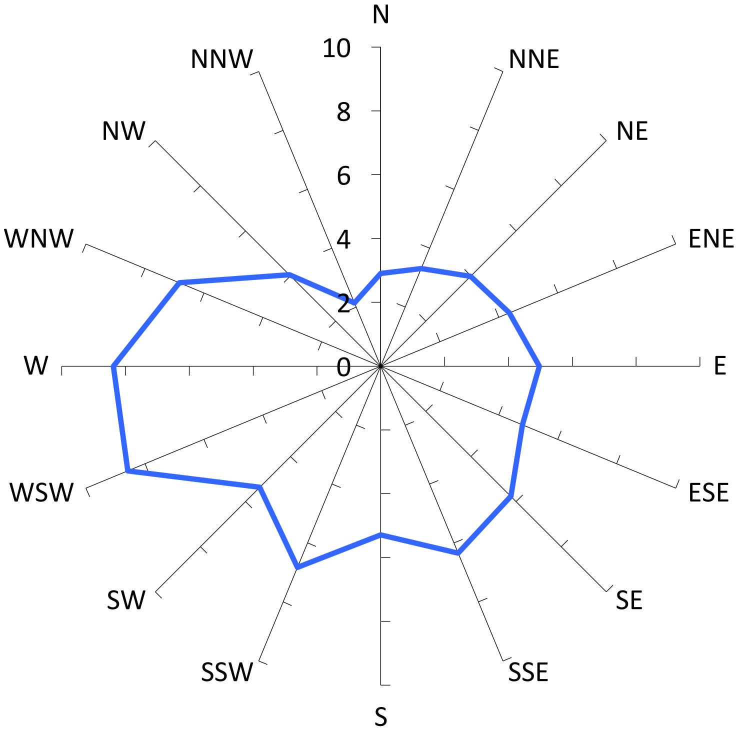
Annual Maximum Gust (m/s)



Desired Criterion
24m/s

Measured Wind Speeds at P32

Weekly Maximum GEM (m/s)



Desired Criterion
6m/s

Prob. of Criterion Exceedence (existing site conditions)
N/A

Probability of Criterion Exceedence (initial test)
18%

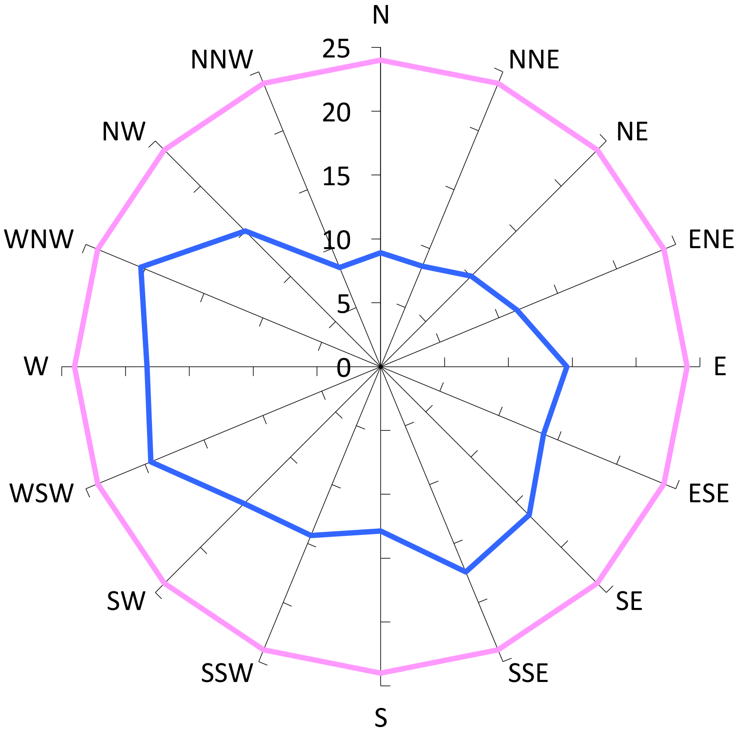
Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.

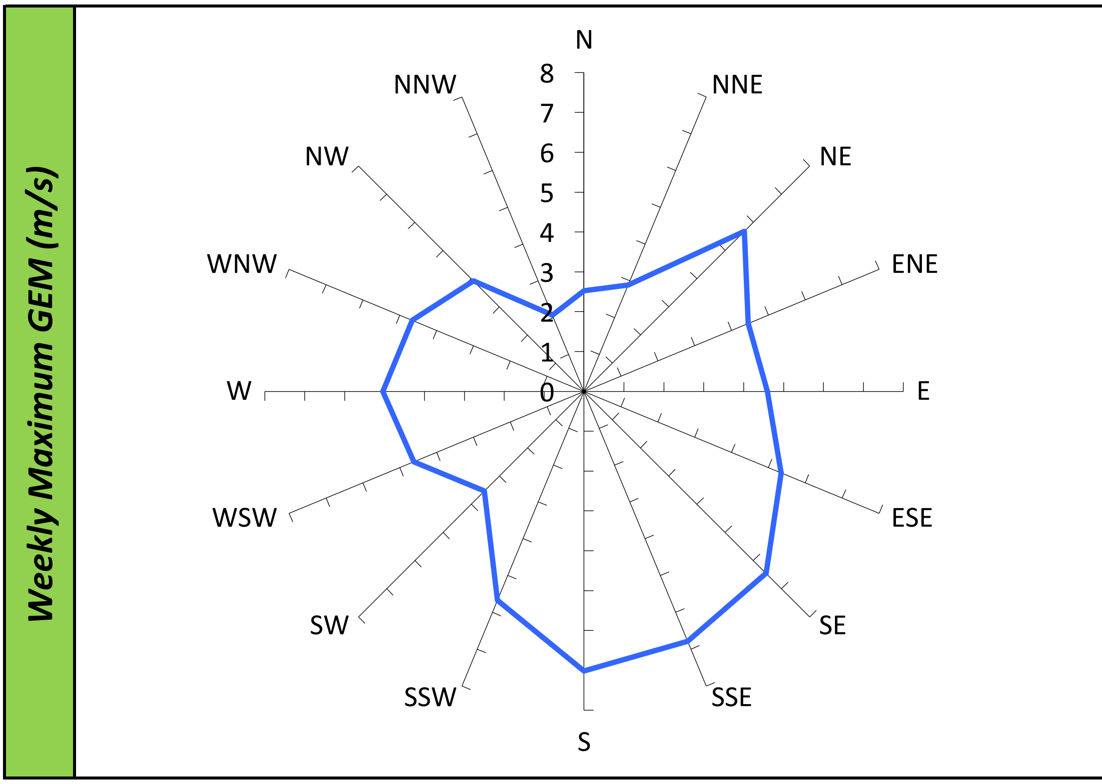
With the Waterloo Metro development as proposed. No vegetation or other treatments.

Annual Maximum Gust (m/s)



Desired Criterion
24m/s

Measured Wind Speeds at P33



Desired Criterion
6m/s

Prob. of Criterion Exceedence (existing site conditions)
N/A

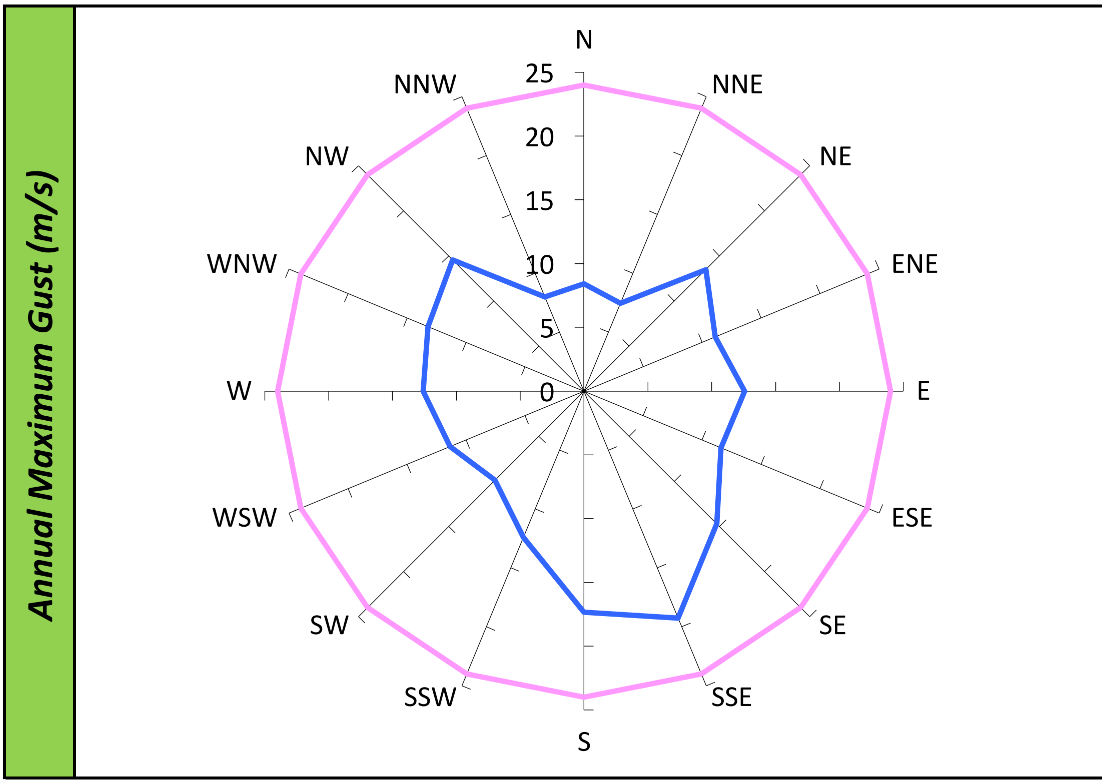
Probability of Criterion Exceedence (initial test)
12%

Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

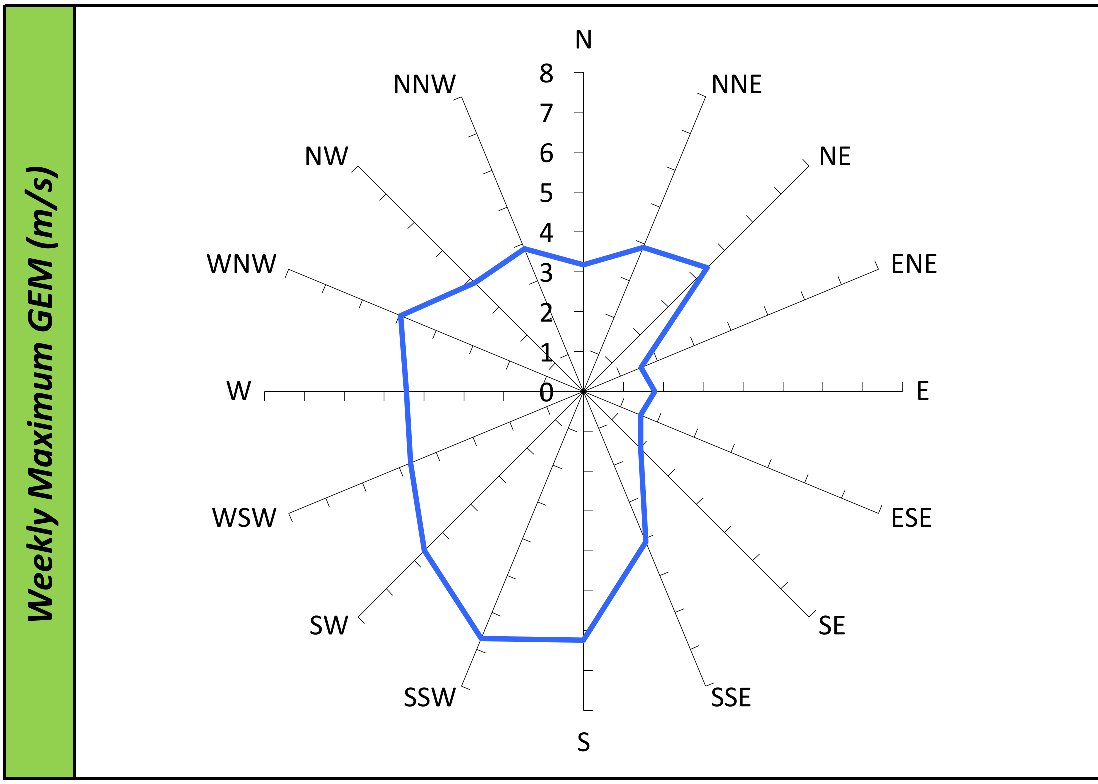
Criterion.

With the Waterloo Metro development as proposed. No vegetation or other treatments.



