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Opus Research Report 17-529H57.00

Wind Tunnel Study: Site 9, Wellington

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1 Introduction

This report describes the test procedures and results of an environmental wind tunnel study of pedestrian level wind conditions around a proposed development for Site 9, which is located on the Wellington Waterfront. The proposal is for a new building that is around 22m high.

The objective of this study is to quantify the extent and magnitude of any significant effects of the proposed development on pedestrian level wind conditions. This investigation is intended for the purpose of obtaining resource consent and to meet the reporting requirements of the Wellington City District Plan provisions concerning wind effects of new buildings.

Wind tunnel testing was carried out in the Opus Research wind tunnel, using our existing 1:264 scale model of Wellington, updated to reflect buildings that currently exist or are under construction. Plans of the proposed development provided by Athfield Architects were used to build a scale model of the new building. The level of detail on this model was consistent with design features expected to have an identifiable 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 the locations for wind speed measurements that were made with a hot-film anemometer. These wind speed measurements were made at selected locations for the four wind directions 170°, 210°, 320°, and 360°, and also 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 Changes

District Plan Changes 48 and 78 to the Wellington City District Plan 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 consideration of the wind effects under the District Plan Changes would form essentially 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 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 development or redevelopment of an existing building.

2 Description of the Site, Area and Development

Site 9 is an approximately rectangular site located immediately to the east of Waterloo Quay/Customhouse Quay, on the section of the Wellington waterfront between Whitmore and Waring Taylor Streets. Wellington Harbour is a short distance to the east. Site 9 is currently vacant and was previously 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. The newer buildings include the building under construction on Site 10, also on the east side of Waterloo Quay to the north of Site 9, the Meridian Building to the south of Site 9, and the BNZ building further along Waterloo Quay to the north. Older buildings include the historic Shed 13 to the south of Site 9, between the Meridian Building and Customhouse Quay, and the historic Shed 21 immediately to the north of Site 10. Surrounding these buildings are relatively large open spaces, including wharves and jetties, as well as paved areas that have been or are used for parking, and are open to the public. Across Waterloo Quay and Customhouse 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 is a large relatively open area across Waterloo Quay from the site, which is currently occupied by a Z service station.

The development proposed for Site 9 is a five-storey block, around 22m high to the top of the plant room, which has an approximately rectangular footprint. This new building has setbacks at ground floor level, most notably at the northern end, where there is a large undercroft. The top floor of the new building also has a large setback along its eastern side, which creates a large deck area.

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.

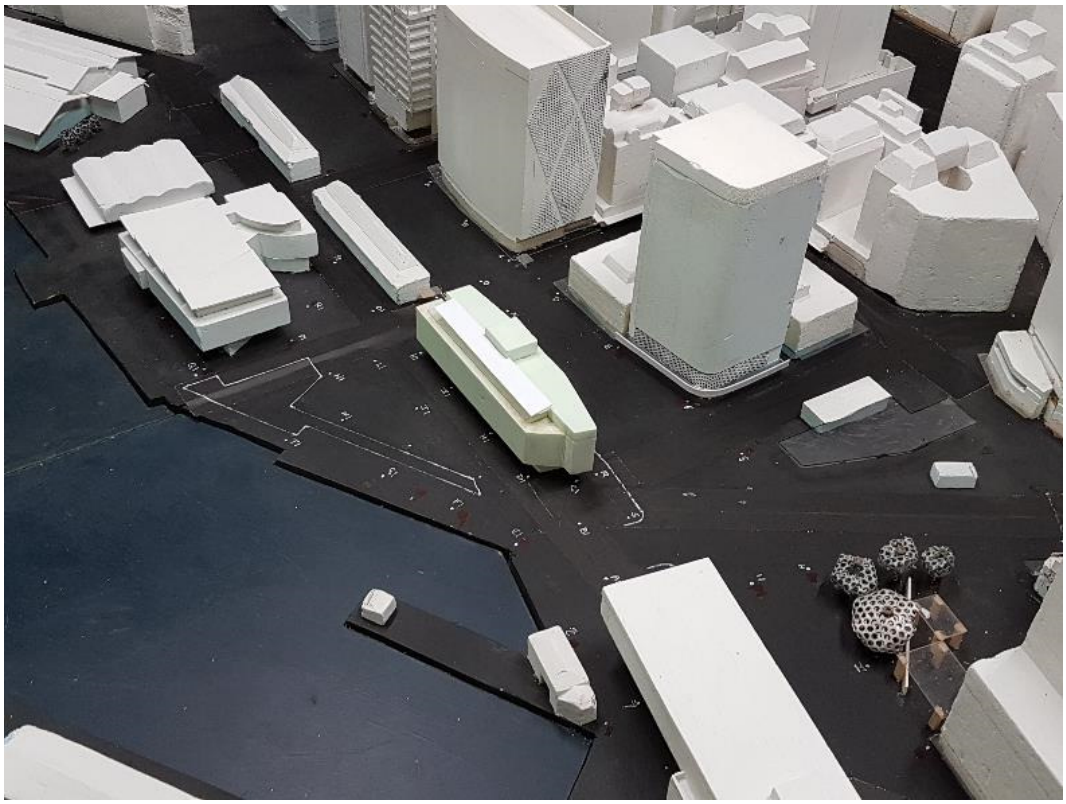


Figure 1 (a): View of the Proposed Development from the Northeast

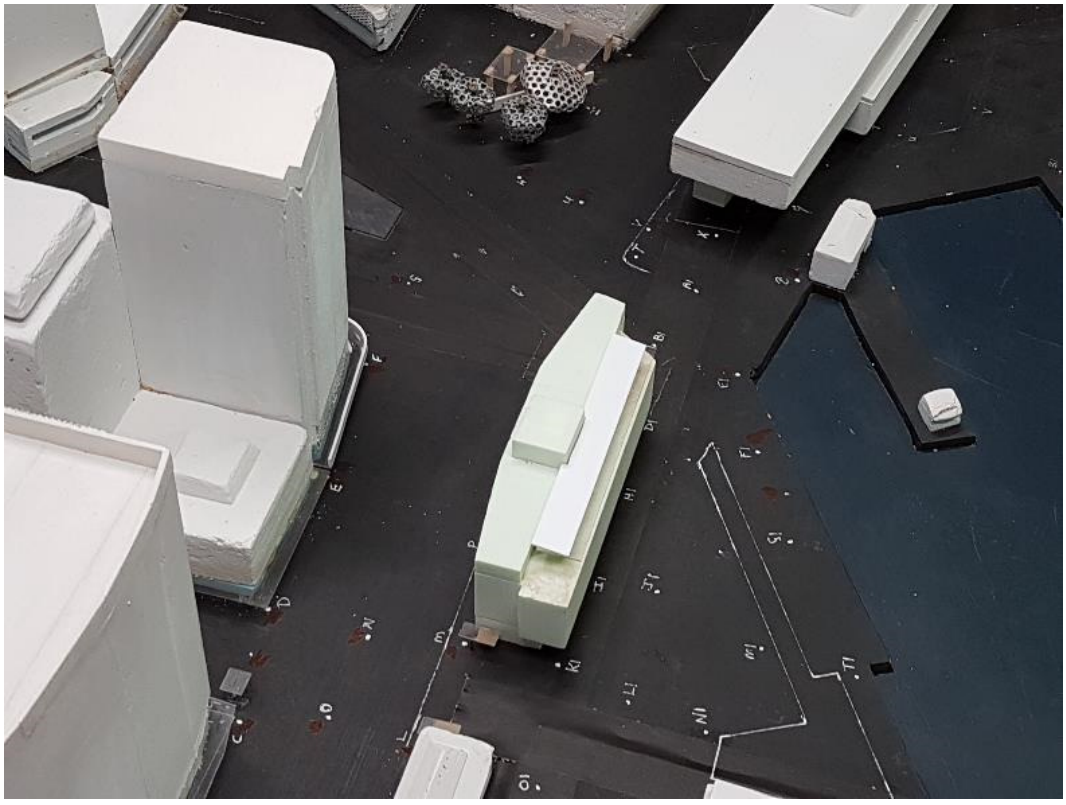


Figure 1 (b): View of the Proposed Development from the South

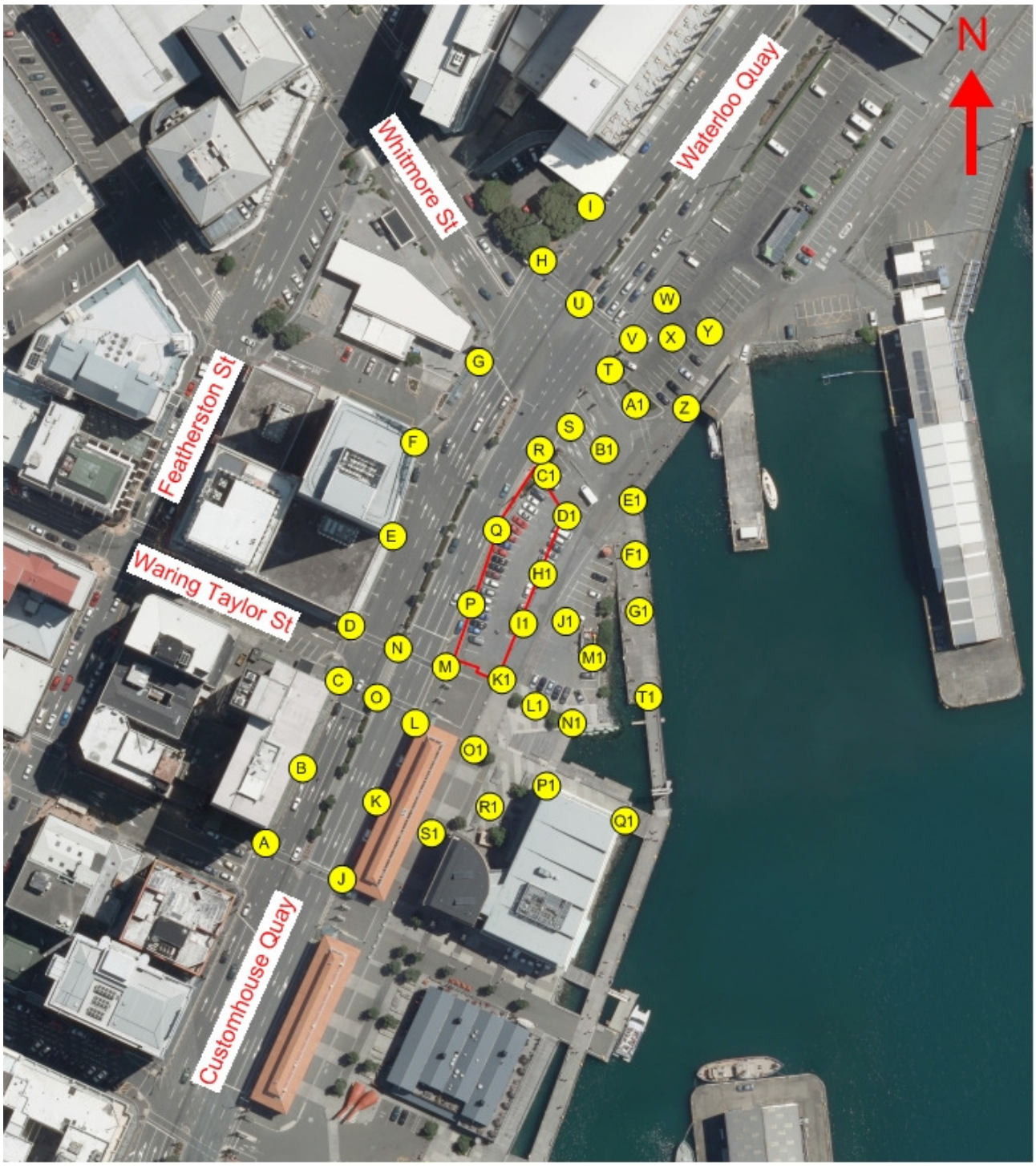


Figure 2: The development site and the surrounding area

Notes: (1) red – building outline
(2) yellow – locations of the wind speed measurements

