LOCAL WIND MODEL IN NEW YORK CITY

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Abstract: According to insurance companies, 70–80 % of economic losses due to natural disasters in the world are caused by extreme winds and related water hazards. Wind behavior assessment in vulnerable areas can mitigate the following damages due to the wind. This study introduces a methodology to specify local wind pattern as a function of location in New York City. A variety of methods can be used to obtain localized wind. These include codes of practice, full-scale, wind tunnel or Computational Fluid Dynamics (CFD) studies. Each of these has their advantages and disadvantages.

Due to the considerable numbers of buildings under-study, codes evaluation was selected. The methodology for determining regional wind speeds and wind multipliers from major wind loading standards, focusing on Minimum Design Loads for Buildings and Other Structures from the American Society of Civil Engineers/ Structural Engineering Institute (7-10) and the Australian Wind Loading Standard AS/NZS 1170.2 (2011) is discussed in this research. Finally, it provides the wind pattern for New York City calculated using the different wind multipliers.

Wind multipliers/coefficients can be considered the basis of local wind determination; without them, the local wind would be meaningless. They convert the national scale wind to the local level by incorporating the effects of direction, height and terrain, topography and shielding. Combining these effects can describe the site wind speed in any location.

1   INTRODUCTION

A variety of methods can be used to obtain localized wind. These include codes of practice, full-scale measurements on actual structures, wind tunnel or Computational Fluid Dynamics (CFD) studies. Based on Dr. Eric Savory (University of western Engineering-London, Ontario, Canada) with the contribution of Prof Peter Richards (University of Aukland, New Zealand) studies, the advantages and disadvantages of these methodologies are listed below:

1. Codes
Advantages: Easy to use. Quick (A few hours or days) Can be carried out by designers who do not have specialised wind engineering knowledge. Inexpensive.
Disadvantages: Only applicable to basic building shapes. Can be too conservative. Codes represent average or idealized scenarios that may deviate from the actual situation.

2. Full-scale:
Advantages: "The Real Thing". The only way to check validity of other techniques.

Disadvantages: Expensive Slow (Many months or years). Results can be site specific. The wind has no "on" switch.

3.   Wind tunnel:
Advantages: Relatively quick (days - weeks). Not too expensive for large developments. New complex designs can be tested. Effects of surrounding buildings can be incorporated. Everything happens 60-100 times faster than in real life. A wide variety of tests are available.
Disadvantages: The wind profile and turbulence must be modelled which is not always possible. Results can be affected by Reynolds number mismatch. Instrumentation needs to respond rapidly. Difficult to measure everything. Requires specialised knowledge.

4.   Computational Fluid Dynamics (CFD):
Advantages: Variations on a design easily studied. Data for all points in the flow are available. Not too expensive.
Disadvantages: Requires expert knowledge. Not always reliable. To solve equations unrealistic simplifying assumptions may have to be made. Still requires significant computer resources. Only mean flows are easily modelled. (Savor, E. and Richards, P)

2   METHODOLOGY

A set of activities was organized to fulfill the objective of this study. A flow chart for activities contributing to this research is shown in Figure 1.
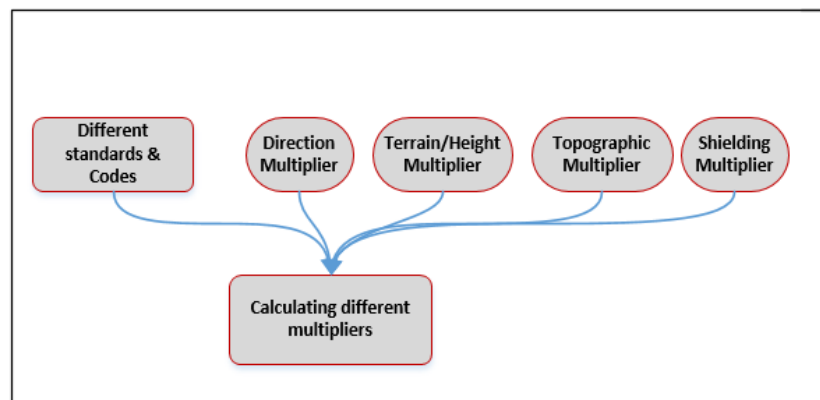

