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Opus Research Report 14-529D91.00

Wind Tunnel Study of the Proposed Site 10 Development, Wellington

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1 Introduction

This report describes the methodology and results of an environmental wind tunnel study of pedestrian level wind conditions around a development proposed for Site 10 on the waterfront in central Wellington. The proposal is for a 6-storey building around 24m high on a site that is currently vacant.

The aim of this study is to establish the extent and magnitude of the effects of the proposed development on wind conditions experienced by pedestrians in its vicinity. This investigation is intended for the purpose of obtaining resource consent and to satisfy the reporting requirements of the Wellington City District Plan provisions concerning wind effects. This wind tunnel study has been conducted under the wind rules contained in District Plan Change 48 (DPC 48) to the Wellington City District Plan.

Wind tunnel testing was carried out using the existing Opus Research 1:264 scale model of Wellington, updated to reflect buildings that currently exist or are under construction. A scale model of the development was built from plans provided by Athfield Architects. The level of detail on this model was consistent with design features expected to have a potential impact on wind conditions.

Flow visualisation tests, using bran flakes, were performed for the four wind directions 170°, 210°, 320°, and 360°, these being representative of the prevailing northerly and southerly wind directions in Wellington. These tests give a qualitative comparison of the degree of windiness in pedestrian areas between the existing situation and the proposed development. The wind flow patterns identified were used as an aid in selecting locations for wind speed measurements that were made with a hot-film anemometer. These wind speed measurements were made for the same four wind directions listed above and for four additional directions of 150°, 190°, 340°, and 020° to allow finer resolution of the effect of direction. Initial test configurations included the existing situation and the proposed development.

1.1 District Plan Change 48

District Plan Change 48 included changes to the wind rules. These changes did not require significant changes to the wind tunnel testing methodology and procedures. Rather they represented significant changes to the way that the measured wind speed data is processed and

presented. The intention of the changes was not to make it more difficult to meet the criteria contained in the District Plan, but to present the information in a format that is more readily understandable to Wellington City Council planners and other lay people involved in the resource consent process. The aim was that an assessment of the wind effects under DPC 48 would form the same conclusions as an assessment under the wind rules that have been in place largely unchanged for over 20 years.

The changes to the wind rules in DPC 48 involved the retention of a gust wind speed criteria as a means to describe and specify a safety criteria. They also incorporated a "frequency of occurrence" approach to define acceptable levels of comfort and also to define acceptable changes in wind conditions that can occur with a proposed new building or redevelopment of an existing building.

2 Description of the Site, Area and Development

Site 10, as it is referred to, is an approximately rectangular site located immediately to the east of Waterloo Quay, on the section of the Wellington waterfront between Bunny and Whitmore Streets. Wellington Harbour is a very short distance to the east. Site 10 vacant and is currently used for parking.

There are relatively few buildings in this area of the Wellington waterfront, and these are a mix of older historic buildings and newer developments, such as the Meridian Building to the immediate south of Sites 8 and 9, and the BNZ building further along Waterloo Quay to the north. Much of the area remains open space, some of which is used for parking, some encompasses the wharves and jetties, and some comprises flat open paved areas that are open to the public. Across Waterloo Quay to the west is the central Wellington business district, which is made up of a generally compact grouping of medium-rise and high rise buildings. However, there are two significant largely open areas across Waterloo Quay from the site, these being the space in front of Wellington Railway Station, and the space associated with the Z service station.

The development proposed for Site 10 is a six-story (~24m) block which has an approximately rectangular footprint, but which also has significant setbacks at ground floor level on all four sides, as well as a diagonal accessway cutting through the building. There are also significant setbacks on the uppermost floors, some of which create extensive deck areas for the adjacent office space.

Figure 1 shows views of the wind tunnel model of the development and its immediate surroundings. This illustrates the size and scale of the development proposal compared to other buildings in the area. Figure 2 shows a plan of the area surrounding the development site, including the locations of the wind speed measurements.

Figure 1 (a): View of the Proposed Development from the South

Figure 1 (b): View of the Proposed Development from the Northwest

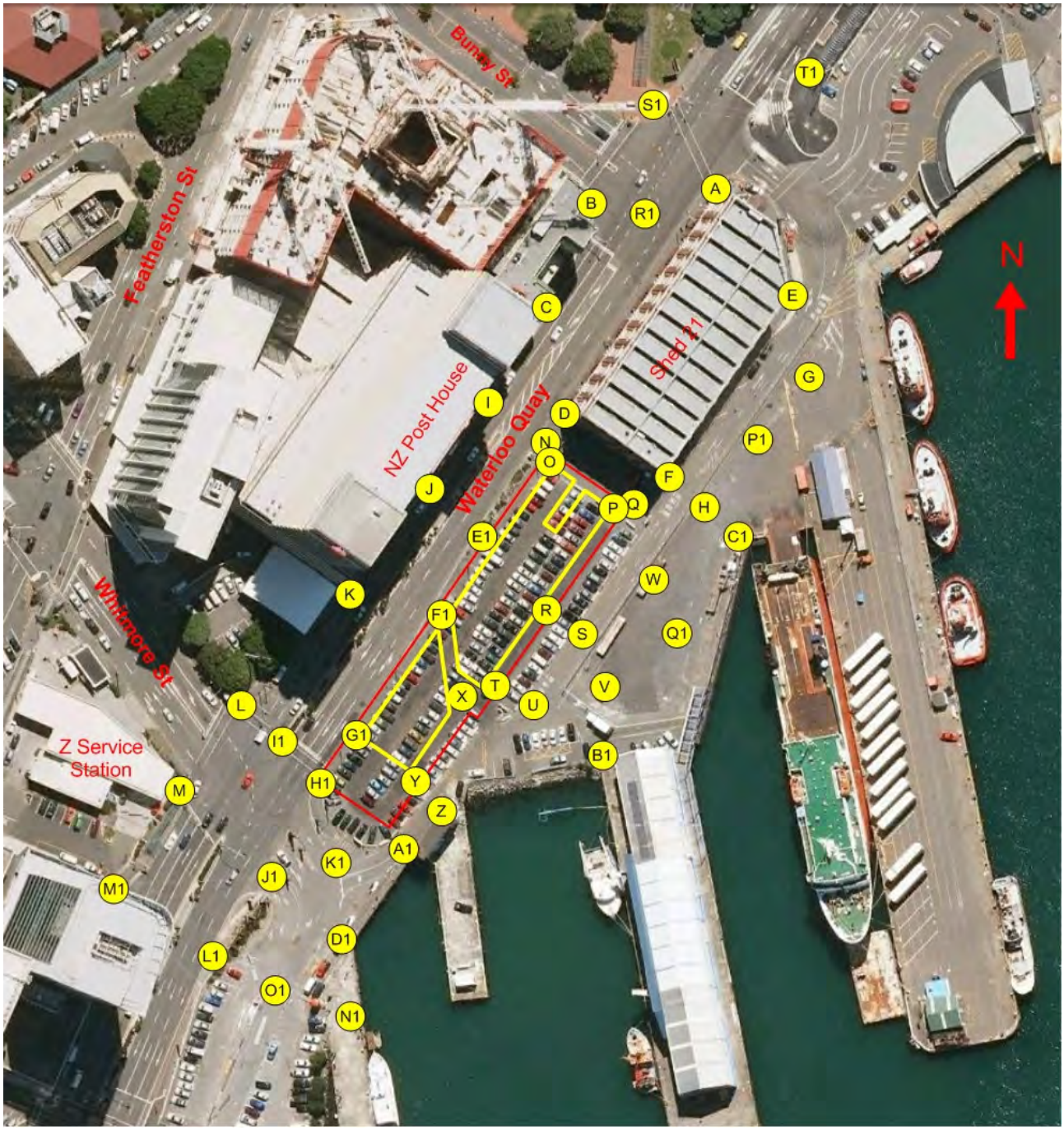


Figure 2: The development site and the surrounding area (includes the locations of the wind speed measurements, (aerial image © Google, 2014)

Note: The footprint of the building is shown in red, and the ground floor outline is shown in yellow.

3 Wind Tunnel Test Procedures

Wind tunnel tests were performed in the Opus Research wind tunnel, using a 1:264 scale model of the proposed development and the surrounding area of Wellington. The model of the proposed development was positioned at the centre of the wind tunnel turntable, with the surrounding area modelled to a full-scale radius of approximately 300-400m. The wind tunnel boundary layer was set up to reproduce conditions for terrain category 3, as defined in Appendix D, for all the wind directions. Two methods of testing were employed:

(1) flow visualisation using bran flakes; and
(2) wind speed measurements using a hot film anemometer.

The flow visualisation method provides a means of quickly identifying the areas of highest relative wind speed on the surface of the model. This involves sprinkling a thin layer of small bran flakes on the model surface and then running the wind tunnel at increasing speeds. A camera mounted directly above the model is used to record the erosion patterns as the test proceeds. The areas cleared first are assumed to be the windiest. Details of the test method are given in Appendix E. Flow visualisation tests were carried out for the four wind directions, 170°, 210°, 320° and 360°, which are representative of the prevailing wind directions for Wellington City (refer Appendix C). These were carried out for the existing situation and the proposed development.

Wind speed measurements made with a hot-film anemometer involve measuring the ratio of the wind speeds at a point on the model (at a scale height of 2 metres) to a reference wind speed (at a scale height of 150 metres). Using these measurements and relating them to full-scale meteorological wind data, it is possible to estimate the wind conditions that will be experienced at a particular point and thus classify the wind performance of the area (refer Appendix A). The wind speed measurements were made using a hot-film anemometer for the eight wind directions 150°, 170°, 190°, 210°, 320°, 340°, 360° and 020°. These measurements were carried out for the existing situation and the proposed development.

The measured wind speed data is processed in two different ways:

(1) The mean wind speed and the corresponding standard deviation in the wind speed are combined to provide a "calculated gust speed". This is a measure of the overall windiness of a location, including the influence of the mean wind speed, turbulence and gusts. The calculated gust speed is therefore not simply a measure of the speed of a single wind gust.

The calculated gust speed, V_c, is defined as: $\mathbf{V_c = V_{mean} + 3.7V_{rms}}$

where V_{mean} is the maximum annual hourly mean wind speed, and V_{rms} is the standard deviation corresponding to this mean speed. The calculated gust speed measurements are compatible with the Safety Criteria for wind speeds specified in the Wellington City District Plan (refer Appendix B).

(2) The mean wind speeds for each location for each wind direction are divided by the directional mean reference wind speed to provide a mean velocity ratio. These are then combined with the Wellington City wind climate data listed in Appendix C to calculate the hours of occurrence for which mean wind speeds of 2.5m/s (moderate winds) and 3.5m/s (strong winds) are equalled or exceeded in a year.

4 Flow Visualisation Tests

Photographic records of each flow visualisation test have been processed to give images that show the relative degree of windiness in the area around the development. These images are shown in Figures 3 to 6. The images in each figure (as described in Appendix E) show the wind patterns for the existing situation and then those with the proposed development. All of the photographs are mounted so that the wind flow is directly from the left. The proposed building is located approximately in the centre of the photographs.

4.1 Bran Tests – Northerly Winds

The main observations from the flow visualisation studies for northerly winds are:

(a) The erosion contour images show that the area of Waterloo Quay adjacent to the site is exposed to strong wind flows that are squeezed between NZ Post House and Shed 21. These then diffuse across the open areas of the waterfront, including the open area of Site 10.

(b) The primary effects of the proposed development on wind flow patterns can be seen for both northerly wind directions investigated. Increased shelter is afforded those areas downstream of the proposed development by the bulk of the new building. Changes to the wind flow and pressure fields suggest that Waterloo Quay is also generally made less windy by the new building. There are also indications that wind flows are channelled between the new building and the neighbouring Shed 21. These are more apparent for a wind direction of 360°.

4.2 Bran Tests – Southerly Winds

The main observations from the flow visualisation studies for southerly winds are:

(a) Wind flow patterns for the existing situation are primarily dominated by horizontal wind flows, with windier locations around the windward corners and sides of buildings. However, there are also contributions from vertical wind flows deflected down the windward faces of some buildings, most notably from NZ Post House across Waterloo Quay to the west. The erosion patterns show that the windward corners at the south end of Shed 21, to the north of Site 10, are the windiest locations in the immediate area.

