BEFORE THE HEARINGS PANEL APPOINTED BY CANTERBURY REGIONAL COUNCIL

UNDER	the Resource Management Act 1991 (RMA)
AND	
IN THE MATTER	of an application by Canterbury Regional Council for resouce consent to discharge agrichemicals to rivers and their connected waterbodies, air and the coastal marine area, and the clearance of vegetation, for the purposes of weed management to provide flood, erosion, drainage and river enhancement works.

STATEMENT OF EVIDENCE OF Dr Brian Richardson
ON BEHALF OF CANTERBURY REGIONAL COUNCIL (APPLICANT)

8 March 2024

SUMMARY STATEMENT

Introduction

1 My full name is Brian Richardson. I am employed as a Principal Scientist at the New Zealand Forest Research Institute Ltd operating “Scion” and I have held this position since January 2016.

2 I have been asked to undertake modelling, and provide expert evidence, for the Applicant, in regards to quantifying potential drift of agrichemicals when discharged from helicopters.

Qualifications and Experience

3 My significant qualifications are:

- BSc (Hons) Biological Sciences (specialising in Plant Physiology and Ecology), Lancaster University, 1981.
- MSc (Bio-Aeronautics), Cranfield University, 1982.
- PhD (Forest Ecology), Oregon State University, 1988.

My MSc focused on the sciences that underpin aerial pesticide spraying technologies. After receiving my MSc, I was employed by the NZ Forest Research Institute (part of the NZ Forest Service) in February 1983 to work on a project to improve the efficiency of aerial herbicide application in forestry. From then until today, I have had many roles but a consistent activity over those 40+ years has been researching aerial spray application with the aim of achieving good management practices that are cost-effectively and environmentally sound.

In the late 1980s I started a collaboration with the US Forest Service, working on an aerial application simulation model they were developing. This model eventually became known as AGDISP, which is the most widely used model of its kind. Some of the contributions to model development and use that I have led or supported include:

- Code checking for first personal computer-based version of the AGDISP (formerly known as FSCBG).
- Collection of field data for model validation.
- Development of first system to integrate model outputs with biological response data to calculate treatment efficacy and environmental impacts.
- Development of first spatial version of AGDISP.

- Sensitivity analysis to develop good practice aerial spraying guidelines for the forest industry.
- During the painted apple moth incursion response, modelling data helped change the entire approach to the response and was used as a treatment quality control tool.
- Evaluation and improvement of the plant canopy deposition model within AGDISP.
- Evaluation of unmanned aerial vehicles as spraying platforms.
- Developing good practice guidelines for aerial spraying to control wilding conifers.
- Many reports using AGDISP modelling have been prepared for clients including MPI, Councils, forestry companies, NZ EPA.

My work has been recognised in various ways e.g.

- Recipient of NZ Plant Protection Medal awarded by NZ Plant Protection Society (2022).
- Science New Zealand lifetime achievement award (2019).
- Superior Paper' Award from the American Society of Agricultural and Biological Engineers (2018; 2019).
- Awarded "Forester of the Year" by NZ Institute of Forestry (2015).
- Numerous invited speaker invitations at science conferences.
- Some refereed science publications related to aerial spray application are listed in Appendix 1.

Code of Conduct

4 I can confirm that I have read and am familiar with the Code of Conduct for Expert Witnesses contained in the Environment Court Practice Note 2023. I have complied with the Code of Conduct in preparing this evidence and I agree to comply with it while giving any oral evidence during this hearing. Except where I state that I am relying on the evidence of another person, my evidence is within my area of expertise. I have not omitted to consider material facts known to me that might alter or detract from the opinions that I express.

5 Although I have been contracted by the applicant, I am conscious that in giving evidence in an expert capacity that my overriding duty is to the Hearings Panel.

Scope of evidence

6 I have been asked to provide evidence on behalf of the applicant to inform resource consent applications to discharge agrichemicals and clear vegetation.

7 The modelling and my interpretation and recommendations based on those results are included in Attachment 1 which forms the substantive content of my evidence. I have not seen any need to update the recommendations in this report since its preparation and the executive summary follows:

The problem

8 Canterbury Regional Council (trading as Environment Canterbury) carries out aerial herbicide applications on islands in braided riverbeds to control a range of weed species. Typically, the sprays contain either glyphosate or a mix of glyphosate and triclopyr as active ingredients. With aerial operations there is a risk of off-target spray drift onto sensitive areas beyond the target zone, including water bodies. The purpose of this report was to use the AGDISP spray simulation model to quantify predicted levels of spray drift for a range of spraying scenarios relevant to operational riverbed spraying. Buffer distances (the distance between the spray zone and the sensitive area) needed to avoid unacceptable levels of drift were defined based on the lowest value of the EEL (environmental exposure level) or MAV (maximum acceptable value for drinking water) for herbicide applications using triclopyr or glyphosate plus triclopyr. Model results were used to develop recommendations on buffer zones for herbicide applications in riverbeds.

Key results

Factors having the biggest influence on the buffer zone width needed to ensure herbicide concentrations do not exceed EELs are:

- the choice of nozzle (droplet size),
- wind speed and direction,
- spray release height, and
- the characteristics of the river next to the spray area.

Recommendations

When spraying weeds in riverbeds, no-spray buffer zones can effectively manage the risk of exceeding acceptable herbicide concentrations in water defined using the environmental exposure limits (EELs).

With the smallest droplet size class tested (coarse spectrum; ~350 µm VMD), a buffer zone of about 10 m is reasonable as long as the flying height is no greater than 3 m above the target vegetation and wind speed is less than 10 km/hr. At greater release heights or windspeeds a buffer of 20 m would be recommended.

With nozzles producing larger drops and a very low driftable fraction (e.g. Accuflo, Thru-valve boom), a buffer zone of 12 m would be adequate for all conditions tested as long as the wind speed does not exceed 15 km/hr. With these nozzles, buffers could be reduced to about 5 m if there is enough confidence that flying height will be less than 3 m above the vegetation and wind speeds in the direction of the water body will be less than 10 km/hr.