Figure 1 Suggested process to calculate the local wind in NYC

This study was conducted in the United States and aimed to mitigate the current vulnerability of New York City buildings due to wind. The focus of this task was to calculate the site wind speed/local wind in the studied area. Countries doing pioneer wind studies in civil and structural engineering have their own standards and codes for wind load assessment. These codes were studied to determine similarities; related aspects of these codes that can affect regional wind were extracted following a comprehensive approach (Holmes, J.D, 2015). Four main criteria were found to have the main impacts on local wind. These criteria include direction, terrain/height, topography, and shielding. The efficiency of each of these parameters can be expressed in a multiplier/ coefficient format. The methodology used in this study to determine the wind multipliers is based on Minimum Design Loads for Buildings and Other Structures from ASCE 7-10 (*ASCE/SEI 7-10,*2010) and Australian Wind Loading Standard (AS/NZS 1170.2: 2011) with the most similarities amongst the other codes. Each of these standards has their own processes to apply wind multipliers and relate regional wind speed to building pressure. Although ASCE 7-10 doesn't define multipliers to generate regional wind speed, it includes them in its next step and applies the multipliers directly to the velocity pressure. Different methodologies to obtain multipliers were evaluated for the city and eventually local wind speed was calculated for the Manhattan borough of New York City.

3   RESULTS AND CONCLUSION

3.1   Wind direction multiplier

Evaluating extreme hourly gust data in three available weather stations in New York City from 1984 to February 2016 indicated the dominant direction of wind in each of these stations. These stations include Central Park and John F. Kennedy and La Guardia Airports. According to ASCE 7-10, data from the nearest weather station should be considered for the wind calculation procedure. Since the case studies selected in this research were located in Manhattan, the closest weather station was Central Park. Therefore, data from this station were chosen to determine the wind direction.

The historical records were analyzed to derive the probabilities the wind exceeds various thresholds in various situations. In order to combine the wind speed probabilities in certain directions and computing the wind direction multiplier, an accepted wind speed threshold by meteorologists should be used. This threshold will separate light winds from high winds. The Threshold used for the purpose of the current study is taken from Beaufort Wind scale force.

An Irish royal navy commander called Francis Beaufort standardized this scale in 1805. At first it was used for naval purposes to relate the qualitative wind conditions with he effects on the sails of a frigate until 1850 in which it was adapted for non-naval usages. It was not until 1923 that scale numbers came to this standard by Gorge Simpson the director of the United Kingdom Meteorological Office.

Wind speeds, their classification and their impact on water and land is described in Table 1. According to this Table, the boundary of light wind and high wind is 24 m/h.