3 Wind Tunnel Test Procedures

Wind tunnel tests were performed in the Opus Research re-circulating 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 approximately 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 contour images that show the relative degree of windiness in the area around the development site. 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 from the right side of the page. 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) Wind flow patterns in the area around the site are currently dominated by strong horizontal flows, with much of this blowing through the gap occupied by the Z service station across Waterloo Quay. These flows combine with a smaller contribution blowing along Waterloo Quay from the north. These strong horizontal flows currently blow across the open waterfront area that includes Site 9 and Site 8.

(b) The main effect of the proposed development is to constrain a proportion of the horizontal wind flows that previously spilled across the site to the adjacent area of Customhouse Quay. These flows are also deflected around the windward corners and ends of the building. However, the new building does provide additional shelter for those areas on the leeward side of the proposed development. This effect is much more noticeable for the more northwesterly wind direction of 320°, to which the new building presents a much broader face.

4.2 Bran Tests – Southerly Winds

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

(a) Existing wind flow patterns for a southerly wind direction of 170° are largely dominated by strong horizontal wind flows blowing across the open waterfront areas and along Customhouse Quay and Waterloo Quay. For this wind direction there is also evidence of vertical wind flows being deflected down into Customhouse Quay and Waterloo Quay off the windward faces of the high-rise building west of these streets. For the more southwesterly wind direction of 210° the waterfront area is much more sheltered by the grouping of building in the CDB west of Customhouse Quay.

(b) The erosion images show that as the proposed development is aligned approximately parallel to the prevailing southerly wind directions, it has relatively small impact on the wind flows patterns. There is some evidence of small localised windy regions around the windward corners of the new building. However, for the more exposed wind direction of 170° there is also some evidence of increased shelter downwind of the new building which extends north past the intersection of Waterloo Quay and Whitmore Streets.

