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1 PURPOSE OF MEMORANDUM

To estimate the theoretical drift distance and possibility of overspray of water droplets generated by the proposed Tower Sprays at Neptune Bulk Terminals (NBT) in North Vancouver, BC

2 EXECUTIVE SUMMARY

Drift distances for water droplets depends on droplet size (small droplets drift further than larger ones), the height at which the droplet falls from, the wind velocity, and evaporation.

Droplet size depends upon the nozzle design and pressure. In reality, a nozzle produces a range of droplet sizes ranging from very small (comparable to light fog) to very large (comparable to heavy rain). The distribution for these droplet sizes is of log normal type with a relatively small standard distribution. In other words, the number of very small droplets and very large droplets is quite low relative to the total number of droplets that are propelled through the nozzles. In addition, it is important to note that although the number of small droplets is comparable to the number of large droplets, they constitute only a minimal portion of the total propelled volume.

Nozzle pressure affects droplet size, with higher pressures producing smaller droplets with consequently greater drift distances. However, the effect of pressure on droplet size is non-linear and there are limits to its effect on droplet size.

Wind velocities for the Neptune site can reach 60 km/h, though this is a relatively rare event. The predominant direction is blowing to the east (westerly wind). For overspray concerns, the most vulnerable direction is almost due north, which occurs much less frequently. For the purposes of this memorandum, maximum drift distance analysis was based upon a wind velocity of 45 km/h in a northerly direction.

Evaporation, although beneficial in regards to overspray, is not a significant factor for the VMD droplet sizes produced by the proposed nozzles.

Analyses for maximum drift distances were performed for the volume median diameter ($D_{v0.5}$ or VMD) droplet size and for a 10 percentile volume diameter ($D_{v0.1}$) size (see memorandum for terminology details). The analysis indicates that there will not be significant drift beyond the site boundary; although some smaller droplets would leave the site boundary during high wind events (greater than 30 km/h) they would probably, in a worst case scenario, be only a very light mist. The results of the analyses are shown graphically in Figure 7 of the memorandum.

If reality trumps the theoretical analyses herein, overspray could be eliminated by increasing the droplet size either by reducing nozzle pressure or, in an extreme situation, by changing out the nozzles to a model that produces larger droplet sizes.

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3 GENERAL FACTORS AFFECTING DROPLET DRIFT DISTANCE

The drift distance of a water droplet is a function of it's horizontal velocity and the time spent in the air. The time spent in the air is directly related to the terminal vertical velocity of the water droplet and the height at which it falls from. Vertical terminal velocity and horizontal velocity are determined by:

3.1 Droplet size

The size of the droplet effects the vertical velocity at which it falls. A larger droplet will fall at a greater speed than a smaller droplet in the same conditions. When evaluating the average drop size produced by a particular nozzle, the Volume Mean Diameter (VMD) is typically used. The VMD is a value where 50% of the total volume of liquid sprayed is made up of drops with diameters larger than the median value and 50% smaller than the median value (Schick, R.J., 2006). Table 1 below describes water droplets at particular diameters.

Table 1: Water Droplet VMD Description (Grisso, R. et al, 2013)

Droplet Diameter (microns)	Type of Droplet
5 (VF)[1]	Dry fog
10 (VF)	Dry fog
20 (VF)	Wet fog
50 (VF)	Wet fog
100 (VF)	Fine mist
150 (F)	Fine mist
200 (F)	Fine drizzle
300 (M)	Fine rain
500 (VC)	Light rain
1,000 (XC)	Heavy rain

For the prevention of dust generation for stockpiles, standard hydraulic nozzles that produce drops between 200 and 1200 µm are generally used.

The drop size distribution from most nozzles follow a typical curve, approximately a log normal distribution, as shown in Figure 1 below. Note: the VMD is shown as $D_{V0.5}$. Also shown is the $D_{V0.1}$, representing the diameter where 10% and 90% of the total sprayed volume is made up of smaller and larger diameters respectively.

