Ecological Mitigation Support Document to Support Endangered Species Strategies

Version 1.0

July 2024

Office of Pesticide Programs
Office of Chemical Safety and Pollution Prevention
U.S. Environmental Protection Agency
Washington, DC

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1 Executive Summary

The purpose of this document is to support strategies for identifying and implementing early mitigation measures to address potential population-level impacts to federally threatened or endangered (hereafter referred to as "listed") species across groups of conventional pesticides (e.g., herbicides, rodenticides, insecticides), groups of species, in certain regions across the United States, or across pesticide use patterns as described in EPA's Workplan and Update for its Pesticide Program (USEPA, 2022a; USEPA, 2022b). These strategies are intended to inform pesticide actions such as EPA's registration and registration review decisions to address population-level exposures and impacts relevant to listed species. EPA may also use the information to support EPA's pesticide actions more generally where it identifies spray drift, runoff, and erosion mitigation measures for pesticide actions to which the strategies are not applicable.

This document describes mitigations that EPA has identified to date that reduce offsite transport of pesticides in spray drift, surface water runoff (referred to as runoff), and soil erosion (referred to as erosion) to address impacts to non-target species, and describes their efficacy in terms of their design, empirical data (e.g., observations from the scientific literature) and computer model simulations.

For runoff and erosion, this document identifies a suite of potential mitigation measures, and describes EPA's evaluation of land characteristics (e.g., slope, susceptibility to runoff and erosion) that, in and of themselves, reduces the potential for exposure from runoff and erosion. For spray drift, as described in more detail in this document, the main approach to reduce exposure to non-target organisms is a buffer between the edge of the treated area and non-target areas. It also identifies measures EPA identified that may be included in a pesticide registration or registration review decision that would allow an applicator to employ to reduce any such buffer and describes the technical basis for associated reductions. This document also describes EPA's consideration of growers that participate in conservation programs or that work with a technical expert.

EPA received public comments on earlier drafts of these mitigation measures as part of formal public comment periods (USEPA, 2022b; USEPA, 2023a; USEPA, 2023c). This document includes improvements gained from public comments provided on those drafts. Among other things, EPA incorporated additional mitigation measures, expanded definitions of existing mitigation measures, as well as revised the efficacy of some measures based on the information provided by the public[1,2]

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[2] Comments were received on the Draft Herbicide Strategy, Vulnerable Species Pilot, and associated mitigation measures as posted to the docket in 2023 (https://www.regulations.gov/docket/EPA-HQ-OPP-2023-0327; https://www.regulations.gov/docket/EPA-HQ-OPP-2023-0365).

2 Introduction

2.1 Purpose of Document

The primary purpose of this document is to describe the mitigation measures that EPA identified to date to reduce offsite transport of pesticides in spray drift, surface water runoff (referred to as runoff), and soil erosion (referred to as erosion) to address population-level impacts to listed species and to summarize its evaluation of the efficacy of those mitigation measures. EPA is using the information in this document to inform the development of current ESA strategy efforts (Herbicide Strategy, Insecticide Strategy, Vulnerable Species Pilot, the Hawaii Strategy, and, when finalized, to inform applicable conventional pesticide registration decision or registration review decision). EPA similarly expects to use this information in the development of future strategies (e.g., Fungicide Strategy). EPA may also use the information to support EPA's pesticide actions more generally where it identifies spray drift, runoff, and erosion mitigation measures for pesticide actions to which the strategies are not applicable. At this time, this document is focused on mitigations that can be employed in cultivated agricultural settings. EPA expects to issue updated versions of this document to include additional measures as information (including new efficacy data) becomes available and to include additional mitigations applicable to non-agricultural pesticide uses and non-cultivated agriculture (e.g., rangeland) within the scope of future strategies. EPA acknowledges that the mitigations will continue to evolve over time and EPA will continue to update the mitigations as new information becomes available.

Section 3 describes the approach EPA used to evaluate identified mitigation measures. **Sections 4** and **5** discuss EPA's evaluation of the efficacies of mitigations for spray drift and runoff/erosion, respectively.

2.2 Overview of Pesticide Fate and Transport Processes

Pesticides are directly applied to agricultural and other areas to prevent damage from pests such as insects, competing weeds, *etc*. Pesticides may move off of treated areas via spray drift (pesticide movement as spray droplets at the time of application), surface water runoff pesticide movement with water), runoff of sediment-bound residues (erosion), leaching into groundwater, wind erosion, and volatilization. For the majority of pesticides, EPA identifies spray drift and runoff/erosion as dominant transport pathways leading to non-target organism exposures. Other transport routes noted above (i.e., leaching, wind erosion, volatilization) are sometimes relevant to specific pesticides, but are not commonly routes of concern for the majority of pesticides. As such, these transport routes are outside of the scope of this document. If other exposure routes are relevant to a chemical or species that are not covered by this document, EPA would identify any needed mitigations as part of those actions (e.g., registration, registration review, development of a biological evaluation).

Pesticide spray drift is the movement of pesticide droplets through the air at the time of application or soon after, to any site other than the area intended. Pesticide droplets are produced by spray nozzles used in application equipment for spraying pesticides. Spray drift deposition decreases exponentially as the distance from the edge of the treated area increases. In other words, spray drift exposure is much higher near the treated area than farther from the field. The extent of offsite spray drift transport that will occur is primarily dictated by application method, application rate, droplet size distribution, windspeed and direction, and atmospheric conditions, and any device or barrier that blocks spray droplets from moving off the application area. Spray drift does not include movement that occurs after the first time the material lands on the ground or foliar surfaces followed by re-entering the air (i.e., volatilization), which is often chemical specific, and which may occur over longer periods of time and larger distances.

Pesticide runoff is the movement of pesticide in water from the treated area to non-target areas. Pesticide erosion occurs when pesticide attached to the soil moves from the treated field during rainfall and irrigation-driven runoff events. Pesticide concentrations in runoff/erosion are highest in runoff coming directly from the area and in areas near the treated area. Those concentrations decrease with distance from the treated area as the runoff is diluted with water/soil that does not contain the pesticide. For pesticides that degrade, concentrations in runoff decrease over time. The amount of runoff/erosion transport of a pesticide is influenced by factors related to the weather (particularly rainfall), environment (e.g., slope, soil), application (e.g., method, rates), pesticide properties (e.g., partitioning, half-lives), and agronomic practices of the crop.

Ecological exposure from spray drift and runoff/erosion are different due to the timing of when they occur, the locations of where they may occur and their magnitudes. In regard to timing, movement of a pesticide off-site through spray drift occurs on the same day of the application (generally within seconds-minutes). Runoff/erosion likely occurs days to weeks after the application but under some conditions (e.g., application before winter snowfall) may be weeks to months after application. Spray drift exposure likely occurs in areas adjacent to the treated areas that are down wind of the pesticide application. Runoff/erosion exposure occurs in areas that are down slope from the treated areas (water runs down slope). In cases where wind is blowing in a direction that is down slope, spray drift and runoff/erosion exposures will likely occur in the same locations, and when they are not in same direction, spray drift transport and runoff/erosion will likely occur in different locations. Exposures due to spray drift transport and runoff/erosion are expected to vary due to weather, application and pesticide properties. Due to differences in spray drift and runoff/erosion transport, EPA typically evaluates the potential for impacts to non-target organisms and mitigates these transport routes separately. Runoff and erosion are grouped and mitigated with similar practices because they are similar in that they are dependent on rainfall/irrigation and the same menu of practices can reduce concentrations in both routes.

3 Approaches for Considering Inclusion of and Evaluating the Efficacy of Mitigation Measures

When identifying mitigations to reduce the off-field transport of spray drift, runoff and erosion, EPA considered whether the mitigation measures would be effective at reducing exposure and would not in themselves be so burdensome to prevent the intended use. EPA identified mitigations that are already used by various applicators and growers and included as many measures as possible (meaning EPA had enough information to evaluate it for potential inclusion here) to ensure flexibility and allow growers to use mitigations that are economically and technologically feasible to them.

EPA relied upon multiple sources of information about mitigations that are utilized in agriculture for spray drift, runoff and erosion. EPA also included information about other landscape management practices that may effectively achieve similar reductions in spray drift, runoff and erosion. While runoff/erosion mitigation practices may have previously been installed to reduce transport of nutrients and/or soil, they would also be effective in reducing transport of pesticides. This also applies to mitigation measures such as windbreaks which can be installed to protect wind-sensitive crops and control soil-wind erosion, but they can also be effective in reducing pesticide spray drift. This is discussed in more detail in **Section 5**. In this document, EPA evaluated the effectiveness of mitigation practices in reducing pesticide transport. The process EPA followed for considering the inclusion of a mitigation in this document was based on the following primary lines of evidence:

- Scientific principles, the mitigation is likely to result in meaningful reductions in pesticide spray drift, runoff or erosion based upon the design, placement, and characteristics of the mitigation;
- Existing EPA models indicate a potential reduction in environmental exposure if the mitigation were in place;
- Empirical studies describe the reductions in pesticide concentration as a result of the mitigation;
- The mitigation is similar to other mitigations such that they are functionally equivalent.

These lines of evidence represent a mixture of qualitative (conceptual) and quantitative information and the extent to whether each is available varies from mitigation to mitigation. To the extent they are applicable to a mitigation, EPA reviewed each of these lines of evidence in their totality to establish a level of confidence in the information. EPA's evaluation of the efficacy for each mitigation measure is based on the best available data and EPA's best professional judgment of the mitigation's potential to be effective at reducing offsite transport of pesticides.

3.1 Consideration of the of the design, placement, and characteristics of mitigations

To evaluate a mitigation measure, EPA first needed to understand what the measure represented in practice and also needed to gauge how the measure may influence the reduction of off-site exposure of pesticides through reduction of spray drift, runoff or erosion. To do so, EPA primarily relied upon open literature, technical manuals, comments provided during the public review process, and government documents. Typically, EPA's classification of the effectiveness of a mitigation measure was informed by multiple factors. Some of the factors include the consideration of the physical structure for spray drift (e.g., windbreak height), functional properties (e.g., chemical sorption potential), size and distribution (e.g., in-field vegetative strips), and connectivity with off-farm environments for runoff/erosion (e.g., tailwater return systems).

3.2 Consideration of the similarity of the mitigations and functional equivalence

EPA evaluated the descriptions of each mitigation measure and considered if the design of the measure was unique, or if it shared common features with other mitigations that EPA had already evaluated for efficacy in reducing spray drift, runoff or erosion (e.g., in-field vegetative strips and off-field vegetative strips). In many cases, where mitigations were similar in design and effectiveness, for purposes of describing a mitigation measure, EPA combined them into a single mitigation measure (e.g., reduced tillage and no-till; hedgerows and windbreaks).

3.3 Consideration of the use of modeling to estimate reductions in exposure

When applicable, the Agency relied upon EPA-approved models[3,4] to estimate the efficacy of spray drift and runoff/erosion mitigations. EPA compared the results of the models with and without the mitigation to estimate a relative percent reduction in exposure. For example, EPA conducted modeling to support the potential reduction in exposure associated with a 48-hour rain restriction, for identifying areas less vulnerable to pesticide runoff, to support the vegetative filter strip efficacy, and to evaluate drift reduction technologies and newly submitted drift deposition data.

3.4 Consideration of the empirically measured reduction of pesticide exposure under test conditions

In evaluating available literature, submitted data, and reports on the effectiveness of a particular mitigation measure, EPA considered: 1) the number and quality of available studies and 2) whether those studies collectively show a percent reduction in offsite transport. Pesticide mass transported offsite tends to correlate with the amount of spray drift, runoff

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[3] https://www.epa.gov/pesticide-science-and-assessing-pesticide-risks/models-pesticide-risk-assessment#aquatic

[4] Although VFSMOD is not an EPA approved model, it was considered as an additional line of evidence to support pesticide reduction efficiencies for vegetated filter strips; for more information on this model visit https://abe.ufl.edu/faculty/carpena/vfsmod/index.shtml

and/or erosion, but not necessarily in a readily predictable manner. In addition, an evaluation of the existing data demonstrates that the efficacy of mitigations is highly variable from one site to the next and is often dependent on the study conditions. For example, for some measures, the range of the efficacy from the studies is from 0% to 100%. For any given mitigation measure, a range of efficacy is expected depending on the specific implementation of the measure, the environmental conditions of the treated field, and the physical-chemical properties of the pesticide.

When evaluating data from empirical studies, EPA assumed the results represents the effectiveness of mitigations that are appropriately maintained and that working effectively during the study. EPA also understands that currently available data may reflect efficacies that represent well understood mitigations that have been implemented fairly widely and conversely that some may be in the earlier stages of implementation. Additionally, the breadth of the available data varies across mitigation measures. As such, for certain mitigation measures, EPA bridged this gap by supplementing the available data with data on mitigation measures determined to be functionally equivalent, as that represents the best available data.

Examples of studies being used to bridge a lack of information can be seen with flat fields and field terracing. There are limited studies on the effectiveness of flat fields at reducing runoff, whereas there are numerous studies on field terracing. Since both mitigation measures rely on the slope of a field, it is reasonable to use information from studies on terracing to supplement the information on flat fields. Similarly, there is limited information for tailwater return systems, which often include a sedimentation basin. In this instance, EPA used studies on the sedimentation basins to supplement the literature on tailwater return systems. EPA may update the efficacy analysis of a mitigation measure as additional information related to the efficacy becomes available.

The available studies may also vary with respect to the methods used and how EPA views the appropriateness of that method. In some cases, EPA placed more emphasis on the methods used to generate empirical data for spray drift mitigation measures than it did for runoff and erosion mitigations because the Agency can quantitatively assess the effectiveness of spray mitigations (% reduction) but qualitatively assessed the effectiveness of runoff and erosion mitigations (low, medium, and high). For example, EPA used spray drift models to quantitatively evaluate the impact of increases in droplet size used during an application. However, EPA also considered data in a qualitative manner for spray drift. For example, EPA evaluated the effectiveness of hooded sprayers using data that indicated less spray drift deposition when using a hooded sprayer than predicted by the models. These conclusions were drawn from observation of plant injury (which is an indirect way of evaluating spray drift deposition) as opposed to measuring the deposition directly (using drift deposition cards). Therefore, this information, while still scientifically reliable, was considered qualitatively with support from other modeling lines of evidence.

3.5 Strength of the body of evidence

EPA considered the strength of the body of evidence for each individual mitigation, the evidence for similar mitigations, the number of studies, the quality and relevance of the studies, and the other lines of evidence to quantitatively and/or qualitatively demonstrate a level of confidence for each mitigation measure.

One factor in the strength of the body of evidence for empirical data is the number of studies or experiments available for a given mitigation. As the number of sites/studies increases, EPA can gain a better understanding of the efficacy of the measure in different environmental conditions. As multiple scientific studies confirm previous research, there is greater confidence in the efficacy of the measure across different environments and pesticides. Where possible, EPA used information on the strength of the body of evidence for a mitigation from *Mitigating the Risks of Plant Protection Products in the Environment* (Alix *et al.*, 2017), an international working group which reviewed efficacy data for runoff and erosion mitigations for pesticides.

The Alix *et al.* (2017) document summarized several mitigation measures efficacy as an average percent reduction in the amount of pesticides moving offsite from a treated field. EPA also relied on other studies and reviews that were not evaluated in Alix *et al.* (2017). EPA acknowledges that one study may cover multiple sites and another only a few sites. Additionally, the quality of the studies also influences the reliability of the results. These factors all need to be considered when evaluating the efficacy of a measure at reducing offsite transport.

3.6 Classification of the efficacy of a mitigation measure

As discussed in **Section 3.1**, EPA relied upon the totality of the best available data and information and the strength of that data and information when evaluating a mitigation measure's efficacy. In the runoff/erosion mitigation literature, the average percent reduction was the most commonly reported efficacy measure, which was often reported with a very wide range. Additionally, literature on the same mitigation measure often had widely varying results, showing a wide range of efficacy for a particular mitigation measure. EPA also considered if the models had the potential to bias the results in one direction (i.e., may overestimate exposure), or do not represent a particular application/exposure scenario. The Agency categorized the effectiveness of each run-off/erosion mitigation measure as “low”, “medium”, or “high” based on empirical evidence, modeling, the efficacy of functionally equivalent measures, and best professional judgement. Therefore, these categorizations of mitigation consider the wide variability in effectiveness, multiple lines of evidence, and EPA's confidence in the available information. EPA used the same approach as it did for runoff/erosion to determine spray drift mitigation efficacies. EPA used several lines of evidence and relied on spray drift models, information (typically reported as percent reductions) reported in the literature or submitted to the Agency, efficacy of similar spray drift measures, and best professional judgement. EPA categorized the efficacy of spray drift mitigations as percent reductions that could be applied to an identified spray drift buffer distance. For both runoff/erosion and spray drift, the efficacy scores are not associated with a precise amount of reduction in exposure. The actual reduction that would occur in the environment is pesticide specific.

While the effectiveness of each mitigation measure is determined individually, in practice, mitigation measures may be combined in numerous ways. There is limited evidence in how to evaluate the overall effectiveness that may occur when measures are combined (Alix *et al.*, 2017; Reichenberger *et al.*, 2007). For instance, it is unclear if a combination of mitigations would result in a multiplicative or additive impact, or somewhere in between (Alix *et al.*, 2017). EPA recognizes this uncertainty in combining different practices, and for simplicity purposes in implementation is treating the individual mitigation measures for spray drift as additive (e.g., a 50% reduction in buffer distance for one measure plus a 15% reduction in buffer for another measure, when used in combination results in an overall 65% reduction in an identified buffer).

In addition to the variability in the available efficacy data based on site and pesticide specific factors, EPA acknowledges that some of run-off/erosion mitigation measures (including saturation buffers and controlled drainage areas) may be overwhelmed by extreme weather events, lowering their efficacy. While the efficacy may be reduced in high rain events, such events may not be frequent, depending on the site. Even when these large rainfall events occur, the frequency and duration of these higher runoff and erosion events is expected to be reduced with these mitigation measures.

3.7 Systems for quantifying spray drift and runoff/erosion mitigation measures and efficacy categories

EPA uses its assessment of the potential for population-level impacts to inform its identification of mitigations to reduce spray drift and runoff/erosion to non-target habitats. As discussed in the Strategies, EPA classifies that potential as not likely, low, medium, or high. The potential impacts and any identified mitigations depend on the exposure route. For each exposure route, as applicable, EPA identifies different mitigations based on differences in the potential of population-level impacts. For example, low impacts would be addressed with less mitigations than medium or high potential impacts and no mitigations would be identified if the potential is unlikely. Where EPA identifies mitigations, the mitigation goal is to reduce exposure such that population-level impacts are not likely. Overall, the mitigation measures for spray drift, runoff, and erosion are expected to reduce exposure potential for non-target species, and their habitats by including measures that are known to be effective and practicable.

4 Spray Drift Mitigation Measures

Spray drift exposures are a potential concern for spray applications that are made via broadcast application equipment. Broadcast spray applications are commonly made via aerial, ground or airblast equipment. Applications may also occur through certain types of chemigation equipment (overhead sprayers such as center pivot and traveler sprayers). This section describes the types and levels of spray drift mitigations for broadcast applications. For aerial, ground and airblast equipment, spray drift buffers are a primary mitigation measure to reduce pesticide exposure off-site from spray drift. For the strategies, EPA expresses the spray drift buffers as a distance downwind from the edge of the application site (e.g., field). This is to reduce exposure via spray drift when there is a potential for population-level impacts. The distance varies depending on the potential for population-level impacts (low, medium, high). This section also explains available measures EPA has identified for reducing the distance of any identified spray drift buffer and the basis for the associated percent reduction for each measure. This section also explains, if a buffer is used to represent that distance, what types of areas can represent that buffer. This section explains how EPA plans to calculate that distance. For chemigation, when there is a potential for population-level impacts, EPA did not identify a spray drift distance, but rather identified other mitigation measures intended to reduce exposure from potential irrigation water overspray to non-target areas. Finally, this section clarifies application methods where EPA finds that the potential for population-level impacts from spray drift is not likely.

This section includes EPA's:

- Approach to determine the spray drift buffer distances for aerial, ground and airblast applications (**Section 4.1 and Section 4.2**).
- Analysis and justification for mitigations that could be used to reduce spray drift buffer distances and the associated percent reductions (**Section 0**).
- Descriptions of managed areas that can be subtracted from spray drift buffer distances (**Section 4.4**)
- Analysis and justification for approaches that are not included as potential mitigations to reduce the spray drift distances (**Section 4.5**).
- Discussion of spray drift associated with a subset of chemigation methods (**Section 4.6**)
- Mitigation measures that could be used to reduce overspray and spray drift for overhead and impact sprinkler chemigation methods (**Section 4.7**).
- Discussion of application methods that are unlikely to lead to population-level impacts (**Section 4.8**)

In developing the ecological spray drift distances and mitigation measures presented in this document, EPA revised its AgDRIFT® modeling parameters for aerial applications. Stakeholders (including the National Agricultural Aviation Association (NAAA)) provided feedback to EPA that some of the standard assumptions previously used as default inputs in AgDRIFT® do not reflect the most common agronomic practices for aerial applications, resulting in over predictions of offsite deposition. EPA did an analysis to evaluate that feedback, and the details of that analysis are presented in **Appendix I**. EPA's spray drift update includes use of the Tier III module for aerial applications and revisions to input parameters to represent a more commonly used aircraft type (which impacted other parameters such as swath width, number of passes, and boom length). EPA also updated the aircraft swath displacement, use of medium droplet size as the default, and other meteorological parameters such as atmospheric stability, wind speed and height of wind speed measurement.

Furthermore, EPA identified several measures that it generally includes on pesticide product labels to reduce spray drift exposure to non-target species. Because these measures are common mitigations included on pesticide product labels, EPA incorporated these measures into the model to identify spray drift buffers distances, and they typically include:

- restricting the maximum windspeed to 15 miles per hour,
- prohibiting applications during temperature inversions,
- boom length restrictions and swath displacements for aerial applications,
- maximum release heights for ground and aerial applications and
- directing sprays into the canopy for airblast and turning off the outer nozzles at the last row.

4.1 Approach to Determine Lower Limit Spray Drift Buffer Distance

For pesticides with low potential for population-level impacts, EPA is identifying for aerial, airblast, and ground applications what it refers to as lower limit buffers. EPA based the identified lower limit buffers distances on the points on the distribution curves generated in AgDRIFT where the deposition fraction is estimated to be 10% of the application rate for the different application methods. This equates to 50, 25, and 10 feet, for aerial, airblast, and ground applications, respectively. EPA based these distances for an application method on the common droplet size distribution for aerial (medium), the common droplet size distribution for ground (fine) and high boom and on the sparse orchard setting for airblast (**Table 4-1**).

Table 4-1. Spray drift deposition fractions supporting the development of buffers for chemicals with low potential for population-level impacts

Application method	Droplet size distribution	Distance (ft) at which estimated deposition fraction is ~0.1	Low limit distance (ft) based on most common deposition curve[1]
Aerial	Fine	154	50
	Medium	**46**	
	Coarse	20	
	Very coarse	0	
Ground, high boom	**Very fine to fine**	**26**	10
	Fine-medium-coarse	7	
Ground, low boom	**Very fine to fine**	**10**	
	Fine-medium-coarse	3	
Airblast (normal)	All	0 ft	25

Application method	**Droplet size distribution**	**Distance (ft) at which estimated deposition fraction is ~0.1**	**Low limit distance (ft) based on most common deposition curve**[1]
Airblast (dense)		3	
Airblast (sparse)		**26**	
Airblast (vineyard)		0	
Airblast (orchard)		13	

[1]Most commonly used deposition curve in **bold;** values rounded**.**

4.2 Approach to Determine Chemical Specific and Maximum Spray Drift Distance

Where EPA identifies a medium potential for population-level impacts for aerial, airblast and ground applications, the Agency plans to use AgDRIFT to identify a chemical specific buffer distance. This calculation would be the distance to where the deposition exposure is equal to the toxicity threshold. This distance is anticipated to be between the lower limit and at or lower than the maximum buffer distance.

Where EPA identifies a high potential for population-level impacts for aerial, airblast and ground applications, the Agency plans to identify a maximum spray drift distance at a distance beyond which exposure does not substantially change using the AgDRIFT model. The main reasons for determining a maximum buffer distance include: 1) the impact of the buffer in reducing exposure decreases with distance, such that at distances far offsite there is only a small change in the spray drift deposition, 2) the uncertainty that exposure will be similar to what is predicted by the model increases with distance, and 3) the larger a buffer is, the less feasible it is for many applicators. In many cases, the likelihood that spray drift will be partially intercepted by a drift barrier (e.g., trees, crop canopy or other vegetation, buildings) increases with distance, and as such the model may over-estimate the maximum spray drift buffer because it assumes a bare treated area with no obstructions to intercept spray droplets that drift off-field. The maximum spray drift buffer will be different for different application equipment (i.e., aerial and ground) and droplet size (e.g., medium, or coarse).

The amount and rate of spray deposition decrease as distance from the edge of the application site increases. As distance from the edge of the application field increases, the change in deposition can be small over a large distance. Because of these small differences, the efficacy of buffers as drift reduction measures plateaus with distance. For example, a low boom ground application of fine to medium coarse droplets results in 0.27% of the application rate deposited at 200 ft off-field and 0.088% deposited at 700 ft off-field. While there is a three-fold reduction in relative deposition from 200 to 700 ft, the deposition changes relative to the amount applied is less than 0.2% after 200 ft. Therefore, little would be gained in terms of mitigation between 200 and 700 ft despite the significant increase in distance.

Figure 4-1 depicts another example of a deposition curve in which deposition rapidly declines in the first 200 feet off the treated field and then declines more slowly thereafter. **Appendix A** summarizes EPA’s standard spray drift modeling assumptions and the underlying data to estimate buffer distances. Beyond where the deposition curve plateaus, spray drift reductions become more limited and eventually negligible.

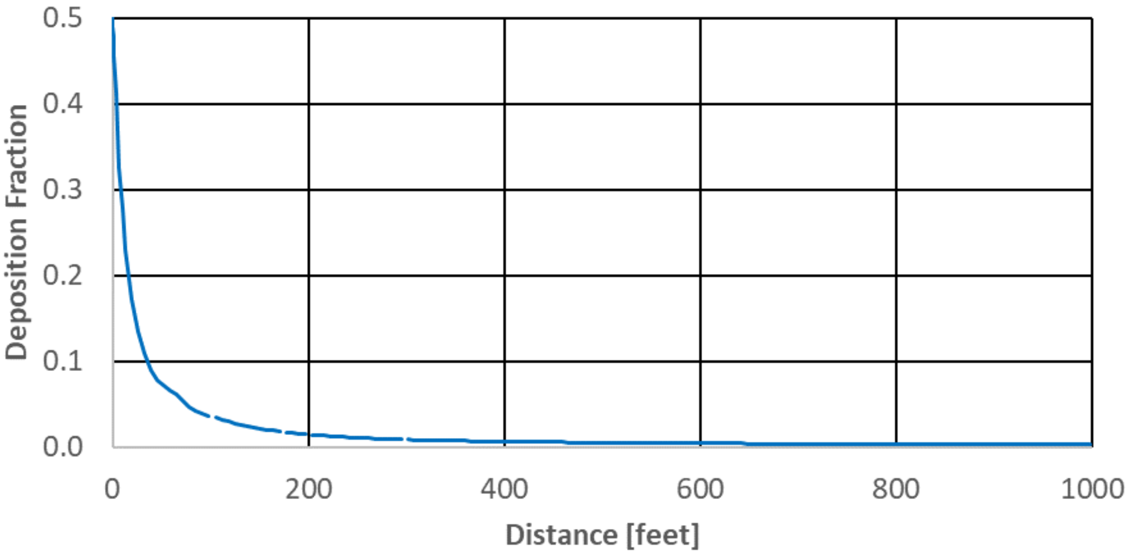

Figure 4-1. Fraction of Applied Pesticide with Distance for Aerial Application with Coarse to Very Coarse Droplets with AgDRIFT® Tier I Aerial Module.

When EPA released a draft version of this document with the draft Herbicide Strategy, it identified two approaches to identify the point on the spray drift deposition curve that represents the distance at which the rate of spray drift deposition declines. Public commenters generally requested that EPA employ a discrete, mathematical function rather than the identified approaches[5]. EPA agrees that mathematical models can be used to determine the point on the curve for ground and airblast applications, as the AgDRIFT® model employs two mathematical functions (derived from SDTF data with one for near-field and one for far-field) to predict spray drift deposition. However, because mathematical equations to estimate aerial deposition are more complex than those for ground and airblast deposition, EPA uses a mechanistic model to predict spray drift deposition from aerial applications. See **Appendix B**. for additional discussion on the identified approaches and related stakeholder comments.

Given stakeholder's interest for EPA to estimate maximum spray drift distances with a more discrete approach and EPA's intent to estimate distances consistently across application methods, EPA evaluated the slope of the deposition curve via the results of AgDRIFT® modeling for each application method, which provide deposition estimates at 2-meter (6.6 feet) increments. Assuming linear decline between 2-meter increments, EPA identified a common deposition decline (or slope) for each application method and droplet size distribution (DSD)

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[5] Though commenters provided suggestions on a different method for calculation of maximum distances, no specific comments were received on proposing new maximum buffers though some comments indicated a preference for larger or smaller maximum spray drift buffers.

combination. This slope provided specific maximum distances that minimize deposition differences across application methods, while also minimizing differences from maximum distances previously identified.

This updated method allows for distinct maximum distance for each application method and spray quality combination, whereas the previously identified method included equivalent maximum distances for spray qualities with differing spray drift potential. In addition, the deposition fractions at maximum buffer distances identified using the updated approach for the three application methods span one order of magnitude from highest (Aerial Fine deposition fraction of 0.0409) to lowest (Airblast Sparse deposition fraction of 0.0038). This range in deposition values is consistent with the range of variability seen across comparable aerial spray drift trials (2x to 4x, (Bird *et al.*, 1996)), comparable ground spray drift trials (3x, MRID 43058001), and comparable airblast drift trials (10x, MRID 43925701).

See **Table 4-2** below for a summary of maximum spray drift distances associated with each deposition curve and **Figure 4-2** for where maximum spray drift distances occur on exponential deposition curves. EPA is using the typical droplet size distributions for aerial and ground (medium DSD for aerial and high boom with very fine to fine DSD for ground) to inform the maximum distances used for mitigations. Note that in **Figure 4-2**, the y-axis is plotted on an exponential scale to more clearly show the deposition differences and decline associated with each curve. While the maximum distances maximize potential spray drift reduction, as seen by **Figure 4-2**, spray drift may continue to occur beyond this distance, however for reasons discussed above it is likely to be limited and unlikely to be at a level that would lead to potential population-level impacts.

Table 4-2. EPA's previously identified and current maximum drift distances established for aerial, ground and airblast applications.

Type of Application	Application Parameters Assumed in Tier 1 AgDRIFT® Modeling	Maximum Distance in Feet		Current Method: Deposition Fraction at Maximum Distance
		Previous Method[1]: <1% change over 100 ft	Current Method: Slope at 6.6 ft increments	
Aerial Application	Fine DSD	500	500	0.0409
	Medium DSD	300	320	0.0182
	Coarse DSD	300	250	0.0124
	Very Coarse DSD	200	200	0.0083
Ground Boom Application	Very fine to fine DSD; high boom	200	230	0.0103
	Very fine to fine DSD; low boom	100	130	0.0075
	Fine to medium-coarse; high boom	100	100	0.007
	Fine to medium-coarse; low boom	100	80	0.0052
Airblast	Sparse	100	160[2]	0.0038

DSD=Droplet Size Distribution; Low boom height=release height is less than 2 feet above the ground; high boom=release height is greater than 2 feet above the ground.[1] As identified in the Draft Herbicide Strategy, Draft Vulnerable Species Pilot, and associated mitigation measures as posted to the docket in 2023 (https://www.regulations.gov/docket/EPA-HQ-OPP-2023-0327; https://www.regulations.gov/docket/EPA-HQ-OPP-2023-0365).

[2] See **Appendix B** for rationale on increased maximum distance for airblast

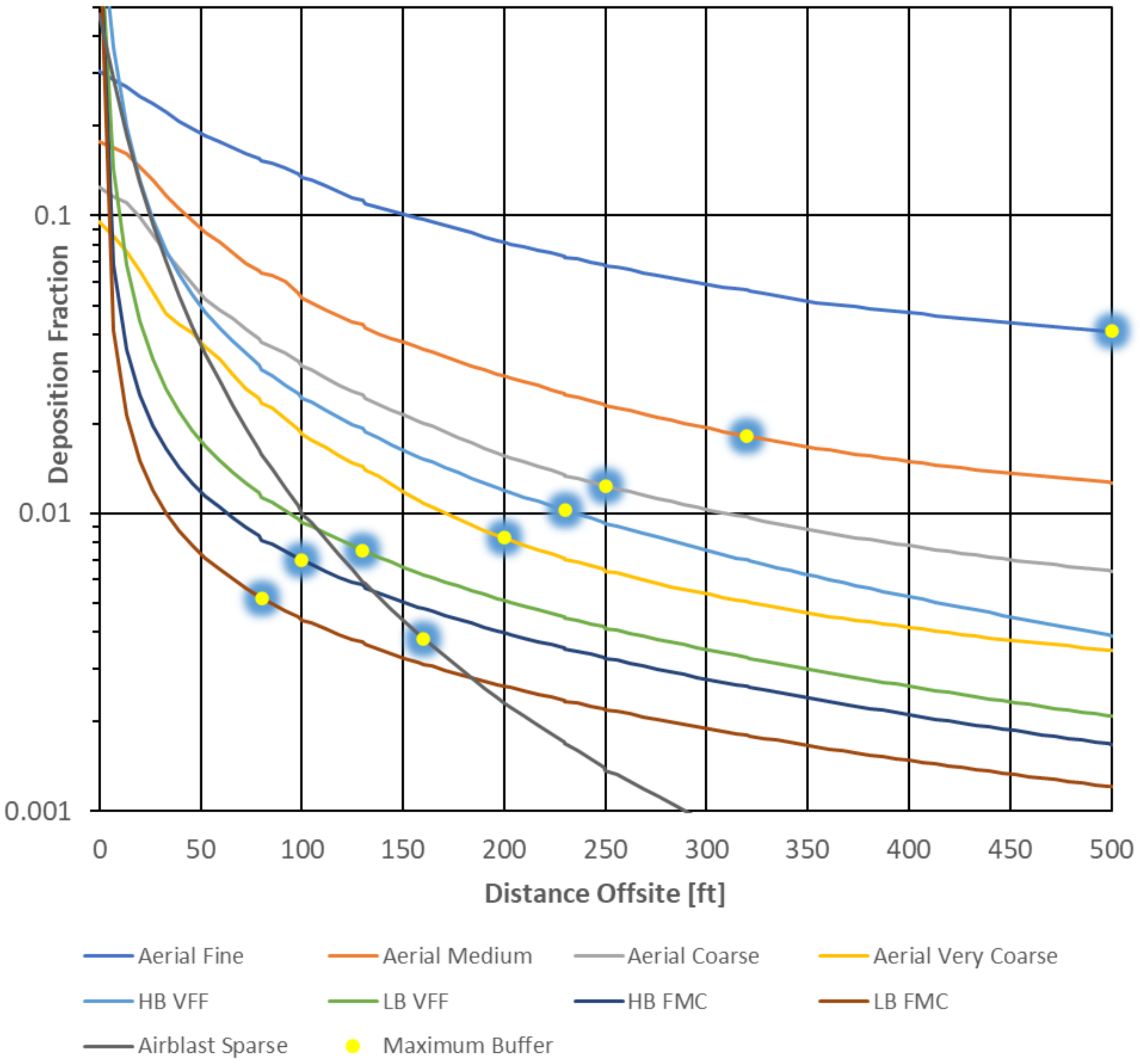

Figure 4-2. Exponential Curve Showing Fraction of Applied Pesticide with Distance for Ground and Airblast Applications based on AgDRIFT® Tier I Modules and Aerial based on AgDRIFT® Tier III Module with Different Droplet Size Distributions used to determine Maximum Spray Distance (buffer).

In addition to the small changes in deposition as distance increases as shown on the spray drift curves, in many cases, the likelihood that the spray drift plume will be partially intercepted by a drift barrier (*e.g.,* trees, crop canopy, buildings) increases with distance, particularly when obstructions (*e.g.,* vegetation, building) may be present that impede the movement of droplets far afield from the application site. As such, the likelihood that EPA's modeling may result in an over-estimation of exposure increases with distance. However, for near-field deposition close to an application site, this does not hold true. In many agricultural areas, there are multiple fields with minimal vegetation on the field near planting and emergence. The Spray Drift Task Force's (SDTF)[6] data represents on low-cut grass canopies has been that it provides a conservative scenario for measuring spray drift and at the time the studies were conducted, it was not practicable to field test a large range of terrain and canopy types (USEPA, 1997). Therefore, the near-field deposition in typical field settings is more likely to resemble what is estimated in AgDRIFT® (no or few drift barriers at typical field edges) because the likelihood of a drift barrier occurring decreases closer to the treated field. In other words, AgDRIFT® assumptions are used to assess exposure in many agricultural scenarios but results are most applicable when there are large fields next to each other all in the near planting phase at the time of application with downwind habitat in a similarly bare condition.

4.3 Percent Reductions for Measures to Reduce Spray Drift Buffer

EPA has identified a number of spray drift mitigation measures that effectively reduce spray drift deposition. These measures can be selected by applicators to reduce the spray drift distance. This section explains the basis for the percent reduction for each measure.

Table 4-3. Mitigation measures identified when making broadcast aerial applications.

Mitigation Measure	% Reduction in Distance
Application Parameters	
Reduced single application rate	% reduction corresponds to application rate reduction from maximum on pesticide product label
Coarse DSD[1]	20%
Very coarse DSD[1]	40%
Spray drift reducing adjuvants, Medium DSD	30% for herbicides Under evaluation for insecticides[2]
Spray drift reducing adjuvants, Coarse or Very coarse DSD	15% for herbicides Under evaluation for insecticides[2]
Reduced proportion of field treated (number of airplane/helicopter passes[3])	
1 pass	55%
2-4 passes	20%
5-8 passes	10%
Other Mitigation Measures	
Downwind windbreak/hedgerow/riparian/forest/woodlots/shrubland	50% for basic windbreak/hedgerow 75% for advanced windbreak/hedgerow

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[6] The SDTF was a consortium of approximately 40 pesticide registrants, active from 1990 to 1999, producing spray drift field data for aerial, ground, airblast, and chemigation application methods. Results and analysis are published in Hewitt *et al.* (2002); (Johnson, 1995a; Johnson, 1995b); Teske (2009).

	100% for riparian/forests/shrubland/woodlots ≥60ft width
Relative humidity is 60% or more at time of application	10%

DSD = droplet size distribution

[1] This % reduction is based on the assumption/baseline of using medium droplet size for aerial.

[2] EPA anticipates receiving spray drift reduction adjuvant data for insecticide formulations and will be evaluating this as a mitigation measure for insecticides prior to finalizing the Insecticide Strategy.

[3] A spray drift buffer applies to downwind non-target areas. The reduced number of passes applies to the upwind part of the treated field.

Table 4-4. Mitigation measures identified when making broadcast ground applications.

Mitigation Measures	% Reduction in Distance
Application Parameters	
Reduced single application rate	% reduction corresponds to application rate reduction from maximum on pesticide product label
High boom, fine to medium-coarse DSD[1]	55%
High boom, coarse DSD[2]	65%
Low boom, very fine to fine DSD[1]	40%
Low boom, fine to medium-coarse DSD[1]	65%
Low boom, coarse DSD[2]	75%
Over-the-top Hooded Sprayer	50%
Row-middle Hooded Sprayer	75%
Sprays below crop using drop nozzles or layby nozzles	50%
Spray drift reducing adjuvants, Medium DSD	30% for herbicides Under evaluation for insecticides[3]
Spray drift reducing adjuvants, Coarse or Very coarse DSD	15% for herbicides Under evaluation for insecticides[3]
Reduced proportion of field treated (number of tractor passes[4])	
1 pass	75%
2-4 passes	35%
5-10 passes	15%
Other Mitigation Measures	
Downwind windbreak/hedgerow/riparian/forest/shrubland/woodlots	50% for basic windbreak/hedgerow 75% for advanced windbreak/hedgerow 100% for riparian/forests/shrubland/woodlots ≥60ft width
Relative humidity is 60% or more at time of application	10%

DSD = droplet size distribution

Low boom height=release height is less than 2 feet above the ground

high boom=release height is greater than 2 feet above the ground

[1] This % reduction is based on the assumption/baseline of using high boom, very fine to fine droplet size for ground.

[2] Based on evaluation of additional ground spray drift data for an additional 10% reduction in distance beyond fine/medium DSDs.

[3] EPA anticipates receiving spray drift reduction adjuvant data for insecticide formulations and will be evaluating this as a mitigation measure for insecticides prior to finalizing the Insecticide Strategy.

[4] A spray drift buffer applies to downwind non-target areas. The reduced number of passes applies to the upwind part of the treated field.

Table 4-5. Mitigation Measures identified when making airblast applications.

Mitigation Measure	% reduction in distance
Application Parameters	
Reduced single application rate	Divide % reduction in application rate by 2
Reduced proportion of orchard treated (Number of Treated Rows[1])	
1 row	70%
2-4 rows	30%
5-10 rows	15%
Other Mitigation Measures	
Downwind windbreak/hedgerow/riparian/forest/woodlots/shrubland	50% for basic windbreak/hedgerow 75% for advanced windbreak/hedgerow 100% for riparian/forests/shrubland/woodlots ≥60ft width

[1]A spray drift buffer applies to downwind non-target areas. The reduced number of treated rows applies to the upwind part of the treated field.

4.3.1 Application Rate Reduction

This mitigation measure involves less pesticide mass applied to a field (e.g., a lower single maximum application rate), which results in less pesticide mass that can be transported via spray drift. Overall, if application methods and droplet size distribution are held constant, as application rates decrease, the spray drift buffer would also decrease. Based on the AgDRIFT modeling, the relationship between application rate and spray drift deposition reduction is not linear as the deposition reduction is more sensitive to application rate as buffer sizes increase and the slope of the deposition curve decreases (**Figure 4-2**). Additionally, deposition curve slopes differ depending on application method and spray quality (**Figure 4-2**). But in general, a percent reduction in application rate corresponds to a similar magnitude of reduction in buffer size for aerial and ground applications (e.g., a 25% reduction in rate results in equivalent exposure at a distance reduced by 18 to 32% for spray drift distances between 75 and 200 ft). Therefore, for simplicity, EPA is identifying the percent reduction in the spray drift buffer to be proportional to the application rate for aerial and ground applications. Deposition declines more rapidly with distance for airblast applications than for ground or aerial applications. Considering this difference, for airblast, EPA is identifying the percent reduction in the spray drift buffer distance to half the application rate reduction from maximum on label (e.g., an airblast rate reduction of 40% would correspond to a 20% reduction in buffer distance).

4.3.2 Droplet Size Distributions

EPA is using the most commonly used application scenarios for aerial and ground spray to identify the maximum distances used for mitigation of spray drift. For aerial applications, this is a medium droplet size distribution (320 ft). For ground, this is very fine to fine droplet size distribution with a high boom (230 ft). Increasing the droplet size to a coarser droplet during an application reduces the amount of spray drift as larger droplets are not as likely to travel as far off-site. Applicators may choose a larger droplet size distribution. If so, they can reduce the size of their buffer. To account for coarser droplets in ground applications, EPA compared and analyzed aerial modeling capabilities and available ground deposition data and modeling. EPA calculated the reduction in buffer distance using the relative difference between the maximum buffer distances for a droplet size distribution compared to the maximum buffer distance for the commonly used application scenarios. If it is identified for a particular use or pesticide that a finer droplet size than the one identified as typical is needed (e.g., very fine), then that will be handled on a case-by-case basis.

Aerial modeling indicates a 2X difference in off-field deposition between medium and coarse droplets, starting at approximately 75 ft (23 m) offsite and continuing to far field (997 ft (extent of model) or 300 m). EPA estimated equivalent point deposition at 100 ft (medium DSD) and 60 ft (coarse DSD) offsite, resulting in a 40 ft difference associated with differing droplet sizes. Equivalent point deposition was estimated at approximately 150 ft (medium DSD) and 90 ft (coarse DSD) offsite, resulting in a 60 ft difference associated with the different droplet sizes. Because aerial spray drift modeling is only indirectly applicable to conditions present for ground applications, this 60 ft difference is not taken at face value for ground applications and a 10% buffer reduction of spray drift buffers is considered for ground application that use coarse or coarser droplets.