Table 1 Beaufort wind force scale

| Wind (m/h)	WMO Classification	United States and Canada Classifications	Appearance of Wind Effects	
			On the Water	On Land
Less than 1	Calm	Light Winds	Sea surface smooth and mirror-like	Calm, smoke rises vertically
1-3	Light Air		Scaly ripples, no foam crests	Smoke drift indicates wind direction, still wind vanes
4-7	Light Breeze		Small wavelets, crests glassy, no breaking	Wind felt on face, leaves rustle, vanes begin to move
8-12	Gentle Breeze		Large wavelets, crests begin to break, scattered whitecaps	Leaves and small twigs constantly moving, light flags extended
13-18	Moderate Breeze		Small waves 1-4 ft. becoming longer, numerous whitecaps	Dust, leaves, and loose paper lifted, small tree branches move
19-24	Fresh Breeze		Moderate waves 4-8 ft taking longer form, many whitecaps, some spray	Small trees in leaf begin to sway
25-31	Strong Breeze	High Winds	Larger waves 8-13 ft, whitecaps common, more spray	Larger tree branches moving, whistling in wires
32-38	Near Gale		Sea heaps up, waves 13-19 ft, white foam streaks off breakers	Whole trees moving, resistance felt walking against wind
39-46	Gale	Gale-Force	Moderately high (18-25 ft) waves of greater length, edges of crests begin to break into spindrift, foam blown in streaks	Twigs breaking off trees, generally impedes progress
47-54	Strong Gale		High waves (23-32 ft), sea begins to roll, dense streaks of foam, spray may reduce visibility	Slight structural damage occurs, slate blows off roofs
55-63	Storm	Storm-Force	Very high waves (29-41 ft) with overhanging crests, sea white with densely blown foam, heavy rolling, lowered visibility	Seldom experienced on land, trees broken or uprooted, "considerable structural damage"
64-72	Violent Storm		Exceptionally high (37-52 ft) waves, foam patches cover sea, visibility more reduced	Widespread vegetation and structural damage likely.
Greater than 73	Hurricane	Hurricane-force	Air filled with foam, waves over 45 ft, sea completely white with driving spray, visibility greatly reduced	Severe widespread damage to vegetation and structures. Debris and unsecured objects are hurled about.
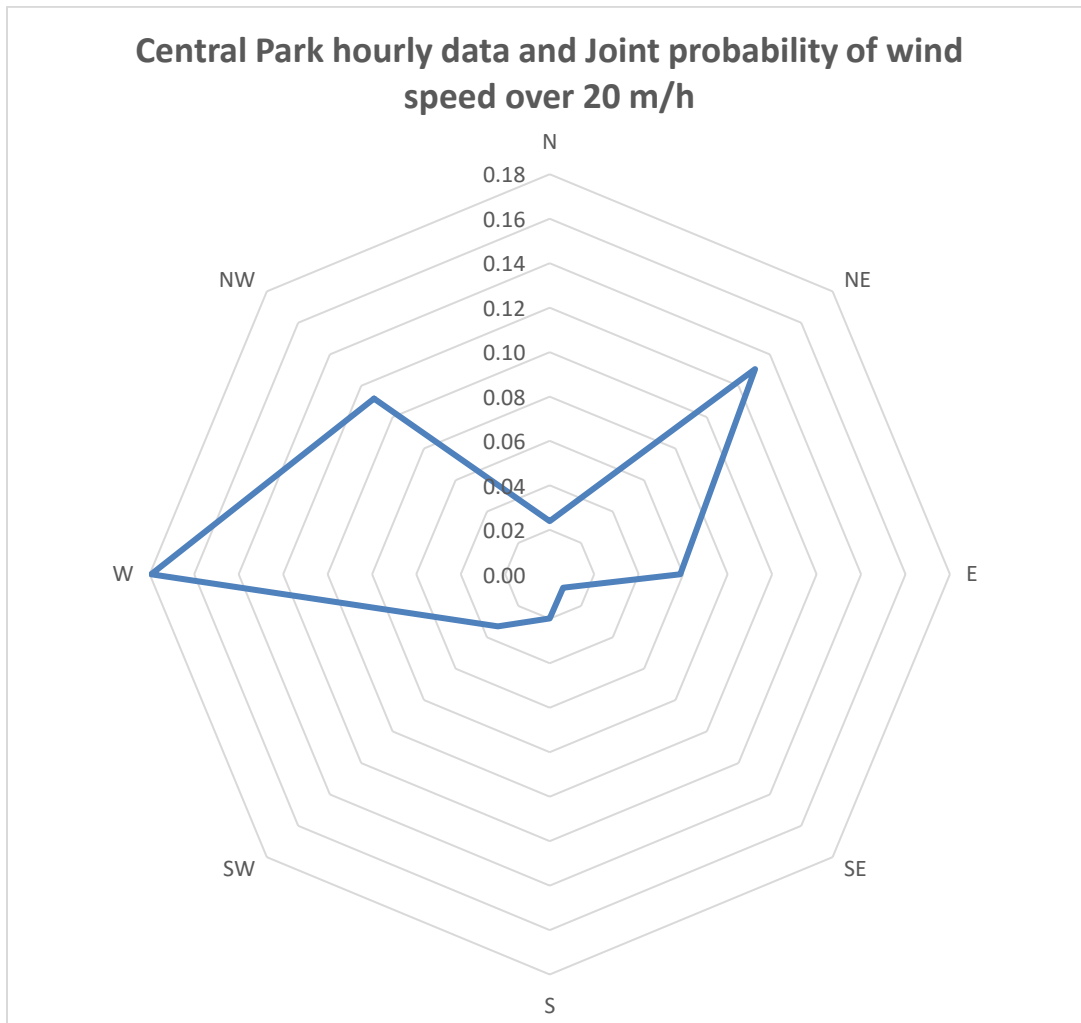
Figure 2 Central Park Wind direction pattern over 30 years