Dated 8 March 2024

B Richardson

Brian Richardson

Appendix 1: Example Refereed Science Journal Papers on Aerial Spraying

Chyrva, I., Jermy, M., Strand, T., Richardson, B. 2022. Evaluation of the pattern of spray released from a moving multicopter. Pest Management Science. doi.org/10.1002/ps.7320

Rolando, C., Richardson, B., Paul, T., & Somchit, C. (2021). Refining tree size and dose–response functions for control of invasive *Pinus contorta*. Invasive Plant Science and Management, 14(2), 115-125. doi:10.1017/inp.2021.7

Richardson, B., Rolando, C.A., Hewitt, A., Kimberley, M.O. 2020. Meeting droplet size specifications for aerial herbicide application to control wilding conifers. NZ Plant Protection, 73; 13-23. https://doi.org/10.30843/nzpp.2020.73.11712

Rolando, C.A., Gaskin, R.E., Horgan, D.B., **Richardson, B**. 2020 Effect of dose and adjuvant on uptake of triclopyr and dicamba into *Pinus contorta* needles. Plant Environment Interactions 1: 57-66.

Richardson, B., Rolando, C.A., Kimberley, M.O. 2020. Quantifying spray deposition from a UAV configured for ‘spot’ spray applications to individual plants. Trans ASABE 63(4): 1049-1058

Richardson, B., Kimberley, M.O., Rolando, C.A. Coker, G.W., Gous, S. 2019. Optimising spot weed control regimes for Pinus radiata plantations. Canadian Journal of Forest Research 49: 759-766

Richardson, B., Rolando, C. A., Kimberley, M. O., & Strand, T. M. (2019a). Spray Application Efficiency from a Multi-Rotor Unmanned Aerial Vehicle Configured for Aerial Pesticide Application. *Transactions of the ASABE, 62*(6), 1447-1453.

Richardson, B., Rolando, C. A., Somchit, C., Dunker, C., Strand, T. M., & Kimberley, M. O. (2019b). Swath pattern analysis from a multi-rotor unmanned aerial vehicle configured for pesticide application. Pest Management Science. doi:https://doi.org/10.1002/ps.5638

Ogilvie, S.; McCarthy, A.; Allen, W.; Grant, A.; Mark-Shadbolt, M.; Pawson, S.; Richardson, B.; Strand, T.; Langer, E.R.; Marzano, M. Unmanned Aerial Vehicles and Biosecurity: Enabling Participatory-Design to Help Address Social Licence to Operate Issues. Forests 2019, 10, 695. https://doi.org/10.3390/f10080695

Richardson, B., Strand, T., Thistle, H.W., Hiscox, A., Kimberley, M.O. and Schou, W.C. 2017. Influence of a young *Pinus radiata* canopy on aerial spray drift. Transactions of the American Society of Agricultural and Biological Engineers 70: 1851-1861.

Strand, T.M., Rolando, C.A., **Richardson, B.**, Gous, S., Bader, M.K.F., and Hammond, D. (2014) An aerial spot-spraying technique: a pilot study to test a method for pest eradication in urban environments. SpringerPlus, 3:750, 1-8. http://www.springerplus.com/content/pdf/2193-1801-3-750.pdf

Brockerhoff, E.G., Suckling, D.M., Kimberley, M.O., **Richardson, B**., Coker, G. Gous, S., Lance, D.R., Strand, T. and Zhang, A. 2012. Aerial application of pheromones for mating disruption of an invasive moth as a potential eradication tool. PLoS ONE 7(8), e43767.

Richardson, B., Kimberley, M.O., Watt, M.S. 2012. Generic dose response curves for predicting effects of herbicides on weeds or sensitive plant species. New Zealand Journal of Forestry Science 42, 73-80.

Thistle, H.W., Thompson, D.G., **Richardson, B.**, Bird, S.L., Kees, G., Throop, W., Gous, S., Storwold, D. 2012. Deposition of aerially released BT over a 2 km sampling grid. Transactions of the ASABE 55(6): 2067-2078.

Richardson, B., Kimberley, M.O. and Gous, S.F. 2011. Aircraft calibration for pest eradication operations using pesticides formulated as solid baits. Transactions of the ASABE 54(4): 1-10.

Teske, M E, Thistle, H W, Schou, W C, Miller, P C H, Strager, J M, **Richardson, B**, Butler Ellis, M C, Barry, J W, Twardus, D B, Thompson, D G. (May 2011). A review of computer models for pesticide deposition and prediction. Transactions - American Society of Agricultural Engineers: General Edition 54(3), 789-801.

Richardson, B; Kimberley, M O; 2010. Lessons learned from monitoring the effectiveness of the Asian Gypsy moth aerial spraying eradication programme. Applied Engineering in Agriculture 26(3): 355-361.

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Richardson, B. and Thistle, H.W. 2006: Measured and predicted aerial spray interception by a young *Pinus radiata* canopy. Transactions of the American Society of Agricultural and Biological Engineers 49(1): 15-23.

Richardson, B., Watt, M.S., Mason, E.G. and Kriticos, D.J. 2006. Advances in modelling and decision support systems for vegetation management in young forest plantations. Forestry 79: 29-41.

Richardson, B., Kay, M.K., Kimberley, M.O. and Gresham, B.A. 2005: Evaluating the benefits of dose-response bioassays during aerial pest eradication operations. NZ Plant Protection 58: 17-23.

Thistle, H., R. Reardon, M. Teske, **B. Richardson,** G. Cormier, D. Davies, S, Cameron, A. Hewitt, M. LeClerc and A. Karipot. 2005. 'Variability in Spray Application and Utilization of a Time Varying Model'. Annual Review of Agricultural Engineering. 4(1) 187-196.

Richardson, B., Kimberley, M.O. and Schou, W.C. 2004. Defining acceptable levels of herbicide deposit variation from aerial spraying. Applied Engineering in Agriculture 20: 259-267.

Richardson, B. 2002. Evaluating the concept of targeted aerial spraying for insect control using Btk. NZ Plant Protection 55: 168-171.

Richardson, B. and Newton, M. 2001. Analysis of plant canopy structure to predict herbicide deposit distribution. New Zealand Journal of Forest Science 31: 224-234.

Richardson, B. and Newton. M. 2000. Spray deposition within plant canopies. NZ Plant Protection 53: 248-252.