EPA completed a review of the available data to directly compare the offsite deposition fraction between medium and coarse DSDs for ground applications with a 60 cm (2 ft) boom height (USEPA, 2022c; Wolf, 2016). In the given dataset, deposition at approximately 30 ft offsite was very similar between the DSDs with a 3% average difference. At approximately 65 ft (20 m), 130 ft (40 m), and 260 ft (80 m) offsite, the difference in deposition between Medium and Coarse DSDs increased to 35%, 47%, and 35%, respectively. These data are consistent with the aerial modeling exercise above using Tier III AgDRIFT® point deposition, considering that the comparable distances of 65 ft and 130 ft produce similar deposition differences of 40% and 43%, respectively.

This again demonstrates that exposure reduction can be expected when using coarser droplets and supports a spray drift buffer reduction of 10% for ground applications when coarse droplets are used. Though point deposition differences between medium and coarse DSDs were less than 10% near the field edge, the average difference is expected to be equal or greater than 10% when averaged over a larger area (*i.e.*, a terrestrial area >66 ft wide would include distances where point deposition differs by 35% according to available data), and therefore a 10% reduction is the spray drift buffer distance is identified. The referenced dataset is not the exclusive source of information for spray drift from Coarse and coarser DSDs but is suggestive of a spray drift reduction. EPA continues to evaluate other information on coarse and coarser DSDs which may result in a modified percent reduction in the future.

Table 4-6 presents the percent decrease in distance that can be applied to different aerial and ground droplet size distributions.

Table 4-6. Decreases in distances associated with larger droplet size distributions than typically applied.

Type of Application	Droplet size distribution	Boom height	Distance (feet)	% difference compared to reference
Aerial Application	Medium	NA	320*	0
	Coarse	NA	250	20
	Very Coarse	NA	200	40
Ground Boom Application	Very fine to fine	High	230*	0
	Very fine to fine	Low	130	40
	Fine to medium-coarse	High	100	55
	Fine to medium-coarse	Low	80	65
	Coarse DSD[1]	High	NA	65
	Coarse DSD[1]	Low	NA	75

NA = not applicable
Low boom height=release height is less than 2 feet above the ground;
high boom=release height is greater than 2 feet above the ground.
*Reference distance used to establish maximum distance for ground or aerial applications. % reductions in spray drift distances are relative to this value.
[1] Based on evaluation of additional ground spray drift data for an additional 10% reduction in distance beyond fine/medium DSDs.

4.3.3 Adjuvants

Adjuvants are non-pesticidal chemicals that may be included in pesticide formulations or added to tank mixtures. Adjuvants have a variety of purposes, including improving performance of the pesticide in controlling pests and reducing spray drift. For this effort, EPA focused on adjuvants that may reduce spray drift exposures. These types of adjuvants include oil and polymer-based adjuvants. At this time, the majority of the information EPA has is for oil-based emulsions and for herbicide formulations and so this analysis focuses on these types of adjuvants and herbicides. Spray drift retardants work by increasing the sizes of spray droplets and reducing the amount of fine droplets that are more prone to drift. The concentration of adjuvant in the tank mix influences the effectiveness of spray drift reduction. EPA used a combination of empirical wind tunnel studies with adjuvants and AgDRIFT modeling to evaluate the effectiveness of oil-based adjuvants and herbicides on spray drift reductions.

For ground applications, wind tunnel studies simulate the initial release of the tank mix just above the site of application, but do not take into account other variables that will impact off-field drift, such as boom height, variable windspeed, and humidity. However, the available wind tunnel studies that include the use of a drift reducing adjuvants indicate droplet size changes (e.g., Medium to Coarse) influence the amount of spray drift downwind by reducing the amount of driftable fine particles more consistently than the use of a drift reducing adjuvant. As indicated above EPA continues to evaluate other information on ground spray drift deposition data and if this impacts this mitigation measure, it could be updated in the future.

For aerial applications, a limited amount of wind tunnel (Henry *et al*. 2016) and field data (Lan *et al.*, 2008) are available and are generally indicative that fines reduction observed in CPDA wind tunnel trials is consistent with aerial applications given the concentration of adjuvant in a given tank mix is sufficient. Based on the AgDRIFT sensitivity analysis, the spray drift buffer reduction associated with changes in spray quality for aerial applications are 40% to 50% for medium droplet size distributions. Given the established comparison between ground and aerial deposition reduction, EPA based the percent reduction on the lower 90th percentile confidence bound of the mean and on the average for herbicides when oil emulsion adjuvants are utilized given the same rationale presented for ground applications around tank mix uncertainty. The 2.5% volume to volume (v:v) is the only adjuvant concentration at which there is data supporting consistent reduction in fines when an adjuvant is added to the tank mix for aerial applications (Lan *et al.,* 2008) as the wind tunnel study conducted at aerial windspeeds did not show consistent fines reduction at the tank mix concentrations of 0.25 to 0.31% v:v (Henry *et al*. 2016). For aerial spray buffers, the adjuvant-based reduction is connected to the droplet size, and EPA identified a 15% reduction for coarse and very coarse and a 30% reduction for medium droplets. Due to limitations within the current datasets, EPA is unable to provide a percent reduction for fine droplets or airblast.

See **Table 4-7** for percent reductions in any identified buffer distance associated with oil emulsion adjuvants for herbicides. **Appendix C** includes the full details of EPA's current analysis of available adjuvant data.

Table 4-7. Spray drift buffer reduction with use of an oil emulsion adjuvant for herbicides.

ASABE Spray Quality	Aerial Application (minimum rate of 2.5% v:v*)	Ground Application (minimum rate of 0.3% v:v)	Airblast Application
Fine	N/A*	N/A*	N/A*
Medium	30%	30%**	
Coarse	15%*	15%**	
Very Coarse	15%	15%**	

*Percent reduction may be changed with submission of additional data

**Percent reduction may be changed with submission and further analysis of droplet size distribution impact

Although the available wind tunnel datasets are informative, they do not fully address the complexity of the potential for oil emulsions drift reducing adjuvants to reduce drift. Most importantly, the complexity associated with tank mixes is not fully characterized at this time. Based on CPDA's published analysis of its dataset, EPA 's interpretation is that pesticidal active ingredient type is the variable with the most explanatory power in the dataset (more so than spray pressure, nozzle orifice size, adjuvant type or nozzle). While the active ingredient itself is expected to have little impact on spray drift, other aspects of the formulated product can have substantial impact on its spray drift potential (i.e., whether it is a suspension concentrate or already includes a drift reducing adjuvant). Given that a typical herbicide application can often include five end use products[7] in a given tank mix, it may be expected that one or more

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[7] Herbicide premix products can include up to five active ingredients. This an indication of the approximate number of end-use products an applicator may tank mix together.

herbicides included in the tank mix will have some drift reduction properties. Given this, additional pesticidal products in a tank mix would be expected to change the efficacy of the drift reducing adjuvant. This characterization could be improved with additional data on tank mix interactions. For this reason, at this time, a value between the lower 90th percentile confidence bound of the mean and the average is identified for deriving a buffer reduction, as it accounts for the uncertainty associated with a dataset focused on single end-use products. Buffer reduction is also only identified for the pesticide type that is best represented in the dataset (*i.e.,* herbicides). With future submission of drift reduction adjuvant data with insecticides and fungicides (with spray pressure and nozzle configurations appropriate for their expected use), buffer reduction may be expanded beyond the herbicide pesticide type.

4.3.4 Lower Boom Heights for Ground Spray

EPA is using the most commonly used application scenarios for ground spray to set the maximum distances used for mitigation of spray drift. For ground, this is very fine to fine droplet size distribution with a high boom (230 ft). EPA calculated the reduction in buffer distance using the relative difference between the maximum buffer distances for high and low boom with different droplet size distributions. **Table 4-8** presents the % decrease in distance that can be applied for low boom with either very fine to fine or fine to medium-coarse droplet size distributions.

Table 4-8. Decreases in distances associated with larger droplet size distributions than typically applied.

Type of Application	Droplet size distribution	Boom height	Distance (in ft)	% difference compared to reference
Ground Boom Application	Very fine to fine	High	230*	0
	Very fine to fine	Low	130	40
	Fine to medium-coarse	High	100	55
	Fine to medium-coarse	Low	80	65

NA = not applicable
Low boom height=release height is less than 2 feet above the ground;
high boom=release height is greater than 2 feet above the ground.
*Reference distance used to establish maximum distance for ground or aerial applications. % reductions in spray drift distances are relative to this value.

4.3.5 Hooded Sprayers

Hooded sprayers may be part of ground spray equipment. Hooded sprayers physically block droplets, making them have inherent benefit for reducing spray drift. EPA considers two types of hooded sprayers that are used with ground spray equipment: over-the-top (covers nozzles but does not extend to the ground) and row middle (extends to the ground). EPA assigned a 50% reduction in distance for the over-the-top hooded sprayer and 75% reduction for the row middle hooded sprayer. At this time, EPA is not considering hooded sprayers for airblast applications due to insufficient data[8].

EPA assigned a 50% reduction in spray drift distances for over-the-top hooded sprayers based on three major lines of evidence. First, showed a 50% reduction in spray drift (up to 100 ft off site) for ground application to soybean of fine to medium droplet sizes. The spray drift reductions reported by Foster *et al.* (2018) were measured considering wind speeds of 5 to 11 mph, which is within the range expected for most pesticide applications. Second, an EPA assessment conclusion and registration (USEPA, 2020b) of a specific pesticide allowed for a 54% spray drift distance reduction (from 240 feet to 110 feet) when over-the-top hooded sprayers are utilized for cotton and soybean. These two lines of evidence generally support the 50% reduction in distance. The third line of evidence involves the logical extension of this percent reduction to other crops (for which data are not available) and droplet size distributions (that were not tested) based on the way this mitigation functions through physically blocking spray droplets. EPA assumes that the 50% reduction also applies for droplet sizes larger than medium; however, reductions in spray drift may be less at distances greater than 14 m (46 ft) offsite for spray qualities larger than and less prone to spray drift than those represented by AgDRIFT® (very coarse and ultra coarse).

EPA assigned a 75% buffer distance for row-middle hooded sprayers based on two lines of evidence. First, a University of Georgia (UGA) field trial with a row-middle hooded sprayer showed an 83% reduction in non-target plant damage (at 3 ft from the edge of the field) associated with spray drift for ground application to soybean of ultra coarse droplet sizes[9]. In this study, plant damage was observed as far 72 ft from the edge of field without the hooded sprayer and only 3 ft from the field with the hooded sprayer. In general, EPA prefers to quantify spray drift reductions using deposition cards and quantification of chemical concentrations because the amount of chemical transported in spray drift can be more precisely measured. Use of plant damage as a measure of reduced spray drift is considered qualitative because the observation of plant injury and severity is related to presence/absence or a subjective score. Nonetheless, the UGA data is useful in demonstrating substantial reductions in spray drift associated with use of row-middle hooded sprayers. EPA's second line of evidence is the logical conceptual basis of this mitigation measure. This mitigation functions by physically blocking spray. Also, applications are made between crop rows, so, the crop can also intercept spray droplets. Conceptually, this mitigation can be compared to advanced windbreaks that also block spray through a physical action.

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[8] Some drift reduction can likely be demonstrated with use of hooded sprayers with airblast equipment; however, according to literature reductions have not yet been quantified (Otto *et al.*, 2015) nor has EPA found readily available data to do so.

[9] Docket EPA-HQ-OPP-2023-0365. Comment by A. Stanley Culpepper and Taylor Randell-Singleton. University of Georgia – Weed Science

4.3.6 Sprays Below Crop Using Drop Nozzles or Layby Nozzles

EPA investigated the impact of on-field crop on reducing offsite spray drift. When ground spray applications have release heights below the height of the standing crop, the crop vegetation effectively acts similarly to a hedgerow or windbreak (which should always be equal to or higher than the application release height) and can therefore reduce the amount of spray drift that is deposited off-site. As discussed above, the dimensions and composition of a hedgerow are important characteristics related to the efficacy of that mitigation measure.

For a crop on the field to perform like a hedgerow or windbreak in reducing spray drift deposition off-site it should have similar characteristics. Efficacy of the crop canopy is dependent upon the height of the pesticide spray applications, such that the height of the crop is higher than the release height of the application. The greater the crop height relative to the spray release height, the better the windbreak will be at capturing the drift. Because of a lack of empirical data for on-field crop and spray drift that meet these conditions, there is uncertainty in the effectiveness evaluation. Crops will not likely have the same depth as a hedgerow or windbreak when considering only a single row, but when considering several rows in tandem (parallel), the depth will likely be the same as for a hedgerow/windbreak. In identifying windbreaks or hedgerows as a mitigation measure for reducing off-site spray drift, a hedgerow or windbreak comprised of non-woody vegetation (*e.g.*, elephant grass, corn, etc.) the vegetation should be at least 5 feet or more. While gaps between crop rows may result in higher drift movement as compared to a hedgerow or windbreak in that space, the rows are likely to be repeating over the landscape such that EPA considers the effectiveness similar to that of EPA's basic windbreak measure which is identified as a depth of at least 5 feet. Therefore, these conditions are similar to the basic hedgerow/windbreak that is described which identified a 50% reduction in the spray drift buffer distance.

Based on the available information and consideration of application parameters, EPA is basing the percent reduction for this mitigation on two factors:

1) the difference between crop height and release height is $\geq$ 1 ft, and
2) there are more than 4 consecutive rows of crop on the field that meet the crop height vs spray release height parameter ($\geq$ 1 ft).

EPA identified two types of ground spray application methods (drop nozzles; layby sprayers) that likely meet these two factors and for which this percent removal is appropriate. Under these conditions, EPA estimates their effectiveness at reducing spray drift deposition to be 50%, which is the same percent reduction as that for a basic hedgerow/windbreak.

4.3.7 Reduction in Proportion of Field Treated

In general, pesticides are applied to a field or orchard (treated area) by making multiple passes (e.g., of a tractor or airplane) in parallel rows of that treated area. With each pass, spray drift may move from the treated area to the non-treated area in the direction of the wind. Pesticide accumulates in the non-target area from each pass. The more passes or rows that are treated, the greater the pesticide accumulation in the non-target area (**Figure 4-3**).

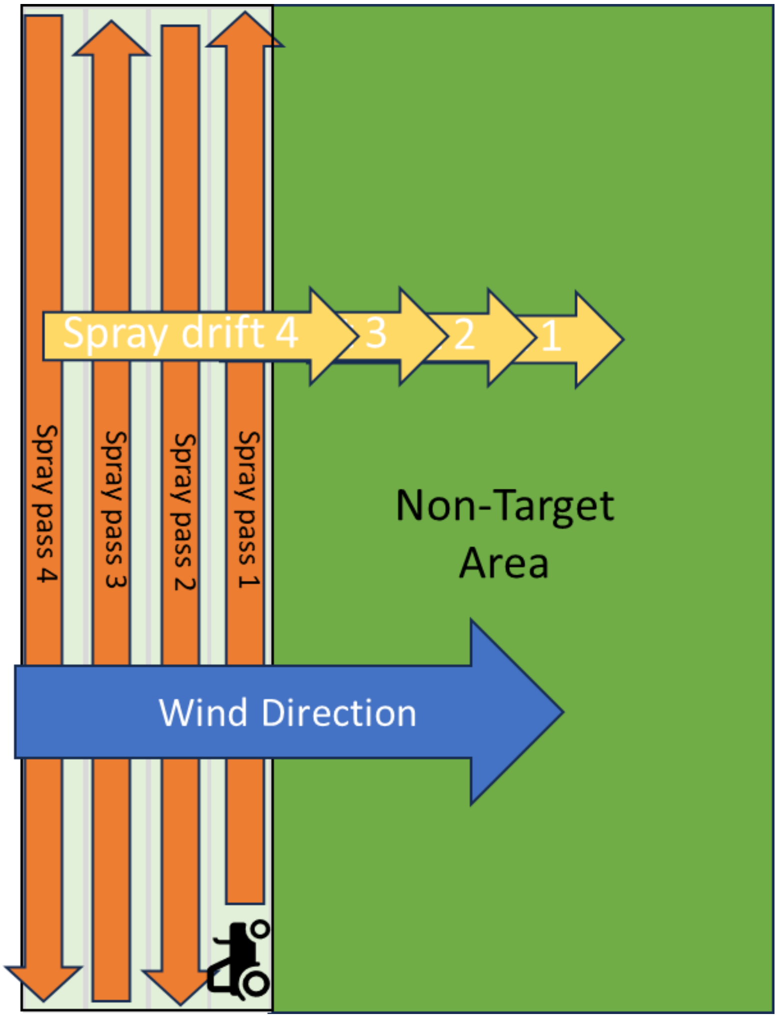

Figure 4-3. Cumulative spray drift in non-target area from tractor passes on 4 parallel rows on treated area.

Spray drift deposition and the spray drift buffer distances calculated for a chemical (either lower limit, chemical specific or maximum) are based on the AgDRIFT model. In the model, the standard size of the treated area is related to the swath width (or the width of the pass) and the number of passes, flight lines, or rows treated. When using the AgDRIFT model, EPA assumes the following:

- For ground applications: 20 spray passes with a 45 ft swath (approximately 900 linear feet);
- For aerial applications: 15 flight lines with an 80 ft swath width (approximately 1,200 linear feet from the downwind edge); and
- For airblast applications: 20 rows treated.

These assumptions determine the cumulative spray deposition from combined spray passes. If a field width or treated area is smaller than the assumed area, then EPA's spray drift distances are biased and overestimate exposure for that condition. Furthermore, it is common for some pesticides to be sprayed only on a perimeter area (e.g., 1-2 passes) or in a select area of the field for pest management control. Also, an applicator may treat a field, leaving an infield buffer and then treat that in field buffer later in time.

EPA completed a series of simulations using the AgDRIFT model with 1, 4, 8 or 10 passes to estimate the reductions in deposition in non-target areas when a full field is not treated with a pesticide due to fewer passes than assumed in AgDRIFT. These passes are assumed to represent smaller fields and cases where only the field perimeter is treated (including when an infield buffer is treated later in time than the rest of the field). **Table 4-9** provides a range of percent reductions representing different boom heights (ground), droplet size assumptions (ground and aerial) and density assumptions (airblast). EPA calculated the percent reduction using point deposition measured at 100ft downwind of the treated area because this represents a reasonable mid-point of the maximum distance for ground and other application methods. Based upon these simulations EPA calculated a percent distance reduction for each application method based upon the average reduction for various reduced number of passes. The buffer distance reduction can be applied when fewer passes are made to the field. For example, when four passes of a ground application are made, as shown in **Table 4-9**, the buffer distance could be reduced by 35%. EPA expects boom lengths (swath widths) to vary; however, the default lengths are considered representative of typical practices. These buffer distance reductions are considered representative of typical spray drift reductions associated with fewer passes than 20 for ground and airblast and 15 for aerial.

Table 4-9. Reduced spray drift distance associated with fewer passes.

Ground Application			Aerial Application			Airblast		
Number of passes	**Range of Percent Reduction**	**Buffer Distance Reduction**	**Number of Passes**	**Range of Percent Reduction**	**Buffer Distance Reduction**	**Number of treated rows**	**Range of Percent Reduction**	**Buffer Distance Reduction**
10	10 to 16	15%	8	8 to 13	10%	10	11 to 17	15%
4	29 to 41	35%	4	20 to 27	20%	4	23 to 50	30%
1	66 to 75	70%	1	52 to 64	55%	1	63 to 83	70%

4.3.8 Windbreaks, Hedgerows, and Forests/Woodlots/Riparian/Shrubland areas

Windbreaks and Hedgerows

Hedgerows and windbreaks are structures adjacent to the treated area that are effective at reducing spray drift transport (downwind of the application). Windbreaks/hedgerows function by reducing windspeed, intercepting spray droplets and ultimately reducing the amount of spray droplets and distance they travel. Windbreak/hedgerow structure (i.e., height, width, density, composition, length, orientation, and continuity) determines the effectiveness of a windbreak. EPA has identified two types of windbreak/hedgerow structures that have different levels of effectiveness and thus different % reductions in distance. EPA assumes a 50% reduction in spray drift to offsite habitat for typical windbreaks/hedgerows (described below). EPA based this reduction on average measured reduction in studies with one row of a windbreak equal in height to the pesticide spray release height (Brown *et al.*, 2004; De Schampheleire *et al.*, 2009; van de Zande *et al.*, 2000). EPA assumes a 75% reduction in spray drift for higher efficacy windbreaks. EPA based this reduction on average measured reduction for a wider windbreak and for windbreaks that are taller than the release height of the pesticide spray (Hancock *et al.*, 2019; Lazzaro *et al.*, 2008; Wolf *et al.*, 2005). This is consistent with international regulatory bodies' recommendations (FOCUS, 2007) and recent pesticide registration decisions (USEPA, 2023c).

The minimum parameters that EPA included in its efficacy evaluation for a basic hedgerow/windbreak measure include:

- Vegetation the full length of the treated crop with leaves visible over the entire length, with no significant gaps
    - windbreak height is equal or greater than the chemical release height, and
    - at least one row of tree/shrubs or 4 ft wide strip of non woody vegetation.
- **Or** an artificial windbreak (*e.g*., a curtain or netting) with the same height and uniformity (no gaps).

The minimum parameters for a high efficiency hedgerow/windbreak measure that EPA included in its efficacy evaluation include:

- Vegetation the full length of the treated crop with leaves visible over the entire length, with no significant gaps
    - windbreak height is **2X** or greater than the chemical release height, and
    - at least **two** rows of tree/shrubs or at least **8 ft** wide strip of non woody vegetation.
- **Or** an artificial windbreak (*e.g*., a curtain or netting) with the same height and uniformity (no gaps).

EPA used available empirical data in the open literature from hedgerow studies to estimate the associated percent reduction in the buffer. No one study represents exactly the same windbreak description, but parts of each study (height or width) support the characteristics of EPA's two windbreak/hedgerow categories discussed above. A discussion of these characteristics and their influence on the efficacy of the windbreaks in each study and how they relate to EPA's windbreak measures is provided here.

The relationship of the release height of a spray as compared to the height of the windbreak is a key factor determining if a windbreak meets the description of a basic or high efficiency windbreaks (**Table 4-10**). Using wind tunnel studies, De Schampheleire *et al.* (2009) found reduction in drift deposition when drift reducing structures are at least equal to the height of the spray nozzles. When a spray was released 50 cm (1.6 ft) lower than the height of the windbreaks, deposition was reduced 65 to 80% over a range of conditions at 6 m (20 ft) downwind from the application area. When nozzles were 25 cm (10 in.) lower than the height of the windbreaks, deposition was reduced 30 to 70%. When nozzles were equal to the height of the windbreaks, deposition was reduced 20 to 50%. These conditions match with a windbreak height equal to or higher than the release height. In this case a 50% reduction is on the higher end of the deposition reduction range for a chemical release of equal height but closer to average when the spray height was around 10 inches lower. Several studies also show reductions in spray drift deposition during full field studies. A 7 to 8 m (22 to 25 ft) tall hedgerows consisting of shrubs resulted in spray drift reduction of 73% to 98% at windspeeds up to 2.5 miles per hour for ground applications (Lazzaro *et al.*, 2008). Hancock *et al.* (2019) studied pesticide deposition to streams and ditches after aerial application and found a deposition to be 65-97% lower at vegetated sites compared with non-vegetated sites. Vegetated sites had a mean vegetation height and width of 6.6 m (22 ft).

Table 4-10. Relationship of spray release height relative to windbreak height.

Spray Height Relative to Windbreak Under Study conditions		Percent reduction in deposition	Citation
Spray and windbreak height approximately equal	equal	20-50%	De Schampheleire et al. 2009
	10 inches lower	30-70%	De Schampheleire et al. 2009
	equal	50%	van de Zande et al. 2000
Spray height lower than windbreak height	18 inches lower	65-80%	De Schampheleire et al. 2009
	>18 inches lower	≥75%	De Schampheleire et al. 2009
	~3ft lower	80-90%	van de Zande et al. 2000
	~10 ft lower	65-97%	Hancock et al. 2019
	>22ft lower	73-98%	Lazzaro et al. 2008

Many types of vegetation have been studied and used as a windbreak. In the previously discussed studies, vegetation such as trees and woody shrubs as well as artificial structures provide reductions in spray drift deposition downwind. Depending upon the type of vegetation the width or number of rows can influence the effectiveness. van de Zande *et al.* (2000) found that a 4 ft (1.25 m) wide strip of *Miscanthus* sp. (elephant grass) that was taller than the chemical release height had greater than 50% reduction in drift. Similarly, Vieira *et al.* (2018) found that a 17 ft (5.3 m) wide strip of corn that was taller than the chemical release height also reduced chemical drift downwind by more than 80%. Hancock *et al.* (2019) and Lazzaro *et al.* (2008) studied wide riparian windbreaks which were significantly higher than the pesticide spray height and reported efficacies as high as 97% and 98% respectively. Based upon these lines of evidence many types of vegetation or artificial screens can be used as an effective windbreak/hedgerow, but they improve with increasing windbreak width.

EPA selected a 50% reduction in the spray drift distance for the basic windbreak/hedgerow because of lower efficiency of release heights that are close to the height of the windbreak (~50% reduction), densities of windbreaks that may be lower (e.g., an establishing windbreak;

25-50% for intermediate foliage) and narrow width windbreaks (50% for ~4 ft). Therefore, when the conditions are met for a basic windbreak, the associated percent reduction in the spray drift buffer distance is 50%.

EPA identified a 75% reduction in distances for windbreaks/hedgerows that are expected to intercept more spray drift than the basic design. EPA considers increased windbreak efficiency when windbreak dimensions are wider with 2 or more rows of trees/shrubs or are 8+ ft in width for windbreaks comprised of herbaceous vegetation. As discussed in the study data, the studies reporting the greatest reductions were wide riparian areas serving as windbreaks. The other studies are less robust and reflect reductions of approximately 75%. Windbreak height is an important factor in efficacy. The available data reports numerical distances to measure release heights and hedgerow height. To relate this measure to any application and height combination a comparison measure best reflects windbreak efficiency. Therefore, a higher efficiency windbreak should be at least 2 times taller than the release height of the pesticide spray. When the conditions are met for a high efficiency windbreak measure, wind directional buffers may be reduced by 75% of the distance.

Forests/Woodlots/Riparian Areas/Shrublands

Based on the data discussed above riparian landscapes or those that would be similar to forested/shrubland/wooded areas indicate reductions in spray deposition greater than 90%. Additionally, AgDRIFT modeling assumes a bare field with no interception, which overestimates off-site spray drift due to interception by trees and shrubs in a riparian/forest/shrubland habitat. Many listed species occur in habitats where spray drift interception is expected (e.g., shrubland, chaparral, forest). When forests, woodlots, shrublands or wooded riparian areas of sufficient depth (>60 feet) and height (2X the release height) are present along the entire downwind side of the application area, EPA identified a 100% reduction in the spray drift distance. This 100% reduction in the spray drift distance could also be applied to the riparian area mitigation for runoff/erosion if that area is located on the downwind side of the application site.

4.3.9 Relative Humidity at Application Site

Relative humidity (RH) is a measure of moisture in the air relative to ambient air temperature. It is generally understood that lower RH increases the evaporation rate of spray droplets (Sezen and Gungor, 2023), thus making large droplets smaller over time and impacting spray drift. EPA used AgDRIFT to simulate spray drift deposition from aerial applications at different levels of RH (20, 40 and 60%; **Figure 4-4**). Ground specific data are not available to evaluate differences in relative humidity (because the empirical trials used in AgDRIFT for ground applications have low RH). Therefore, simulations for aerial are used as a surrogate for ground.

Based on this analysis, EPA identified a 10% buffer reduction for aerial and ground applications where RH is 60% or greater at the time of application. Approximately 10% difference in deposition is observed at the maximum aerial (320 ft) and ground (230 ft) spray distances when going from 40 to 60% RH; however, the decrease is even higher when going from 20% to 60% RH. Large parts of the country are expected to have a RH >60% in the morning but a RH <60% in the afternoon. This means that buffer reduction would be contingent on time of day in these areas and that applicators should plan to conduct their field edge applications in the morning (i.e., the part of day with higher humidity) if they intend to leverage the high humidity buffer reduction. Additional information on EPA's RH analysis is included in **Appendix H**.

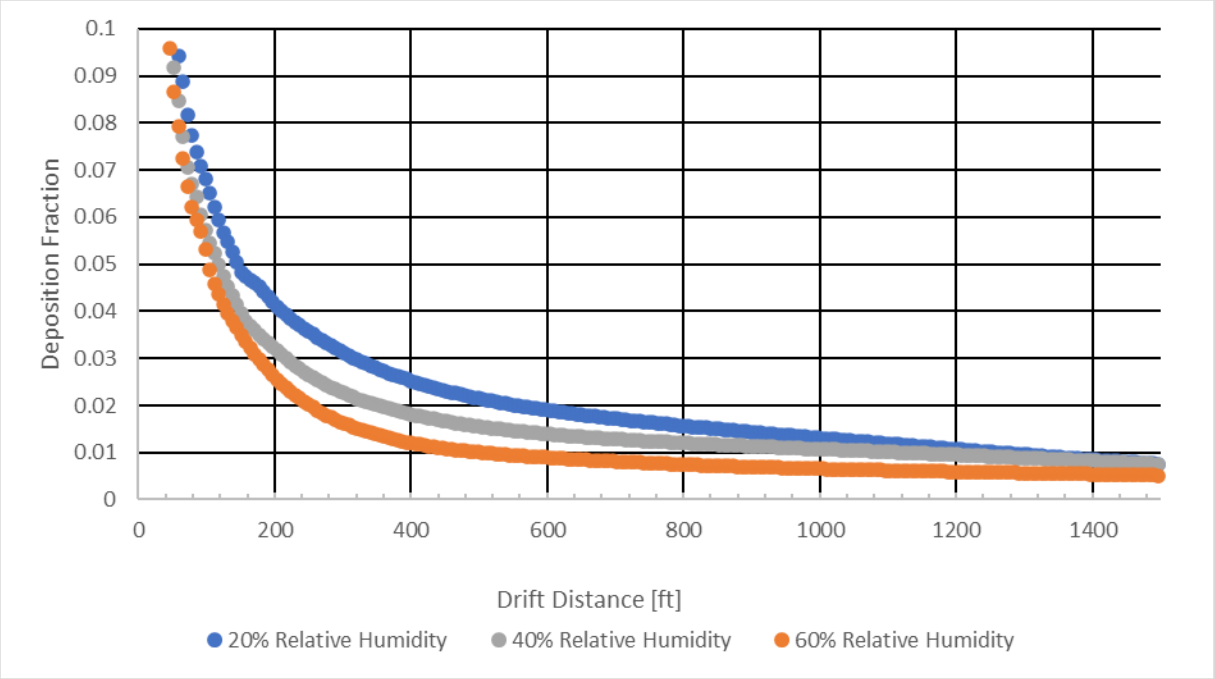

Figure 4-4. Variable relative humidity assumptions with medium droplet size distribution for aerial applications (AgDRIFT® v2.1.1).

4.4 Description of Managed Areas that can be Subtracted from Spray Drift Distances

As described above, EPA relies upon the AgDRIFT® model for ground and aerial spray drift estimations. The models for ground and aerial drift were developed based on several underlying assumptions, including drift depositing onto a bare field, no obstructions to intercept spray droplets that drift off-field, and a prevailing wind direction. In practice, farms may have managed lands in areas adjacent to a pesticide application. While these managed practices may not be intentionally created for the purpose of mitigating pesticides, their composition and size on the landscape could act like a buffer (e.g., roads) or intercept spray drift (which the model does not take into account) and reduce the distance it may travel. Therefore, to the extent that such managed areas are downwind and immediately adjacent to a pesticide application (and they themselves not being treated with the pesticide), EPA has included these areas in what can be considered within the buffer distance. In other words, growers/applicators could subtract managed areas immediately adjacent to treated field from their identified buffer distance. See **Table 4-11** for a list of the downwind managed areas EPA has identified that may be included in spray drift buffers.

Table 4-11. Downwind managed areas that can represent spray drift buffers.

When spray drift buffers are identified as mitigations, the following managed areas can be included in the buffer if they are immediately adjacent/contiguous to the treated field in the downwind direction and people are not present in those areas (including inside closed buildings/structures). If the pesticide product label has a requirement that prohibits or restricts spray drift in any of these specific managed areas, that prohibition/restriction must be followed.

a. Agricultural fields, including untreated portions of the treated field;
b. Roads, paved or gravel surfaces, mowed grassy areas adjacent to field, and areas of bare ground from recent plowing or grading that are contiguous with the treated area;
c. Buildings and their perimeters, silos, or other man-made structures with walls and/or roof;
d. Areas maintained as a mitigation measure for runoff/erosion or drift control, such as vegetative filter strips (VFS), field borders, hedgerows, Conservation Reserve Program lands (CRP)[1], and other mitigation measures identified by EPA on the mitigation menu;
e. Managed wetlands including constructed wetlands on the farm; and
f. On-farm contained irrigation water resources that are not connected to adjacent water bodies, including on-farm irrigation canals and ditches, water conveyances, managed irrigation/runoff retention basins, and tailwater collection ponds.

[1] Growers may need to ensure that pesticide use does not cause degradation of the CRP habitat.

In some cases, areas maintained as a mitigation measure for drift or run-off/erosion control, managed areas, and CRP lands could potentially represent habitat for listed species. There can be significant benefits of these habitats to listed species, with a net gain to the species when considering benefits vs. impacts of pesticides. Not all of these areas represent high quality habitat for listed species (e.g., listed plants are not expected to occur within these areas). In some cases, individuals of a species may be attracted to an area that represents habitat (e.g., insects may be attracted to habitat created for pollinators); however, not enough individuals are expected to be impacted within the portion of the exposed area of the habitat such that there would be an impact on the population that would outweigh the overall benefit provided by creation of the habitat. EPA does not want to disincentivize growers from providing such habitats, which may have considerable benefits to species, their environment, and pesticide use reductions. Therefore, managed areas that include habitat may be part or all of the spray drift buffer.

Figure 4-5 and **Figure 4-6** represent examples of how a spray drift buffer on a label can be reduced where a pesticide product label identifies a 50-foot downwind spray drift buffer. The grower could subtract the 10 foot off-field area downwind where the grower has CRP land and the 20-foot-wide downwind windbreak, leaving only a 20 foot in-field buffer to meet the identified buffer distance (**Figure 4-5**). In contrast, if the off-field downwind areas of the CRP land and windbreak totaled 50 feet or more this would equal the identified spray drift buffer distance (as shown in **Figure 4-6**).

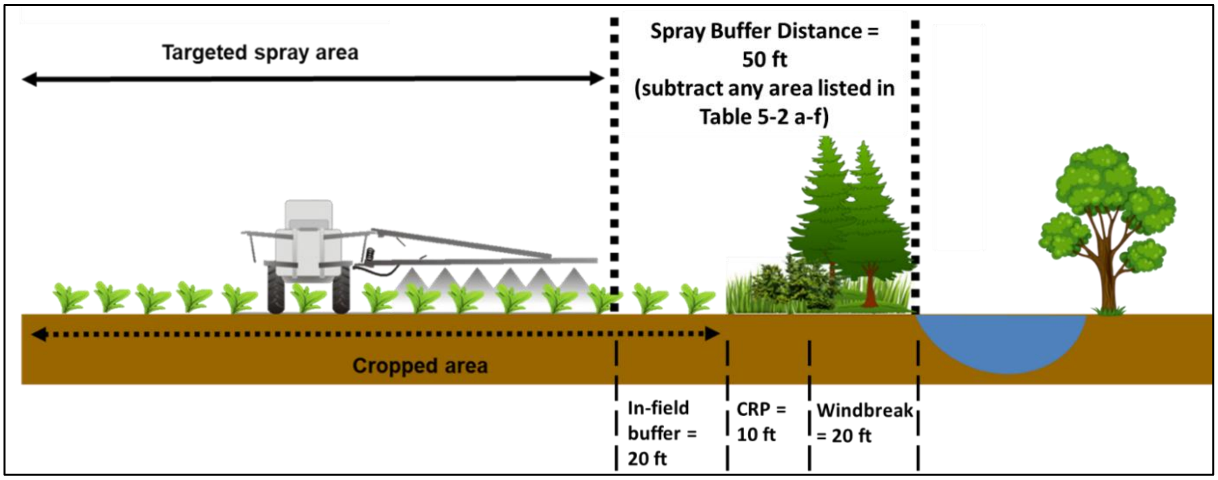

Figure 4-5. Diagram of the field (cropped area) with a downwind spray drift buffer which includes a portion of the cropped area because the adjacent managed areas are less than the identified spray drift buffer distance. [10]

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[10] This figure is based on a diagram from the Pest Management Regulatory Agency of Health Canada (2020), which EPA was permitted to reproduce. The original figure is available at: https://www.canada.ca/en/health-canada/services/consumer-product-safety/pesticides-pest-management/growers-commercial-users/drift-mitigation/protecting-habitats-spray-drift.html. EPA has edited the original figure to provide an example of the areas that can be subtracted from spray drift buffer distances.

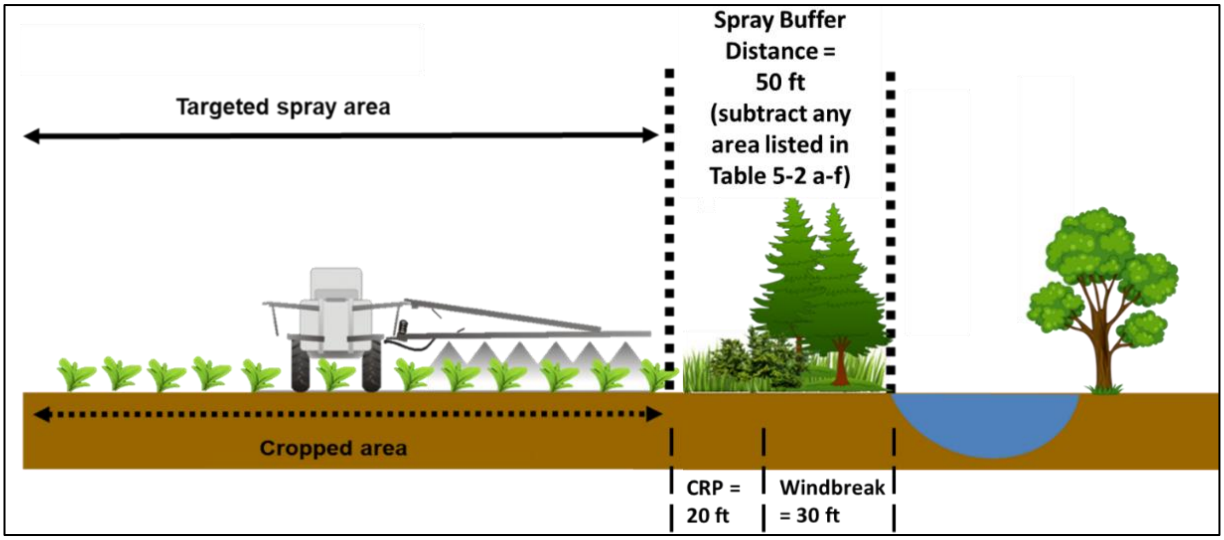

Figure 4-6. Diagram of the field (cropped area) with no cropped area included in the downwind spray drift buffer because adjacent managed areas are equal to the identified spray drift buffer distance.[10]

4.5 Evaluations of Measures Not Included as Mitigation Measures

EPA evaluated several additional measures or weather conditions; however, the Agency is not including them as measures to reduce spray drift distances. The analyses of these measures are discussed below.

4.5.1 Temperature

EPA evaluated whether temperature as an independent factor could be used to reduce the buffer distance. EPA decided that mitigating spray drift based on temperature distinctions is not supported at this time because of 1) the underlying temperature data associated with spray drift modeling are representative of temperatures across the lower 48 states, and 2) EPA's model is not sensitive to temperature when compared to RH sensitivity. More explanation is provided below.

Temperatures in the SDTF data (**Table 4-12**) are an average of 74 degrees Fahrenheit (^{o}F) and are broadly representative of average high temperatures across the lower 48 states during a pre-emergence herbicide usage season (*i.e.,* March to May; **Figure 4-7**). A temperature parameterization change from 60 ^{o}F to 90 ^{o}F, coupled with a relative humidity (RH) of 50%, resulted in an 11 to 16% difference in the deposition of medium-size droplets at 200 and 300 ft, respectively. For comparison, a Tier I aerial parameterization is 86^{o}F and 50% RH. The difference in deposition given a 30^{o} change in the air temperature indicates that temperature (while holding RH constant) is not a sufficiently sensitive parameter in the drift model to consider it as an effective approach for reducing spray drift.

Table 4-12. Range of Temperatures in Ground Boom Trials Conducted in Texas, 1992-1993 (Teske, 2009)

Temperature (°F)	Proportion of Trials within Temperature Range (n=24)
<60	21%
60-70	4%
70-80	25%
80-90	46%
>90	4%

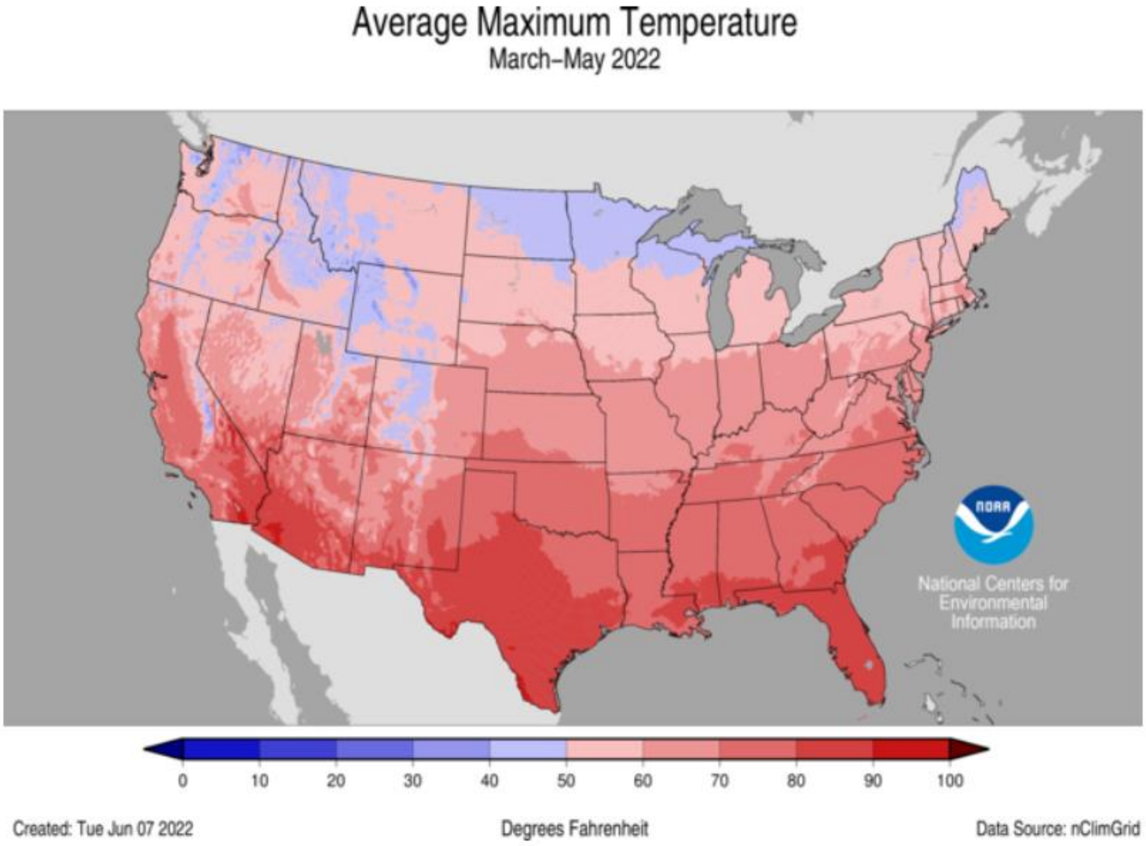

Figure 4-7. Average daily high temperature - March 2022 to May 2022 (NOAA, 2023)

Temperature has indirect impacts on spray drift not captured in modeling. For instance, temperature is a determinant of RH, as RH is a measure of water vapor relative to the temperature of the air (i.e., at the same absolute humidity, air will have a higher RH in cooler temperatures and a lower RH in warmer temperatures). Additionally, temperature inversions (when surface temperatures are cooler than relatively warm air aloft) are atmospheric conditions prone to spray drift and also not directly accounted for in spray drift models (temperature cannot be varied with height in the model). While temperature also has direct impacts on spray drift as indicated in **Table 4-16**, the impact across a broad range of temperatures is small when compared to similarly broad range of RH.

Table 4-13. Aerial deposition differences with temperature for the medium droplet size distribution (AgDRIFT® v2.1.1)

Distance from edge of field (feet)	Deposition Fraction		
	90 °F	74 °F	60 °F
200	0.037	0.034	0.033
300	0.024	0.021	0.020

In summary, temperature does not result in determinative changes to model results. EPA has not identified other current sources of information that support a temperature-based spray drift buffer reduction at this time.