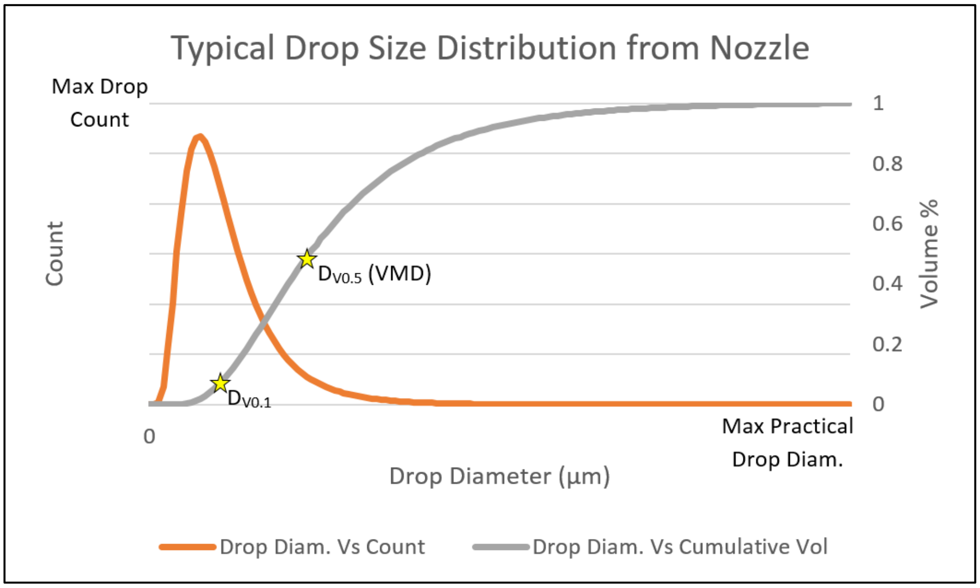

Figure 1: Typical Drop Size Distribution from Nozzle

Drop size and uniformity will vary based on several factors: viscosity of the liquid, the spray nozzle design, flow through the spray nozzle, and the air pressure if two-fluid nozzle are being used (Schick, R.J., 2006).

3.2 Wind Speed

The wind speed determines the horizontal velocity of the water droplets. Due to a high drag force on a droplet relative to its size, the horizontal velocity is considered the same as the wind velocity for practical purposes. In other words, the discharge velocity of droplet as it leaves the nozzle is disregarded.

3.3 Evaporation

Evaporation can be a factor for very small droplets and /or long fall distances.

4 SITE SPECIFIC FACTORS AFFECTING DROPLET DRIFT DISTANCE AT NEPTUNE TERMINALS

4.1 Droplet Size

The VMD can be affected by the nature of the fluid e.g. viscosity, vapor pressure or temperature extremes. However Neptune Bulk Terminals proposed Spray Towers will operate under fundamental conditions i.e. clean water entering normal atmospheric conditions. Therefore, the VMD can be estimated by considering only the type of nozzle and the water pressure at the nozzle head for a given flow.

4.1.1 Nozzle Type:

There will be two types of nozzles on the Tower Sprays: Whirljet 8-15W which produce a mean droplet diameter of approximately 500 µm @ 40 psi and Whirljet 15-15W with a mean droplet diameter of approximately 650 µm @ 40 psi (see Appendix A). At a single tower, two-thirds of the nozzles will be 8-15Ws and one-third will be 15-15Ws. The 8-15W droplet drift distance will be investigated further, since they produce smaller droplets and represent the majority of the nozzles.