Desired Criterion
24m/s

Measured Wind Speeds at P34



Desired Criterion
8m/s

Prob. of Criterion Exceedence (existing site conditions)
N/A

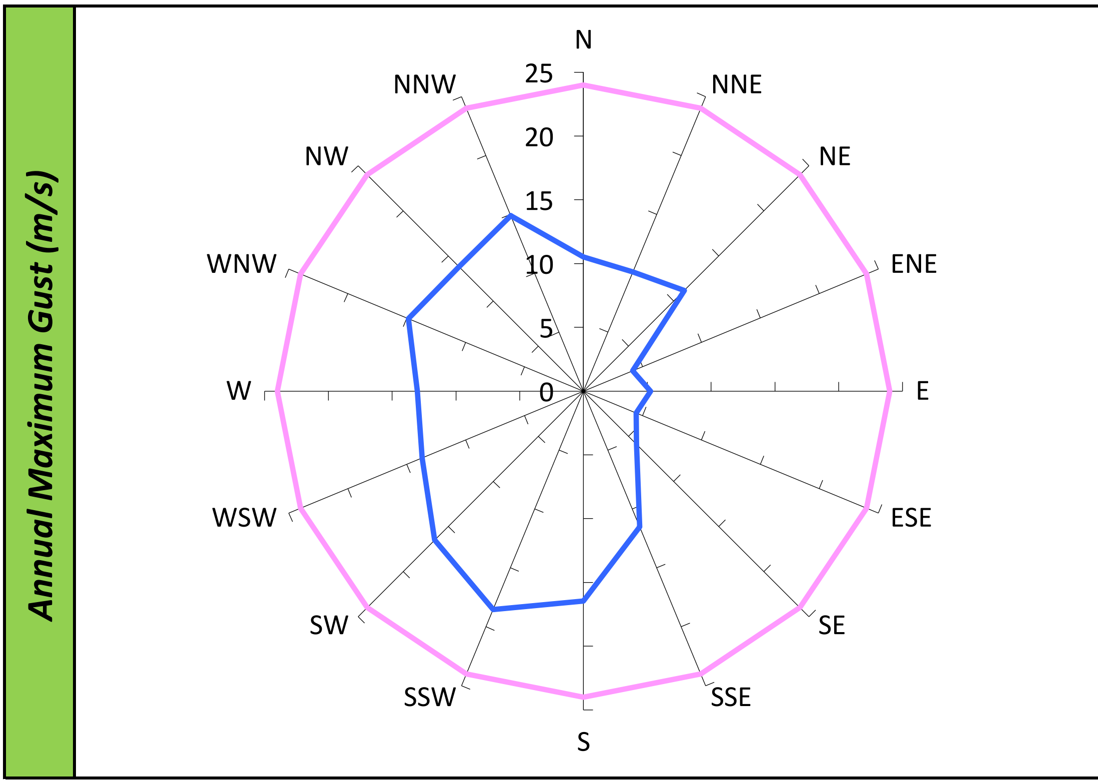
Probability of Criterion Exceedence (initial test)
1%

Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

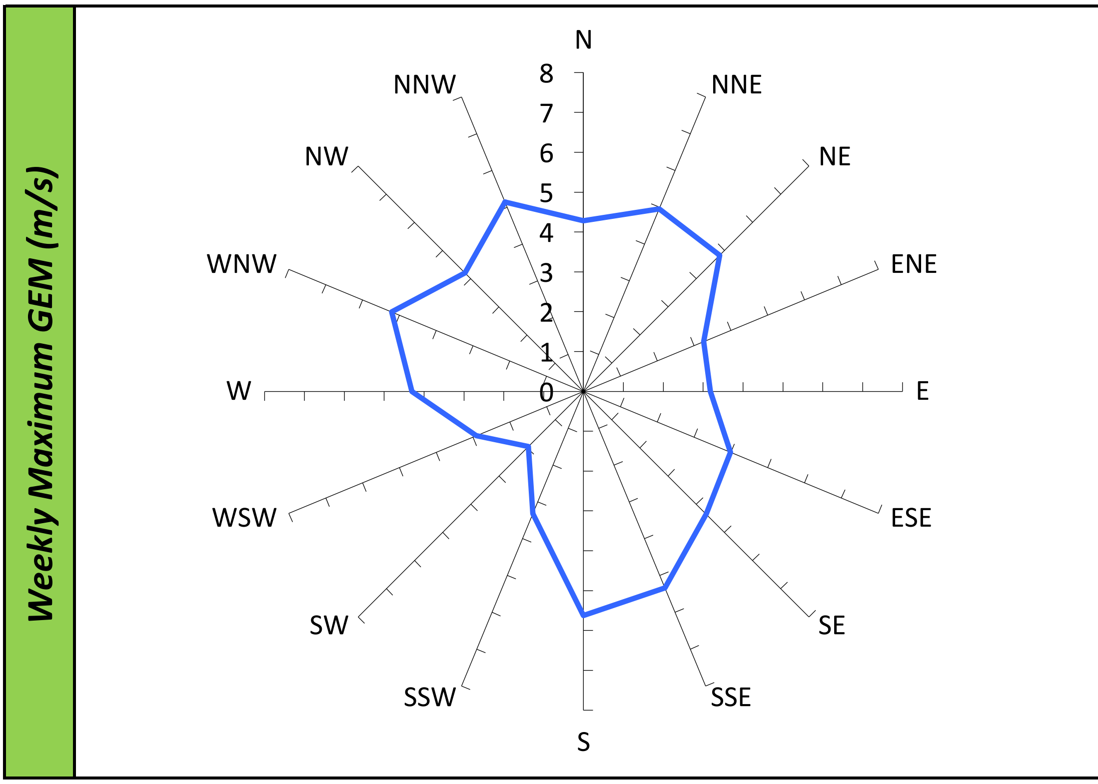
Criterion.

With the Waterloo Metro development as proposed. No vegetation or other treatments.



Desired Criterion
24m/s

Measured Wind Speeds at P35



Desired Criterion
8m/s

Prob. of Criterion Exceedence (existing site conditions)
N/A

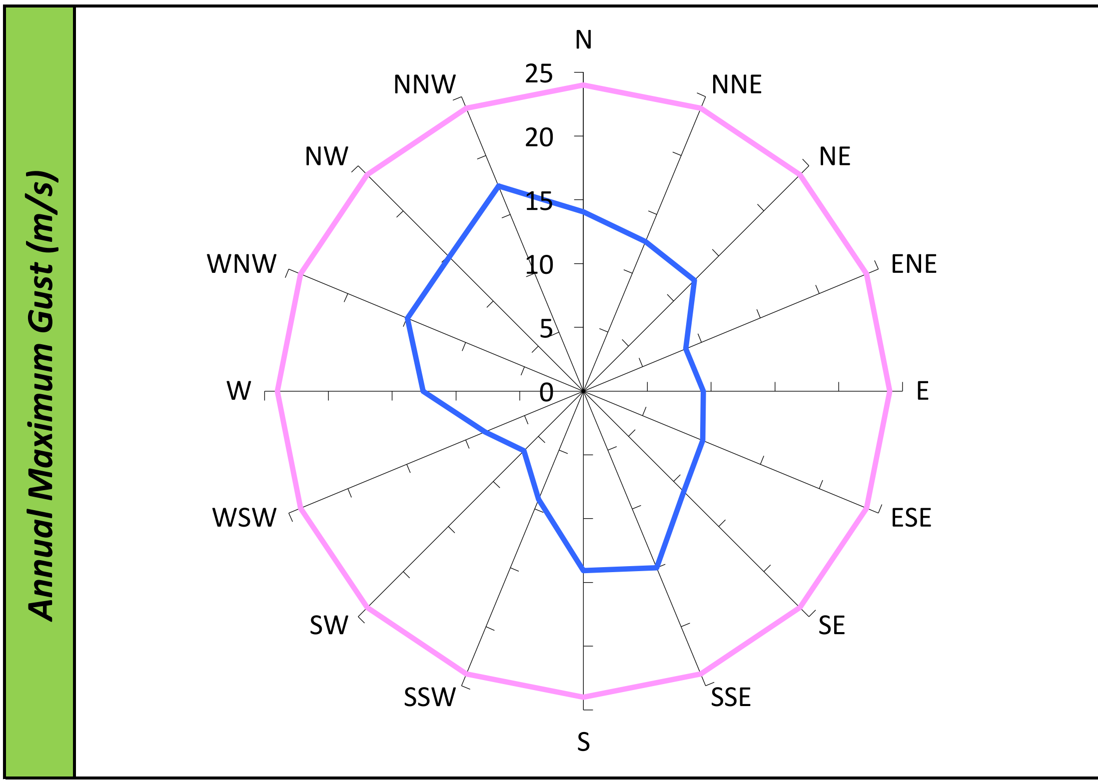
Probability of Criterion Exceedence (initial test)
1%

Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

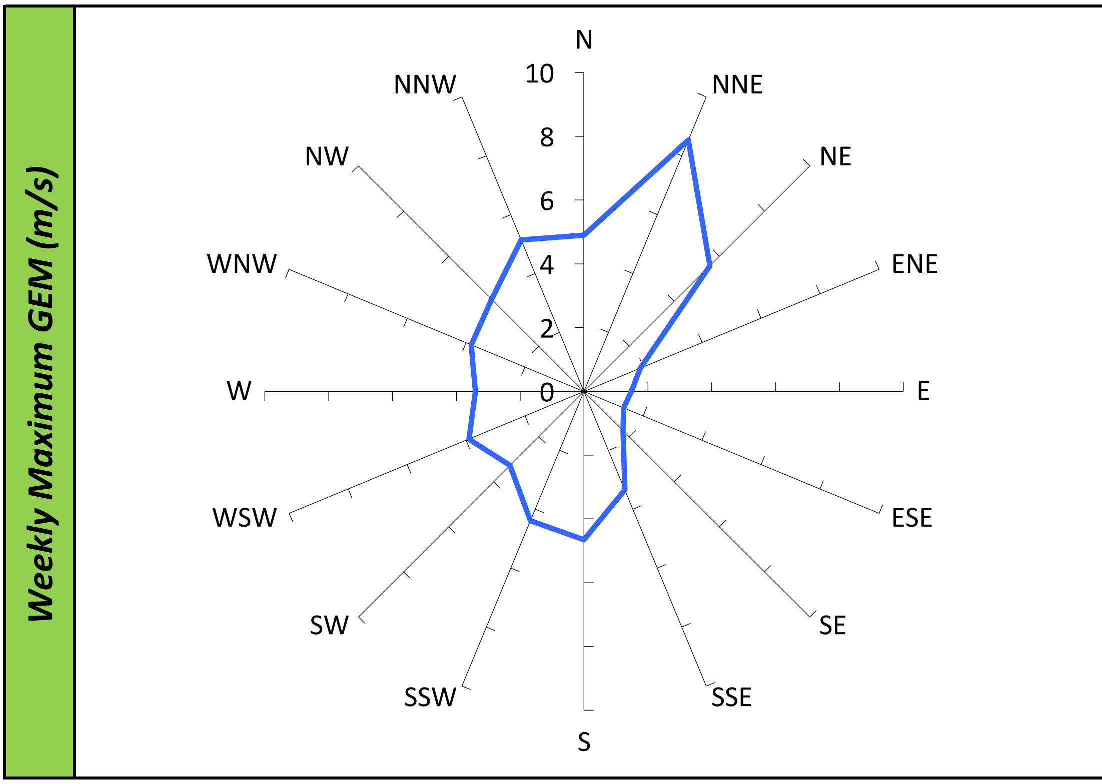
Criterion.

With the Waterloo Metro development as proposed. No vegetation or other treatments.



Desired Criterion
24m/s

Measured Wind Speeds at P36



Desired Criterion
8m/s

Prob. of Criterion Exceedence (existing site conditions)
N/A

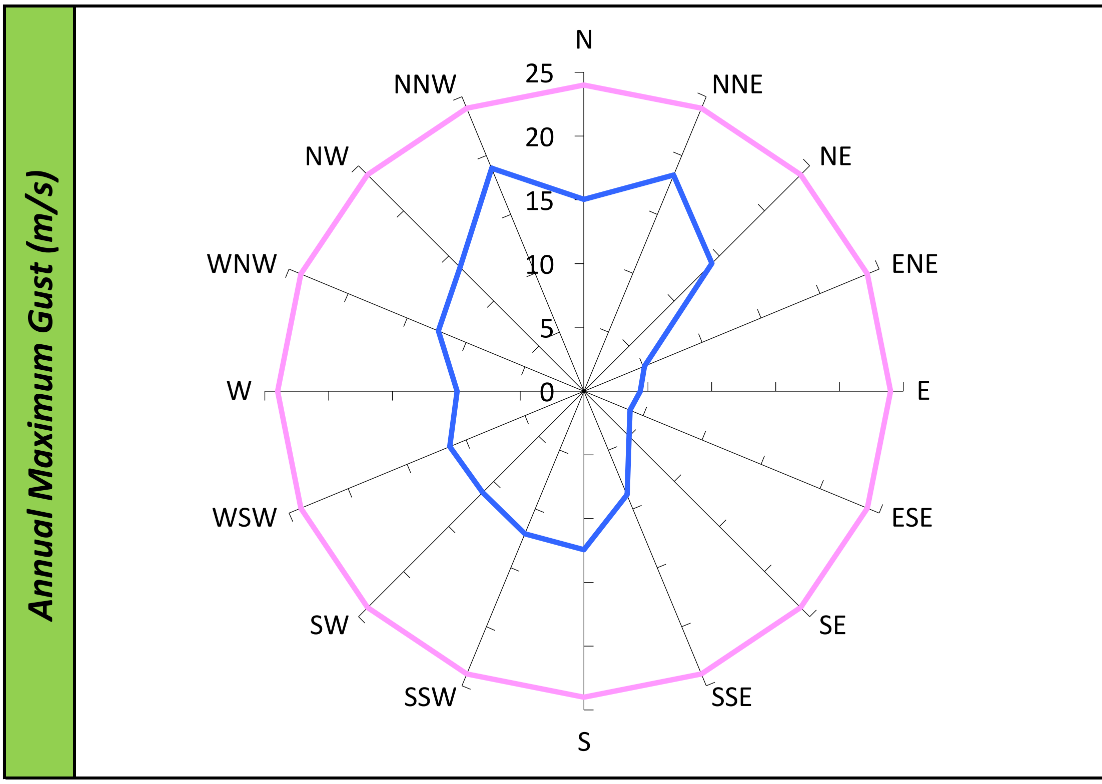
Probability of Criterion Exceedence (initial test)
2%

Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.

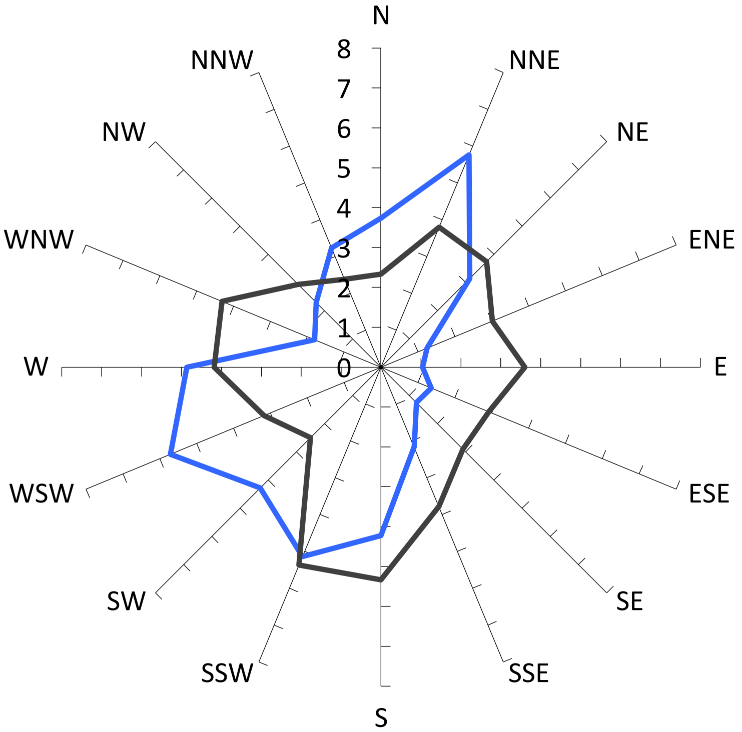
With the Waterloo Metro development as proposed. No vegetation or other treatments.