(b) The main effects of the proposed development are to transfer the windy locations around the south end of Shed 21 to its own southern end. However, there are also indications that the new building does afford more shelter to the adjacent areas of Waterloo Quay for both wind directions investigated, but most notably for a wind direction of 210°

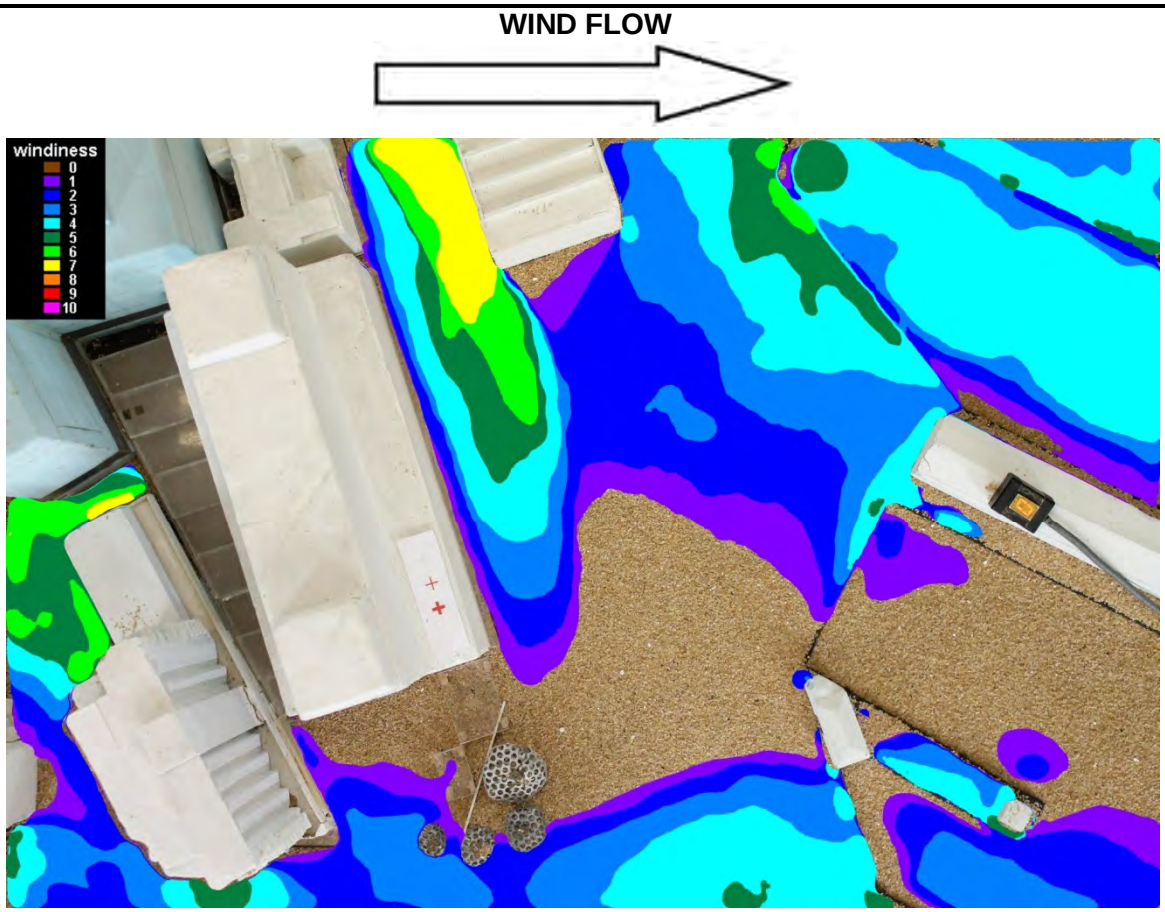


Figure 3a: Relative Windiness - Existing Situation - Wind From 320°

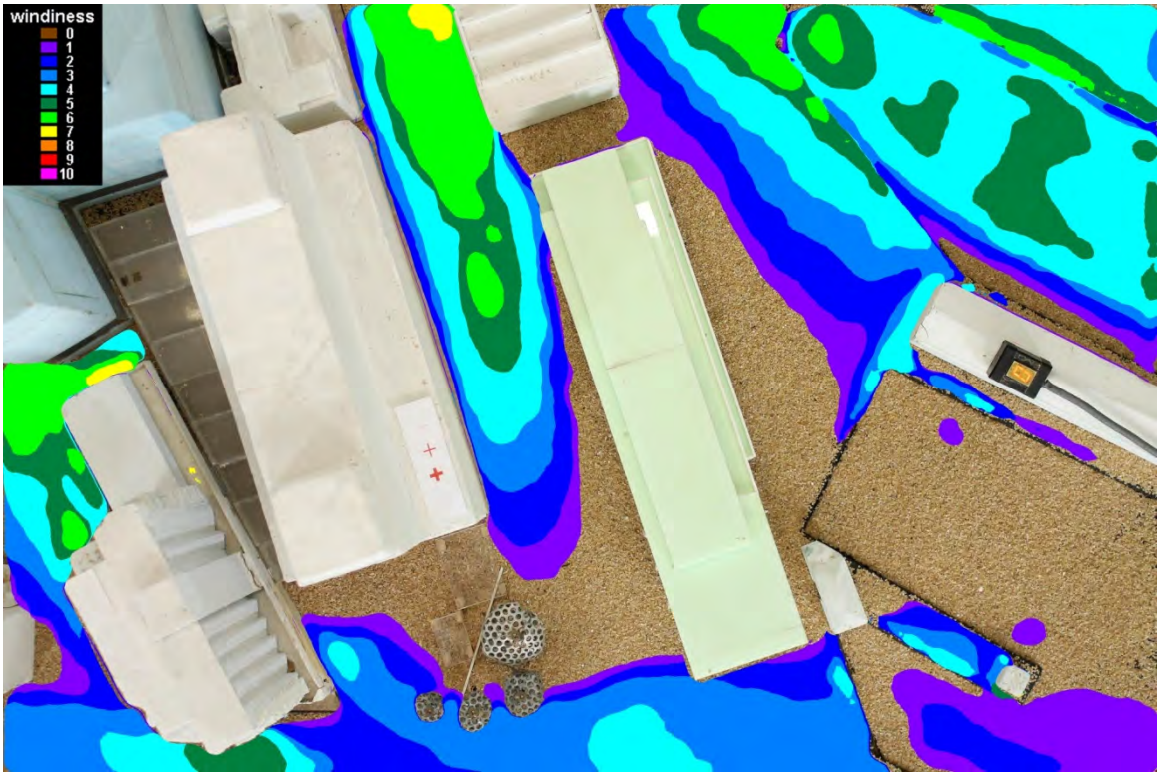


Figure 3b: Relative Windiness - Proposed Development - Wind From 320°

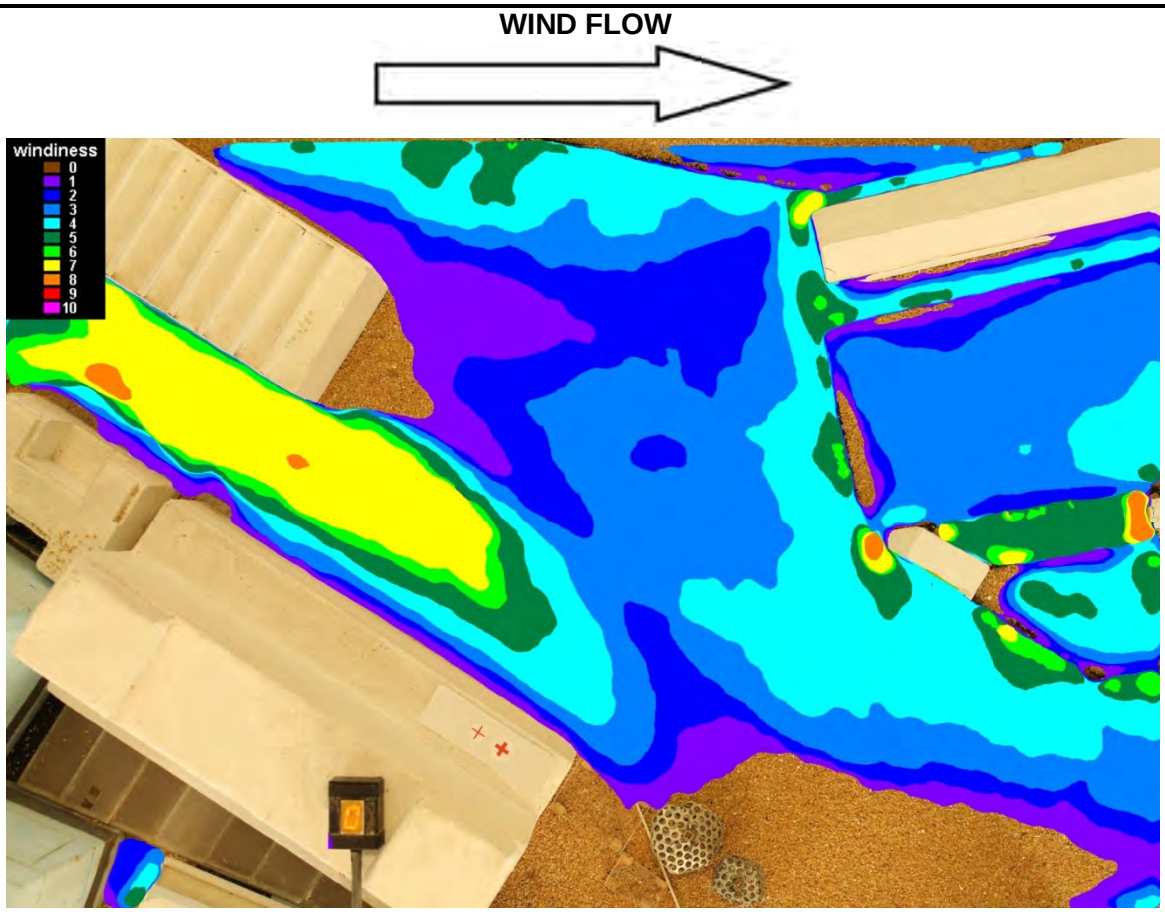


Figure 4a: Relative Windiness – Existing Situation - Wind From 360°

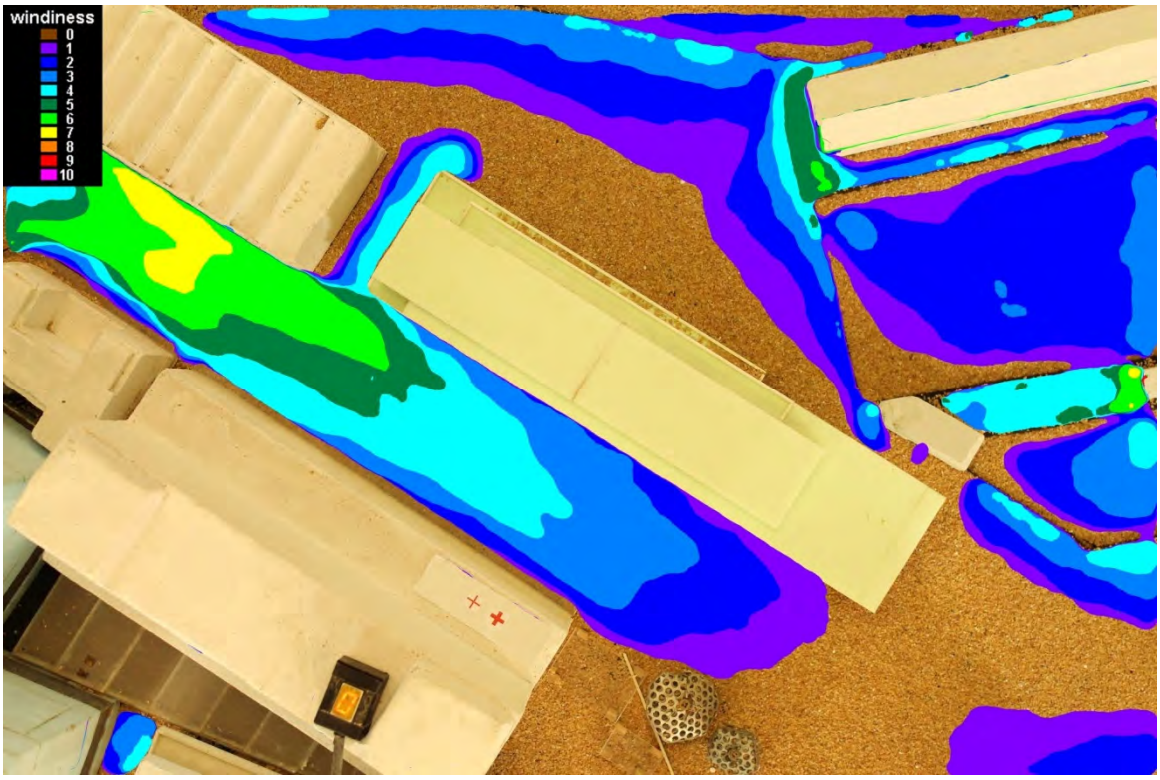


Figure 4b: Relative Windiness - Proposed Development - Wind From 360°

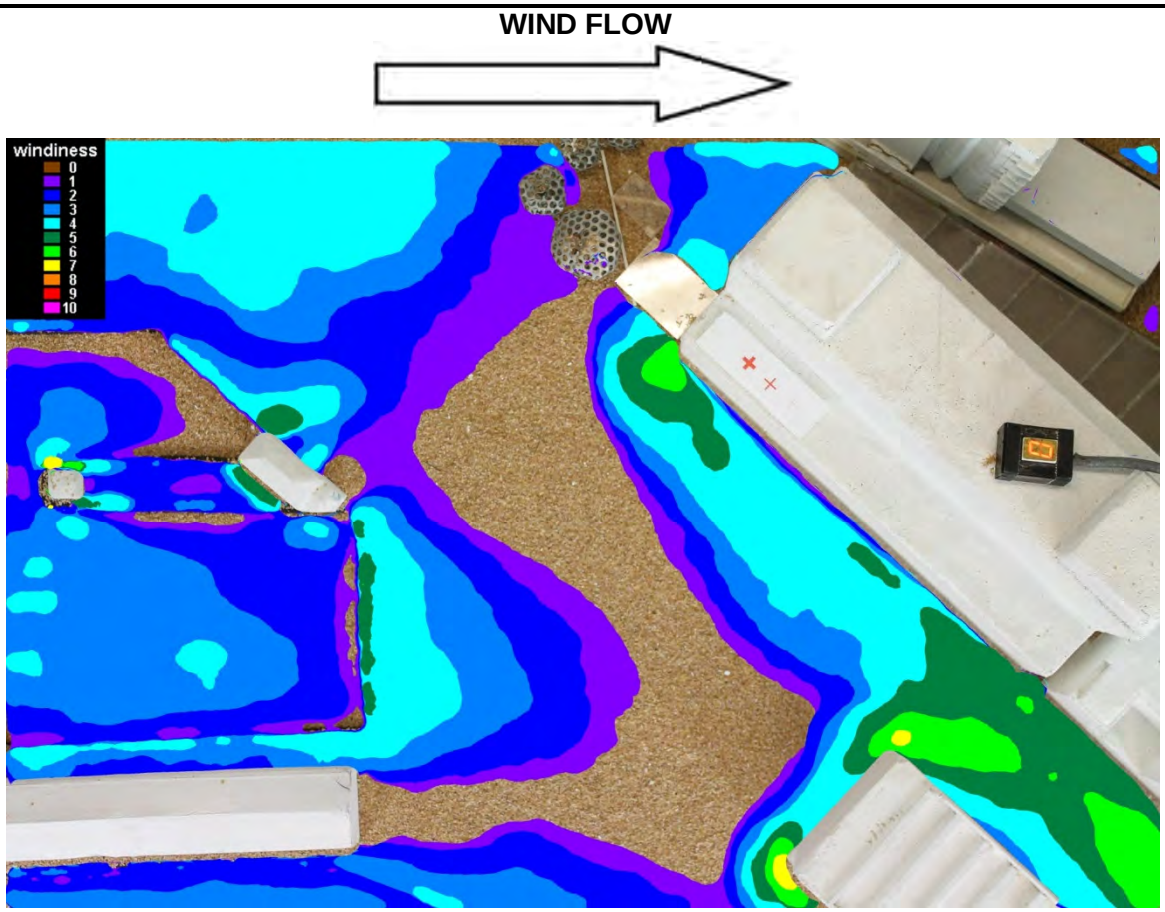


Figure 5a: Relative Windiness – Existing Situation - Wind From 170°

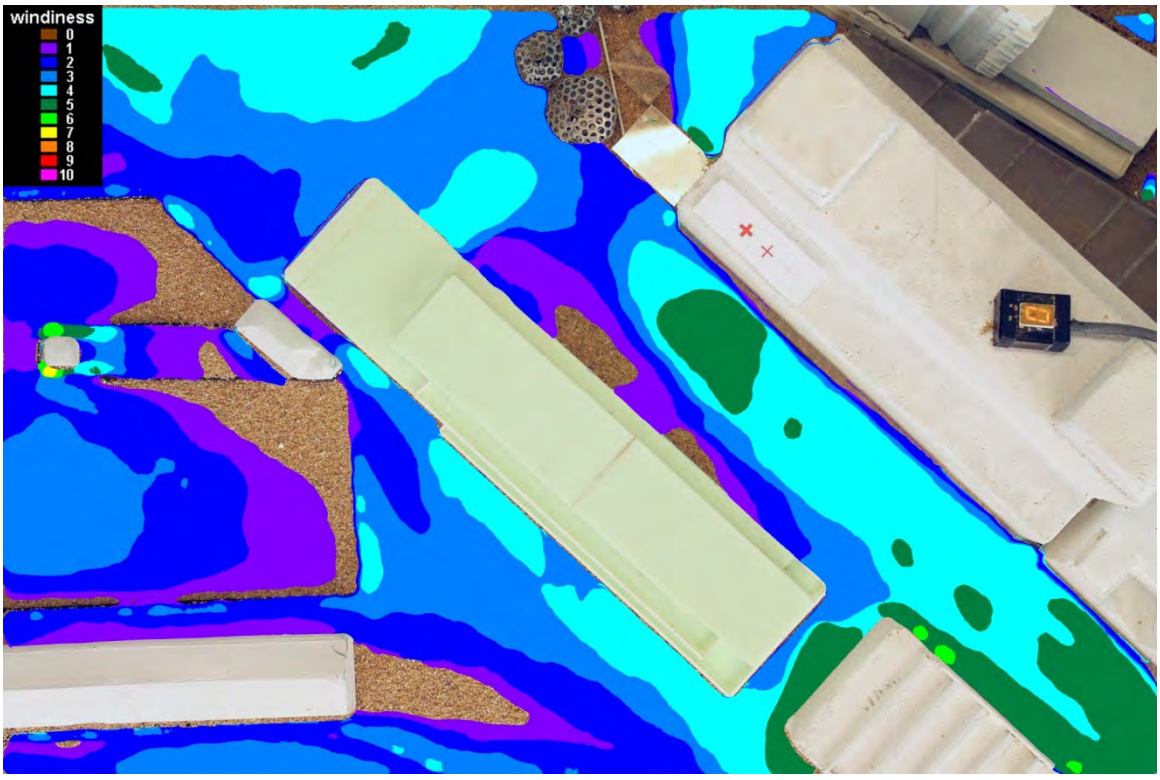