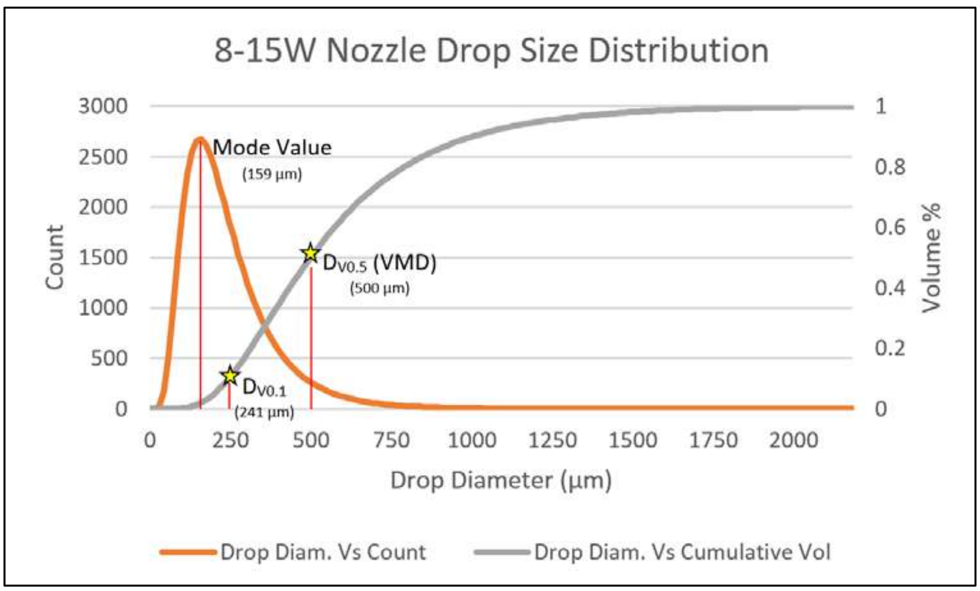

Figure 2: 8-15W Nozzle Drop Size Distribution

Two drop sizes will be evaluated: a droplet of the nozzles VMD value ($D_{V0.5}$) and a droplet of the nozzles ($D_{V0.1}$) value. In reference to Table 1, this will evaluate a droplet characteristic of light rain, and a droplet characteristic of a fine drizzle respectively.

4.1.2 Pressure

Droplet drift distance has been estimated using the VMD produced by a design water pressure at the nozzles of 40 psi. VMD is inversely correlated with water pressure. The following equation can be used to estimate the change in VMD with a change in pressure (BETE, 2016):

$$\left(\frac{D_2}{D_1}\right) = \left(\frac{P_2}{P_1}\right)^{-0.3} \quad \textbf{(Equation 1)}$$

Figure 3 was produced using Eq. 1 and the Spraying Systems data from Appendix A.

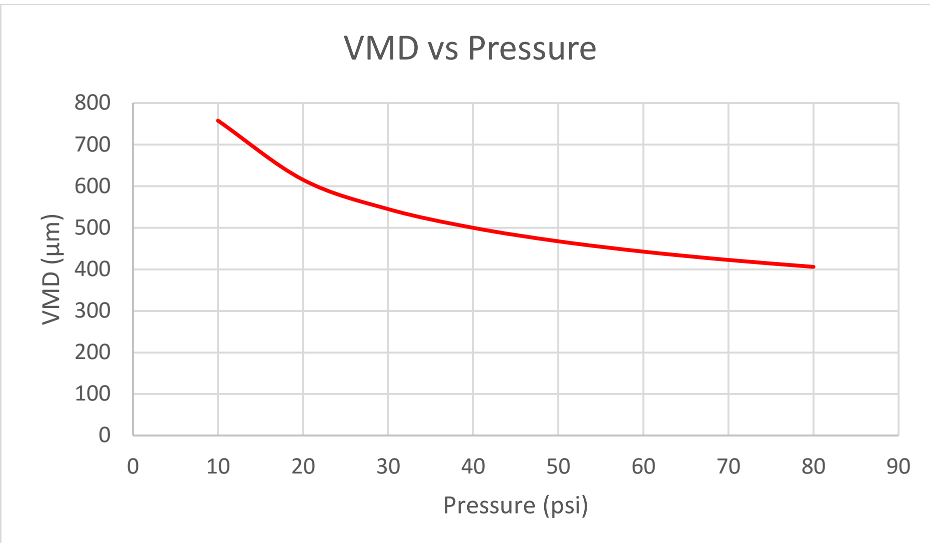

Figure 3: VMD vs Pressure

Since the VMD is inversely correlated with water pressure and the pressure can be modified on site, the VMD can be adjusted within the limits shown. Therefore, if overspray is ever an issue during normal operation, the pressure can be reduced to increase droplet size and thereby shorten the drift distance.