Desired Criterion
24m/s

Measured Wind Speeds at P71

Weekly Maximum GEM (m/s)



Desired Criterion
8m/s

Prob. of Criterion Exceedence (existing site conditions)
0%

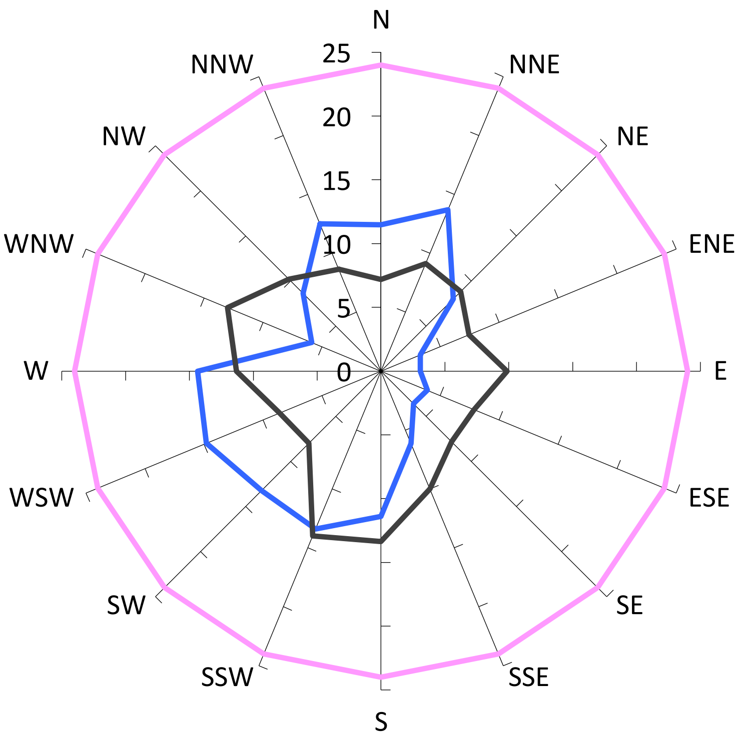
Probability of Criterion Exceedence (initial test)
0%

Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.
With the Waterloo Metro development as proposed. No vegetation or other treatments.
Existing Site Conditions

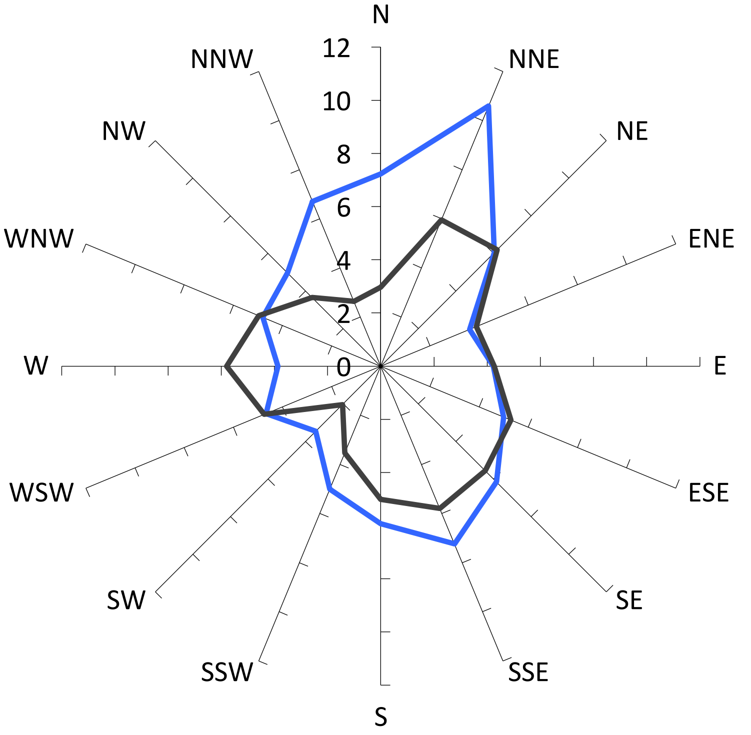
Annual Maximum Gust (m/s)



Desired Criterion
24m/s

Measured Wind Speeds at P72

Weekly Maximum GEM (m/s)



Desired Criterion
8m/s

Prob. of Criterion Exceedence (existing site conditions)
1%

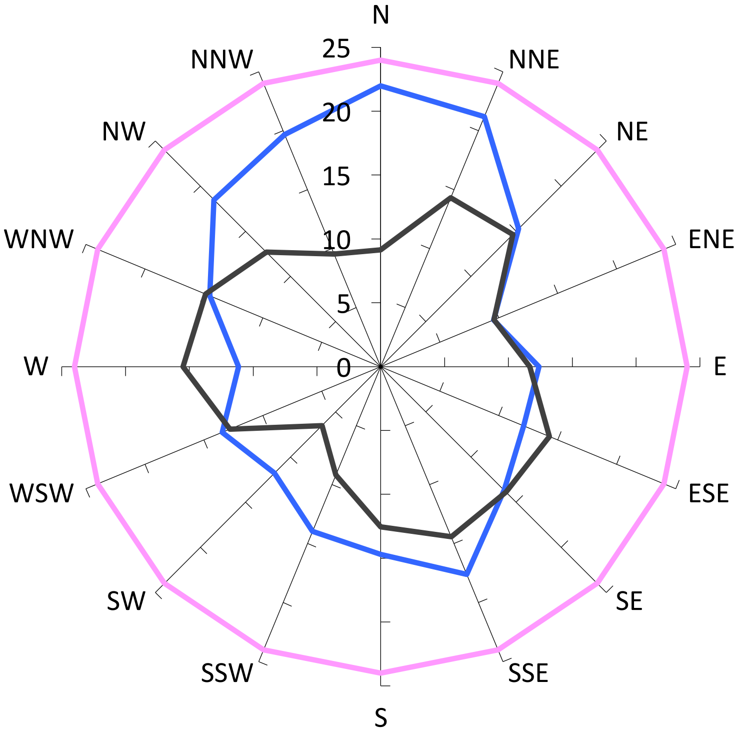
Probability of Criterion Exceedence (initial test)
9%

Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.
With the Waterloo Metro development as proposed. No vegetation or other treatments.
Existing Site Conditions

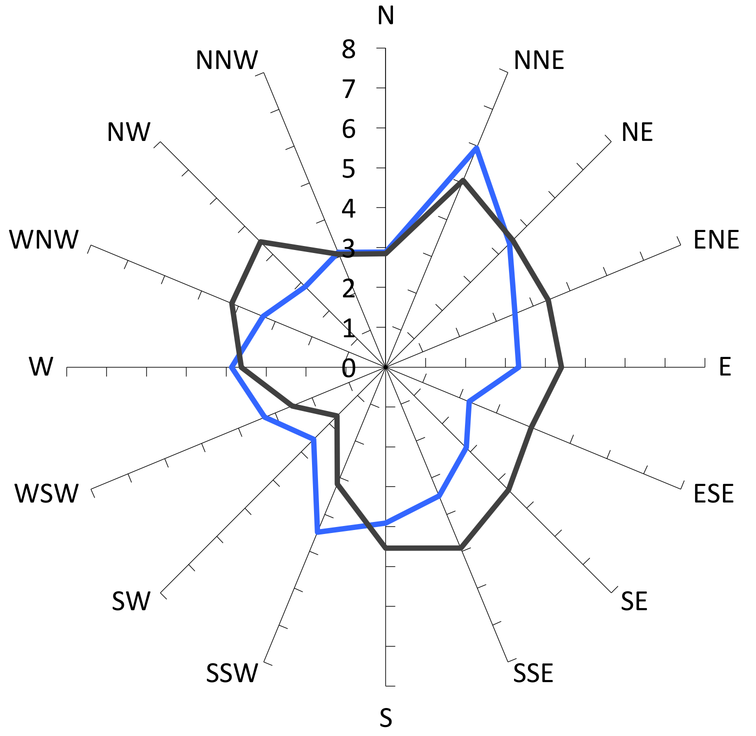
Annual Maximum Gust (m/s)



Desired Criterion
24m/s

Measured Wind Speeds at P73

Weekly Maximum GEM (m/s)



Desired Criterion
8m/s

Prob. of Criterion Exceedence (existing site conditions)
0%

Probability of Criterion Exceedence (initial test)
0%

Probability of Criterion Exceedence (final retest)
N/A

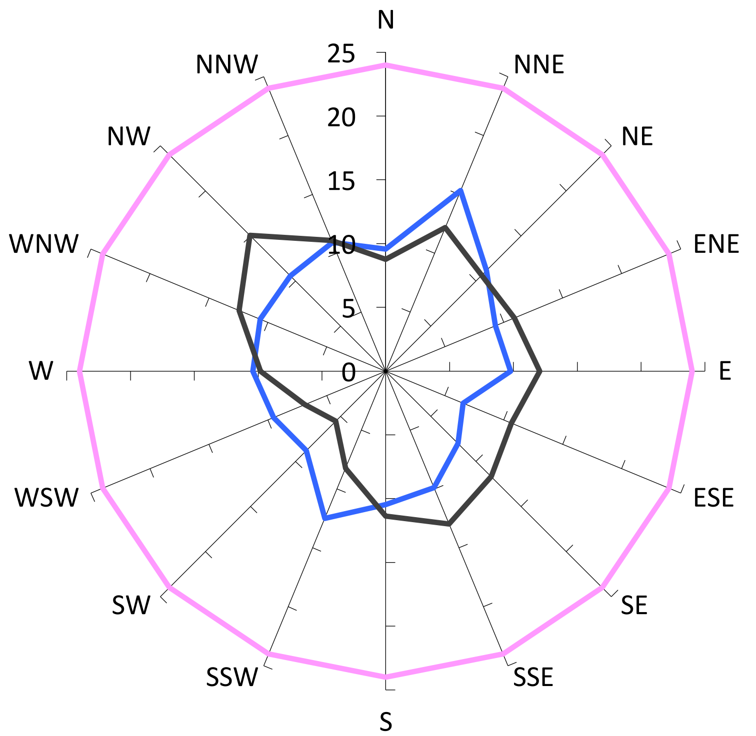
NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.

With the Waterloo Metro development as proposed. No vegetation or other treatments.

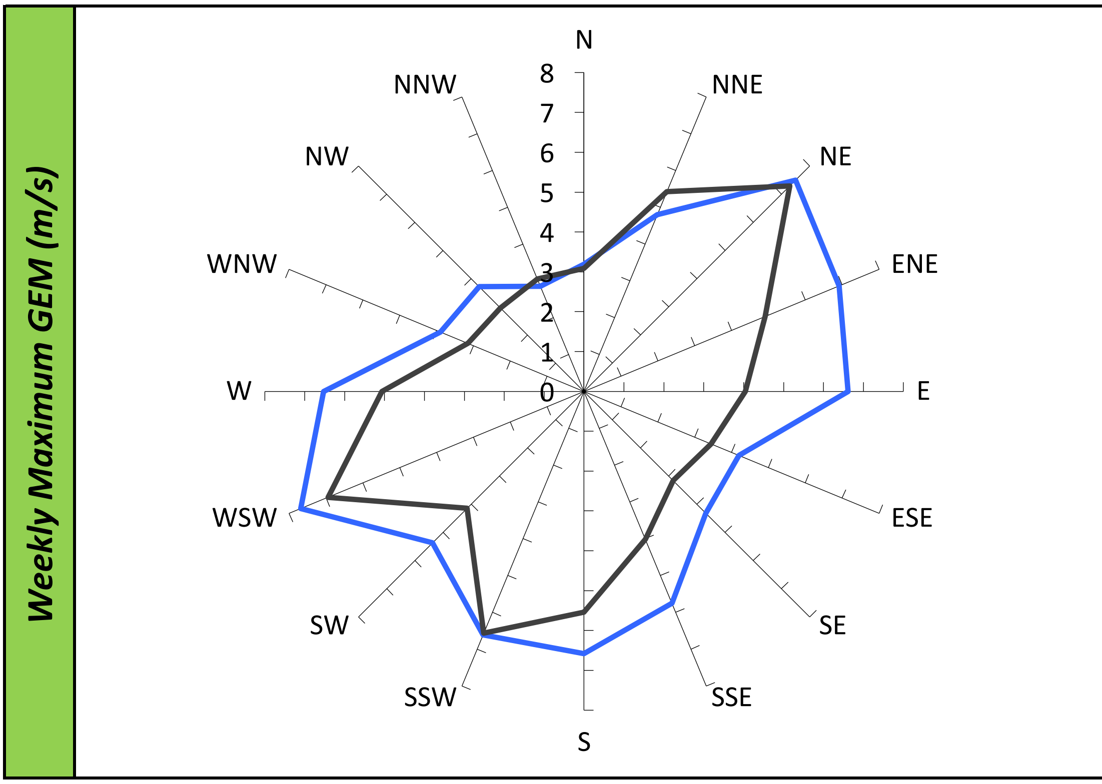
Existing Site Conditions

Annual Maximum Gust (m/s)



Desired Criterion
24m/s

Measured Wind Speeds at P74



Desired Criterion
8m/s

Prob. of Criterion Exceedence (existing site conditions)
1%

Probability of Criterion Exceedence (initial test)
4%

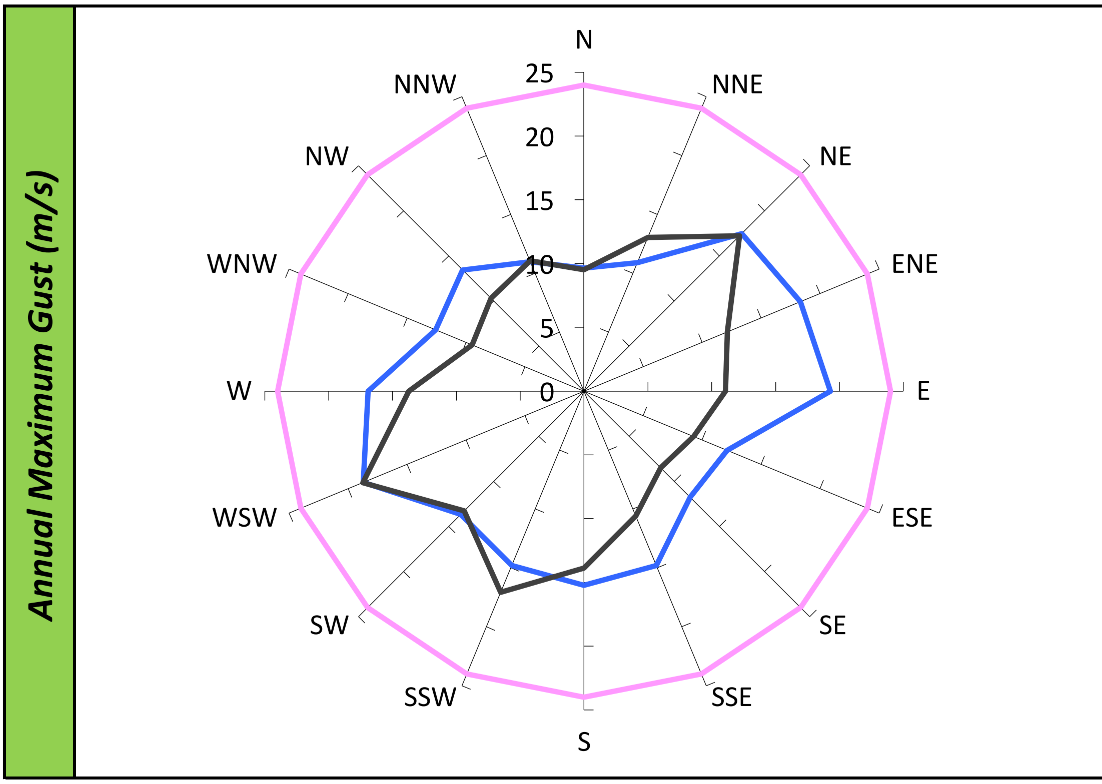
Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.