Ray, J.W., **Richardson, B.,** Schou, W.C, Teske, M.E., Vanner, A.L., and Coker, G.C. 1999. Validation of SpraySafe Manager, an aerial herbicide application decision support system. Canadian Journal of Forest Research 29: 875-882.

Richardson, B., Schou, W., and Teske, M., Ray, J. and Eav, B. 1997. SpraySafe Manager: A Decision Support System for aerial application of herbicides in forestry. NZ Plant Protection 50: 539.

Ray, J.W, Vanner, A.L**., Richardson, B**., Coker, G. 1996. Determination of the no observable effect level (NOEL) of four commonly used forestry herbicides on tomatoes. Proceedings of the 49th NZ Plant Protection Society Conference: Pp. 188-191.

Richardson, B., Ray, J., Vanner, A., Davenhill, N. and Miller, K. 1996. Nozzles for minimising aerial herbicide spray drift. . NZ Journal of Forestry Science 26: 438-448.

Richardson, B., Ray, J., Miller, K., Vanner, A., and Davenhill, N. 1995. Evaluation of FSCBG, an aerial application simulation model. Applied Engineering in Agriculture 11: 485-494

Richardson, B., Ray, J.W. and Vanner, A.L. 1993: Quantification of herbicide spray deposit variation following aerial application. NZ Plant Protection 48: 319-324.

Richardson, B. and Ray, J. 1991: The effect of spray thickening anti-drift adjuvants on flow rates through nozzles. NZ Plant Protection 44: 112-115.

Richardson, B., Ray, J.W. and Vanner, A.L. 1989: Evaluation of techniques to measure aerial spray deposition. NZ Plant Protection 42: 132-136.

Richardson, B., Ray, J., and Vanner, A. 1986. Retention of spray on bracken pinnae: effect of application volume and formulation. NZ Journal of Forestry Science 16: 87-95.

Confidential

Buffer zone estimation to minimise water exposure from aerial spraying with glyphosate or triclopyr

Brian Richardson (Scion) and Wayne Schou (Scion)

March 2023

Report information sheet

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Executive summary

The problem

Canterbury Regional Council (trading as Environment Canterbury) carries out aerial herbicide applications on islands in braided riverbeds to control a range of weed species. Typically, the sprays contain either glyphosate or a mix of glyphosate and triclopyr as active ingredients. With aerial operations there is a risk of off-target spray drift onto sensitive areas beyond the target zone, including water bodies. The purpose of this report was to use the AGDISP spray simulation model to quantify predicted levels of spray drift for a range of spraying scenarios relevant to operational riverbed spraying. Buffer distances (the distance between the spray zone and the sensitive area) needed to avoid unacceptable levels of drift were defined based on the environmental exposure level (EEL) for triclopyr, the lowest value of the EEL or MAV (maximum acceptable value for drinking water) for glyphosate and triclopyr. Model results were used to develop recommendations on buffer zones for herbicide applications in riverbeds.

Key results

Factors having the biggest influence on the buffer zone width needed to ensure herbicide concentrations do not exceed EELs are:

- the choice of nozzle (droplet size),
- wind speed and direction,
- spray release height, and
- the characteristics of the river next to the spray area.

Recommendations

When spraying weeds in riverbeds, no-spray buffer zones can effectively manage the risk of exceeding acceptable herbicide concentrations in water defined using the environmental exposure limits (EELs).

With the smallest droplet size class tested (coarse spectrum; ~350 µm VMD), a buffer zone of about 10 m is reasonable as long as the flying height is no greater than 3 m above the target vegetation and wind speed is less than 10 km/hr. At greater release heights or windspeeds a buffer of 20 m would be recommended.

With nozzles producing larger drops and a very low driftable fraction (e.g. Accuflo, Thru-valve boom), a buffer zone of 12 m would be adequate for all conditions tested as long as the wind speed does not exceed 15 km/hr. With these nozzles, buffers could be reduced to about 5 m if there is enough confidence that flying height will be less than 3 m above the vegetation and wind speeds in the direction of the water body will be less than 10 km/hr.

Buffer distances to minimise risk of water contamination from wilding conifer aerial herbicide applications

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Introduction

Aerial herbicide application is a cost-effective treatment for weed control at scale or, when using helicopters or unmanned aerial vehicles (UAVs), in difficult to access locations (Bretthauer, 2015; Richardson, et al., 2017; Richardson, et al., 2019). Canterbury Regional Council uses helicopters for controlling a range of weed species found on islands in braided riverbeds. Typical treatments include glyphosate or a mix of glyphosate, triclopyr and surfactants. Each mix is made up to a total spray volume of 400 L/ha with water.

As with any herbicide application, it is important to ensure that spray drift beyond the target zone is below thresholds of concern for any sensitive areas. Such thresholds can often be defined using published environmental exposure limits (EEL) or maximum acceptable values (MAV) for drinking water standards. However, it can be challenging to quantify drift levels from any spray operation because so many interacting variables influence droplet trajectories when released from an aircraft.

AGDISP (Bilanin, et al., 1989; Teske, et al., 2003) is a mechanistic model that simulates the landing position of droplets released in aerial herbicide applications. A strength of AGDISP is that it includes an aircraft wake model, and it is undoubtedly the most widely used and rigorously tested system of its kind (Bird, et al., 2002; Hewitt, et al., 2002; Teske, et al., 2011). Regulators around the world, including the U.S. Environment Protection Agency, are increasingly relying on AGDISP as part of their regulatory processes. A companion stream assessment model has been incorporated into AGDISP to predict the concentration of aerially applied chemicals in streams adjacent to the sprayed area (Teske, et al., 2002).

Like any model, AGDISP makes many simplifying assumptions and limitations. For example, the model assumes a steady state for meteorological conditions and does not account for variance in meteorological inputs or factors such as aircraft speed or height above the ground. Terrain factors, such as slopes or hills, can have a significant influence on local meteorology but AGDISP does not directly model these effects. While the basic AGDISP model is well-validated within certain constraints, the stream module has had limited validation (Teske, et al., 2002).