Note: the pressure can only be modified within practical limits. For example, the pressure in the Spray Tower piping should never exceed its pressure ratings. On the opposite end of the spectrum, the spray emitting from the nozzles will become a stream as the water pressure approaches zero.

4.2 Vertical Fall Velocity

The vertical fall velocity is determined by droplet diameter. As water droplets greater than 100 µm become unstable in a free fall scenario, Stokes Law does not apply.

Instead, Figure 4 shows the graphed experimental data Gunn & Kinzer's "The Terminal Velocity of Fall for Water Droplets in Stagnant Air".

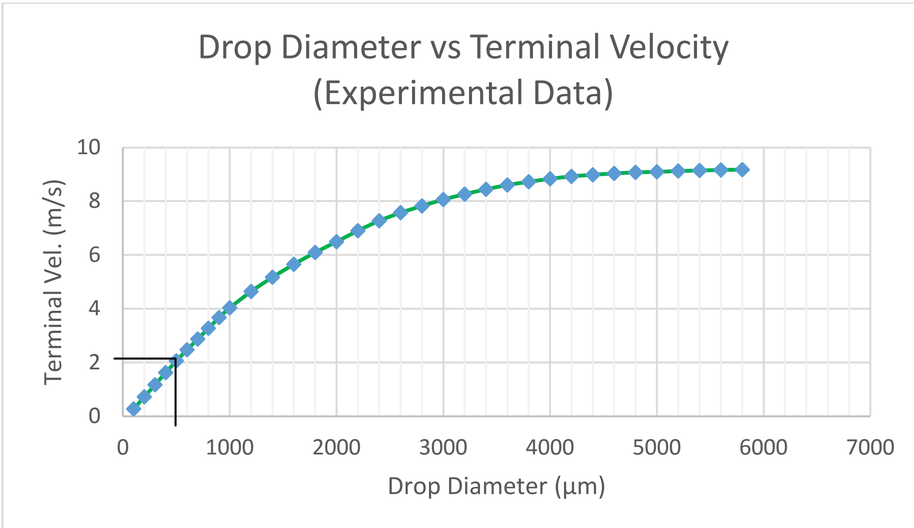

Figure 4: Drop Diameter vs Terminal Velocity

As interpolated from the data points presented, the vertical velocity of a 500 μm droplet is 2.06 m/s

Note: the leftmost data point is that of 100 μm diameter; all smaller droplets' terminal velocities may be calculated using Stokes Law.

4.3 Wind Velocity

The historical wind data at the Vancouver Airport can be found in Appendix B. From this data, the following wind speeds can be gathered:

Typical day-to-day: ~15 km/h

Typical weekly high: ~30 km/h

Typical high (gale force): ~45 km/h

Westerly winds are the most common winds through the Burrard Inlet. However, to be conservative, we will assume these winds can travel in the path most consequential to overspray when evaluating drift distances.

4.4 Evaporation

Water drops that are greater than 300 μm in diameter will experience negligible evaporation from a fall over 1000 m in an atmosphere with a relative humidity as low as 40% (Pruppacher &

Klett, 1980; Gunn & Kinzer, 1951). Figure 5 below shows the distance a droplet falls before evaporating.