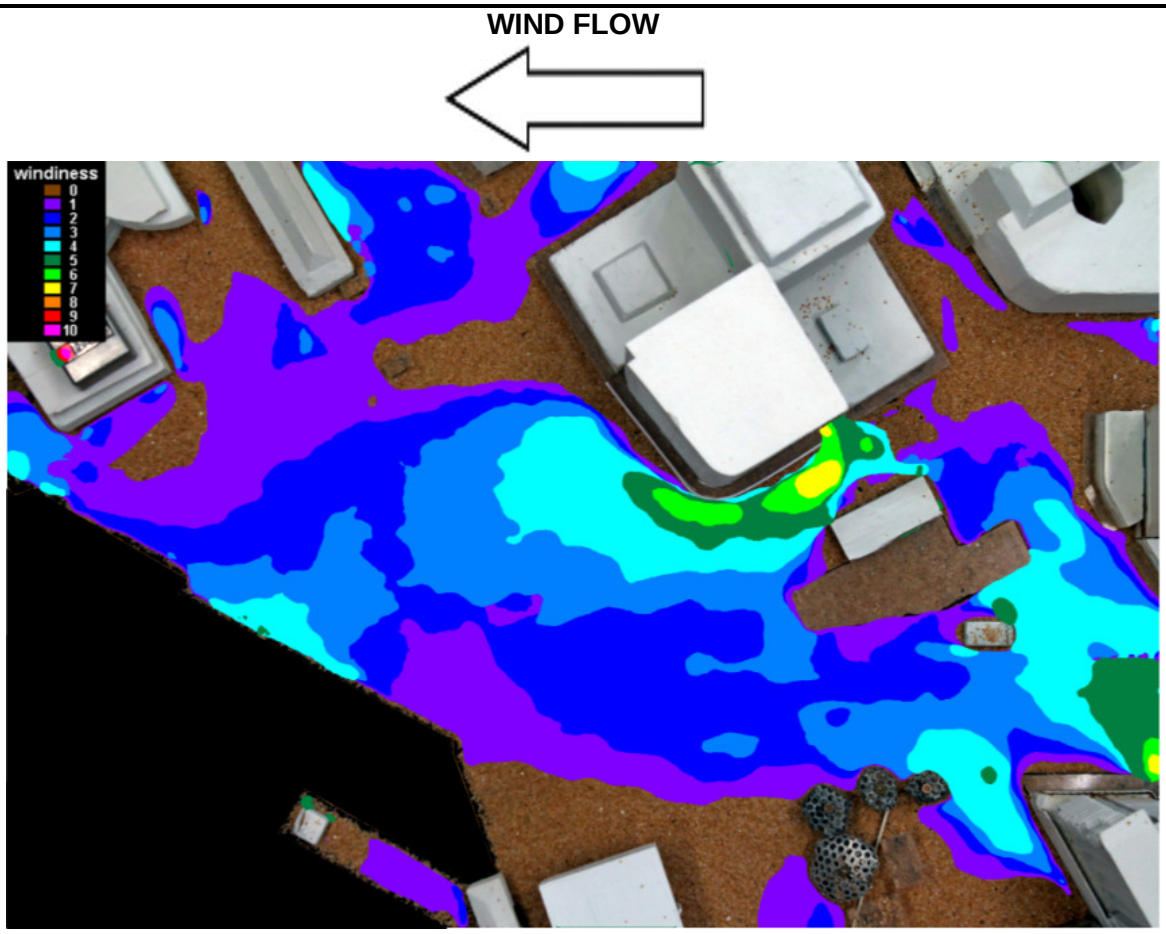


Figure 3a: Relative Windiness - Existing Situation - Wind from 320°

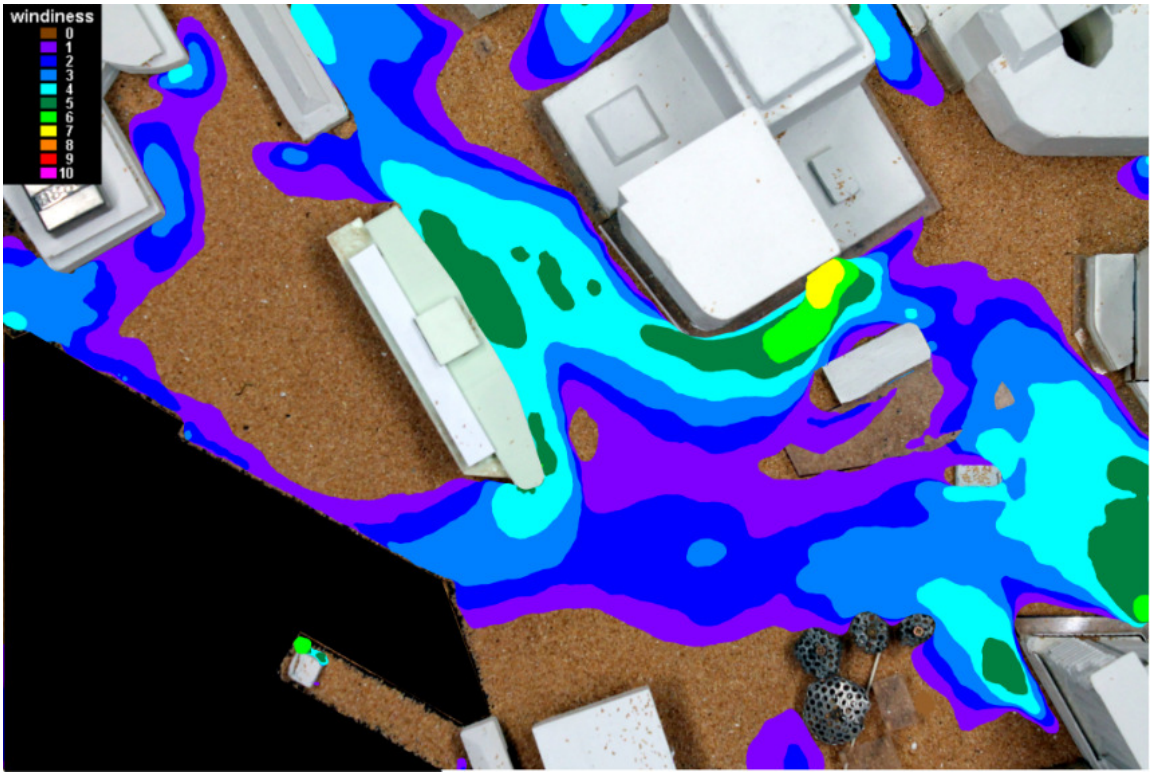


Figure 3b: Relative Windiness - Proposed Development - Wind from 320°

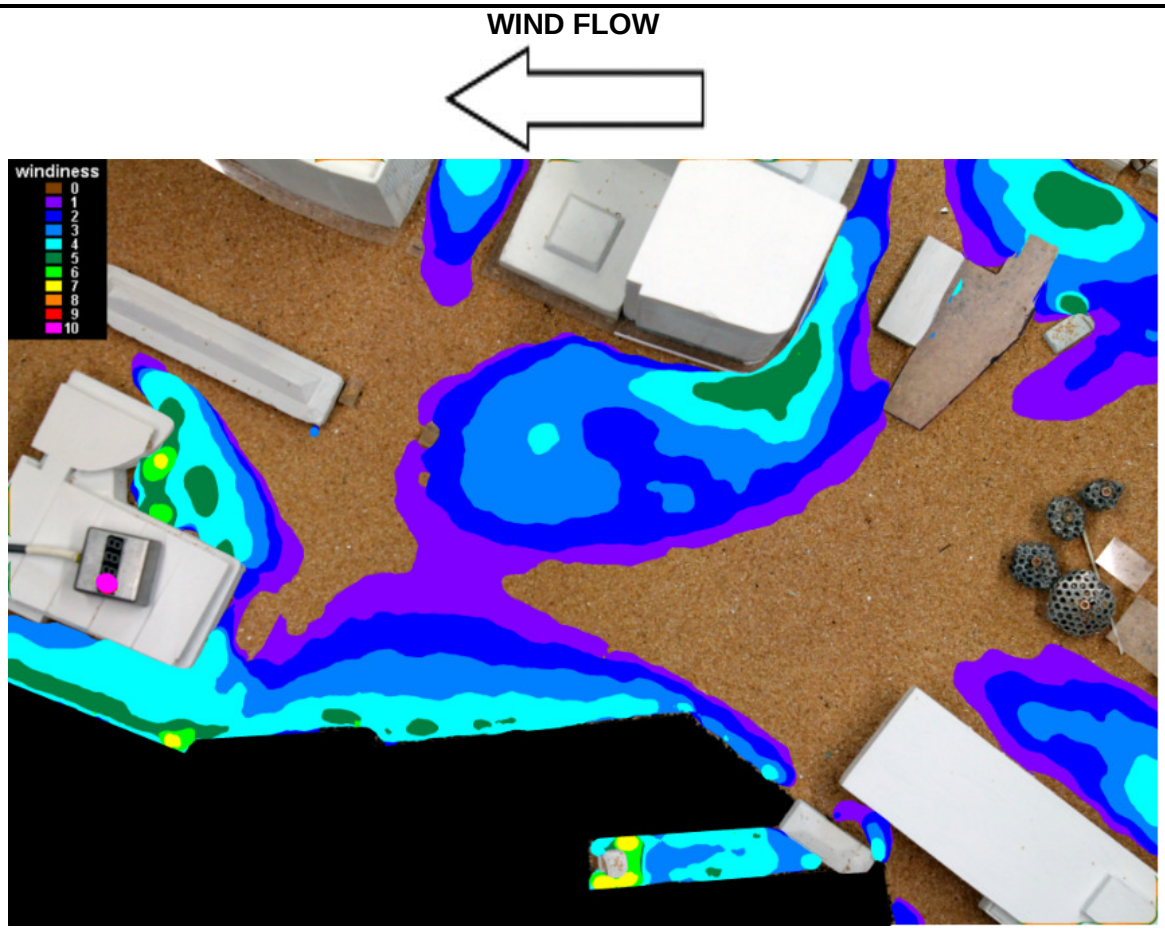


Figure 4a: Relative Windiness – Existing Situation - Wind from 360°

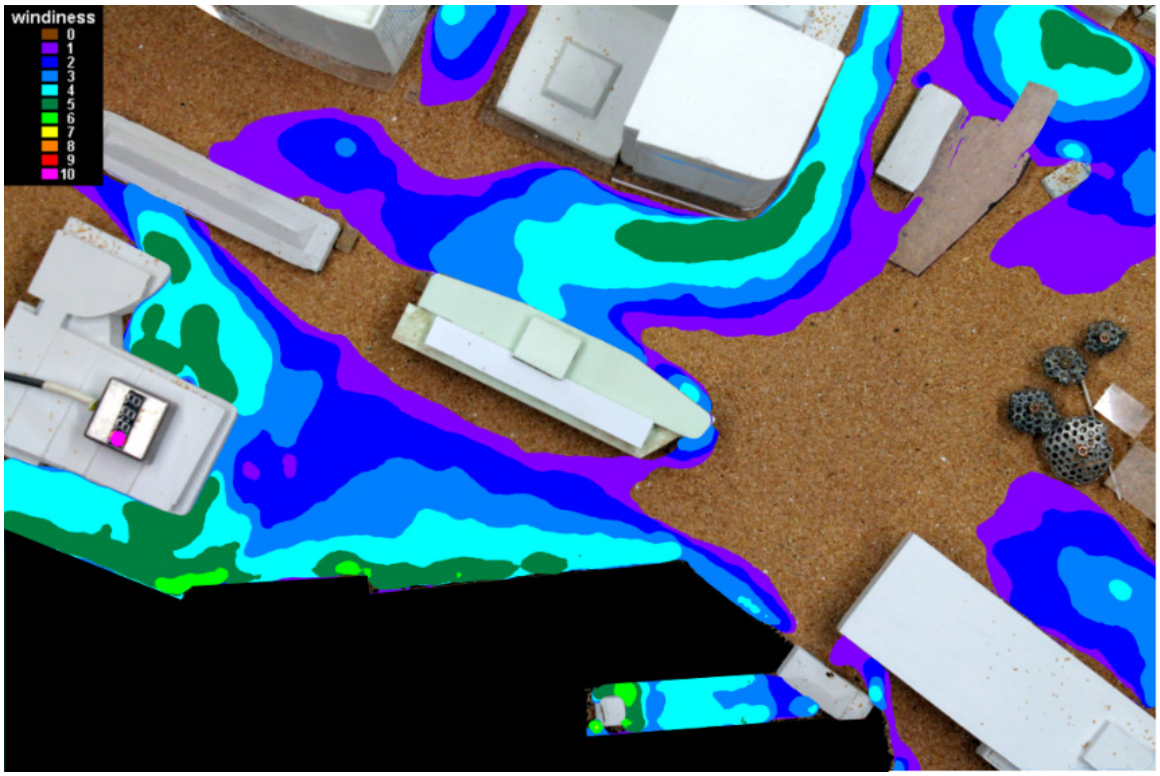


Figure 4b: Relative Windiness - Proposed Development - Wind from 360°

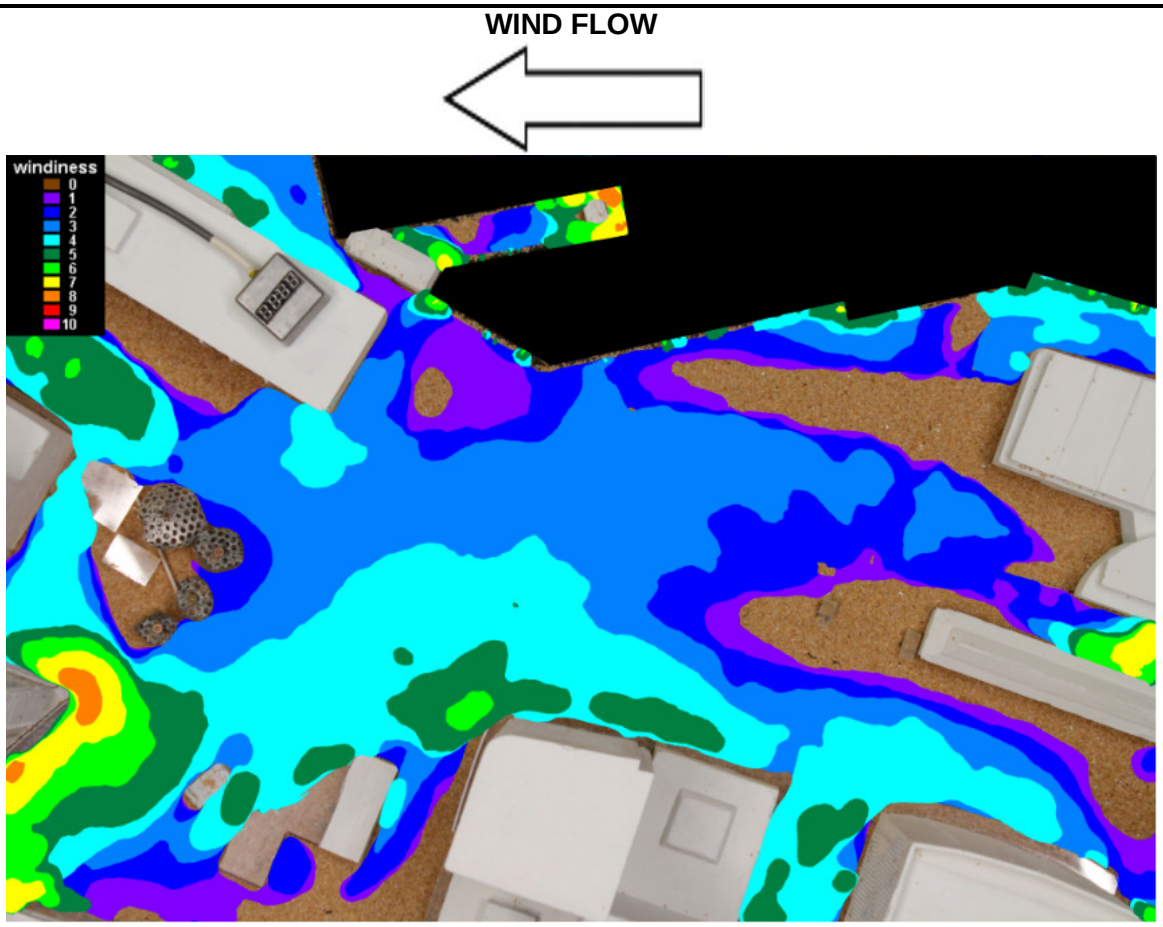


Figure 5a: Relative Windiness – Existing Situation - Wind from 170°

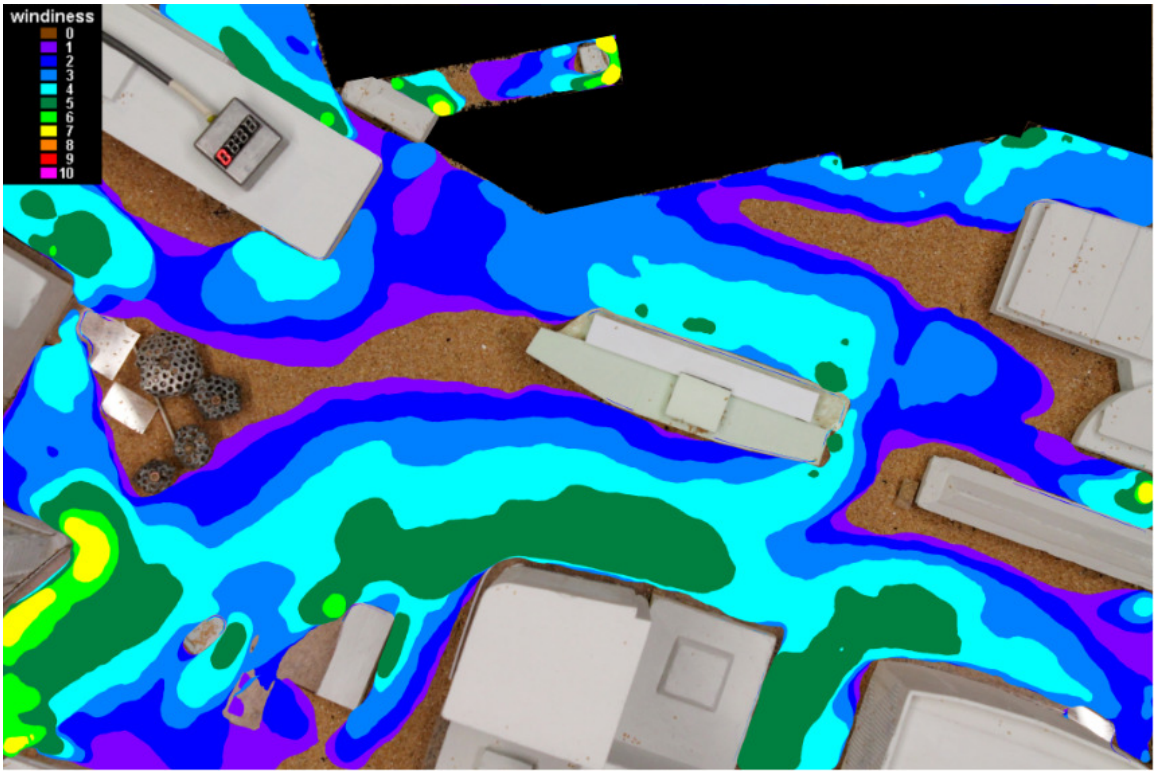


Figure 5b: Relative Windiness - Proposed Development - Wind from 170°

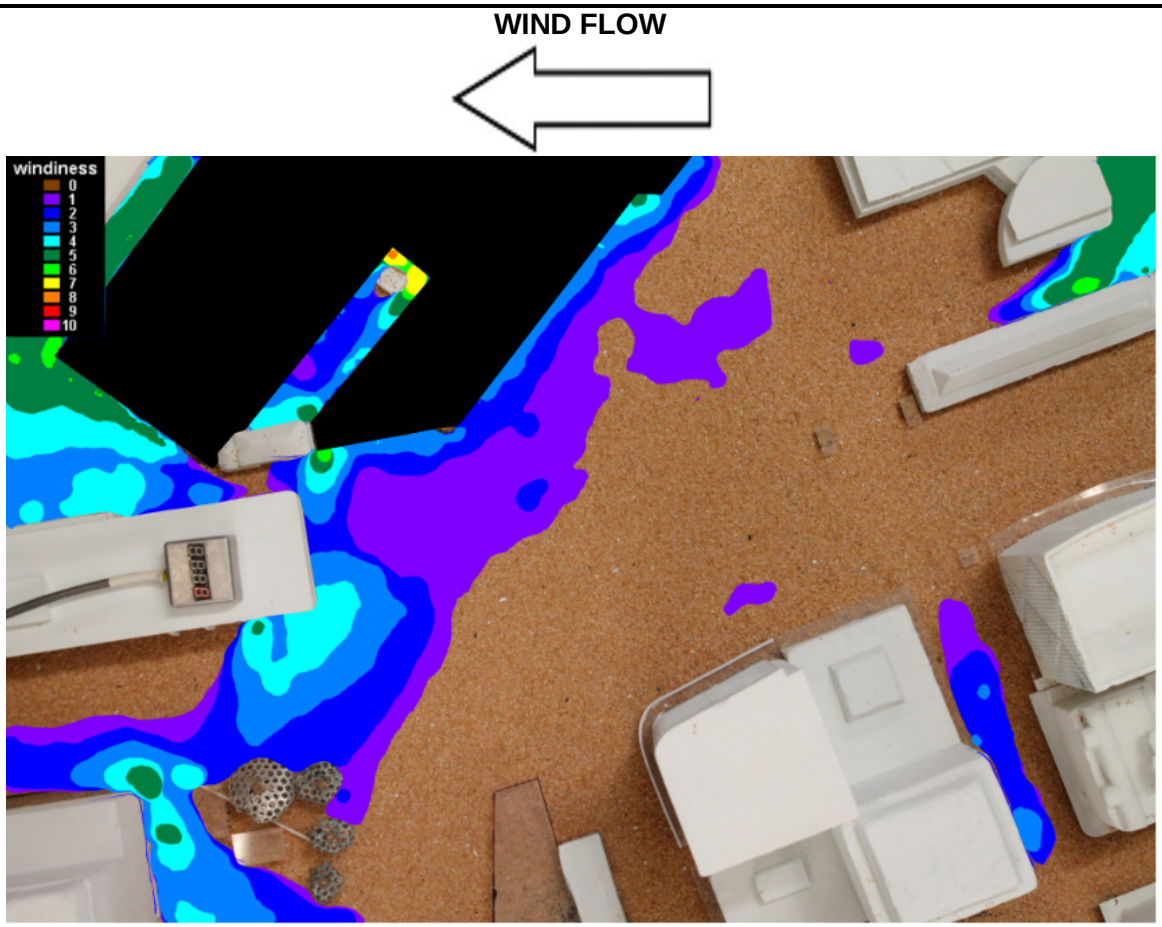


Figure 6a: Relative Windiness – Existing Situation - Wind from 210°