Figure 5b: Relative Windiness - Proposed Development - Wind From 170°

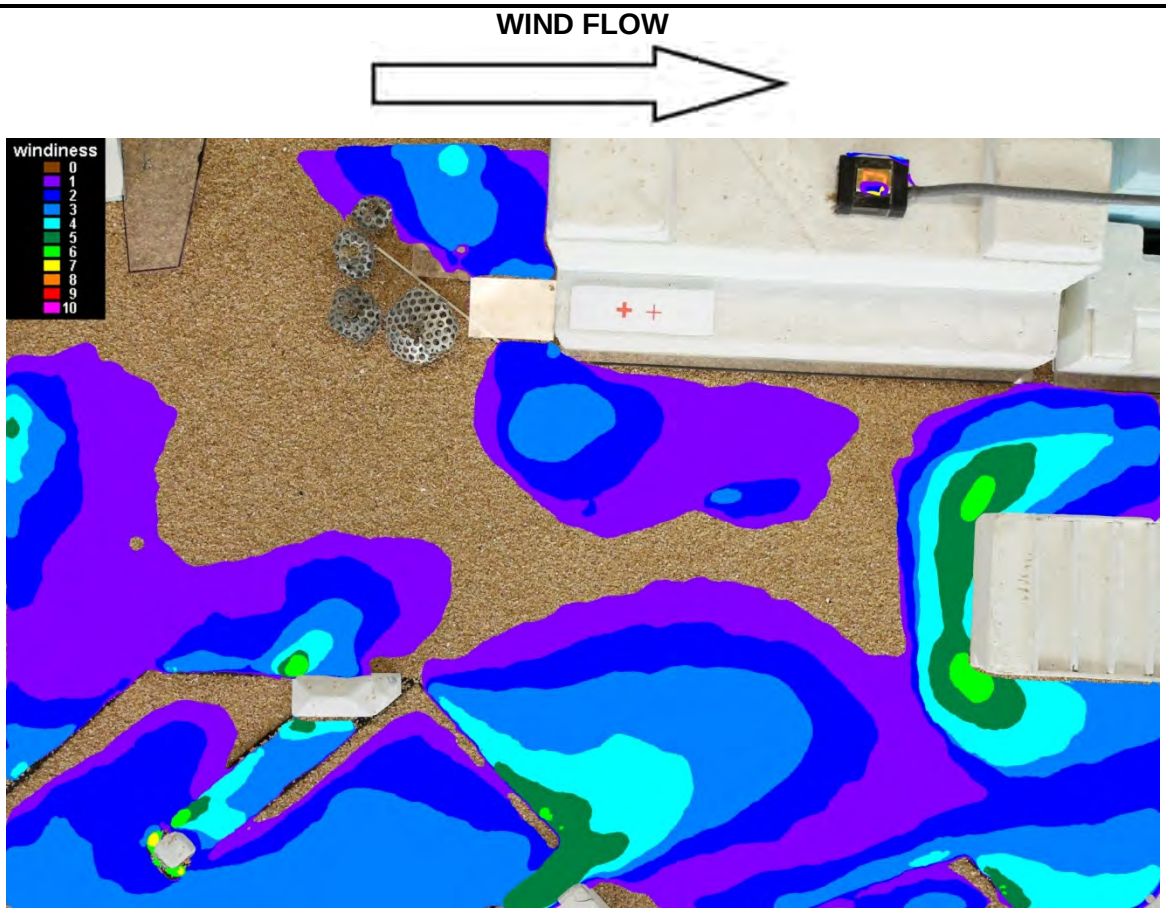


Figure 6a: Relative Windiness – Existing Situation - Wind From 210°

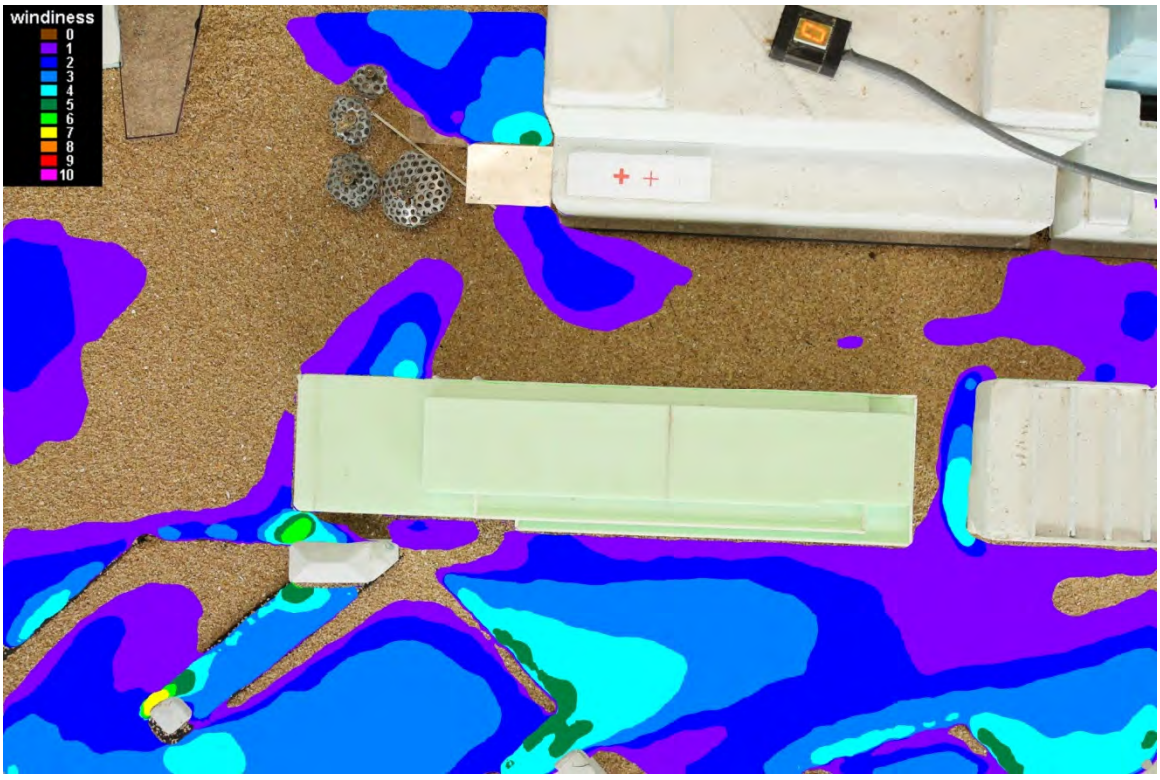


Figure 6b: Relative Windiness - Proposed Development - Wind From 210°

5 Wind Speed Measurements

Wind speed data was measured for the existing situation and with the proposed development in place for the eight wind directions described in Section 3. The resulting maximum calculated gust wind speeds at each location out of the eight wind directions are listed in Table 1 for these configurations. These speeds can be compared with the Safety Criteria wind speed of 20m/s specified in District Plan Change 48 of the Wellington City District Plan. A change of 1m/s in the wind speed is not considered significant within the limitations of the test method. The individual directional wind speeds are listed in full in Appendix F.