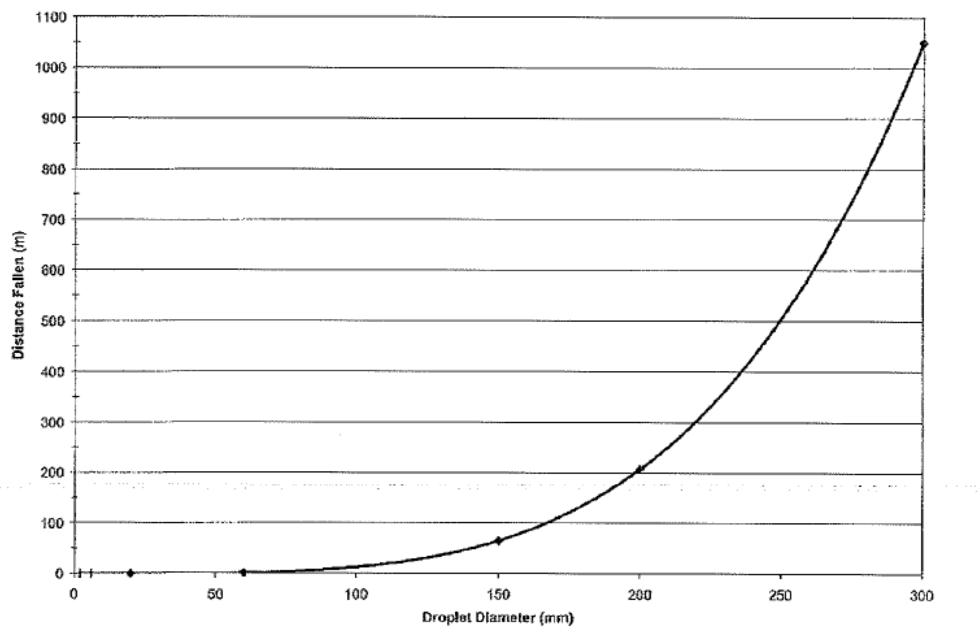

Figure 5: Droplet Fall Distance Before Evaporation

(The above fall distances assume isothermal conditions with a temperature of 7°C and an ambient saturation ratio of 0.8 (Rogers, 1979).

Since the fall distance from the Spray Tower will be no more than 40 m and the VMD is 500 µm , we are basically off the chart ie the effects of evaporation for the VMD can be disregarded. However, very small droplets which theoretically would drift beyond the site boundaries under extreme wind conditions, will evaporate in hot summer weather. This potentially beneficial effect has been disregarded for purposes of this memorandum.

5 THEORETICAL ESTIMATION OF DRIFT DISTANCE

Theoretical drift distances can be evaluated using the following information from the previous sections:

- Droplet Diameter using Whirljet 8-15W nozzle at 40 psi
  - $D_{V0.5}$ (VMD) = 500 µm; const. vert velocity = 2.06 m/s
  - $D_{V0.1}$ = 241 µm; const. vert velocity = 1.09 m/s
- Constant horizontal velocities = 15 km/h, 30 km/h, 45 km/h
- Evaporation = negligible
- Direction = north

The drop distance from the Tower Spray nozzles will be approximately 40 m above ground at its base.

Figure 6: Critical Droplet Drift Path

The critical path was chosen along the profile line A-D. Points of reference along the line are

A. Tower spray (closest to public road and residential property)
B. Stacker/reclaimer rails
C. Keith Road south retaining wall
D. Nearest residential housing

It is assumed that the spray poles running along the north side of the site will be shut off in southerly (blowing north) winds. Therefore, the possibility of overspray from these spray poles is ignored.

Figure 7 on the following page shows the profile along reference points A-D along with the projected drift distances during 15km/h, 30 km/h, and 45 km/h winds. Approximate elevations have been found using Google Earth.