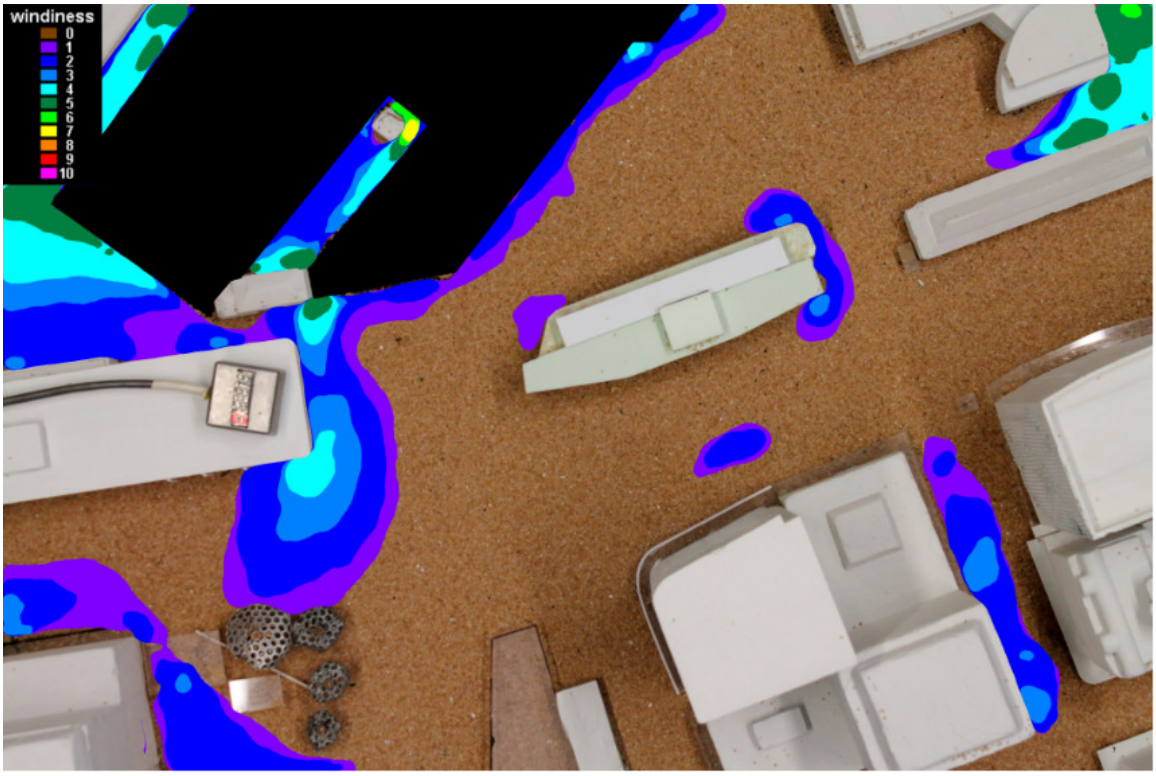


Figure 6b: Relative Windiness - Proposed Development - Wind from 210°

5 Wind Speed Measurements

Wind speeds were measured for the existing situation and the proposed development 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. These speeds can be compared with the Safety Criteria wind speed of 20m/s specified in the Wellington City District Plan. A change of 1 m/s in the wind speed is not considered significant within the limitations of the test method. Figure 7 shows those locations where the proposed development has either (1) increased or decreased the gust speed by 2m/s or more, or (2) increased the gust speed above the 20m/s Safety Criteria Threshold. The individual directional wind speeds are listed in full in Appendix F.