With the Waterloo Metro development as proposed. No vegetation or other treatments.

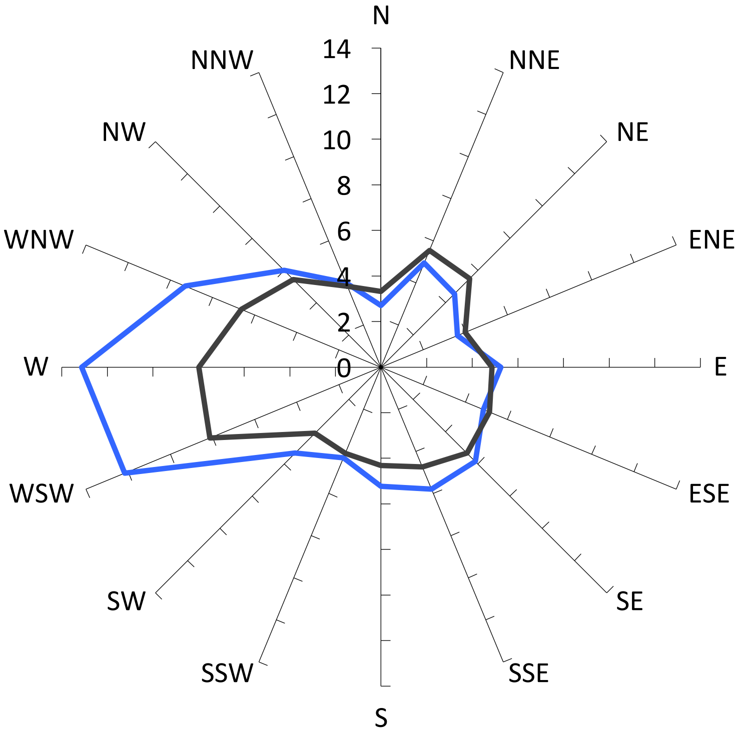
Existing Site Conditions



Desired Criterion
24m/s

Measured Wind Speeds at P75

Weekly Maximum GEM (m/s)



Desired Criterion

8m/s

Prob. of Criterion Exceedence (existing site conditions)

4%

Probability of Criterion Exceedence (initial test)

12%

Probability of Criterion Exceedence (final retest)

N/A

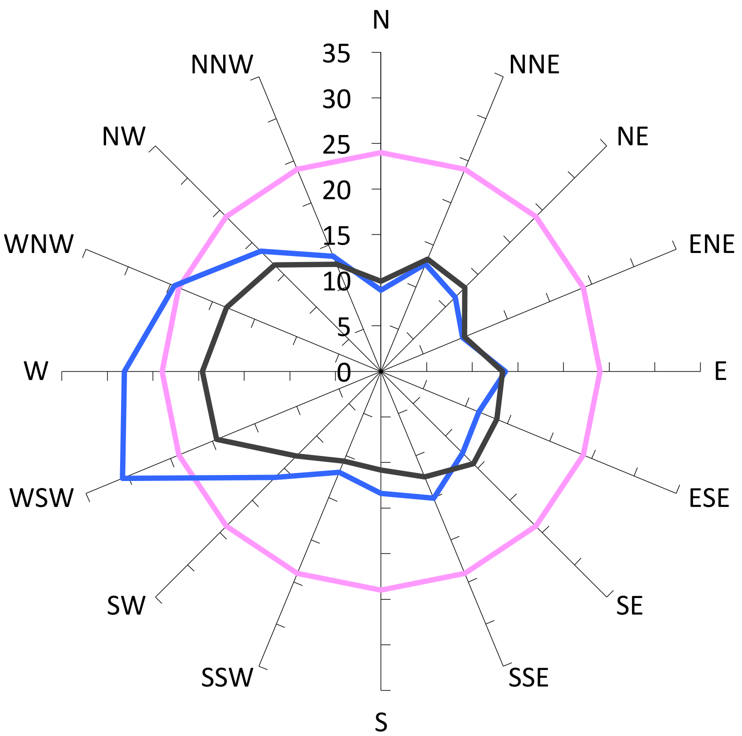
NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.

With the Waterloo Metro development as proposed. No vegetation or other treatments.

Existing Site Conditions

Annual Maximum Gust (m/s)

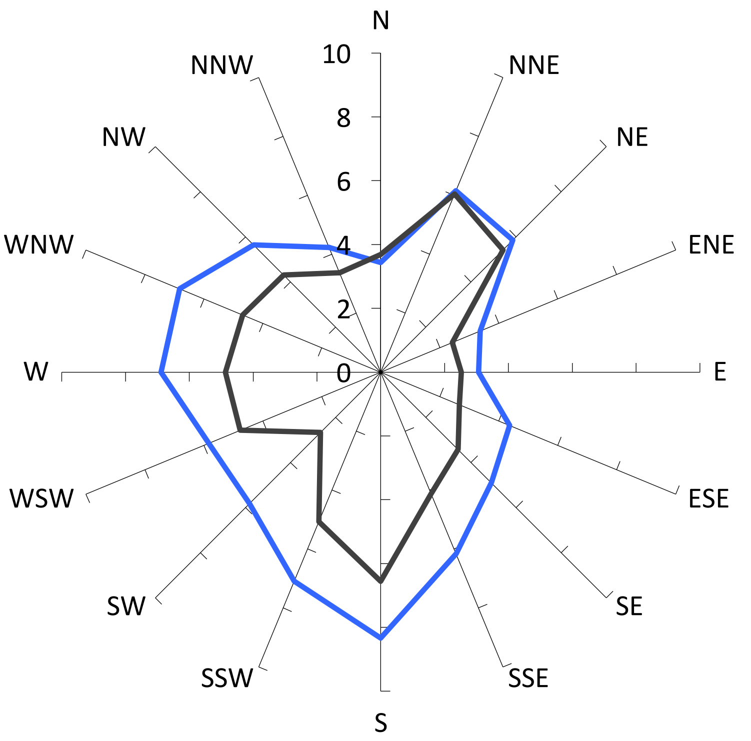


Desired Criterion

24m/s

Measured Wind Speeds at P76

Weekly Maximum GEM (m/s)



Desired Criterion
8m/s

Prob. of Criterion Exceedence (existing site conditions)
1%

Probability of Criterion Exceedence (initial test)
5%

Probability of Criterion Exceedence (final retest)
N/A

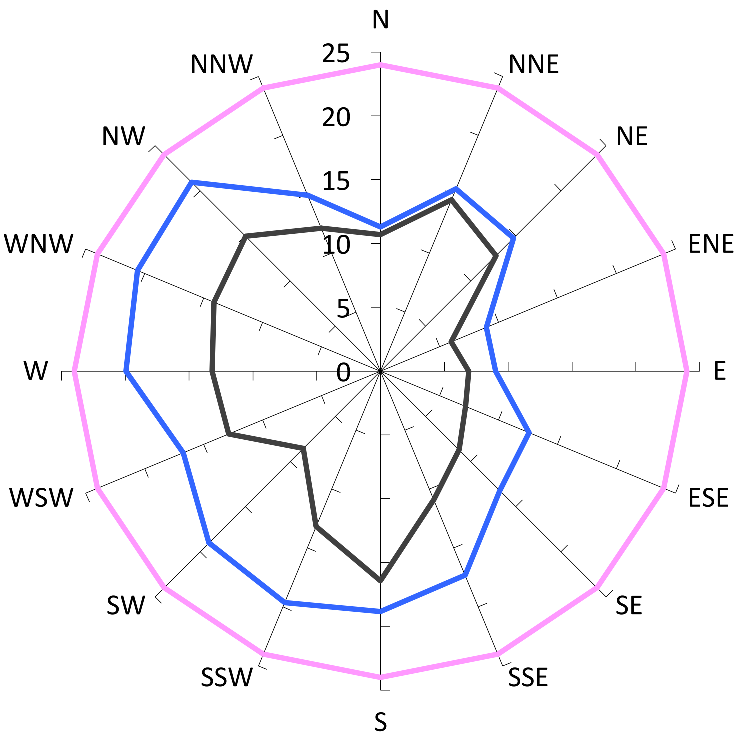
NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.

With the Waterloo Metro development as proposed. No vegetation or other treatments.

Existing Site Conditions

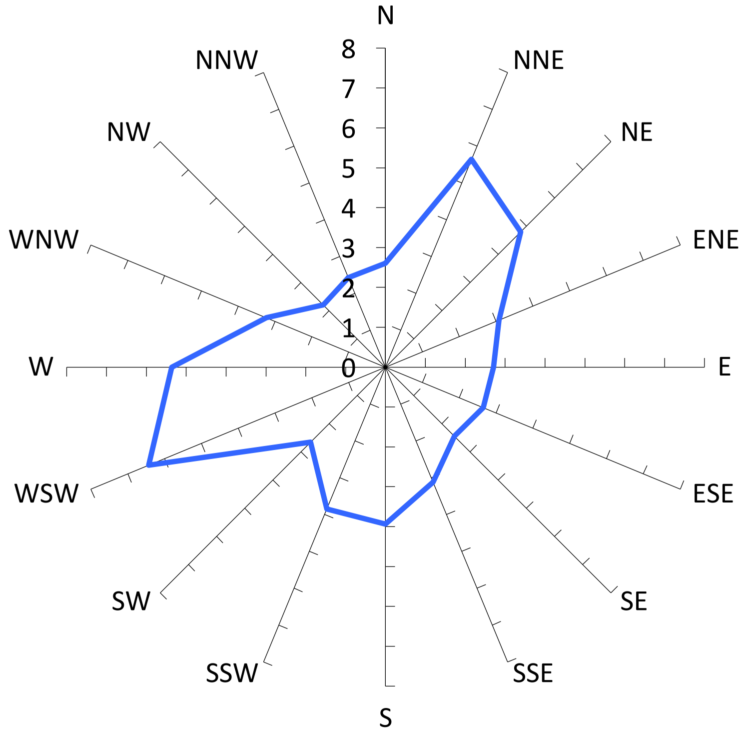
Annual Maximum Gust (m/s)



Desired Criterion
24m/s

Measured Wind Speeds at P100

Weekly Maximum GEM (m/s)



Desired Criterion
8m/s

Prob. of Criterion Exceedence (existing site conditions)
N/A

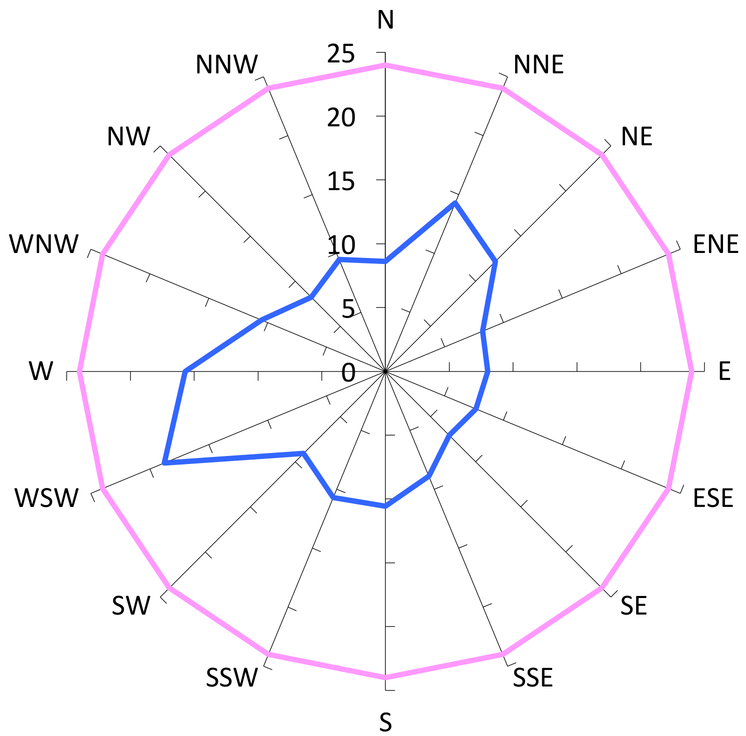
Probability of Criterion Exceedence (initial test)
0%

Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.
Surrounding Points Point

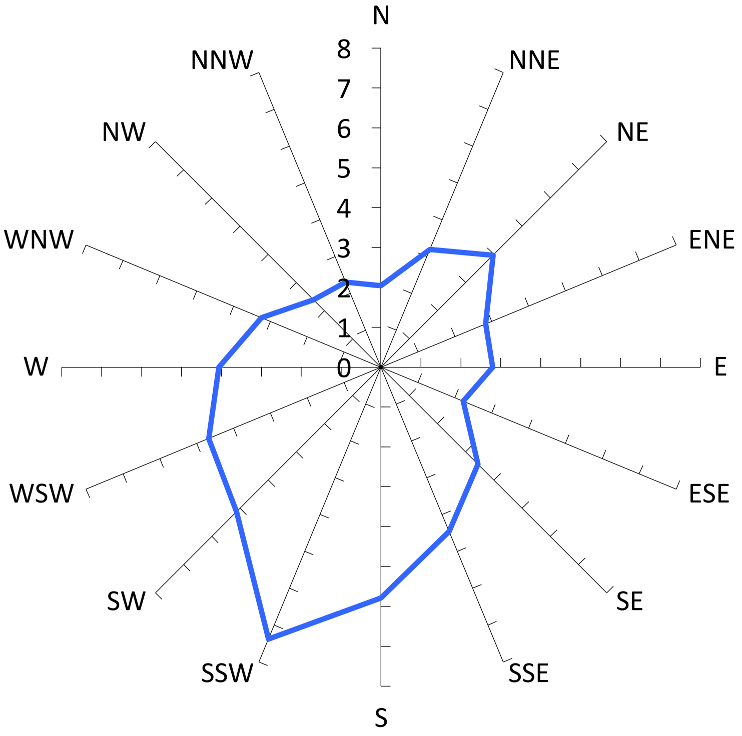
Annual Maximum Gust (m/s)



Desired Criterion
24m/s

Measured Wind Speeds at P101

Weekly Maximum GEM (m/s)



Desired Criterion

8m/s

Prob. of Criterion Exceedence (existing site conditions)

N/A

Probability of Criterion Exceedence (initial test)

1%

Probability of Criterion Exceedence (final retest)

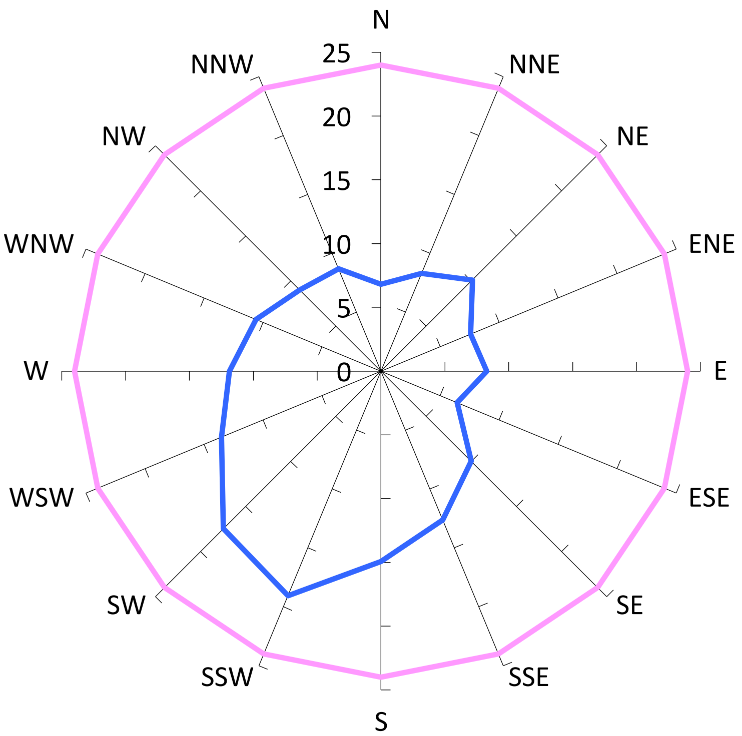
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.