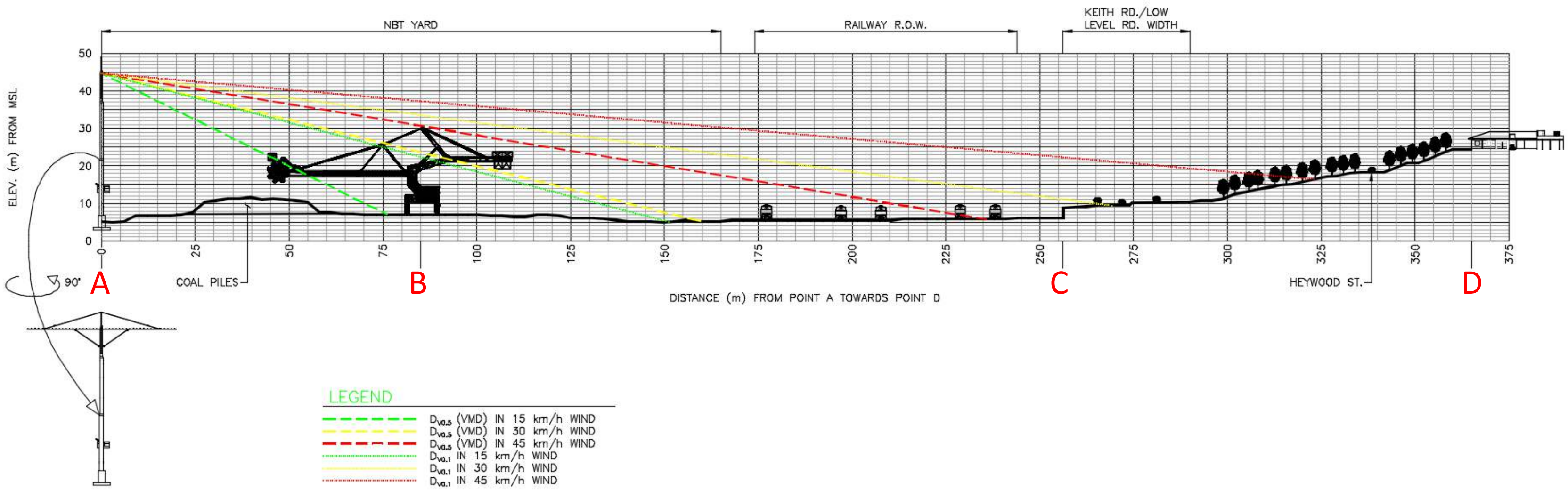

Figure 7: Droplet Drift Distance Profile (Natural Scale)

These drift profiles refer to the travel distance for $D_{V0.5}$ and $D_{V0.1}$ droplet sizes. As discussed previously, the nozzles will produce droplet diameters in a distributed manner. There will be droplets that are smaller in diameter than what is shown, and will therefore travel farther. However, the volume of water that these droplets constitute is considered small enough to ignore.

Also, it should be readdressed that west is the wind's most primary direction in the Burrard Inlet. In the last year, the wind blew north (direction along the profile line) less than 5% of the time.

6 CONCLUSION

As evident from Figure 7, water droplets from the Spray Towers will not leave the NBT yard in any direction during a 15 km/h wind event; the mean wind velocity in Vancouver. During a 30km/h wind event, which is considered a typical weekly high in Vancouver, a water droplet will travel to approximately the extents of the NBT Yard. During a one-year, 60 km/h wind event, a water droplet could reach the most vulnerable section of road along Keith Road/Low Level Road. However the droplets that make it this far are of very small diameter and will constitute something approximating a fine mist. Under anything other than hurricane force winds, residential properties are not vulnerable to overspray.

If it turns out that the Tower Spray nozzles do produce overspray beyond the theoretical drift distance, it will be possible to reduce the drift distance by increasing the droplet size either by manipulating the site pressure, as seen in Figure 3 or, in an extreme case, by changing out the nozzles to a model that produces larger droplets.

7 REFERENCES

BETE, 2016: “BETE 0813 Spray Nozzle Catalogue”, p 129.

Grisso, R. et al, 2013: “Nozzle: Selection and Sizing”, Publication 442-032, p 5. Virgina Cooperative Extension

Gunn, R. & G.D. Kinzer, 1949: “The Terminal Velocity of Fall for Water Droplets in Stagnant Air”, p 243. Journal of Meteorology, Volume 6, US Weather Bureau, Washington, D.C.