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

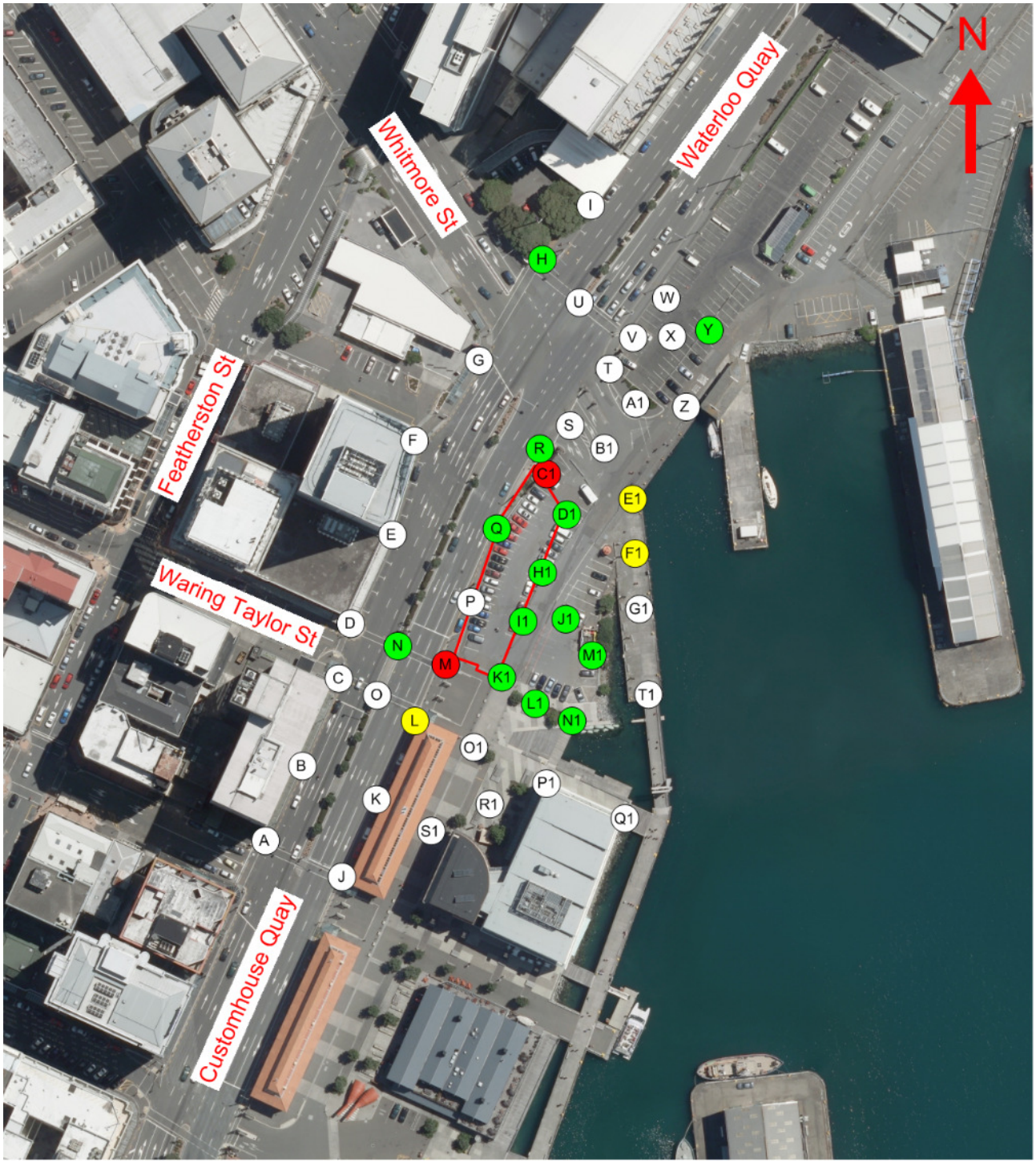
Notes:
Exg = with existing situation, New = with proposed development
= calculated gust speed > 20m/s Safety Criteria, - = not measured
▲ = increase of 2m/s or more over existing maximum wind speed,
▽ = decrease of 2m/s or more over existing maximum wind speed

Location	Exg		New
A	15		14
B	18		19
C	19		18
D	20		19
E	21		20
F	25		25
G	21		21
H	18	▽	16
I	17		17
J	18		17
K	18		19
L	15	▲	17
M	17	▲	22
N	20	▽	18
O	20		20
P	22		21
Q	23	▽	14
R	20	▽	18
S	19		18
T	18		17
U	19		18
V	19		18
W	21		20
X	15		15
Y	17	▽	15
Z	18		19
A1	16		17
B1	19		19
C1	20	▲	22

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

Notes: **Exg = with existing situation, New = with proposed development**
= calculated gust speed > 20m/s Safety Criteria, - = not measured
▲ = 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
D1	20	▽	18
E1	17	▲	19
F1	17	▲	20
G1	18		18
H1	20	▽	15
I1	20	▽	13
J1	20	▽	18
K1	19	▽	14
L1	19	▽	17
M1	19	▽	17
N1	19	▽	17
O1	17		18
P1	18		18
Q1	19		19
R1	19		19
S1	19		19
T1	20		19



	Decrease of 2m/s or more		Increase of 2m/s or more		Increased over 20m/s Safety Threshold		No Change/ Not Measured

Figure 7: Significant Gust Speed Changes

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	92	81	-11	A1	98	116	18
B	61	62	1	B1	148	149	1
C	121	131	10	C1	179	100	-79
D	120	115	-5	D1	160	107	-53
E	57	73	16	E1	112	146	34
F	206	203	-3	F1	154	166	12
G	202	193	-9	G1	158	144	-16
H	121	116	-5	H1	171	39	-132
I	122	114	-8	I1	158	24	-134
J	91	99	8	J1	161	120	-41
K	69	98	29	K1	132	51	-81
L	77	72	-5	L1	149	112	-37
M	75	186	111	M1	153	128	-25
N	112	122	10	N1	153	132	-21
O	128	128	0	O1	117	123	6
P	157	123	-34	P1	111	118	7
Q	198	94	-104	Q1	231	222	-9
R	189	97	-92	R1	151	143	-8
S	168	113	-55	S1	149	146	-3
T	130	134	4	T1	197	171	-26
U	149	145	-4				
V	115	125	10				
W	88	83	-5				
X	57	62	5				
Y	78	89	11				
Z	54	52	-2				

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	30	19	-11	A1	44	62	18
B	35	35	0	B1	92	92	0
C	51	55	4	C1	111	67	-44
D	61	54	-7	D1	95	52	-43
E	28	42	14	E1	49	81	32
F	145	137	-8	F1	69	82	13
G	135	124	-11	G1	75	62	-13
H	68	51	-17	H1	96	14	-82
I	48	47	-1	I1	78	4	-74
J	37	44	7	J1	82	45	-37
K	13	54	41	K1	55	11	-44
L	13	29	16	L1	66	39	-27
M	15	121	106	M1	78	52	-26
N	47	54	7	N1	70	53	-17
O	50	66	16	O1	40	43	3
P	75	77	2	P1	33	48	15
Q	126	26	-100	Q1	154	142	-12
R	121	42	-79	R1	68	70	2
S	107	60	-47	S1	73	74	1
T	74	69	-5	T1	112	86	-26
U	78	67	-11				
V	61	60	-1				
W	53	46	-7				
X	26	28	2				
Y	21	23	2				
Z	27	25	-2				

Figure 8 shows the differences in the time for which the Cumulative Effect Criteria threshold of 2.5m/s (moderate winds) is exceeded between the existing situation and the proposed development. The diagram for the Cumulative Effect Criteria Threshold of 3.5m/s (strong winds) has not been reproduced as the locations and general trends are very similar.

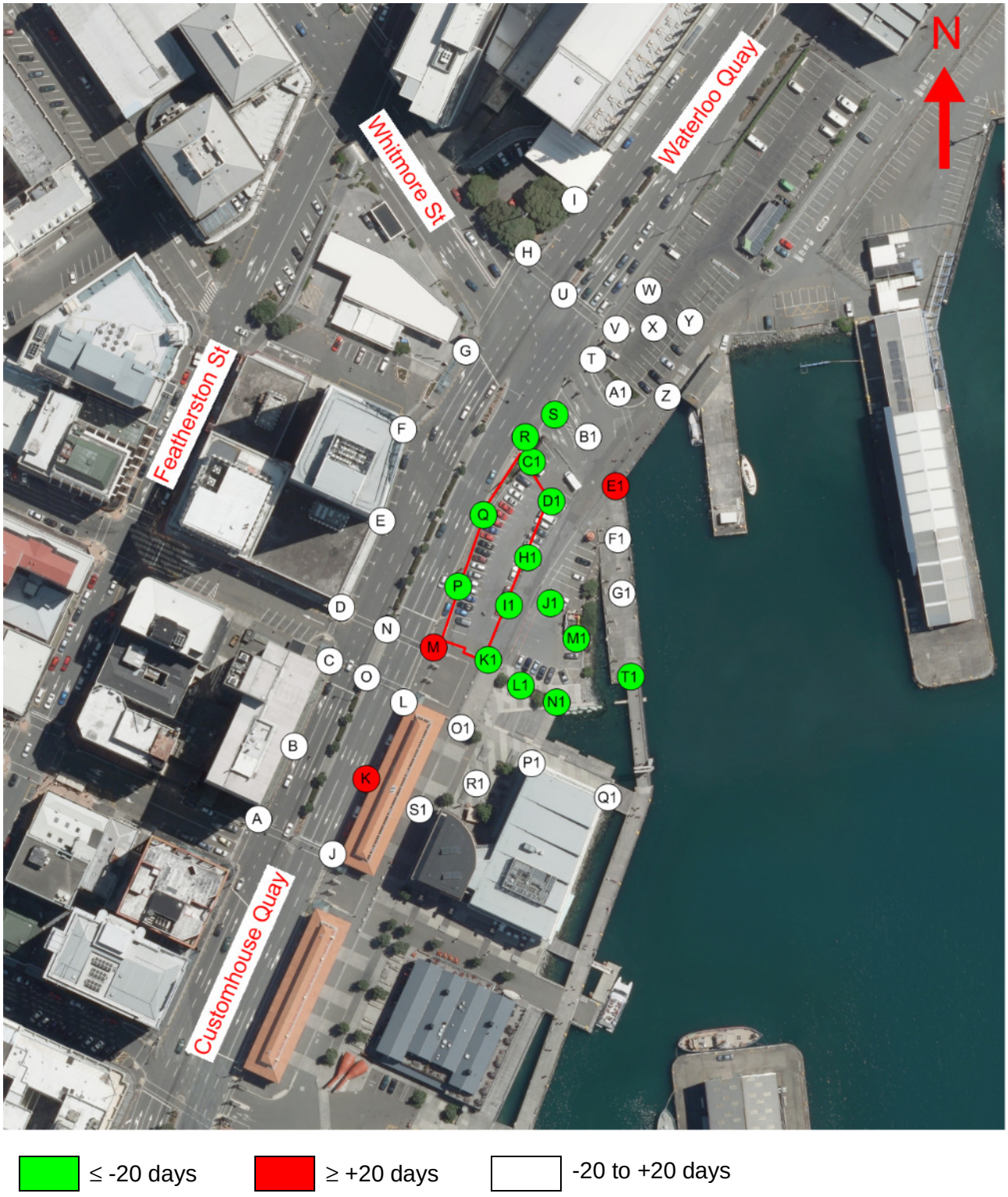


Figure 8. Changes in Number of Days Exceeding 2.5m/s Cumulative Effect Criteria

7 Discussion of Results

7.1 Existing Local Wind Environment

This area of the Wellington waterfront is quite exposed to strong horizontal flows in both northerly and southerly winds, primarily because of the large open areas that include Customhouse Quay and Waterloo Quay, along the waterfront in general, and also the large expanse of Wellington Harbour. There are only well separated low-rise and medium-rise buildings that can provide direct shelter. Consequently, existing gust wind speeds range from low to extremely high depending on the degree of shelter afforded to different areas. At many locations existing gust speeds can be well over 20m/s in both northerly and southerly winds. These 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. Typically, the more sheltered areas are mostly localised areas downwind of buildings.