Table 1: Calculated Gust Speeds, V_c (m/s)

Notes: **Exg = with existing situation, New = with proposed development, - = not measured, = calculated gust speed > 20m/s Safety Criteria, ▲ = increase of 2m/s or more over existing maximum wind speed, ▽ = decrease of 2m/s or more over existing maximum wind speed**

Location	Exg		New
A	29		30
B	23		24
C	20		20
D	26		27
E	24		24
F	23	▽	16
G	23		24
H	22		22
I	21		20
J	18		18
K	18		18
L	17		18
M	20		20
N	15		15
O	18		17
P	18		18
Q	20		19
R	18	▽	15
S	18		17
T	20		20
U	20	▽	18
V	18		17
W	17		17
X	21	▽	16
Y	21		20
Z	22	▽	18
A1	19	▽	16
B1	24		23
C1	23		23
D1	19		18
E1	20	▽	14

Table 1: Calculated Gust Speeds, V_c (m/s) - continued

Notes: **Exg = with existing situation, New = with proposed development, - = not measured,**
= calculated gust speed > 20m/s Safety Criteria,
▲ = increase of 2m/s or more over existing maximum wind speed,
▽ = decrease of 2m/s or more over existing maximum wind speed

Location	Exg		New
F1	20	▽	13
G1	20		21
H1	19		18
I1	18		19
J1	20		19
K1	20	▽	18
L1	20		21
M1	23		23
N1	20		19
O1	19		20
P1	24		24
Q1	20		19
R1	25	▽	23
S1	27		27
T1	20		21

6 Frequency of Occurrence

The wind speeds presented in Section 5, and in Appendix F, can also be described in terms of the number of days per year for which the Wellington City District Plan Cumulative Effect mean wind speed criteria thresholds of 2.5m/s (moderate winds) and 3.5m/s (strong winds) will be equalled or exceeded. This does not change the underlying data, but simply changes the variable from wind speed to days per year. Tables 2 and 3 list the total days per year that 2.5m/s and 3.5m/s are equalled or exceeded respectively, for the existing situation and the proposed development. A change of 20 days/year is the minimum level considered to be a change in wind conditions. Note that, in this context, a day is defined as a cumulative duration of 24 hours, which may be spread over a number of calendar days and different wind directions.

Table 2: Days per year Cumulative Effect Criteria (2.5m/s) Are Equalled or Exceeded

Notes: **Exg** = existing situation, **New** = proposed development, - = not measured.
Δ = change between existing situation and proposed development.
= increase in time of occurrence > 20days,
= decrease in time of occurrence > 20days

Location	Days			Location	Days		
	Exg	New	Δ		Exg	New	Δ
A	222	240	18	A1	137	57	-80
B	229	240	11	B1	221	210	-11
C	204	187	-17	C1	215	215	0
D	257	209	-48	D1	160	121	-39
E	257	255	-3	E1	149	23	-126
F	179	120	-59	F1	139	42	-97
G	261	262	1	G1	131	95	-36
H	197	192	-5	H1	128	140	12
I	185	160	-25	I1	92	160	68
J	133	134	1	J1	175	181	6
K	144	168	24	K1	165	101	-64
L	92	121	29	L1	207	214	7
M	170	186	16	M1	190	189	-1
N	107	97	-10	N1	190	174	-16
O	110	146	36	O1	199	181	-18
P	149	97	-52	P1	203	202	-1
Q	163	123	-40	Q1	175	171	-4
R	150	73	-77	R1	247	247	0
S	149	116	-33	S1	240	225	-15
T	164	118	-46	T1	195	200	5
U	172	127	-45				
V	166	157	-9				
W	151	155	4				
X	152	63	-89				
Y	133	107	-26				
Z	120	128	8				

Table 3: Days per year Cumulative Effect Criteria (3.5m/s) Are Equalled or Exceeded

Notes: **Exg** = existing situation, **New** = proposed development, - = not measured.
Δ = change between existing situation and proposed development.
= increase in time of occurrence > 20days,
= decrease in time of occurrence > 20days

Location	Days			Location	Days		
	Exg	New	Δ		Exg	New	Δ
A	159	185	26	A1	69	24	-45
B	174	189	15	B1	139	125	-14
C	136	112	-24	C1	132	133	1
D	202	139	-63	D1	75	48	-27
E	203	198	-5	E1	80	2	-78
F	107	47	-60	F1	74	4	-70
G	208	211	3	G1	62	52	-10
H	116	109	-7	H1	58	69	11
I	114	88	-26	I1	46	83	37
J	68	78	9	J1	103	112	9
K	72	102	30	K1	81	47	-34
L	42	65	23	L1	132	143	11
M	102	118	16	M1	123	124	1
N	35	35	0	N1	107	89	-18
O	46	69	23	O1	119	108	-11
P	74	49	-25	P1	126	124	-2
Q	87	64	-23	Q1	83	81	-2
R	67	22	-45	R1	181	180	-1
S	63	53	-10	S1	174	154	-20
T	80	60	-20	T1	111	117	6
U	87	58	-29				
V	77	72	-5				
W	64	71	7				
X	73	20	-53				
Y	69	42	-27				
Z	63	47	-16				

7 Discussion of Results

7.1 Existing Local Wind Environment

This area of the waterfront around the development site is a windy one in the context of the Wellington central city area. Existing gust wind speeds are well over 20m/s at many locations in both northerly and southerly winds. This is primarily due to the degree of exposure that the area has to the prevailing winds, and the resulting strong horizontal wind flows, with only scattered low-rise and medium-rise buildings to provide direct shelter. Consequently, existing wind speeds range from extremely high to very low depending on the degree of shelter that is afforded to different locations. The more sheltered areas are mostly localised areas downwind of buildings. Windier regions mostly occur around the windward corners and sides of the more exposed buildings, at the intersections of streets and in large open areas.

7.2 Hot-Film Wind Speed Measurements

Table 4 below summarises the calculated gust wind speed data. This includes the average, maximum and minimum gust speeds across the individual directions and locations. Also included in this table are the numbers of locations at which the 20m/s Safety Criteria gust speed is exceeded.

Table 4: Summary of Calculated Gust Speed Results

Parameter	Configuration	
	Exg	**New**
Average Gust Wind Speed (m/s)	16.2	15.4
Maximum Wind Speed (m/s)	29	30
Minimum Wind Speed (m/s)	7	4
Number of locations where calculated gust speed V_c > 20m/s	17	15

Tables 1 and 4 show the following:

- Across all directions and locations the average calculated gust wind speed is slightly lower for the proposed development.
- The highest gust wind speeds for any direction or locations are about the same for the proposed development and the existing situation.
- There are seventeen locations where the existing wind speeds are above the 20m/s Safety Criteria threshold, with a maximum gust speed of 29m/s at location A. This compares with fifteen locations for the proposed development, and a maximum gust speed of 30m/s, also at location F. At many of these locations the speeds are either the same as for the existing situation, or differ by 1m/s, which is not considered a change.
- There are no locations where the maximum gust speed is increased above the 20m/s threshold by the new building.
- There are ten locations where the maximum gust speed is reduced by 2m/s or more, and there were no locations where the gust speed was increased by 2m/s or more.

7.3 Frequency of Occurrence Data

Table 5 summarises the frequency of occurrence data for both the 2.5m/s and 3.5m/s Cumulative Effect Criteria thresholds. Included in this table are the numbers of locations where changes in the frequency of occurrence are greater than the ±20days/year. A change of 20 days/year is the minimum level considered to be a change in wind conditions that can be attributed to a building configuration change according to the test methodology.

Table 5: Summary of Time of Occurrence Results

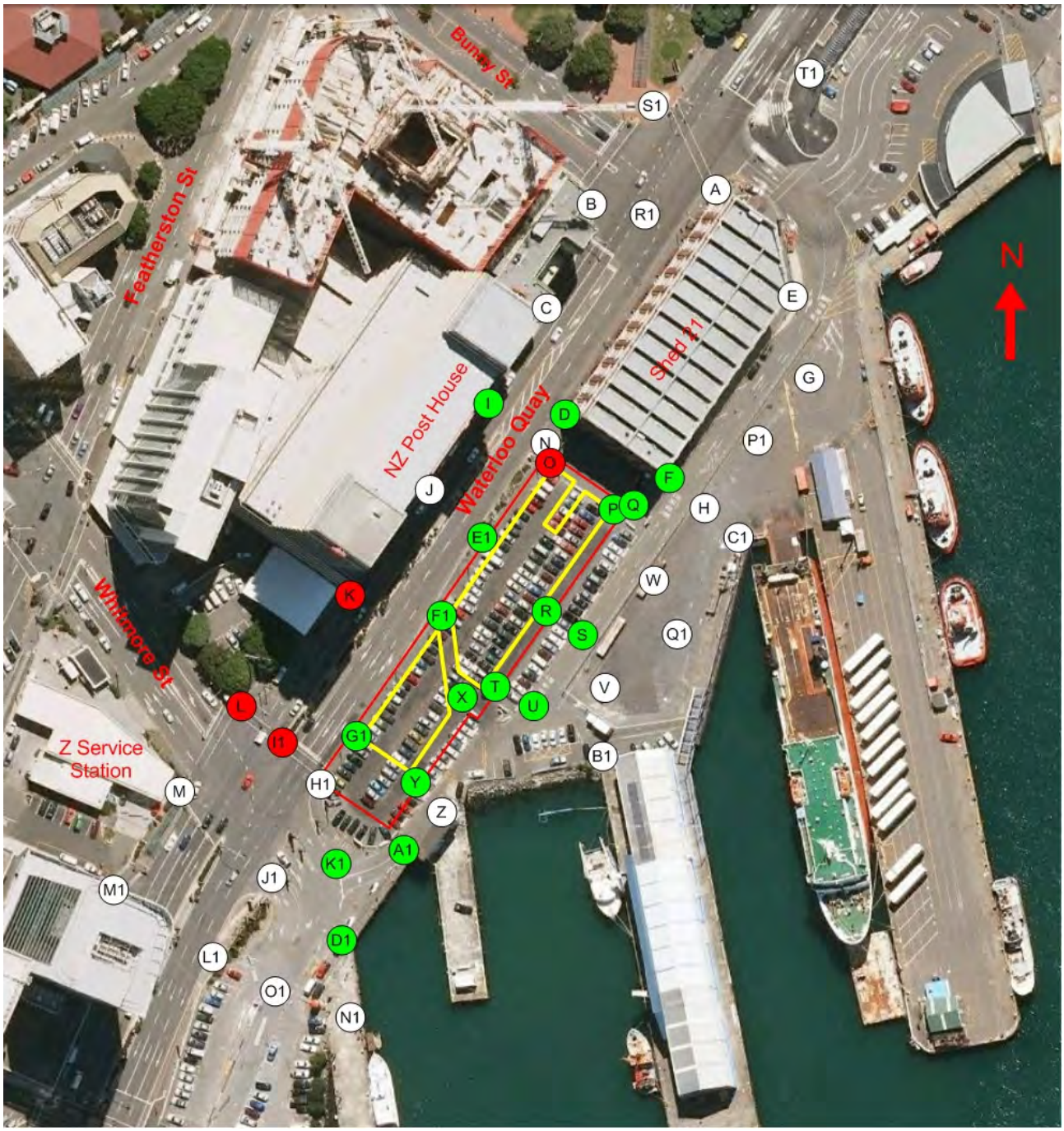
Parameter	2.5m/s Threshold		3.5m/s Threshold	
	Exg	New	Exg	New
Average Days Exceeding (1)	173	155	101	90
Maximum Days Exceeding (at any location)	261	262	208	211
Minimum Days Exceeding (at any location)	92	23	35	2
Number of locations where increase > 20 days	4		5	
Number of locations where decrease > 20 days	17		16	
Largest increase in days exceeding	68		37	
Largest decrease in days exceeding	-127		-78	

(1) – this is the average of the hours across all directions and locations that exceed the threshold

Figures 7 and 8 show the differences in the time for which the Cumulative Effect Criteria thresholds of 2.5m/s (moderate winds) and 3.5m/s (strong winds) are exceeded between the existing situation and the proposed development.

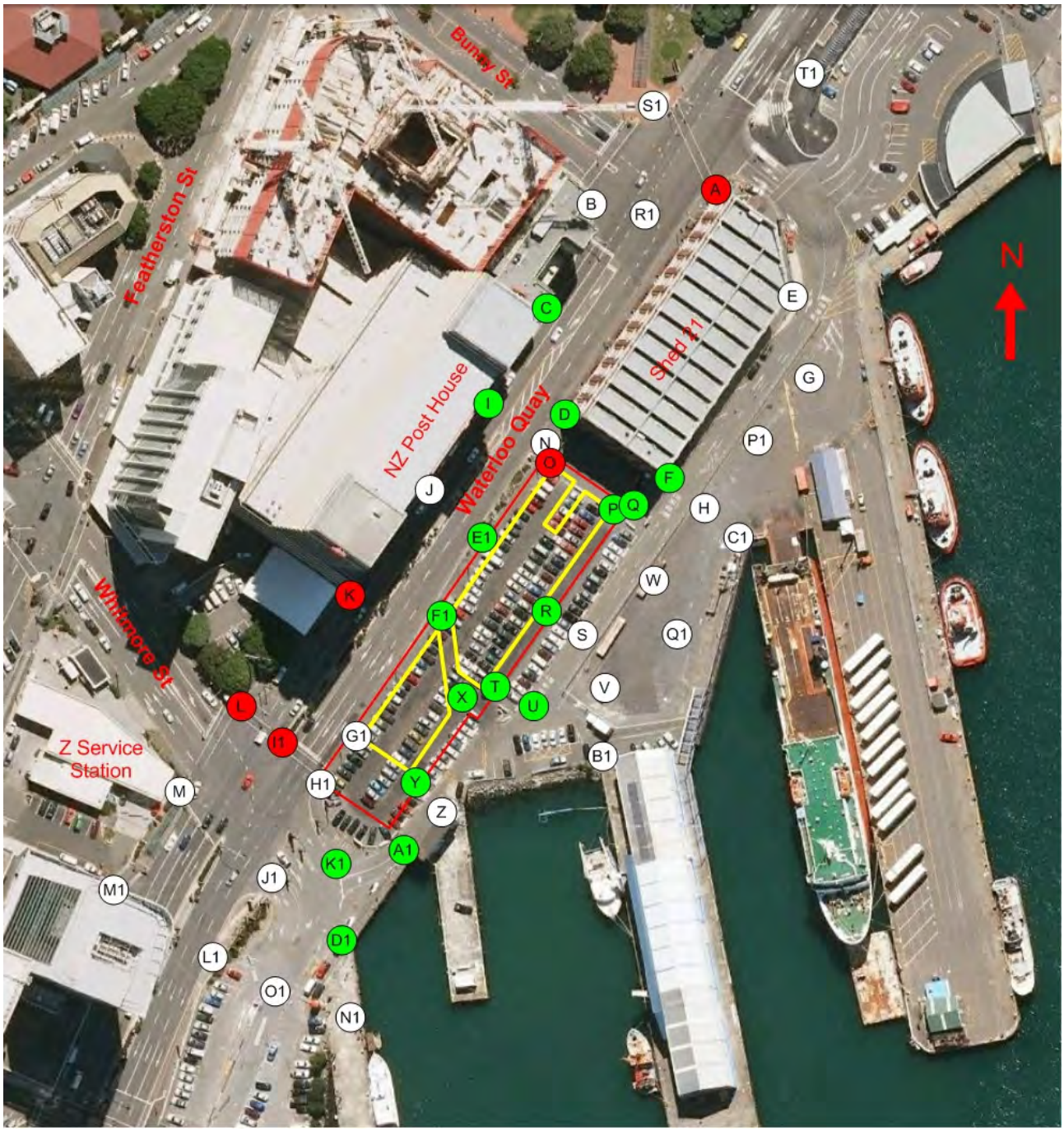
Table 5 and Figures 7 and 8 show the following:

- The average number of days that the mean wind speeds exceed the Cumulative Effect Criteria thresholds is notably lower with the proposed development.
- There are only a small number of locations where the increases in the amount of time that the Cumulative Effect Criteria thresholds are exceeded were greater than 20 days. There are many more locations where the decreases in the amount of time that the Cumulative Effect Criteria thresholds are exceeded were greater than 20 days.



≤ -20 days ≥ +20 days -20 to +20 days

Figure 7. Changes in Number of Days Exceeding 2.5m/s Cumulative Effect Criteria



≤ -20 days ≥ +20 days -20 to +20 days

Figure 8. Changes in Number of Days Exceeding 3.5m/s Cumulative Effect Criteria

7.4 Overall Assessment of Building Design

The gust speed measurements show that there are no locations where the speed has been increased over the Safety Criteria threshold speed of 20m/s by the proposed building, and that there were ten locations were an existing speed greater than 20m/s was reduced by the new building. However, there were a total of fifteen locations where the gust speed with the new building exceeded the 20m/s threshold.

The frequency of occurrence data does show that, taken overall, there is a notable improvement in the local wind environment with the new building. When considered over the full range of locations and wind directions the overall effect is quite beneficial, but for a number of locations and for certain wind directions the changes were considered to warrant investigation of the cause of the effects and potential mitigation.

7.5 Investigation of Different Design Configurations

Given the identified effects of the new building, a limited range of additional wind speed measurements was carried out to (1) identify the effects for an 18.6m block (this being the trigger height for a wind report), and (2) investigate the potential to improve wind conditions compared to the original design. The following configurations, with screen locations as shown in Figure 9, were investigated:

(1) An 18.6m slab-side block with the same footprint as the new building, with no overhangs;
(2) Vertical screens, 2.5m high, and with porosity of around 35%, at the four corners of the building, directly under the overhangs
(3) A vertical 2.5m high, 35% porous, screen across between the new building and Shed 21 along the line of the existing wharf gate pillars

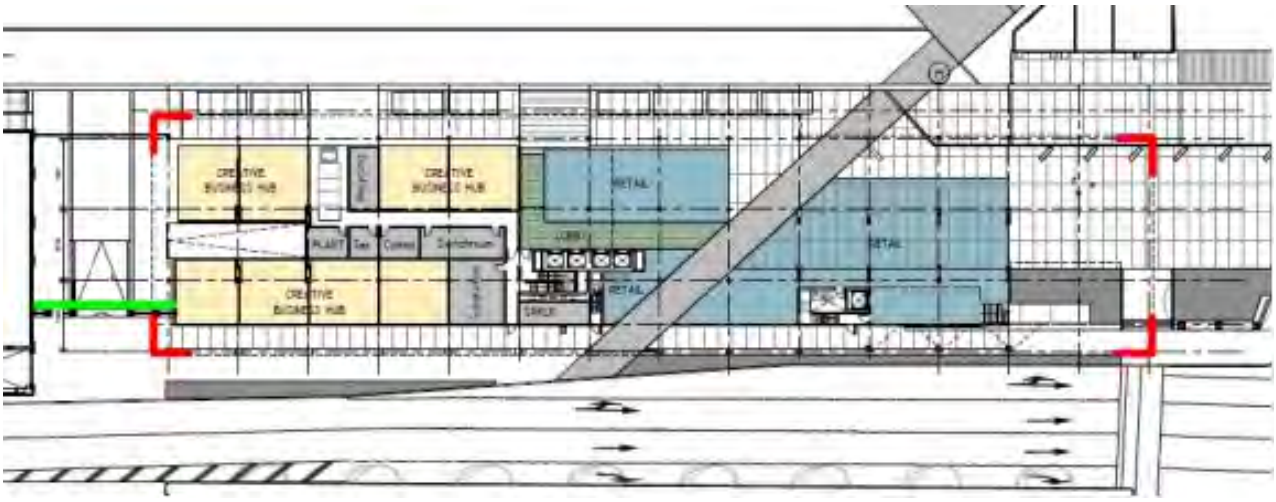


Figure 9 Locations of vertical screen options investigated

Measurements were made for selected wind directions showing either the largest changes compared to the existing situation, or the highest gust wind speeds. It is expected that the different

design configurations would perform similarly for the other wind directions.The measured data was processed to produce gust speeds, and the results are listed in Table 6.

Table 6: Design Configurations – Calculated Gust Speeds

Notes: **E** = existing situation, **N** = proposed development, - = not measured, Configurations as numbered above.

Point	150°				170°					190°					340°			360°		
	Exg	New	2	3	Exg	New	1	2	3	Exg	New	1	2	3	Exg	New	1	Exg	New	1
B	18	14	-	-	21	21	-	-	-	14	17	16	-	-	23	24	-	24	24	-
C	13	12	-	-	18	15	16	-	-	19	16	16	-	-	18	18	19	20	20	20
D	16	14	-	-	23	15	18	-	-	24	15	17	-	-	23	23	21	26	27	26
F	11	13	-	-	15	17	16	-	-	24	15	16	-	-	19	16	17	15	13	13
K	13	10	-	-	15	15	14	-	-	14	18	17	-	-	19	19	19	18	17	17
L	16	16	-	-	17	18	-	-	-	17	18	-	-	-	13	15	-	11	13	-
O	11	14	14	14	13	17	-	16	17	16	15	-	15	15	19	17	-	13	14	-
P	10	15	14	15	12	18	-	18	17	14	17	-	17	16	19	12	-	14	10	-
Q	10	15	15	14	12	19	19	19	18	16	17	-	18	18	21	16	-	15	11	-
V	11	12	-	-	17	16	15	-	-	18	18	17	-	-	17	16	17	15	12	13
W	11	13	-	-	14	17	17	-	-	17	17	16	-	-	17	17	17	15	13	14
Y	7	11	-	12	9	13	-	-	11	17	20	-	-	20	22	15	-	18	11	-
Z	11	11	-	11	10	13	13	-	12	11	18	17	-	18	22	16	-	17	13	-
A1	14	13	-	13	18	16	16	-	15	19	17	14	-	16	12	9	8	18	8	9
G1	10	16	-	17	14	19	-	-	20	20	21	-	-	21	19	10	-	17	14	-
H1	13	14	-	-	18	17	18	-	-	20	18	21	-	-	13	14	14	17	15	14
I1	15	15	-	-	18	18	19	-	-	18	19	22	-	-	12	14	-	12	16	-

From the results of the additional measurements the following observations are made:

1. Gust wind speeds for the 18.6 m block are generally similar to those for the proposed development, and at some locations are higher, most notably at location I1. These results indicate that it is not primarily the building height that produces most of the changes in the wind environment, and that the building has a significant effect on deflecting horizontal wind flows.

2. The vertical screen between the new building and Shed 21 had no measurable effect on the gust speeds at the locations used.

3. The vertical screens at the corners of the new building also had no significant effect on the gust speeds at the locations used. However, measurements made immediately in the lee of the screens (10-12m/s) suggest that such screens could be used to provide localised shelter, or could potentially be more effective if they were more extensive. However, given our experience in dealing with consent issues for other waterfront buildings, wind shelter will often need to be balanced against other design considerations, e.g. urban designs and views.

8 Conclusions

(1) Wind conditions around the proposed development site currently range from very low to extremely high. The open nature of the area, with few buildings to provide significant shelter, means that there is considerable exposure to strong wind flows for some or all of either the prevailing northerly or southerly wind directions. What wind shelter that is available depends significantly on the wind direction, occurring mostly at locations downwind of buildings for particular wind directions.

(2) The development site is currently vacant. Any building on the site will change the local wind flow patterns because the wind that currently blows across the open site will be forced to take other paths. Accordingly, some changes to the existing wind environment, both increases and reductions, were expected.

Gust Speeds – Safety Criteria

(3) Existing gust wind speeds varied from a low value of 7m/s to a very high 29m/s, compared with a range of 4m/s to 30m/s for the proposed building. This shows that the windiest conditions with the proposed development are no worse than they are currently. Taken over all directions and locations the average gust speed is slightly lower for the proposed development.

(4) There were seventeen locations for the existing situation where the gust speeds exceeded the 20m/s Safety Criteria in the Wellington District Plan. This compares with fifteen locations for the new building.

(5) There were no locations where the gust speed was increased significantly, such that they exceeded the 20m/s Safety Threshold. There were ten locations where existing wind speeds over the 20m/s threshold were significantly reduced.

Frequency of Occurrence – Cumulative Effect Criteria

(6) The average number of days per year over all locations and wind directions that the gust speeds exceed the Cumulative Effect Criteria thresholds was notably lower with the new building.

(7) There were only a small number of locations where the increases in the amount of time that the Cumulative Effect Criteria thresholds were exceeded were greater than 20 days. There were many more locations where the decreases in the amount of time that the Cumulative Effect Criteria thresholds are exceeded were greater than 20 days.

Overall Assessment of Building Design

(8) Overall, the proposed development caused a notable improvement in the local wind environment over quite sizeable areas around the building, primarily due to the redistribution of existing horizontal wind flow patterns.

Design Configuration Changes

(9) Additional testing showed that any building of substantial size on this site will typically cause significant redistribution of wind flow patterns and wind speeds, and that the new building's setbacks help it to perform better than a lower slab-sided building at some locations.

(10) The additional testing also showed that vertical screens could potentially be used to provide localised screening at specific locations if considered appropriate, although it is realised that the desire for wind shelter would need to be balanced against other design considerations.

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Appendix A: Wind Effects On People

One of the primary parameters in any assessment of how wind affects people are the peak gust speeds and the associated rates of change of the wind speed. Table A-1 below gives a summary of the typical effects of 3-second gust speeds on people in an urban situation (after Penwarden).

Table A-1 Typical effects of a 3-second gust on pedestrians.

Wind Description	Gust Speed (m/s)	Effects
Moderate breeze	5 – 8	Raises dust, dry soil and loose paper; hair disarranged.
Fresh breeze	8 – 11	Force of wind felt on body; limit of agreeable wind.
Strong breeze	11 - 14	Walking irregular; hair blown straight; umbrellas used with difficulty.
Near gale	14 - 17	Walking difficult to control; wind noise unpleasant; body leans into wind.
Gale	17 - 21	Great difficulty with balance; body blown sideways; dangerous for elderly people.
Strong gale	21 - 24	People blown over by gusts.
Storm	24 - 28	Impossible to stand up; necessary to crouch and hold onto a support.
Violent Storm	>28	Unlikely to be ever experienced.

The wind performance of an urban area may be classified in a number of different ways, but one of the simplest and most widely accepted is in terms of the "annual maximum 3 second gust". The criteria used (after Melbourne) have been established internationally for some time and are given in the Table A-2. A location which experiences a maximum annual gust speed within a certain category in Table A-2 will typically also experience a range of wind conditions throughout the year, which result in the criteria being appropriate.

The expression "annual maximum 3 second gust" is shorthand for a description of the probability of occurrence of a certain level of wind speed, given that both weather conditions and wind turbulence vary in an unpredictable manner. It should be noted that the expression describes a wind speed which is in fact a little less than the highest wind speed that one would be likely to record if an anemometer were mounted in a city street for a year.

Table A-2 Pedestrian level gust speed comfort criteria.