Surrounding Points Point

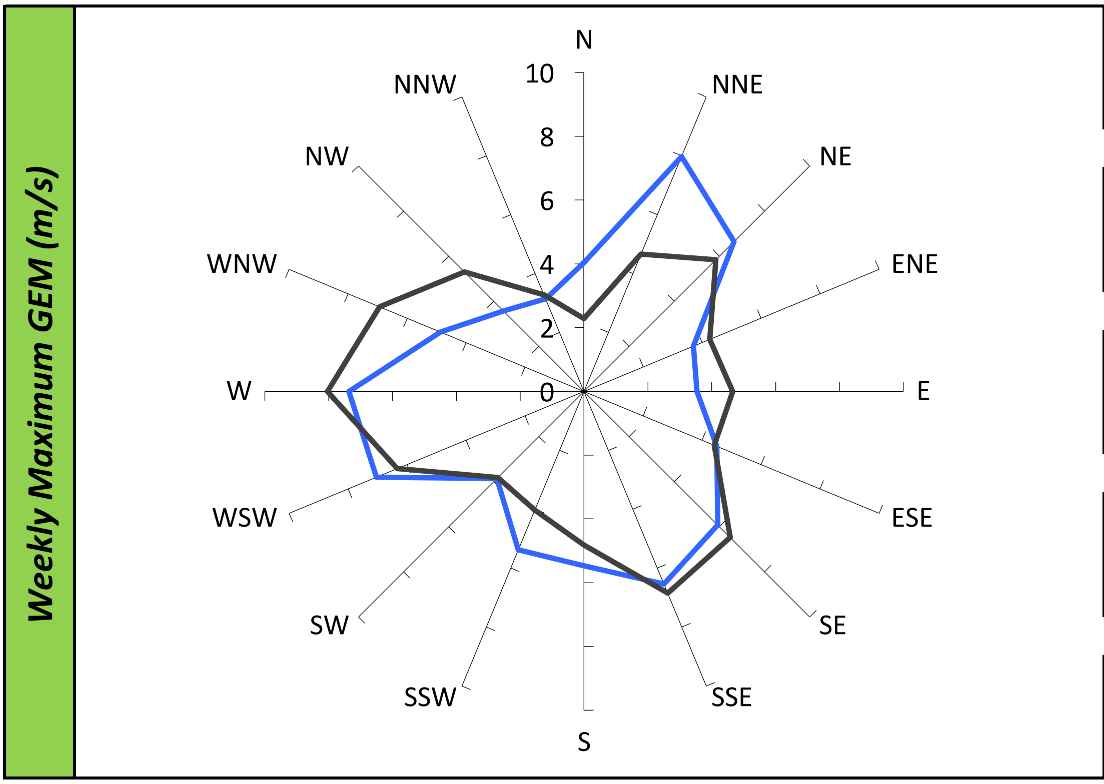
Annual Maximum Gust (m/s)



Desired Criterion

24m/s

Measured Wind Speeds at P102



Desired Criterion
8m/s

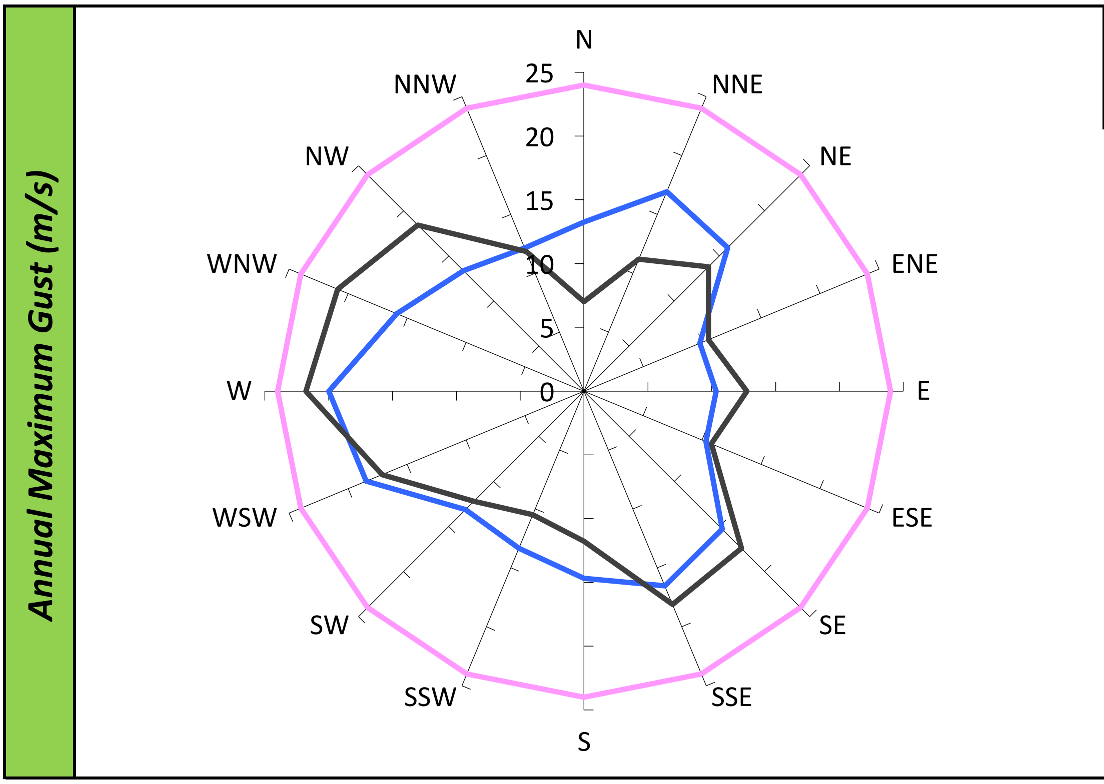
Prob. of Criterion Exceedence (existing site conditions)
3%

Probability of Criterion Exceedence (initial test)
3%

Probability of Criterion Exceedence (final retest)
N/A

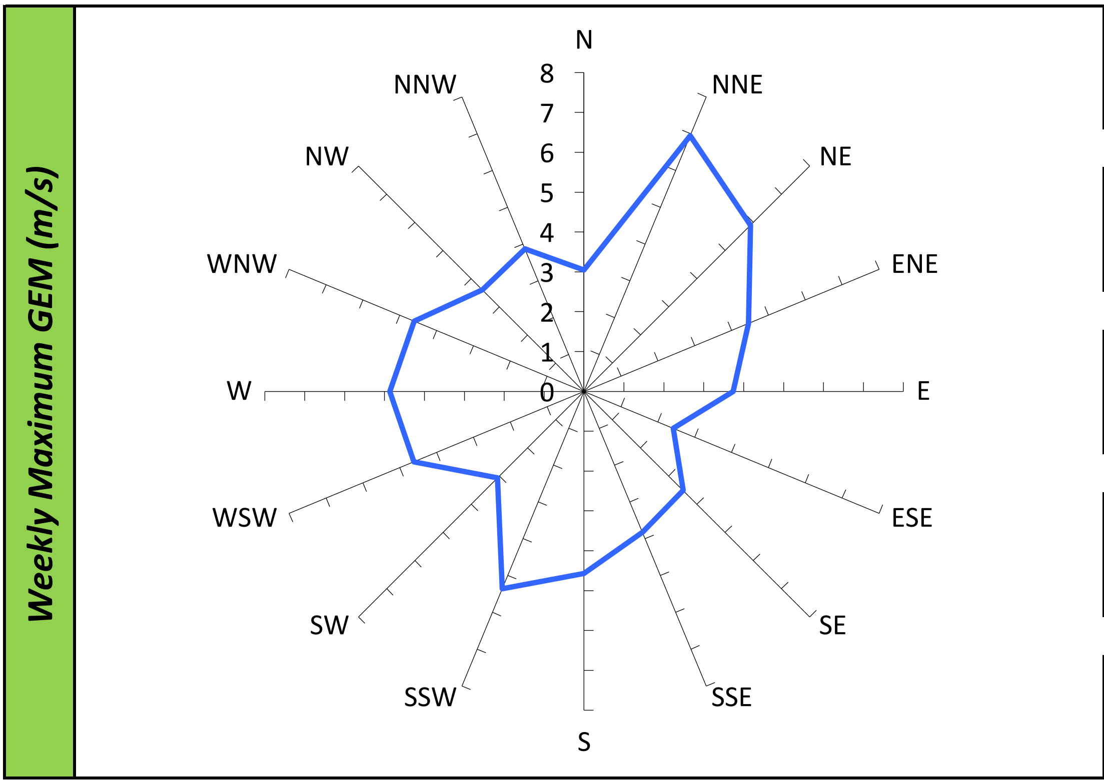
NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.
Surrounding Points Point
Existing Site Conditions



Desired Criterion
24m/s

Measured Wind Speeds at P103



Desired Criterion

8m/s

Prob. of Criterion Exceedence (existing site conditions)

N/A

Probability of Criterion Exceedence (initial test)

1%

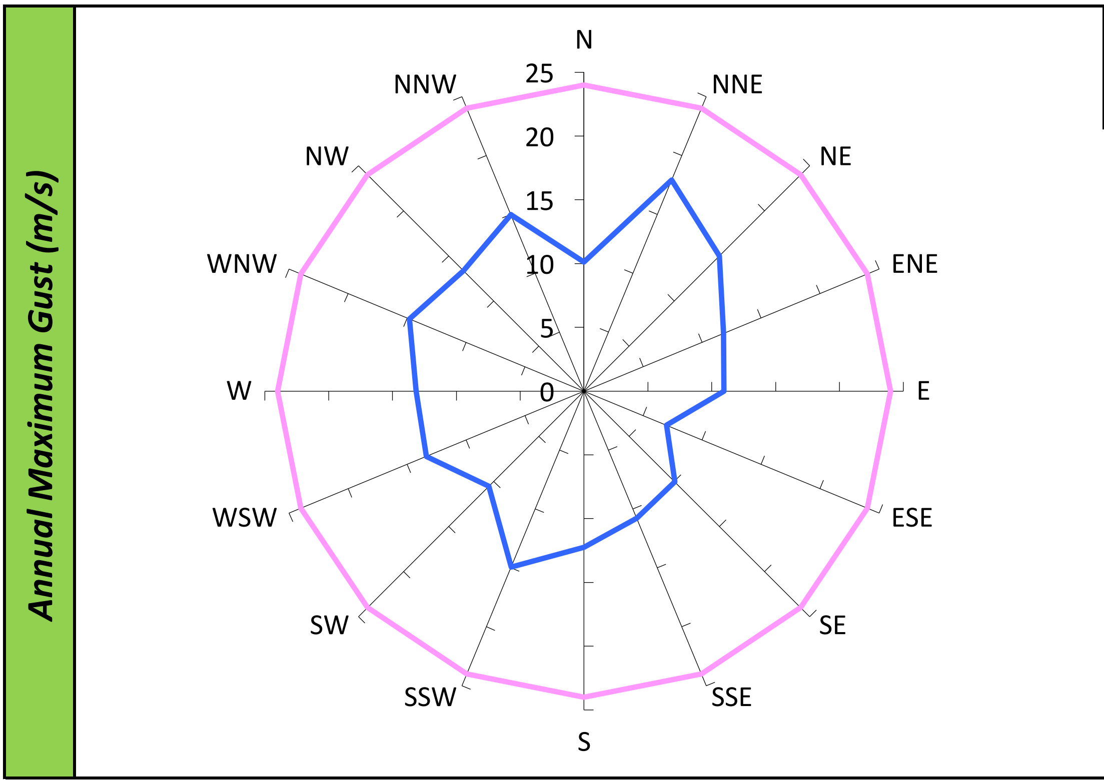
Probability of Criterion Exceedence (final retest)

N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.