7.2 Hot-Film Wind Speed Measurements

Table 4 below summarises the calculated gust wind speed data from Table 1 and Appendix F. The numbers of locations where the 20m/s Safety Criteria speed is exceeded are also included in this table.

Table 4: Summary of Calculated Gust Speed Results

Exg = existing situation, **New** = proposed development

Parameter	Configuration	
	Exg	**New**
Average Gust Wind Speed $(m/s)_1$	14.9	13.8
Maximum Wind Speed $(m/s)_2$	25	25
Minimum Wind Speed $(m/s)_2$	4	5
Number of locations where calculated gust speed V_c > 20m/s	6	5

1 – average over the eight wind directions measured, 2 – maximum or minimum value from the eight wind directions measured

Tables 1 and 4 show the following:

- The average calculated gust wind speed is lower for the proposed development compared to the existing situation.
- The highest gust wind speed for any direction or location is the same for the proposed development and for the existing situation.
- The lowest gust wind speed for any direction or location is about the same for the proposed development and the existing situation.
- There are six locations where the existing wind speed is above the 20m/s Safety Criteria threshold, with a maximum gust speed of 25m/s across Customhouse Quay adjacent to Maritime Tower, at location F. This compares with five locations for the proposed development, and a maximum speed of 25m/s, also at location F.
- There are only two locations where proposed development caused the calculated gust speed to increase over the 20 m/s threshold, and one location where it was reduced below it.

- There are five locations where the maximum gust speed is increased by 2m/s or more, compared to thirteen locations where the gust speed is reduced 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
Exg = existing situation, **New** = proposed development

Parameter	2.5 m/s Threshold		3.5 m/s Threshold	
	Exg	New	Exg	New
Average Days Exceeding (1)	132	117	67	57
Maximum Days Exceeding (at any location)	231	222	154	142
Minimum Days Exceeding (at any location)	54	24	13	4
Number of locations where increase > 20 days	3		3	
Number of locations where decrease > 20 days	14		12	
Largest increase in days exceeding	+111		+106	
Largest decrease in days exceeding	-134		-100	

(1) – this is the average of the hours for all locations that exceed the threshold

Table 5 and Figure 8 show the following:

- The average number of days that the mean wind speeds exceed the Cumulative Effect Criteria thresholds is lower for the proposed development than the existing situation, as are the maximum numbers of days.
- There are three scattered locations (K, M and E1) where the increase in the amount of time that the Cumulative Effect Criteria thresholds exceeded 20 days/year. This is more than offset by the large areas where the decreases exceed 20 days/year.

7.4 Overall Assessment of Building Design

The gust speed measurements and the frequency of occurrence data show that, overall, the proposed development produces an identifiable improvement in the local wind environment and amenity around the site. This occurs primarily because of the additional shelter that the new building affords downwind areas in both northerly and southerly winds. When considered over the full range of locations and wind directions the overall effect is quite beneficial. However, the effects at a number

of locations and for certain wind directions were considered to warrant investigation of potential mitigation.

7.5 Investigation of Design Configuration Changes

Given the changes in the local wind environment identified with the proposed development, namely two locations where the gust speeds were increased over the 20m/s Safety Threshold (points M and C1, and the corresponding amenity deterioration, it was considered appropriate to investigate potential mitigation options. Accordingly, a limited range of additional wind speed measurements was carried out for the following configurations:

(1) An 18.6m block occupying the entire site, this being the height that triggers the District Plan requirement for a wind report.

(2) A triangular canopy along the southern end of the Customhouse Quay frontage of the building.

(3) Extension of the vertical glass panelling associated with the historic gate structure near the southwest corner of the new building.

(4) Vertical screens or planting around 3m-4m high in the area around the northern end of the new building.

Options 2-4 are shown in Figure 9 to illustrate their location and approximate size.

Figure 9: Location and approximate extent of mitigation options (2-4 as above)

Wind speed measurements were carried out for the specific wind directions where the largest effects on the gust speeds and frequency of occurrence data were identified. The corresponding gust speed data is listed in Table 6. The frequency of occurrence data for the mean speed threshold of 2.5m/s is listed in Table 7.

Table 6: Effects of Design Configurations

Notes: Exg = with existing situation, New = with proposed development, - = not measured, options 1-4 as numbered above.

Point	Calculated Gust Speeds (m/s)																	
	340°						360°						170°					
	Exg	New	1	2	3	4	Exg	New	1	2	3	4	Exg	New	1	2	3	4
K	18	19	19	19	19	-	13	14	14	14	13	-	13	11	-	11	-	-
L	15	17	18	17	17	-	13	13	13	13	13	-	14	12	-	12	-	-
M	17	22	22	22	11	-	15	16	17	16	12	-	11	19	19	18	-	-
C1	19	22	-	-	-	16	15	15	-	-	-	13	19	6	-	-	-	6
F1	17	16	-	-	-	15	17	15	-	-	-	15	17	20	21	-	-	19

Table 7: Effect of Design Configurations – Frequency of Occurrence (days>2.5m/s)

Notes Exg = with existing situation, New = with proposed development, - = not measured, options 1-4 as numbered above.

Point	Frequency of Occurrence (days>2.5m/s)																	
	340°						360°						170°					
	Exg	New	1	2	3	4	Exg	New	1	2	3	4	Exg	New	1	2	3	4
K	28	45	43	46	46	-	12	28	26	31	27	-	12	6	-	6	-	-
L	21	33	34	36	33	-	20	19	15	15	17	-	12	3	-	4	-	-
M	29	52	50	49	0	-	28	44	43	39	0	-	2	34	35	33	-	-
C1	51	55	-	-	-	21	35	32	-	-	-	20	33	0	-	-	-	0
F1	37	36	-	-	-	31	45	49	-	-	-	23	21	30	29	-	-	26

The results in Tables 6 and 7 show that:

(a) The gust wind speeds and frequency of occurrence data for the 18.6 m block are generally very similar to those for the proposed development, most notably at location M. These results indicate that the localised increases are not being primarily driven by the building height, but rather the constraint and deflection of horizontal wind flows.

(b) Incorporating a small canopy along the Customhouse Quay frontage had little effect on wind conditions. This further illustrates that the localised increases with the new building are being driven largely by changes in the horizontal flow patterns.

(c) Extending the vertical screen associated with the historic gate at the southwest corner of the new building produced some sizeable reductions in the gust speeds and frequency of occurrence data, and could provide good shelter for pedestrians waiting to cross Customhouse Quay.

(d) Screening and/or planting has the potential to significantly improve wind conditions around the northern end of the building, particularly under the large undercroft.

8 Conclusions

(1) Existing wind conditions in the immediate area range from quite low to very high. At many locations, and for many wind directions the gust speeds are moderate, but there are a significant number of locations where the gust speeds are around, or above, the Safety Criteria threshold of 20m/s.

(2) As the development site is currently vacant, any building of significant size will change the wind flows patterns because wind that currently blows across the site will be forced to take other paths around or over the building. Accordingly, significant changes in wind conditions, both increases and reductions, are typically expected in this sort of situation.

Gust Speeds – Safety Criteria

(3) Existing gust wind speeds varied from a low value of 4m/s to a maximum of 25m/s, and this range was similar for the proposed building, with a minimum value of 5m/s and a maximum value also of 25m/s.

(4) Taken over all locations and directions, the average gust speed was lower for the proposed development than for the existing situation.

(5) Gust speeds exceeded the 20m/s Safety Criteria in the Wellington District Plan at six locations for the existing situation, which was reduced to five for the proposed development. There were two locations where the gust speed was increased over the 20m/s threshold, where the resulting speeds were both 22m/s.

(6) There are five locations where the maximum gust speed is increased by 2m/s or more, compared to thirteen locations where the gust speed is reduced by 2m/s or more.

Frequency of Occurrence – Cumulative Effect Criteria

(7) The average number of days per year over all locations and wind directions that the mean speeds exceed the Cumulative Effect Criteria thresholds is lower for the proposed development compared to the existing situation.

(8) There are only three locations where the increase in the amount of time that the Cumulative Effect Criteria thresholds exceeded 20 days/year. This is more than offset by the large areas where the decreases exceed 20 days/year.

Overall Assessment of Building Design

(9) Overall, the proposed development caused a significant improvement in the local wind environment.

Design Configuration Changes

(10) Additional testing showed that any building of substantial size on this site will typically cause significant redistribution of wind flow patterns and wind speeds.

(11) The additional testing also showed that the very localised increases in wind speeds and frequency of occurrence could be largely ameliorated through targeted use of a combination of screens and landscaping.

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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° 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 can be obtained from the Wellington City Council website (http://wellington.govt.nz/your-council/plans-policies-and-bylaws/district-plan/eplan).

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.