Category	Annual Maximum 3 Second Gust (m/s)	
A	23 and above	Dangerous. Completely unacceptable in a main public area.
B	16 to 23	Undesirable in a main public area.
C	Less than 16	Generally acceptable for walking.
D	Less than 13	Generally acceptable for stationary short exposure activities (e.g. window shopping, standing or sitting in plazas).
E	Less than 10	Generally acceptable for stationary long exposure activities (e.g. outdoor restaurants).

For Wellington wind tunnel studies, we calculate a gust speed gust speed, which is based on the annual maximum hourly mean speed for a particular wind direction and the corresponding standard deviation of the wind speed multiplied by a factor. It describes the wind conditions which are equalled or exceeded during 6 hours per year, within a 20^0 sector centred on a particular wind direction. These gust wind speeds are as defined in the Wellington City District Plan.

The Wellington City District Plan specifies a gust speed criteria of 20m/s as a maximum safety limit. However, existing wind conditions often exceed this limit in many parts of the city. The criteria therefore describe a desired wind environment, which may not always be achievable in practice.

We suggest the use of the descriptive terms in Table A-3 as a means of interpretation of how the wind speeds measured in a wind tunnel study compare with the speeds which typically occur at other locations in Wellington City. It may be seen that the speed of 20m/s, which is the maximum required by the Wellington City Council, is only in the moderately high category using these descriptions. Note that this table simply compares the level of wind speeds that occur from place to place within Wellington, whereas Table A-1 describes the effects of these wind speeds on people.

Note the differences between the three tables listed here, as they use similar wind speed measurements, but describe different issues:

Table A-1: Describes the effects on people when they experience a gust of wind.
Table A-2: Internationally recognised criteria for determining the acceptability of wind conditions at a certain location throughout the year.
Table A-3: Relative descriptions of the variation of wind conditions that occur at different locations in Wellington.

Table A-3 Suggested descriptive terms for the range of gust wind speeds which typically occur at different locations within Wellington City.

Annual maximum gust speed (m/s)	
11 and below	very low
12 – 14	low
15 – 17	moderate
18 – 20	moderately high
21 – 23	high
24 – 26	very high
27 and above	extremely high

Appendix B: Wellington City District Plan

The sections of the Wellington City District Plan, which make specific reference to wind are currently being amended. The most recent publically available versions can be obtained from the Wellington City Council website.

Appendix C: Wellington City Wind Climate

The wind over Wellington City is predominantly either northerly or southerly. This is demonstrated by a sample wind rose, plotted in Figure C-1, for the wind at a height of 150 m. The rose is obtained from the wind data listed in Figure C-2.

The wind data is derived from that recorded over a 47 year period at Wellington Airport. The mean wind speed at 150 m over the city is calculated to be the same as that at the airport reference anemometer at a height of 10 m, but with the northerly winds rotated 10 degrees to the west. This relationship is based on work carried out by Jackson (1976). It is also consistent with the Deaves and Harris (1978) wind model.

From this data, the following values have been estimated for the mean hourly wind speeds that occur during 6 hours per year for a 20° sector, centred on the listed wind direction.

Reference Wind Speeds for Wellington City

Direction (degrees)	150	170	190	210	320	340	360	020
Speed (m/s)	15	20	22	22	19	22	20	15

The measured wind speeds around a building, as quoted in this report, are calculated gust speeds based on the maximum annual hourly mean wind speed and the corresponding standard deviation in the wind speed.

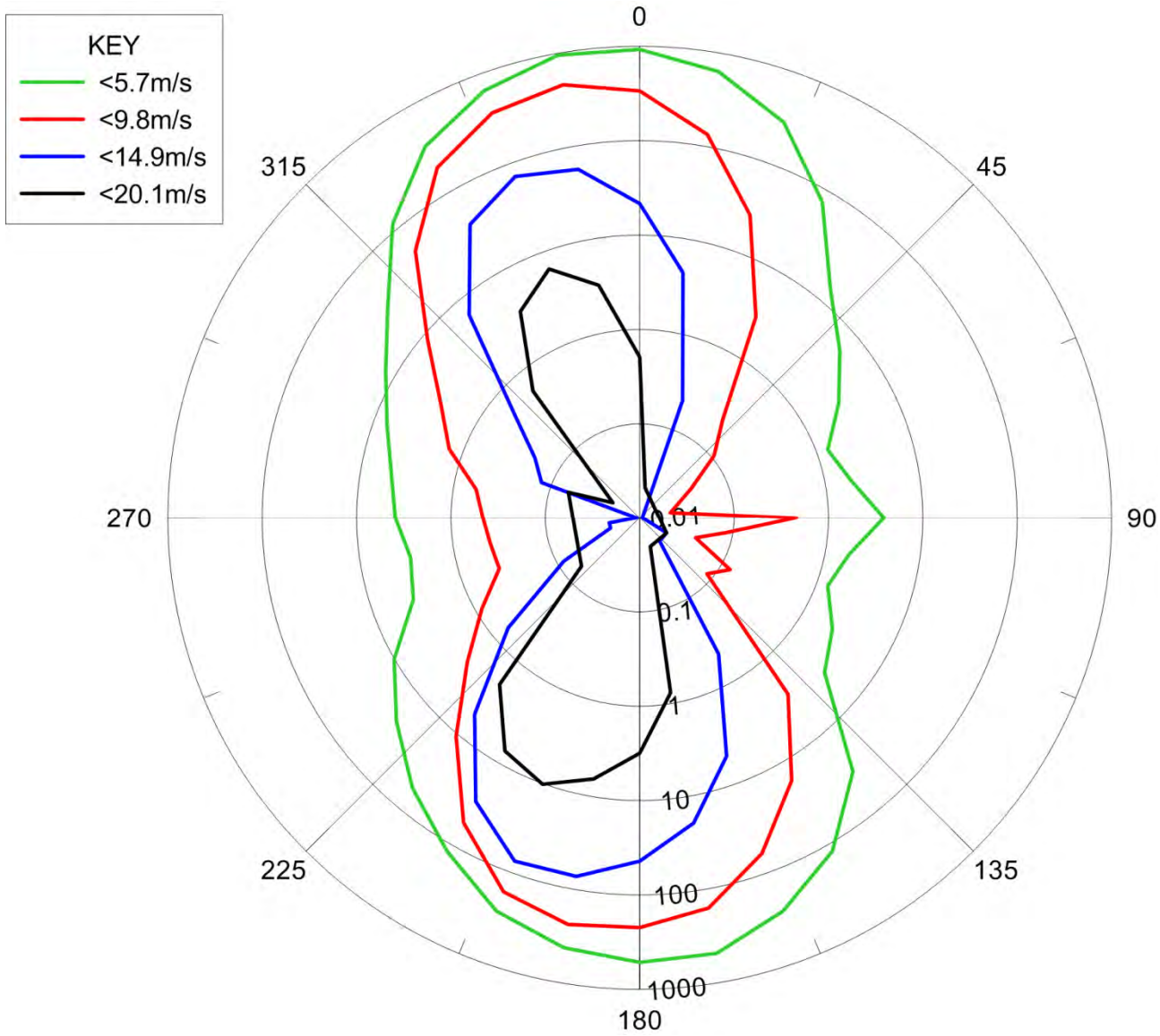

Figure C-1. **Wind Rose for Wellington City – 150m above ground level**
(Number of hours/year wind speeds are equalled or exceeded)

Wellington City mean wind speed data at 150m. Jan 1960 - Oct 2007. Based on 8760 hours per year.
This table gives the hours per year that the wind is likely to equal or exceed a given wind speed for a given direction.

Direction	kts	1.0	3.0	5.0	7.0	9.0	11.0	13.0	15.0	17.0	19.0	21.0	23.0	25.0	27.0	29.0	31.0
	m/s	0.5	1.5	2.6	3.6	4.6	5.7	6.7	7.7	8.7	9.8	10.8	11.8	12.9	13.9	14.9	15.9
10		868.6	846.6	807.7	731.4	638.3	541.0	419.3	309.8	211.9	134.3	76.2	44.5	24.1	10.0	4.4	1.7
20		494.5	468.9	425.3	357.6	290.5	218.3	140.2	84.6	47.1	26.2	11.2	6.3	2.7	0.7	0.2	0.1
30		190.0	168.9	134.9	99.3	74.2	51.3	28.2	14.4	6.4	2.9	0.9	0.3	0.2	0.0	0.0	0.0
40		70.8	55.5	37.1	21.9	14.0	8.7	4.1	1.8	0.7	0.2	0.1	0.0	0.0	0.0	0.0	0.0
50		44.0	31.8	20.8	10.4	5.9	3.3	1.5	0.7	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0
60		22.5	15.1	9.5	5.3	2.7	1.4	0.3	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
70		13.8	9.1	5.8	3.1	1.3	0.6	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
80		15.3	10.9	7.8	3.9	1.9	0.8	0.3	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
90		9.1	7.6	6.4	4.9	3.9	3.0	2.3	1.5	1.0	0.5	0.3	0.1	0.1	0.0	0.0	0.0
100		13.2	9.9	7.1	4.0	1.8	0.7	0.3	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
110		13.1	10.6	6.9	3.4	1.3	0.4	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
120		20.2	16.7	11.4	5.2	2.3	1.1	0.5	0.3	0.2	0.1	0.1	0.1	0.0	0.0	0.0	0.0
130		24.2	21.0	15.3	7.4	3.6	2.0	1.1	0.6	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0
140		68.7	65.2	57.4	43.6	32.8	23.8	15.8	10.1	5.8	2.8	1.2	0.6	0.3	0.0	0.0	0.0
150		174.0	168.6	159.2	141.6	121.0	99.7	73.7	49.9	29.4	16.6	8.7	5.0	2.9	1.4	0.5	0.1
160		335.6	331.2	322.3	301.6	274.1	239.9	189.2	140.5	94.3	61.3	38.6	25.8	16.4	8.6	4.9	2.1
170		561.9	557.4	547.3	523.9	489.1	438.7	367.2	292.0	219.2	159.1	109.7	78.6	53.3	31.2	19.4	10.9
180		603.1	596.4	583.7	555.0	516.6	467.5	401.7	335.8	274.2	221.0	169.5	133.5	100.3	65.8	43.9	26.5
190		527.6	521.5	508.2	470.9	425.6	384.2	341.5	306.6	273.0	239.1	203.6	173.7	140.8	102.1	72.7	47.2
200		374.4	368.1	353.9	315.7	274.6	241.4	214.1	196.0	180.8	166.1	150.5	135.1	117.0	95.6	75.1	53.9
210		190.1	184.4	173.5	148.5	121.2	95.6	77.0	66.8	59.9	54.2	48.5	45.0	41.2	35.2	29.8	24.0
220		99.0	95.6	88.2	73.4	55.6	39.2	26.1	18.1	13.3	10.7	9.2	8.2	7.2	6.1	5.3	4.3
230		47.5	45.0	40.1	31.6	23.2	15.1	8.6	5.4	3.3	2.4	1.7	1.4	1.1	0.8	0.7	0.3
240		25.6	23.0	19.6	14.6	10.1	6.6	3.7	2.3	1.4	0.9	0.5	0.4	0.3	0.2	0.1	0.1
250		11.2	9.7	7.4	5.3	3.6	2.7	1.5	1.0	0.6	0.4	0.2	0.1	0.1	0.0	0.0	0.0
260		8.2	6.7	5.6	4.0	2.9	2.1	1.5	1.1	0.7	0.4	0.3	0.1	0.1	0.0	0.0	0.0
270		9.1	7.6	6.4	4.9	3.9	3.0	2.3	1.5	1.0	0.5	0.3	0.1	0.1	0.0	0.0	0.0
280		9.7	8.4	7.3	5.8	4.7	3.6	2.6	1.7	1.0	0.6	0.4	0.2	0.1	0.1	0.0	0.0
290		13.2	11.7	10.5	8.7	7.1	5.8	4.5	3.3	2.2	1.4	0.7	0.4	0.3	0.1	0.1	0.1
300		18.9	17.5	16.7	15.0	12.8	11.2	8.9	6.6	4.4	2.7	1.8	1.1	0.6	0.2	0.2	0.1
310		40.0	38.3	36.3	33.8	30.5	27.1	22.5	18.0	12.8	8.6	5.1	3.4	1.9	1.1	0.6	0.2
320		137.2	134.1	130.4	124.8	118.1	109.0	95.9	81.4	65.2	49.9	35.5	26.4	18.9	10.7	6.5	3.6
330		383.4	379.1	372.7	362.9	351.5	334.7	308.4	277.1	238.0	195.2	152.6	120.5	90.2	59.1	39.3	23.6
340		722.5	715.8	705.5	683.6	660.4	630.1	584.0	523.6	450.0	371.3	288.4	222.6	165.0	106.3	71.3	41.6
350		1074.1	1062.4	1044.2	1003.7	957.7	900.6	818.5	716.1	591.2	461.4	334.1	243.1	163.5	94.1	56.7	29.4
360		1099.4	1083.4	1058.0	997.5	926.5	845.9	733.2	604.5	468.2	336.0	219.7	144.1	87.2	41.3	21.6	8.8
Totals :		**8333.7**	**8103.5**	**7750.6**	**7128.2**	**6465.2**	**5760.2**	**4900.8**	**4073.8**	**3258.2**	**2527.0**	**1869.3**	**1420.9**	**1036.1**	**670.7**	**453.3**	**278.8**

Hours of calm : 426.3
Total hours : 8760.0

Figure C-2. Wellington City Wind Data

Wellington City mean wind speed data at 150m. Jan 1960 - Oct 2007. Based on 8760 hours per year.
This table gives the hours per year that the wind is likely to equal or exceed a given wind speed for a given direction.