Despite the potential limitations when using any complex models such as AGDISP, they can be extremely useful tools for providing operational guidelines and for quantifying the sensitivity or importance of specific variables (Richardson, et al., 2021). **The purpose of this report was to quantify the risks of spray drift into streams from a variety of riverbed spraying scenarios relevant to ECAN herbicide application operations.**

Materials and methods

Model scenarios

AGDISP 9.0 was used to quantify spray deposition within and downwind of a spray zone for a range of scenarios as described below. One important point is that all of the scenarios assume that the wind is blowing directly towards a sensitive area, in this case assumed to be a water body. This situation is a worst-case scenario and drift into a sensitive area will be minimal or non-existent if the wind is blowing away from that sensitive area.

A total of 288 spraying scenarios were initially modelled (Tables 1 and 2). Variables that were systematically changed in this sensitivity analysis were spray release height, flying speed, number of flight lines, droplet size, spray mix, and wind speed. Four droplet size spectra were used, characterised according to the volume median diameter (VMD). From smallest to largest, these sizes were representative of the follow standards classes according the ASABE (American Society of Agricultural and Biological Engineers Classification): Coarse (353 µm), Ultra Coarse (> 650 µm), and two classes exceeding Ultra Coarse (785, 958 µm).

Table 1: Baseline and variable AGDISP inputs.

Input variable	Value
Aircraft and spray block:	
Aircraft type	AS 350, B2 3A
Release height above vegetation canopy of 3 m	3 m, 5 m
Aircraft speed	30, 50 knots; (15.4, 25.7 m/s)
Nominal lane separation	4 m
Number of flight lines	3, 12, 20
Application technique:	
Nozzle location	Distributed evenly to 80% rotor diameter i.e. a boom width of approximately 8.5 m
Volume median diameter (VMD)	~353, 659, 785, 958 µm (see Appendix 1 for details)
Meteorology (2 m reference ht):	
Wind speed	5, 10, 15 km/hr (1.39, 2.78, 4.17 m/s)
Wind direction (relative to flight lines)	Crosswind (-90°)
Temperature	22
Relative humidity	75
Atmospheric stability	Overcast
Canopy:	
Height	3 m

Two spray mixes were used in the simulations (Table 2), one containing only glyphosate and the other a mix of glyphosate (at the same rate as glyphosate alone) and triclopyr plus adjuvants. Both spray mixes were applied at a total spray volume of 400 L/ha.

Table 2: Spray mix details for AGDSIP simulations.

	Spray mix 1	Spray mix 2
Active ingredient	Glyphosate	Glyphosate (G) + triclopyr (T)
Product rate	7 L/ha	7 L/ha (G) + 2 L/ha (T)
Active ingredient (AI) rate	7 x 0.49 = 3.43 kg/ha	7 x 0.49 = 3.43 kg/ha (G) + 2 x 0.60 = 1.20 kg/ha (T)
Adjuvants	-	2 L/ha Excel oil or an organosilicone surfactant
Total spray volume	400 L/ha	400 L/ha
Active fraction	0.00858	0.01158
Non-volatile fraction	0.0175	0.0275

Modelled spray deposition, threshold definition and buffer distances

For each of the scenarios (all combinations of variables in Table 1), spray deposition was modelled within and downwind of the target area (Figure 1). Buffer distances were all referenced from the flight line i.e. the centre of the aircraft.

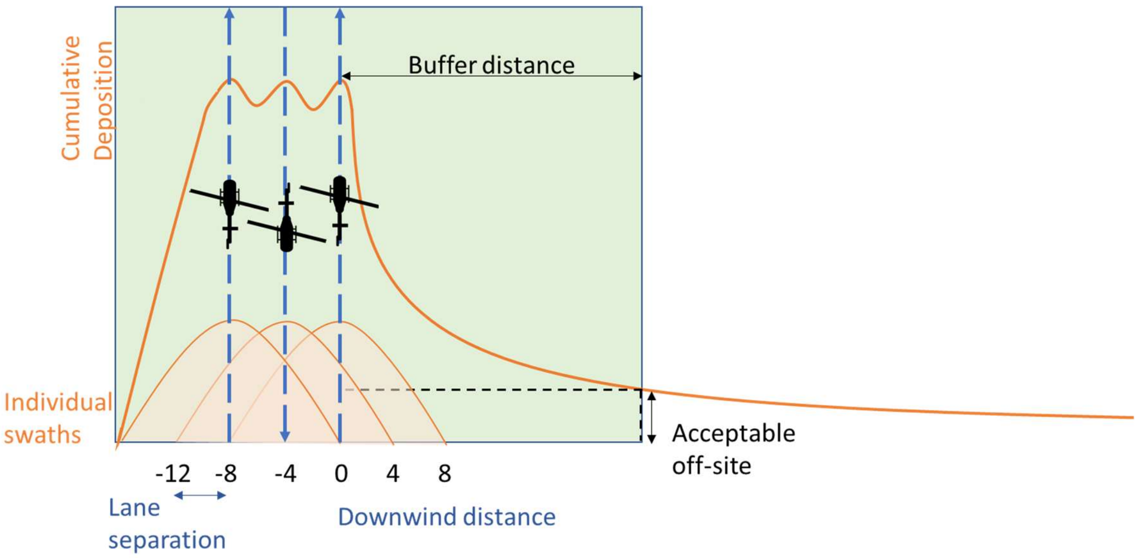

Figure 1. Overlapped swaths from 3 flight lines are summed to give total deposition both within and downwind of the spray block. Estimation of a suitable buffer distance depends on defining an acceptable threshold value of off-site deposition.

Spray deposition typically attenuates rapidly with distance downwind of the spray area. However, small quantities of herbicide may still be deposited at large distances downwind. The question is how to define a level of deposition that is biologically insignificant in terms of the risks being managed. One option is to use published thresholds, such as the Maximum Acceptable Values (MAV) for drinking water standards and Environmental Exposure Limits (EELs) (Table 3). As EELs have a consistently lower acceptable concentration than MAVs for these herbicides (i.e. you can exceed an EEL without exceeding a MAV), EELs were used here as the threshold values for defining acceptable and unacceptable herbicide concentrations. Using the EEL threshold value, buffer distances were calculated for each model run. This buffer distance represents the distance required between the most downwind flightline and the sensitive area to ensure that the EEL value is not exceeded in the sensitive area.

Table 3: Maximum acceptable values (MAV) for drinking water standards and Environmental Exposure Limits (EELs) for glyphosate and triclopyr (active ingredient values).