Surrounding Points Point

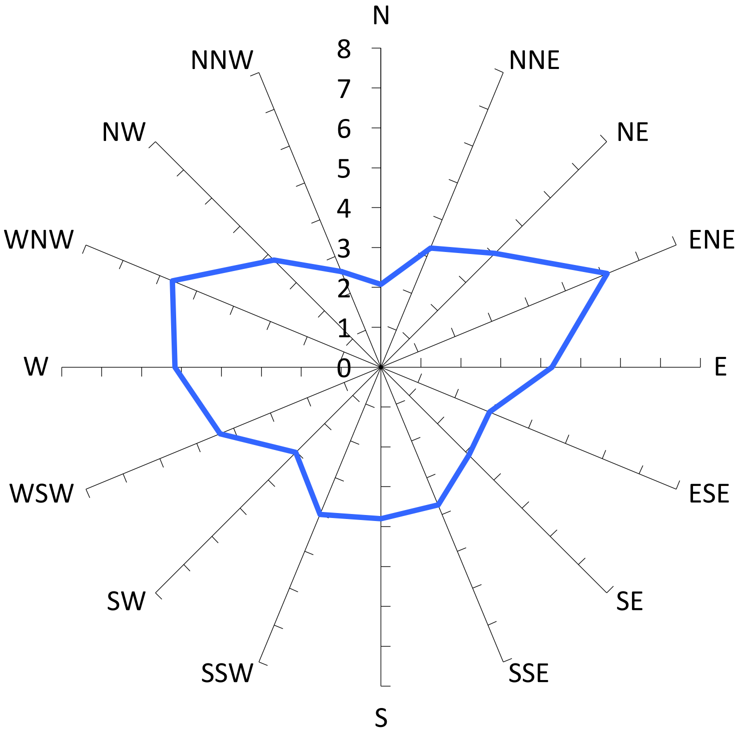


Desired Criterion

24m/s

Measured Wind Speeds at P104

Weekly Maximum GEM (m/s)



Desired Criterion
8m/s

Prob. of Criterion Exceedence (existing site conditions)
N/A

Probability of Criterion Exceedence (initial test)
0%

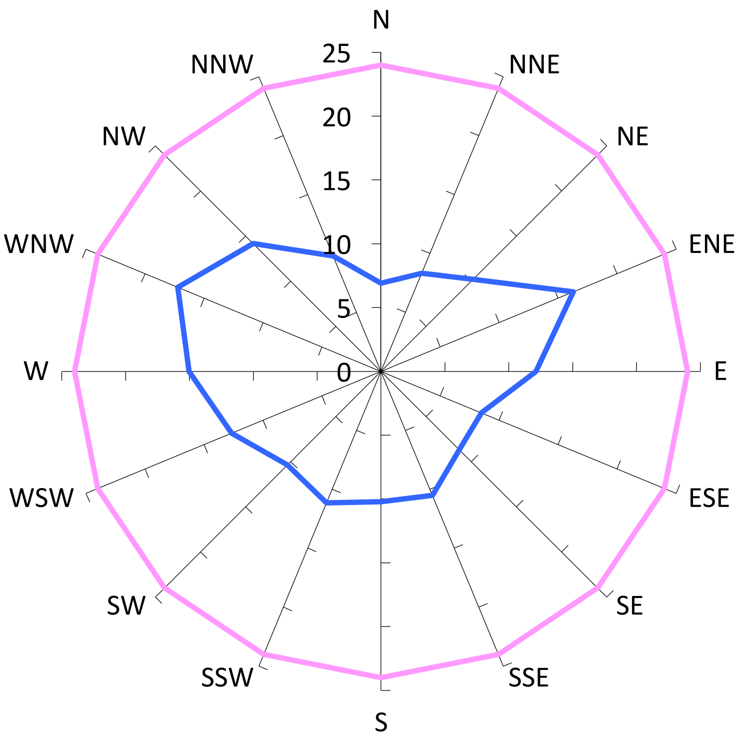
Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.

Surrounding Points Point

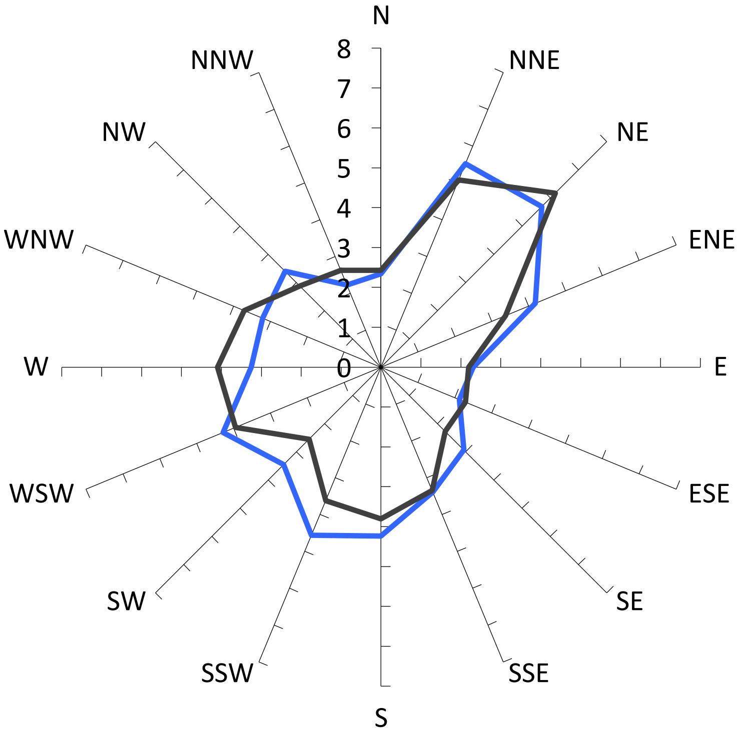
Annual Maximum Gust (m/s)



Desired Criterion
24m/s

Measured Wind Speeds at P105

Weekly Maximum GEM (m/s)



Desired Criterion
8m/s

Prob. of Criterion Exceedence (existing site conditions)
0%

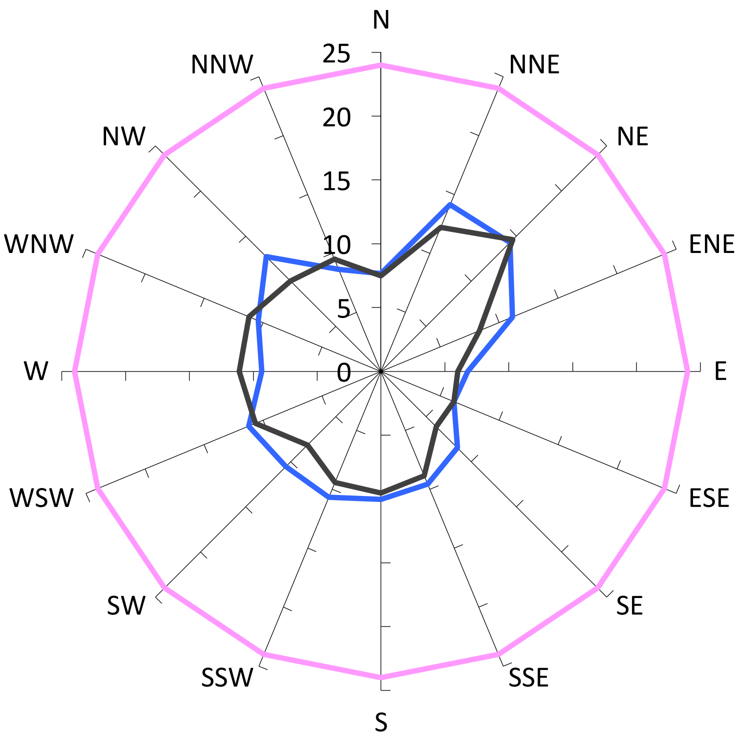
Probability of Criterion Exceedence (initial test)
0%

Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.
Surrounding Points Point
Existing Site Conditions

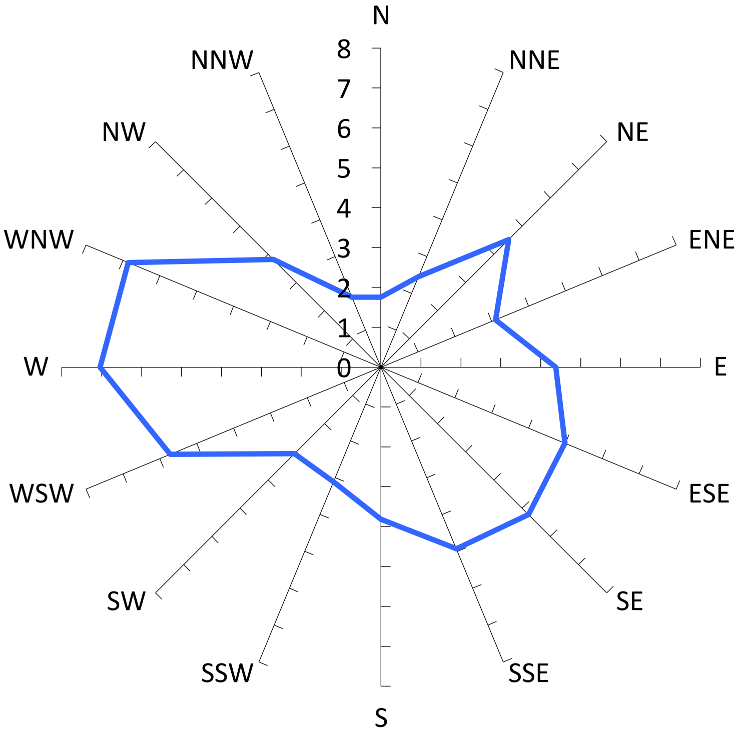
Annual Maximum Gust (m/s)



Desired Criterion
24m/s

Measured Wind Speeds at P106

Weekly Maximum GEM (m/s)



Desired Criterion

8m/s

Prob. of Criterion Exceedence (existing site conditions)

N/A

Probability of Criterion Exceedence (initial test)

1%

Probability of Criterion Exceedence (final retest)

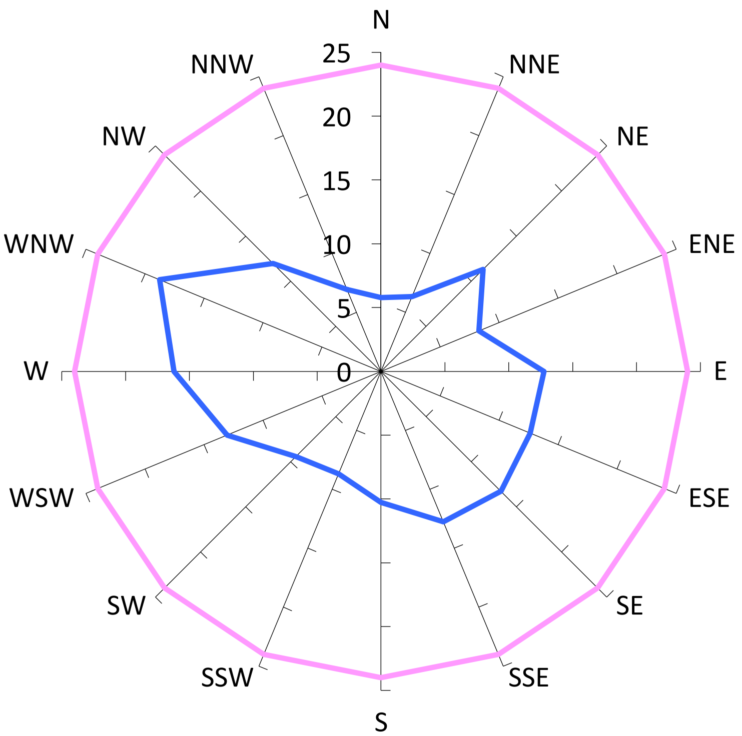
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.

Surrounding Points Point

Annual Maximum Gust (m/s)

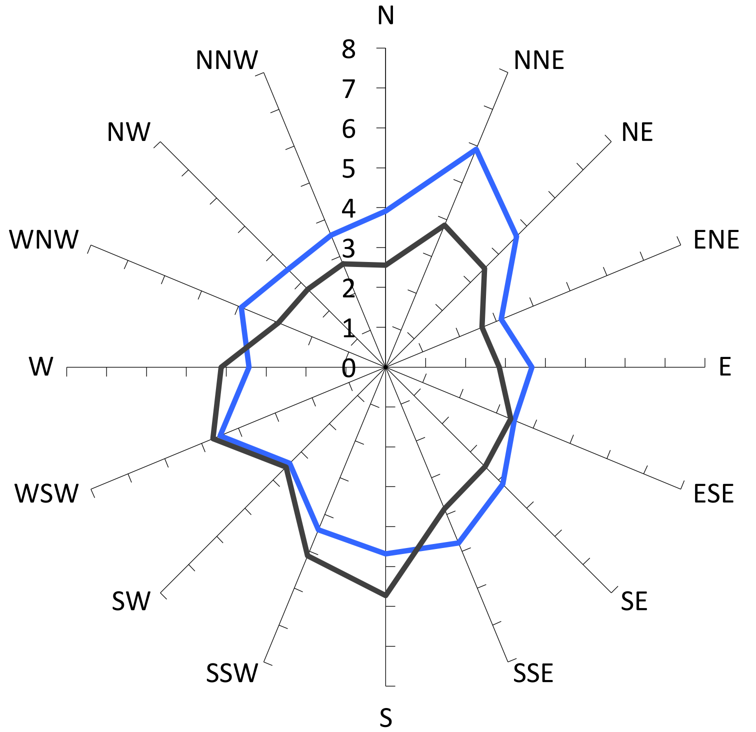


Desired Criterion

24m/s

Measured Wind Speeds at P903

Weekly Maximum GEM (m/s)



Desired Criterion
8m/s

Prob. of Criterion Exceedence (existing site conditions)
0%

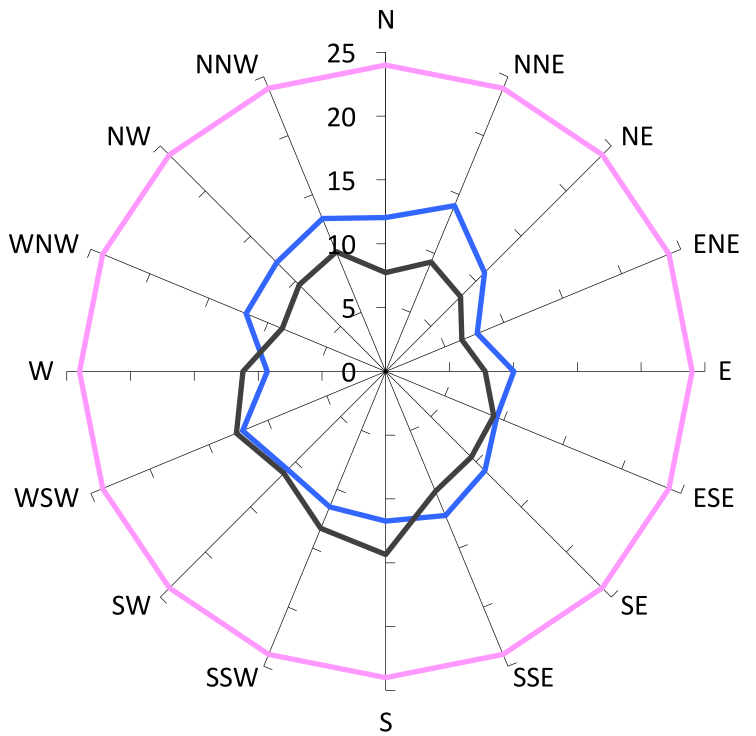
Probability of Criterion Exceedence (initial test)
0%