Direction	kts	33.0	35.0	37.0	39.0	41.0	43.0	45.0	47.0	49.0	51.0	53.0	55.0	57.0	59.0	61.0	63.0
	m/s	17.0	18.0	19.0	20.1	21.1	22.1	23.2	24.2	25.2	26.2	27.3	28.3	29.3	30.4	31.4	32.4
10		0.7	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
50		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
60		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
70		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
80		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
90		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
100		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
110		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
120		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
130		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
140		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
150		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
160		1.2	0.5	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
170		7.1	4.3	2.2	0.8	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
180		17.7	10.9	5.8	3.2	1.1	0.5	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
190		32.3	21.2	11.4	6.5	3.3	1.8	1.0	0.5	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
200		38.5	25.4	15.6	10.2	6.3	4.0	2.8	1.8	1.0	0.6	0.4	0.3	0.1	0.1	0.1	0.0
210		19.4	15.0	10.1	7.2	5.1	3.9	3.0	2.0	1.3	0.7	0.5	0.3	0.2	0.0	0.0	0.0
220		3.7	3.2	2.5	2.0	1.6	1.2	0.9	0.6	0.3	0.1	0.1	0.1	0.1	0.0	0.0	0.0
230		0.2	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
240		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
250		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
260		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
270		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
280		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
290		0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
300		0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
310		0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
320		2.4	1.7	0.9	0.6	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
330		15.5	9.7	5.8	3.4	2.0	1.4	0.9	0.5	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0
340		28.4	18.3	11.1	6.5	3.4	2.0	1.1	0.7	0.4	0.2	0.1	0.0	0.0	0.0	0.0	0.0
350		18.6	10.7	5.6	3.2	1.6	1.0	0.5	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
360		4.8	2.5	1.1	0.5	0.2	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Totals :		190.9	124.3	72.4	44.2	25.0	16.1	10.8	6.3	3.5	1.7	1.1	0.7	0.4	0.2	0.2	0.1

Hours of calm : 426.3
Total hours : 8760.0

Figure C-2. Wellington City Wind Data (continued)

Appendix D: Wind Tunnel and Boundary Layer

The Opus Research wind tunnel is an open return type, with an overall length of 68 m. The working section measures 2.74 m wide x 1.22 m high (9 ft x 4 ft). The airflow is generated by a six blade, 1.52 m diameter, 34 kW axial flow Woods fan downwind of the working section. The maximum air speed in the working section is about 12 m/s. A variable speed motor controller controls the air speed.

The long upwind section of the wind tunnel allows the development of a deep turbulent boundary layer to simulate the natural atmospheric boundary layer at an appropriate scale. The correct velocity and turbulence profiles are generated by an adjustable fence and an array of wooden blocks on the floor of the tunnel.

The Deaves and Harris (1978) mathematical model of the structure of strong winds is recognised as the recommended model for engineering design purposes. It is used in the code of practice for wind loading on buildings, AS1170.2. The four terrain categories defined in AS1170.2 are as follows.

Terrain Categories

1 Flat, treeless plains, sea coasts

2 Open terrain, well scattered obstructions (air fields)

3 Suburban, industrial and well wooded areas

4 City centre condition

Appendix E: Bran Flake Flow Visualisation

Flow visualisation using bran flakes provides a means of quickly identifying the relative wind speeds over the surface of a model.

The bran flakes are sieved to provide flakes between 1.0 mm and 1.4 mm in size. With the wind tunnel switched off, the model is sprinkled with a thin uniform layer of the bran. The layer is approximately two bran flakes deep, but it completely obscures the surface of the model. The wind tunnel speed is then steadily increased over a period of 20 minutes and the bran is progressively blown away. The areas where the bran first blows away indicate where the highest gust speeds are likely to occur. In other areas the bran accumulates slowly and these are generally where the lowest gust speeds occur. The changing patterns in the bran are photographed as the test proceeds.

The photographs from each test are processed to give the contour images shown in the wind report. Areas of the photographs that change from one photograph to the next in the test sequence are coloured, to give contours of increasing erosion. These contours correspond loosely to gust wind speeds on the surface of the model, although no accurate gust speed can be determined for a particular location from the contours. It is possible to compare the results from two separate tests, but the comparison must be made with caution because each test is inevitably slightly different. Ideally, the bran tests should only be used as a rough visual indication of where the highest wind speeds occur and as a guide to where hot wire speed measurements should be concentrated.

While the test is in progress, the movement of the bran is also useful for visualisation of the flow around the model. Usually this only indicates the direction of the flow at ground level, but in certain flow conditions (e.g. in vortices or in high turbulence) the bran flakes also become airborne and the three dimensional flow is then apparent. Unfortunately this movement is not detectable in the still photographs.

The details of the test procedure are as follows:

Windiness	Elapsed Time (minutes)	Fan Control Frequency (Hz)	Photograph	Reference Tunnel Speed (m/s)
	0	0	0	0.0
10	2	10	1	2.2
9	4	14	2	3.1
8	6	18	3	4.0
7	8	22	4	4.9
6	10	26	5	5.8
5	12	30	6	6.7
4	14	35	7	7.8
3	16	40	8	9.0
2	18	45	9	10.1
1	20	50	10	11.2

The tunnel speed is held constant at each control setting for two minutes before taking each photograph. This provides a reasonable time for the bran erosion to stabilise after each speed increase.

Although the local gust speed is the greatest single factor in producing movement of the bran flakes, there are numerous other factors that make it difficult to produce an accurate correlation. These include:

The model surface:	The bran can accumulate on rough or sticky surfaces and in cracks and hollows.
Loose bran flakes:	The bran moves more easily when it is loose, e.g. at the edge of a cleared area, than when it is closely packed. Therefore a clearing may expand rapidly once it has been initiated.
Discontinuities:	The bran tends to be disturbed around corners and small obstructions in the airflow. It is not easily disturbed in regions of flat, uniform flow.
Vertical wind flow:	The bran is more easily disturbed where there is a downward component in the air velocity than where the flow is horizontal.
Turbulence:	The bran tends to be disturbed by turbulence and fluctuating flow direction.
Tunnel gusts:	Occasional random low frequency fluctuations in the tunnel speed produce rapid changes in the bran erosion patterns. These tunnel gusts occur about once or twice per minute.
Vortices:	Bran flakes can accumulate in the core of a steady local vortex. This then appears to be a comparatively calm area in the photographs because the vortex is not visible.
Bran mounds:	The bran can accumulate in mounds as each test proceeds, and the mounds subsequently modify the flow conditions in their vicinity.

Calibration of the Bran Flake Erosion

Figure E2 shows a bran erosion contour image for the calibration building specified in Appendix 7 of the Wellington City District Plan. The calibration building is an isolated rectangular block, measuring 60m high, and 15m square in plan, at full-scale. This building was built at a scale of 1:264, which is the scale of the Opus Research wind tunnel model of Wellington City. The building was tested in the standard terrain category 3 atmospheric boundary layer simulation, which is used for environmental building studies in Wellington City. Figure E1 shows the grid on the wind tunnel floor that was used to determine the extent of the erosion. The circle marked in Figure E1 indicates an area 50m in diameter (at full-scale) which is centred on the back face of the model, as specified in the Wellington City District Plan. Contour number 7 (i.e. windiness=”7”) corresponds to approximately 80% of this circle being cleared of bran.

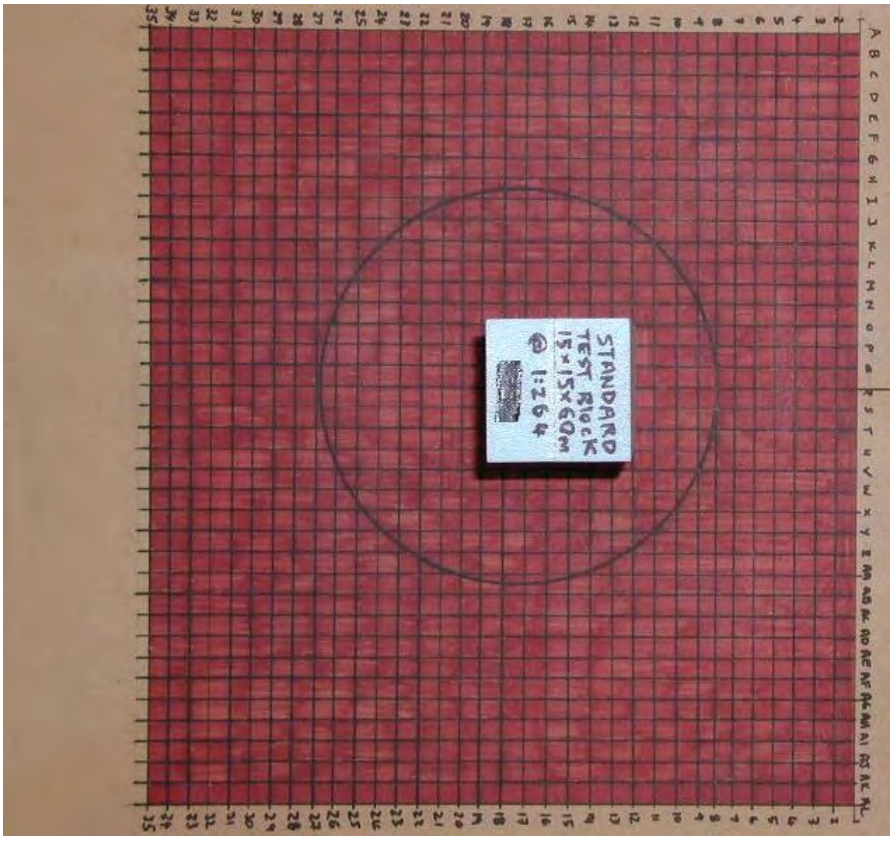

Figure E1. Aerial view of the calibration model building and measurement grid.

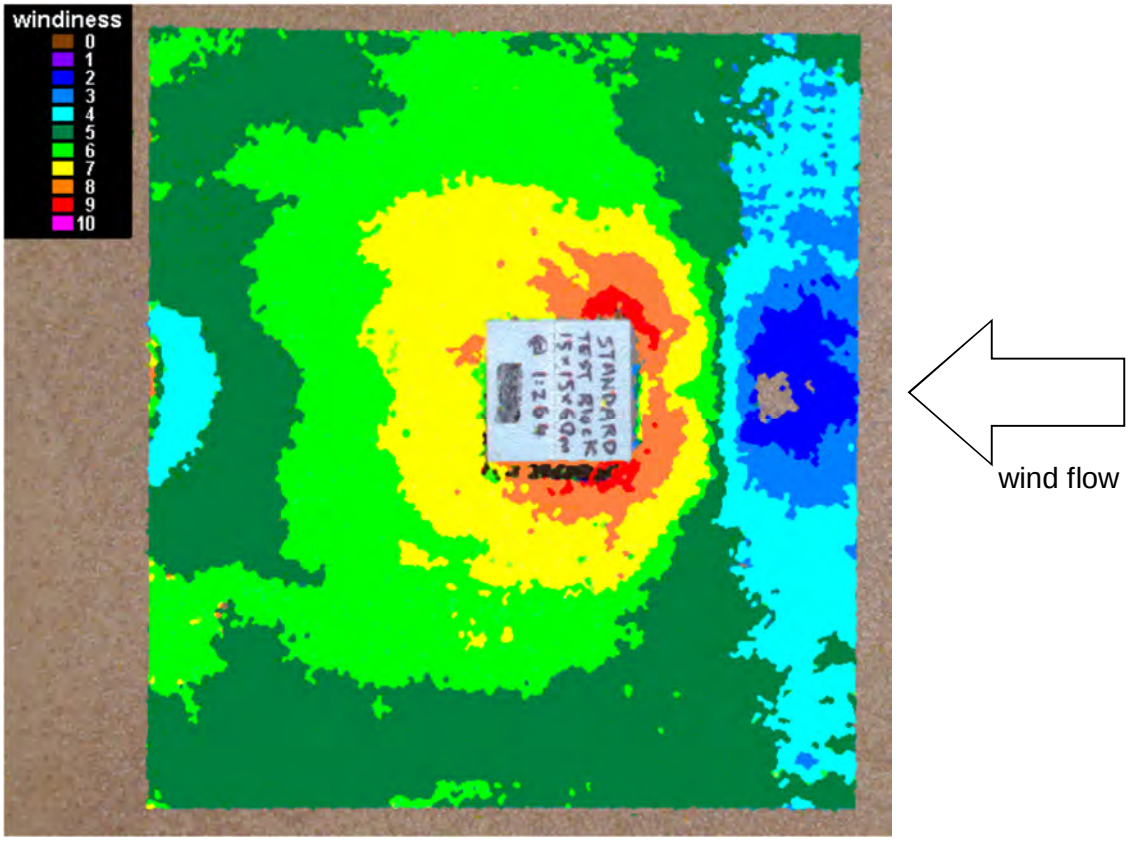

Figure E2. Erosion contours for calibration building (60m×15m×15m).