Table 2 Probability of having the wind in each direction in Central Park Weather Station, calculation of wind multiplier

DIRECTION	20-30	30-45	45-60 and 60-more	Probability of having wind	Normalized multiplier 0.8-1.0
N	0.023	0.001	0.0000	0.02	0.85
NE	0.114	0.016	0.0005	0.13	0.90
E	0.052	0.007	0.0001	0.06	0.85
SE	0.008	0.001	0.0000	0.01	0.80
S	0.019	0.001	0.0000	0.02	0.85
SW	0.030	0.003	0.0000	0.03	0.85
W	0.162	0.017	0.0001	0.18	0.95
NW	0.101	0.010	0.0000	0.11	0.90
VARIABLE	0.398	0.035	0.0011	0.43	1.00

Having the direction multiplier can not only enlighten the structural analysis and design, but it can also be a guiding tool for architects when designing plans, choosing façade materials, assessing the shape and design of the building, placing corners, cornices, and sharp points in their appropriate sides. Most of the wind damage that occurs during and after construction can be avoided by considering wind direction and choosing the best sides for curtain walls and huge pieces of glass, antennas, etc.

3.2   Terrain/Height Multiplier

The velocity pressure exposure coefficient, Kz, is calculated in Table 27-3-1 in ASCE 7-10. The coefficients for a height of 33 ft. above ground level and 600 to 1200 ft. above ground level were added to that table and the results are shown in Table 9. In order to use the appropriate column and formula in Table 3, the incident exposure (B, C, or D) needs to be identified. Exposure D includes three islands of New York City: Elis Island, Governor's Island, and Liberty Island. These islands did not report any incidents to 311 during windy days. The incidents that were reported to 311 were located in exposures B and C. Figure 3 shows the incidents that occurred in exposures B and C. 50 samples were used to identify local wind multipliers. These samples were randomly selected through 500 incidents occurred from 2010-2015 and were reported to 311.

Table 3 Multiplier Terrain/Height

Height above ground level, Z	MT/H (Exposure B)=	MT/H (Exposure C)=	MT/H (Exposure D)=
0-15	0.57	0.85	1.03
20	0.62	0.9	1.08
25	0.66	0.94	1.12
30	0.7	0.98	1.16
33	**0.72**	**1.00**	**1.18**
40	0.76	1.04	1.22
50	0.81	1.09	1.27
60	0.85	1.13	1.31
70	0.89	1.17	1.34
80	0.93	1.21	1.38
90	0.96	1.24	1.4
100	0.99	1.26	1.43
120	1.04	1.31	1.48
140	1.09	1.36	1.52
160	1.13	1.39	1.55
180	1.17	1.43	1.58
200	1.2	1.46	1.61
250	1.28	1.53	1.68
300	1.35	1.59	1.73
350	1.41	1.64	1.78
400	1.47	1.69	1.82
450	1.52	1.73	1.86
500	1.56	1.77	1.89
600	1.65	1.85	1.96
700	1.72	1.91	2.01
800	1.79	1.96	2.06
900	1.85	2.01	2.10
1000	1.91	2.06	2.14
1200	2.01	2.14	2.21
Zg =	1200	900	700
α=	7	9.5	11.5

$$V_z = V_{ref}(b(z/zr_{ef})^{2/\alpha})$$

NYC wind exposures and wind related incidents

KEY
- ◆ 50 samples
- ☐ All reported incidents
- Exposure C
- Exposure B

0   0.5   1   2 Miles

Sources:
311 Data for incidents:
https://nycopendata.socrata.com/Social-Services/311-Service-Requests-from-2010-to-Present/erm2-nwe9
Borough Boundaries- BYTES of the BIG APPLE archive:
https://www1.nyc.gov/site/planning/data/maps/open-data/districts-download-metadata.page

Figure 3 NYC wind exposures and wind-related incidents

According to ASCE 7-10's definition and the 2014 NYC Building Code Exposure C in Manhattan includes:
buildings within a distance of 2600 feet from the shoreline.

3.3   Topographic Multiplier

According to ASCE 7-10 and Australian code AS1170.2, a set of complex conditions must be satisfied in order to have a topographic multiplier other than 1.0. One of these conditions is having the slope of H/L_h greater than or equal to 20% for the building sites.