Herbicide	MAV (mg/L)	EEL (mg/L)
Triclopyr	0.1	0.059
Glyphosate	0.9	0.37

As the AGDISP simulations calculate deposition as an amount per unit area, a method is required for converting the area-based deposition to a concentration if we are to use the EEL values as thresholds. Hence, it was assumed that spray was deposited on to a static water body of 1 m depth to enable conversion of the deposition data to a concentration. If it is assumed that the nominal application rates were deposited on the static water body, it would represent a concentration of over twice the EEL value for triclopyr but about 7% below the EEL value for glyphosate. For this reason, the analysis primarily focused on generating buffer distance requirements for triclopyr as the worst-case scenario.

Moving water body

Once the primary analysis was completed using the 1 m static water body to define herbicide concentrations, a small number of additional model runs (16) were carried out using the stream model in AGDISP (Figure 2). The stream assessment model considers:

- The spray line length (assumed to run parallel to the stream).
- Turnaround time (how long it takes the pilot to change from spraying one flight line to the next).
- Stream width, depth and flow rate.
- Distance from the edge of the application area to the centre of the stream.

- Riparian interception factor (an index of the amount of active material removed from the air by vegetation growing upwind of the stream but downwind of the sprayed area).
- Instream chemical decay rate (assumed to be negligible in this analysis).
- Recharge rate – the flow rate per unit distance downstream for fresh water entering the stream.

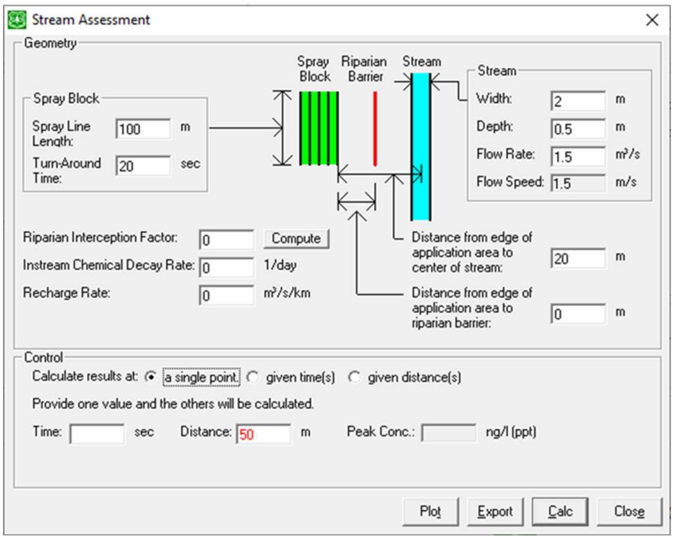

Figure 2. AGDISP stream assessment module, highlighting geometry of spray block and stream.

Details of the stream model inputs are summarised in Tables 4 and 5.

Table 4: Stream factor model inputs.

Input variable	Value
Spray line length (parallel to stream) (m)	100
Number of flight lines	12
Helicopter turn-around time (s)	20
Riparian interception factor	0.0
Instream chemical decay rate (1/day)	0
Recharge rate (m^3 s^{-1} km^{-1})	0
Distance (m) from edge of spray block to stream centre	Based on buffer calculated in main analysis
Sampling location (m)	50 m

Table 5: Modelled stream scenarios

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Stream width	2 m	5 m	25 m	200m
Stream depth	0.5 m	1 m	1 m	2 m
Flow rate	1.0 m^3/s	1.88 m^3/s	50 m^3/s	300 m^3/s
Flow speed	1.0 m/s	0.376 m/s	2 m/s	0.75 m/s

Data analysis

Using the triclopyr data as the worst-case scenario, summary statistics were generated for the key variables in the analysis to quantify their sensitivity in terms of buffer distance requirements. Subsequently, the interactions between most sensitive variables were graphed to visualise buffer requirements for a range of scenarios.

The buffer distances calculated for a small number of scenarios (16) were inserted into the stream model for each of the stream scenarios (Table 5). The calculated herbicide concentration for each stream scenario was compared with the EEL value to determine whether the buffer estimated for the static water (baseline) scenario was sufficient for achieving below-EEL concentrations across all of the stream scenarios.

Results and Discussion

Sensitivity analysis

As expected from many previous analyses, the variables droplet size, wind speed and spray release height had the biggest influence on the distance needed (i.e. the buffer distance) between the downwind flightline (measured from the centre of the aircraft) and a sensitive area to ensure triclopyr values would be below EEL values (Figures 3 – 5). Of these variables, wind speed gave the greatest range in buffer distance, from 4.9 to 10.5m. However, it should be noted that all of the droplet spectra were made up of relatively larger droplet sizes with volume median diameters VMD's ranging from 353 to 958 μm.

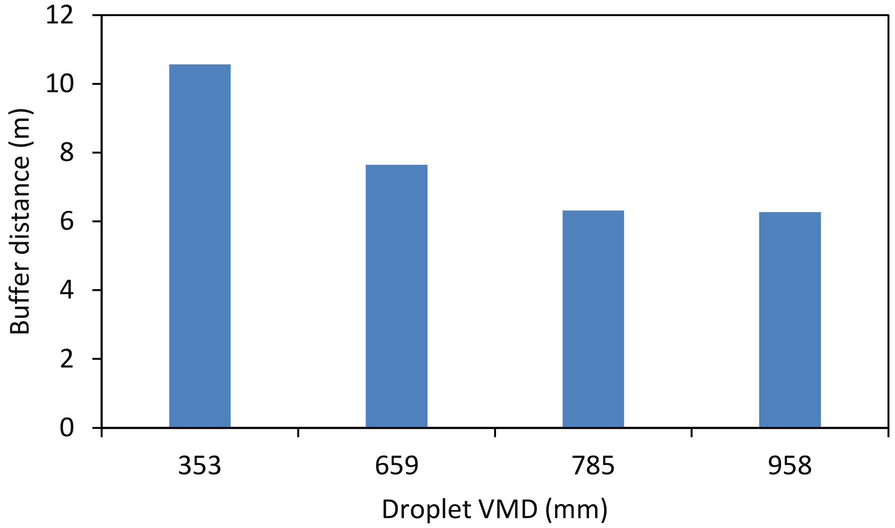

Figure 3. Buffer distance for each VMD (droplet size), averaged across all other factors.