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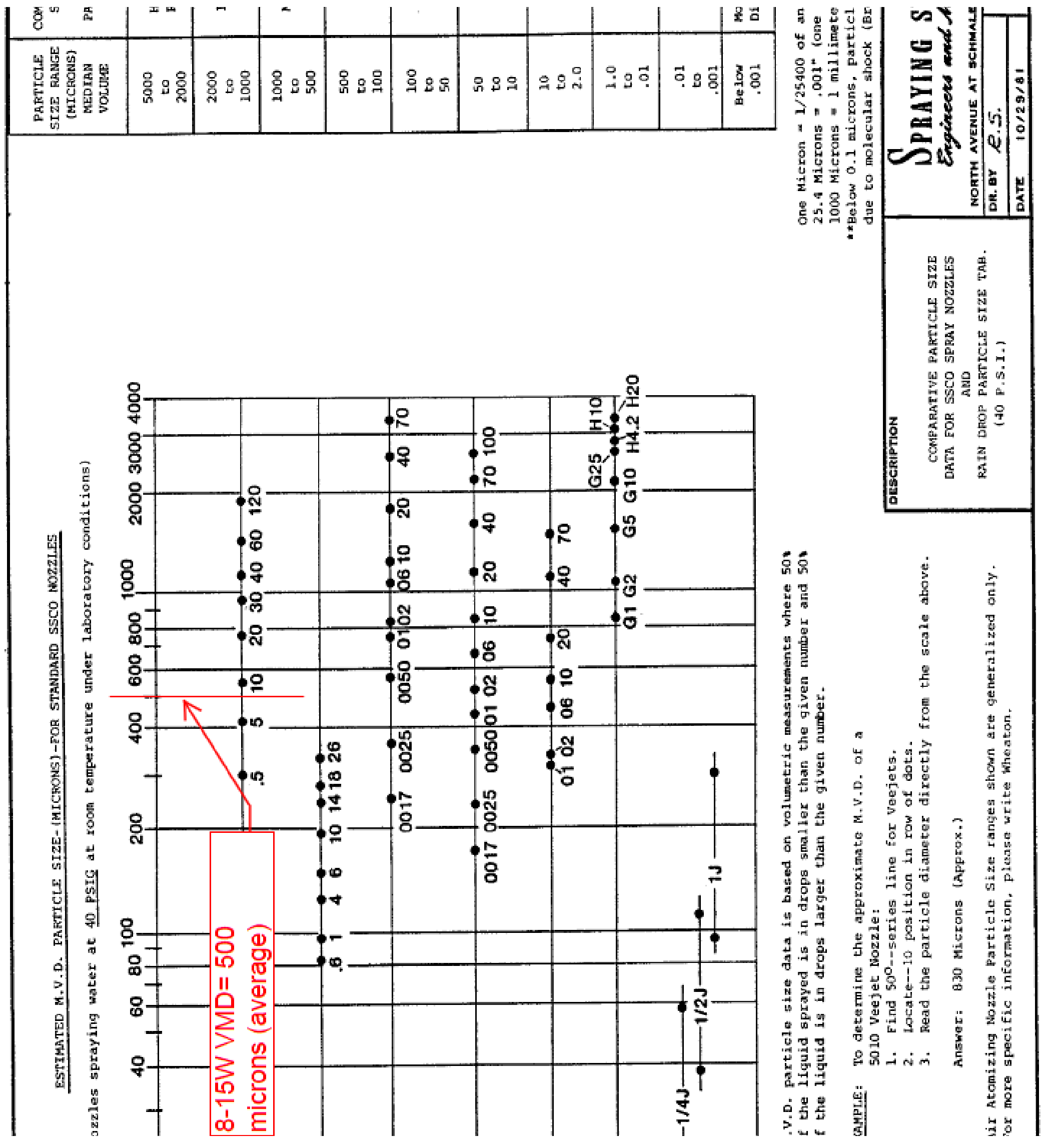
Pruppacher, H.R. & J.D. Klett, 1980: “Microphysics of Clouds and Precipitation”, p 445. D. Reidel Publishing Company, Dordecht, Holland.