4.5.2 Crop on Field (over the top sprays)

To investigate the impact of on-field crop on reducing offsite spray drift, EPA performed a sensitivity analysis of on-field surface roughness and considered it when evaluating updating its AgDRIFT Tier III modeling. In that evaluation, EPA decided to not change the default parameter for surface roughness (current parameter reflects applications to bare ground), as the model only allows for modeling surface roughness and does not consider canopy density, which, at crop maturity, was shown by Hoffmann *et al.* to result in field deposition comparable to bare ground. Because each crop has different canopy growth, it is difficult to predict at which growing stages this model input parameter value should be when applied to as a default across many different crop types.

In considering it as a mitigation measure, EPA used the AgDISP™ User Manual's recommended ranges, and the AgDRIFT® Tier III was parameterized to account for the presence of crop on the field. For surface roughness, EPA used an average crop value (0.32 ft) instead of the default of bare ground (0.0246 ft). This reduced downwind deposition by 9 to 11% at 100 ft (30 m) offsite and 24% at 300 ft (91 m) offsite. The minimum crop value (0.13 ft) produces similar results to the average value (**Table 4-14**). Nearly equivalent point deposition was estimated at 200 ft (61 m) for bare ground and 175 ft (53 m) for cropped field, resulting in a 25 ft (7.6 m) difference associated with differing field conditions at this distance. Distances at which nearly equivalent point depositions occur increase to nearly 50 ft (15 m) at 300 ft (91 m) from the field edge. While the impact of having crop on the field increases with distance from the pesticide application, the absolute difference in deposition is relatively consistent over distance when comparing bare ground to the minimum crop assumption and decreases with distance when comparing bare ground to the average crop assumption (**Table 4-14**). This reduction is most relevant for off-field distances ≥100 feet, which is greater than many of the identified spray drift buffers for both ground and aerial. As such, EPA did not include it as a spray drift mitigation measure.

Table 4-14. Surface roughness comparison (AgDRIFT® 2.1.1).

Offsite Distance from the Application	Deposition Fraction of Applied Pesticide for a Medium Droplet Size Distribution				
	Bare ground assumption - 0.0246 ft	Minimum crop assumption - 0.13 ft	Average crop assumption - 0.32 ft	Absolute Difference – Bare Ground to Minimum	Absolute Difference – Bare Ground to Average
100 ft	0.0755	0.0709	0.067	0.0046	0.0085
125 ft	0.0574	0.0526	0.0487	0.0048	0.0087
150 ft	0.0475	0.0427	0.0388	0.0048	0.0087
175 ft	0.041	0.0356	0.0326	0.0054	0.0084
200 ft	0.0355	0.0303	0.0279	0.0052	0.0076
225 ft	0.0316	0.0266	**0.0243**	0.005	0.0073
250 ft	0.0282	**0.0234**	0.0213	0.0048	0.0069
275 ft	0.0252	0.0208	0.019	0.0044	0.0062
300 ft	**0.0228**	0.0189	0.0173	0.0039	0.0055

Distances at which depositions are similar in **bold.**

4.6 Exposure Associated with Different Chemigation Methods

During the development of the draft Herbicide Strategy, EPA received differing comments on chemigation with some asserting that it doesn't lead to spray drift and others reporting drift incidents associated with chemigation (Kasner *et al.*, 2021). Chemigation can be split into two general categories: 1) methods that generate negligible off-site exposure (e.g., micro-sprinklers, drip-tape, drip emitters, subsurface or flood), and 2) methods that could have off-site exposure via overspray and potentially drift (e.g., center pivot, overhead systems, traveler systems that have sufficient pressure, end guns). Therefore, EPA considered these two categories of chemigation separately.

Chemigation methods that generate negligible off-site exposure operate at low pressures (approximately <20 psi), have sprinkler heads as low or lower than ground boom release heights (<5 ft) or do not release water in a spray (*e.g.* flood, micro sprinklers, soaker hose, drip tape, drip emitters, subsurface). Since these methods do not generate drift, potential population-level impacts are unlikely (**Section 4.8**).

Chemigation methods that could potentially generate off-site exposure including overspray and/or drift are primarily comprised of overhead sprinkler irrigation systems that are of sufficient pressure (>20 psi) and/or configuration (e.g., center pivot, traveler sprayers, or impact sprinkler systems with higher pressure and/or end-guns). These systems have sprinkler heads along a boom that can have release heights near the crop canopy or ≥5 ft above the canopy. The primary purpose of these systems is to distribute water for irrigation. While it is anticipated that these irrigation systems with an end gun or impact sprinklers and/or those with higher pressure or release heights will not be commonly used to apply pesticides with the irrigation water, they may be used in certain situations (USDA, personal communication). The end gun can distribute water and, if used, pesticides far from the end of the boom (~200 ft) by shooting a spray of water and pesticides up into the air in an arch. Data evaluated by EPA and SDTF suggest that under certain conditions the end gun use and spray release heights in excess of 5 ft (potentially higher pressure) can result in deposition off of the irrigated/treated area equivalent to or exceeding drift generated from ground sprays.

EPA does not currently have a model to estimate spray drift deposition from overhead chemigation. The SDTF produced a high quality chemigation spray drift dataset; however, the dataset was not large enough to support the development of deposition curves for use in EPA's modeling (Johnson, 1995b). Therefore, EPA compared these data to EPA's modeling for ground sprays. As shown **Table 4-15**, the SDTF studies were conducted under several treatments. Studies were conducted under two general spray nozzles characterized as either high pressure (70 psi) or low pressure (20 psi) conditions, two different release heights (12 or 5 feet) and either used an end-gun sprayer or not.

The offsite deposition from overhead chemigation can be broadly categorized as intended overspray and likely unintentional spray drift. Intended overspray is apparent in offsite deposition data when average deposition at is at least an order of magnitude greater than comparable ground deposition data for high pressure (70 psi) and high release height (12 ft) conditions, particularly when an end-gun is used, or within two orders of magnitude -than comparable data for low pressure (20 psi) and low release height (5 ft) conditions (**Table 4-15**). As compared to AgDRIFT estimates for ground sprays (Fine to Medium/Coarse – High Boom), the studies that used end-guns (01 and 03) have 9X higher deposition 25 ft from field edge and approximately 2X higher deposition 50 ft from field edge. Therefore, when an end gun is used, the offsite deposition at 25 ft meets the conditions for overspray for both high pressure/release height and low pressure/release height conditions. This is indicative that the end-gun impact sprinklers represented in available data have an overspray distance of 25 to 50 ft. At 50 ft, the deposition for the end-gun studies is similar to the AgDRIFT ground spray modeled estimates.

Almost all of the studies that did not include end-guns had approximately an order of magnitude less deposition when compared to the AgDRIFT model estimates for ground sprays at all distances. The exceptions were the high-pressure tests with windspeeds greater than 4.5 mph. One high-pressure test was conducted with windspeeds of 11 mph, and deposition was greater than ground sprays out to ~100 ft, but within an order of magnitude. Given the potential distance these systems can spray water, discerning overspray with potentially driftable fines (or spray drift) at further distances may not always be possible. With regard to impacts of windspeed on off-site exposure via chemigations, overall, average windspeed for ground sprayer trials (10 mph) is like the high-pressure (no end gun) trial (11 mph), which is similar to typical spray drift mitigations of maximum wind speeds of either 10 or 15 mph.

In summary, these data suggest overhead chemigation uses with sufficient pressure (>20 psi) **and** release heights (>5 ft) as well as impact sprinklers may result in overspray (i.e., direct application off of the target area) and under some conditions may result in spray drift equivalent to ground sprays. For ground, airblast and aerial spray applications, spray drift buffers are a mitigation approach that can be accommodated by adjusting the treatment area.

However, because of the static design of irrigation systems, buffers are not anticipated to be a feasible option to mitigate the off-site transport. EPA has identified several mitigation measures related to both the overspray and spray drift potential of the chemigation system to reduce the potential for population-level impacts identified for a chemical (**Section 4.7**).

Table 4-15. Downwind deposition on horizontal alpha-cellulose as percent of application rate compared to AgDRIFT outputs.

Distance offsite (ft)	AgDRIFT Model Output	Chemigation Treatment Replicates											
		End Gun				No End Gun							
	90th F-M/C High Boom	HP -9.1 mph	HP – 4.8 mph	LP – 8.7 mph	LP – 6.0 mph	HP – 2.4 mph	HP – 11.2 mph	LP – 8.6 mph	LP – 2.9 mph	HP – 4.5 mph	HP – 5.0 mph	LP – 6.2 mph	LP – 5.6 mph
		01-1	01-2	03-1	03-2	02-1	02-2	04-1	04-2	05-1	05-2	06-1	06-2
25	2.10	**39.1**	**8.33**	**31.5**	**17.9**	0.201	**3.39**	0.088	0.032	0.564	1.32	0.141	0.135
50	1.20	**4.83**	**1.43**	**2.61**	1.08	0.082	**6.03**	0.09	0.035	0.154	0.956	0.065	0.046
75	0.87	**2.07**	0.77	**0.95**	0.48	0.088	**4.23**	0.056	0.012	0.344	0.557	0.033	0.028
100	0.70	**1.25**	0.32	0.6	0.32	0.039	**2.24**	0.036	0.007	0.058	0.297	0.026	0.026
150	0.51	**0.64**	0.054	0.21	0.084	0.033	**0.65**	0.021	0.004	0.017	0.065	0.01	0.013
200	0.40	**0.47**	0.027	0.079	0.04	0.015	0.3	0.015	0.003	0.003	0.032	0.005	0.006
300	0.28	0.093	0.014	0.034	0.01	0.010	0.08	0.006	0.001	0.007	0.01	0.005	0.005
449	0.19	0.071	0.008	0.081	0.006	0.003	0.079	0.006	0.001	<0.001	0.003	0.002	0.003
600	0.14	0.018	0.003	0.001	0.001	0.019	0.002	0.003	<0.001	0.002	0.003	0.002	0.002

Source: MRID 43845901

HP – High pressure (70 PSI): applies to impact sprinklers with a 12 ft release height and end guns.

LP – Low pressure (20 PSI): applies to spinner nozzles with a 5 ft release height.

Shaded cells indicate deposition in the chemigation treatment data was within an order of magnitude (orange) or two orders of magnitude (yellow) of deposition from comparable modeled deposition ground spray. Bolded values exceed the modeled ground spray estimate.

4.7 Mitigation Measures for Overhead Chemigation and Impact Sprinklers

As discussed in Section 4.6, potential mitigation for with overhead and impact sprinkler chemigation systems were identified (**Table 4-16).**

Mitigations measures for overhead chemigation

Based upon the available data (**Table 4-15**) the use of end guns has a greater potential to result in overspray and significant exposure within 50 ft of the field. To reduce this, one mitigation identified is to turn off the end gun for chemicals that have the potential for population-level impacts. Additionally, for some chemicals, the reduction of spray drift resulting from chemigation may be identified. The available data for low pressure (20 psi) and low release height (5ft; **Table 4-15**) indicate that deposition is less than that of estimates using AgDRIFT® for ground sprays. Therefore, reducing the pressure of the system <20 psi and dropping the release height will reduce the potential for population level impacts. Increasing the length of drop nozzles is frequently done with chemigation systems to effectively reduce the release height within <5 ft of the crop canopy or soil surface.

Mitigations measures for Overhead and Impact Sprinkler Chemigation Systems

Impact sprinklers, similar to end guns, can throw water in excess of 200 ft. Similar to end guns these systems have a higher likelihood of overspray and drift. Since impact sprinklers may comprise the entire chemigation system, turning them off as could be done for an overhead end-gun is not a reasonable mitigation measure. These sprinklers can have adjustments to the pressure and the throw angle, as well as the position of the sprinkler within the field. EPA’s mitigation approach for impact sprinkler systems when potential population level impacts are identified is to adjust the spray pattern from the impact sprinkler to limit the throw distance to the edge of the field.

Lastly the use of windbreaks (as described in **Section 4.3.8**) would be effective at reducing spray drift from both overhead chemigation and impact sprinklers, however control of overspray is still identified.

Table 4-16. Mitigation measures identified when making pesticide applications via overhead and impact sprinkler chemigation systems.

Overhead Chemigation [1]	Non-End Gun Impact Sprinklers Mitigation Measures
No End Gun	Limit throw distance to edge of field (treated area) by either: Reduce pressure and/or Reduce throw angle
Use low pressure (≤20 psi)	
Reduce spray release height ≤5 feet	
Downwind windbreak/hedgerow/riparian/forest/shrubland/ woodlots	Downwind windbreak/hedgerow/riparian/forest/shrubland/ woodlots

[1] Refers to center pivot, overhead systems, traveler systems that have sufficient pressure/end guns

4.8 Application Methods Where EPA did not Identify Spray Drift Mitigations because Exposure to Non-Target Species is Unlikely

Previous sections in this document discussed ground, aerial, airblast, and overhead chemigation applications of pesticides. There are additional application approaches where the potential for population-level impacts is unlikely for spray drift. These application methods include the following:

- **Chemigation methods, including: micro-sprinklers, drip-tape, drip emitters, subsurface or flood**. These are methods that generate negligible drift as they operate at low pressures (approximately <60 psi), have sprinkler heads low to the ground (<5 ft) or do not release water in a spray. Applications made under non-permeable plastic surfaces would also expect to be kept on the field.
- **In-furrow sprays when nozzle height is ≤8 inches above soil surface**. This application method results in negligible drift because the spray release height of the pesticide is practically at the soil surface, the spray target is a furrow (opening in the soil surface caused by mechanical separation), and the nozzle position is below the mechanical equipment (tractor and plow/planter), thereby reducing any drift that may occur beneath the equipment.
- **Tree trunk drench, tree trunk paint, tree injection.** These application methods of pesticides do not generate spray drift as the chemical is directly applied to the tree trunk with a brush or as a poured liquid, painted onto the surface or injected into the tree.
- **Soil injection** application of pesticides does not generate spray drift as the chemical is directly injected below the soil surface.
- **Solid formulations that are used as a solid:** This refers to planting of treated seed (pesticide coated) or propagule, granule formulation. Solid formulations that are applied using a spray solution (e.g., wettable dispersible granules) do not fit in this category.
- **Less than 1/10 acre (<4356 square feet) treated and spot treatment (<1000 sq ft treated)**. This provision applies to applications that total 1/10 of an acre or less to a field or a spot treatment of <1000 sq ft. These small footprint applications are often made using backpack sprayers, hand-held sprayers and other small equipment, but under some conditions larger smart technology application equipment may be used. Spray-drift that could result from these small-treated areas would be limited, and as discussed above this would result in lower spray drift exposure than broadcast ground boom equipment. Therefore, treatments that are less than 0.1 total acres or spot treatments <1000 sq ft are unlikely to result in pesticide concentrations from spray drift that would lead to population-level impacts.

5 Runoff/Erosion Mitigation Measures

Where EPA determines a potential for population-level impacts associated with runoff/erosion to be low, medium, or high, EPA would also identify the level of mitigation to reduce exposures so that those impacts are no longer likely. The level of runoff and erosion mitigations on the label is expressed as points, up to nine. Fewer points are identified for low solubility pesticides as detailed in **Section 5.1**. This accounts for the lower mobility of soil particles relative to water and increased effectiveness of mitigation practices in reducing soil in runoff. A mitigation measure (or combination of mitigation measures) that achieves three points is equivalent to approximately an order of magnitude reduction in off-field exposure concentrations of pesticides transported via runoff or erosion. This order of magnitude reduction is equivalent to the reduction needed to drop from one category of potential for population-level impacts to a lower category (e.g., from high to medium).

This section summarizes the runoff/erosion mitigation measures that EPA identified and their associated effectiveness that EPA would use to inform mitigations for listed species in future pesticide registration and registration review decisions. As described in **Section 5.1**, EPA determined a single efficacy score for each mitigation measure based on the totality of information available for that measure, including the mobility of the pesticide. In general, a mitigation with a low, medium, or high efficacy achieves an average of 10-30%, 30-60%, and ≥60% reduction, respectively. When percent reductions were reported with a wide range (*e.g.,* 5 – 95%), EPA generally adjusted the efficacy to account for the uncertainty in the percent reductions associated with this variability. Deviations from this approach are described in individual sections on mitigation measures.

EPA categorized these runoff/erosion mitigation measures as follows:

- **Application Parameters (Section 5.2)** that users may elect to employ to reduce potential pesticide runoff and erosion (i.e., reduced annual application rate, reduction in proportion of field treated, and soil incorporation).
- **Field Characteristics (Section 5.3)** are characteristics of the field that are likely to indicate the field will have less runoff and erosion than other fields and thus need fewer mitigation measures to reduce offsite transport. For example, fields with a low slope likely have less runoff. Similarly, permeable sandy soils have less runoff than high clay content soils. These factors also play a role in the general vulnerability of pesticide runoff across different geographies.
- **In-Field Mitigation Measures (Section 5.4)** that users may elect to employ to reduce potential pesticide runoff and erosion are those that involve the management of the field. For example, management of irrigation water, cover crops, or reduced tillage are in-field management mitigation measures. Some measures may occur on the field and also adjacent to the field, so they are included in both categories (e.g., VFS).
- **Adjacent to the Field Mitigation Measures (Section 5.5)** are those that occur next to the field and down-gradient from where the pesticide application occurs and between

the treated field and species' habitat, including examples such as a grassed waterway, VFS, or wetlands.

- **Systems that Capture Runoff and Discharge (Section5.6)** are those that capture, collect, and discharge runoff through discrete conveyances. These include water retention systems such as ponds and sediment basins and tile drainage systems.
- **Other Mitigation Measures (Section 5.6.4)** are those that may be considered but that do not fit into the categories above, employing on-field and adjacent to the field mitigations.
- **Mitigation Measures not Included (Section 5.85.8)** are those mitigation measures that EPA has considered but is unable to include as a mitigation measure at this time due to a lack of efficacy data.

Section 5 also discusses the following:

- **Consideration of the Soil/Water Partitioning of a Pesticide (5.1)**: how EPA incorporated this pesticide property into their review of a mitigation measure's effectiveness.
- **Pesticide Runoff Vulnerability (Section 5.95.9)**: an analysis of pesticide runoff vulnerability across the lower 48 states that may influence the amount of runoff/erosion mitigation for a particular site.
- **Areas 1000 ft Down-Gradient from Application Areas (Section 5.105.10)**: areas where population-level impacts from off-site exposure to runoff/erosion from pesticide applications are unlikely.
- **Conservation Program and Runoff/Erosion Specialist/Mitigation Tracking (Section 5.11):** recognition that growers/applicators that work with a runoff/erosion specialist or participate in a conservation program would likely achieve higher than average mitigation measure efficacy and benefits of mitigation tracking.

Additionally, EPA has identified several mitigation measures and application methods that would make the potential for population-level impacts to listed species resulting from pesticide exposure in surface water runoff unlikely. These include:

- **Systems with Permanent Berms (Section 5.6.3.1)**
- **Tailwater Return Systems (Section 5.6.3.2)**
- **Subsurface Tile-drains, *with* Controlled Drainage Structures (Section 5.6.3.3)**
- **Less than 1/10 Acre Treated or Spot Treatment (<1000 sq ft) (Section 5.75.7)**
- **Soil Injection (Section 5.75.7)**
- **Tree Injection (Section 5.75.7)**
- **Chemigation applied to the subsurface and under non-permeable plastic mulch (Section 5.75.75.7)**

Table 5-1 identifies the mitigations that EPA has identified to date to reduce offsite transport of pesticides in surface water runoff and soil erosion to protect non-target species, including listed species, and their associated efficacy (low, medium, and high). Detailed descriptions of each measure and the evidence supporting the efficacy are included in **Sections 5.2** through **5.6.4.**

Within these categories, EPA grouped mitigation measures that are similar in practice and efficacy together. For example, since alley cropping, strip cropping, and inter-row vegetative filter strips (VFS) all have inter-row VFS, EPA included all of them in a mitigation measure titled VFS (In-Field). This simplifies the list of mitigation measures and provides a bridge to common terminology.

Table 5-1. Runoff/erosion mitigation measures and associated efficacy at reducing exposure.

Mitigation Measure Title[1]	Measures Included in Mitigation Category[1,2]	Efficacy
Application Parameters		
Reduction in Pesticide Application Rate	Any application 10% to <30% less than the maximum labeled annual application rate	Low
	Any application 30% to <60% less than the maximum labeled annual application rate	Medium
	Any application ≥60% less than the maximum labeled annual application rate	High
Reduction in Proportion of Field Treated	10 to <30% of Field Area treated (Banded application, partial treatment, precision sprayers)	Low
	30 to <60% of Field Area treated (Banded application, partial treatment, precision sprayers)	Medium
	≥60% of Field Area treated (Banded application, partial treatment, precision sprayers)	High
Soil Incorporation	Watering-in or mechanical incorporation distributing pesticide to specified depth	Low
Field Characteristics[3]		
Field with Slope ≤ 3%	Fields having a slope of 0-3%	Medium
Predominantly Sandy Soils[4]	Fields with sand, loamy sand, or sandy loam soil without a restrictive layer that impedes the movement of water through the soil	Medium
In-Field Mitigation Measures[3]		
Conservation Tillage	Reduced tillage, mulch tillage, strip till, ridge tillage	Medium
	No-till	High
Reservoir Tillage	Reservoir tillage, furrow diking, basin tillage	High
Contour Farming	Contour farming, contour tillage, contour orchard and perennial crops	Medium
Vegetative Strips – In-Field	Inter-row vegetated strips, strip cropping, alley cropping, prairie strips, contour buffer strips, contour strip cropping, prairie strip, alley cropping, vegetative barrier (occuring in a contoured field)	Medium
Terrace Farming	Terrace farming, terracing, field terracing	Medium
Cover Crop/Continuous	Cover crop, double cropping, relay cropping	Low (Tillage used)

Mitigation Measure Title[1]	**Measures Included in Mitigation Category[1,2]**	**Efficacy**
Ground Cover		Medium (No tillage, short term)
		High (No tillage, long term)
Irrigation Management	Use of soil moisture sensors/evapotranspiration meters with center pivots & sprinklers; above ground drip tape, drip emitters; micro-sprinklers	Medium (General irrigation management)
	Below tarp irrigation, below ground drip tape; dry farming, non-irrigated lands	High (Subsurface irrigation; No Irrigation)
Mulching with Natural and Artificial Materials	Mulching with artificial materials (*i.e.*, landscape fabrics, synthetic mulches)	Low
	Mulching with natural materials	High
Erosion Barriers	Wattles Silt Fences	Medium
Adjacent to Field Mitigations[5]		
Grassed Waterway	Grassed waterway	Medium
Vegetative Filter Strips (VFS) – Adjacent to the Field	Vegetative barrier, field border 20 to <30 ft	Low
	Vegetative barrier, field border 30 to <60 ft	Medium
	Vegetative barrier, field border >60 ft	High
Vegetated Ditch	Vegetated drainage ditch	Low
Riparian Area	Riparian forest buffer, riparian herbaceous cover 20 to <30 ft	Low
	Riparian forest buffer, riparian herbaceous cover 30 to <60 ft	Medium
	Riparian forest buffer, riparian herbaceous cover >60 ft	High
Constructed and Natural Wetlands	Constructed wetlands, artificial wetlands, restoration/enhancement/creation of natural wetlands	High
Terrestrial Habitat Landscape Improvement	Terrestrial landscape/habitat improvement 20 to <30 ft	Low
	Terrestrial landscape/ habitat improvement 30 to <60 ft	Medium
	Terrestrial landscape/ habitat improvement >60 ft	High
Filtering Devices with Activated Carbon or Compost Amendments	Filters, sleeves, socks, or filtration units containing activated carbon	High
	Filters, sleeves, socks containing compost	Low
Systems that Capture Runoff and have Controlled Discharges		
Water Retention Systems	Retention pond, sediment basins, catch basins, sediment traps	Medium
Subsurface Drainages and Tile Drainage Installed *without* Controlled Drainage Structure	Subsurface tile drains, tile drains	Low

Mitigation Measure Title[1]	Measures Included in Mitigation Category[1,2]	Efficacy
Other Mitigation Measures[6]		
Mitigation measures from multiple categories (*i.e.*, in-field, adjacent to the field, or water retention systems) are utilized.[6]	See measures in categories above.	Low

[1] EPA's mitigation menu and measure descriptions specific to pesticides are available in the following websites: https://www.epa.gov/pesticides/mitigation-menu and https://www.epa.gov/pesticides/menu-measure-descriptions. If the state has a more restrictive requirement, that may be followed instead. Not all measures are applicable to all fields and crops.

[2] Only one of the measures that qualify from a 'mitigation menu item' can be used. For example, a user could get mitigation points for cover cropping or double cropping but not both.

[3] Multiple field characteristics may apply to an individual field.

[4] Soil texture is as defined by USDA's soil classification system. See USDA's Web Soil Survey tool to determine soil texture: https://websoilsurvey.nrcs.usda.gov/app/.

[5] Adjacent to the field mitigations should be located downgradient from a treated field to effectively reduce pesticide exposure in runoff and erosion.

[6] For example, if a cover cropping and adjacent to the field VFS are both utilized, the efficacy of the mitigation measures in combination may be increased.

5.1 Consideration of the Soil/Water Partitioning of a Pesticide

While a multitude of factors determine the fate and transport of a pesticide in the environment, one fundamental physio-chemical property is the organic-carbon normalized solid-water distribution coefficient, otherwise known as the K_{oc}. This property describes whether a chemical tends to adsorb to soil particles or remain in water (USEPA, 2006). Chemicals with a higher K_{oc} tend to adsorb to soil particles and are considered slightly mobile to immobile, while chemicals with lower K_{oc} tend to partition to water and are considered moderately mobile to highly mobile (USEPA, 2006).

Several of the runoff/erosion mitigation measures listed in the following sections function by either capturing soil from runoff or by reducing soil erosion. As such, these mitigations also reduce the amount of soil-sorbed pesticides in runoff. Because of this relationship, EPA considered information on the effectiveness of a mitigation measure at either removing pesticides or soil from runoff or reducing soil erosion on the field. For empirical studies that focused on soil removal or reducing soil erosion from a field, EPA was reasonably able to infer that soil-sorbed pesticides were also removed and with similar or greater efficacy.

As discussed in the individual sections for several of these mitigation measures, these systems are inherently more efficient at removing higher K_{oc} pesticides, which tend to sorb to soils. Examples of this phenomena can be seen in the literature for various mitigation measures, including vegetative filter strips, sedimentation basins, and cover crops/mulching. Across these three examples, mitigation measures were found to be 20-30% more efficacious for sediment prone pesticides than runoff prone pesticides. Details on the differences in efficacies for each of these measures for runoff and erosion is discussed within their respective subsections.

When available data or modeling results indicate a difference between efficacy for runoff prone vs. erosion prone chemicals, EPA selected the efficacy based on runoff prone chemicals, to ensure they accounted for the limited removal of runoff-prone pesticides. When the difference in efficacy for runoff prone vs. erosion prone chemicals is not discussed for a particular mitigation measure, it is due to a lack of available data. In these instances, EPA categorized an efficacy based on the information that was available.

5.2 Mitigation Measures: Application Parameters

5.2.1 Reduction in Pesticide Application Rate

Pesticide labels generally specify a maximum annual application rate for that particular pesticide. As such, that is the value that EPA uses for determining potential for population-level impacts. However, pesticide applicators may not need to utilize the entire annual maximum application rate to achieve their pest control and crop management goals while still maintaining its pesticidal efficacy. For example, when insect pest pressures are not high, the lower end of a range of insecticide application rates may be utilized by a grower/applicator.

Because the potential for population-level impacts is directly related to the quantity of pesticides applied, reducing that quantity similarly reduces any identified potential for impacts. The reduction in potential for a population-level impact is expected to be proportional to the application rate reduction, with the percent reduction calculated as the total annual applied rate (lbs/a.i.) divided by the maximum total annual application rate on the label (lbs/a.i.)

On a site-specific basis, users may be able to reduce the total number of applications within a year or the single application rate. In both cases the amount of pesticide being applied to a field is reduced, resulting in less offsite pesticide movement. EPA expects any reduction of the annual application rate to result in a proportional reduction in pesticide exposure in runoff/erosion.

As discussed above, in general, a mitigation with a low, medium, or high efficacy achieves an average of 10-30%, 30-60%, and ≥60% reduction, respectively. The proportional reduction in application rate is linear with the reduction in EECs (e.g., 50% reduction in application rate is equivalent to a 50% reduction in EECs). Therefore, the efficacy of application rate reductions is categorized as low, medium or high, depending upon the level of rate reduction reached.

Table 5-2. Pesticide application rate efficacy summary

Mitigation	Measures Included in this Category	Efficacy	Percent Reduction Reported
Less than maximum annual application rate on label	Applying less than the maximum times allowed on the label. Reducing the single maximum application rate but no lower than the minimum single rate indicated on the label.	Low, Medium or High Proportional to Reduction	Proportional to Reduction

5.2.2 Reduction in the Proportion of Field Treated

When determining the potential for population-level impacts, EPA assumes the entire field is treated. EPA makes this assumption because it is a common practice, consistent with typical labeling, simplifies the assessment process, and enables a more simplified direct comparison across uses and geographies. If less than an entire field is treated, then potential exposure to off field habitats is lower than EPA's estimates because there is less mass of pesticide available to leave the field. Users may be able to treat a portion of the field by employing various application methods such as spot treatments (see **Section 5.7**), in-field border area treatments, banded applications, and precision spraying equipment. For example, technologies that can scout for weeds in advance of pesticide application or equipment that applies herbicides only where weeds are present could reduce the portion of the field treated and therefore, the amount of pesticide applied.

When an applicator makes a partial treatment of the field, a proportional reduction in the pesticide mass per acre is achieved (e.g., a 50% reduction in the treated area is equivalent to 50% reduction in pesticide mass and 50% reduction in pesticide concentrations in runoff). EPA can model changes in the EECs when less of a field is treated. Results of modeling exercises using EPA's PWC demonstrate that the reduction in EECs following a partial area treated is equivalent to reducing the application rate for a field with 100% treated at the same percentage (see **Section 5.2.1)**. However, this reduction in exposure only accounts for the reduction in the amount of pesticide applied and available to enter a water body. It does not account for landscape features of the untreated portion of the field that can play an important role in the movement of water and sediment in a similar way as several in-field mitigation measures in **Table 5-1** (e.g., in-field vegetative filter strips, contour farming, alley cropping). These in-field mitigation measures generally have a medium efficacy (see **Table 5-1**). EPA also has greater confidence in the extent of exposure reduction that occurs when less mass is available for runoff to begin with.

Considering the field characteristics of the untreated area and the improved sorption, dilution, and interception of pesticides provided by this untreated area, the amount of mitigation points for each category of efficacy based on reduced EECs alone associated with partial field treatment is increased by an additional 1 point. Therefore, in situations where 10 to 30% of the field it untreated, an applicator would obtain 2 points. When 30 to less than 60% of the field is untreated, an applicator would obtain 3 points. If greater than 60% of the field is untreated, the applicator would obtain 4 points. General features of agricultural fields are not necessarily designed to reduce runoff in the same way that the in-field mitigation measures are (which typically are scored as medium efficacy; **Table 5-1**). Therefore, assigning more than one additional mitigation point to account for the field characteristics of the untreated area was not warranted.

Table 5-3. Partial application efficacy summary.

Mitigation	Measures Included in this Category	Efficacy	Percent Reduction Reported
Proportional reduction in the field treated.	Banded application, partial treatment, precision sprayers	Medium, High, or >High Proportional to Reduction	Proportional to Reduction and Consider Field Characteristics

5.2.3 Soil Incorporation

The benefits of incorporating pesticides into the soil at the time of application for reducing the amount of pesticide in runoff and erosion events has been recognized for decades (Wauchope, 1978), and was included in early EPA regulatory models like GENeric Estimated Environmental Concentration (GENEEC) model, where estimated environmental concentration (EEC) reductions were proportional to the incorporation depth . Soil incorporation can reduce the susceptibility of pesticides to runoff/erosion (Young and Fry, 2019) with greater depths being less accessible, resulting in less mass of the pesticide in runoff/erosion. The soil depth that is accessible to runoff/erosion generally ranges from 1 to 3 cm (about 0.5 to 1.5 inches) with pesticides below that being essentially unavailable to surface transport (Ahuja, 1986; Steenhuis and Walter, 1980; Young and Fry, 2019). Because runoff/erosion more readily extracts pesticides located closer to the surface than pesticides at greater depth, application methods that incorporate the pesticide deeper into the soil (e.g., watering-in or by mechanical means) would reduce the mass of the pesticide in runoff/erosion. From a purely modeling standpoint using the PWC, incorporation of pesticide upon application to 1 inch (2.5 cm) results in a 20% reduction in runoff uptake of pesticide compared to unincorporated assumption, therefore EPA categorized the efficacy as low (**Table 5-4**).

Table 5-4. Soil incorporation efficacy summary

Mitigation	Measures Included in this Category	Efficacy	Percent Reduction Reported
Soil Incorporation	Water-in or mechanically incorporate to distribute pesticide to at least 1 inch depth	Low	Average 20% (EPA Modeling)

5.3 Mitigation Measures: Field Characteristics

The characteristics of the field onto which a pesticide is applied influence the potential for offsite transport via runoff/erosion. The main factors affecting offsite transport of pesticides include soil texture and structure, permeability of subsoil, depth to the groundwater table, slope, and weather (Reichenberger *et al.*, 2007). While these factors are currently considered in EPA's standard modeling for risk assessments and in its assessments of potential population-level impacts to listed species at the HUC-02 watershed level, they are not spatially explicit exposure estimates for a particular field but are high-end estimates for a broad region[11] or subregion, which may overestimate EECs for fields that are less likely to generate runoff and erosion.

Therefore, to account for site-specific field characteristics for which EPA would have over-estimated the potential for population-level impacts, EPA identified site specific conditions where that modeling might overestimate EECs and provides EPA's classification for mitigation points for these site-specific conditions.

5.3.1 Fields with Less than a 3% Slope

Slope of a field can influence runoff and soil erosion and the associated offsite transport of pesticides. Runoff and erosion increase with increasing field slope (Neal, 1938), and this relationship has been confirmed in other studies (El Kateb *et al.*, 2013). Slope is a consideration in the calculations of runoff/erosion EECs, as the PWC model incorporates a variant of the Universal Soil Loss Equation (Wischmeier and Smith, 1978), which is the standard for erosion modeling and accounts for slope. EPA's PWC model developers recently released selected high-end runoff and erosion scenarios inputs for slopes in the PWC for conservative representation of areas with higher-than-average erosion. Because the scenarios produce higher than average runoff and erosion, actual fields with slopes that are lower than these PWC scenario values should produce less erosion.

EPA recently developed PWC scenarios (released in April-May 2023[12]) that represent are as vulnerable to pesticide transport by runoff and erosion. These highly vulnerable scenarios were chosen by ranking all the possible agricultural areas by their ability to transport pesticide offsite, and choosing the ones that represent roughly the 90th percent most vulnerable. Even

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[11] Watersheds are delineated by United States Geological Survey (USGS) using a nationwide system based on surface hydrologic features. This system divides the country into 21 regions (2-digit), 222 subregions (4-digit), 370 basins (6-digit), 2,270 subbasins (8-digit), about 20,000 watersheds (10-digit), and about 100,000 sub-watersheds (12-digit). A hierarchical hydrologic unit code (HUC) consisting of 2 additional digits for each level in the hydrologic unit system is used to identify any hydrologic area (see Federal Standards and Procedures for the National Watershed Boundary Dataset, 4th ed. 2013). A complete list of Hydrologic Unit codes, descriptions, names, and drainage areas can be found in the USGS Water-Supply Paper 2294, entitled "Hydrologic Unit Maps" (https://nas.er.usgs.gov/hucs.aspx).

[12] PWC scenarios are available at: https://www.epa.gov/pesticide-science-and-assessing-pesticide-risks/models-pesticide-risk-assessment#aquatic.

though they are highly vulnerable to pesticide transport, the scenarios generally have low slopes, with 70% of scenarios having slopes of 3% or less and about 50% of the scenarios having slopes of 1% or less, but some scenarios have slopes as high as 48%. The higher-sloped scenarios (which include slopes up to 48%) likely drive risk assessments, especially for low mobility (high K_{OC}) chemicals, meaning EPA's identification of the potential for population-level impacts could be driven by specific geographic areas represented by slopes exceeding 3%. In these cases, EPA would likely overpredict the potential for exposure to runoff for fields with slopes below 3%.

EPA recognizes that many of the erosion and runoff mitigation measures in **Table 5-1** (e.g., contour farming, terracing, etc.) are designed for use with and can only be effectively implemented on sloped fields, limiting the availability of those mitigation measures for flat fields. Since the relationship between field slope and runoff and erosion has been widely established and understood, there has been limited recent research published specifically looking at this relationship. Therefore, EPA relied on the efficacy classification and literature associated with terracing, which is the conversion of a sloped field into a series of smaller fields low-sloping or flat fields (≤3% slope). As described in **Section 5.4.5**, EPA categorized terracing as medium efficacy. EPA considers the level of mitigation associated with having a naturally low-sloping field to be functionally similar to terracing. Given these considerations, EPA similarly categorized the efficacy for fields with less than 3% slope as medium. A limit of 3% is chosen because it is consistent with NRCS's definition of a nearly level field having a slope of 0 – 3% (USDA, 2017).

Table 5-5. Flat Field (<3% slope) efficacy summary

Mitigation	Measures Included in this Category	Efficacy	Percent Reduction Reported
Flat Field (<3% slope)	Fields having a slope of 0 – 3%	Medium	Not available

5.3.2 Predominantly Sandy Soils

Soils with a sand, loamy sand, or sandy loam soil texture (Hydrologic Soil Group (HSG)[13] A and B soils) without a restrictive layer or high water table have a low runoff potential, even when thoroughly wetted (USDA and NRCS, 2007). This results in reduced runoff and erosion from these soil types as compared to HSG C (i.e., sandy clay loam soil texture) and D soils (i.e., clay loam, silty clay loam, sandy clay, silty clay, or clay soil texture). Risk assessments are typically driven by modeling the higher

Soil Texture Determination:
Soil texture is defined by USDA's soil classification system. See USDA's Web Soil Survey tool to determine soil texture: https://websoilsurvey.nrcs.usda.gov/app/.

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[13] Hydrologic soil groups were developed to characterize soils based on measured rainfall, runoff, and infiltrometer data (USDA and NRCS, 2007). They are used by hydrologists along with land use, management practices, and hydrologic conditions to predict a soil's associated runoff curve number. Runoff curve numbers are used to estimate direct runoff from rainfall (USDA and NRCS, 2007).

runoff scenarios (with C and D soils), which would overestimate runoff for actual fields with A and B soils. EPA categorized the efficacy of this field characteristic as medium.

EPA compared runoff EECs for HSG Groups A, B, C, and D soils to explore the impact of sandy soils on EECs (**Appendix G.4**). The analysis indicates that the distribution of EECs for each soil type is lognormally distributed; therefore, EPA compared median values of EECs for different soil types because extreme values overly influence the average in these situations. The results of the analysis show that the median EECs for B soils are approximately 60% lower than C soils (**Appendix G.4**). The reduction is greater when compared with EECs for D soils as shown in Appendix G. However, there is overlap at the tails with the 25th percentile concentration for C soils being lower than the 75th percentile for B soils. Therefore, a number of B soils have higher EECs than those of C soils. For this reason, while a 60% reduction in median EECs for B versus C soils suggests a high efficacy, the overlap of EECs between B and C soils at the tail ends of the distributions provides some uncertainty in the consistency of the efficacy. Therefore, a medium level of efficacy was set for fields with sandy soils (**Table 5-6**)

Table 5-6. Predominantly sandy soils efficacy summary.

Mitigation	Measures Included in this Category	Efficacy	Percent Reduction Reported
Predominantly sandy soils	Fields with sand, loamy sand, or sandy loam soil without a restrictive layer that impedes the movement of water through the soil	Medium	EPA Modeling Median = 60% Range of concentrations are overlapping, and 25th and 75th percentiles overlap

5.4 Mitigation Measures: In-Field

5.4.1 Conservation Tillage

This category of measures includes conservation tillage measures such as no-till, strip-till, ridge-till, and mulch-till. Each of these involves management of the amount, orientation and distribution of crop and other plant residue on the soil surface year-round while limiting the soil-disturbing activities used to grow and harvest crops in systems where the field surface is tilled, raked, or left undisturbed prior to planting.

Reduced Tillage and **No-Tillage** involve limiting soil disturbance to manage the amount, orientation, and distribution of crop and plant residue on the soil surface. A field may have no-till or reduced till management.

Justifications for the efficacy classification of individual practices that fall within the description of this mitigation measure are discussed in the following subsections (**Sections 5.4.1.1** through **5.4.1.2**)

Table 5-7. Reduced tillage and no tillage efficacy summary.

Mitigation	Measures Included in this Category	Efficacy	Percent Reduction Reported
Reduced Tillage	Reduced till, mulch till, strip till, ridge till	Medium	Average: 50 to 75% (Alix *et al.*, 2017) Range: 0 to 100% (Gaynor *et al.*, 1992; Glenn and Angle, 1987; Shipitalo and Owens, 2003)
No Tillage	No-till	High	27% greater than reduced tillage (Sun *et al.*, 2015) Range: Unknown

5.4.1.1 Reduced Tillage

Reducing tillage promotes soil macroporosity and maintains the structure of soil aggregates; increasing infiltration of runoff water and decreasing erosion (Fawcett *et al.*, 1994). Reducing tillage also increases soil organic matter in the top layers, increasing the retention of pesticides in this zone and also keeps microbial communities (bacteria, fungi, protozoa, *etc*.) intact, increasing the level of microbial degradation (Alletto *et al.*, 2010). As with mulching, residues on the soil surface may also sorb pesticides (Fawcett *et al.*, 1994).

The benefits of reducing tillage on runoff and erosion are variable in the literature. Some studies have found reduced tillage does not impact (Gaynor *et al.*, 1992; Glenn and Angle, 1987; Shipitalo and Owens, 2003) or increases pesticide concentrations/loads in runoff water (Gaynor *et al.*, 1995). However, other studies support tillage management as an effective measure to reduce runoff, erosion, and movement of pesticides from fields (Alletto *et al.*, 2010; Potter *et al.*, 2015; Seitz *et al.*, 2019). Alix *et al.* (2017) found that the average percent reduction seen in available data was 50 to 75%. EPA categorized this mitigation measure as medium given the average percent reductions and the wide variability in percent reductions (0 to 100%) seen in the literature (Alix *et al.*, 2017; Gaynor *et al.*, 1992; Gaynor *et al.*, 1995; Glenn and Angle, 1987; Shipitalo and Owens, 2003). This efficacy evaluation pertains to any tillage system that leaves ≥ 30% crop residue on the soil surface, including: strip tillage, ridge tillage, and the use of vertical tillage tools.

5.4.1.2 No Tillage

To maximize the amount of crop residue left on the field growers can practice no tillage (no-till). No-till differs from reduced tillage because no tillage operations are performed after the harvest of the previous crop, until the planting of the current year's crop, thereby maximizing the amount of crop residue left on the field. Studies have found that no tillage treatments decreased pesticide loads in runoff by 42% (Pantone *et al.*, 1996) or by as much as 100% when infiltration in the no-till treatment resulted in no runoff from the field (Glenn and Angle, 1987).

No-till can reduce soil losses by 56 to 75% (Seitz *et al.*, 2019) or up to 100% in some published studies (Fawcett *et al.*, 1994). Research shows the increased effectiveness of no-till compared to reduced tillage measures, allowing no-till to be distinguished from reduced tillage in effectiveness as a mitigation measure (Sun *et al.*, 2015). EPA categorized the efficacy of no-till as high given its classification of reduced tillage and the data demonstrating average percent reductions of 27% higher than reduced tillage.

Perennial crops (e.g., blueberries) and perennial forages (grasses for hay, alfalfa) are essentially no-tillage systems, except during the year of establishment or renovation. While marketable crops are harvested during the growing season, permanent vegetation remains on the field throughout the entire year. Studies have shown that erodibility of permanent hay production to be similar to no-till crop production (Zheng *et al.*, 2004). Given this, EPA included cranberry and perennial forages under this mitigation measure, except in the year of establishment or renovation.

5.4.2 Reservoir Tillage

Reservoir tillage is a tillage operation that uses a specific tillage tool that creates depressions in the soil in the rows between the crop plants. The depressions act like pools to collect rainwater and irrigation water. The depressions allow for increased water penetration into the soil, thereby decreasing erosion and runoff.

> **Reservoir Tillage** is the use of a specific tillage tool that runs between the rows of a crop and created depressions in the soil. These depressions collect precipitation and irrigation water allowing the water to infiltrate into the soil, thereby reducing erosion and runoff.