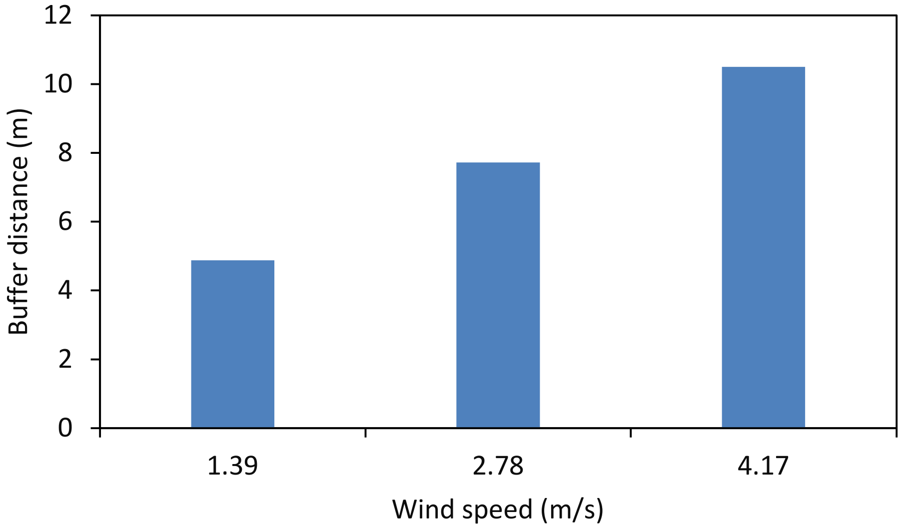

Figure 4. Buffer distance for each wind speed, averaged across all other factors.

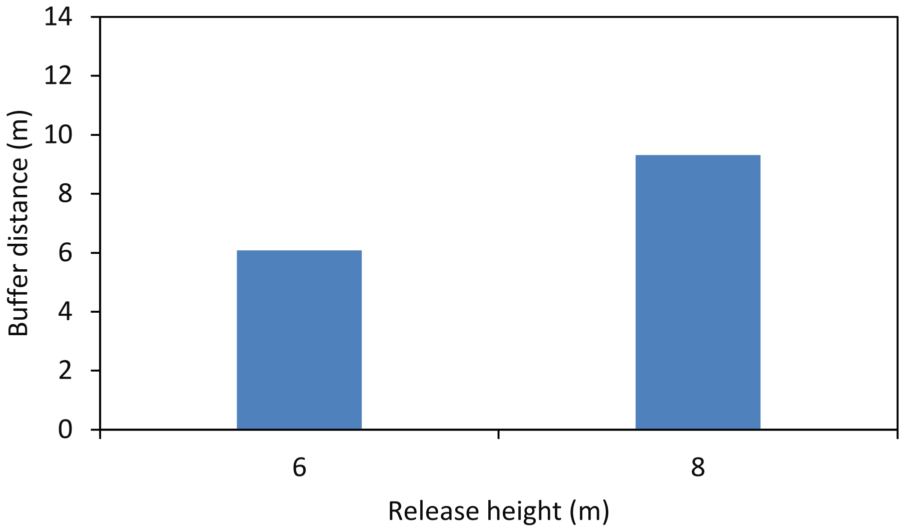

Figure 5. Buffer distance for each release height, averaged across all other factors.

The other variables evaluated, including the number of flight lines and flying speed had a relatively small effect on buffer distance (Figure 6). While the most downwind flight line has the potential to make the greatest contribution to stream deposition because of its proximity, successive flight lines also have the potential to add additional spray deposition to the stream. However, with the relatively large droplet sizes used in all cases, this variable only had a minor effect on buffer distance.

While this analysis did not test the sensitivity of other variables, such as temperature and humidity, previous analyses have shown that they were unlikely to have had a major effect on buffer distance within the ranges of relevance to these scenarios.

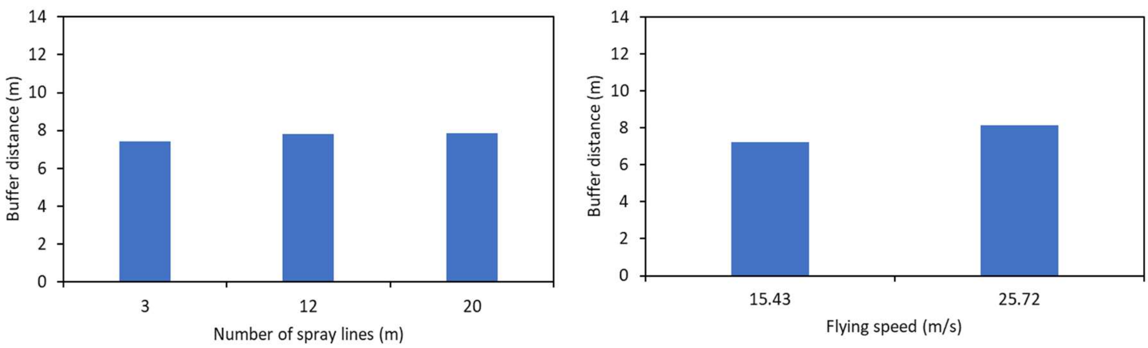

Figure 6. Buffer distance for each number of spray lines and flying speed.

Interactions among the three key variables

The effects of droplet size, wind speed, and spray release height on buffer distance, averaged across other factors, are summarised in Figures 7 and 8. With the smallest droplet VMD tested (353 µm) and the highest wind speed, the required buffer distance ranged from 11.1 m to 17.4 m for the 6 m and 8 m spray release heights (i.e. 3 m and 5 m above vegetation canopy of 3 m), respectively. At the lowest wind speed tested but for the same droplet size, buffer distances reduced to between 5.6 and 8.0 m for the 6 m and 8 m spray release heights, respectively.