According to the definitions that ASCE 7-10 have for H and L_h, where the L_h is the distance upwind of crest to where the difference in ground elevation is half the height of hill or escarpment that will make a slope of 10% for H/L_h. Spatial analysis of the DEM maps illustrates that none of the building sites were located in such an area. So, for the purpose of this study, the topographic multiplier was considered to be 1.0.

3.4   Shielding Multiplier

The shielding factors for a structure located near an identical or higher upstream structure have been found to be most sensitive to separation distance, building aspect ratio, turbulence characteristics, and wind angle of attack.[1] In this study, the influence of the first three variables was investigated.
According to the Australian/ News land Code, the shielding parameter can be calculated by Equation 1.

$$[1] \quad s = \frac{Ls}{\sqrt{hs\ bs}}$$

In which:

Ls=average spacing of shielding buildings, given by Equation 2.

$$[2] \quad Ls = h\left(\frac{10}{ns} + 5\right)$$

h_s= average roof height of shielding buildings

b_s= average width of shielding buildings, normal to the wind stream

h= average roof height, above ground, of the structure being shielded

ns= number of upwind shielding buildings within a 45°sector of the radius in 20h and with their height is greater than the structure being shielded (hs ≥ z)

To calculate the shielding factor, the following steps were taken.

- Amongst 500 incidents that happened during the windy days in New York City, 50 buildings were randomly selected by spatial analysis for further calculation.

- These points were transferred to AutoCAD for further drawings of sectors with 20 times their roof-height.
- They were then returned to GIS to assign the buildings to a fan.

- This information was exported to excel for further calculation. Special coding was done to evaluate the buildings in each fan that were equal to or taller than the shielded structure as there were up to 5100 buildings in some of the fans. Units were converted to SI, average heights and widths were computed and shielding parameters were calculated for each fan or each case.

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[1] Recent Advances in Wind Engineering, 1990, Ahsan Kareem

- After calculating the shielding parameters, shielding multipliers were then interpolated using Table 4.

Table 4 Shielding Multiplier according to AS/NZS 1170.2:2011

SHIELDING MULTIPLIER (M_s)	
Shielding parameter (s)	Shielding multiplier (M_s)
≤1.5	0.7
3.0	0.8
6.0	0.9
≥12.0	1.0

Table 5 shows the results of calculating shielding parameters and interpolating shielding multipliers for each fan.

Table 5 Shielding parameter and Shielding multiplier for different FANs in Manhattan-New York City

FAN	Shielding parameter (s)	Shielding multiplier (Ms)	FAN	Shielding parameter (s)	Shielding multiplier (Ms)	FAN	Shielding parameter (s)	Shielding multiplier (Ms)
0	3.53	0.818	17	8.66	0.945	34	2.87	0.791
1	5.94	0.898	18	10.16	0.970	35	10.90	0.982
2	2.96	0.798	19	1.41	0.700	36	5.70	0.890
3	12.00	1.000	20	3.68	0.823	37	2.64	0.776
4	12.00	1.000	21	3.36	0.812	38	4.43	0.847
5	2.51	0.768	22	3.21	0.807	39	2.32	0.755
6	5.06	0.869	23	3.91	0.830	40	4.87	0.862
7	5.77	0.892	24	4.95	0.865	41	7.74	0.929
8	6.59	0.910	25	3.66	0.822	42	2.48	0.766
9	3.94	0.831	26	2.96	0.798	43	2.64	0.776
10	2.94	0.796	27	2.79	0.786	44	3.08	0.803
11	4.93	0.864	29	3.87	0.829	45	2.31	0.754
12	2.88	0.792	30	2.55	0.770	46	10.86	0.981
13	3.03	0.801	31	5.61	0.887	47	7.71	0.929
14	3.54	0.818	32	7.70	0.929	48	12.00	1.000
15	3.53	0.818	33	5.80	0.893	49	3.73	0.824

3.5 Combined multiplier

Figure 4 illustrates the combined wind multiplier throughout New York City that was computed for 50 samples. According to the figure, in Manhattan, the areas that experience the greatest local wind are Downtown, Midtown, the Upper West Side, the Upper East Side, and Uptown.