Reservoir tillage has been shown to be highly effective at reducing runoff and erosion compared to conventional tillage systems. Using a rainfall simulator to investigate and quantify water storage from reservoir tillage, Salem *et al.* (2014) showed that reservoir tillage reduced surface runoff by 61% and sediment loss by 79%. In a study of tillage practices for wheat, reservoir tillage reduced runoff by 56% and soil loss by 61% compared to conventional tillage (Salem *et al.*, 2015). Under center pivot irrigation, reservoir tillage has been seen to decrease runoff by 73% to 100% across multiple crops (potatoes, beans, corn, small grains) and field slopes in the Columbia Basin in Washington state (Kincaid *et al.*, 1990). Similarly, Gordon *et al.* (2011) reported that basin tillage reduced runoff by 78% compared to conventional tillage in potato production systems in Canada. Basin tillage is analogous to reservoir tillage in that small dams are created in a field’s furrows to enhance infiltration, reducing runoff (Gordon *et al.*, 2011). EPA categorized the efficacy of reservoir tillage as high based on percent reduction ranging from 56 to 100% across varies studies (Gordon *et al.*, 2011; Kincaid *et al.*, 1990; Salem *et al.*, 2015; Salem *et al.*, 2014).

Table 5-8. Reservoir tillage efficacy summary.

Mitigation	Measures Included in this Category	Efficacy	Percent Reduction Reported
Reservoir Tillage	Reservoir tillage, furrow diking, basin tillage	High	Average: Not available Range: 56 to 100% (Salem *et al.*, 2015) (Kincaid *et al.*, 1990)

5.4.3 Contour Farming

By farming along the contour, ridges are created that slow the velocity of runoff, enhancing infiltration and increasing sedimentation (Gathagu *et al.*, 2018). In a field study, (Van Doren *et al.*, 1951) observed a 0 to 92% reduction in sediment loads and a 0 to 86% reduction in runoff compared to noncontoured plots. Deasy *et al.* (2010) measured the reduction in overwintering loss of runoff and suspended solids from fields planted with winter cereals in the United Kingdom. The average percent relative change was 64 to 76% for runoff and 45 to 79% for suspended solids for contour cultivation in a field with clay, based on the results from three different soil types in the United Kingdom (Deasy *et al.*, 2010). With modeling studies, Gathagu *et al.* (2018) calculated a 36% reduction in sediment loads with contour farming compared to the baseline scenario.

There are many studies available evaluating the efficacy of contour farming at reducing offsite transport of pesticides. Although an average reduction in suspended solids of 45 – 79% was reported in Deasy *et al.* (2010), wide ranges of effectiveness were seen in Van Doren *et al.* (1951). Therefore, EPA categorized the efficacy for contour farming without vegetated field strips to be medium (**Table 5-9**). While contour farming generally applies to field cropping systems, orchards and other perennial cropping systems can also be planted along the contour. EPA expects the planting of orchards and other perennial crops perpendicular to the slope would have similar efficacy to contour farming associated with field crops.

> **<u>Contour Farming</u>** involves planting or tilling following the contour lines of the field and perpendicular to the slope. The lines slow down or change the direction of runoff from directly downslope to across the slope. The disruption of downslope flow slows the runoff velocity and allows more time for runoff to infiltrate the field soils, thereby reducing runoff.

Table 5-9. Contour farming efficacy summary.

Mitigation	Measures Included in this Category	Efficacy	Percent Reduction Reported
Contour Farming	Contour farming, Contour tillage, Contour orchard and perennial crops	Medium	Average: 45 to 79% (Deasy *et al.*, 2010) Range: 0 to 92% (Van Doren *et al.*, 1951)

5.4.4 Vegetative Filter Strips (In-Field)

Vegetation in a vegetation filter strip (VFS) intercepts flow, and thereby slow down the movement of runoff and erosion (Arora *et al.*, 2003). This allows for increased sedimentation, infiltration of runoff water, sorption of pesticides to vegetation and soil, and degradation in the vegetation rhizosphere following infiltration of runoff water (Krutz *et al.*, 2005).

In-field vegetative strips include various methods of breaking up the crop in the field with strips of vegetation, such as: inter-row vegetated strips, strip cropping (inter-row vegetative strips in annual crops), alley cropping (inter-row vegetative strips in perennial crops), and prairie strips. When multiple VFS are installed in-field (as opposed a single VFS adjacent to a field), the ratio of the area of the field to the area of the VFS is increased and therefore the capacity to capture pesticide transport also increases (see **Figure 5-1**). Locating a VFS closer to the runoff/erosion source would also increase the efficiency of a VFS when compared to an adjacent to the field VFS, due to its ability to limit the potential for concentrated flow (Reichenberger *et al.*, 2007).

Vegetative Filter Strips are managed areas of grass or other permanent herbaceous vegetation that intercept and disrupt flow of runoff, trap sediment, and reduce pesticide concentrations in solution. Generally, a filter strip can vary in width (typically 20 to 120 feet wide). Filter strips are usually planted with native grasses and perennial herbaceous plants. Nutrients, pesticides, and soils in the runoff water are filtered through the grass, potentially sorbed to soil, and potentially taken up by the plants.

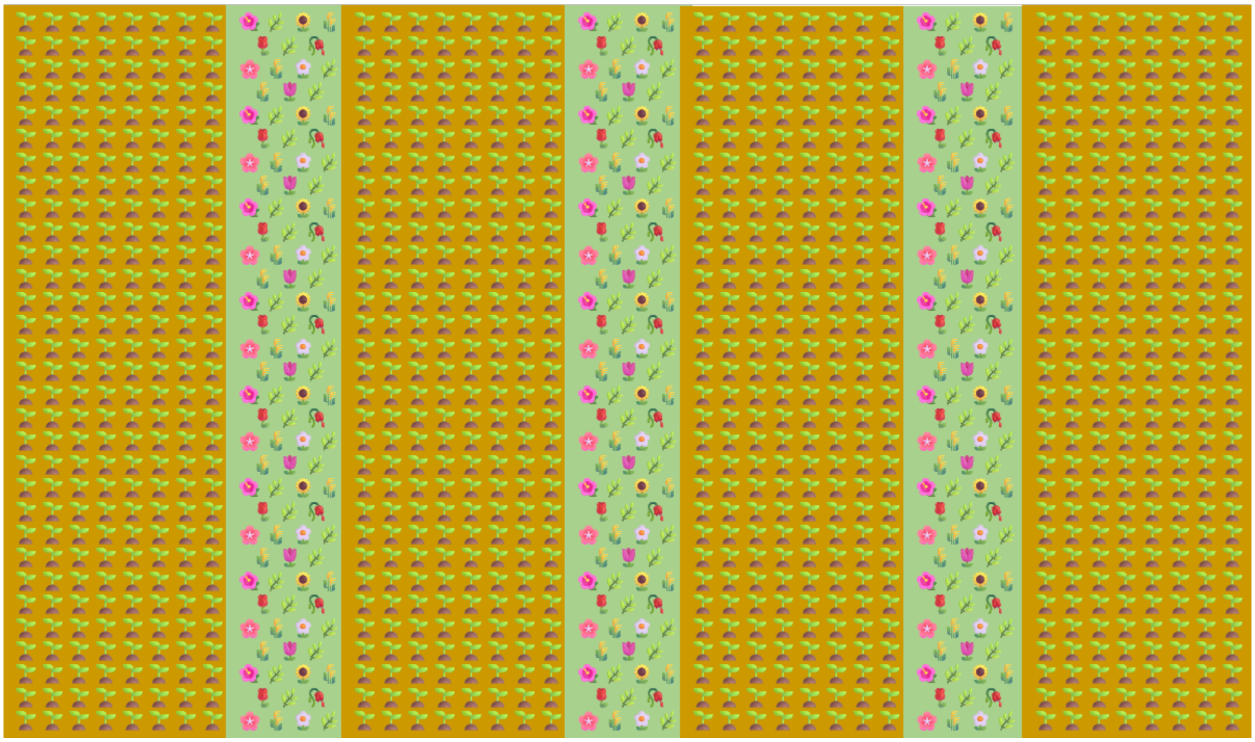

Figure 5-1. Diagram of Inter-row Vegetated Filter Strips.

Alix *et al.* (2017) summarizes numerous studies on the percent reduction of pesticide runoff from edge of field VFS and determined an average reduction of 50% and median of 70% when compared to fields without VFS (**Table 5-10**). Average reductions for contour buffer strips were between 44 to 59%, between 56- 100% for strip cropping for erosion-prone pesticides, and between 33 to 72% for alley cropping (Arora *et al.*, 2010; Ghosh *et al.*, 1989). The wide range of efficacies for VFS (11 to 94%) includes data from single buffers or filter strips, and may underestimate the efficacy of multiple buffers located within a field. Therefore, EPA categorizes these measures as medium considering the average reported efficacy for each of these measures.

Justifications for the individual practices that fall within the description of this mitigation measure are discussed in the following subsections (**Sections 5.4.4.1** through **5.4.4.4**)

Table 5-10. In-field vegetative strips efficacy summary

Mitigation	Measures Included in this Category	Efficacy	Percent Reduction Reported
In-Field Vegetative Strips	Inter-row vegetated strips, In-field Vegetative Strips, Contour Strip Cropping, Contour Buffer Strips,	Medium	Average: 50% (VFS); 44 to 59% (Contour buffer strips); (Alix *et al.*, 2017; Arora *et al.*, 2010)

Mitigation	Measures Included in this Category	Efficacy	Percent Reduction Reported
	Contour Alley Cropping, Strip Cropping, Alley Cropping, Prairie Strips		Range: 11 to 94% (Mickelson *et al.*, 2003; Poletika *et al.*, 2009)

5.4.4.1 Strip Cropping or Intercropping

With strip cropping strips of erosion-resistant crops, like perennial grasses or forages, decrease the velocity of surface water runoff and allow for trapping of sediments.

A meta-analysis of soil conservation literature in the Mediterranean demonstrated that erosion reduction is slightly higher than runoff reduction using strip cropping. Based on Soil and Water Assessment Tool (SWAT) modeling of pesticide runoff, simulated strip cropping was the most effective technique for reducing pesticide loading compared with contour farming and 5-m buffer strips, with a 37% decrease in dissolved and 81% decrease in sorbed pesticide (Holvoet *et al.*, 2007). Strip-cropping of cowpea in corn in India reduced runoff by 11% and erosion by 8.3% (Khokhar *et al.*, 2021). In three studies of buffer strips planted with fescue, intercropped with tomatoes, and receiving natural rainfall in Kentucky pesticide loadings were reduced in combined runoff and erosion by 56 – 100% for three erosion-prone chemicals (Arora *et al.*, 2010). As strip cropping is a subcategory of in-field VFS (**Section 5.4.4**), EPA categorized the efficacy for strip cropping is equivalent to in-field VFS.

> In **strip cropping,** a field is managed with rotations of row crops, forage crops, small grains, or fallow in a systematic arrangement of equal width strips. Crops are typically arranged so that a strip of grass or forage crop (low erosional risk because of their fibrous root system) is alternated with a strip of row crop (high erosional risk; e.g., corn). This practice differs from contour strip cropping in that rows do not need to be planted along a contour, which allows strip cropping to be used on land without a contour.

5.4.4.2 Alley Cropping

Alley cropping is the planting of food, forage, or specialty crops between rows of trees; erosion is reduced by covering bare soil with a crop. Similar to strip cropping, it is most effective on contoured land but may also be used on land without contours. Therefore, the efficacy of alley cropping may be comparable to strip cropping (intercropping) and therefore, comparable to in-field vegetative filter strips. In addition to the benefits garnered by strip cropping, alley cropping also provides benefits due

> **Alley Cropping** involves planting single or multiple rows of plants within the allies of woody plants. This measure is commonly utilized in orchards and where crops can be grown in combination.

to the reach and depth of tree roots compared to other crops. Tree roots may increase percolation of water to deeper soil layers, thereby decreasing runoff, and may increase plant uptake of systemic pesticides (Andrianarisoa *et al.*, 2016; Pavlidis *et al.*, 2020).

In a field experiment in India, Ghosh *et al.* (1989) observed a 33% reduction in runoff in mimosa (*Leucaena sp.)* production with cassava intercropping compared to mimosa alone, but up to a 72% reduction in runoff in mimosa with cassava compared to cassava alone. Soil loss was reduced by 35% in mimosa with cassava intercropping compared to mimosa alone and by 64% in *Eucalyptus* with cassava intercropping compared to cassava alone. As alley cropping is a subcategory of in-field VFS (**Section 5.4.4**), the efficacy categorization for alley cropping is equivalent to in-field VFS.

5.4.4.3 Contour Farming with Vegetated Strips

Contour farming includes multiple practices, including contour buffer strips and contour strip cropping. Contour buffer strips are strips of permanent herbaceous vegetation planted along the field contour and are alternated with wider cultivated strips. These strips of permanent vegetation reduce runoff and trap sediment. Contour buffer strips typically consist of perennial plants such as grass; these strips differ from other forms of in-field VFS, such as prairie strips, which may be planted with native plant species and are not required to be planted on a field's contour (ISU, 2024). Because contour buffer strips are established on the field's contour, runoff flows more evenly across the entire surface of the strip, thereby reducing erosion. The vegetation also slows runoff, increasing infiltration. Sediment and pesticides are filtered from the runoff as it flows through the contour buffer strip thereby improving surface water quality.

Contour Buffers Strips are narrow strips of permanent, vegetative cover established around a hill or slope and alternated with wider crop strips that are farmed down the slope of the hill.

Arora *et. al*. (2010) summarized two studies where edge-of-field contour strips were evaluated and on average 44 to 59% reduction was observed (Arora *et al.*, 2003; Boyd *et al.*, 2003). This level of reduction has been reported in other studies as well (Krutz *et al.*, 2005; Tim and Jolly, 1994; Zhu *et al.*, 2020). The slope of the contour may reduce the time that water has for infiltration as compared to a field with a low slope.

In contour strip cropping, a field is managed with planned rotations of row crops, forage crops, small grains, or fallow in a systematic arrangement of equal width strips following the contour across a field. Crops are typically arranged so that a strip of grass or forage crop (low erosional risk) is alternated with a strip of row crop (high erosional risk; e.g., corn). Contour strip cropping differs from contour buffer strips in that crops

Contour Strip Cropping is a management practice of planting alternating crops in equal widths across the contour of a field. Crops are arranged to minimize soil erosion.

can be planted across the entire field. As contour farming with vegetated strips is a subcategory of in-field VFS (**Section 5.4.4**), the efficacy categorization for alley cropping is equivalent to in-field VFS.

5.4.4.4 Vegetative Barrier

> **Vegetative barriers** are narrow, permanent strips of stiff stemmed, erect, tall and dense vegetation established in parallel rows on the contour of fields to reduce soil erosion and sediment transport. These barriers function similarly to contour buffer strips and may be especially effective in dispersing concentrated flow, thus increasing sediment trapping and water infiltration. Because the vegetative barrier is typically comprised of grasses and established on the contour, runoff is restricted. This allows the water to infiltrate into the soil, which reduces sheet flow and concentrated flow-based erosion.

Vegetative barriers are a subcategory of contour farming with vegetative strips (**Section 5.4.4**). Vegetative barriers are similar to in-field VFS but are planted along the contour. In vegetative barriers, more specific vegetation requirements (e.g., stiff, dense vegetation) are included than for contour buffer strips. EPA expects similar factors contribute to the efficacy of contour buffer strips as VFS and this is supported by field studies (Arora *et al.*, 2010). As vegetative barriers are a subcategory of contour farming with vegetated strips, the efficacy categorization for vegetative barriers is equivalent to contour farming with vegetative strips.

5.4.5 Terrace Farming

> **Terraces** are earthen embankments or a combination of ridge and channel systems that are built across a slope to intercept and store runoff water. Terraces are described as a stair stepping technique of creating flat or nearly flat crop areas along a gradient. Some terraces are built level from end to end to contain water used to grow crops and recharge groundwater. Others, known as gradient terraces, are built with some slope or grade from one end to the other and can slow water runoff.

Field terracing slows the velocity of water by breaking slopes into short sections, decreasing slope length and gradient. Field terracing also increases surface roughness and vertical surface relief, leading to increased infiltration, soil water holding capacity, and soil moisture (Chow *et al.*, 1999; Deng *et al.*, 2021). The efficacy of field terraces is affected by the formation of embankments, plant species, terrace age, spatiotemporal distribution, land use, and topography (Deng *et al.*, 2021). Field terracing has been seen to reduce runoff water from 5 to 87%, on average by over 42% (Deng *et al.*, 2021), and from 0 to 92% when paired with a grassed waterway (Chow et al., 1999). Terracing reduced erosion by 28 to 90%, depending on the terrace type (Deng *et al.*, 2021) and by 62 to 95% when paired with a grassed waterway (Chow *et al.*, 1999).

Many studies are available to support the efficacy of terracing at reducing offsite transport of pesticides (Alix *et al.*, 2017; Deng *et al.*, 2021). Average percent reductions in offsite movement were estimated to be approximately 25 to 50%, depending on the source and pesticide K_{OC} (Alix *et al.*, 2017; Deng *et al.*, 2021; USDA, 2014), with wide ranges in percent reductions observed (Chow *et al.*, 1999; Deng *et al.*, 2021). While the observed percent reductions are highly variable, EPA categorized the efficacy as medium (**Table 5-11**) reflecting the average percent reductions reported and understanding that terracing is a well-established practice specifically designed to reduce the amount of runoff and erosion coming from sloped fields.

Table 5-11. Terracing efficacy summary.

Mitigation	Measures Included in this Category	Efficacy	Percent Reduction Reported
Terrace Farming	Terrace farming, terracing, field terracing	Medium	Average: 25 to 50% (Alix *et al.*, 2017) Range: 5 to 95% (Chow *et al.*, 1999; Deng *et al.*, 2021)

5.4.6 Cover Crop/Continuous Vegetation

> A **cover crop** is a close-growing crop that temporarily protects the ground from wind and water erosion. Common cover crops include cereal rye, oats, clover, crown vetch, and winter wheat, or combinations of these crops. Cover crops may be used successively after one crop is harvested or relay-planted (similar to double cropping) where the second crop is planted into the first crop before harvest.

Some growers may work beds in the fall with tillage and attempt to keep them free of vegetation until a crop is planted. These growers would have no cover crop/continuous cover mitigations in place. Other growers may use cover crops to protect the ground from erosion. The quantity, duration, and distribution of cover crop residues and plant canopies impact the effectiveness of a cover crop in reducing erosion, runoff, and pesticide concentrations (Kaspar and Singer, 2011). Generally, cover crops increase water infiltration, consequently reducing surface water runoff, by reducing soil bulk density[14] and increasing the number of macropores in the soil (Blanco-Canqui and Ruis, 2020; Haruna *et al.*, 2018). Cover crops also improve soil structure by increasing soil organic matter. The canopy of cover crops intercepts rain drops, decreasing rainfall impact and thereby decreasing erosion (Haruna *et al.*, 2018; Kaspar and Singer, 2011). In addition to reducing sediment transport and surface water runoff, cover crops increase sorption of pesticides to organic matter and promote microbial degradation (Cassigneul *et al.*, 2015; Cassigneul *et al.*, 2016).

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[14] Soil bulk density is the mass of particles making up soil divided by total volume occupied by the soil.

The effect of cover crops on reducing sediment and water runoff has been well researched. Yuan *et al.* (2022) summarized reviews on the performance of various conservation measures and reported that across 25 studies, cover crops resulted in a mean sediment load reduction of 73%. Langdale *et al.* (1991) found that use of a cover crop resulted in an 11 to 99% reduction in soil losses across different tillage systems, cover crops, and spring crops across different southern U.S. locations. Gómez *et al.* (2018) saw an 86% reduction in soil loss in olive groves in Spain, when compared to plots managed with conventional tillage.

Cover crops can also be combined with other mitigation measures. Using cover crops in conjunction with reduced tillage measures may further reduce surface runoff from fields (Blanco-Canqui and Ruis, 2020; Hartwig and Ammon, 2002; Haruna *et al.*, 2018; Langdale *et al.*, 1991). When combined with no-till residue management, cover crops resulted in a 95 to 100% pesticide loss associated with sediment (Hartwig and Ammon, 2002). In the same study, an 67 to 95% reduction in pesticide loss was seen associated with the aqueous phase (Hartwig and Ammon, 2002).

In a literature review of 98 studies, Blanco-Canqui and Ruis (2020) found that cover crops increased water retention more in no-till versus tilled soils. In the same review study, Blanco-Canqui and Ruis (2020) evaluated cover crop influence on water quality and determined cover crops increased infiltration in 82% of 17 studies, with the infiltration rates ranging from 5 to 462% and cumulative infiltration averaging 43% (Blanco-Canqui and Ruis, 2020). Blanco-Canqui and Ruis (2020) note that this variability indicates that the extent that infiltration increases can vary with site-specific management of cover crops.

In a meta-analysis of various measures effectiveness on mitigating erosion and runoff, Rajbanshi *et al.* (2023) found that across cover crops, mulching, and several other mitigation measures, there was moderately higher mean effect rates for reducing soil erosion (53 – 71%) than runoff (28 – 47%). When analyzing the tradeoff between runoff reduction efficiency and soil erosion reduction efficiency, Rajbanshi *et al.* (2023) found both cover crops and mulching were significantly more efficient in soil erosion reduction than runoff reduction. In a comparison of the runoff reduction efficiency (RRE) and soil erosion reduction efficiency (SERR), mulching had a ratio of RRE:SSRE of 83%, while cover crops had a ratio of RRE:SSRE of approximately 72%. These ratios show that cover crops are more effective at mitigating soil erosion than runoff.

How effective cover crops are as a mitigation varies with several factors, including: cover crop variety, planting date, termination date, and environmental conditions during growth. The effectiveness of cover crops is most strongly correlated to the amount of biomass and subsequent plant residue produced by the cover crop. Two of the main factors that affect the amount of biomass and plant residue left after cover crops are terminated are the length of time that cover crops are on the field and the use of tillage during or after cover crop termination (Miller *et al.*, 2022; Tubaña *et al.*, 2020). Cover crops that are terminated later or that are grown for extended periods of time are able to produce more biomass than those that are terminated earlier (Blanco-Canqui and Ruis, 2020). The length of time a cover crop is on a field and the tillage used are both management decisions that require planning by the grower.

As stated above, many factors influence the efficacy of cover crops in mitigating runoff/erosion. However, two factors with the greatest impact are how the cover crop/continuous ground cover is terminated (i.e. tillage) and the duration a cover crop/continuous ground cover is present on the field (i.e., short-term or long-term ground cover). Because of the change in effectiveness due to these different management decisions, EPA determined three categories of efficacy for cover crops based on the termination method used and the amount of time the cover crop spends on the field each year, with the effectiveness ranging from low to high (**Table 5-12**).

Further discussion of these categories and their associated efficacy classification is provided in the following subsections (**Sections 5.4.6.1** through **5.4.6.3**).

Table 5-12. Cover crop/ continuous ground cover efficacy summary

Mitigation	Measures Included in this Category	Efficacy	Percent Reduction Reported
Cover Crop/ Continuous Ground Cover	Cover crop, double cropping, relay cropping	Low (Tillage used)	Average: 50% (Alix *et al.*, 2017) Range: 11 to 99% (Langdale *et al.*, 1991)
		Medium (No tillage, short term)	
		High (No tillage, long term)	

5.4.6.1 Cover Crop: Tillage Used

Some growers may plant a cover crop prior to or after harvest or allow winter annual weeds to completely cover the field to have continuous ground cover throughout the winter and early spring, but the grower intends to till the ground as a form of terminating the ground cover (instead of relying on herbicides). This would serve as a short duration continuous ground cover that would offer runoff erosion mitigations for several months between harvest and planting.

The use of tillage to terminate a cover crop or the use of a tillage operation between cover crop termination and cash crop planting removes a primary benefit of having cover crop biomass or residue on the field at the time of pesticide application, reducing the effectiveness of the measure for runoff and erosion mitigation. However, other runoff mitigation benefits of cover crops, including improvement of soil structure and subsequent improvement in water infiltration into the soil which would reduce run-off, still occur.

Therefore, EPA categorized the efficacy of any cover crop that is terminated using a tillage operation or any cover crop where tillage is used between cover crop termination and planting of the subsequent crop as low.

5.4.6.2 Cover Crop: No Tillage Used, Short Term Duration,

Other growers may choose to work the ground after harvest and then plant a cover crop or allow annual winter weeds cover the worked ground so there is plant residue present throughout the winter and early spring. Since the beds were formed in the winter, these growers would rely on herbicides to remove the vegetation prior to or at planting. Therefore, these fields would have a mitigation measure in place for most of the time after harvest through planting, and the soil would not be disturbed by tillage after the continuous vegetation is established.

Short duration cover crops that are not terminated with tillage and where tillage does not occur before the planting of the subsequent crop combine the improvements in soil structure and tilth with the runoff mitigation benefits of the cover crop biomass and residue remaining on the soil surface. However, the short duration that these cover crops are on the field limits the amount of biomass that the cover crops can produce. Even so, the presence of cover crop biomass and residue on the soil surface improves runoff reduction efficacy compared to cover crop used with tillage operations. For example, Alliaume *et al.* (2014) found that a terminated cover crop left on the soil surface decreased erosion and runoff by 50% compared to conventional tillage systems, including a conventional tillage system where cover crop biomass was incorporated into the soil with tillage, in tomato production systems in Uruguay.

Therefore, EPA categorized the efficacy of any short duration cover crops where tillage is not used to terminate the crop and no tillage operation occurs between cover crop termination and planting as medium. Short duration cover crops include: cover crops planted in the spring, prior to a spring planted crop; cover crops planted in the fall, terminated due to winter conditions, and are not actively growing in the spring; or cover crops grown between subsequent short-season crops within a single growing season**.**

5.4.6.3 Cover Crop: No Tillage Used, Long Term Duration

Other growers may establish a cover crop before or after harvest and have a continuous ground cover until planting occurs. However, this is likely uncommon in many large row crop systems because actively growing vegetation present at the time of planting can exacerbate insect and disease problems. However, some perennial crops (e.g., fruit orchards) have continuous ground cover present throughout the entire growing season. Additionally, some specialty crops may have continuous ground cover in the row middles for the entire season which would provide season-long runoff/erosion mitigation in the field.

Cover crops planted the fall after the preceding crop and allowed to grow until they are terminated prior to planting of the current year’s crop can maximize both the biomass and residue benefits, as well as the soil building benefits of cover crops. Fall planting allows cover crops to germinate and establish in the fall of the year, overwinter, and then be able to take full advantage of spring growth conditions prior to planting of the current year’s cash crop. If the fall planted cover crop is not terminated with tillage and no tillage occurs between cover crop termination and planting of the current year's cash crop, this functionally combines cover cropping with no-till production, a scenario that evidence suggests greatly decreases pesticide movement off-field via runoff and erosion (Hartwig and Ammon, 2002).

Use of cover crops as a mitigation measure by growers will require planning. To achieve high efficacy, the grower must plan to plant a fall-planted cover crop after the previous growing seasons cash crop is harvested. For example, a grower desiring to use a fall-planted cover crop as a runoff and erosion mitigation measure for the current year's soybean crop would have had to plant an appropriate cover crop after the previous year's corn crop. The necessity of planning associated with cover crop use may make cover crops difficult or impossible to implement for all fields or with all crops within a rotation, particularly in the first year(s) of transitioning to cover crop use. However, over time the incorporation of cover crops into crop production system will become more routine and less impactful to growers.

Furthermore, EPA recognizes that best management practices for cover crops can vary by cropping system and location within the U.S. and can affect important crop production considerations, like access to crop insurance programs (USDA, 2020).

Cranberry and perennial forages (e.g., grasses for hay, alfalfa) have continuous vegetation/ground cover on the soil throughout the year and particularly when pesticides are being applied. The continuous vegetation of cranberry and perennial forage production systems works analogously to the incorporation of cover crops into annual field crop production systems, representing a high efficacy practice. However, cranberry bogs and perennial forage fields periodically need to be renovated. In the year that cranberry bogs or perennial forage fields are planted or terminated and replanted, the efficacy would not be high, but rather low, consistent with cover crops used with tillage operations (**Section 5.4.6.1**). High efficacy can only be applied once the renovated bog or field has returned to a mature stand with regular harvest operations.

Any fall planted cover crops that are not terminated with tillage and where tillage does not occur before planting of the subsequent crop is able to maximize the effectiveness of this measure at mitigating runoff and erosion. Therefore, EPA categorized the efficacy as high.

5.4.7 Irrigation Water Management

While rainfall often drives EPA's risk assessments, irrigation can also lead to runoff and offsite transport of pesticides. Typical surface irrigation (such as furrow and border-strip irrigation) is conducted to have approximately 15 to 20% of the applied water runoff the field as tailwater, with as much as 30% of the irrigation water running off the field (Schwankl, Hanson*, et al.*, 2007; Schwankl, Pricharg*, et al.*, 2007; USEPA, 2003). This ensures that there is sufficient infiltration time for the lower edge of a field to be adequately irrigated (Schwankl, Pricharg*, et al.*, 2007). While tailwater runoff is commonly seen with furrow and border-strip irrigation systems, it is rarely produced with well-managed and well-designed sprinkler or micro-irrigation systems (Schwankl, Pricharg*, et al.*, 2007).

Irrigation water management works to control the volume and frequency of irrigation water applied to crops, conserving water resources, and reducing runoff, while still meeting the crop's needs. This, in turn, reduces the amount of runoff occurring from irrigation. Furthermore, controlled irrigation can serve to incorporate ground applied pesticides and reduce the mass of pesticides in runoff.

With irrigation water management, a grower is able to know the water needs of the crop and the water-holding capacity of the soil, and thereby apply the proper amount of water and avoid excessive runoff. This can be accomplished either by using technologies to determine when irrigation should occur or by using more precise irrigation methods.

Water measuring devices (*e.g*., irrigation water meter, flume, or weir) are useful tools that are available to help growers manage the amount of water applied (USEPA, 2003). University extension literature recommends that growers understand soil infiltration rates so that irrigation systems can water at a rate that is low enough that the water infiltrates the soil, preventing runoff from occurring (Hansen and Trimmer, 1986). These technologies are commonly combined with irrigation methods that are typically used for large acreage field crops, such as large-scale center pivot irrigation or flood/furrow irrigation in areas where irrigation is common. Alternatively, specialty crop producers generally rely on more targeted irrigation measures like drip tape and micro-sprinkler irrigation.

The different irrigation measures vary in the likelihood that a runoff event will occur, and therefore, have varying potential for population-level impacts. As such, EPA created different categories of efficacy for irrigation water management methods based on the likelihood of a runoff event to occur following irrigation (**Table 5-13**). Further descriptions of the measures included in each tier and the basis for their efficacy classification are provided in the following subsections (**Sections 5.4.7.1** through **5.4.7.3**).

Table 5-13. Irrigation water management efficacy summary

Mitigation	Measures Included in This Category	Efficacy	Percent Reduction Reported
Irrigation Management	Use of soil moisture sensors/evapotranspiration meters with center pivots & sprinklers; above ground drip tape, drip emitters; micro-sprinklers	Medium (General irrigation management)	Not available
	Below tarp irrigation, below ground drip tape; dry farming, non-irrigated lands	High (Subsurface irrigation; No Irrigation)	

5.4.7.1 General Irrigation Management

This category of mitigation measures includes center pivot, sprinklers (e.g., overhead, wheel line, wheel move, laterals, hand-set irrigation sprinklers), flood, and furrow irrigation technologies that include the use of soil moisture sensors or evapotranspiration meters to schedule irrigation (Schwankl, Hanson*, et al.*, 2007; Smith, 2016). In the case of furrow irrigation, computerized hole selection and surge values are used (Yonts and Eisenhauer, 2008). When sprinklers are properly sized and irrigation is properly timed, runoff events should not occur.

Above ground drip tape, drip emitters, and micro-sprinklers are more targeted irrigation methods than overhead irrigation like center pivots and furrow/flood type irrigation. These irrigation measures emit lower volumes of water in more targeted areas of the field including directly next to the crop or directly in the row of plants. These irrigation measures can also be utilized with soil moisture sensors and other irrigation scheduling technology.

In the absence of natural precipitation these mitigation measures would functionally eliminate runoff from the field associated with irrigation. However, even in ares with limited precipitation, a precipitation event could occur after an irrigation potentially resulting in runoff and erosion from an irrigated field. Therefore, due to the risk of runoff and erosion from unforeseen precipitation following an irrigation even, EPA is considering general irrigation management to have medium efficacy.

5.4.7.2 Subsurface Irrigation

Subsurface irrigation methods include below-tarp irrigation and below ground trip tape. In below ground irrigation systems, water is applied directly to the root zone of the crop and not the soil surface (Reich *et al.*, 2014). The depth the drip tape is buried depends on the crop, soil type, and top soil depth, but generally depths vary from 3 – 24 inches deep (Reich *et al.*, 2014). Below tarp irrigation is similar, however, instead of being buried, the drip tape at the surface is covered by a tarp.

In irrigation systems where water is applied to the crop below the soil surface, no runoff or erosion occurs due to the irrigation (Reich *et al.*, 2014). While a precipitation driven runoff event may still occur, the likelihood is lessened as the top layer of soil is not receiving irrigation. Therefore, EPA categorized the efficacy of subsurface irrigation methods as high.

5.4.7.3 Dry Farming and Non-Irrigated Lands

Non-irrigated lands include two different cultivation techniques: rainfed systems, and dryland farming. Rainfed systems encompass any non-irrigated agriculture that solely rely on natural precipitation for a crop’s water needs and can be implemented in under any climatic condition. Dry farming, or dryland farming, is a subset of rainfed systems which is typically associated with semiarid or arid climates in which annual precipitation is approximately 20-35% of potential evaporation, where growers utilize drought tolerant crops and strive to retain precipitation on the land and limit evaporation from the soil surface (Stewart, 2016).

Because these measures depend on an absence of irrigation, EPA expects them to be at least as efficacious as subsurface irrigation methods and therefore categorized the efficacy as high.

5.4.8 Mulching with Natural and Artificial Materials

Mulching with natural materials reduces runoff concentrations of pesticides by sorbing pesticides and promoting microbial degradation (Aslam *et al.*, 2014; Chalker-Scott, 2007; Gan *et al.*, 2003). Mulch materials may also intercept and retain pesticides upon application (Aslam *et al.*, 2014). The composition of organic materials comprising the mulch may impact its ability to sorb pesticides (Aslam *et al.*, 2014), and organic mulches in particular can promote microbial degradation (Chalker-Scott, 2007; Gan *et al.*, 2003). For erosion, mulching with natural materials additionally reduces movement of soil off field (Marble, 2015).

Mulching is applying plant residues or other materials (either natural or artificial) to the land surface.

As discussed previously in **Section 5.4.6,** Rajbanshi *et al.* (2023) found that across cover crops, mulching, and several other mitigation measures, there was moderately higher mean effect rates for reducing soil erosion (53 – 71%) than runoff (28 – 47%). When analyzing the tradeoff between runoff reduction efficiency and soil erosion reduction efficiency, Rajbanshi *et al.* (2023) found both cover crops and mulching were significantly more efficient in soil erosion reduction than runoff reduction. In a comparison of the runoff reduction efficiency (RRE) and soil erosion reduction efficiency (SERR), mulching had a ratio of RRE:SSRE of 83%, while cover crops had a ratio of RRE:SSRE of approximately 72%. These ratios show that mulching is more effective at mitigating soil erosion than runoff.

Use of artificial materials such as landscape fabrics and chipped materials could also serve as a mulching technique since functionally, they would serve similar to natural materials with the ability to intercept pesticides; however, EPA does not have the data on the specific properties (*i.e.,* surface roughness), sorption capacity (*i.e.*, binding sites) of the various artificial mulching materials leading to uncertainty of their properties. In addition, artificial materials are not expected to offer comparable moisture retention and microbial degradation as organic mulches because artificial materials are not expected to degrade and offer comparable nutrient and organic matter content to surrounding soil that fosters moisture retention, microbial growth, diversity and community structure. Moisture retention and microbial growth as seen in organic mulches will decrease run off because the biomass retains the moisture and also pesticide degradation may be increased.

Jiang *et al.* (2011) found that straw cover reduced pesticide loads in runoff by 68% compared to bare soil, likely due to sorption/interception, and that straw reduced soil erosion by 95%.

Research from Chalker-Scott (2007) aligned with results from Jiang *et al.* (2011), with Chalker-Scott reporting that straw mulch reduced erosion by 86%. Many studies investigated the impact of mulching combined with no/reduced tillage, so it is often difficult to distinguish which impacts are from mulching and which are from no/reduced tillage (Kanazawa *et al.*, 1975).

However, EPA has higher confidence in the experimental design and methodology in recent studies that demonstrate high efficacy for mulching with natural materials. Many studies indicate that mulching with natural materials can be an effective measure at reducing runoff and erosion; the measure reduces offsite transport from 68 to 95% (**Table 5-14**). Therefore, EPA categorized mulching with natural materials as high efficacy. Mulching with artificial materials was categorized with an efficacy of low because of the uncertainty surrounding the specific properties of the artificial materials and artificial materials are not expected to have the moisture retention and microbial growth that would reduce the potential for runoff and erosion as compared to mulching with natural materials.

Table 5-14. Mulching efficacy summary.

Mitigation	Measures Included in this Category	Efficacy	Percent Reduction Reported
Mulching with Natural Materials	Mulching with natural materials	High	Average Not available Range: 68 to 95% (Jiang *et al*., 2011)
Mulching with Artificial Materials	Mulching with artificial materials (*i.e*., landscape fabrics, synthetic mulches)	Low	Average Not available

5.4.9 Erosion Barriers (e.g.: Wattles, Silt Fences)

Wattles are fiber-filled (*e.g.*: straw, coir) rolls in a mesh netting designed to control soil erosion by capturing sediment and reducing flow velocity by distributing water across the landscape allowing infiltration and thereby reducing runoff. **Silt Fences** are sediment barriers made of porous fabric. Typically, wattles and silt fences are held in place by wooden stakes and applications can be seen at construction sites and post-forest fire remediation sites where sloping occurs. Wattles and silt fences can also be used as perimeter control surrounding fields and waterbodies.

An erosion barrier such as a straw wattle is designed to slow runoff and store eroded sediment on hillslopes, thereby decreasing erosive energy, increasing infiltration, and reducing downstream sedimentation (Robichaud and Brown, 1999). In 2000, an opportunity to measure wattle effectiveness mitigating post-fire runoff and erosion occurred after the Valley Complex Fire burned 86,000 hectares in the Bitterroot Valley of Montana. In the remediation effort, 297 hectares of straw wattles were utilized to stabilize burned acres. Results reported wattles reduced peak runoff rates by allowing runoff to pool, thereby reducing runoff velocities. In addition, the mean sediment-trapping efficiency for the first storm of 2001 was 83% but declined to 43% at the end of 2001 (Robichaud *et al.*, 2008). There is limited literature available on wattle effectiveness on runoff and erosion of pesticides. However, by design and with proper selection of sorbent material and placement, wattles would be considered effective at capturing, filtering, or slowing down pesticides in runoff and erosion as compared to no erosion barrier in place.

The data demonstrates to function as an effective mitigation measure, erosion barriers must be correctly installed and maintained. There are several best management practices (BMPs) available on design and placement of erosion barriers and EPA recommends consulting with a runoff/erosion specialist for proper installation and maintenance. Percent reductions are not available for pesticides; however, by design and with proper selection of sorbent material (*i.e.,* wattles) and proper placement, erosion barriers would be considered effective at capturing, filtering, or slowing down pesticides in runoff and erosion as compared to no erosion barrier in place. Based on these considerations and the range of percent reduction, the efficacy score for an erosion barrier is considered medium (**Table 5-15**).

Table 5-15. Erosion barrier efficacy summary.

Mitigation	Measures Included in this Category	Efficacy	Percent Reduction Reported
Erosion Barrier	Wattles Silt Fences	Medium	Average: Not available Erosion Range: 43 to 83% (Robichaud et al., 2008)

5.5 Mitigation Measures: Adjacent to the Field

5.5.1 Grassed Waterway

Grassed waterways are natural or constructed vegetated channels designed to direct surface water flowing at non-erosive velocities to a stable outlet (e.g., another vegetated channel or earth ditch). Grassed waterways are used to control gully erosion. In concentrated flow areas, grassed waterways can act as an important component of erosion control by slowing the flow of water and filtering sediment.

In concentrated flow areas, grassed waterways filter sediment and slow the flow of water, increasing infiltration of surface water runoff (Asmussen *et al.*, 1977). Fields where a grassed waterway is needed to control channelized flow (such as in highly erodible lands and wet environments with large slopes) are likely more vulnerable to runoff and erosion, and installation of a grassed waterway is the recommended conservation measure to minimize this.

Compared to fields without an adjacent grassed waterway, Fiener and Auerswald (2003) observed a 77 to 97% reduction in sediment loss and a 10 to 90% reduction in runoff from grassed waterways, depending on the maintenance conditions (where an unmanaged grassed waterway performed better than a mowed waterway) and design of the grassed waterway. Asmussen *et al.* (1977) evaluated offsite transport of 2,4-D (a runoff prone chemical with average K_{oc} of 72 mL/g-oc) through surface runoff in a grassed waterway with a flow length of 24.4 m for wet and dry antecedent moisture conditions under a simulated rainfall. Study results suggest the waterway retained approximately 70% of applied 2,4-D irrespective of antecedent soil moisture conditions.

There are few scientific studies evaluating the reductions of pesticide moving offsite via addition of grass waterways adjacent to the field. While the literature suggests that grassed waterways may be an effective mitigation measure (i.e., at least 10% reduction observed for some pesticides), there is some evidence that they are less effective for runoff-prone chemicals (Shipitalo *et al.*, 2012). In this study, the use of filter socks filled with compost increased the reduction in various nutrient concentrations (Shipitalo *et al.*, 2012). The available data demonstrates a high potential for grassed waterways to limit offsite movement of pesticides in runoff and erosion. However, due to the limited data available and the highly variable efficacies reported in literature for runoff-reduction, grassed waterways were categorized as medium efficacy (**Table 5-16**).

Table 5-16. Grassed waterway efficacy summary.

Mitigation	Measures Included in this Category	Efficacy	Percent Reduction Reported
Grassed Waterway	Grassed waterway	Medium	Average: Not available Range: 0 to 100% (Asmussen *et al.*, 1977; Fiener and Auerswald, 2003)

5.5.2 Vegetative Filter Strips (Adjacent to the Field)

5.5.2.1 Vegetative Filter Strips

> **Vegetative Filter Strips** are managed areas of grass or other permanent herbaceous vegetation that intercept and disrupt flow of runoff, trap sediment, and reduce pesticide concentrations in solution. Generally, a filter strip can vary in width (typically 20 to 120 feet wide). Filter strips are usually planted with native grasses and perennial herbaceous plants. Nutrients, pesticides, and soils in the runoff water are filtered through the grass, potentially sorbed to soil, and potentially taken up by the plants.

As discussed in **Section 5.4.4**, vegetation in a VFS intercepts flow, and thereby reduces the flow velocity of runoff (Arora *et al.*, 2003). This allows for increased sedimentation, infiltration of runoff water, sorption of pesticides to vegetation and soil, and degradation in the vegetation rhizosphere following infiltration of runoff water (Krutz *et al.*, 2005). That section discussed VFS that are in the field and this section discusses VFS adjacent to the field. Adjacent to the field VFS consist of a single filter strip installed at the downgradient treated field edge, in between the treated field and aquatic areas, while the in-field VFS mitigation measure described in **Section 5.4.4** above are interspersed throughout a cropped field and are typically comprised of more than one strip in a field. The efficacy data summarized below are from studies in which a single VFS is located at the edge of the treated field.

Single vegetative filter strips have been reported to reduce pesticide loads in surface water runoff by 1 to 91% (Krutz *et al.*, 2005; Mickelson *et al.*, 2003; Poletika *et al.*, 2009) and to reduce sediment loads by 11 to 94% (Mickelson *et al.*, 2003; Poletika *et al.*, 2009). The efficacy of single VFS at reducing surface water runoff and sediment in runoff varies depending on the type of vegetation grown in the VFS, the density of the vegetation, the width of the VFS, whether channelized flow paths are able to form over the width of the VFS (Caron *et al.*, 2012; Krutz *et al.*, 2005; Mickelson *et al.*, 2003; Poletika *et al.*, 2009), the flow-rate, the field-to-VFS area ratio (Arora *et al.*, 2003; Boyd *et al.*, 2003), and the amount of rainfall, among other factors. The VFS have been shown to be effective at reducing runoff with low flow (Boyd *et al.*, 2003).

In an extensive review of studies evaluating the potential for pesticide reductions in runoff and erosion using single VFS (Alix *et al.*, 2017), the authors provided average reduction efficiencies for runoff and erosion prone chemicals, categorized by VFS width. For runoff prone chemicals, the median reduction of pesticide mass in runoff and erosion was 40%, 60%, and 70% for VFS with widths of 5 m (16 ft), 10 m (32 ft), and 20 m (66 ft). For erosion prone chemicals the average reductions were 50%, 75%, and 90% for VFS with widths of 5 m (16 ft), 10 m (32 ft), and 20 m (66 ft).