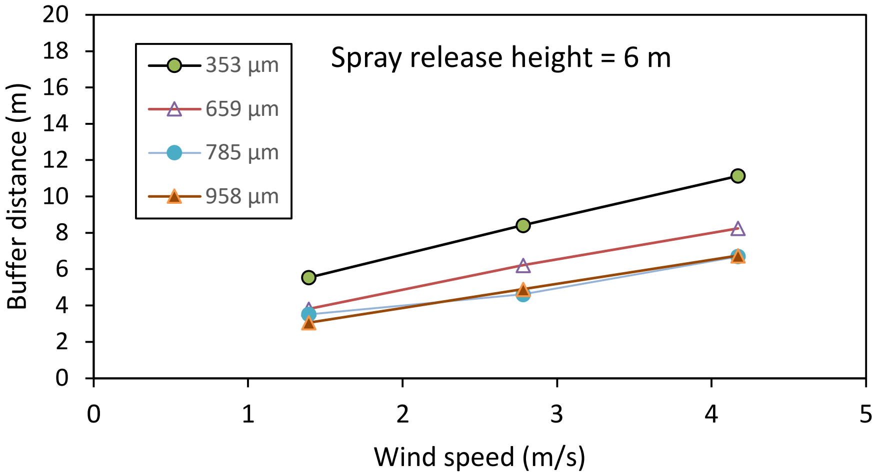

Figure 7. Effect of wind speed and droplet size on buffer distance for a 6 m release height.

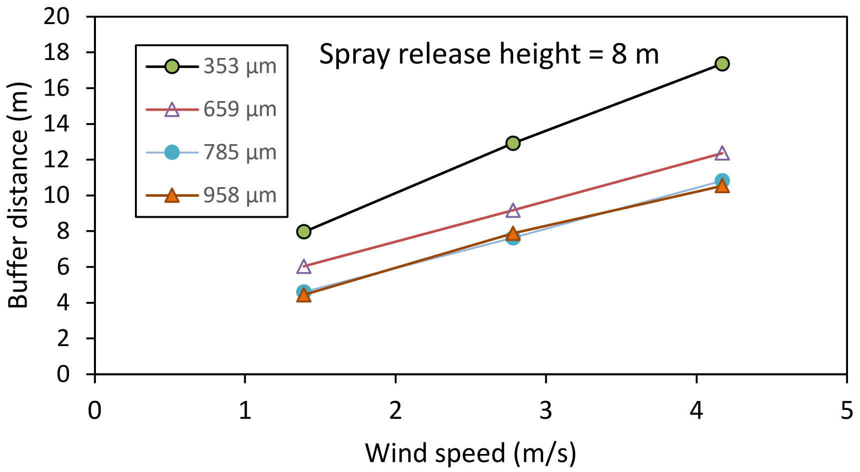

Figure 8. Effect of wind speed and droplet size on buffer distance for an 8 m release height.

At the other end of the droplet size scale, there was little difference in buffer distances required for the two larger droplet size classes, primarily because they had very similar driftable fractions (volume of spray in droplets less than 150 µm). For these droplet sizes, buffer distances ranged from 3.1 m for the lowest wind speed and release height to 10.8 m for the strongest wind and greatest spray release height.

Comparison of results with the stream model

The results presented above are all predicated on the calculated concentration of triclopyr deposited in a 1 m deep static water body. If the same analysis was undertaken assuming a different static water volume e.g., a 0.5 m deep static water body, the results would have shown a requirement for greater buffer distances. To evaluate whether the results are reasonable for real operational situations, results were compared with stream simulations as described in Tables 4 and 5. A caveat to this analysis is that the AGDISP stream model has had little validation and testing. If the results from this analysis are deemed useful, it is recommended that a more rigorous evaluation of the stream model is carried out.

Using a 1 m deep static water body as a baseline for converting spray deposition data to herbicide concentrations generated buffer distances that provided protection for 13 out of 16 stream scenario/spray method combinations tested (Table 6). The main exception was stream scenario 1, the shallowest stream scenario, where there were two EEL exceedances. For the three cases where there were EEL exceedances, implementing a 10 m buffer would have provided adequate protection (Table 7).

Table 6: Calculated peak herbicide concentrations for all combinations of 4 AGDISP runs and 4 stream scenarios. Coloured boxes indicate: red = exceedance of EEL; green = below EEL.

VMD (µm)	Height (m)	Spray Lines	Wind speed (m/s)	Air speed (m/s)	Buffer (baseline) (m)	Herbicide (mg/L) for stream scenario			
						1	2	3	4
785	6	12	1.39	15.43	3.52	0.2297	0.0757	0.0069	0.0001
785	8	12	4.17	25.72	11.72	0.0328	0.0113	0.0012	0.0000
353	6	12	1.39	15.43	5.31	0.0762	0.0391	0.0047	0.0001
353	8	12	4.17	25.72	18.73	0.0289	0.0167	0.0024	0.0001

Table 7: Buffer distances that provide protection for all stream scenarios. Green coloured boxes indicate herbicide concentrations below the EEL threshold.

VMD (µm)	Height (m)	Spray Lines	Wind speed (m/s)	Air speed (m/s)	Updated buffer (m)	Herbicide (mg/L) for stream scenario			
						1	2	3	4
785	6	12	1.39	15.43	10	0.0085	0.0041		
353	6	12	1.39	15.43	10	0.0334			

Water concentrations are reduced with wide, deep and fast flowing rivers. The model averages overall herbicide concentration across the entire water body. Where the river is wide, the amount of spray deposited into the upwind edge of the river will be much higher than the downwind edge. Hence, although the overall result reported represent an average peak concentration across that width, the actual peak value at the upwind edges will be higher than reported.

Results with glyphosate

Results with glyphosate have not been shown because even a direct overspray of glyphosate into a water body, as described in the Methods section, will not result in EEL exceedance. Nevertheless, drift mitigation options described below will still ensure minimal stream contamination occurs.

Droplet size selection

A key decision influencing the width of buffer zone, regardless of other conditions is droplet size. The VMD of a droplet spectrum is usually inversely related to the driftable fraction, the total spray volume in droplets less than about 150 µm i.e. the larger the VMD, the lower the driftable fraction. Going to large droplet sizes significantly reduces the driftable fraction and the buffer distance requirement but using larger droplets can also have down sides. For example, more accurate flying is needed with large drops because of the steep cut-off to swath patterns. Further, herbicide efficacy is often related to the degree of coverage on the target plant, especially when using poorly translocated herbicides such as triclopyr (glyphosate by contrast is generally well translocated). Target coverage will decrease as droplet size increases (at least within the limits described in this report), hence there is an incentive to use smaller droplets from an efficacy perspective. By contrast, as shown by the results of this analysis, the potential for drift also increases with smaller drops, requiring larger buffer distances.