These results confirm the everyday wind measurements and tools that address the wind in different locations of the city. This map can be applied by overlaying a base map, such as the street and building footprint, to clarify the exact boundaries of different layers of the overall multiplier. It can then be useful for engineers, architects, urban designers, and academic researchers.
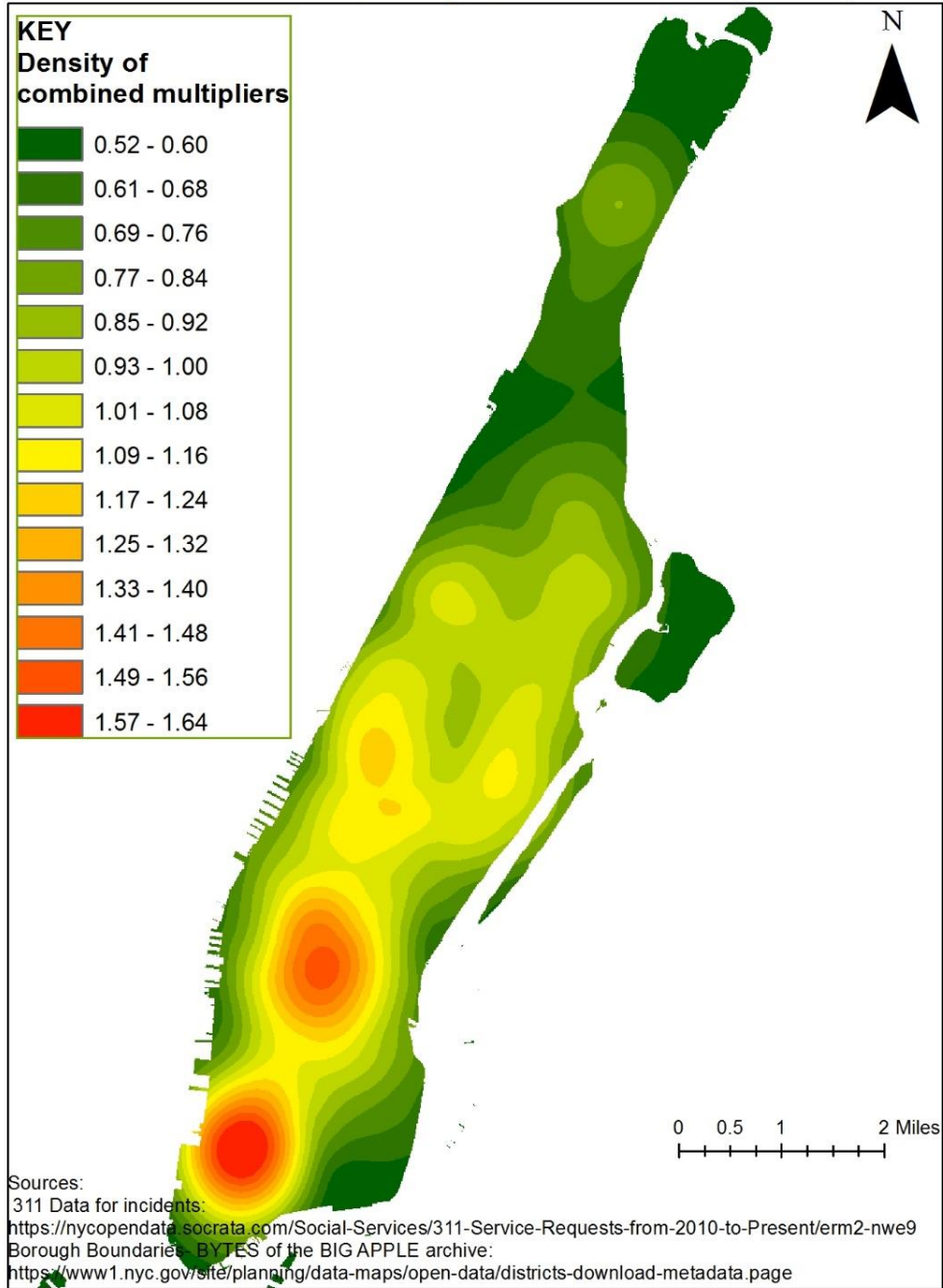
Figure 4 NYC combined wind multipliers

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