In addition to a literature review of the efficacy of vegetated filter strips, EPA evaluated the efficacy using the Vegetated Filter Strip Modeling System (VFSMOD v4.5.1). VFSMOD is a mechanistic event-based model that simulates trapping of runoff, sediment, and pesticide transport through a vegetated filter strip. For its evaluation, the EPA used the Vegetative Filter Strip Modeling System (VFSMOD v4.5.1) along with PWC (v2.001) and associated crop scenarios and weather files to evaluate reductions in pesticide mass for high runoff events (95th percentile for the weather file) specific to each Hydrologic Unit Code 2 (HUC2) region. These high-end runoff events were then simulated across a range of K_{OC} values (1, 10, 100, 1,000, and 10,000 L/kg-oc) and VFS strip widths (20, 30, 50, 98 ft). Results from this evaluation are expressed as percent reductions of dissolved and sediment bound pesticide residues. EPA first summarized the results as the 50th percentile reductions each soil texture, VFS width, and Koc combination. The 50th percentile reductions were then further aggregated into soil class groups, VFS width classes, and Koc classes. The lower bound 50th percentile reductions of these groups are presented in **Table 5-17**. These percent reductions represent median reductions from VFSMOD modeled high end runoff events over a wide range of climatic conditions across the United States. Generally, the modeled results are consistent with studies, in that larger VFS widths with coarser textured soils, and sediment bound pesticides are estimated to achieve greater reductions in pesticide transport than smaller width VFS with finer textured soils and more runoff prone pesticides. EPA notes that the 0% reductions for some soil/Koc classes are due to the selection of high-end runoff events (95th percentile) and lower bound percent reductions within the soil class/VFS class/Koc class grouping. EPA expects some level of reduction of pesticide transport in these soils and pesticides for smaller runoff events. A more detailed summary of EPA's VFSMOD analysis is available in **Appendix F**.

Table 5-17. VFSMOD Lower-Bound Predicted EEC Percent Reductions

Soil Class (# PWC scenarios)	VFS Class[2]	50th percentile reductions[1]	
		Low K_{OC}[3]	High K_{OC}[3]
Loamy sand (61)	Low	30	50
	High	50	70
Loam (120)	Low	10	30
	High	20	40
Silty loam, Sandy loam (272)	Low	0	20
	High	10	30
Sandy clay loam, Clay loam, Silty clay loam (95)	Low	0	10
	High	0	10

[1] Based on 95th percentile starting runoff value, rounded to nearest 10%.

[2] VFS Class: Based on 1) VFS width where low is 20 or 30 ft width, and high is 50 or 100 ft width; and 2) Field:VFS area where low is ratios of 50:1 (20 ft VFS width) or 30:1 (30 ft VFS width) and high is ratios of 20:1 (50 ft VFS width) or 10:1 (100 ft VFS width)
[3] K_{OC} Class: Low is 1, 10, or 100 L/kg-oc; High is 1,000 or 10,000 L/kg-oc.

Although VFS widths may vary, the minimum effective VFS width should be at least 20 ft (USDA, 2016). This is consistent with less than 5% to 35% reduction for pesticides in the aqueous phase and a 30 to 100% reduction for pesticides in the solid-phase across a range of soils, field lengths, and assumed standard rainfall events (Dosskey *et al.*, 2008). However, the actual percent reductions will be specific to the environmental conditions. Again, as noted in **Section 5.4.4**, although VFS size is most often referenced in terms of width, it is the ratio of the field to VFS area that has the most impact on its capacity to reduce pesticide transport. VFS of the same size (e.g., a 20 ft VFS) will be more effective at reducing pesticide transport when installed adjacent to a 10-ha field than a 1,000-ha field, due to the volume of eroded sediment and runoff.

There are abundant studies and modeling analyses evaluating the effectiveness of single VFS adjacent to the field for at reducing offsite transport of pesticides. On average for both runoff and erosion-prone pesticides, literature indicates that VFS reduce pesticide mass for by 40%, 65%, and 80% for VFS widths of 5m (16 feet), 10m (33 feet), and 20m (66 feet), respectively (Alix *et al.*, 2017; Reichenberger *et al.*, 2007; USDA, 2014). In general, especially for strongly sorbing pesticides, increased VFS widths correlate with an increase in pesticide reduction in off-field pesticide exposure. Therefore, based on average efficacy data adjusted for the wide range of efficacy in literature and in modeling, EPA categorized this measure as low, medium, and high for single adjacent to the field VFS with widths of between 20 to 30 ft, between 30 to 60 ft, and greater than 60 ft, respectively (**Table 5-18**).

Table 5-18. Adjacent to the field vegetative filter strip efficacy summary.

Mitigation	Measures Included in this Category	Efficacy	Percent Reduction Reported
Vegetative Filter Strip	Field border, vegetative barrier: 20 to <30 ft wide	Low	Average: 40% (5 m), 65% (10 m), and 80% (20m) (Alix *et al.*, 2017; Reichenberger *et al.*, 2007; USDA, 2014) Range: 1 to 94% (Krutz *et al.*, 2005; Mickelson *et al.*, 2003; Poletika *et al.*, 2009)
	Field border, vegetative barrier: 30 to <60 ft wide	Medium	
	Field border, vegetative barrier: ≥60 ft wide	High	

5.5.2.2 Field Border

A **field border** is a strip of permanent dense vegetation established at the edge or around the perimeter of a field. The minimum length to reduce runoff/erosion is 20-. A field border can reduce runoff-based erosion and protect soil and water quality by slowing the flow of water, dispersing concentrated flow, and increasing the chance for soil infiltration.

Although distinctly different from VFS, field borders are similar to VFS in that both measures represent a vegetated zone immediately adjacent to an agricultural field. Field borders are a type of VFS that is immediately adjacent to an agricultural field. Therefore, due to their similarities and a lack of literature specifically addressing the efficacy of field borders, EPA assigned the same efficacy for field borders as for VFS.

5.5.3 Vegetated Ditch

A vegetated ditch may be used to catch water as it comes off the field and convey it to an adjacent aquatic area. Ditch networks are primarily designed for transporting water and erosion prevention, but when vegetated and properly managed, can provide other ecosystem services, including pesticide retention (Dollinger *et al.*, 2015). A review study of managing agricultural ditches for various ecosystem services (Dollinger *et al.*, 2015) found that pesticide retention in ditches can vary from 3 to 99%, depending on various characteristics of the ditch. These characteristics include: the reach length, percent of vegetated cover, hydraulic retention time, substrate characteristics, and mobility of the pesticide (Dollinger *et al.*, 2015).

Phillips *et al.* (2017) evaluated different treatment designs to reduce pesticides in agricultural runoff, including vegetated ditches with and without additional treatments. Vegetated ditches planted with native grasses provided up to 90% reduction in pesticide concentrations.

Moore *et al.* (2008) evaluated the reduction in pesticide concentrations in different types of vegetated drainage ditches by comparing pesticide concentrations at the inflow to pesticide concentrations at the outflow. The concentrations and half-life values with distance were calculated. The vegetated ditch was effective at reducing pesticide loading downstream, particularly for erosion-prone pesticides. The amount of reduction in concentration was dependent on the distance, vegetation, ditch shape, and pesticide properties.

While several studies are available evaluating the reduction in pesticide offsite transport for vegetated ditches, the available data indicate that their effectiveness can vary widely depending on the mobility of the pesticide, as well as the individual characteristics and management of the vegetated ditch (Alix *et al.*, 2017; Dollinger *et al.*, 2015; Moore *et al.*, 2008; Phillips *et al.*, 2017; USDA, 2014; Werner *et al.*, 2010). EPA categorized vegetated ditches as low based on the average efficacy across studies and the wide variability of effectiveness.

Table 5-19. Vegetated drainage ditch efficacy summary.

Mitigation	Measures Included in this Category	Efficacy	Percent Reduction Reported
Vegetative Ditch	Vegetated drainage ditch	Low	Average: 50% (Dollinger *et al.*, 2015) Range:3-99% (Dollinger *et al.*, 2015)

5.5.4 Riparian Area

> **Riparian buffer zone (herbaceous or forest)** refers to the ecosystem adjacent to or near flowing water. There may be a range of vegetation types in these areas. Vegetation in these buffers is tolerant to intermittent flooding and saturated soil and managed until established in the transitional zone between a field and an aquatic habitat. Herbaceous buffers are planted with non-woody vegetation, while forest buffers are planted with trees and shrubs. waterbody.

Riparian buffers (riparian herbaceous and riparian forest zones) function the same as VFS and field borders but are located on the banks of a stream downslope of a field and may or may not be immediately adjacent to the field. Therefore, riparian buffers and VFS share the same mechanisms of reducing surface water runoff, sediment loading, and pesticide loading, and the same factors will contribute to the efficacy of the riparian buffer.

Regarding sediment removal (and implicitly, sorbed pesticide removal), Lee *et al.* (2003) demonstrated 97% removal of sediment in a switchgrass/woody buffer zone, and Broadmeadow and Nisbet (2004) reported that 30 m (approximately 100 ft) buffers were effective at reducing 80 to 90% of sediment loads. In a meta-analysis of 16 studies, Stutter *et al.* (2021) reported that riparian buffers reduced pesticide loads from 0 to 100%, indicating a high level of uncertainty for riparian buffer effectiveness. The average reduction across the studies was 62%. This is consistent with the efficacy estimates available from other sources, where a 50% reduction was estimated for both runoff-prone and erosion-prone pesticides (USDA, 2014).

For pesticide removal, several studies are available examining the effectiveness of riparian buffers at reducing offsite transport of pesticides (Stutter *et al.*, 2021; Wenger, 1999; Wu *et al.*, 2023); however, there is uncertainty and variability in the efficacy based on the specific environment and pesticide. Just like VFS, riparian buffers vary in efficacy by the characteristics of the area, soil texture, vegetation, and whether the riparian area is well maintained. Despite this potential variability in efficacy, riparian systems can provide and improve the terrestrial and aquatic habitat and reduce pesticide residues in many environments (FOCUS, 2007). Additionally, NMFS indicated that this measure was considered to have a high reduction rating (NMFS, 2023) when used as a reasonable and prudent alternative. Therefore, EPA assigned the same efficacy for riparian buffers as for VFS (**Table 5-20**). Just as with VFS, increasing widths of a riparian buffer will increase its efficiency.

Table 5-20. Riparian areas efficacy summary.

Mitigation	Measures Included in this Category	Efficacy		Percent Reduction Reported
Riparian Area	Riparian forest buffer, riparian herbaceous cover	20 – <30 ft	Low	Average: 62% (Stutter *et al.*, 2021) Range: 0 to 100% (Stutter *et al.*, 2021) From VFS: Average: 40% (5 m), 65% (10 m), and 80% (20m) (Alix *et al.*, 2017; Reichenberger *et al.*, 2007; USDA, 2014) Range: 1 to 94% (Krutz *et al.*, 2005; Mickelson *et al.*, 2003; Poletika *et al.*, 2009)
		30 - <60 ft	Medium	
		≥ 60 ft	High	

5.5.5 Constructed and Natural Wetlands

Natural wetlands are similar to riparian areas, as they are vegetated ecosystems that function as transitional areas between land and water (NRC, 2002; USEPA, 1995; USEPA, 2003; USEPA, 2005). These areas have a multitude of ecosystem services, including being able to significantly reduce nonpoint source pollution by intercepting surface runoff, allowing the settling, filtering, or storing of sediment and associated pollutants (NRC, 2002; Øygarden et al., 1997; USEPA, 2003; USEPA, 2005). Constructed or artificial wetlands are typically defined as engineered treatment systems that replicate the natural processes found in wetlands to treat various types of effluent (USEPA, 2000).

In agricultural settings, constructed wetlands capture agricultural runoff and allow for the sedimentation, sorption, and degradation of pesticides (Øygarden *et al.*, 1997). These wetlands or riparian areas are typically located between uplands and adjacent water bodies, allowing them to act as buffers between agricultural fields and nearby waterways (Øygarden et al., 1997; USEPA, 2003). An agricultural best practice is to use these systems to control sediment and runoff, preventing them from entering waterways directly from the farm (Meinen and Robinson, 2020).

The efficacy of these systems depends, amongst other factors, on the hydraulic residence time, depth, and vegetation of the system (Budd et al., 2009; Iseyemi et al., 2021).
In constructed wetlands, Budd *et al.* (2009) observed a 52 to 94% reduction in seasonal pesticide concentrations; however, the constructed wetland was less effective at removing some pesticides than others. In their literature review of the efficacy of artificial wetlands, Alix

et al. (2017) found that constructed wetlands had an average pesticide reduction of 75%. However, for runoff prone pesticides the reduction was 60% and for erosion prone pesticides, the reduction was 90% (Alix et al., 2017).

Kay *et al.* (2009) reviewed several papers that looked at the effect of constructed wetlands on the mass losses of pesticides due to surface waters. This study summarized the results across nine pesticides and found constructed wetlands had an average reduction of pesticide mass loss was 80%, with a range of 25 – 100%. Kay *et al.* (2009) also noted that the size of a wetland relative to the catchment from which it is receiving runoff a major factor in the efficacy of these systems.

Abundant studies are available evaluating the efficacy of constructed wetlands to reduce pesticide offsite transport (Alix et al., 2017; Budd et al., 2009; Kay et al., 2009). There is also a long-standing understanding of the ability of naturally occurring wetlands and riparian areas to reduce nonpoint source pollution (USEPA, 2005) (NRC, 2002).

The efficacy of these systems is determined by several factors, most notably: 1) the physio-chemical properties of the pesticide (i.e. K_{oc}), 2) the plant coverage in the wetland, and 3) the residence time in the system. Based on the high average efficacy of available literature EPA categorizes these measures as high. (**Table 5-21**).

Table 5-21. Constructed and natural wetland efficacy summary.

Mitigation	Measures Included in this Category	Efficacy	Percent Reduction Reported
Constructed and natural wetlands	Constructed wetlands, artificial wetlands, restoration/enhancement/creation of natural wetlands	High	Average: 80% (Kay *et al.*, 2009) Range: 25 to 100% (Kay *et al.*, 2009)

5.5.6 Terrestrial Habitat Landscape Improvement

Upland Habitat refers to an area of land located above where water or flooding occurs, generally at higher elevations.

This mitigation measure represents a collection of upland habitat improvements that, when located in an area down gradient from an application site and in a location that would collect or receive runoff/erosion from the application site, would serve a similar functional role as other runoff/erosion mitigation measures in **Table 5-1**. The purpose of these improvements is to create and improve habitat for animals and plants. Improvements may include but are not limited to manipulation or establishment of vegetation which may serve as shelter and/or a food source for animals.

In **Sections 5.4.4** and **5.5.2**, EPA describes vegetative filter strips (VFS) as managed in- or off-field areas of grass or other permanent herbaceous vegetation that intercepts and disrupts flow of runoff, traps sediment, and reduces pesticide concentrations in water. Generally, a filter strip can vary in width (typically 20 to 120 feet wide). Filter strips are usually planted with native grasses and perennial herbaceous plants. Nutrients, pesticides, and soils in the runoff water are filtered through the vegetation, potentially adsorbed by the soil, and potentially taken up by the plants. The effectiveness of filter strips to reduce pesticide loading into an adjacent surface waterbody depends on many factors, such as topography, field conditions, hydrologic soil group, antecedent moisture conditions, rainfall intensity, properties of the pesticide, application methods, width of the filter strip, and types of vegetation within the strip. Therefore, pesticide reductions from the use of filter strips may vary.

Since upland habitat improvements also typically incorporates the establishment of vegetation, EPA has determined that this mitigation measure will function similar to VFS by reducing pesticide movement through runoff and/or drift when located down gradient from a pesticide application area. Unlike VFS, the intended purpose for this measure is to create and improve habitat, and are not intentionally created or used for the reduction of sediment and contaminants contained in surface runoff; however, their composition, design, and size would make them at least as efficient at capturing, filtering, or slowing down pesticides in runoff/erosion as those measures described under the vegetative filter strips measures (**Sections 5.4.4** and **5.5.2**).

EPA considers the efficacy information for vegetative filter strip measures (**Sections 5.4.4** and **5.5.2**) suitable for the estimation of the efficacy of these other mitigations. Therefore, the upland landscape/habitat improvement measure has the same efficacy as discussed for the adjacent to the field vegetative filter strip measure.

Table 5-22. Terrestrial habitat/landscape Improvement measure efficacy summary.

Mitigation	Measures Included in this Category	Efficacy	Percent Reduction Reported
Terrestrial Habitat/Landscape Improvement	Terrestrial Habitat/Landscape Improvement 20 to <30 ft wide	Low	EPA Vegetative Filter Strips (Adjacent to the Field) See **Section 5.5.2**
	Terrestrial Habitat/Landscape Improvement 30 to <60 ft wide	Medium	
	Terrestrial Habitat/Landscape Improvement ≥ 60 ft wide	High	

5.5.7 Filtering Devices with Activated Carbon or Compost Amendments (Adjacent to the Field)

Applications of filtering devices that incorporate activated carbon or compost amendments in filters, sleeves, socks or filtration units for receiving drains or water outlets is a mitigation measure that is implemented adjacent to agricultural fields.

A filter with granular activated carbon (GAC) is a proven measure to remove certain chemicals, particularly organic chemicals such as pesticides from water. Phillips *et al.* (2017) reported 95% average reduction of chlorpyrifos (an erosion prone but moderately mobile chemical with average K_{oc} of 6,040 L/kg-oc) using a granulated activated carbon (GAC) sock/sleeve in a constructed bare drainage ditch.

Limited information is available for pesticide reduction specifically, utilizing compost in filters, socks, and sleeves. However, understanding that compost is an organic material with sorption potential to sorb like organic compounds, compost materials used in filter socks would be expected to sorb pesticides in runoff and trap sediment limiting erosion. USDA ARS research has shown this mitigation practice can physically filter fine and coarse sediment and chemically filter soluble pollutants from stormwater. Performance of compost filter socks, straw bales, and mulch berms was evaluated on field test plots. Compost filter socks reduced runoff total suspended solids (TSS) and turbidity by 76% and 29%, straw bales by 54% and 12%, and mulch berms by 51% and 8%, respectively (Faucette *et al.*, 2009). Another study evaluated the hydraulic flow-through rate for compost filter socks versus a silt fence. It was determined that compost filter socks have a 50% greater flow-through rate than a silt fence without a reduction in sediment removal efficiency performance (Keener *et al.*, 2007).

Most studies evaluating activated carbon in filters or filtration units are from laboratory-based studies. There is uncertainty in the efficacy of filters to treat larger runoff volumes at the field scale and with the pesticide carrying capacity of the activated carbon amendment over time. However, the available GAC studies demonstrate high effectiveness under field and laboratory conditions for many chemicals, which increases EPA's confidence in the effectiveness of GAC based filters. The efficacy score for activated carbon amendments in filters, sleeves, socks, or filtration units adjacent to the field was categorized as high based on literature reviews and EPA's confidence in the available data. Due to the uncertainty around the percent reduction specific to pesticides and the compost quality, the efficacy for compost amendments in filters, sleeves and socks adjacent to the field was categorized as low based on literature reviews and EPA's confidence in the available data (**Table 5-23**).

Table 5-23. Carbon or compost amendments efficacy summary.

Mitigation	Measures Included in this Category	Efficacy	Percent Reduction Reported
Carbon Amendment	Filters, sleeves, socks, or filtration units containing activated carbon	High	Average: 95% (Phillips et al, 2017) Range: Not available
Compost Amendment	Filters, sleeves, socks containing compost	Low	Average : 18% (Phillips et al, 2017) Range : Not available

5.6 Mitigation Measures: Systems that Capture Runoff and Discharge

There are various water management systems that are designed to reduce or effectively eliminate runoff from a field. In some of these systems, runoff is captured, held onsite and potentially reused, before being discharged based on the water management needs of the grower. Other systems, such as tile drains, capture and move runoff offsite. In all of these systems, water is discharged from a discernible, confined and discrete conveyance (such as a pipe, ditch, channel, etc.)[15]. While exposure to nearby waterbodies can still occur from any of these discharges, sheet flow runoff from the field is not driving the exposure, differentiating these systems from other runoff mitigation measures. This section is subcategorized as follows:

- **Water Retention Systems (Section 5.6.1)** are mitigation measures that capture and store runoff, allowing sediment and sediment sorbed pesticides to settle out of the water.
- **Subsurface Drainage and Tile-Drainage Installed *without* Controlled Drainage Structure (Section 5.6.2)***,* which qualify as mitigation measures.
- **Systems that Capture Runoff and Discharge Where Exposure to Non-Target Species is Unlikely (Section 5.6.3)** are systems deemed as unlikely to lead to the potential for population-level impacts to listed species from resulting pesticide exposure from discharges.

5.6.1 Water Retention Systems

Water retention systems (such as retention ponds, sediment traps, catch basins, and sediment basins) capture and store runoff, and allow suspended solids to settle out into the basin (Long et al., 2010; Reyes, 2002; USEPA, 2003). To evaluate the efficacy of this mitigation measure, EPA considered systems where the irrigation water drains into a retention system, such as a catchment basin, such that sediment is captured in the system, effectively removing sediment-bound pesticides from the discharge water (Meinen and Robinson, 2020).

More broadly, water retention systems can promote water infiltration and sedimentation, as well as degradation and sorption of pesticides (Budd et al., 2009; Reyes, 2002; Rose et al., 2006; USEPA, 2003). These systems function by temporarily holding irrigation surface runoff, reducing the velocity and turbulence of flow, which enables suspended sediments and their associated pesticide load to settle out, as well as providing time for the pesticide to degrade (Alix et al., 2017; Long et al., 2010; Reyes, 2002; Rose et al., 2006). The efficacy of these systems depends,

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[15] As defined in Section 502(14) of the Clean Water Act, the term *point source* means any discernible, confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, channel… from which pollutants are or may be discharged. This term does not include agricultural stormwater discharges and return flows from irrigated agriculture. The term *nonpoint source* is defined to mean any source of water pollution that does not meet the legal definition of *point source*. (USEPA, 2003)

amongst other factors, on the hydraulic residence time[16], depth of the system, and the K_{oc} of the pesticide (Long et al., 2010).

When runoff flow rates into the basin are lower (resulting in a higher hydraulic retention time), sediment basins are effective at reducing offsite movement of sediment containing adsorbed pesticides (Prichard et al., 2016). However, the efficiency of sediment basins declines rapidly if water moves through the system too quickly, as in a high volume runoff event (Prichard et al., 2016).

Another important factor in the efficiency of sediment basins and retention ponds is the type of soil entering the basin (Alix et al., 2017; Long et al., 2010). Long *et al.* (2010) notes that coarse-grained or larger aggregated soil particles settle out of runoff much more rapidly than finer-grained silt and clay particles, on which the majority of sediment-associated pesticides would be carried. This is caused by differences of settling (i.e., fall) velocities of soil types. The settling velocity[17] of a soil particle is determined in part by the diameter of the sediment grain, with smaller particles (such as clay, silt, and some sandy soils) take much longer to settle out of suspension, if they settle at all (ASCE, 2008).

Multiple studies are available that evaluated the efficacy of water retention systems at reducing offsite pesticide transport (Alix et al., 2017; Long et al., 2010; Rose et al., 2006). Alix *et al.* (2017) found the average efficacy from available data was 60% for high K_{oc} pesticides. Long *et al.* (2010) reported a 39% reduction in suspended sediment concentrations (g/L) between the inlet and outlet of a sediment trap during the first irrigation event of the trial but did not see reductions in subsequent irrigation events. Rose et al. (2006) found that the average reduction of three pesticides in an open pond ranged from 0 – 35%.

Additionally, these studies demonstrate that the highest efficacy is achieved in systems with a long hydraulic residence time with effectiveness dropping considerably in systems with a short hydraulic residence times. Other factors, such as whether the system is vegetated, the soil type present in the runoff, and the K_{oc} of the pesticide, contribute to a wide range of efficacy. Due to this variability, water retention systems are categorized with a medium efficacy (**Table 5-24**).

Table 5-24. Water retention systems efficacy summary

Mitigation	Measures Included in this Category	Efficacy	Percent Reduction Reported
Water Retention Systems	Retention ponds, sediment basins, catch basins, sediment traps	Medium	Average: 60% (Alix *et al.*, 2017) Range: Not available

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[16] The *hydraulic residence time* (t) also known as the *detention time* or *retention time* in water systems, is a ratio between the volume of a system (V) and the flow rate of the water entering the system (Q) (Davis and Masten, 2004).

[17] The *settling velocity*, also known as the fall velocity, of a sediment grain in water is determined by the grain's diameter and density, as well as the viscosity of water. Falling under gravity, a particle will reach a constant, terminal velocity once the drag equals the submerged weight of the particle. (ASCE, 2008)

5.6.2 Subsurface Drainage and Tile-Drainage Installed without Controlled Drainage Structure

Tile drains and artificial drainage of agricultural fields are a common practice utilized by farms to manage drainage of finer textured soils. Abundant literature is available describing the effectiveness of artificial drainage and tile drains to improve soil water conditions, increase crop yields, and reduce flooding, ponding, and runoff and erosion from agricultural fields. In a review of more than 30 North American studies of artificially drained fields, pesticide losses from tile drainage water were found be up to an order of magnitude less than that from surface runoff (Kladivko *et al.*, 2001).

Although erosion-prone chemicals have a high potential for reduced offsite movement in tile drained fields, mobile pesticides dissolved in water can be rapidly transported through soil macropores via preferential flow to tile drains and surface waters(Ng *et al.*, 1995). Given the available information and based on the efficacy for mobile chemicals, EPA has categorized such systems in this mitigation measure as low efficacy (**Table 5-25**).

Table 5-25. Subsurface tile drains installed without controlled drainage structure efficacy summary.

Mitigation	Measures Included in this Category	Efficacy	Percent Reduction Reported
Subsurface Tile Drains, without a controlled outlet	Subsurface tile drains, tile drains	Low	Highly Variable

5.6.3 Systems That In and Of Themselves Reduce Exposure Such That Potential Population-level Impacts Are Unlikely.

A subset of systems that capture runoff and discharge are unlikely to lead to the potential for population-level impacts to listed species from resulting pesticide exposure from surface water runoff. Such systems are described in the following subsections.

5.6.3.1 Systems with Berms

There are several systems in use across the country that have berms/levee/dikes (referred to as berms throughout) surrounding flat fields, which capture irrigation and stormwater runoff. Some berms may be permanent, while others may be built annually. The key requirement around these structures is that they are in place at the time of application and carried through the cropping season, so that they are in place to capture runoff following an application. These systems effectively eliminate runoff discharges, although discharges through discrete conveyances may still occur.

Examples of these systems, which have been deemed as unlikely to lead to a potential for population-level impacts to listed species from resulting pesticide exposure from discharges, are described below. EPA developed it's understanding of these systems based on descriptions found in crop production and best management practice manuals (i.e., technical manuals) (Averill *et al.*, 2008; CCCGA, 2001; Espino *et al.*, 2023; FDACS, 2015; Hill *et al.*, 1992; Reyes, 2002; Schwankl, 2007).

5.6.3.1.1 Seepage Irrigation Systems:

One subset of systems with berms in place to manage runoff can be seen in South Florida, where flat fields are surrounded by drainage ditches connected to canal systems. These ditches are in turn surrounded by berms that are higher than the field and designed to direct all runoff flows into the surrounding ditches (FDACS, 2015). As such, these systems allow for the collection of all irrigation water and rainwater (FDACS, 2015). Due to the high water table and soil texture, growers are able to utilize these ditches to irrigate fields through seepage irrigation, as the naturally high water table is raised to a level where water moves to the field by capillary action (FDACS, 2015).This method of irrigation is typically practiced in humid regions on drought-prone soils (USEPA, 2003). An example of this can be seen in South Florida, where this is a common practice with many vegetable growers (FDACS, 2015). In these areas, ditches typically contain water all year long; however, precise control of the water table is difficult to achieve because of factors on the field level (*e.g.* soil characteristics, topography, depth to water table, irrigation schedule, etc.) (FDACS, 2015).

5.6.3.1.2 Cranberry Bogs:

Similar systems occur in a subset of cranberry production areas; however, growers may use either sprinkler irrigation or seepage irrigation (Hilary Sandler *et al.*, 2004). When cranberry bogs are constructed on mineral soils, the site's existing hydrology may be adapted to allow manipulation of the water table (Averill *et al.*, 2008). This may be accomplished by installing layers to confine water and organic material below the perched water table[18], beneath the cranberry bog (Averill *et al.*, 2008). The bog itself is then surrounded by ditches, which are in turn surrounded by elevated dikes (i.e. berms) (Averill *et al.*, 2008). The goal of such bog constructions is to establish a continuous, confining layer that restricts water permeability below the root zone of the cranberry bog, which extends beneath the drainage ditches and into the interior of the dikes (Averill *et al.*, 2008). This allows growers to impound water for harvest, leaf litter removal, pest control, and winter protection (Averill *et al.*, 2008).

5.6.3.1.3 Rice Paddies:

Another example of systems that employ berms and do not have sheet flow runoff discharges is Californian rice paddies. In these rice paddies, there are several water management systems

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[18] A perched water table is groundwater that is separated from the true or natural groundwater table by an unsaturated zone.

commonly used: flow through systems, recirculating tailwater recovery systems, static water irrigation systems (Espino *et al.*, 2023). In all of these systems, a shallow flood is typically established over the field (Espino *et al.*, 2023). Water is kept on the field throughout the growing season, except for short term drainage, and is only removed at the end of the growing season (Espino *et al.*, 2023).

In a flow through system, water is not held on the field. Instead, water is supplied to the top-most basin and sequentially floods each successive basin, with excess water being discharged as needed to manage the system (Espino *et al.*, 2023). In a recirculating tailwater recovery system, tailwater is captured and reused, limiting the occurrence of discharges (Espino *et al.*, 2023). In static water irrigation systems, a canal runs along the edge of the field, and each basin is irrigated from this canal, in parallel but separate from each other (Espino *et al.*, 2023). Treated water is kept out of the supply canal through a system of flap gates, therefore, any discharges of water from the canal do not contain pesticides (Hill *et al.*, 1992). Tailwater recovery systems are covered as a separate mitigation measure (**Section 5.6.3.2**). Static water irrigation systems are categorized as a system where exposure to nontarget species is unlikely, due to these systems ability to consistently prevent pesticides in discharges.

Outside of California, many rice growers also employ berms that retain precipitation within the rice field . However, there is some variability in how rice producers use berms to manage irrigation that is an important consideration. For instance, growers who drill seed rice on precision graded fields often plant into fields with no levees because it is easier to maneuver farm equipment (*e.g.,* planters, sprayers) across a field without berms than a field with berms. Growers then build levees when weather conditions allow, but strive to have them built by the time rice begins to tiller so that they can flood fields (USEPA, 2018). Therefore, growers may make early season pesticide applications to rice fields when berms are not present and, consequently, growers would not have necessary runoff/erosion mitigations (i.e., berms) in place to capture runoff/erosion at the time of application. This mitigation measure only applies to rice producers when growers have built berms sufficient for holding floods at the time of pesticide application.

5.6.3.2 Tailwater Return Systems

As previously discussed in **Section 5.4.7**, typical surface irrigation (such as furrow and border-strip irrigation) is conducted to have approximately 15 to 20% of the applied water runoff the field as tailwater, with as much as 30% of the irrigation water running off the field (Schwankl, Pricharg*, et al.*, 2007; USEPA, 2003). This ensures that there is sufficient infiltration time for the lower edge of a field to be adequately irrigated (Schwankl, Pricharg*, et al.*, 2007). While tailwater runoff is commonly seen with furrow and border-strip irrigation systems, it is rarely produced with sprinkler and micro-irrigation systems (Schwankl, Pricharg*, et al.*, 2007).

Tailwater return or recovery systems collect, store, and transport irrigation tailwater for reuse in an irrigation distribution system (Omer *et al.*, 2018; Reyes, 2002). These systems require a means of collecting the tailwater, such as a storage pond or sedimentation basin, and a way of returning the water into circulation for future irrigation (FDACS, 2015; Omer *et al.*, 2018; Reyes, 2002; USDA, 2023). These systems are designed to retain runoff on agricultural fields, thereby reducing the amount of effluent reaching downstream waterbodies (Omer *et al.*, 2018). Oftentimes, these systems are also used to collect runoff from rain events (USDA, 2023); however, they are not generally designed to store runoff from precipitation events that occurs during wetter seasons (Schwankl, Pricharg*, et al.*, 2007). Additionally, growers may choose to reduce seepage from these systems by installing impervious liners, increasing the volume of water available for reuse and potentially discharged (USDA, 2023).

Several factors influence the effectiveness of these systems at reducing pesticides in the reuse water. As these systems incorporate a sedimentation basin, they have the same limitations in removing sediment and sediment-sorbed pesticides as discussed in **Section 5.1.** This includes the retention time of the system and the type of soil entering the system. The retention time in the system effects how much deposition occurs of sediment and sediment-sorbed pesticides and the amount of pesticide that breaks down in the recovered water (Omer *et al.*, 2018; USDA, 2023). The efficiency of these systems is also effected by the type of sediment in the runoff, with coarser-grained or larger aggregated soil particles settle out of runoff much more rapidly than finer-grained silt and clay particles, on which the majority of sediment-associated pesticides would be carried (Alix et al., 2017; Long et al., 2010).

Additional factors that determine the effectiveness of tailwater recovery systems include how much water is in the system prior to an irrigation event and the timing between irrigation events (Omer *et al.*, 2018). A study of six tailwater return systems found that while concentrations in sediment did not differ between the influent and effluent of the systems, the mass loading leaving the field was reduced by 43%. This indicates a major benefit of these systems is a reduction in the load leaving the field is due to the reduction in water usage (Iseyemi *et al.*, 2021; Omer *et al.*, 2018).

These systems are most commonly used in row and field crop systems, while not being typically used in surface-irrigated orchards and vineyards (Prichard *et al.*, 2016; Reyes, 2002). As such, they are used throughout the country, in both water-scarce regions, such as California, as well as in the Lower Mississippi River Basin and eastern Arkansas to alleviate groundwater depletion and in Massachusetts to manage water levels in cranberry beds (CCCGA, 2001; Iseyemi *et al.*, 2021; Omer *et al.*, 2018; Popp *et al.*, 2004; Reyes, 2002; Schwankl, 2007).

There are multiple studies available evaluating the efficacy of water retention systems to reduce pesticide offsite transport (Iseyemi et al., 2021; Omer et al., 2018; Reyes, 2002; Schwankl, 2007). Additionally, there are multiple studies that evaluate the efficacy of water retention systems, such as sediment basins, to reduce pesticide offsite transport (Alix et al., 2017; Long et al., 2010; Rose et al., 2006). Since tailwater return systems include and improve upon a water retention basin, these studies were considered to supplement the limited research on tailwater return systems. Tailwater return systems have been deemed as unlikely to lead to the potential for population-level impacts to listed species from pesticide exposure.

5.6.3.3 Subsurface Tile-drains, with Controlled Drainage Structure

If a field has subsurface drainage installed (*e.g*., tile drains), runoff from the field will be greatly reduced. Maintained tile drains are known to reduce erosion, and pesticides with a high K_{OC} may have less offsite transport than runoff prone pesticides when compared to fields without tile drains (Skaggs *et al.*, 1982). If tile drains are not maintained, erosion could occur from a field due to the drain clogging. Subsurface tile drains that release the effluent (water) into water-controlled drainage structures or a saturation buffer zone that do not release water into downstream off-farm aquatic areas serve to contain any potential pesticide residues in runoff. If runoff and/or effluent from tile drains from the entire field is controlled and directed into a pond/saturation zone, EPA expects the potential for population-level impacts to be unlikely to nearby listed species.

5.6.4 Mitigations from Multiple Categories (i.e., on-field, adjacent to the field)

The mitigations available to reduce runoff from agricultural fields can generally be grouped into on-field mitigations, such as reduced tillage and cover crops, and adjacent to field mitigations like vegetative filter strips. On-field mitigations reduce offsite transport by slowing water movement, allowing precipitation to infiltrate into the soil, thereby reducing runoff and erosion. Adjacent to the field mitigations reduce offsite transport of pesticides by capturing runoff and erosion that do leave the field (Wenger, 1999).

Combining on-field mitigations and adjacent to the field mitigations is likely to result in greater than additive decreased offsite pesticide movement as on-field mitigations result in more pesticide staying in the field and any pesticide leaving the field can be captured by adjacent to field mitigations. Increasing infiltration on the field will reduce the loading to the adjacent area (Alix *et al.*, 2017; Tomer *et al.*, 2013); resulting in higher efficacy of that mitigation measure (Alix *et al.*, 2017; Tomer *et al.*, 2013). (**Table 5-26**). The Minnesota Board of Soil and Water allows for reduced vegetative buffer distances when vegetative filter strips are combined with reduced tillage and/or cover crops, indicating that there is synergy incorporating both on-filed and adjacent to field mitigations (Minnesota Board or Water and Soil Resources, 2019). In a review of herbicide runoff from agricultural fields with vegetative filter strips, Krutz *et al.* (2005) suggest that in-field best management practices, such as conservation tillage, contour buffers, grassed waterways, and cover crops decrease the amount of sediment arriving at the field-VFS interface and can therefore improve the efficacy of the VFS. Similarly, Hayes and Dillaha (1992) indicate that reducing on-field runoff and erosion can improve the effectiveness of vegetative filter strips. A study in Nebraska found that narrow grass hedges (similar to a vegetative filter strip) reduced runoff from tilled corn by 22%, but decreased runoff from no-till corn by 52%, a 30% increase in effectiveness from the combination of an in-field practice (no-till) and an adjacent-to-field practice (grass hedge)(Gilley *et al.*, 2000) .

Table 5-26. Mitigation measures from multiple categories efficacy summary.

Mitigation	Measures Included in this Category	Efficacy	Percent Reduction Reported
Mitigation measures from multiple categories (*i.e.*, in-field, and adjacent to the field) are utilized.	Not applicable	Low	30%

5.7 Application Methods Where Exposure to Non-Target Species is Unlikely from Runoff and Erosion

EPA's evaluation indicated the run-off/erosion exposure from several application methods would be limited and thus the potential for population-level impacts is unlikely. These application methods include the following:

- **tree injection:** tree injection application methods do not generate runoff as the chemical is directly injected into the trunk of the tree.
- **chemigation applied to the subsurface and under non-permeable plastic mulch:** these application methods place the pesticide below either the soil surface or a plastic layer that is kept on the field for at least the entire season of the crop.
- **soil injection:** application of pesticides is not likely to result in offsite transport in runoff/erosion as the chemical is directly injected below the soil surface.
- **less than 1/10 acre (<4356 square feet) treated and spot treatment (<1000 sq ft treated)**. This provision applies to applications that total 1/10 of an acre or less to a field or a spot treatment of <1000 sq ft. These small footprint applications are often made using backpack sprayers, hand-held sprayers and other small equipment, but under some conditions larger smart technology application equipment may be used. Run-off/erosion that could result from these small-treated areas would be limited. EPA's modeling of runoff EECs for ponds and wetlands assume that 10 hectares (25 acres) is treated and all runoff and mobilized pesticides drain into a nearby pond or wetland. Treating 0.1 acres or less means at least a 250-fold (25 acres / 0.1 acres) lower treatment area than EPA's standard models assume. As described in Section 5.2.2, EPA expects additional reductions in exposure from the physical features of untreated portions of fields that result in improved sorption, dilution, and interception of pesticides in soil and water in a similar way as several in-field mitigation measures summarized in **Table 5-1**. Taken together, the lower mass of pesticide applied to these small areas and additional reductions from in-field landscape features would reduce the impact of runoff and erosion and reduce the likelihood of population-level impacts. Therefore, treatments that are less than 0.1 total acres or spot treatments <1000 sq ft are unlikely to result in pesticide concentrations in water or sediment that would lead to population-level impacts.

5.8 Mitigation Measures: Not Currently Included

EPA also received suggestions for other mitigations for inclusion as s a potential mitigation measure for run-off/erosion. After considering them, EPA is not adding them at this time primarily due to insufficient description of the practice, lack of data to evaluate their efficacy, or environmental concerns with the practice.

These practices include:
- Polyacrylamide Anionic Erosion Control (PAM)
- Flooded Agriculture
- Crop Row Spacing
- Biochar as In-Field Carbon Amendment
- Biochar in Filtering Devices Adjacent to Field
- Integrated Pest Management (IPM)

5.8.1 USDA Practices Not Currently a Run-off/Erosion Mitigation Measure

EPA determined that the USDA practices shown in **Table 5-27** are not suitable for managing runoff and/or erosion from cultivated agriculture, or are no longer active in USDA, therefore EPA has not included them as a run-off/erosion mitigation measure at this time.

Table 5-27. USDA Practices Not Currently Eligible for Mitigation Points

USDA Practice	USDA Practice Code
Pasture and Hay Planting	512
Forage Harvest Management	511
Grazing Land Mechanical Treatment	548
Land Reclamation, Landslide Treatment	453
Prescribed Grazing	528
Range Planting	550
Silvopasture	381
Heavy Use Area Protection	561
Stream Crossing	578
Nutrient Management	590
Watering Facility	614
Dry Hydrant	432
Land Smoothing[1]	466
Windbreak Shelterbelt Renovation[1]	650
Tree Shrub Planting[1]	660

[1] NRCS no longer implements these practices.

5.9 Pesticide Runoff Vulnerability

Several factors influence whether a pesticide will be present in surface water runoff from an agricultural field. Of note are the local soil texture and weather patterns, as well as whether a pesticide is on the field at the time of a weather event. EPA evaluated the vulnerability of areas across the lower 48 states to pesticide runoff using PWC to simulate pesticide runoff transport from approximately 3 million scenarios across the lower 48 states. These scenarios comprise 54 years of weather data, soil and slope characteristics, 16 different crop categories. The scale of this modeling simulation was conducted at a much finer resolution than that of EPA's standard aquatic modeling for regulatory actions (i.e. 2-digit HUC resolution).

EPA used the total PWC-simulated pesticide mass leaving each scenario field to estimate each scenario's vulnerability. Because the simulation's resolution was so high, it was necessary to average the scenarios about the weather grid (about 17 miles apart). This reduces the resolution to make the map more viewable and understandable. Although vulnerability is expressed in terms of EECs, this is not a concentration expected to be observed in a waterbody, and its absolute value should be ignored. Instead, vulnerability values should only be used in relative comparisons to other scenarios.

Pesticide Runoff Vulnerability Score is the EEC used to indicate a location's vulnerability to pesticides occurring in runoff. This score is derived from the median of the long-term average EECs at each weather grid, under modeling inputs that ensure runoff is the driver of pesticide movement offsite.

This vulnerability assessment does not consider chemical-specific factors, such as usage. Additionally, this approach has many of the same limitations as the regulatory standard model, including not taking into account local hydrological characteristics or the impact of local management practices (*e.g.,* tile drains). Even so, this approach allows EPA to combine standard modeling practices with a hypothetical situation to discern an area's relative vulnerability to pesticide runoff across the lower 48 states.

EPA divided the pesticide runoff vulnerability scores into four mitigation categories based on the magnitude of difference from the nationwide maximum score (**Table 5-28**). These categories allow EPA to recognize areas with significantly less potential for pesticides occurring in runoff (very low and low), the transition zone across the middle of the country (medium), and areas most prone to pesticides occurring in runoff (high) (**Table 5-28**).

Table 5-28. Categories of magnitude of difference from nationwide maximum pesticide runoff vulnerability score with corresponding associated percentiles and classifications. Coloring corresponds to Figure 5-2.

Order of Magnitude Lower than Max	Pesticide Runoff Vulnerability	
	Percentile	Classification
~2	0 – 9%	Very low
~1	10 – 49%	Low
~Half	50 – 84%	Medium
Maximum	85 – 100%	High

Weather grid locations occur at approximately a 17 by 17-mile scale. As communicating mitigations at this scale is untenable, EPA chose to scale this level of resolution to a county level. EPA evaluated approaches to determine pesticide runoff vulnerability at smaller resolutions, however, ultimately decided that a county scale was appropriate as it is meaningful to stakeholders, easily communicated, and maintained much of the variability seen on smaller scales.