Droplet size is influenced by a wide range of factors including:

- Type and size (flow rate) of nozzle.
- Nozzle orientation relative to the flight direction.
- Spraying pressure.
- Air speed.
- Spray formulation physical properties.

It is very difficult to predict droplet sizes because of all of these interacting factors. However, there are good sources where droplet size information can be accessed. Manuals produced by nozzle manufacturers generally classify nozzles according to the droplet spectrum they produce. While this information is useful for the relative performance of different nozzles, it has limited value for aerial spraying because the manuals generally assume the applications are from ground sprayers and do not include the important effects of nozzle orientation, air speed and formulation. However, there are a number of publications and online sources with databases of droplet spectra measurements relevant to aerial application e.g. (MPI, 2022; Richardson, et al., 2020).

Managing risk of stream contamination

The AGDISP analysis presented here is based on a worst-case scenario with the assumption of steady-state meteorology including a constant wind speed blowing towards the sensitive area (water body). Good practice for aerial application dictates that spraying should only take when the wind is blowing away from any sensitive areas. If this principle is followed, the risk of water body contamination is low and should only occur if there are sudden wind shifts or unexpected local wind flows. However, it is not always possible to spray with the wind blowing away from the sensitive area, especially if spraying an island in a riverbed surrounded by water or if meteorological conditions suddenly change during an operation.

Results from this study, based on the triclopyr EEL and assuming the water body conditions are as described in the Methods, indicate that the risk of water body contamination from aerial spraying can be managed through implementation of buffer zones i.e. no spray zones between the sprayed area and water body to be protected. The width of the buffer zone needed to ensure any spray deposition into water results in concentrations below EEL values depends on the characteristics of the spray application and of the water body.

A key decision influencing the width of buffer zone is the choice of nozzle and droplet size. With the smallest class tested, a buffer zone of about 10 m is reasonable as long as the flying height is no greater than 3 m above the target vegetation and wind speed is less than 10 km/hr. At greater release heights or windspeeds a buffer of 20 m would be recommended.

With nozzles producing a very low driftable fraction (e.g. Accuflo, Thru-valve boom) a buffer zone of 12 m would be adequate for all conditions tested as long as the wind speed does not exceed 15 km/hr. Buffers could be reduced to about 5 m if there is enough confidence that flying height will be less than 3 m above the vegetation and wind speeds in the direction of the water body will be less than 10 km/hr.

It is important to note that all situations are different and weather conditions are dynamic so these recommendations cannot be taken as absolute. Other factors that reduce spray drift risk could also be considered when making decision on buffer zone width including the presence of vegetation hanging over the water (captures spray that would otherwise be deposited in the water), and rivers that are wide, deep and fast flowing.

Conclusions

When spraying weeds in riverbeds, no-spray buffer zones can effectively manage the risk of exceeding acceptable herbicide concentrations in water defined using the environmental exposure limits (EELs). Factors having the biggest influence on the buffer zone width needed to ensure herbicide concentrations do not exceed EELs are:

- the herbicide type and EEL,
- the choice of nozzle (droplet size),
- wind speed and direction,
- spray release height, and
- the characteristics of the river next to the spray area.

Use of nozzles that produce a low driftable fraction (e.g. Accuflo, Thru-valve booms) significantly reduce the risk of exceeding EEL values. However, for the triclopyr herbicide mix, buffers of between 5 and 20 m, depending on the spray operational and river characteristics, can provide adequate protection with a coarse droplet spectrum and within the meteorological and operational limits defined in this study.

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Appendix 1 – Droplet spectrum information

Medium Coarse (VMD = 353µm)	
Upper size (µm)	Cumulative % volume
40.57	0.100
47.03	0.200
54.50	0.400
63.16	0.800
73.23	1.300
84.85	1.800
98.12	2.500
113.71	3.700
131.73	5.800
152.79	8.700
177.84	11.850
205.84	15.600
238.45	21.800
276.48	30.450
320.60	42.200
372.18	55.350
430.74	68.500
498.91	80.400
578.54	89.250
670.72	93.350
777.39	95.100
900.61	96.550
1044.42	97.800
1210.66	99.000
1403.04	100.000

Ultra Coarse (VMD = 659µm)	
Upper size (µm)	Cumulative % volume
68.62	0.310
105.11	0.730
143.14	1.470
182.76	2.670
224.06	4.460
267.09	6.950
311.93	10.230
358.66	14.340
407.36	19.280
458.11	25.010
510.99	31.450
566.10	38.460
623.52	45.810
683.37	53.190
745.73	60.500
810.71	67.450
878.43	73.820
949.00	79.470
1022.54	84.340
1099.18	88.410
1179.04	91.690
1262.26	94.240
1348.98	96.140
1439.35	97.500
1533.53	98.430
1631.67	99.040
1733.93	99.430
1840.51	99.660
1951.56	99.800
2067.29	100.000

Accuflo (VMD =785µm	
Upper size (µm)	Cumulative % volume
36	0.000
44	0.000
52	0.000
62	0.000
74	0.000
86	0.000
100	0.000
120	0.000
150	0.000
180	0.000
210	0.000
250	0.050
300	0.140
360	0.330
420	0.570
500	1.340
600	6.480
720	32.230
860	74.360
1020	97.300
1220	99.570
1460	99.570
1740	99.970
2060	100.000
2460	100.000
2940	100.000

TVB (VMD =958µm)	
Upper size (µm)	Cumulative % volume
40.50	0.000
46.83	0.000
54.33	0.000
63.00	0.000
73.00	0.000
84.67	0.000
98.17	0.010
113.67	0.030
131.83	0.060
152.83	0.110
176.67	0.200
205.00	0.350
238.33	0.640
275.00	1.210
320.00	1.940
370.00	2.870
430.00	4.780
498.33	8.680
576.67	14.990
668.33	23.420
775.00	33.580
898.33	45.200
1041.67	57.870
1206.67	71.540
1400.00	85.630
1621.67	100.050