Rogers, R.R., 1979: “A Short Course in Cloud Physics”, p 92. Pergamon Press, Oxford, England

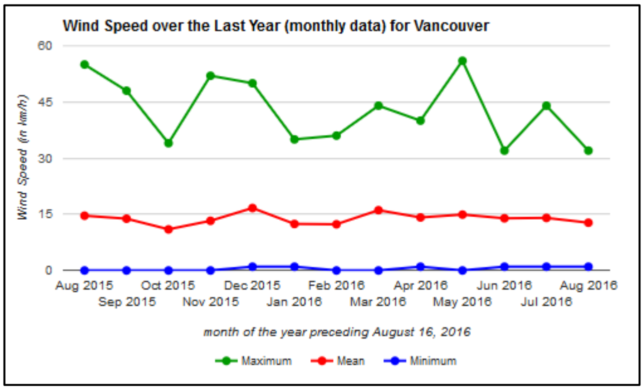
Schick, R.J., 2006: “Spray Technology Reference Guide: Understanding Drop Size”, p 16. Spray Analysis and Research Services, Spraying Systems, USA.

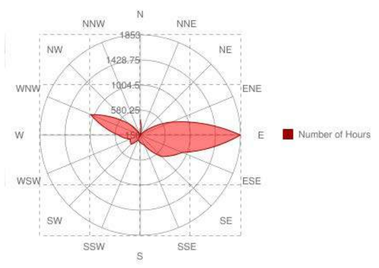
8 APPENDIX A Nozzle VMD Droplet



9 APPENDIX B Wind Velocities

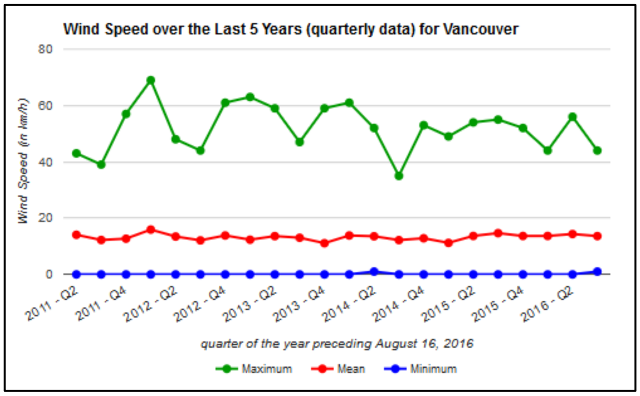
YEARLY WIND SPEED RECORDS (AUG 2015 – AUG 2016)

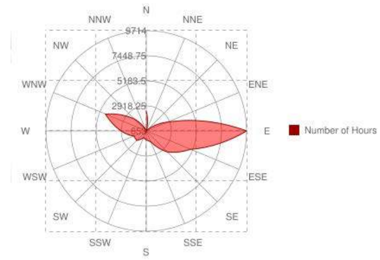




Direction	Number of Hours
N	426 hour(s)
NNE	156 hour(s)
NE	218 hour(s)
ENE	731 hour(s)
E	1,853 hour(s)
ESE	927 hour(s)
SE	669 hour(s)
SSE	339 hour(s)
S	282 hour(s)
SSW	241 hour(s)
SW	377 hour(s)
WSW	339 hour(s)
W	524 hour(s)
WNW	1,064 hour(s)
NW	431 hour(s)
NNW	161 hour(s)

5-YEAR WIND SPEED RECORDS (AUG 2011 – AUG 2016)





Direction	Number of Hours
N	2,432 hour(s)
NNE	653 hour(s)
NE	864 hour(s)
ENE	2,751 hour(s)
E	9,714 hour(s)
ESE	4,998 hour(s)
SE	3,336 hour(s)
SSE	1,707 hour(s)
S	1,452 hour(s)
SSW	1,300 hour(s)
SW	1,872 hour(s)
WSW	1,862 hour(s)
W	2,923 hour(s)
WNW	4,653 hour(s)
NW	2,193 hour(s)
NNW	753 hour(s)