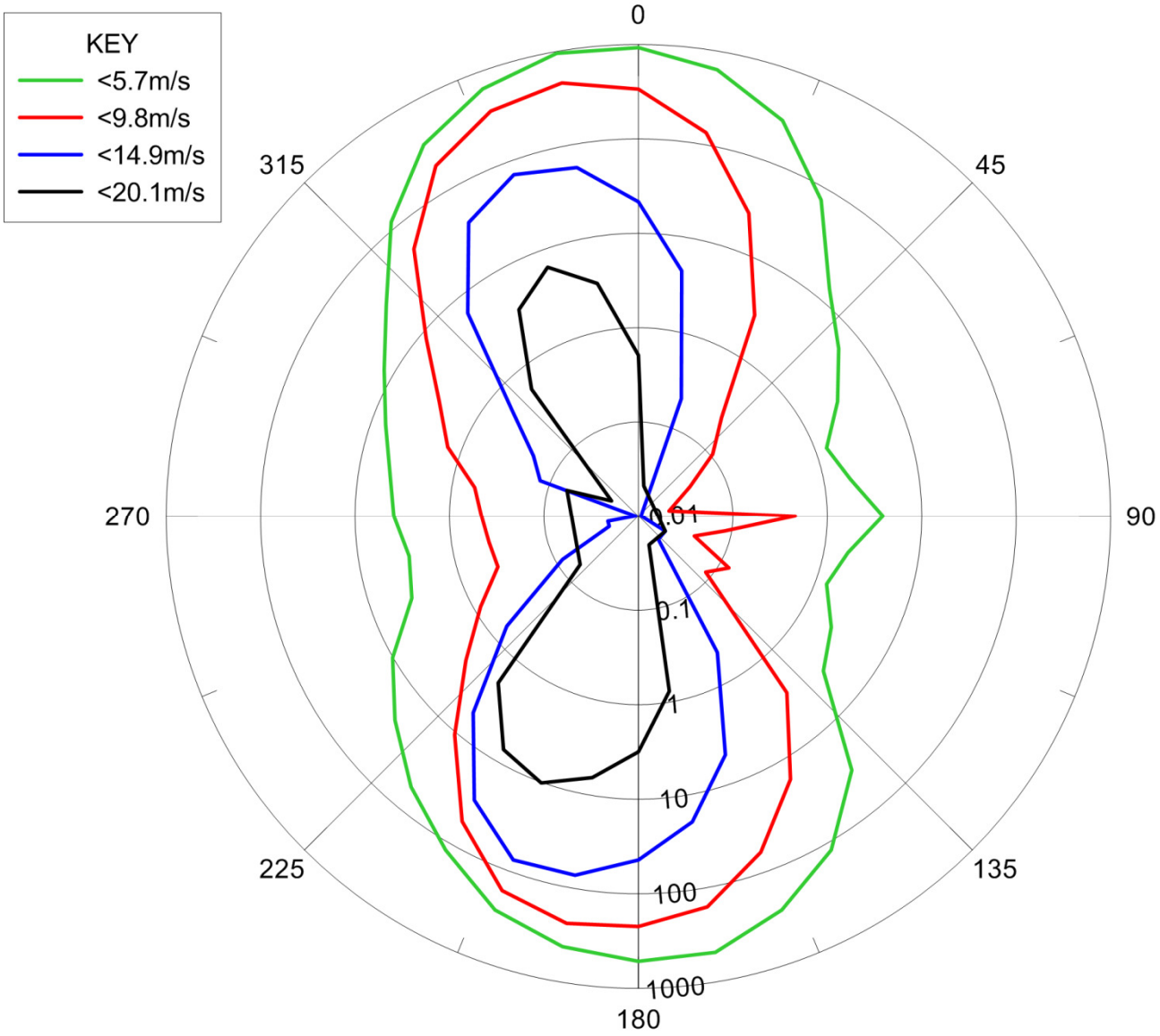

Figure C-1. **Wind Rose for Wellington City – 150m above ground level**
(Number of hours/year wind speeds are equalled or exceeded)

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 a recirculating type, with an overall length of approximately 30 m. The working section measures 3.0 m wide x 1.5 m high. The airflow is generated by a six blade, 2.0 m diameter, 45 kW axial flow fan in the upper circular section of the wind tunnel. The maximum air speed in the working section is around 15m/s. A variable speed drive controls the air speed. Figure D1 shows a view of the Opus Research wind tunnel.

The section of the wind tunnel upwind of the turntable 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 vertical spires, horizontal fence elements 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

Figure D1. Opus Research Wind Tunnel

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	7	1	2.2
9	4	10	2	3.1
8	6	13	3	4.0
7	8	16	4	4.9
6	10	18	5	5.8
5	12	21	6	6.7
4	14	25	7	7.8
3	16	28	8	9.0
2	18	32	9	10.1
1	20	35	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.

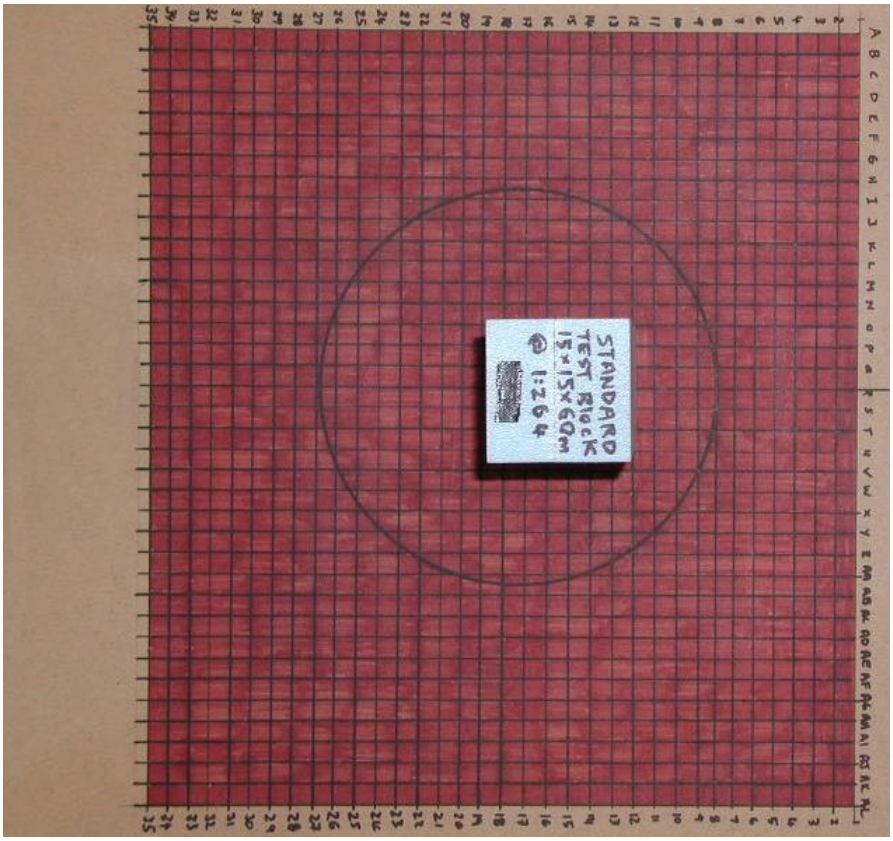

Figure E1. Aerial view of the calibration model building and measurement grid.

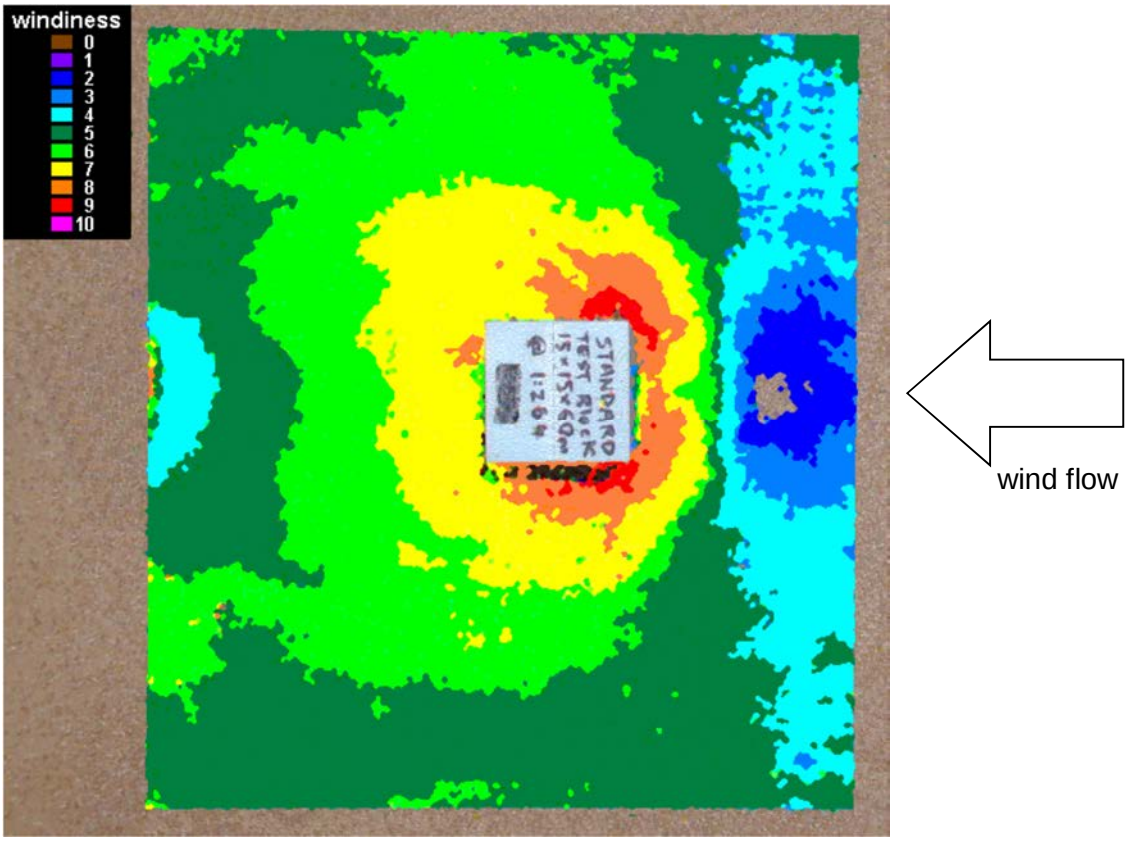

Figure E2. Erosion contours for calibration building (60m x 15m x 15m).

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 generally 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