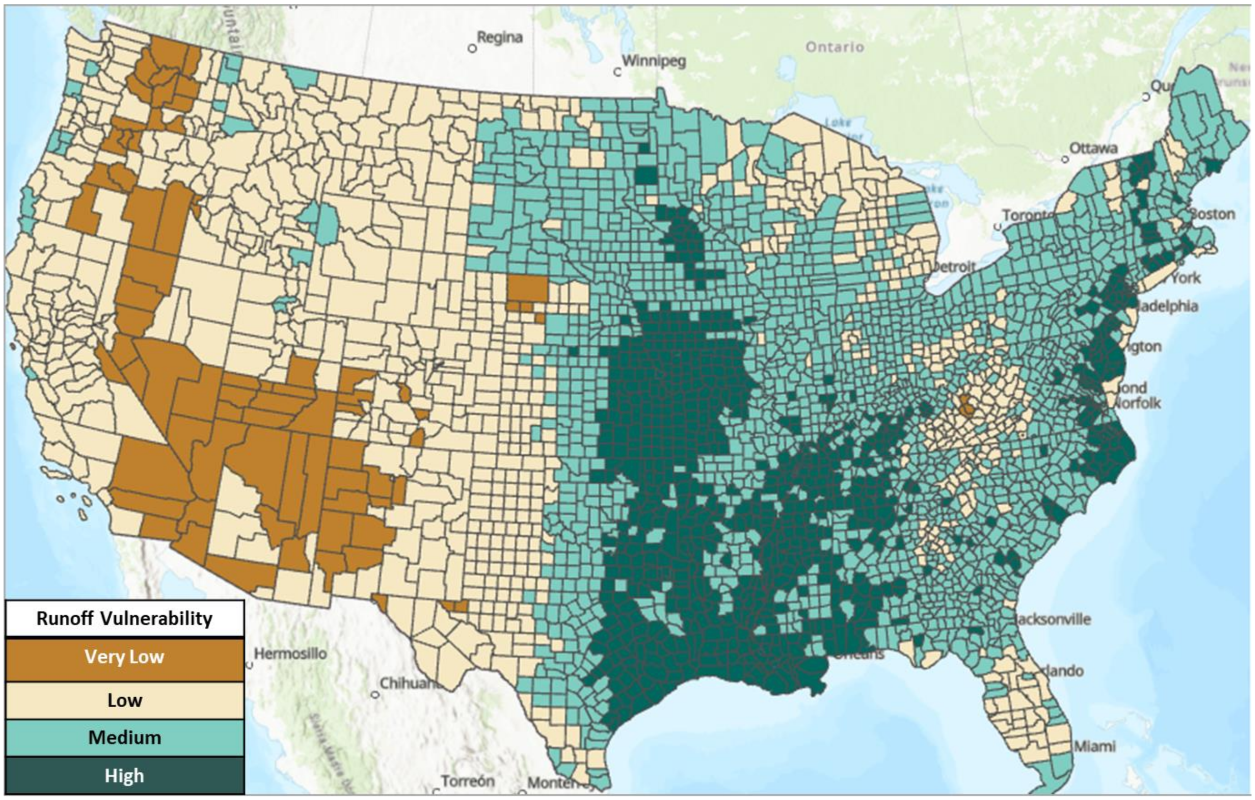

Figure 5-2. Geography mitigation relief points as informed by pesticide runoff vulnerability.

Figure 5-2 illustrates the variability of pesticide runoff vulnerability on the county scale across the lower 48 states. The more arid Western U.S. has pesticide runoff variability ranging from very low to low, whereas the Central and Eastern U.S. generally range from medium to high; there are exceptions to pesticide runoff vulnerability within each of these regions.

EPA evaluated the magnitude of differences across the categories of pesticide runoff vulnerability scores, as summarized in **Table 5-28**. Counties classified as highly vulnerable to pesticides occurring in runoff would reflect conditions that EPA assumes when it evaluates a potential for population-level impacts. For medium, low, and very low vulnerability areas, EPA's evaluation shows the potential for population-level impacts based on conditions associated with areas highly vulnerable to pesticides may be increasingly overestimated. As described in Section 5, three points represents an order of magnitude reduction equivalent to the reduction needed to drop from one category of potential for population-level impacts to a lower category (e.g., from high to medium). Using this same logic (see **Table 5-30**), EPA determined that for areas with very low pesticide run-off vulnerability, its approach likely overestimates the potential for population level impacts by approximately two orders of magnitude and EPA would identify 6 mitigation relief points to account for bias in the approach. For areas with low pesticide run-off variability, that overestimation is approximately an order of magnitude, and EPA would identify 3 mitigation relief points. For areas with medium pesticide run-off variability, that overestimation is approximately ½ order of magnitude, and EPA would identify 2 mitigation relief points.

Additional analyses reached similar conclusions to the pesticide runoff vulnerability modeling. These analyses looked at how the proportion of offsite pesticide movement due to runoff varies across the country, as well as where regions with higher levels of precipitation or surface runoff and agriculture (and therefore, pesticide application) occur.

See **Appendix G** for in-depth descriptions of the pesticide runoff vulnerability analysis and the additional lines of evidence used to corroborate the pesticide runoff vulnerability classifications.

5.10 Areas 1000 ft Down-gradient from an Application Area

As described in **Section 2**, exposure to pesticides by non-target organisms and their habitat through runoff/erosion is highest the closer the non-target species are to the pesticide application area. Runoff and erosion are directional, meaning off-site transport occurs when an adjacent area is at a lower elevation than a pesticide application area.

When runoff occurs over surface that is flat or has low slope, it can be described as overland flow or sheet flow. After approximately 100 ft, shallow concentrated flow usually begins as overland flow and converges to form small rills, gullies, and swales (NRCS, 2010). The maximum distance shallow concentrated flow travels will vary for different watersheds and waterbodies but has been assumed to be 1,000 ft to 1,200 feet (305 to 366 m) by several engineering texts (TXDOT, 2019; USDA, 2010; VaDEQ, 1992). Wu and Lane (2017) calculated overland flow path lengths[19] for 41,449 wetlands in the prairie pothole region, and the majority had a flow path length of less than 1,312 ft (400 m) with a mean of 453 ft (138 m).

Considering the totality of the information above, EPA assumes that runoff can be represented by overland flow that extends downslope over a maximum distance of 1,000 feet from the application (Wu and Lane, 2017). Accordingly, areas beyond 1,000 feet are likely to receive less runoff and erosion from the treated field, if at all, making the potential for population-level impacts unlikely. This 1,000 ft proximity is also considered by other countries and National

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[19] Overland flow path lengths are defined as "*the distance between the spilling point of an upslope wetland and the inlet of a downslope wetland or stream" (Wu and Lane, 2017)*.

Marine Fisheries Service (NMFS)[20] in determining the need for and amount of runoff and erosion mitigation needed at a site (Bauer *et al.*, 2014; NMFS, 2023).

EPA does not expect to identify runoff/erosion mitigations for pesticide applications areas more than 1,000 feet downwind from a terrestrial or aquatic habitat for listed species. EPA has received comments from a wide variety of stakeholders that EPA should not rely on habitat descriptions to determine if an application is within 1,000 feet of such habitats because stakeholders could not readily identify them based on those descriptions. When EPA develops Pesticide Use Limitation Areas for geographically specific run-off/erosion mitigations, it ensures the geographic extent of the mitigations does not extend beyond 1,000 feet from those areas it identifies for conservation of a listed species and its critical habitat. However, in some cases, EPA expects to identify mitigations for listed species that would apply across the full spatial extent of a use pattern (e.g., specific crops) within the contiguous U.S., specifying the mitigations on the general pesticide product label. In this case, EPA similarly does not want growers/pesticide applicators to implement mitigations unless they are within 1,000 feet of terrestrial or aquatic habitat. To account for this and in light of the stakeholder comments, rather than describe habitats, EPA is identifying areas adjacent to a field that likely wouldn't contain habitat. Many farms have highly managed lands in areas adjacent to a pesticide application. This 1,000 ft may include managed and/or developed lands and landscapes in areas adjacent to a pesticide application. While these managed practices may not be intentionally created for the purpose of mitigating pesticides, their composition and size on the landscape would make them as efficient as permeable land or more efficient (e.g., vegetative filter strips) at intercepting runoff and reducing the distance it may travel. Moreover, EPA does not expect these managed lands to contain sufficiently suitable species habitat that enough individuals would be exposed to rise to a potential population-level impact. Therefore, to the extent that managed areas represent the entirety of 1,000 feet downwind and immediately adjacent to a pesticide application (and they themselves not being treated with the pesticide), EPA concludes that growers/applicators would not need to implement run-off/erosion mitigations. **Table 4-11** describes the managed areas that EPA has identified for purposes of run-off/erosion mitigation.

5.11 Conservation Program and Runoff/Erosion Specialist Consideration

EPA's evaluation of available efficacy data for many of the runoff/erosion mitigation measures demonstrates that the efficacy of many mitigations is highly variable from one study to the next (and from site to the next). For example, for some measures, studies show that efficacy may range from 0% to 100%. For any given mitigation measure, a range of efficacy is expected depending on the specific implementation of the measure, the environmental conditions of the area, site and soil characteristics of the treated field, maintenance, upkeep of the mitigation measure, and the physical-chemical properties of the pesticide.

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[20] In a March 2023 draft Biological Opinion for carbaryl and methomyl, the NMFS applied reasonable and prudent alternatives (RPAs) to uses that were in close proximity (300 meters) to listed species habitat (NMFS, 2023).

Often, growers/applicators work with a technical expert in runoff/erosion control or a conservation program with a goal of reducing runoff/erosion. Because these experts consider and make recommendations for the site-specific conditions, when a grower/applicator installs a runoff/erosion measure to the specifications from such an expert, EPA has higher confidence that mitigation measures identified and implemented at the field level would achieve the higher end of the available efficacy data. As such, EPA is providing mitigation points for growers/applicators that work with a qualifying technical expert **or** participate in a qualifying conservation program.

A grower/applicator may receive mitigation points working with a technical expert or participating in a conservation program, but not both. The grower/applicator would receive points for any of their fields that are included in the expert consultation or conservation program, which could be an entire farm or a fraction of it (e.g., some fields, but not all within a farm). The grower/applicator would not get additional points for both working with an expert/specialist and for participating in a conservation program, since the expert/specialist is inherently part of the program. Additionally, these points are not applicable to each mitigation measure but rather would be in addition to the points a grower/applicator obtains from other relief points (e.g., if the farm is located in an area of low run-off vulnerability) and for implementing mitigation measures. Each of these options and the associated mitigation points are described in more detail below.

5.11.1 Follow Recommendations from a Runoff/Erosion Specialist

Growers/Applicators may work with a technical expert to develop mitigation plans that work for their field and that are efficacious in reducing runoff and/or erosion. As described above, when a grower is working with a technical expert who embodies the characteristics below, EPA expects that the mitigation measures would be selected and implemented considering site-specific conditions, including the soil type, field slope, hydrology, local climate, crop(s) grown, pest concerns, drainage systems, irrigation needs, and equipment availability. Specific cropping systems and regions have established norms and practices based on real-world experience that on-site professionals (i.e., technical experts) can account for in the planning process. In this case, EPA expects the efficacy of runoff/erosion mitigation measures would be on the higher end of the range of efficacy. To account for this, EPA is providing one runoff/erosion mitigation point to growers/applicators that work with a runoff/erosion technical expert that meets the characteristics described below. The point for working with the technical expert is in addition to the points for implementing mitigation measures identified in the strategy.

EPA has reviewed available information regarding characteristics that often apply to meet the description of a technical expert. At a minimum, there is usually an education (and a continuing education) and an experience component. Based on this review, EPA identified three benchmarks for technical experts, which include:

- Have technical training, education and/or experience in an agricultural discipline, water or soil conservation, or other relevant discipline that provides training and practice in the area of runoff or erosion mitigation technologies/measures; **And**

- Participate in continued education or training in the area of expertise which should include run off and erosion control; **And**
- Have experience advising on conservation measures designed to develop site specific runoff and erosion plans that include mitigation measures described in **Sections 4 and 5**.[21]

EPA has identified the following examples of technical experts: NRCS and similar state or regional level program staff, Certified Crop Advisor, Pesticide Control Advisor, Certified Professional Agronomist, National Alliance of Independent Crop Consultants (NAICC), EnviroCert International, Inc., Certified Professionals in Erosion and Sediment Control, Technical Service Providers, and extension agents. **EPA acknowledges that this list is not exhaustive, and the inclusion of an organization should not be construed as an endorsement of any particular group by EPA.**

5.11.2 Participate in a Conservation Program

Conservation programs provide technical expertise as described above, as well as additional support to growers/applicators. Based on EPA's review of available information on existing programs, this support may include oversight in the form of a review of design, installation, and upkeep/maintenance plan for the identified mitigations. In addition, the programs typically include documentation demonstrating the site-specific plan meets any program requirements.

While conservation programs are not solely designed to reduce offsite transport of pesticides, several of the same types of mitigations that reduce offsite transport of nutrients and/or soil erosion from an agricultural field also reduce offsite transport of pesticides. Evaluating a field for the purpose of reducing nutrients in runoff and/or soil erosion is likely to result in similar recommended mitigations as those EPA identified to reduce pesticide runoff/erosion.

However, with few exceptions, EPA is not aware of any conservation programs that are designed specifically to reduce offsite transport to an extent where population-level impacts to listed species are unlikely. Therefore, while existing conservation programs may recommend similar mitigation measures, these measures may or may not be enough to address potential impacts to listed species. In addition, data is not readily available on the extent to which growers that participate in these conservation programs (and participation is voluntary) implement all program recommendations. For these reasons and given the goals of the strategies, EPA is not able to provide a full exemption for these programs at this time. Rather, EPA is providing two runoff/erosion mitigation points to growers that participate in a conservation program. The additional mitigation point provided for participation in a conservation program over consulting a technical expert is because programs include some additional minimum characteristics summarized below.

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[21] EPA's mitigation menu is available at: https://www.epa.gov/pesticides/mitigation-menu and a description of the mitigations is available at https://www.epa.gov/pesticides/menu-measure-descriptions.

EPA has developed the following minimum characteristics for a conservation program:

- The program has to provide advice from individuals who meet the same benchmarks provided above for technical experts; **And**
- The program provides site-specific guidance tailored to the grower's crop and/or location; **And**
- The program focuses on reducing or managing runoff and/or erosion (including for example, soil loss, soil conservation, water quality protection) from agricultural fields or other pesticide use sites; **And**
- The program provides documentation of program enrollment. EPA is **not** suggesting that this documentation be provided to EPA; **And**
- The program includes verification of implementation of the recommended measures or activities (measures were established and maintained). Verification can be done through the conservation program and provided to the program enrollee. Verification is **not** required to be submitted to EPA.

Note: Past participation in programs that meet the minimum characteristics also allows users to claim these mitigation points, provided that measures are currently on the field, have been maintained over time, and are recertified by a runoff and erosion technical expert [federal, state, or local; e.g., Certified Crop Advisor, Pesticide Control Advisor, Conservation Crop Protector, Certified Professional Agronomist, National Alliance of Independent Crop Consultants (NAICC), agronomists that are part of grower cooperatives].

5.11.3 Mitigation Tracking

All of the mitigation measures identified in in this support document (and any associated strategy) have been determined by EPA to provide some level of reduction of the potential for population-level impacts to listed species from pesticide exposure in runoff/erosion. Keeping track of the mitigations a grower/applicator employs at the field and farm level could provide several benefits to the grower/applicator. Tracking of the employed mitigation measures could help a grower ensure that they are achieving the number of points to satisfy any labeling requirements that include mitigations to address population-level impacts. Additionally, tracking the mitigations employed could assist with future planning of farm needs, and is generally aligned with the concepts of agricultural best management practices (commonly known as BMPs). Where a grower/applicator has a well thought out plan for the growing season which includes the tracking of mitigation measures employed EPA would have increased confidence that measures have been implemented and properly accounted for. Therefore, EPA is assigning one available point for any grower/applicator who tracks their mitigations in addition to any points for working with a specialist or participating in a conservation program. Working with a runoff/erosion specialist and/or participation in a program is not required to be eligible for this point, and therefore this point is available for any grower that tracks their mitigation measures.

6 Abbreviations

A: acres
a.i.: active ingredient
ASABE: American Society of Agricultural and Biological Engineers
BMP: best management practice BMP
CDL: cropland data layer
CVC: coarse to very coarse (droplet size distribution)
DSD: Droplet size distribution
EEC: estimated environmental concentration
^{o}F: degrees Fahrenheit
FM: fine to medium (droplet size distribution)
FMC: fine to medium/coarse (droplet size distribution)
ft: feet
EEC: estimated environmental concentration
EPA: U.S. Environmental Protection Agency
ESA: Endangered Species Act
FIFRA: Federal Insecticide, Fungicide, Rodenticide Act
FWS: U.S. Fish and Wildlife Service
GENEEC: GENeric Estimated Exposure Concentration
HUC: Hydrologic Unit Code
IEM: interim ecological mitigation
in.: inch
K_d: solid-water distribution coefficient
K_{OC}: organic-carbon normalized solid-water distribution coefficient
m: meter
MAgPIE: Model of Agricultural Production and its Impact on the Environment
MC: medium to coarse (droplet size distribution)
mph: miles per hour
NMFS: National Marine Fisheries Service
NOAA: National Oceanic and Atmospheric Administration
NRCS: Natural Resources Conservation Service
OPMP: Office of Pest Management Policy
OPP: Office of Pesticide Programs
PAM: polyacrylamide anionic erosion control
PWC: Pesticide in Water Calculator
RH: relative humidity
RPA: reasonable and prudent alternative
RPM: reasonable and prudent measure
SDTF: Spray Drift Task Force
SSURGO: Soil Survey Geographic Database
USDA: U.S. Department of Agriculture
VFF: very fine to fine (droplet size distribution)
VFS: vegetative filter strip

7 Literature Cited

Ahuja, L. R. 1986. *Characterization and Modeling of Chemical Transfer to Runoff.* Paper presented at the Advances in Soil Science, New York, NY.

Alix, A., Brown, C., Capri, E., Goerlitz, G., Golla, B., Knauer, K., et al. 2017. *Mitigating the Risks of Plant Protection Products in the Environment: MAgPIE*.

Alletto, L., Coquet, Y., Benoit, P., Heddadj, D., & Barriuso, E. 2010. Tillage management effects on pesticide fate in soils. A review. *Agronomy for Sustainable Development, 30*(2), 367-400.

Alliaume, F., Rossing, W. A. H., Tittonell, P., Jorge, G., & Dogliotti, S. 2014. Reduced tillage and cover crops improve water capture and reduce erosion of fine textured soils in raised bed tomato systems. *Agriculture, Ecosystems & Environment, 183*, 127-137.

Andrianarisoa, K. S., Dufour, L., Bienaimé, S., Zeller, B., & Dupraz, C. 2016. The introduction of hybrid walnut trees (Juglans nigra × regia cv. NG23) into cropland reduces soil mineral N content in autumn in southern France. *Agroforestry Systems, 90*(2), 193-205.

Ang, A. H.-S. 2007. *Probability concepts in engineering: emphasis on applications in civil & environmental engineering* (2nd ed.). New York: Wiley.

Arora, K., Mickelson, S. K., & Baker, J. L. 2003. Effectiveness of vegetated buffer strips in simulated runoff. *Transactions of the ASAE, 46*(3), 635-644.

Arora, K., Mickelson, S. K., Helmers, M. J., & Baker, J. L. 2010. Review of pesticide retention processes occurring in buffer strips receiving agricultural runoff. *JAWRA Journal of the American Water Resources Association, 46*(3), 618-647.

ASCE. 2008. *Sedimentation Engineering (Manual 110): Processes, Measurements, Modeling, and Practice*: American Society of Civil Engineers.

Aslam, S., Benoit, P., Chabauty, F., Bergheaud, V., Geng, C., Vieuble-Gonod, L., et al. 2014. Modelling the impacts of maize decomposition on glyphosate dynamics in mulch. *European Journal of Soil Science, 65*(2), 231-247.

Asmussen, L. E., White Jr., A. W., Hauser, E. W., & Sheridan, J. M. 1977. Reduction of 2,4-D load in surface runoff down a grassed waterway. *Journal of Environmental Quality, 6*(2), 159-162.

Averill, A., Caruso, F., Carolyn, D., Jeranyama, P., LaFleur, J., McKenzie, K., et al. 2008. *Cranberry Production Guide*. CP-08. December 2008. Cranberry Station, College of Natural Resources and the Environment, University of Massachusetts Amherst. Available at: https://scholarworks.umass.edu/cranberry_prod_guide/8.

Bauer, F., Dyson, J., Henaff, G. L., Laabs, V., Lembrich, D., Mezeray, J., et al. 2014. *Run-off Best Management Practices to Reduce Water Pollution with Plant Protection Products from Run-off and Erosion*. TOPPS Project. Available at: http://www.topps-life.org/uploads/8/0/0/3/8003583/_en_runoff_book.pdf.

Bird, S. L., Esterly, D. M., & Perry, S. G. 1996. Off-Target Deposition of Pesticides from Agricultural Aerial Spray Applications. *Journal of Environmental Quality, 25*(5), 1095-1104.

Blanco-Canqui, H., & Ruis, S. J. 2020. Cover crop impacts on soil physical properties: A review. *Soil Science Society of America Journal, 84*(5), 1527-1576.

Boyd, P. M., Baker, J. L., Mickelson, S. K., & Ahmed, S. I. 2003. Pesticide transport with surface runoff and subsurface drainage through a vegetative filter strip. *Transactions of the ASAE, 46*(3), 675.

Broadmeadow, S., & Nisbet, T. R. 2004. The effects of riparian forest management on the freshwater environment: a literature review of best management practice. *Hydrol. Earth Syst. Sci., 8*(3), 286-305.

Brown, R. B., Carter, M. H., & Stephenson, G. R. 2004. Buffer zone and windbreak effects on spray drift deposition in a simulated wetland. *Pest Manag Sci, 60*(11), 1085-1090.

Budd, R., O'Geen, A., Goh, K. S., Bondarenko, S., & Gan, J. 2009. Efficacy of constructed wetlands in pesticide removal from tailwaters in the Central Valley, California. *Environmental Science & Technology, 43*(8), 2925-2930.

Buisman, P., Sundaram, K. M. S., Sundaram, A., & Trammel, K. 1989. Field deposit patterns of a diflubenzuron spray mix, after application to an apple orchard using an air-blast sprayer; and a laboratory evaluation of physical properties and atomization characteristics. *Journal of Environmental Science and Health, Part B, 24*(4), 389-411.

Caron, E., Lafrance, P., & Auclair, J.-C. 2012. Temporal evolution of atrazine and metolachlor concentrations exported in runoff and subsurface water with vegetated filter strips. *Agronomy for Sustainable Development, 32*(4), 935-943.

Cassigneul, A., Alletto, L., Benoit, P., Bergheaud, V., Etiévant, V., Dumény, V., et al. 2015. Nature and decomposition degree of cover crops influence pesticide sorption: Quantification and modelling. *Chemosphere, 119*, 1007-1014.

Cassigneul, A., Benoit, P., Bergheaud, V., Dumeny, V., Etiévant, V., Goubard, Y., et al. 2016. Fate of glyphosate and degradates in cover crop residues and underlying soil: A laboratory study. *Science of The Total Environment, 545-546*, 582-590.

CCCGA. 2001. *Cranberry Water Use*. Cape Cod Cranberry Growers Association, University of Massachusetts Amherst.

Chalker-Scott, L. 2007. Impact of mulches on landscape plants and the environment — A Review. *Journal of Environmental Horticulture, 25*(4), 239-249.

Chikowo, R., Faloya, V., Petit, S., & Munier-Jolain, N. M. 2009. Integrated Weed Management systems allow reduced reliance on herbicides and long-term weed control. *Agriculture, Ecosystems & Environment, 132*(3), 237-242.

Chow, T. L., Rees, H. W., & Daigle, J. L. 1999. Effectiveness of terraces/grassed waterway systems for soil and water conservation: A field evaluation. *Journal of Soil and Water Conservation, 54*(3), 577-583.

Cooley, D. R., & Autio, W. R. 1997. Disease-management components of advanced integrated pest management in apple orchards. *Agriculture, Ecosystems & Environment, 66*(1), 31-40.

Cooperation, C. f. E. 2011. *Museum of Vertebrate Zoology, University of California, Berkeley. Total Annual Precipitation, 1950 - 2000*. Available at: https://tiles.arcgis.com/tiles/oF9CDB4lUYF7Um9q/arcgis/rest/services/NA_Annual_Precipitation/MapServer.

D. Fox, R., D. Brazee, R., L. Reichard, D., & R. Hall, F. 1990. Downwind Residue From Air Spraying Of A Dwarf Apple Orchard. *Transactions of the ASAE, 33*(4), 1104-1108.

D. Fox, R., L. Reichard, D., D. Brazee, R., R. Krause, C., & R. Hall, F. 1993. Downwind Residues from Spraying a Semi-dwarf Apple Orchard. *Transactions of the ASAE, 36*(2), 333-340.

Davis, M. L., & Masten, S. J. 2004. *Principles of Environmental Engineering and Science*: McGraw-Hill Higher Education.

De Schampheleire, M., Nuyttens, D., Dekeyser, D., Verboven, P., Spanoghe, P., Cornelis, W., et al. 2009. Deposition of spray drift behind border structures. *Crop Protection, 28*(12), 1061-1075.

Deasy, C., Quinton, J., Silgram, M., Bailey, A., Jackson, B., & Stevens, C. 2010. Contributing understanding of mitigation options for phosphorus and sediment to a review of the efficacy of contemporary agricultural stewardship measures. *Agricultural Systems, 103*, 105-109.

Deng, C., Zhang, G., Liu, Y., Nie, X., Li, Z., Liu, J., et al. 2021. Advantages and disadvantages of terracing: A comprehensive review. *International Soil and Water Conservation Research, 9*(3), 344-359.

Dexter, R. W. 2001. The Effect of Fluid Properties on the Spray Quality from a Flat Fan Nozzle. In (pp. 27-43).

Dollinger, J., Dagès, C., Bailly, J.-S., Lagacherie, P., & Voltz, M. 2015. Managing ditches for agroecological engineering of landscape. A review. *Agronomy for Sustainable Development, 35*(3), 999-1020.

Dosskey, M. G., Helmers, M. J., & Eisenhauer, D. E. 2008. A design aid for determining width of filter strips. *Journal of Soil and Water Conservation, 63*(4), 232-241.

El Kateb, H., Zhang, H., Zhang, P., & Mosandl, R. 2013. Soil erosion and surface runoff on different vegetation covers and slope gradients: A field experiment in Southern Shaanxi Province, China. *CATENA, 105*, 1-10.

Espino, L., Brim-Deforest, W., Leinfelder-Miles, M., Al-Khatib, K., Grettenberger, I., Linquist, B., et al. 2023. *Rice Production Manual* University of California, Division of Agriculture and Natural Resources. University of California Davis, Department of Plant Sciences. Califorina Cooperative Rice Research Foundation Inc., Rice Experiment Station.

Faucette, L. B., Governo, J., Tyler, R., Gigley, G., Jordan, C. F., & Lockaby, B. G. 2009. Performance of compost filter socks and conventional sediment control barriers used for perimeter control on construction sites. *Journal of Soil and Water Conservation, 64*(1), 81-88.

Fawcett, R. S., Christensen, B. R., & Tierney, D. P. 1994. The impact of conservation tillage on pesticide runoff into surface water: A review and analysis. *Journal of Soil and Water Conservation, 49*(2), 126-135.

FDACS. 2015. *Water Quality/Quantity Best Management Practices for Florida Vegetable and Agronomic Crops*. In F. D. o. A. a. C. Services (Ed.) (2015 ed.).

Fiener, P., & Auerswald, K. 2003. Effectiveness of grassed waterways in reducing runoff and sediment delivery from agricultural watersheds. *Journal of Environmental Quality, 32*(3), 927-936.

FOCUS. 2007. *Landscape and Mitigation Factors in Aquatic Risk Assessment. Volume 1: Extended Summary and Recommendations. Version 2*. EC Document Reference SANCO/10422/2005. September 2007. Report of the FOCUS Working Group on landscape and mitigation factors in ecological risk assessment. Available at: https://esdac.jrc.ec.europa.eu/projects/focus-landscape-mitigation.

Foster, H. C., Sperry, B. P., Reynolds, D. B., Kruger, G. R., & Claussen, S. 2018. Reducing herbicide particle drift: effect of hooded sprayer and spray quality. *Weed Technology, 32*(6), 714-721, 718.

Fry, M. M., Rothman, G., Young, D. F., & Thurman, N. 2016. Daily gridded weather for exposure modeling. *Environmental Modeling & Software, 82*, 167-173.

Gan, J., Zhu, Y., Wilen, C., Pittenger, D., & Crowley, D. 2003. Effect of planting covers on herbicide persistence in landscape soils. *Environmental Science & Technology, 37*(12), 2775-2779.

Gathagu, J., Mourad, K., & Sang, J. 2018. Effectiveness of contour farming and filter strips on ecosystem services. *Water, 10*.

Gaynor, J. D., MacTavish, D. C., & Findlay, W. I. 1992. Surface and subsurface transport of atrazine and alachlor from a Brookston clay loam under continuous corn production. *Archives of Environmental Contamination and Toxicology, 23*(2), 240-245.

Gaynor, J. D., Tan, C. S., Drury, C. F., van Wesenbeeck, I. J., & Welacky, T. W. 1995. Atrazine in surface and subsurface runoff as affected by cultural practices. *Water Quality Research Journal, 30*(3), 513-532.

Gholamahmadi, B., Jeffery, S., Gonzalez-Pelayo, O., Prats, S. A., Bastos, A. C., Keizer, J. J., et al. 2023. Biochar impacts on runoff and soil erosion by water: A systematic global scale meta-analysis. *Science of The Total Environment, 871*, 161860.

Ghosh, S. P., Kumar, B. M., Kabeerathumma, S., & Nair, G. M. 1989. Productivity, soil fertility and soil erosion under cassava based agroforestry systems. *Agroforestry Systems, 8*(1), 67-82.

Gilley, J. E., Eghball, B., Kramer, L. A., & Moorman, T. B. 2000. Narrow grass hedge effects on runoff and soil loss. *Journal of Soil and Water Conservation, 55*(2), 190.

Glenn, S., & Angle, J. S. 1987. Atrazine and simazine in runoff from conventional and no-till corn watersheds. *Agriculture, Ecosystems & Environment, 18*(4), 273-280.

Goebel, K. M., Davros, N. M., Andersen, D. E., & Rice, P. J. 2022. Tallgrass prairie wildlife exposure to spray drift from commonly used soybean insecticides in Midwestern USA. *Sci Total Environ, 818*, 151745.

Gómez, J. A., Campos, M., Guzmán, G., Castillo-Llanque, F., Vanwalleghem, T., Lora, Á., et al. 2018. Soil erosion control, plant diversity, and arthropod communities under heterogeneous cover crops in an olive orchard. *Environmental Science and Pollution Research, 25*(2), 977-989.

Gordon, R. J., VanderZaag, A. C., Dekker, P. A., De Haan, R., & Madani, A. 2011. Impact of modified tillage on runoff and nutrient loads from potato fields in Prince Edward Island. *Agricultural Water Management, 98*(12), 1782-1788.

Hancock, J., Bischof, M., Coffey, T., & Drennan, M. 2019. The effectiveness of riparian hedgerows at intercepting drift from aerial pesticide application. *Journal of Environmental Quality, 48*(5), 1481-1488.

Hansen, H., & Trimmer, W. 1986. *Irrigation Runoff Control Strategies*. PNW 287. A Pacific Northwest Extension Publication. Oregon State University. Available at: https://ir.library.oregonstate.edu/downloads/tt44pn145.

Hartwig, N. L., & Ammon, H. U. 2002. Cover crops and living mulches. *Weed Science, 50*(6), 688-699.

Haruna, S. I., Nkongolo, N. V., Anderson, S. H., Eivazi, F., & Zaibon, S. 2018. In situ infiltration as influenced by cover crop and tillage management. *Journal of Soil and Water Conservation, 73*(2), 164-172.

Hayes, J., & Dillaha, T. 1992. Vegetative filter strips. I. Site suitability and procedures. *American Society of Agricultural Engineers (USA)*.

Henry, R., Fritz, B., Hoffmann, W., & Kruger, G. 2016. An Evaluation of Three Drift Reduction Adjuvants for Aerial Application of Pesticides. *GSTF Journal on Agricultural Engineering, 2*.

Hewitt, A. J., Johnson, D. R., Fish, J. D., Hermansky, C. G., & Valcore, D. L. 2002. Development of the Spray Drift Task force database for aerial applications. *Environmental Toxicology and Chemistry, 21*(3), 648-658.

Hilary Sandler, Carolyn DeMoranville, & Lampinen, B. 2004. *Cranberry Irrigation Management*. February 2004. Cranberry Station, College of Natural Resources and the Environment, University of Massachusetts Amherst.

Hill, J. E., Scardacis, S. C., Roberts, S. R., Tiedman, J., & Williams, J. F. 1992. *Rice Irrigation Systems for Tailwater Management*. Publication 21490E. University of California, Division of Agriculture and Natural Resources, Cooperative Extension.

Holvoet, K., Gevaert, V., van Griensven, A., Seuntjens, P., & Vanrolleghem, P. A. 2007. Modelling the effectiveness of agricultural measures to reduce the amount of pesticides entering surface waters. *Water Resources Management, 21*(12), 2027-2035.

Iseyemi, O., Reba, M. L., Haas, L., Leonard, E., & Farris, J. 2021. Water quality characteristics of tailwater recovery systems associated with agriculture production in the mid-southern US. *Agricultural Water Management, 249*, 106775.

ISU. 2024. *What are prairie strips?* STRIPS, Iowa State University of Science and Technology. Available at: https://www.nrem.iastate.edu/research/STRIPS/content/what-are-prairie-strips.

Jiang, L., Dami, I., Mathers, H. M., Dick, W. A., & Doohan, D. 2011. The effect of straw mulch on simulated simazine leaching and runoff. *Weed Science, 59*(4), 580-586, 587.

Johnson, D. 1995a. *Drift from Orchard Airblast Applications: Integration and Summary of 1993 and 1994 Field Trials. .* Document Number: Lab Project Number: I95-004, F93-018, F94-020. 43925701. Prepared by Stewart Agricultural Research Services, Inc. .

Johnson, D. 1995b. *Spray Drift Task Force 1994 Field Chemigation Study.* Document Number: Lab Project Number: F94-022, SDTF-AM-003. 43854901. Prepared by Stewart Agricultural Research Services, Inc. .

Kanazawa, J., Isensee, A. R., & Kearney, P. C. 1975. Distribution of Carbaryl and 3,5-Xylyl Methylcarbamate in an Aquatic Model Ecosystem. *Journal of Agricultural and Food Chemistry, 23*(4), 760-763.

Kasner, E. J., Prado, J. B., Yost, M. G., & Fenske, R. A. 2021. Examining the role of wind in human illness due to pesticide drift in Washington state, 2000-2015. *Environ Health, 20*(1), 26.

Kaspar, T. C., & Singer, J. W. 2011. The Use of Cover Crops to Manage Soil. In *Soil Management: Building a Stable Base for Agriculture* (pp. 321-337). Available at: https://acsess.onlinelibrary.wiley.com/doi/abs/10.2136/2011.soilmanagement.c21.

Kay, P., Edwards, A. C., & Foulger, M. 2009. A review of the efficacy of contemporary agricultural stewardship measures for ameliorating water pollution problems of key concern to the UK water industry. *Agricultural Systems, 99*(2), 67-75.

Keener, H. M., Faucette, B., & Klingman, M. H. 2007. Flow-Through Rates and Evaluation of Solids Separation of Compost Filter Socks versus Silt Fence in Sediment Control Applications. *Journal of Environmental Quality, 36*(3), 742-752.

Khokhar, A., Yousuf, A., Singh, M. J., Sharma, V., Sandhu, P., & Chary, G. 2021. Impact of land configuration and strip-intercropping on runoff, soil loss and crop yields under rainfed conditions in the Shivalik Foothills of north-west, India. *Sustainability, 13*, 6282.

Kincaid, D. C., McCann, I. R., Busch, J. R., & Hasheminia, M. 1990. *Low pressure center pivot irrigation and reservoir tillage*.

Kladivko, E. J., Brown, L. C., & Baker, J. L. 2001. Pesticide Transport to Subsurface Tile Drains in Humid Regions of North America. *Critical Reviews in Environmental Science and Technology, 31*(1), 1-62.

Kruger, G. R., Klein, R. N., Ogg, C. L., & Vieira, B. C. 2019. *Spray Drift of Pesticides*. September 2019. Institude of Agriculture and Natural Resources. Universityof Nebraska-Lincoln. Nebraska Extension. Available at: https://extensionpublications.unl.edu/assets/pdf/g1773.pdf.

Krutz, L. J., Senseman, S. A., Zablotowicz, R. M., & Matocha, M. A. 2005. Reducing herbicide runoff from agricultural fields with vegetative filter strips: a review. *Weed Science, 53*(3), 353-367, 315.

Lan, Y., C. Hoffmann, W., K. Fritz, B., E. Martin, D., D. Lopez, J., & Jr. 2008. Spray Drift Mitigation with Spray Mix Adjuvants. *Applied Engineering in Agriculture, 24*(1), 5-10.

Langdale, G., Blevins, R., Karlen, D., McCool, D., Nearing, M., Skidmore, E., et al. 1991. Cover crop effects on soil erosion by wind and water. *Cover crops for clean water*, 15-22.

Lark, T. J., Mueller, R. M., Johnson, D. M., & Gibbs, H. K. 2017. Measuring land-use and land-cover change using the U.S. Department of Agriculture's cropland data layer: Cautions and recommendations. *International Journal of Applied Earth Observation and Geoinformation, 62*, 224-235.

Lazzaro, L., Otto, S., & Zanin, G. 2008. Role of hedgerows in intercepting spray drift: Evaluation and modelling of the effects. *Agriculture, Ecosystems & Environment, 123*(4), 317-327.

Lee, K.-H., Isenhart, T. M., & Schultz, R. C. 2003. Sediment and nutrient removal in an established multi-species riparian buffer. *Journal of soil and water conservation, 58*(1), 1-8.

Liu, Q., Shan, C., Zhang, H., Song, C., & Lan, Y. 2023. Evaluation of Liquid Atomization and Spray Drift Reduction of Hydraulic Nozzles with Four Spray Adjuvant Solutions. *Agriculture, 13*(2), 236.

Long, R., Hanson, B. R., Fulton, A. E., & Weston, D. P. 2010. Mitigation techniques reduce sediment in runoff from furrow-irrigated cropland. *California Agriculture, 64*(3), 135-140.

Makhnenko, I., Alonzi, E. R., Fredericks, S. A., Colby, C. M., & Dutcher, C. S. 2021. A review of liquid sheet breakup: Perspectives from agricultural sprays. *Journal of Aerosol Science, 157*, 105805.

Marble, S. C. 2015. Herbicide and mulch interactions: A Review of the literature and implications for the landscape maintenance industry. *Weed Technology, 29*(3), 341-349, 349.

Martin, S. M., Kookana, R. S., Van Zwieten, L., & Krull, E. 2012. Marked changes in herbicide sorption-desorption upon ageing of biochars in soil. *J Hazard Mater, 231-232*, 70-78.

Meinen, B. U., & Robinson, D. T. 2020. Where did the soil go? Quantifying one year of soil erosion on a steep tile-drained agricultural field. *Science of The Total Environment, 729*, 138320.

Mickelson, S. K., Baker, J. L., & Ahmed, S. I. 2003. Vegetative filter strips for reducing atrazine and sediment runoff transport. *Journal of Soil and Water Conservation, 58*(6), 359-367.

Miller, J., Shober, A., & VanGessel, M. 2022. *Cover crop biomass and termination considerations*. March 25, 2022. Delaware Agronomy Blog, University of Delaware Cooperative Extension. Available at: https://sites.udel.edu/agronomy/2022/03/25/cover-crop-biomass-and-termination-considerations/.

Moore, M. T., Denton, D. L., Cooper, C. M., Wrysinski, J., Miller, J. L., Reece, K., et al. 2008. Mitigation assessment of vegetated drainage ditches for collecting irrigation runoff in California. *Journal of Environmental Quality, 37*(2), 486-493.

Mun, R., Young, B., & Boger, D. 1999. Atomization of Dilute Polymer Solutions in Agricultural Spray Nozzles. *Journal of Non-Newtonian Fluid Mechanics, 83*.

Muñoz-Carpena, R., & Parsons, J. 2004. A design procedure for vegetative filter strip using VFSMOD-W. *Transactions of the ASAE, 47*.

Neal, J. H. 1938. *The effect of the degree of slope and rainfall characteristics on runoff and soil erosion*: University of Missouri, College of Agriculture, Agricultural Experiment Station.

Ng, H. Y. F., Gaynor, J. D., Tan, C. S., & Drury, C. F. 1995. Dissipation and loss of atrazine and metolachlor in surface and subsurface drain water: A case study. *Water Research, 29*(10), 2309-2317.

NMFS. 2023. *Conference and Biological Opinion on the Environmental Protection Agency's Registration Review of Pesticide Products containing Carbaryl and Methomyl*. March 9, 2023. U.S. Department of Commerce. National Oceanic and Atmospheric Administration. Office of Protected Resources. National Marine Fisheries Service. Available at: https://www.epa.gov/pesticides/epa-posts-draft-biological-opinion-carbaryl-and-methomyl-public-comment#:~:text=In%20its%20draft%20biological%20opinion,adversely%20modify%2036%20critical%20habitats.

NOAA. 2009. *Comparative Climatic Data (CCD)*. National Centers for Environmental Information, National Oceanic and Atmospheric Administration. Available at: https://www.ncei.noaa.gov/products/land-based-station/comparative-climatic-data.

NOAA. 2023. *National Maps*. National Oceanic and Atmospheric Administration (NOAA). National Centers for Environmental Information (NCEI). Available at: https://www.ncei.noaa.gov/access/monitoring/us-maps/.

NRC. 2002. *The National Academies Press. Riparian Areas: Functions and Strategies for Management*. Board on Environmental Studies and Technology, Division on Earth and Life Studies, National Research Council. Available at:

https://nap.nationalacademies.org/catalog/10327/riparian-areas-functions-and-strategies-for-management.

NRCS, U. 2010. *Chapter 15: Time of Concentration, Part 360 Hydrology, Hydraulics and Hydrology - Technical References, NRCS National Engineering Handbook*. National Resources Conservation Service, U.S. Department of Agriculture. Available at: https://www.hydrocad.net/neh/630contents.htm.

Omer, A. R., Miranda, L. E., Moore, M. T., Krutz, L. J., Czarnecki, J. M. P., Kröger, R., et al. 2018. Reduction of solids and nutrient loss from agricultural land by tailwater recovery systems. *Journal of Soil and Water Conservation, 73*(3), 284-297.

Otto, S., Loddo, D., Baldoin, C., & Zanin, G. 2015. Spray drift reduction techniques for vineyards in fragmented landscapes. *Journal of Environmental Management, 162*, 290-298.

Øygarden, L., Kværner, J., & Jenssen, P. D. 1997. Soil erosion via preferential flow to drainage systems in clay soils. *Geoderma, 76*(1), 65-86.

Pantone, D. J., Potter, K. N., Torbert, H. A., & Morrison Jr., J. E. 1996. Atrazine loss in runoff from no-tillage and chisel-tillage systems on a Houston black clay soil. *Journal of Environmental Quality, 25*(3), 572-577.

Pavlidis, G., Karasali, H., & Tsihrintzis, V. A. 2020. Pesticide and fertilizer pollution reduction in two alley cropping agroforestry cultivating systems. *Water, Air, & Soil Pollution, 231*(5), 241.

Payne, N. J., Helson, B. V., Sundaram, K. M. S., & Fleming, R. A. 1988. Estimating buffer zone widths for pesticide applications. *Pesticide Science, 24*(2), 147-161.

Pecenka, J. R., Ingwell, L. L., Foster, R. E., Krupke, C. H., & Kaplan, I. 2021. IPM reduces insecticide applications by 95% while maintaining or enhancing crop yields through wild pollinator conservation. *Proceedings of the National Academy of Sciences, 118*(44), e2108429118.

Phillips, B. M., Anderson, B. S., Cahn, M., Rego, J. L., Voorhees, J. P., Siegler, K., et al. 2017. An integrated vegetated ditch system reduces chlorpyrifos loading in agricultural runoff. *Integr Environ Assess Manag, 13*(2), 423-430.

Poletika, N. N., Coody, P. N., Fox, G. A., Sabbagh, G. J., Dolder, S. C., & White, J. 2009. Chlorpyrifos and atrazine removal from runoff by vegetated filter strips: experiments and predictive modeling. *Journal of Environmental Quality, 38*(3), 1042-1052.

Popp, J. S. H., Wailes, E. J., Young, K. B., & Smartt, J. 2004. *Assessing the Benefits of On-Farm Reservoirs and Tail-Water Recovery Systems*, *Selected Paper*. Available at: https://ageconsearch.umn.edu/record/20210/files/sp04po03.pdf.

Potter, T. L., Bosch, D. D., & Strickland, T. C. 2015. Tillage impact on herbicide loss by surface runoff and lateral subsurface flow. *Science of The Total Environment, 530-531*, 357-366.

Prichard, T. L., Grant, J. A., & Schwankl, L. J. 2016. *Controlling Offsite Movement of Agricultural Chemical Residues: Walnuts*. Publication 8460. University of California. Division of Agriculture and Natural Resources. Available at: https://anrcatalog.ucanr.edu/pdf/8460.pdf.

Rajbanshi, J., Das, S., & Paul, R. 2023. Quantification of the effects of conservation practices on surface runoff and soil erosion in croplands and their trade-off: A meta-analysis. *Science of The Total Environment, 864*, 161015.