Probability of Criterion Exceedence (final retest)
N/A

NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

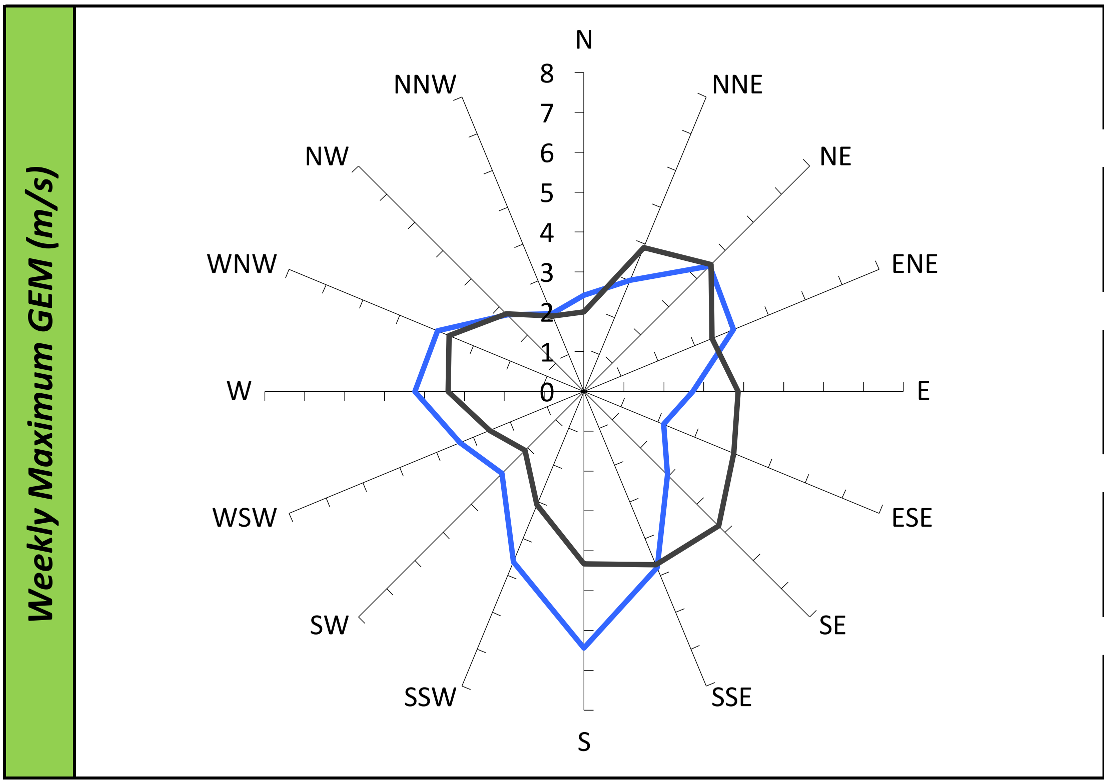
Criterion.
Surrounding Points Point
Existing Site Conditions

Annual Maximum Gust (m/s)



Desired Criterion
24m/s

Measured Wind Speeds at P905



Desired Criterion
8m/s

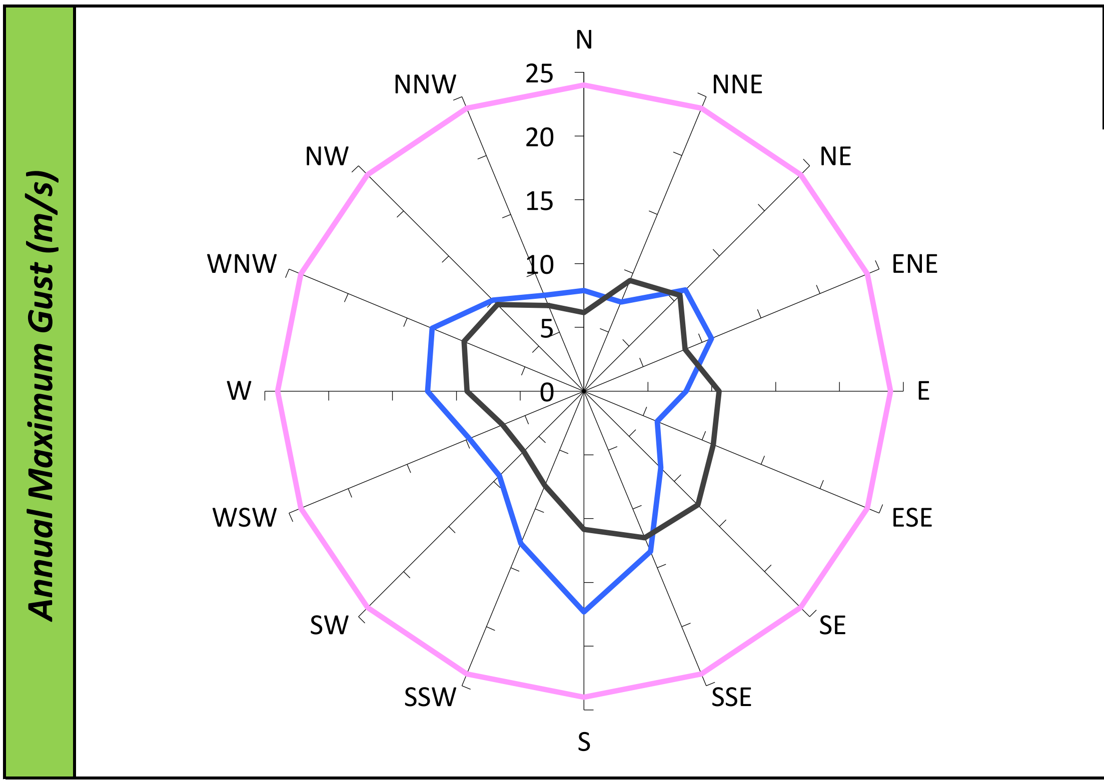
Prob. of Criterion Exceedence (existing site conditions)
0%

Probability of Criterion Exceedence (initial test)
0%

Probability of Criterion Exceedence (final retest)
N/A

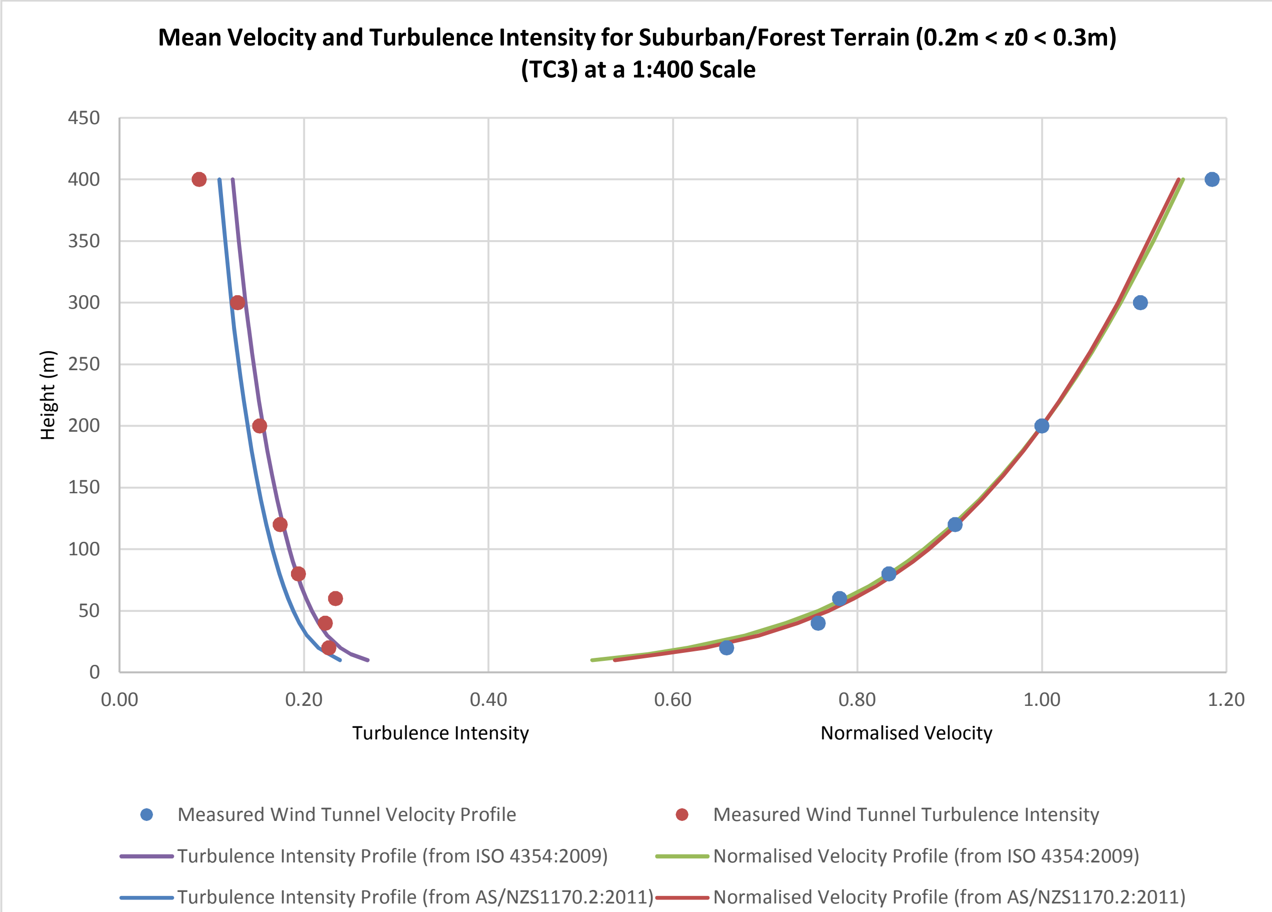
NOTE: The desired criterion is exceeded if the probability of exceedence is greater than 5%

Criterion.
Surrounding Points Point
Existing Site Conditions

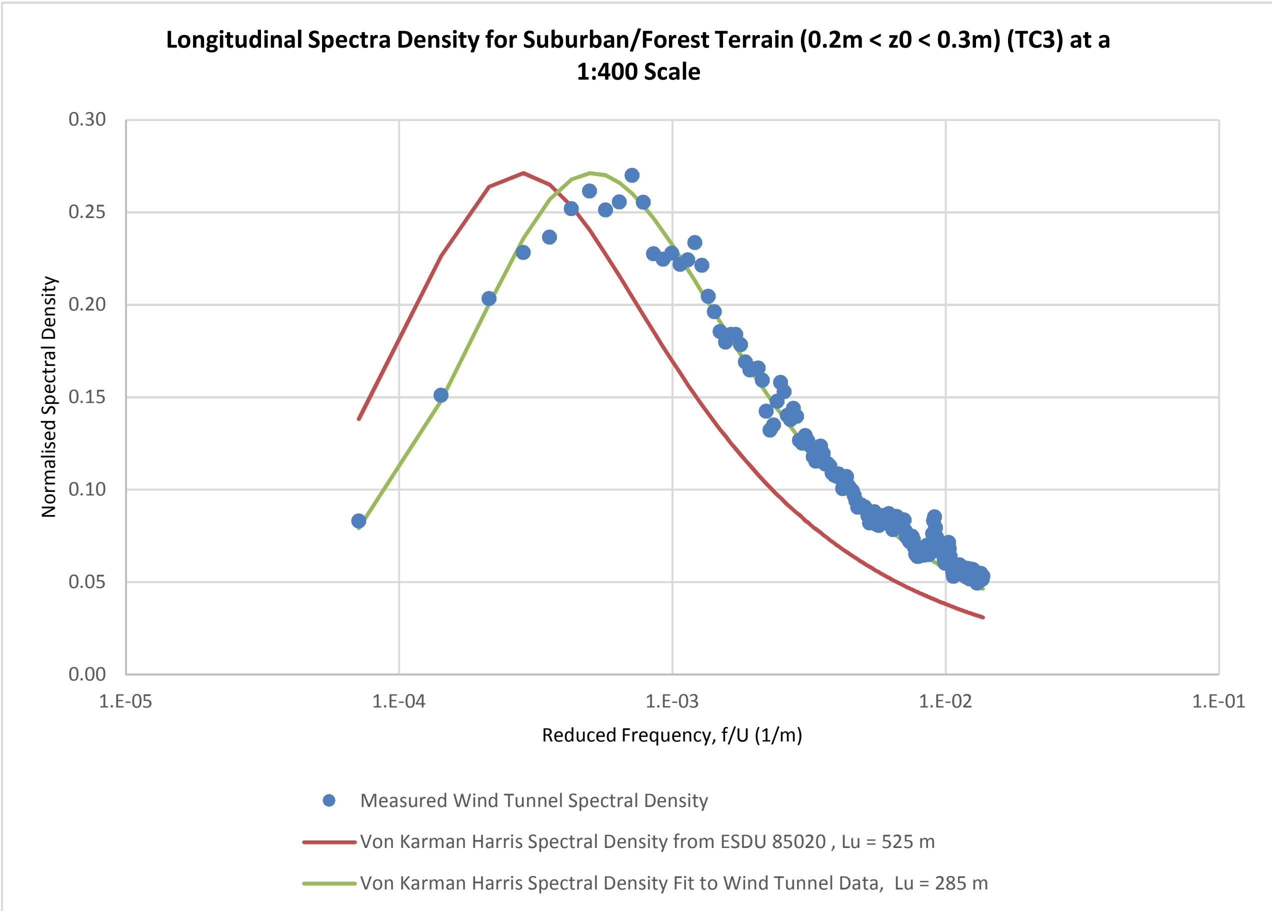


Desired Criterion
24m/s

APPENDIX B - VELOCITY AND TURBULENCE INTENSITY PROFILES



Mean Velocity and Turbulence Intensity for Suburban/Forest Terrain (0.2m < z0 < 0.3m) (TC3) at a 1:400 Scale
Height (m)
Turbulence Intensity
Normalised Velocity
Measured Wind Tunnel Velocity Profile
Measured Wind Tunnel Turbulence Intensity
Turbulence Intensity Profile (from ISO 4354:2009)
Normalised Velocity Profile (from ISO 4354:2009)
Turbulence Intensity Profile (from AS/NZS1170.2:2011)
Normalised Velocity Profile (from AS/NZS1170.2:2011)



Longitudinal Spectra Density for Suburban/Forest Terrain (0.2m < z0 < 0.3m) (TC3) at a 1:400 Scale
Normalised Spectral Density
Reduced Frequency, f/U (1/m)
Measured Wind Tunnel Spectral Density
Von Karman Harris Spectral Density from ESDU 85020 , Lu = 525 m
Von Karman Harris Spectral Density Fit to Wind Tunnel Data, Lu = 285 m

APPENDIX C - PUBLISHED ENVIRONMENTAL CRITERIA

C.1 Wind Effects on People

The acceptability of wind in an area is dependent upon the use of the area. For example, people walking or window-shopping will tolerate higher wind speeds than those seated at an outdoor restaurant. Quantifying wind comfort has been the subject of much research and many researchers, such as A.G. Davenport, T.V. Lawson, W.H. Melbourne, and A.D. Penwarden, have published criteria for pedestrian comfort for pedestrians in outdoor spaces for various types of activities. This section discusses and compares the various published criteria.