	320 Deg		340 Deg		360 Deg		20 Deg		150 Deg		170 Deg		190 Deg		210 Deg	
Location	Exg	New	Exg	New	Exg	New	Exg	New	Exg	New	Exg	New	Exg	New	Exg	New
A	12	11	14	14	12	11	10	9	11	12	15	14	11	12	11	10
B	7	8	8	9	6	7	8	9	16	15	18	19	14	14	8	8
C	11	11	15	15	14	14	10	11	16	15	19	18	11	13	11	11
D	16	14	20	19	15	12	8	7	15	15	17	17	12	12	12	12
E	8	10	11	12	10	11	7	8	19	19	21	20	12	14	6	9
F	18	17	25	25	19	18	12	12	18	19	21	21	16	17	8	8
G	17	15	19	19	15	14	12	12	17	18	21	21	19	17	11	10
H	17	16	16	16	12	13	8	8	14	14	18	16	18	15	16	16
I	14	13	15	15	17	17	9	10	13	11	15	13	16	15	17	15
J	11	13	12	14	10	12	10	9	11	11	17	16	18	17	11	13
K	15	17	18	19	13	14	9	9	10	10	13	11	11	9	7	6
L	13	15	15	17	13	13	11	9	13	12	14	12	11	8	8	7
M	13	18	17	22	15	16	10	9	11	13	11	19	11	20	9	14
N	14	14	19	17	13	14	10	9	18	16	20	18	13	16	11	12
O	12	13	16	17	13	14	9	9	18	17	20	20	14	14	10	10
P	17	18	22	21	18	15	10	9	13	9	14	10	15	10	11	8
Q	20	13	23	14	17	11	11	7	16	12	17	12	16	11	12	10
R	17	14	20	18	15	13	10	8	15	12	19	14	19	10	15	9
S	19	16	19	18	14	14	9	9	15	12	19	12	18	12	16	12
T	18	16	17	17	11	13	7	7	13	12	17	15	17	17	17	17
U	17	16	15	15	15	15	9	9	13	13	18	15	19	17	18	18
V	16	15	13	14	12	12	8	8	13	13	17	16	17	18	19	18
W	10	9	9	9	14	12	9	7	13	13	19	18	21	20	20	19
X	11	12	11	11	8	9	4	5	12	12	15	15	15	15	14	15
Y	9	9	14	13	10	11	7	9	12	14	14	15	17	15	14	13
X1	11	10	9	9	8	8	9	9	11	12	16	15	18	17	17	19
A1	16	16	15	17	9	9	6	7	12	12	15	17	16	17	16	16
B1	18	16	18	19	13	14	7	8	14	13	19	18	19	19	16	16
C1	16	19	19	22	15	15	8	9	17	6	19	6	20	5	17	5
D1	17	13	20	8	14	14	8	9	15	15	19	18	18	18	16	14
E1	17	17	16	19	13	13	8	8	13	12	16	18	16	18	15	15
F1	17	15	17	16	17	15	10	10	13	12	17	20	17	18	15	15
G1	18	10	17	13	17	16	10	11	13	13	15	17	15	18	15	14
H1	18	8	20	6	15	8	10	7	16	11	18	15	17	13	15	10
I1	19	6	20	5	16	7	10	6	14	10	16	13	15	12	12	11
J1	18	8	20	13	16	15	10	9	15	13	18	18	16	17	13	13
K1	16	8	19	9	15	11	10	9	12	10	14	14	14	14	12	12
L1	16	9	19	12	15	15	11	10	14	12	17	17	15	14	13	12
M1	17	11	19	14	18	17	11	10	11	11	14	16	15	17	13	14
N1	15	11	18	14	17	15	11	11	12	13	16	17	16	16	13	13
O1	12	14	14	18	15	14	10	10	11	11	15	15	17	15	13	13
P1	11	10	13	13	18	18	13	13	11	11	14	13	13	12	11	11
Q1	14	12	19	17	19	18	14	13	16	14	18	17	19	19	18	18
R1	11	9	13	13	19	19	14	14	13	12	16	14	14	13	12	11
S1	12	12	14	12	18	19	14	14	10	12	17	17	17	16	13	12
T1	17	12	18	14	17	19	13	13	15	14	18	17	20	17	16	17

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 significant within the limitations of the test method, and generally indicates a reproducible 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

	320 Deg		340 Deg		360 Deg		20 Deg		150 Deg		170 Deg		190 Deg		210 Deg	
Location	Exg	New	Exg	New	Exg	New	Exg	New	Exg	New	Exg	New	Exg	New	Exg	New
A	7	6	34	27	8	10	1	0	2	5	22	16	14	14	4	4
B	0	0	0	1	0	0	0	0	8	8	33	34	20	19	0	0
C	2	3	28	25	28	35	2	4	12	11	36	36	8	13	4	3
D	10	6	50	43	10	6	0	0	7	9	23	28	13	17	6	5
E	0	2	3	4	0	1	0	0	9	11	33	35	12	19	0	1
F	10	9	52	52	63	54	7	8	13	13	38	38	22	27	0	0
G	12	12	52	52	48	47	7	6	12	13	38	37	30	25	2	2
H	10	11	32	33	2	11	0	0	10	9	34	25	27	20	6	6
I	3	4	20	15	45	52	0	0	5	3	20	13	23	21	6	6
J	3	8	17	21	3	8	7	5	4	4	29	27	25	22	3	4
K	3	11	28	45	12	28	6	6	2	2	12	6	6	1	0	0
L	2	8	21	33	20	19	8	4	4	3	12	3	8	0	1	0
M	3	12	29	52	28	44	3	4	3	8	2	34	6	28	2	5
N	5	6	39	26	7	19	2	4	9	11	27	30	18	22	5	4
O	2	7	28	24	26	28	5	5	11	11	32	33	19	18	4	3
P	6	12	46	54	51	49	6	3	7	0	16	1	20	2	4	0
Q	12	9	54	34	53	22	6	0	10	6	32	10	26	10	5	3
R	12	10	53	47	42	26	2	0	9	2	35	8	29	2	6	1
S	13	12	52	52	24	33	1	1	9	3	34	4	28	6	7	3
T	11	12	41	44	3	16	0	0	10	8	31	23	27	24	7	7
U	10	11	33	33	23	33	0	0	10	10	35	27	30	25	8	7
V	9	9	22	26	5	13	0	0	10	9	33	30	28	29	8	8
W	2	3	2	1	5	6	0	0	8	7	32	28	32	30	8	8
X	1	4	3	3	0	1	0	0	7	7	18	20	22	21	6	6
Y	0	1	27	17	19	34	0	0	3	6	6	9	19	17	5	4
Z	1	3	1	1	0	0	0	0	2	2	20	16	23	22	7	7
A1	9	11	29	36	0	0	0	0	7	8	24	27	24	26	7	7
B1	12	12	50	51	12	15	0	0	8	7	32	28	29	28	6	7
C1	11	13	51	55	35	32	1	0	10	0	33	0	31	0	7	0
D1	11	5	52	0	23	27	1	2	8	9	30	32	28	27	6	6
E1	11	12	34	47	9	19	0	1	7	7	22	28	23	26	6	6
F1	11	8	37	36	45	49	4	5	7	6	21	30	23	26	6	7
G1	11	2	43	23	50	55	6	9	7	6	15	20	19	23	6	6
H1	11	1	50	0	35	0	3	0	9	1	30	22	26	15	6	1
I1	9	0	49	0	39	0	4	0	8	1	22	12	22	10	5	2
J1	10	2	50	19	39	40	4	3	6	3	25	26	21	23	5	5
K1	6	0	46	0	36	17	5	3	4	2	11	10	19	15	4	5
L1	7	1	47	11	41	46	6	6	7	5	18	20	18	19	5	5
M1	11	3	48	23	55	55	8	8	2	2	8	11	17	21	5	5
N1	7	2	46	15	44	47	6	8	3	5	21	26	21	23	5	5
O1	4	5	20	35	42	38	6	6	2	2	16	13	23	19	5	5
P1	3	1	14	12	48	60	10	12	5	3	13	11	14	14	4	5
Q1	8	6	48	45	68	68	21	20	11	10	35	33	31	31	9	9
R1	3	1	17	13	61	66	18	20	7	5	22	18	18	17	4	4
S1	3	4	20	14	65	68	23	23	1	2	14	15	18	17	4	3
T1	12	4	46	25	52	62	12	13	10	8	31	27	27	24	7	7

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

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

	320 Deg		340 Deg		360 Deg		20 Deg		150 Deg		170 Deg		190 Deg		210 Deg	
Location	Exg	New	Exg	New	Exg	New	Exg	New	Exg	New	Exg	New	Exg	New	Exg	New
A	3	2	13	7	0	1	0	0	0	1	9	5	4	3	1	1
B	0	0	0	0	0	0	0	0	3	3	22	22	11	9	0	0
C	0	0	7	6	6	10	0	0	9	8	27	28	1	3	1	1
D	5	2	37	24	1	0	0	0	2	4	10	14	3	7	3	3
E	0	0	0	2	0	0	0	0	4	6	22	24	2	10	0	0
F	6	4	40	42	41	27	1	2	11	11	32	32	13	19	0	0
G	9	8	42	42	19	18	1	1	9	10	32	29	22	17	0	0
H	6	7	11	12	0	1	0	0	6	4	22	12	19	11	5	4
I	0	1	4	2	16	25	0	0	1	1	8	3	15	12	4	4
J	0	3	2	10	0	2	1	1	1	1	15	14	16	13	1	1
K	0	7	7	31	1	15	1	1	0	0	3	1	0	0	0	0
L	0	4	4	17	2	7	1	0	1	1	3	0	1	0	0	0
M	0	9	8	40	6	24	0	0	0	3	0	22	0	21	0	2
N	1	2	18	10	0	4	0	0	4	6	14	17	8	13	2	1
O	0	2	7	13	4	13	1	0	7	8	20	21	10	8	1	0
P	2	10	28	46	24	21	1	0	2	0	5	0	11	0	1	0
Q	9	4	46	13	25	3	1	0	6	2	19	2	18	1	2	0
R	10	5	43	31	14	4	0	0	5	0	24	2	22	0	4	0
S	10	9	40	41	4	8	0	0	4	1	23	0	20	0	5	1
T	7	8	20	26	0	1	0	0	5	3	17	9	19	16	5	5
U	6	7	12	12	3	8	0	0	6	5	24	13	22	17	6	5
V	4	5	5	6	0	1	0	0	5	5	21	17	21	21	6	6
W	0	0	0	0	0	0	0	0	3	2	19	14	24	22	6	6
X	0	1	0	0	0	0	0	0	3	3	6	8	13	12	4	4
Y	0	0	7	2	2	9	0	0	1	2	1	2	9	7	2	1
Z	0	0	0	0	0	0	0	0	0	0	7	5	14	13	5	5
A1	4	7	8	15	0	0	0	0	2	3	11	14	15	18	5	5
B1	9	8	36	40	1	1	0	0	3	2	19	15	21	21	5	5
C1	8	11	39	49	9	8	0	0	6	0	22	0	23	0	5	0
D1	8	1	40	0	3	5	0	0	3	3	17	20	20	18	5	4
E1	6	9	13	31	0	2	0	0	3	2	9	15	14	18	4	5
F1	8	3	16	15	16	20	0	1	2	2	8	19	14	18	4	5
G1	8	0	24	5	22	28	1	2	2	2	5	7	9	14	4	4
H1	7	0	37	0	10	0	0	0	4	0	16	9	18	5	4	0
I1	5	0	34	0	12	0	0	0	3	0	9	3	13	1	2	0
J1	6	0	36	3	12	12	0	0	1	1	12	12	12	14	3	2
K1	2	0	28	0	10	2	1	0	1	0	2	2	10	5	1	2
L1	2	0	31	1	13	17	1	1	2	1	6	8	9	9	1	2
M1	6	0	33	5	28	28	1	1	0	0	1	2	7	12	1	2
N1	2	0	29	2	16	19	1	2	1	1	8	13	12	15	1	3
O1	0	1	3	14	15	11	1	1	0	0	5	4	14	10	2	2
P1	0	0	2	1	19	35	2	3	1	0	4	2	4	4	1	1
Q1	3	2	32	28	49	49	9	8	6	5	25	21	23	23	7	7
R1	0	0	3	1	37	45	7	8	2	1	9	6	8	7	1	1
S1	0	1	3	2	44	49	11	11	0	0	4	5	9	7	1	0
T1	8	1	28	6	25	39	3	4	5	3	18	14	19	15	5	5

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