Reich, D., Gordin, R., Chavez, J. L., & Broner, I. 2014. *Subsurface Drip Irrigation. Fact Sheet No. 4.716*. Colorado State University Extension. Available at: https://extension.colostate.edu/docs/pubs/crops/04716.pdf.

Reichenberger, S., Bach, M., Skitschak, A., & Frede, H.-G. 2007. Mitigation strategies to reduce pesticide inputs into ground- and surface water and their effectiveness; A review. *Science of The Total Environment, 384*(1), 1-35.

Reyes, E., Menconi, M. 2002. *Agricultural Practices and Technologies*. Central Valley Region, Regional Water Quality Control Board, California Environmental Protection Agency.

Riley, C., Wiesner, C., International, A., Testing, A. S. f., & Materials. 1990. *Off Target Pesticide Losses Resulting from the Use of an Air-assisted Orchard Sprayer*: ASTM International.

Robichaud, P., & Brown, R. E. 1999. What happened after the smoke cleared: onsite erosion rates after a wildfire in Eastern Oregon. *Wildland Hydrology Conference*, 419-426.

Robichaud, P. R., Pierson, F. B., Brown, R. E., & Wagenbrenner, J. W. 2008. Measuring effectiveness of three postfire hillslope erosion barrier treatments, western Montana, USA. *Hydrological Processes, 22*(2), 159-170.

Rose, M. T., Sanchez-Bayo, F., Crossan, A. N., & Kennedy, I. R. 2006. Pesticide removal from cotton farm tailwater by a pilot-scale ponded wetland. *Chemosphere, 63*(11), 1849-1858.

Salem, H. M., Valero, C., Muñoz, M. Á., & Gil-Rodríguez, M. 2015. Effect of integrated reservoir tillage for in-situ rainwater harvesting and other tillage practices on soil physical properties. *Soil and Tillage Research, 151*, 50-60.

Salem, H. M., Valero, C., Muñoz, M. Á., Gil-Rodríguez, M., & Barreiro, P. 2014. Effect of reservoir tillage on rainwater harvesting and soil erosion control under a developed rainfall simulator. *Catena, 113*, 353-362.

Salyani, M., & P. Cromwell, R. 1992. Spray Drift From Ground and Aerial Applications. *Transactions of the ASAE, 35*(4), 1113-1120.

Schwankl, L., Hanson, B., & Prichard, T. 2007. *Reducing Runoff from Irrigated Lands: Causes and Management of Runoff from Surface Irrigation in Orchards*. Publication 8214. University of California. Division of Agriculture and Natural Resources. Available at: https://anrcatalog.ucanr.edu/pdf/8214.pdf.

Schwankl, L., Pricharg, T., & Hanson, B. 2007. *Reducing Runoff from Irrigated Lands: Tailwater Return Systems*. Publication 8225. Febuary 1, 2007. University of California, Division of Agriculture and Natural Resources.

Schwankl, L. J., Pricharg, T.L., Hanson, B.R. 2007. *Reducing Runoff from Irrigated Lands: Tailwater Return Systems*. Publication 8225. Febuary 1, 2007. University of California, Division of Agriculture and Natural Resources.

Seitz, S., Goebes, P., Puerta, V. L., Pereira, E. I. P., Wittwer, R., Six, J., et al. 2019. Conservation tillage and organic farming reduce soil erosion. *Agronomy for Sustainable Development, 39*(1), 4.

Sezen, K., & Gungor, A. 2023. Water droplet evaporation in atmospheric air stream. *Physics of Fluids, 35*(1).

Shipitalo, M. J., Bonta, J. V., & Owens, L. B. 2012. Sorbent-amended compost filter socks in grassed waterways reduce nutrient losses in surface runoff from corn fields. *Journal of Soil and Water Conservation, 67*(5), 433-441.

Shipitalo, M. J., & Owens, L. B. 2003. Atrazine, deethylatrazine, and deisopropylatrazine in surface runoff from conservation tilled watersheds. *Environmental Science & Technology, 37*(5), 944-950.

Skaggs, R. W., Nassehzadeh-Tabrizi, A., & Foster, G. R. 1982. Subsurface drainage effects on erosion. *Journal of Soil and Water Conservation, 37*(3), 167-172.

Smith, C. 2016. *Irrigation Strategies. Technology improves water-use efficiency and profitability*. Cotton Farming. Available at: https://www.cottonfarming.com/cover-story/irrigation-strategies/.

Steenhuis, T., & Walter, M. 1980. Closed Form solution for pesticide loss in runoff water. *Transactions of the ASAE, 23*, 0615-0620.

Stewart, B. A. 2016. Dryland Farming. In *Reference Module in Food Science* Elsevier. Available at: https://www.sciencedirect.com/science/article/pii/B9780081005965029371.

Stutter, M., Costa, F. B., & Ó hUallacháin, D. 2021. The interactions of site-specific factors on riparian buffer effectiveness across multiple pollutants: A review. *Science of The Total Environment, 798*, 149-238.

Sun, Y., Zeng, Y., Shi, Q., Pan, X., & Huang, S. 2015. No-tillage controls on runoff: A meta-analysis. *Soil and Tillage Research, 153*, 1-6.

Taha, S. M., Amer, M. E., Elmarsafy, A. E., & Elkady, M. Y. 2014. Adsorption of 15 different pesticides on untreated and phosphoric acid treated biochar and charcoal from water. *Journal of Environmental Chemical Engineering, 2*(4), 2013-2025.

Teske, M., Thistle, H., & Mickle, R. 2000. Modeling finer droplet aerial drift and deposition. *Applied Engineering in Agriculture, 16*(4), 351-357.

Teske, M. E. 2009. Initial development and validation of a mechanistic spray drift model for ground boom sprayers. *Transactions of the ASABE, v. 52*(no. 4), pp. 1089-1097-2009 v.1052 no.1084.

Tim, U. S., & Jolly, R. 1994. Evaluating agricultural nonpoint-source pollution using integrated geographic information systems and hydrologic/water quality model. *Journal of Environmental Quality, 23*(1), 25-35.

Tomer, M. D., Porter, S. A., James, D. E., Boomer, K. M. B., Kostel, J. A., & McLellan, E. 2013. Combining precision conservation technologies into a flexible framework to facilitate agricultural watershed planning. *Journal of Soil and Water Conservation, 68*(5), 113A-120A.

Tubaña, B., Campos, B., Forestieri, D., & Mite, J. 2020. *College of Agriculture, Louisana State University. Planting date effect on cover crops biomass yield and nutrient turnover*. Fall 2020. Louisana Agriculture. Available at: https://repository.lsu.edu/louisianaagriculture/vol63/iss4/1.

USDA. 2014. *Agronomy Technical Note No. 5. Conservation Planning Process*. February 2014. United States Department of Agriculture. Natural Resources Conservation Service.

USDA. 2016. *Conservation Practice Standard Overview: Field Strip (Code 393)*. NRCS Code 393. September 2016. Natural Resources Conservation Service, United States Department of Agriculture. Available at: https://www.nrcs.usda.gov/sites/default/files/2022-09/Filter_Strip_393_Overview_Sep_2016.pdf.

USDA. 2017. *Soil Survey Manual*. March 2017. Soil Science Division. Natural Resources Conservation Service. U.S. Department of Agriculture.

USDA. 2018a. *Cropland Data Layer (2014-2018)*. National Agricultural Statistics Service, United States Department of Agriculture. Available at: https://nassgeodata.gmu.edu/CropScape/

USDA. 2018b. *Gridded Soil Survey Geographic (SSURGO) Database*: United States Department of Agriculture. Natural Resources Conservation Service. Available at: http://datagateway.nrcs.usda.gov/.

USDA. 2020. *Cover Crops and Crop Insurance*. February 2020. Risk Management Agency, United States Department of Agriculture. Available at: https://www.rma.usda.gov/-/media/RMA/Cover-Crops/202002-NRCSRMA-CoverCrop-Brochure-Letter.ashx?la=en.

USDA. 2023. *Conservation Practice Overview: Irrigation and Drainage Tailwater Recovery (Code 447)*. NRCS Code 447. August 2023. Natural Resources Conservation Service, U.S. Department of Agriculture. Available at: https://www.nrcs.usda.gov/sites/default/files/2023-08/447_NHCP_PO_Irrigation_and%20Drainage_Tailwater_Rec.pdf.

USDA, & NRCS. 2007. Chapter 7 - Hydrologic Soil Groups. In *Part 630 Hydrology National Engineering Handbook* United States Department of Agriculture. National Resources Conservation Service. Available at: https://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=17757.wba.

USEPA. 1992. *Guidelines for Exposure Assessment*. EPA/600/Z-92/001. May 1992. United States Environmental Protection Agency. Available at: https://www.epa.gov/sites/default/files/2014-11/documents/guidelines_exp_assessment.pdf.

USEPA. 1995. *A Handbook of Constructed Wetlands, a guide to creating wetlands for: agricultural wastewater, domestic wastewwater, coal mine drainage, stormwater; in the Mid-Atlantic Region; Volume 1: General Considerations*. PS5384RSEZ. Region III, United States Environmental Protection Agency.

USEPA. 1997. *Estimating Drinking Water Exposure as a Component of the Dietary Risk AssessmentSpray Drift Program. Scientific Advisory Panel*. December 10-11, 1997. United States Environmental Protection Agency. Available at: https://archive.epa.gov/scipoly/sap/meetings/web/pdf/finaldec.pdf.

USEPA. 2000. *Guiding Principles for Constructed Treatment Wetlands: Providing for Water Quality and Wildlife Habitat*. E. 843-B-00-003. October 2000. Office of Wetlands, Oceans and Watersheds, US Environmental Protection Agency. Available at: https://nepis.epa.gov/Exe/ZyPDF.cgi/2000536S.PDF?Dockey=2000536S.PDF.

USEPA. 2001. *GENEEC2 Description*. May 1, 2001. Office of Pesticide Programs, U.S. Environmental Protection Agency. . Available at: https://archive.epa.gov/epa/pesticide-science-and-assessing-pesticide-risks/geneec2-description.html.

USEPA. 2003. *National Management Measures for the Control of Nonpoint Pollution from Agriculture*. EPA-841-B-03-004. July 2003. Office of Water, U.S. Environmental Protection Agency.

USEPA. 2005. *National Management Measures to Protect and Restore Wetlands and Riparian Areas for the Abatement of Nonpoint Source Pollution*. July 2005. Nonpoint Source Control Branch, Office of Wetlands, Oceans and Watershed, US Environmental

Protection Agency. Available at: https://www.epa.gov/sites/default/files/2015-10/documents/wetmeasures_guidance.pdf.

USEPA. 2006. *Standardized Soil Mobility Classification Guidance*. April 21, 2006. Environmental Fate and Effects Division, Office of Pesticide Programs, U.S. Environmental Protection Agency.

USEPA. 2018. *Field Worker Contact with Foliage Based on the Phenology of Rice*. Docket ID EPA-HQ-OPP-2015-0052. September 19, 2018. Biological and Economic Analysis Division, Office of Pesticide Programs, U.S. Environmental Protection Agency.

USEPA. 2019. *Guidelines for Human Exposure Assessment*. EPA/100/B-19/001. October 2019. United States Environmental Protection Agency. Risk Assessment Forum. Available at: https://www.epa.gov/sites/default/files/2020-01/documents/guidelines_for_human_exposure_assessment_final2019.pdf.

USEPA. 2020a. *Creating New Scenarios for Use in Pesticide Surface Water Exposure Assessments*. September 2020. Environmental Fate and Effects Division, Office of Pesticide Programs, U.S. Environmental Protection Agency.

USEPA. 2020b. *Dicamba DGA and BAPMA salts – 2020 Ecological Assessment of Dicamba Use on Dicamba-Tolerant (DT) Cotton and Soybean Including Effects Determinations for Federally Listed Threatened and Endangered Species*. DP Barcodes 459792, 459793 & 459794. October 26, 2020. Environmental Fate and Effects Division, Office of Pesticide Programs, U.S. Environmental Protection Agency.

USEPA. 2020c. *Estimating Field and Watershed Parameters Used in USEPA's Office of Pesticide Programs Aquatic Exposure Models - The Pesticide Water Calculator (PWC)/Pesticide Root Zone Model (PRZM) and Spatial Aquatic Model (SAM)*. 12/31/2019. Environmental Fate and Effects Division, Office of Pesticide Programs, U.S. Environmental Protection Agency.

USEPA. 2022a. *Balancing Wildlife Protection and Responsible Pesticide Use: How EPA's Pesticde Program Will Meet Its Endangered Species Act Obligations*. D. I. EPA-HQ-OPP-. April 2022. Office of Pesticide Programs, Office of Chemical Safety and Pollution Prevention, United States Environmental Protection Agency. Available at: https://www.epa.gov/endangered-species/epas-workplan-and-progress-toward-better-protections-endangered-species.

USEPA. 2022b. *ESA Workplan Update: Nontarget Species Mitigation for Registration Review and Other FIFRA Actions*. Docket ID EPA-HQ-OPP-2022-0908. November 2022. Office of Pesticide Programs, Office of Chemical Safety and Pollution Prevention, United States Environmental Protection Agency. Available at: https://www.epa.gov/endangered-species/epas-workplan-and-progress-toward-better-protections-endangered-species.

USEPA. 2022c. *Spray Drift Analysis Review Report. Addendum #1 to Data Evaluation Record*. (MRID: 49135901. September 1, 2022. Environmental Fate and Effects Division. Office of Pesticide Programs. U.S. Environmental Protection Agency.

USEPA. 2023a. *Draft Herbicide Strategy Framework to Reduce Exposure to Federally Listed Endangered and Threatened Species and Designated Critical Habitats from the Use of Conventional Agricultural Herbicides*. Docket ID EPA-HQ-OPP-2023-0365. July 2023. Office of Pesticide Programs, Office of Chemical Safety and Pollution Prevention, United States Environmental Protection Agency.

USEPA. 2023b. *EnviroAtlas - Water Balance and Surficial Groundwater by 12-digit HUC for the Conterminuous United States*. Available at: https://catalog.data.gov/dataset/enviroatlas-water-balance-and-surficial-groundwater-by-12-digit-huc-for-the-conterminous-united1.

USEPA. 2023c. *Vulnerable Listed (Endangered and Threatened) Species Pilot Project: Proposed Mitigations, Implementation Plan, and Possible Expansion*. Docket ID EPA-HQ-OPP-2023-0327. June 2023. Office of Pesticide Programs, Office of Chemical Safety and Pollution Prevention, United States Environmental Protection Agency.

USEPA. 2024. *Pesticide in Water Calculator, Version 3*. Environmental Fate and Effects Division, Office of Pesticide Programs, U.S. Environmental Protection Agency. Available at: https://www.epa.gov/pesticide-science-and-assessing-pesticide-risks/models-pesticide-risk-assessment#:~:text=PWC%20(Pesticide%20in%20Water%20Calculator,as%20simple%20ground%20water%20aquifers.

USGS. 2024. *Hydrologic Unit Maps*. 1/9/2024. United States Geologic Survey, United Stated Department of the Interior. Available at: https://water.usgs.gov/GIS/huc.html.

van de Zande, J. C., Michielsen, J. M. G. P., Stallinga, H., & de Jong, A. 2000. The effect of windbreak height and air assistance on exposure of surface water via spray drift. *Proceedings BCPC Conference Pests & Diseases, Brighton (UK), 13-16 November. Franham*.

Van Doren, C. A., Stauffer, R. S., & Kidder, E. H. 1951. Effect of contour farming on soil loss and runoff. *Soil Science Society of America Journal, 15*(C), 413-417.

Vasileiadis, V. P., Otto, S., van Dijk, W., Urek, G., Leskovšek, R., Verschwele, A., et al. 2015. On-farm evaluation of integrated weed management tools for maize production in three different agro-environments in Europe: Agronomic efficacy, herbicide use reduction, and economic sustainability. *European Journal of Agronomy, 63*, 71-78.

Vernay, C., Ramos, L., Douzals, J.-P., Goyal, R., Castaing, J.-C., & Ligoure, C. 2016. DROP IMPACT EXPERIMENT AS A MODEL EXPERIMENT TO INVESTIGATE THE ROLE OF OIL-IN-WATER EMULSIONS IN CONTROLLING THE DROP SIZE DISTRIBUTION OF AN AGRICULTURAL SPRAY. *26*(8), 827-851.

Victoria, A. 2022. *A Guide to Using Agricultural Chemicals in Victoria. Ground-based Spray Application*. Available at: https://agriculture.vic.gov.au/__data/assets/pdf_file/0010/554923/A-guide-to-using-agricultural-chemicals-in-Victoria-ground-based-spraying_Sept-22.pdf.

Vieira, B. C., Butts, T. R., Rodrigues, A. O., Golus, J. A., Schroeder, K., & Kruger, G. R. 2018. Spray particle drift mitigation using field corn (Zea mays L.) as a drift barrier. *Pest Management Science, 74*(9), 2038-2046.

Wauchope, R. D. 1978. The pesticide content of surface water draining from agricultural fields—A Review. *Journal of Environmental Quality, 7*(4), 459-472.

Wenger, S. J. 1999. *Institute of Ecology. A review of the scientific literature on riparian buffer width, extent and vegetation*. March 5, 1999. University of Georgia. Available at: https://dnr.wi.gov/topic/ShorelandZoning/documents/lit_review.pdf.

Werner, I., Deanovic, L. A., Miller, J., Denton, D. L., Crane, D., Mekebri, A., et al. 2010. Use of vegetated agricultural drainage ditches to decrease toxicity of irrigation runoff from tomato and alfalfa fields in California, USA. *Environmental Toxicology and Chemistry, 29*(12), 2859-2868.

White, E. V., & Roy, D. P. 2015. A contemporary decennial examination of changing agricultural field sizes using Landsat time series data. *Geo, 2*(1), 33-54.

Wischmeier, W. H., & Smith, D. D. 1978. *Predicting rainfall erosion Llosses. A guide to conservation planning*. The USDA Agricultural Handbook No. 537. U.S. Department of Agriculture. Science and Education Administration.

Wolf, T. 2016. *Drift 2011 (Database Format).xlsm*. In C. Peck (Ed.).

Wolf, T. M., Cessna, A., Caldwell, B. C., & Pederson, J. L. 2005. Riparian vegetation reduces spray drift deposition into water bodies. In (pp. 212-223).

Wu, C., Liu, X., Wu, X., Dong, F., Xu, J., & Zheng, Y. 2019. Sorption, degradation and bioavailability of oxyfluorfen in biochar-amended soils. *Science of The Total Environment, 658*, 87-94.

Wu, Q., & Lane, C. R. 2017. Delineating wetland catchments and modeling hydrologic connectivity using lidar data and aerial imagery. *Hydrol Earth Syst Sci, 21*(7), 3579-3595.

Wu, S., Bashir, M. A., Raza, Q.-U.-A., Rehim, A., Geng, Y., & Cao, L. 2023. Application of riparian buffer zone in agricultural non-point source pollution control—A review. *Frontiers in Sustainable Food Systems, 7*.

Xue, S., Han, J., Xi, X., Lan, Z., Wen, R., & Ma, X. 2024. Coordination of distinctive pesticide adjuvants and atomization nozzles on droplet spectrum evolution for spatial drift reduction. *Chinese Journal of Chemical Engineering, 66*, 250-262.

Yonts, C. D., & Eisenhauer, D. E. 2008. *Fundamentals of surge irrigation*. G1870. University of Nebraska–Lincoln Extension Division. Available at: https://extensionpublications.unl.edu/assets/html/g1870/build/g1870.htm#:~:text=Surge%20irrigation%20or%20surge%20flow,runoff%20that%20occurred%20during%20irrigation.

Young, D. F. 2019. Estimating Pesticides in Surface Water. In K. Goh & D. F. Young (Eds.), *Pesticides in Surface Water: Monitoring, Modeling, Risk Assessment, and Management*. Washington, DC: American Chemistry Society.

Young, D. F., & Fry, M. M. 2019. Field-scale evaluation of pesticide uptake into runoff using a mixing cell and a non-uniform uptake model. *Environmental Modelling & Software, 122*, 104055.

Yuan, Y., Book, R. S., Mankin, K. R., Koropeckyj-Cox, L., Christianson, L., Messer, T., et al. 2022. An overview of the effectiveness of agricultural conservation practices for water quality improvement. *Journal of American Society of Agricultural and Biological Engineers, 65*(2), 419-426.

Zheng, F., Merrill, S., Huang, C.-h., Tanaka, D., Darboux, F., Liebig, M., et al. 2004. Runoff, Soil Erosion, and Erodibility of Conservation Reserve Program Land under Crop and Hay Production. *Soil Science Society of America Journal, 68*.

Zhu, X., Liu, W., Chen, J., Bruijnzeel, L. A., Mao, Z., Yang, X., et al. 2020. Reductions in water, soil and nutrient losses and pesticide pollution in agroforestry practices: a review of evidence and processes. *Plant and Soil, 453*(1), 45-86.

Appendix A. Standard AgDRIFT® Modeling Assumptions

A.1 Ground Boom Spray Modeling

Currently, the EPA uses the Tier I ground sprayer assessment method to model ground boom spray, which is based on Spray Drift Task Force (SDTF) field data collected in two short grass studies across a range of conditions. EPA used these data to inform the development of a ground module for the AgDRIFT® model to evaluate application efficiency and offsite drift from a range of equipment combinations and agricultural practices used by applicators. To do so, EPA separated the data into two subsets and considers them separately in the AgDRIFT modeling and in these strategies: low boom (20 inches) and high boom (50 inches) from the ground (Teske *et al.*, 2000). The low boom subset is appropriate for modeling use patterns with release heights ≤2 feet from ground. The high boom subset is appropriate for applications >2 feet from the ground up to 4 feet from the crop canopy. For each of the two boom heights, sufficient data were available to produce two American Society of Agricultural and Biological Engineers (ASABE) deposition patterns corresponding to “Very Fine to Fine” and “Fine to Medium/Coarse” droplet size distribution categories. EPA uses these two droplet size deposition curves in environmental exposure assessments, and in these strategies, to estimate deposition from ground boom spraying up to distances of 997 feet, which is the limit extent of the model (corresponding to the limits of the underlying data).

The SDTF data are partitioned into 50th percentile (central tendency) and 90th percentile subsets. Use of the 50th percentile subset provides a central estimate of offsite deposition and the 90th percentile provides a high-end estimate of offsite deposition. EPA relies on the 90th percentile exposure estimate as a baseline approach as a higher end exposure, and acknowledges that variability in exposures are expected (USEPA, 1992; USEPA, 2019).

Under field conditions, droplet size distributions and release heights can be manipulated with more precision than can be quantified with current ground spray modeling. EPA recognizes that incrementally coarser droplets or lower release heights will result in less drift (*e.g.*, a 35-inch release height will result in less spray drift than a 50-inch release height). EPA also recognizes that atmospheric or landscape conditions in many parts of the United States or at many times of day are not fully represented by SDTF data and that conditions less prone to drift may occur in some cases. When available data and supplemental modeling capabilities demonstrate that application or field conditions substantially differ from those represented the 90th percentile deposition curves, that may be taken into account when identifying a spray drift buffer.

A.2 Aerial Spray Modeling

EPA utilizes AgDRIFT® (Version 2.1.1) and AGDISP™ (Version 8.26) to model aerial spray in ecological assessments and in the strategies. These models incorporate different deposition assumptions based on droplet size distribution for aerial applications, where the model developers identified many distributions of spray droplet size based on the available ASABE conventions. Four different droplet size assumptions are available in Tier I aerial modeling (very fine to fine; fine to medium; medium to coarse; coarse to very coarse). Unlike the dataset for ground sprays, the Tier I deposition distributions for aerial applications are derived mechanistically (*i.e.,* based on physics rather than measured deposition data) and are intended to represent reasonable conditions but with higher potential for drift (*e.g.*, 10 mph wind, 50% relative humidity). The default Tier I parameterization for aerial applications assumes pesticide release using an Air Tractor AT-401 airplane which may overestimate distances if using other aircraft types (*e.g.,* more modern fixed-wing airplanes or helicopters, which due to their configuration, may result in lower offsite drift deposition). However, AgDRIFT® has refined assessment options for higher tier modeling that can account for variations in application equipment and other factors affecting drift.

For drift analysis in this document, the Tier III aerial spray drift modeling results[22] are used as a high-end estimate of spray drift deposition and a baseline approach to identify spray drift distances. The Tier I and Tier III modules produce the same results when Tier III parameterization matches the fixed parameters in Tier I. Given this, the Tier III module of AgDRIFT® is utilized to demonstrate effectiveness of mitigation that could not otherwise be demonstrated through Tier I (*e.g.*, changes in windspeed). If data related to specific nozzles are available and resulting droplet size distributions do not correspond well with Tier I distributions, higher tiered modeling can account for the different droplet size distribution.

EPA has received comments from several groups, such as the National Agricultural Aviation Association (NAAA) regarding updates to AgDRIFT's input parameters to be more consistent with advances in aerial application technology. EPA evaluated this feedback and updated its aerial modeling input parameters where appropriate (see **Appendix I**).

A.3 Airblast Spray Modeling

EPA utilized the default airblast application parameterization (sparse canopy) in AgDRIFT® to model airblast spray This default simulates a sparse orchard (dormant and non-bearing vegetation or bearing vegetation between first leaf drop and fully leafed out vegetation), because drift is highest within the first 150 feet off-field when applied to orchards with sparse foliage due to the lack of foliage that could intercept spray droplets and prohibit them from drifting offsite. Buffers related to each airblast deposition curve (others include: Normal, Dense, Vineyard, and Orchard) may provide some characterization of exposure depending on the labeled use or application timing; however, the model does not necessarily take all orchard characteristics into account sufficiently to inform a baseline approach. Airblast spray drift data are limited relative to that which is available for ground boom and only 50th percentile deposition curves are available as opposed to the 90th percentile deposition curves available for ground applications. EPA based this analysis on the default sparse parameterization as a baseline approach to represent a higher end exposure potential.

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[22] AgDRIFT® Tier 1 modeling was utilized in the development of recommended mitigations; however, this does not limit use of AgDRIFT® results to the Tier 1 results.

A.4 Uncertainties in the Spray Drift Analysis

Droplet deposition will be reduced with vegetation interception at distances beyond the obstruction; however, drift that would have been deposited over that distance may be deposited on the obstruction and may be deposited at higher concentrations than estimated by EPA's models. For example, non-target species in interior forests or areas where vegetation will intercept the spray drift deposition, are expected to have less exposure than what is simulated with standard modeling. Also, increasing crop canopy coverage and vertical vegetation density in grasslands (habitat that may be proximate to agriculture) have been shown to reduce the extent of spray drift exposure (Goebel *et al.*, 2022).

Field size has impact on amount of offsite deposition as each swath on a field (*i.e.*, each pass with pesticide spray equipment) contributes to the amount of mass that drifts off field. Tier I parameterization in aerial spray drift modeling assumes 20 swaths (or flight lines) with a swath width of 60 ft (swath width associated with Air Tractor AT-401). If this model parameterization were applied to a square field[23], the application area would be 33 acres in size. For comparison, the median field size in the U.S. is 58 acres with 75% of fields at least 29 acres in size as of 2011 (White and Roy, 2015). This application area is considered to be representative for many field crops[24], but smaller field sizes do exist, especially in specialty crops, which can result in lower spray drift due to a lower number of flight lines. As an example, an eight-acre square field would only utilize 10 flight lines with a 60 ft wide swath. As discussed in **Appendix I**, updated aerial model parameters adjust the swath and flight line assumptions to 80ft and 15 respectively.

With variability in field size established, EPA conducted a field size sensitivity analysis to determine field size impact on offsite spray drift deposition. Assuming a medium droplet spectrum, the modeled differences in spray drift deposition between the 32-acre field and 8-acre field is 0.6% of the application rate at 100 feet off-field. For comparison, an equivalent modeled point deposition[25] difference between results from a 100-foot buffer and a 108-foot buffer when parameterized with an Aerial Medium/Coarse droplet spectrum. Impact of field size becomes more significant for larger buffer distances and finer droplet spectra. Given this, aerial applications to small fields are expected to result in less drift than applications to large fields, and this is reflected in the mitigation measures to reduce spray drift distances.

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[23] If there are 20 lanes each with a width of 60 ft, then the total width would be 1200 ft and if this is a square, then it would 1200 x 1200 or 1.44 x 10^6 sq. ft or 33 acres.

[24] The median field size in the United States was estimated to be 58 acres, with 75% of fields at least 29 acres in size as of 2011 (Lark *et al.*, 2017).

[25] The model estimated deposition expected to occur at an individual location at a given distance downwind from an application area

Ground applications to small fields are also expected to result in less drift. Default ground application modeling assumes a 19-acre field[26] if the field is assumed to be square. If spray drift deposition from this default condition is compared to a rectangular 4-acre field[27], modeled deposition is reduced by 29-38% at 100 ft offsite. For comparison, an equivalent modeled point deposition difference between results from a 100-foot buffer and a 115-foot buffer when a 19-acre field is assumed as constant.

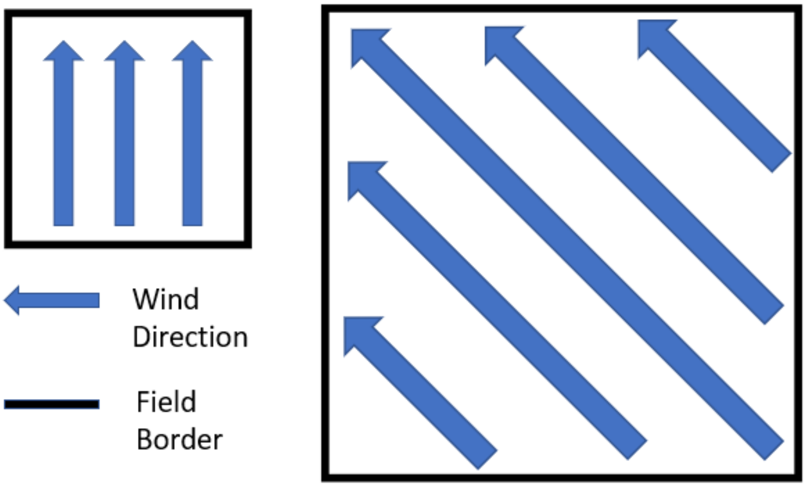

Figure A-1. Field Size and Wind Direction Scale Comparison for an 8-Acre Field with Parallel Wind (left) and a 32-Acre Field with Wind at 45 Degrees from Parallel (right).

Field shape (*i.e., w*ind direction relative to field orientation) also has impact on spray drift deposition, however, impacts are expected to be small (smaller than differences in field sizes characterized above) and not on a field or landscape scale. Modeling assumes wind direction is parallel to two of the sides of a square field. If the square field is rotated 45 degrees, there is the same amount of mass applied and available for drift but the wind traverses across the field on a relatively longer path (*i.e.*, the hypotenuse at its longest extent, which would be 41% longer than the parallel path, see **Figure A1** above) in the center of the field but relatively shorter paths near field edges. When compared to spray drift deposition associated with winds parallel to field edges, there would be a relative increase in spray drift associated with winds traversing the center of the field but a relative decrease in spray drift associated with winds near field edges. However, these relative increases and decreases are smaller than the differences associated with varying field sizes explored above and, as such, changes to buffer distance are not identified based on wind orientation to field shape.

Studies evaluating offsite movement that measure windspeed and direction are summarized in previous assessments and speak to field variability associated with these two factors (USEPA, 2020b). Though analyses of wind direction over the 21- to 28-day study periods indicate that

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[26] 45 ft swath width with 20 swaths results in a 900 ft field depth. 900 ft^2 = 19 acres

[27] 45 ft swath width with 4 swaths on a 1,000 ft long field. 180 ft * 1,000 ft = 4 acres. Field size and shape comparable to Spray Drift Task Force test plots.

high winds (*e.g.*, 10-15 mph) can come from all directions, available data indicate when wind direction variability occurs over the course of a pesticide application it is at lower windspeeds (*e.g.*, <5 mph), and it is expected that these low windspeeds are not prone to spray drift. Most of the studies cited in USEPA (2020b) report a single prevailing wind direction over the course of an application. Therefore, downwind spray drift buffers should be maintained even in low wind conditions to account for the potential for windspeed increases in the prevailing wind direction (*i.e.*, wind gusts) but spray drift buffers are not identified for upwind directions.

Appendix B. Supporting Material for Maximum Spray Drift Distances

Establishing the maximum buffer distance is the selection of a distance within which the slope of the spray drift deposition curves can be evaluated. The current method for evaluating this distance is summarized in **Section 4.2.** The following methods were considered but EPA is relying on these methods to identify spray drift distances.

Method Identified in 2023 Draft Herbicide Strategy:

The following approach was in the June 2023 Technical Support Document Public Comment Draft and involved setting maximum spray drift buffer distances where the predicted fraction of deposition declines by <1% over the prior 100 ft. For example, if the predicted depositions at 100 ft and 200 ft are 1.5% and 0.6%, respectively, the difference is 0.9% and the identified maximum is 100 ft. See **Table B-1** below for a summary of maximum spray drift buffer distances associated with each Tier I deposition curve and **Figure B-1** for where maximum buffers occur on exponential deposition curves based on this method. Note that the y-axis is plotted on an exponential scale in **Figure B-1** to more clearly show the deposition differences and decline associated with each curve.

Table B-1. Identified maximum drift buffer distances from June 2023 Technical Support Document Public Comment Draft for aerial, ground and airblast applications for agricultural herbicides.

Type of Application	Application Parameters Assumed in Tier 1 AgDRIFT® Modeling	Draft Method: <1% change over 100 ft
Aerial Application	Very fine to fine DSD	500
	Fine to medium DSD	300
	Medium to coarse DSD	300
	Coarse to very coarse DSD	200
Ground Boom Application	Very fine to fine DSD; high boom	200
	Very fine to fine DSD; low boom	100
	Fine to medium-coarse; high boom	100
	Fine to medium-coarse; low boom	100
Airblast	Sparse	100

DSD=Droplet Size Distribution; Low boom height= release height is less than 2 feet above the ground; high boom = release height is greater than 2 feet above the ground

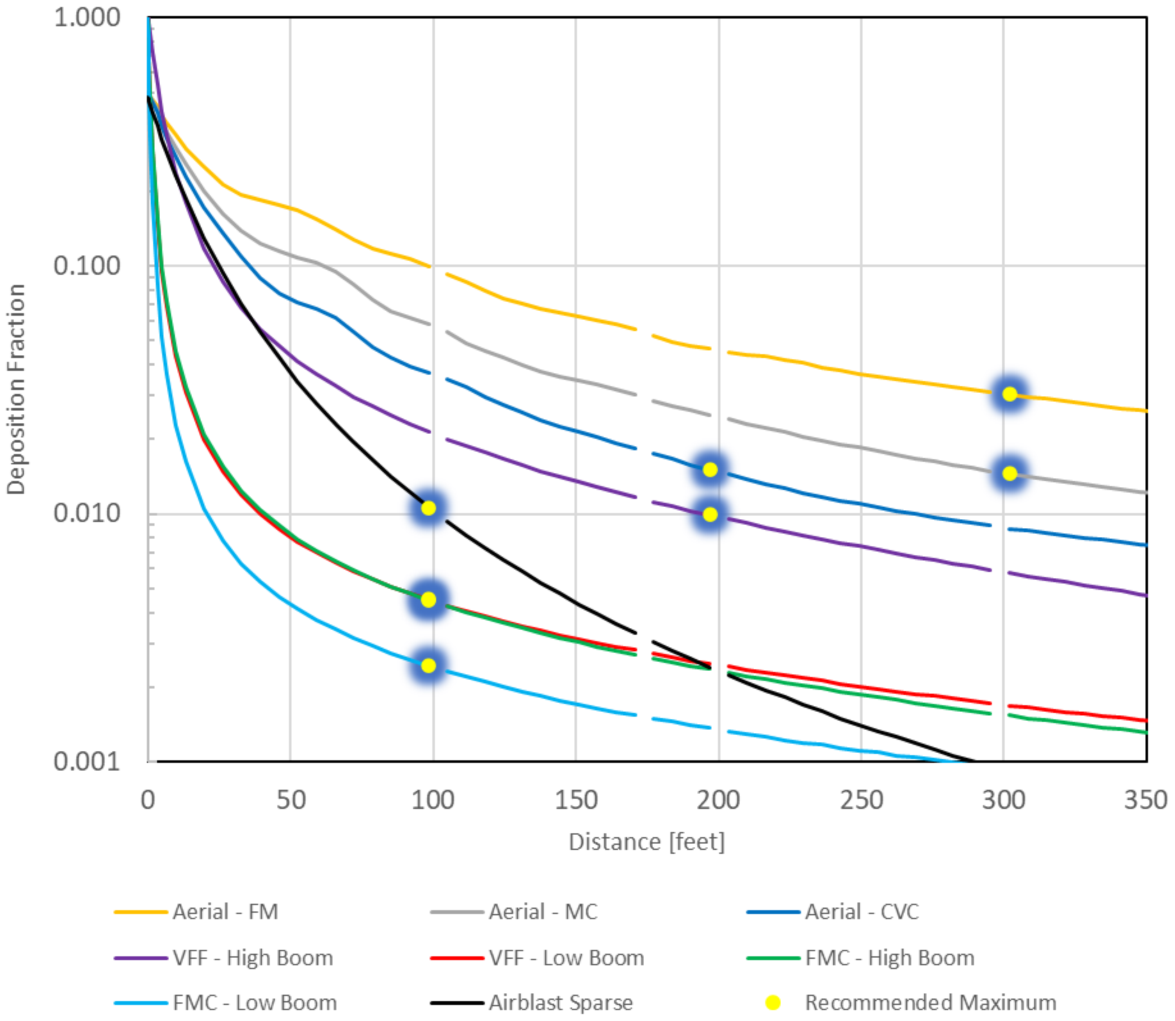

Figure B-1. Exponential Fraction of Applied Pesticide with Distance for Aerial, Ground and Airblast Applications with Different Droplet Size Distributions based on AgDRIFT® Tier I Modules.

Alternate Method introduced in 2023 Draft Herbicide Strategy:

To find the maximum buffer distance, the change in deposition fraction of less than 0.5% of the deposition at five feet off field over a distance of 25 feet for the 90th percentile deposition curves is analyzed. This is equivalent to a change in deposition of 0.03% (for ground applications with low boom and fine droplets) to 0.23% (for aerial applications with very fine droplets) of the application rate over 25 ft. Changes in deposition within this magnitude are within the range of model sensitivity for depositions that can change over the course of a pesticide application (e.g., a change in wind speed from 9 mph to 11 mph changes point deposition from

0.38% to 2.8% depending on droplet size[28]). Changes in wind speed of 2 mph can occur over the course of an application as 90th percentile wind speed changes in 5-minute and 1-hour increments can be 1.5 mph and 2.5 mph, respectively.[29] A point is selected at five feet from edge of field as the baseline for comparison because modeled deposition values at the edge of field are not directly comparable between application methods considering aerial values are near 50% of the application rate (and decline gradually) while ground values are near 100% (and decline rapidly). Five feet from the field edge allows for a comparison more consistent with offsite deposition, and for this analysis it is was used as a transition point between on-site and offsite exposure. A 25-foot distance was selected during the development of the draft method far enough apart to be distinguishable for this analysis effort. This process is applied to each application method (aerial, ground boom, airblast) and all droplet size assumptions.

As described earlier, based on the modeling, exposure may still occur beyond EPA's identified maximum buffer distances, but not substantially changing with distance. See **Figure B-2** below indicating the distances at which deposition is no longer substantially changing with distance according to this method. Deposition fractions in this figure are presented relative to application rate (rather than deposition at five feet from field edge) to allow for a relevant visual comparison of the differing application methods and droplet sizes.

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[28] Teske, M.E., S. Bird, D. Esterly, S. Ray. S. Perry. A User's Guide for AgDRIFT® 2.0.07: A Tiered Approach for the Assessment of Spray Drift of Pesticides: Regulatory Version.

[29] Wind speed measured in April 2023 in Lincoln, Nebraska changes over 5-minute increments with a median change of 0.47 mph and 90th percentile change of 1.5 mph. Over 1-hour increments, the median change is 0.65 mph and 90th percentile change is 2.5 mph. Median and 90th percentile wind speeds during the study period are 3.3 mph and 7.2 mph, respectively. Source: NOAA NCEI. Quality Controlled Datasets.

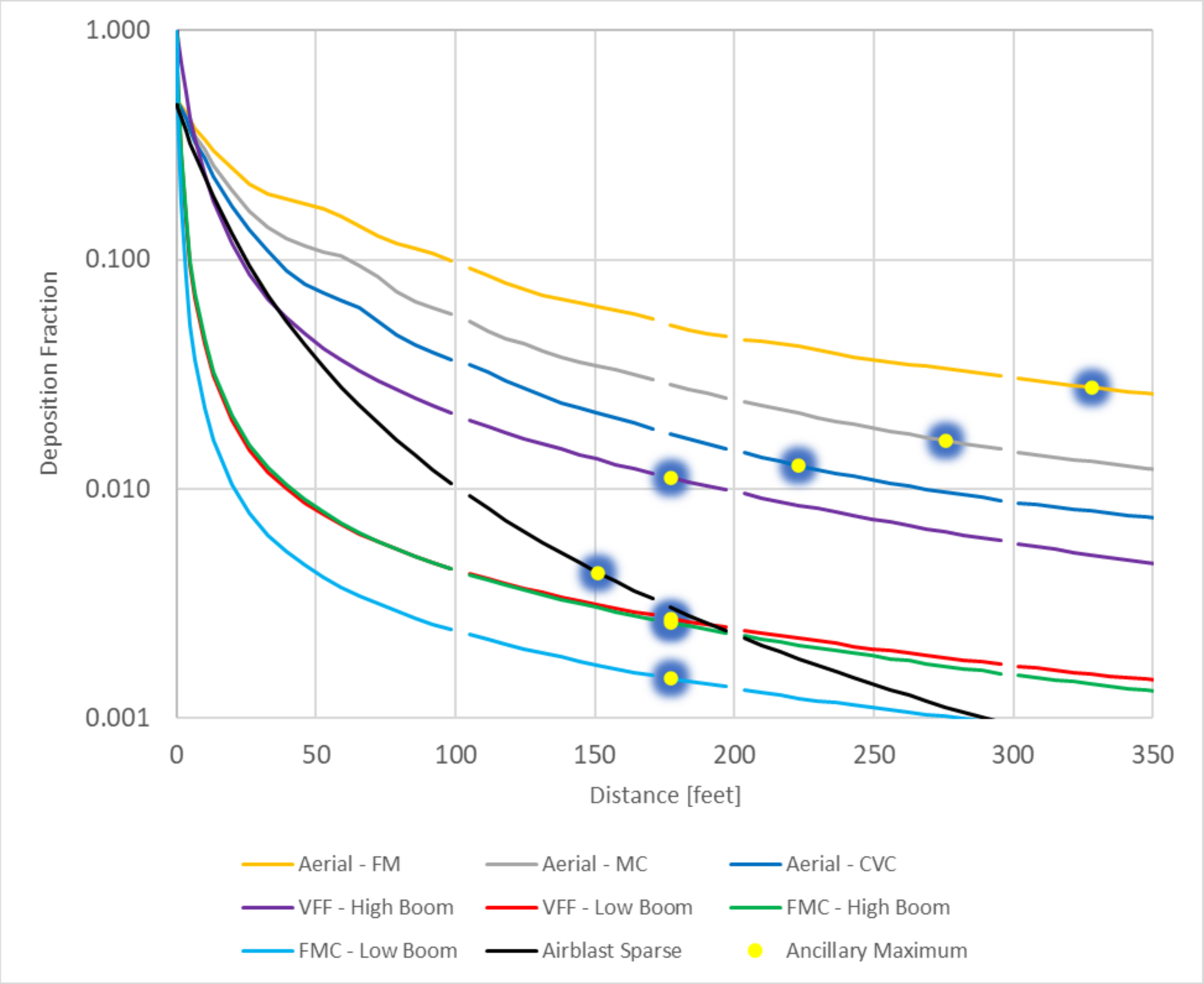

Figure B-2. Fraction of Applied Pesticide with Distance for Aerial, Ground, and Airblast Applications with Different Droplet Size Distributions based on AgDRIFT® Tier I Modules. The ancillary maximum buffer distances show where deposition change over 25 feet is <0.5% when compared to deposition 5 feet off field.

In summary, a 90th percentile curve deposition decline rate of 0.5% over 25 feet from five feet from the field edge results in an array of maximum buffer distances where changes in the amount of exposure are not substantial with increased distance. **Figure B-2** above depicts the maximum buffer extents for eight representative drift curves while **Table B-2** and **Table B-3** below provide a more complete numerical representation of all 13 relevant drift curves.