C.1.1 A.D. Penwarden (1973) Criteria for Mean Wind Speeds

A.D. Penwarden (1973) developed a modified version of the Beaufort scale which describes the effects of various wind intensities on people. Table C.1 presents the modified Beaufort scale. Note that the effects listed in this table refers to wind conditions occurring frequently over the averaging time (a probability of occurrence exceeding 5%). Higher ranges of wind speeds can be tolerated for rarer events.

Table C.1: Summary of Wind Effects on People (A.D. Penwarden, 1973)

Type of Winds	Beaufort Number	Hourly Mean Wind Speed (m/s)	Effects
Calm	0	0 - 0.25	
Calm, light air	1	0 25 - 1.55	No noticeable wind
Light breeze	2	1.55 - 3.35	Wind felt on face
Gentle breeze	3	3.35 - 5.45	Hair is disturbed, clothing flaps, newspapers difficult to read
Moderate breeze	4	5.45 - 7.95	Raises dust, dry soil and loose paper, hair disarranged
Fresh breeze	5	7.95 – 10.75	Force of wind felt on body, danger of stumbling
Strong breeze	6	10.75 – 13.85	Umbrellas used with difficulty, hair blown straight, difficult to walk steadily, wind noise on ears unpleasant
Near gale	7	13.85 – 17.15	Inconvenience felt when walking
Gale	8	17.15 - 20.75	Generally impedes progress, difficulty balancing in gusts
Strong gale	9	20.75 – 24.45	People blown over

C.1.2 A.G. Davenport (1972) Criteria for Mean Wind Speeds

A.G. Davenport (1972) also determined a set of criteria in terms of the Beaufort scale and for various return periods. Table C.2 presents a summary of the criteria based on a probability of exceedance of 5%.

Table C.2: Criteria by A.G. Davenport (1972)

Classification	Activities	5% exceedance Mean Wind Speed (m/s)
Walking Fast	Acceptable for walking, main public accessways.	7.5 - 10.0
Strolling, Skating	Slow walking, etc.	5.5 - 7.5
Short Exposure Activities	Generally acceptable for walking & short duration stationary activities such as window-shopping, standing or sitting in plazas.	3.5 - 5.5
Long Exposure Activities	Generally acceptable for long duration stationary activities such as in outdoor restaurants & theatres and in parks.	0 - 3.5

C.1.3 T.V. Lawson (1975) Criteria for Mean Wind Speeds

In 1973, T.V. Lawson, while referring to the Beaufort wind speeds of A.D. Penwarden (1973) (as listed in Table C.1), quoted that a Beaufort 4 wind speed would be acceptable if it is not exceeded for more than 4% of the time, and that a Beaufort 6 wind speed would be unacceptable if it is exceeded more than 2% of the time. Later, in 1975, T.V. Lawson presented a set of criteria very similar to those presented in A.G. Davenport (1972) (as listed in Table C.2). These criteria are presented in Table C.3 and Table C.4 for safety and comfort respectively.

Table C.3: Safety Criteria by T.V. Lawson (1975)

Classification	Activities	Annual Mean Wind Speed (m/s)
Safety (all weather areas)	Accessible by the general public.	0 – 15
Safety (fair weather areas)	Private areas, balconies/terraces, etc.	0 – 20

Table C.4: Comfort Criteria by T.V. Lawson (1975)

Classification	Activities	5% exceedance Mean Wind Speed (m/s)
Business Walking	Objective Walking from A to B.	8 - 10
Pedestrian Walking	Slow walking, etc.	6 - 8
Short Exposure Activities	Pedestrian standing or sitting for short times.	4 – 6
Long Exposure Activities	Pedestrian sitting for a long duration.	0 - 4

C.1.4 W.H. Melbourne (1978) Criteria for Gust Wind Speeds

W.H. Melbourne (1978) introduced a set of criteria for the assessment of environmental wind conditions that were developed for a temperature range of 10oC to 30oC and for people suitably dressed for outdoor conditions. These criteria are presented in Table C.5, and are based on maximum gust wind speeds with a probability of exceedance of once per year.

Table C.5: Criteria by W.H. Melbourne (1978)

Classification	Human Activities	Annual Gust Wind Speed (m/s)
Limit for Safety	Completely unacceptable: people likely to get blown over.	23
Marginal	Unacceptable as main public accessways.	16 - 23
Comfortable Walking	Acceptable for walking, main public accessways	13 - 16
Short Exposure Activities	Generally acceptable for walking & short duration stationary activities such as window-shopping, standing or sitting in plazas.	10 - 13
Long Exposure Activities	Generally acceptable for long duration stationary activities such as in outdoor restaurants & theatres and in parks.	0 - 10

C.2 Comparison of the Published Wind Speed Criteria

W.H. Melbourne (1978) presented a comparison of the criteria of various researchers on a probabilistic basis. Figure C.1 presents the results of this comparison, and indicates that the criteria of W.H. Melbourne (1978) are comparatively quite conservative. This conclusion was also observed by A.W. Rofail (2007) when undertaking on-site remedial studies. The results of A.W. Rofail (2007) concluded that the criteria by W.H. Melbourne (1978) generally overstates the wind effects in a typical urban setting due to the assumption of a fixed 15% turbulence intensity for all areas. It was observed in A.W. Rofail (2007) that this value tends to be at the lower end of the range of turbulence intensities, and in an urban setting the range of the minimum turbulence intensities is typically in the range of 20% to 60%.

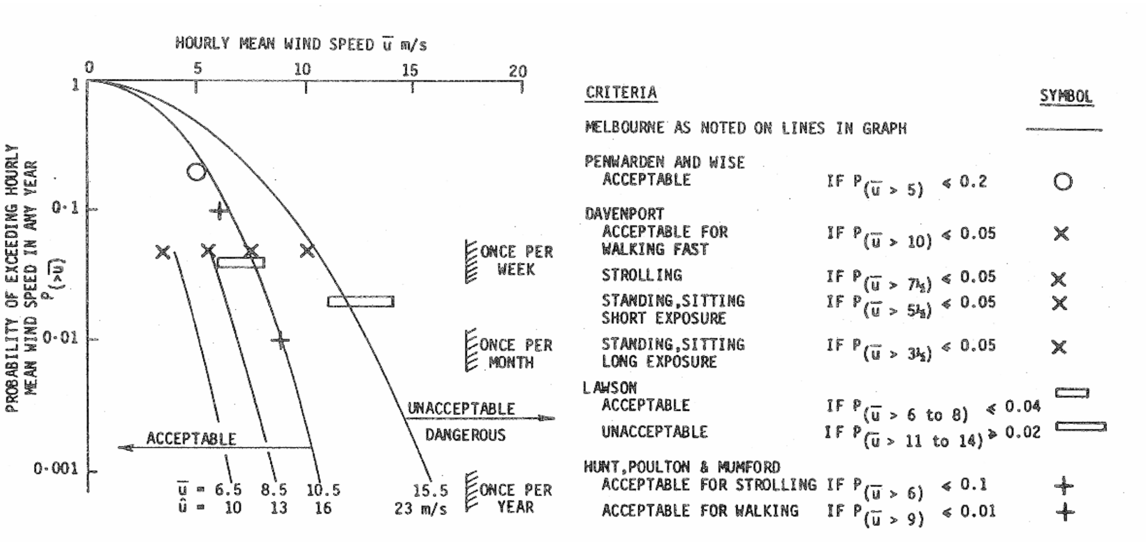


Figure C.1: Comparison of Various Mean and Gust Wind Environment Criteria, assuming 15% turbulence and a Gust Factor of 1.5 (W.H. Melbourne, 1978)

C.3 References relating to Pedestrian Comfort Criteria

Davenport, A.G., 1972, "An approach to human comfort criteria for environmental conditions". Colloquium on Building Climatology, Stockholm.

Davenport, A.G., 1977, "The prediction of risk under wind loading", 2nd International Conference on Structural Safety and Reliability, Munich, Germany, pp511-538.

Lawson, T.V., 1973, "The wind environment of buildings: a logical approach to the establishment of criteria". Bristol University, Department of Aeronautical Engineering.

Lawson, T.V., 1975, "The determination of the wind environment of a building complex before construction". Bristol University, Department of Aeronautical Engineering.

Melbourne, W.H., 1978, "Criteria for Environmental Wind Conditions". Journal of Wind Engineering and Industrial Aerodynamics, vol. 3, pp241-249.

Penwarden, A.D. (1973). "Acceptable Wind Speeds in Towns", Building Science, vol. 8: pp259–267

Penwarden, A.D., Wise A.F.E., 1975, "Wind Environment Around Buildings". Building Research Establishment Report, London.

Rofail, A.W., 2007, "Comparison of Wind Environment Criteria against Field Observations". 12th International Conference of Wind Engineering, Cairns, Australia.

APPENDIX D - DATA ACQUISITION

The wind tunnel testing procedures for this study were based on the guidelines set out in the Australasian Wind Engineering Society Quality Assurance Manual (AWES-QAM-1-2017), ASCE 7-10 (Chapter C31), and CTBUH (2013).

The wind speed measurements for the wind tunnel study were acquired as coefficients by Dantec hot-wire anemometers and converted to full-scale wind speeds using details of the regional wind climate obtained from an analysis of directional wind speed recordings from the local meteorological recording station(s).

D.1 Measurement of the Velocity Coefficients

The study model and proximity model were setup within the wind tunnel which was configured to the appropriate boundary layer profile, and the wind velocity measurements were monitored using Dantec hot-wire probe anemometers at selected critical outdoor locations. The anemometers were positioned at each study location at a full-scale height of approximately 1.5m above ground/slab level. The support of the probe was mounted such that the probe wire was vertical as much as possible to ensure that the measured wind speeds are independent of wind direction along the horizontal plane. In addition, care was taken in the alignment of the probe wire and in avoiding wall-heating effects.

Wind speed measurements were made in the wind tunnel for 16 wind directions, at 22.5° increments. The output from the hot-wire probes was obtained using a National Instruments 12-bit data acquisition card. The data was acquired for each wind direction using a sample rate of 1024Hz. The sample length was determined to produce a full-scale sample time that is sufficient for this type of study.

The mean, gust and standard deviation velocity coefficients were measured in the wind tunnel. The gust velocity coefficients were also derived for each wind direction from by the following relation:

$$\hat{C}_V = \bar{C}_V + g \cdot \sigma_{C_V} \qquad \text{D.1}$$

Where:

$\hat{C}_V$ is the gust coefficient.

$\bar{C}_V$ is the mean coefficient.

g is the peak factor, taken as 3.0 for a 3s gust and 3.4 for a 0.5s gust.

σ_{C_V} is the standard deviation of coefficient measurement.

D.2 Calculation of the Full-Scale Results

The full-scale results determine if the wind conditions at a study location satisfy the designated criteria of that location. More specifically, the full-scale results need to determine the probability of exceedance of a given wind speed at a study location. To determine the probability of exceedance, the measured velocity coefficients were combined with a statistical model of the local wind climate that relates wind speed to a probability of exceedance. Details of the wind climate model are outlined in Section 3.1 and 4.1 of the main report.

The statistical model of the wind climate includes the impact of wind directionality as any local variations in wind speed or frequency with wind direction. This is important as the wind directions that produce the highest wind speed events for a region may not coincide with the most wind exposed direction at the site.

The methodology adopted for the derivation of the full-scale results for the maximum gust and the GEM wind speeds are outlined in the following sub-sections.

Maximum Gust Wind Speeds

The full-scale maximum gust wind speed at each study point location is derived from the measured coefficient using the following relationship:

$$V_{study} = V_{ref,RH}\left(\frac{k_{200m,tr,T=1hr}}{k_{RH,tr,T=1hr}}\right)C_V \qquad \text{D.2}$$

Where:

V_{study} is the full-scale wind speed at the study point location, in m/s.

$V_{ref,RH}$ is the full-scale reference wind speed, measured 3m upstream at the study reference height. This value is determined by combining the directional wind speed data for the region (detailed in Section 4.1) and the upwind terrain and height multipliers for the site (detailed in Section 4.3).

$k_{200m,tr,T=1hr}$ is the standard deviation of the wind speed.

$k_{RH,tr,T=1hr}$ is the hourly mean terrain and height multiplier at the study reference height (see Section 3.3 and 4.3).

C_V is the velocity coefficient measurement obtained from the hot-wire anemometer, which is derived from the following relationship:

$$C_V = \frac{C_{V,study}}{C_{V,200m}} \qquad \text{D.3}$$

Where:

$C_{V,study}$ is the coefficient measurement obtained from the hot-wire anemometer at the study point location.

$C_{V,200m}$ is the coefficient measurement obtained from the hot-wire anemometer at the free-stream reference location at 200m height upwind of the model in the wind tunnel.

The value of $V_{ref,RH}$ varies with each prevailing wind direction. Wind directions where there is a high probability that a strong wind will occur have a higher directional wind speed than other directions. To determine the directional wind speeds, a probability level must be assigned for each wind direction. These probability levels are set following the approach used in AS/NZS1170.2:2011, which assumes that the major contributions to the combined probability of exceedance of a typical load effect comes from only two 45 degree sectors.

Maximum Gust-Equivalent Mean Wind Speeds

The contribution to the probability of exceedance of a specified wind speed (ie: the desired wind speed for pedestrian comfort, as per the criteria) was calculated for each wind direction. These contributions are then combined over all wind directions to calculate the total probability of exceedance of the specified wind speed. To calculate the probability of exceedance for a specified wind speed a statistical wind climate model was used to describe the relationship between directional wind speeds and the probability of exceedance. A detailed description of the methodology is given by T.V. Lawson (1980).

The criteria used in this study is referenced to a probability of exceedance of 5% of a specified wind speed.

D.3 References relating to Data Acquisition

American Society of Civil Engineers (ASCE), ASCE-7-10, 2010, “Minimum Design Loads for Buildings and Other Structures”.

Australasian Wind Engineering Society (AWES), QAM-1, 2017, “Quality Assurance Manual”.

Council on Tall Buildings and Urban Habitat (CTBUH), 2013, “Wind tunnel testing of high-rise buildings”, CTBUH Technical Guides.

Lawson, T.V., 1980, “Wind Effects on Buildings - Volume 1, Design Applications”. Applied Science Publishers Ltd, Ripple Road, Barking, Essex, England.

Standards Australia and Standards New Zealand, AS/NZS 1170.2, 2011, “SAA Wind Loading Standard, Part 2: Wind Actions”.