Appendix F: Complete Listing of Calculated Gust Wind Speeds

A change of 1 m/s in the wind speeds is not considered significant within the limitations of the test method, whereas a change of 2 m/s probably indicates a reproducible wind effect.

Table F1: Calculated Maximum Annual Gust Wind Speeds, V_c (m/s)

Notes: Exg = existing situation, New = proposed development, - = not measured

Location	Wind Direction (°)															
	150		170		190		210		320		340		360		20	
	Exg	New	Exg	New	Exg	New	Exg	New	Exg	New	Exg	New	Exg	New	Exg	New
A	16	16	19	20	18	19	15	15	28	28	29	29	29	30	19	19
B	18	14	21	21	14	17	15	14	21	21	23	24	24	24	17	18
C	13	12	18	15	19	16	14	11	16	15	18	18	20	20	11	10
D	16	14	23	15	24	15	24	12	26	24	23	23	26	27	19	17
E	19	18	22	21	22	22	20	18	19	19	25	24	23	23	18	19
F	11	13	15	17	24	15	20	14	17	16	19	16	15	13	12	11
G	11	12	16	17	23	24	23	22	20	21	24	24	22	23	18	18
H	11	13	15	16	19	19	17	16	19	18	22	22	16	16	14	14
I	12	10	16	13	17	15	10	10	16	16	19	18	21	20	9	10
J	8	6	14	10	16	16	8	9	15	16	18	19	18	18	7	9
K	13	10	15	15	14	18	10	12	15	16	19	19	18	17	7	9
L	16	16	17	18	17	18	11	13	17	17	13	15	11	13	7	8
M	18	19	21	20	18	19	12	12	15	15	18	19	14	15	9	10
N	12	13	14	16	16	15	15	12	11	11	15	14	15	11	11	9
O	11	14	13	17	16	15	14	12	12	15	19	17	13	14	9	11
P	10	15	12	18	14	17	16	15	16	12	19	12	14	10	12	9
Q	10	15	12	19	16	17	16	16	17	15	21	16	15	11	13	12
R	12	12	16	15	18	14	17	12	15	13	19	14	14	7	13	10
S	11	13	16	17	17	17	18	14	15	11	17	14	14	10	14	12
T	13	14	17	18	18	20	16	16	13	12	21	16	16	9	13	11
U	13	11	18	16	17	19	18	15	13	9	21	16	15	10	14	12
V	11	12	17	16	18	18	19	18	14	11	17	16	15	12	15	15
W	11	13	14	17	17	17	16	17	16	15	17	17	15	13	14	15
X	12	13	15	17	18	16	13	12	12	9	21	12	16	7	12	4
Y	7	11	9	13	17	20	12	13	10	10	22	15	18	11	13	8
Z	11	11	10	13	11	18	10	13	11	8	22	16	17	13	14	12
A1	14	13	18	16	19	17	19	15	15	13	12	9	18	8	10	9
B1	10	10	16	15	22	21	24	24	16	14	22	21	17	17	17	17
C1	13	13	17	17	22	23	18	20	20	20	23	23	17	16	15	15
D1	13	13	16	15	20	19	15	14	19	18	15	16	18	15	11	9
E1	11	8	14	10	18	10	14	9	14	7	20	8	15	15	11	8
F1	9	11	12	13	18	11	14	10	12	10	20	10	15	14	10	8
G1	10	16	14	19	20	21	13	18	9	9	19	10	17	14	10	8
H1	13	14	18	17	20	18	13	14	19	18	13	14	17	15	9	8
I1	15	15	18	18	18	19	11	14	18	18	12	14	12	16	7	8
J1	17	16	18	18	20	19	13	12	18	17	19	20	15	15	10	10
K1	13	13	17	16	20	18	14	13	19	19	15	16	19	9	11	6
L1	16	16	18	18	20	20	13	13	17	17	21	21	16	17	11	12
M1	19	19	21	21	17	17	9	9	15	14	23	24	19	20	12	12
N1	13	14	15	15	19	17	16	15	17	16	17	17	21	19	12	12
O1	17	17	19	18	20	19	14	14	17	17	19	20	16	15	11	10
P1	11	12	16	16	20	20	16	16	21	21	24	25	18	18	14	14
Q1	12	10	16	15	20	19	15	16	17	16	18	18	16	15	15	15
R1	18	16	24	23	26	24	18	17	17	18	20	19	21	20	18	18
S1	17	13	21	19	21	22	16	17	27	27	25	25	27	27	21	22
T1	13	14	16	16	15	15	13	13	18	19	21	21	21	21	15	16

Appendix G: Complete Listing of Frequency of Occurrence

A change of more than 20 days in the time exceeding the wind speed thresholds is considered to be significant within the limitations of the test method, and indicates a reproducible wind effect.

Table G1: Days per year that the hourly mean wind speed exceeds 2.5m/s.
Notes: Exg = existing situation, New = proposed development, - = not measured

Point	Wind Direction (°)															
	150		170		190		210		320		340		360		20	
	Exg	New	Exg	New	Exg	New	Exg	New	Exg	New	Exg	New	Exg	New	Exg	New
A	6	9	26	36	26	31	6	6	13	13	53	54	73	75	18	16
B	11	6	27	34	13	22	5	4	13	13	56	56	76	76	29	29
C	11	10	37	32	34	29	7	6	9	8	42	39	65	64	0	0
D	12	7	39	24	36	24	10	5	13	13	47	46	76	75	24	16
E	13	13	39	39	34	35	9	9	12	12	54	54	67	65	28	28
F	1	5	12	24	26	20	8	6	12	11	51	30	56	17	14	6
G	9	9	34	35	35	35	11	11	13	13	55	56	72	73	31	31
H	3	6	24	27	28	30	8	7	12	12	50	50	52	40	20	19
I	7	3	29	19	27	24	1	1	9	9	45	43	66	62	0	0
J	0	0	5	1	21	18	0	0	7	10	42	50	57	54	0	0
K	5	2	12	15	15	30	1	4	6	8	46	48	59	62	0	0
L	10	12	29	34	21	27	3	5	10	11	17	26	3	6	0	0
M	13	13	37	37	24	26	4	4	11	11	47	51	35	40	1	3
N	4	6	19	22	23	22	6	4	4	6	26	30	25	6	2	1
O	3	7	15	23	21	20	5	3	4	10	43	48	17	31	1	4
P	1	10	8	33	18	24	6	6	11	7	47	14	50	3	9	1
Q	1	10	9	34	20	27	6	6	12	9	48	26	50	1	17	9
R	4	4	24	19	24	18	6	3	9	6	42	20	28	0	12	4
S	3	6	23	26	25	27	7	6	9	4	35	33	28	1	19	13
T	6	5	25	23	23	27	6	5	7	2	48	45	35	4	15	8
U	8	3	30	17	24	27	7	6	8	1	47	43	31	15	17	15
V	5	5	28	26	27	29	7	8	9	4	35	37	31	25	24	24
W	2	7	17	27	24	26	7	7	10	9	35	37	35	22	21	20
X	5	5	15	20	21	18	5	2	6	2	51	17	40	0	10	0
Y	0	2	1	6	15	25	3	4	1	1	51	37	50	31	12	0
Z	1	4	1	12	3	23	1	4	2	0	51	35	46	37	16	13
A1	10	5	32	20	28	21	7	5	8	4	6	1	43	0	4	0
B1	4	2	30	27	33	33	11	11	10	8	48	47	56	52	29	29
C1	8	8	32	32	33	34	7	9	12	12	51	51	48	46	23	23
D1	8	7	23	19	28	26	5	5	12	12	26	26	50	25	8	1
E1	3	0	15	3	24	10	5	0	9	0	51	0	40	9	2	0
F1	1	2	6	8	24	6	5	1	4	5	51	6	46	15	3	0
G1	1	9	8	29	26	34	4	6	1	1	40	1	50	15	2	0
H1	8	11	28	33	29	29	4	5	11	11	11	20	37	31	1	0
I1	9	11	29	35	26	30	3	5	11	11	8	30	6	37	0	0
J1	11	11	34	32	31	29	4	4	13	12	48	52	31	37	3	2
K1	8	8	27	23	30	26	5	5	12	11	26	28	52	0	4	0
L1	11	11	32	32	30	29	5	5	11	11	52	54	56	61	10	11
M1	14	14	38	38	23	23	0	0	8	7	51	51	50	50	6	5
N1	7	8	20	16	26	22	6	6	11	11	39	37	65	61	15	13
O1	11	11	31	29	31	29	6	5	11	11	50	52	50	40	9	4
P1	5	7	29	31	33	32	8	7	12	12	52	53	50	46	14	14
Q1	6	3	27	24	29	28	6	6	10	10	33	35	40	40	24	24
R1	13	12	39	39	34	36	8	8	12	12	50	50	64	63	27	27
S1	12	6	36	26	29	29	6	6	13	13	45	45	74	73	26	27
T1	10	11	24	26	18	20	5	4	11	12	51	51	56	57	20	19

Table G2: Days per year that the hourly mean wind speed exceeds 3.5m/s.

Notes: Exg = existing situation, New = proposed development, - = not measured

Point	Wind Direction (°)															
	150		170		190		210		320		340		360		20	
	Exg	New	Exg	New	Exg	New	Exg	New	Exg	New	Exg	New	Exg	New	Exg	New
A	2	4	13	26	18	24	4	4	12	12	43	46	62	64	7	5
B	6	1	14	23	3	13	1	1	11	11	51	52	68	68	19	19
C	6	5	28	20	27	21	5	3	4	3	21	18	44	42	0	0
D	9	2	35	11	30	15	7	1	12	11	29	28	67	65	12	5
E	10	11	35	34	28	29	7	7	9	9	48	45	48	44	19	19
F	0	1	3	11	18	11	6	4	9	7	37	10	29	2	4	1
G	4	4	23	24	29	29	8	8	11	11	50	51	60	61	24	23
H	1	2	11	14	20	23	6	5	9	9	36	36	25	13	8	7
I	2	0	16	7	20	15	0	0	4	4	26	24	46	38	0	0
J	0	0	1	0	12	9	0	0	2	6	21	36	32	27	0	0
K	1	0	3	4	5	22	0	1	1	3	28	33	34	38	0	0
L	6	8	16	23	12	20	0	2	5	6	2	6	0	0	0	0
M	10	11	29	30	15	18	1	1	7	7	31	37	9	13	0	0
N	1	2	7	9	14	13	3	1	1	1	6	10	4	0	0	0
O	1	2	4	10	12	10	2	0	1	6	24	33	2	7	0	0
P	0	5	1	21	7	16	4	3	8	2	29	2	23	0	2	0
Q	0	6	2	23	10	19	5	5	9	5	33	6	23	0	6	2
R	1	1	11	7	16	9	5	0	4	1	21	3	5	0	3	0
S	1	1	10	13	17	19	5	4	4	1	14	12	5	0	7	4
T	2	1	12	10	14	19	3	2	2	0	33	26	9	0	5	1
U	3	0	17	6	15	19	5	3	3	0	31	24	7	1	6	5
V	1	1	15	13	19	21	5	6	4	1	14	16	7	4	11	11
W	0	2	6	14	15	18	5	5	6	5	14	16	9	3	9	8
X	1	1	4	8	12	9	1	0	1	0	37	2	13	0	2	0
Y	0	0	0	1	5	17	0	1	0	0	37	16	23	7	3	0
Z	0	1	0	3	0	14	0	1	0	0	40	14	17	11	5	4
A1	5	1	20	8	20	12	5	2	3	1	0	0	15	0	0	0
B1	1	0	17	14	25	25	8	8	5	3	33	29	29	25	20	20
C1	3	3	20	20	25	27	5	6	9	9	39	40	20	17	11	11
D1	3	2	10	7	20	18	3	3	9	8	6	6	23	4	1	0
E1	0	0	4	0	16	1	3	0	4	0	39	0	13	0	0	0
F1	0	0	1	1	15	0	2	0	1	1	39	0	17	1	0	0
G1	0	4	1	16	18	27	1	4	0	0	20	0	23	1	0	0
H1	3	6	15	21	21	21	1	2	7	8	1	3	11	7	0	0
I1	4	7	16	24	18	22	0	2	7	7	1	10	0	11	0	0
J1	7	6	22	20	23	21	1	1	10	10	33	42	7	11	0	0
K1	3	3	14	10	23	18	2	1	9	8	6	7	25	0	0	0
L1	8	8	20	19	22	21	1	1	8	7	42	47	29	36	2	2
M1	12	12	32	32	14	14	0	0	3	2	39	40	23	23	1	1
N1	2	3	8	5	18	13	5	4	8	7	18	16	44	36	5	4
O1	6	6	18	16	24	21	3	3	7	7	36	41	23	13	2	0
P1	1	2	16	18	26	25	6	5	9	9	41	43	23	17	4	4
Q1	1	1	14	11	21	20	4	5	6	5	12	14	13	13	12	12
R1	11	9	34	34	28	31	6	6	8	9	36	36	42	40	16	16
S1	8	2	25	13	21	21	4	5	10	10	26	26	63	62	15	16
T1	5	7	11	13	9	10	2	1	8	9	39	39	29	32	8	7

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