Table B-2. Fraction of Application Rate at Edge of Field Compared to 5 feet (1.5 m) from Field Edge

Application Assumptions	Edge of Field (Fraction of Applied Pesticide)	5 ft from Field Edge (Fraction of Applied Pesticide)
Aerial, very fine to fine	0.500	0.458
Aerial, fine to medium	0.500	0.406

Aerial, medium to coarse	0.500	0.386
Aerial, coarse to very coarse	0.500	0.369
Ground, high boom, very fine to fine	1.02	0.452
Ground, low boom, very fine to fine	1.01	0.192
Ground, high boom, Fine to Medium/Coarse	1.01	0.0995
Ground, low boom, Fine to Medium/Coarse	1.00	0.0548
Airblast, Sparse	0.476	0.324

Estimated using AgDRIFT® version 2.1.1

Table B-3. Percent Change in Deposition Compared to Deposition 5 feet off the Treated Field across 25-foot Increments with Example Calculation[1]

Distance (m)	Rounded Distance* (ft)	Percent change in deposition compared to 5 feet off the treated field								
		Aerial Application				Ground Boom				Airblast
						High	Low	High	Low	
		VFF	FM	MC	CVC	VFF	VFF	FMC	FMC	Sparse
8	25	13.5	11.3	14.1	17.2	11.1	8.39	9.22	8.96	18.5
16	50	8.11	12.3	9.10	6.60	3.52	2.66	3.44	3.30	5.47
24	75	7.05	4.52	3.84	2.77	1.40	1.09	1.48	1.44	1.79
30	100	6.56	6.22	3.94	2.54	1.20	0.94	1.33	1.31	1.27
38	125	4.62	2.94	2.24	1.64	0.78	0.64	0.92	0.91	0.67
46	150	5.12	2.55	1.48	1.08	0.58	0.46	0.70	0.69	**0.40**
54	175	2.10	1.42	0.93	0.65	**0.33**	**0.27**	**0.41**	**0.40**	0.19
60	200	3.33	1.06	0.95	0.65	0.36	0.30	0.46	0.46	0.18
68	225	2.26	1.27	0.74	**0.46**	0.27	0.23	0.38	0.38	0.13
76	250	1.72	0.81	0.58	0.34	0.23	0.20	0.32	0.31	0.09
84	275	1.87	0.76	**0.45**	0.27	0.19	0.17	0.27	0.27	0.06
92	300	1.18	0.63	0.35	0.19	0.16	0.14	0.22	0.24	0.05
100	325	1.13	**0.41**	0.22	0.13	0.10	0.09	0.16	0.15	0.03
	~									
168	550	0.52								
176	575	**0.25**								

Example calculation: 5 ft Aerial MC deposition = 0.386; 75 ft MC deposition = 0.07296; 100 ft MC deposition = 0.05815. Difference in deposition between 75 ft and 100 ft when compared to deposition 5 ft off the field for Aerial MC:

$$\frac{(0.07296 - 0.05815)}{0.386} \times 100\% = \mathbf{3.84}\%$$

[1] First 25-ft segment with <0.5% change in deposition in **bold**. Gray highlighted cells indicate distances farther off the treated field where deposition is changing by <0.5% relative to 5 feet off the treated field.

”FM” – Fine to Medium droplet size distribution (DSD), “MC” – Medium to Coarse DSD, “CVC” -Coarse to Very Coarse DSD, “VFF” – Very Fine to Fine DSD, “FMC” – Fine to Medium/Coarse, “High” – High Boom, “Low” – Low Boom.

*Exported deposition curves are reported in whole meters. Deposition values closest to the 25 ft increments were used in this analysis.

Appendix C. Supporting Material for Adjuvants

C.1 Background

Agricultural adjuvants are typically added to pesticide tank mixes and some formulations to enhance performance and chemical properties. Adjuvants can potentially improve the permeability and wettability of pesticide formulations or reduce the generation of fine droplets. There are different types of spray adjuvants used in crop protection such as protective agents ("stickers", drift retardants, "thickeners"), silicone and non-silicone surfactants (carriers and spreaders), ionic polymers, oil-based emulsions (crop oils, crop oils concentrates, and methylated seed oils), and guar gums (Henry *et al.*, 2016; Liu *et al.*, 2023; Xue *et al.*, 2024) Spray adjuvants can have the ability to modify application characteristics, such as changes in droplet size distribution, to reduce off target drift potential. Given the potential to reduce off target spray drift potential, EPA evaluated the use of agricultural adjuvants as a potential spray drift mitigation.

There is evidence that the addition of adjuvants may increase the formation of larger spray droplets upon atomization and thus reduce spray driftable fines (Liu *et al.*, 2023). Studies have also indicated that the combination of spray nozzle type and the inclusion of adjuvants (*e.g.,* standard nozzle combined with silicone and oil-based adjuvants) may reduce pesticide spray drift spatially and modify droplet size spectrum evolution when measuring droplet size distribution (DSD) near the nozzle (Xue *et al.*, 2024).

The relationship between the liquid sheet breakup and spray droplet drift has been studied in the presence of adjuvants and commercial spray nozzles (Lui *et al.*, 2023). Longer liquid sheets produce larger droplets (coarser spray), resulting in less driftable fines. Xue *et al.* (2024) found that oil-based and ionic polymer-based pesticide adjuvants can effectively increase the viscosity of pesticide tank mixes, producing larger spray droplets and enhancing droplet adhesion to sprayed surfaces. This reduces the hood of droplets bouncing from the surface and reentering the air.

In addition to the nozzle selection (droplet size and sheet connectivity), the efficacy of an adjuvant is impacted by the amount in the spray volume and the airspeed during spray. A simulation of aerial application of 2,4-D and glyphosate in a high-speed wind tunnel indicated the DSD may shift towards low drift potential when oil-based adjuvants were utilized (Henry *et al.*, 2016). This occurred at rates ranging from 0.25% to 0.31% v:v DRA: tank mix[30] (Henry *et al.*, 2016). The increases of $D_{v0.1}$[31] and decreases in fines (<100 µm) with addition of the oil emulsion adjuvant were found to be significant for a glyphosate test, regardless of nozzle and windspeed. However for 2,4-D, significant changes in $D_{v0.1}$ and fines were only found at lower windspeeds (120 mph as opposed to 160 mph; (Henry *et al.*, 2016)). Based on parameterizing

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[30] Only 2 of 3 adjuvants have rates that can be understood in % v:v units

[31] Droplet diameter at which 10% of the spray volume is composed of droplets less than the size of the given droplet

AGDISP with wind tunnel results, Henry *et al.* (2016) concluded that it would be unlikely to observe the differences between treatments in a field study.

As for contextualizing fines reduction in Henry *et al.* (2016), the average reduction in spray volume <100 µm was reduced by 21% with the use of an adjuvant, at rates of 0.25 to 0.31% v:v. While percent reduction in fines is not directly comparable to drift reduction, it is expected that the associated reduction in drift would be <21%. A field study testing the effect of drift reducing adjuvants (DRAs) found a 30 to 50% reduction in drift 164 ft offsite. This reduction occurred with the use of an oil emulsion adjuvant at a 8 to 10x higher rate than Henry *et al.* (2016)(2.5% v:v DRA:tank mix; (Lan *et al.*, 2008)). The field study was conducted at an airplane airspeed of 135 mph and utilized a different nozzle than the two used in the wind tunnel study. These studies demonstrate the importance of the proportion of adjuvant in the spray volume can increase the drift reduction efficacy.

C.2 Accounting for Adjuvants

At this time, EPA is only considering the effectiveness of adjuvants to reduce spray drift buffer distances for hydrophobic particles, such as emulsion and emulsion modifiers as the majority of spray drift adjuvant studies available to EPA were testing the efficacy of oil emulsions. Oil emulsions have been demonstrated to increase the Volume Median Diameter (VMD) and reduce fines by introducing inhomogeneities in the tank mix (Dexter, 2001; Makhnenko *et al.*, 2021; Vernay *et al.*, 2016). These inhomogeneities cause the spray pattern to break into droplets sooner, thereby increasing droplet size, and have been shown to increase droplet size across both a range of widths of spray sheet and a range of sizes of oil droplets (Dexter, 2001; Makhnenko *et al.*, 2021; Vernay *et al.*, 2016). However, the concentration of emulsion needed to affect the VMD depends on the type of emulsion and on other surfactants in the spray mix (Dexter, 2001).

EPA is not currently considering adjuvants derived from polymers, such as guar gums and polyacrylamide adjuvants. Polymers have been demonstrated to increase VMD and reduce fines by changing the viscoelasticity of the tank mix, but the effect is sensitive to the nozzle used (Mun *et al.*, 1999). Based upon specific product spray drift studies, EPA has previously made decisions for specific pesticide products based on nozzle specific considerations[32]. However, at this time, based on the available information, the differential efficacies of polymer adjuvants to reduce spray drift across nozzle and tank mix combinations does not allow for EPA to determine a broadly applicable efficacy for this category of adjuvant. Additionally, while guar gums and polyacrylamides are known to increase the spreading and wetting ability of the tank mix (Xue *et al.*, 2024), EPA does not have the data to determine the efficacy for these adjuvant types for reducing spray drift exposures. Prior efforts to evaluate spray drift mitigation measures resulted in the development of a study protocol to support drift reduction technology (EPA, 2016). With use of the drift reduction technology protocol and in support of incorporating spray adjuvants into pesticide spray applications, CPDA (Consumer Product Distributors

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[32] https://www.regulations.gov/document/EPA-HQ-OPP-2021-0957-0015

Association) and AEP (Application Enhancement Program) developed two datasets representing more than 100 unique combinations of application conditions, including adjuvant type and rate, end use pesticide product, nozzle, and spray pressure. These datasets demonstrate the spray drift reduction potential associated with various adjuvants for ground boom application conditions (windspeed of 15 mph).

Trials were conducted on 11 different adjuvants or adjuvant combinations that can be broadly categorized as oil emulsions (80% of data) and polymers (20% of data), with one dataset providing generic descriptions of the adjuvant and adjuvant rates (referenced as CPDA data) and the other providing reference to a specific CPDA approved product but lacking adjuvant rate (referenced as AEP data). At a minimum, each product formulation has one set of comparable trials, with and without adjuvant, collected at one DSD with identical parameterization. However, beyond this minimum, there is variation in what data was collected for different products. Some products have trials conducted at multiple application rates, while others have differing adjuvant rates, nozzles, and/or pressures. For example, within this dataset, the effects of pressure on droplet size in the presence of an adjuvant can only be investigated for two end use products at one DSD each. The limitations of this dataset also complicate any analysis on the effect of nozzle selection.

Overall, the data for each end use product are specific to the unique application conditions tested (one formulation + one adjuvant type). This limits the applicability of the data to the specific conditions of the trial and adds uncertainty to broad conclusions for given types of adjuvants or types of pesticide formulation. However, data are available where all conditions are controlled (*e.g.*, nozzle, end use product, end use product rate, etc.) except the for the presence or absence of an oil emulsion drift reducing adjuvant. The following analysis leverages these controlled conditions where possible.

C.3 Analysis

The table below summarizes the CPDA data and compares spray drift deposition based on AgDRIFT droplet size distributions. DSD are derived from 17 to 21 bins representing droplets between 26 and 1460 µm. A caveat with this approach is that EPA is applying DSDs generated at ground application windspeeds (15 mph) to a mechanistic model for aerial applications at higher windspeeds. Based on the available data, this analysis focuses on oil emulsion adjuvant efficacy in herbicides. Few fungicide trials are in the available datasets and what is currently available had no or limited indication of drift reduction when an oil emulsion drift reducing adjuvant was introduced. Insecticide drift reduction adjuvant data is not currently available for analysis but is aware of additional data to be submitted for insecticides and fungicides and EPA will evaluate that data for potential future consideration as a mitigation is aware that data is available and anticipates receiving it for further evaluation. EPA anticipates that the actual active ingredient may not substantially affect how use of an adjuvant may impact spray drift deposition but rather if there are differences in the formulation composition across pesticide types that may impact it.

All emulsion comparisons consider only the highest tested rate when multiple rates are available and directly comparable. For herbicides, oil emulsion adjuvants consistently show fines reduction that would result in 25% to 44% buffer reduction across Medium and Coarse spray qualities in wind tunnel studies at 15 mph when considering average effectiveness and a lower 90th percentile confidence bound on the average effectiveness (**Table C-1**). AEP data is not summarized in the table below as concentration of adjuvant in tank mix (% v:v) is not currently available for that dataset.

Table C-14. Output from AgDRIFT Tier III Aerial Module based on imported Droplet Size Distribution and Updated Tier III Parameterization[1]

Spray Quality (n=number of trials[2])	Average Concentration of Adjuvant in Tank Mix	Initial Buffer Distance	Spray Drift Distance Buffer Reduction with Use of Adjuvant and Given Summary Statistic		
			Lowest	Lower 90th percentile confidence bound on the mean	Average
Very Coarse (n=11)	0.33% v:v	100 ft	0%	12%	15%
		200 ft	3%	11%	19%
		300 ft	7%	15%	28%
Coarse (n=4)	0.28% v:v	100 ft	-[3]	-[3]	36%
		200 ft	-[3]	-[3]	35%
		300 ft	-[3]	-[3]	44%
Medium (n=6)	0.26% v:v	100 ft	-[3]	25%	36%
		200 ft	-[3]	29%	44%
		300 ft	-[3]	31%	48%

[1] See **Appendix A.**

[2] Each trial has 3 to 8 replicates.

[3] Unavailable based on current CPDA submission. May be available pending updated submission.

Analysis below (**Table C-2**) is organized by spray quality proceeding from Very Coarse to Coarse to Medium and supports the summary table above. The lower 90th percentile confidence bound on the mean difference of spray volume at <150 µm is calculated based on the parameters and equation reported in Appendix A of EPA's Input Parameter Guidance (EPA, 2009[33]).

Table C-2. Percent fines for <u>Very Coarse</u> sprays with given end-use product, nozzle, and pressure with and without an adjuvant at a given concentration

End-use product, nozzle, pressure, adjuvant concentration	Spray volume <150 µm with emulsion adjuvant (%)	Spray volume <150 µm with no adjuvant (%)	Emulsion <150 - Average	None <150- Average	Difference in Averages
Chemical 1-	2.48	3.2	2.222	3.195	0.973 (30%)

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[33] USEPA, 2009. Guidance for Selecting Input Parameters in Modeling the Environmental Fate and Transport of Pesticides Version 2.1. October 22, 2009. Environmental Fate and Effects Division. U.S. Environmental Protection Agency. Available at: https://www.epa.gov/pesticide-science-and-assessing-pesticide-risks/guidance-selecting-input-parameters-modeling

AIXR11003 29 psi, 0.25% v:v	2.13 2.18 2.18 2.14	3.25 3.19 3.14			
Chemical 2-DG9505E 40 psi, 4 oz/20 gal, 0.16% v:v	3.76 3.79 3.74 3.72 3.64	5.39 5.26 5.35 5.18 5.16	3.73	5.268	1.538 (29%)
Chemical 3-AIXR11003 29 psi, 0.25 % v:v	2.31 2.33 2.36 2.32	3.47 3.61 3.63 3.58	2.33	3.5725	1.2425 (35%)
chemical 4, AIXR11004, 40 psi, 0.5 % v:v	2.36 2.33 2.35 2.45 2.56	2.82 2.52 2.56 2.53 2.57	2.41	2.6	0.19 (7.3%)
Chemical 5, XR11004, 40 psi, 0.5 % v:v	2.24 2.29 2.23 2.18 2.3	2.43 2.39 2.39 2.46 2.56	2.248	2.446	0.198 (8.1%)
Chemical 6, AI9505E, 40psi, 4 oz/20 gal, 0.16% v:v	4.9 4.89 4.89 4.85 4.99	5.57 5.35 5.45 5.51 5.46	4.904	5.468	0.564 (10%)
Chemical 7, AIXR11004, 40 psi, 0.39 % v:v	2.53 2.49 2.51 2.51 3.34 3.1 3.23 3.15	7.3 7.37 7.59 7.75	2.8575	7.5025	4.645 (62%)
Chemical 8, AIXR11004, 40 psi, 0.5 % v:v	2.73 2.66 2.73 2.79 3.18	3.68 4.12 4.33 4.36 4.36 4.81	2.818	4.276667	1.458667 (34%)
Chemical 9 + 0.5% adj rate	2.31 2.71	3.58 4.3	2.726667	4.096667	1.37 (33%)

AIXR11004, 40 psi, 0.5 % v:v	2.33 3.02 2.96 3.03	4.41			
Chemical 10, AIXR11003 , 40 psi, 1 oz/10 gal, 0.08 %v:v	2.47 2.65 2.75	4.5 4.75 4.71	2.623333	4.653333	2.03 (44%)
Chemical 11, AIXR11004, 40 psi, 0.39% v:v	2.35 2.3 2.32 2.56	3.52 3.52 3.3 3.33	2.3825	3.4175	1.035 (30%)
Average difference ($\bar{t}_{1/2}$)					1.385833
Standard Deviation (s)					1.220502
One-sided Student's t value at α = 0.1 and n=11 ($t_{90,n-1}$)					1.372
Lower 90th percentile confidence bound on the mean					0.88
Lowest difference					0.19

A 0.19% difference in droplet volume at 150 microns (lowest difference) is similar to the difference in the same parameter seen between AEP 300 and AEP 189. A 0.88% difference in droplet volume at 150 microns (lower 90th percentile confidence bound on mean) is similar to the difference in the same parameter seen between CPDA 942 and CPDA 950. A 1.39% difference in droplet volume at 150 microns (average) is similar to the difference in the same parameter seen between AEP 275 and AEP 562 (**Table C-3**).

Table C-3. Metadata for demonstration of adjuvant effect with AgDRIFT for Very Coarse spray quality

Trial/ Replicate Reference	Spray volume <150 µm (%)	EUP	Adjuvant and Rate	Nozzle	Orifice	Pressure	Dv50	RS
Lowest								
AEP 300	4.65	Chemical 17	None	TT11004	0.4	40	470.98	1.27
AEP 189	4.43	Chemical 17	Crop Oil Concentrate*	TT11004	0.4	40	420.64	1.16
Lower 90th percentile confidence bound on the mean								
CPDA 942	5.57	Chemical 6	None	AI9505E	0.5	40	461.43	1.14
CPDA 950	4.85	Chemical 6	Emulsion 0.16% v:v	AI9505E	0.5	40	476.6	1.12
Average								
AEP 275	6.35	Chemical 7	None	TT11004	0.4	40	438.47	1.49
AEP 562	4.92	Chemical 7	Salia*	TT11004	0.4	40	406.24	1.24

*Unknown adjuvant rate

Comparing associated AgDRIFT output indicates a negligible difference in deposition at 100 ft, a 3% difference at 200 ft, and a 7% difference at 300 ft when comparing deposition differences when the lowest difference deposition curves are compared across herbicides with and without an emulsion DRA. Comparing associated AgDRIFT output indicates a 12% difference in deposition at 100 ft, an 11% difference at 200 ft, and a 15% difference at 300 ft when comparing deposition differences when the lower 90th percentile confidence bound on the mean deposition curves are compared across herbicides with and without an emulsion DRA. Comparing associated AgDRIFT output indicates an 15% difference in deposition at 100 ft, a 19% difference at 200 ft, and a 28% difference at 300 ft when comparing deposition differences when the average deposition curves are compared across herbicides with and without an emulsion DRA (**Table C-4** and **Table C-5**).

Table C-4. Percent fines for <u>Coarse</u> sprays with given end-use product, nozzle, and pressure with and without an adjuvant at a given concentration

End-use product, nozzle, pressure, adjuvant concentration	Spray volume <150 µm with emulsion adjuvant (%)	Spray volume <150 µm with no adjuvant (%)	Emulsion <150 - Average	None <150-Average	Difference in Averages
Chemical 1-AIXR11003, 58 psi, 0.25% v:v	4.76 4.73 4.86 4.77	7.17 7.21 7.16 6.97	4.78	7.1275	2.3475 (33%)
Chemical 3-AIXR11003, 58 psi, 0.25% v:v	5.32 5.24 5.2 5.17	6.54 6.35 6.46 6.52	5.2325	6.4675	1.235 (19%)
Chemical 12-DG9505E, 40 psi, 8 oz/15 gal, 0.42 %v:v	3.86 3.76 3.86 3.82	6.37 6 6.14 6.29	3.825	6.2	2.375 (38%)
Chemical 13-GRD12005, 60 psi, 4 oz/15 gal, 0.21 %v:v	6.25 6.17 6.33 6.28 6.19	10.1 10 9.92 9.92 10	6.244	9.988	3.744 (37%)
Average difference (¯t¯$_{1/2}$)					**2.425375**
Standard Deviation (s)					1.027029
One-sided Student's t value at α = 0.1 and n=4 ($t_{90,n-1}$)					1.638
Lower 90th percentile confidence bound on the mean					1.584238
Lowest difference					1.235

A 2.43% difference in droplet volume at 150 microns (average difference) is similar to the difference in the same parameter seen between CPDA 1002 and CPDA 1005.

Table C-5. Metadata for demonstration of adjuvant effect with AgDRIFT for Coarse spray quality

Trial/ Replicate Reference	Spray volume <150 µm (%)	EUP	Adjuvant and Rate	Nozzle	Orifice	Pressure	Dv50	RS
Average								
CPDA 1002	6	Chemical 12	None	DG9505E	0.5	40	387.85	1.069
CPDA 1005	3.86	Chemical 12	Emulsion 0.42% v:v	DG9505E	0.5	40	399.78	0.986

Comparing associated AgDRIFT output indicates a 36% difference in deposition at 100 ft, a 35% difference at 200 ft, and a 44% difference at 300 ft when comparing deposition differences when the CPDA 1002 and CPDA 1005 deposition curves are compared across herbicides with and without an emulsion DRA (**Table C-6**).

Table C-6. Percent fines for Medium sprays with given end-use product, nozzle, and pressure with and without an adjuvant at a given concentration.

End-use product, nozzle, pressure, adjuvant concentration	Spray volume <150 µm with emulsion adjuvant (%)	Spray volume <150 µm with no adjuvant (%)	Emulsion <150 - Average	None <150- Average	Difference in Averages
Chemical 1- XR11003, 29 psi, 0.25% v:v	8.37 8.25 8.25 8.24	15.94 16.16 15.85 16.11	8.2775	16.015	7.7375 (48%)
Chemical 3- XR11003, 29 psi, 0.25% v:v	9.96 10 9.86 9.95	20.32 21.21 22.89 22.76	9.9425	21.795	11.8525 (54%)
Chemical 6- DG9505E, 40 psi, 4 oz/20 gal, 0.16% v:v	13.78 13.4 13.14 13.15 13.12	14.79 14.86 14.74 14.87 14.88	13.318	14.828	1.51 (10%)
Chemical 14- XR11003, 40 psi, 4 oz/15 gal, 0.21% v:v	11.97 12.14 11.95 11.96 12.17	14.64 14.78 14.7 14.57 14.22	12.038	14.582	2.544 (17%)
Chemical 15, XR11003, 43.5 psi, 0.5% v:v	16 15.73 15.4	22.62 22.37 22.75	15.925	22.58	6.655 (29%)

	14.96 15.73 15.67 16.09 15.9 16.15 16.43 16.63 16.41				
Chemical 16-XR11003, 40 psi, 4 oz/15 gal, 0.21% v:v	11.33 11.4 11.56 11.26 11.24	17.49 17.45 17.33 17.38 17.19	11.358	17.368	6.01 (35%)
Average difference ($\bar{t}_{1/2}$)					6.0515
Standard Deviation (s)					3.735985
One-sided Student's t value at α = 0.1 and n=6 ($t_{90,n-1}$)					1.476
Lower 90th percentile confidence bound on the mean					**3.8**
Lowest difference					1.51

A 3.8% difference in droplet volume at 150 microns (lower 90th percentile confidence bound on mean) is similar to the difference in the same parameter seen between AEP 296 and AEP 25. A 6.05% difference in droplet volume at 150 microns (average) is similar to the difference in the same parameter seen between CPDA 836 and CPDA 838 (**Table C-7**).

Table C-7. Metadata for demonstration of adjuvant effect with AgDRIFT for Medium spray quality

Trial/ Replicate Reference	Spray volume <150 µm (%)	EUP	Adjuvant and Rate	Nozzle	Orifice	Pressure	Dv50	RS
10th percentile confidence bound on the mean								
AEP 296	18.77	Chemical 17	None	XR11004	0.4	40	255.78	1.21
AEP 25	15.04	Chemical 17	Nexum NG*	XR11004	0.4	40	265.06	1.15
Average								
CPDA 836	17.38	Chemical 16	None	XR11003	0.3	40	259.11	1.20
CPDA 838	11.33	Chemical 16	Emulsion 0.21% v:v	XR11003	0.3	40	283.63	1.10

*Unknown adjuvant rate

Comparing associated AgDRIFT output indicates a 25% difference in deposition at 100 ft, a 29% difference at 200 ft, and a 31% difference at 300 ft when comparing deposition differences when the deposition curves associated with the lower 90th percentile confidence bound on the mean difference are compared across herbicides with and without an emulsion DRA. Comparing associated AgDRIFT output indicates a 36% difference in deposition at 100 ft, a 44% difference at 200 ft, and a 48% difference at 300 ft when comparing deposition differences when the deposition curves associated with the average difference are compared across herbicides with and without an emulsion DRA.

Appendix D. Pesticide Water Calculator (PWC) and Plant Assessment Tool (PAT) Overview

The Pesticide Water Calculator (USEPA, 2024) is a model for calculating pesticide concentrations in waterbodies for use in pesticide risk assessments as typically used in USEPA regulatory work. A detailed overview can be found in (Young, 2019). Briefly, PWC conceptualizes an agricultural field with a crop and an adjacent water body. After a pesticide is applied to the field, it degrades on the field, and subsequent rainfall and irrigation water may create runoff, erosion, and leaching that can transport the pesticide to the adjacent waterbody or terrestrial areas.

Pesticide spray drift into the waterbody may also occur on the day of application. Buffers (a spatial separation between field and waterbody) may be included in PWC between the field and waterbody to reduce drift inputs to the waterbody. The standard field for USEPA ecological assessments is 10 ha and planted with crops that correspond to the pesticide label. For USEPA standard ecological assessments, the waterbody receiving the pesticide (known as the Farm Pond) is a 1-ha pond, 2 meters deep, and has a 5 cm benthic layer. PWC accounts for waterbody processes such as metabolism, volatilization, photodegradation, leaching, uptake into sediment.

PWC also has the capabilities to produce output for receiving areas other than the standard Farm Pond, namely it can produce estimates TPEZ and WPEZ which are the targets from the Plant Assessment Tool (PAT). The WPEZ is a wetland simulated by the PWC as a 1-ha waterbody with depth dependent on evaporation and runoff water flowing in and out. The TPEZ is a land area (no overlying water) that receives runoff and drift. Note that the latest version of PWC (version 3) can perform these PAT calculations automatically while the previous PWC version (version 2) required external manipulations of PWC output. Details of the WPEZ and TPEZ calculations cand be found in the PWC documentation (USEPA, 2024).

Appendix E. Modeling Supporting Avoiding Applications Before Rain or Irrigation Events

E.1 Background

EPA used Pesticide in Water Calculator (PWC) modeling to investigate the effect in offsite pesticide transport by runoff or erosion that would occur by not applying pesticides 48-hours before rain or irrigation events. on. For this investigation, EPA modeled a wide variety of scenarios that included a range of use patterns and locations (**Table E-1**). Scenarios are inputs to the PWC that describe the crop, land, and weather characteristics of a particular location.

The analysis was not specific to a type of pesticide (e.g., herbicide, insecticide), or specific pesticides, but rather evaluated a range of persistence and mobility. Based on the conceptual model of PWC, aerobic soil metabolism (ASM) and foliar degradation are the most relevant PWC degradation parameters prior to a chemical leaving the field as runoff. However, EPA did not include foliar degradation in this analysis as this information is typically unavailable for EPA ecological risk assessments. Instead, EPA calculated the EECs across various scenarios for a set of mock chemicals with various sorption coefficients (K_{oc}) and aerobic soil metabolism (ASM) half-lives (**Table E-2**).

EECs vary with application date, therefore, for each mock chemical, EPA modeled a 60-day application window (-30 days to +29 days from the original application date) to assess the variability in the application date on the modeling results. EPA kept the pesticide use information (*e.g.,* the application date, application rate, and application type constant) across all runs, except where noted.

As discussed below, the results demonstrate that not applying pesticides 48 hours before a rain or irrigation events is only likely to reduce the EECs for a subset of chemicals.

Table E-1. List of PWC scenarios modeled for analyzing the effect of avoiding pesticide applications 48-hour before rain or irrigation events.

Scenario Name				
CAalfalfa_WirrigOP	FLcitrusSTD	MIAsparagusSTD	NDcanolaSTD	PAtomatoSTD
CAalmond_WirrigSTD	FLcucumberSTD	MIbeansSTD	NECornStd	PAturfSTD
CAcitrus_WirrigSTD	FLnurserySTD_V2	MICherriesSTD	NJmelonStd	PAvegetableNMC
CAColeCropRLF_V2	FLpeppersSTD	MImelonStd	NJnurserySTD_V2	RangeBSS
CAForestryRLF	FLstrawberry_WirrigSTD	MInurserySTD_V2	NYGrapesSTD	RightOfWayBSS
CAfruit_WirrigSTD	FLtomatoSTD_V2	MNalfalfaOP	OHCornSTD	STXcornNMC
CAgrapes_WirrigSTD	FLturfSTD	MNCornStd	ORappleSTD	STXgrapefruitNMC
CAlettuceSTD	GAPeachesSTD	MNsugarbeetSTD	ORberriesOP	STXmelonNMC
CAMelonsRLF_V2	GAPecansSTD	MOmelonStd	OrchardBSS	STXvegetableNMC
CAnurserySTD_V2	IAcornstd	MScornSTD	ORfilbertsSTD	TNnurserySTD_V2
CAOliveRLF_V2	ILalfalfaNMC	MSsoybeanSTD	ORgrassseedSTD	TXalfalfaOP
CArangelandhayRLF_V2	ILbeansNMC	NCalfalfaOP	ORnurserySTD_V2	TXsorghumOP
CArightofwayRLF_V2	ILCornSTD	NCappleSTD	ORsnbeansSTD	WAbeansNMC
CARowCropRLF_V2	INCornStd	NCcornESTD	ORXmasTreeSTD	WAorchardsNMC
CAtomato_WirrigSTD	KSCornStd	NCpeanutSTD	PAalfalfaOP	
FLcabbageSTD	KSsorghumSTD	NCSweetPotatoSTD	PAappleSTD_V2	
FLcarrotSTD	MeadowBSS	NCtobaccoSTD	PAcornSTD	

Table E-2. Modeling parameters for mock chemicals in PWC.

PWC Modeling Parameter	Mock Chemicals
Sorption Coefficient (mL/g)	**Varied**[1]
K_{oc} flag	TRUE
Water Column Metabolism Half-life (day)	0
Water Reference Temperature (°C)	25
Benthic Metabolism Half-life (day)	0
Benthic Reference Temperature (°C)	25
Aqueous Photolysis Half-life (day)	0
Photolysis Reference Latitude	40
Hydrolysis Half-life (days)	0
Soil Half-life (days)	**Varied**[2]
Soil Reference Temperature (°C)	20.5
Foliar Half-life (days)	0
Molecular Weight (g/mol)	201.2
Vapor Pressure (torr)	1.37E-07
Solubility (mg/L)	32
Henry's Constant (unitless)	4.63E-08
Air Diffusion (cm3/d)	--
Heat of Henry (J/mol)	--

[1] The sorption coefficient was varied to include 10, 100, 1,000, 10,000, and 20,000 mL/g.

[2] The soil half-life was varied to include 1, 2, 5, 10, 100, 500, and 3,000 days.

E.2 Methods

EPA completed an investigation into the effectiveness of a 48-hour rain restriction for pesticides across a range of K_{OC} values and persistence. This investigation included modeling a range of use patterns that covered a broad set of agricultural and non-agricultural scenarios in PWC (**Table E-1**), modifying the K_{OC} (10, 100, 1,000, 10,000, and 20,000 mL/g) and aerobic soil metabolism half-lives (1, 2, 5, 10, 100, 500, and 3,000 days) across model runs, with or without a rain or irrigation event occurring after 48 hours of pesticide application (**Table E-2**).

To simulate not applying a pesticide 48 hours before a rain or irrigation event, the rain restriction modeling option in PWC was set to avoid 1 cm of precipitation for 48 hours, with a 7-day optimum application window and 3-day minimum re-treatment interval. Additionally, all modeling was conducted assuming zero spray drift, which ensures that the assessment focused on the effects of the rain restriction and not variability in the amount of spray drift versus runoff in the different scenarios.

For each combination of K_{oc} and ASM half-life, both with or without the rain restriction, the maximum 1-day annual average EEC for the modeling period (approximately 30 years) was averaged across all scenarios and from each application date modeled (30 dates) The percent difference was then calculated according to **Equation 1**.

Equation 1

$$\% \text{ Difference} = \frac{(\mathrm{A}^{\mathrm{NR}} - \mathrm{A}^{\mathrm{RR}})}{\mathrm{A}^{\mathrm{NR}}} \times 100$$

Where:

A^{NR} is the 1-day average without a rain restriction
A^{RR} is the 1-day average with a rain restriction

E.3 Results

The results showed that EECs from chemicals with a K_{OC} of 100 mL/g or 20,000 mL/g did not generally decrease with a 48-hour rain restriction, unless they had an ASM half-life of less than 2 days. For this subset there was about a 20% reduction in EECs compared to no restriction (**Table E-3**). For chemicals with ASM half-lives of 2 or 5 days, the rain-restriction was associated with a 21 and 12% decrease in EECs, while EECs for chemicals with an ASM half-life of 500 days did not decrease. EPA concludes that not applying pesticides 48 hours before a rain or irrigation event will be most effective at reducing EECs for chemicals that are mobile and/or non-persistent.

Table E-3. Estimated Environmental Concentrations (EECs)[1] averaged across all scenarios (with and without a rain restriction) and percent reduction seen

K_{OC} (g/mL)[2]	ASM half-life (days) [2]	EEC (µg/L), with rain restriction	EEC (µg/L), without rain restriction	Difference (%)
10	1	270.0	350.0	22.0
10	2	310.0	390.0	20.0
10	5	370.0	450.0	17.0
10	10	410.0	490.0	15.0
10	100	480.0	550.0	12.0
10	500	490.0	560.0	12.0
10	3000	500.0	560.0	12.0
100	1	160.0	200.0	21.0
100	2	230.0	280.0	19.0
100	5	320.0	380.0	14.0
100	10	410.0	450.0	11.0
100	100	580.0	620.0	6.0
100	500	620.0	650.0	5.5
100	3000	620.0	660.0	5.3
1000	1	23.0	30.0	23.0
1000	2	40.0	49.0	19.0
1000	5	76.0	87.0	12.0
1000	10	120.0	130.0	7.7
1000	100	330.0	340.0	2.1
1000	500	430.0	440.0	1.3
1000	3000	470.0	470.0	1.1
10000	1	1.9	2.6	26.0
10000	2	3.6	4.5	21.0
10000	5	7.3	8.3	12.0
10000	10	12.0	13.0	7.7
10000	100	42.0	42.0	1.6
10000	500	75.0	76.0	0.7
10000	3000	100.0	100.0	0.4
20000	1	1.0	1.4	26.0
20000	2	1.9	2.4	21.0
20000	5	3.9	4.4	12.0
20000	10	6.3	6.8	7.5
20000	100	23.0	23.0	1.4
20000	500	41.0	41.0	0.5
20000	3000	58.0	58.0	0.3

K_{OC} = organic carbon-water partition coefficient; ASM=aerobic soil metabolism half-life

1. For each combination of K_{oc} and ASM half-life, the estimated environmental concentration represents an average of the maximum annual 1-day average EEC across all scenarios.

2. Color coding indicates the variation in mobility and persistence considered for K_{OC} and ASM, respectively. Green represents the lowest values (most mobile, least persistent) and red the highest values (least mobile, non-persistent). For example, chemicals with low K_{OC} and low ASM (green in both columns) would be considered mobile and non-persistent.

Appendix F. Use of the Vegetative Filter Strip Model to Estimate Vegetative Filter Strip Efficacy Using Event Based Assumptions

EPA used the Vegetative Filter Strip Modeling System (VFSMOD v4.5.1) along with PWC (v2.001) and associated crop scenarios and weather files to evaluate reductions in pesticide mass for high runoff events (95th percentile for the weather file) specific to each Hydrologic Unit Code 2 (HUC2) region. These high-end runoff events were then simulated across a range of K_{OC} values (1, 10, 100, 1,000, and 10,000 L/kg-oc) and VFS strip widths (20, 30, 50, 98 ft). These results were summarized to predict percent pesticide mass reduction by soil class.

The results indicate that soil class had the most influence on estimated environmental concentrations (EECs). Soil classes with similar pesticide reduction results are grouped for brevity. The sand, clay, and silty clay results had limited interpretive value because sand had 100% reduction in the EEC[34], and silty clay and clay had a 0% reduction in the EEC. The use of these broad soil texture classes may not capture the variability of pesticide reduction efficiencies from VFS in the field.

The results were further summarized for each soil texture by low K_{OC} (1, 10, 100 L/kg-oc) and high K_{OC} (1,000 and 10,000 L/kg-oc); eastern states (HUC2 regions 1 to 12) and western states (HUC2 regions 13 to 18); and mid and low ratio of field area to VFS strip area. **Table F-1** shows the required buffer width to produce several examples of field area to buffer area ratios for the specific case of EPA's standard pond field size of 10 ha**.**

Table F-1. Summary of Simulated Vegetative Filter Strip (VFS) Width and Field Area to Strip Area Ratio for the EPA Farm Pond Model with a 10-ha field.

VFS Width (ft)	Field Area:VFS Area
20	50:1
30	35:1
50	20:1
98	10:1

EPA used the results of these modeling simulations as an additional line of evidence (along with abundant literature) to estimate the efficacy category for the VFS mitigation measure. These results are shown in **Table F-2**.

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[34] Subsurface transport will be an important transport pathway for sandy soils.

Table F-2. Summary of the Categories of Efficacy by Soil Texture for Vegetative Filter Strips (VFS) by Hydrologic Unit Code (HUC) 2 Regions

Soil Texture	**Eastern 2-Digit HUC regions (01 to 12)**		**Western 2-Digit HUC regions (13 to 18)**	
	K_{OC} <1000 L/kg-oc	**K_{OC} >1000 L/kg-oc**	**K_{OC} <1000 L/kg-oc**	**K_{OC} >1000 L/kg-oc**
Loamy sand	50:1 ratio: Low 20:1 ratio: Medium	High	High	High
Loam	Low	Medium	50:1 ratio: High 20:1 ratio: Medium	High
Silty Loam, sandy loam	Low	Low	50:1 ratio: Medium 20:1 ratio: Low	50:1 ratio: High 20:1 ratio: Medium
Sandy clay loam, clay loam, silty clay loam	None	Low	None	Low

F.1 Analysis of Predicted Pesticide Reductions using VFSMOD

F.1.1 Background

Vegetative filter strips (VFS) can be an effective mitigation measure that may reduce offsite transport of runoff, eroded sediment, and pesticide mass from entering an adjacent receiving waterbody. The Vegetative Filter Strip Modeling System (VFSMOD) is a computer simulation model created to study water, sediment, and pollutant transport through VFS (Muñoz-Carpena and Parsons, 2004). The model is a mechanistic, storm-based model which can be linked in between the treated field simulated with the Pesticide Root Zone Model (PRZM) and the waterbody simulated with the Variable Volume Water Model (VVWM). VFSMOD may be parameterized to simulate a densely planted turf vegetation occurring immediately in between a treated agricultural field and a receiving waterbody.

F.1.2 Methods

EPA conducted analyses using VFSMOD to evaluate estimated model reductions of dissolved pesticide mass in runoff and sorbed pesticide mass in eroded sediment from implementation of VFS. EPA used an event-based approach in which single runoff events were modeled using VFSMOD. This approach enabled EPA to evaluate several K_{OC} values (1, 10, 100, 1,000, and 10,000 L/kg-oc) and VFS width combinations (20, 30, 50, and 100 ft) for all 879 recently approved PWC scenarios[35]. First, all PWC scenarios were run in PWC without VFSMOD, to extract both the individual runoff events as well as initial soil moisture conditions for input in VFSMOD, as well as provide a baseline EEC from which to compare. The resulting PRZM time series output files (*.zts) were next analyzed to extract the 10, 20, 30, …, 90, 95, 96, 97, 98, 99, and 100th percentile runoff event for each standard scenario. Each combination of runoff event, PWC scenario, K_{OC} value, and VFS width was run in VFSMOD to generate edge-of-field pesticide

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[35] PWC scenarios are available at: https://www.epa.gov/pesticide-science-and-assessing-pesticide-risks/models-pesticide-risk-assessment#aquatic

mass loadings in runoff and eroded sediment (denoted as RFLX and EFLX, respectively). The 95th percentile runoff events are the closest approximation to the 1-in-10 year average EEC calculated in PWC for the standard scenarios, and were thus selected for further evaluation and use in mitigation efficacy evaluations.

The resulting reductions of pesticide total mass (sum of pesticide mass in runoff and on eroded sediment) from VFSMOD were grouped according to the soil texture classes of each PWC scenario. Furthermore, the 50th percentiles of total pesticide mass reduction for all the PWC scenarios were selected to represent each soil texture. The various groupings are given in **Table F-3**.

Table F-3. Soil Class (a), Vegetative Filter Strip (VFS) Class (b), and K_{OC} Class (c) used to Model Pesticide Runoff/Erosion Reductions in VFSMOD

(a)

Soil Class
Loamy Sand
Loam
Silty loam and sandy loam
Sandy clay loam, clay loam, and silty clay loam

(b)

VFS Class	Field:VFS Area	VFS Width
Low	50:1, 30:1	20 ft, 30 ft
High	20:1, 10:1	50 ft, 100 ft

(c)

K_{OC} Class	K_{OC} (L/kg-oc)
Low	1, 10, 100
High	1,000 and 10,000

The modeled pesticide reductions are presented below in **Table F-4**. Across the groupings of soil class, VFS class, and K_{OC}, the lowest pesticide reduction is reported to represent the low-end of potential reductions, rounded to the nearest 10 percent. The range of predicted reductions across all chemical classes and soil textures is highly variable and site-specific, with predicted reductions ranging from 0 to 100% in some cases.

Table F-4. Lower bound Pesticide Reductions from VFSMOD in Runoff and Eroded Sediment

Soil Class (# scenarios)	VFS Class[2]	50th percentile reductions[1]	
		Low K_{OC}[3]	High K_{OC}[3]
Loamy sand (61)	Low	30	50
	High	50	70
Loam (120)	Low	10	30
	High	20	40
Silty loam, Sandy loam (272)	Low	0	20
	High	10	30

Soil Class (# scenarios)	**VFS Class[2]**	**50th percentile reductions[1]**	
		Low K_{OC}[3]	**High K_{OC}[3]**
Sandy clay loam, Clay loam, Silty clay loam (95)	Low	0	10
	High	0	10

[1] Based on 95th percentile starting runoff value, rounded to nearest 10%.

[2] VFS Class: Based on 1) VFS width where low is 20 or 30 ft width, and high is 50 or 100 ft width; and 2) Field:VFS area where low is ratios of 50:1 (20 ft VFS width) or 30:1 (30 ft VFS width) and mid is ratios of 20:1 (50 ft VFS width) or 10:1 (100 ft VFS width)

K_{OC} Class: Low is 1, 10, or 100 L/kg-oc; High is 1,000 or 10,000 L/kg-oc.

F.1.3 Results

Overall, percent reductions of pesticide mass from VFSMOD are higher for smaller rain events and lower for higher rainfall events. Three soil textures were identified in this analysis as limited in their interpretive value: sand, silty clay, and clay. In the case of sand, the coarsest of all analyzed soil textures, the majority of pesticide reductions were predicted to be 100%; however, the small runoff events associated with these reductions are typically not impactful. For silty clay and clay soils, the finest soil textures analyzed, infiltration is predicted to be low and therefore most runoff is not impacted by the VFS. Average pesticide reductions for these soils were predicted to be 0%; however, EPA acknowledges that the extreme ends of the finest textured soils coupled with high-end runoff events, may not be representative of localized field conditions, and that some reduction of pesticide loss may occur.

Appendix G. Pesticide Runoff Vulnerability

G.1 Pesticide Runoff Vulnerability

G.1.1 Background

Movement of pesticides through the environment varies depending on the environmental conditions and pesticide properties. Pesticide movement from areas of application may occur by runoff, erosion, leaching, volatilization, and/or drift (USEPA, 2020a). Runoff and erosion are geographically dependent, being driven by soil type, slope, crop, and precipitation. Thus, areas vulnerable to runoff and erosion are readily mappable and would provide a useful visual for risk managers when considering the best areas to employ runoff and/or erosion mitigations.

Runoff and erosion occur together, therefore a distinction is necessary to understand how pesticide mitigation measures can be most effective in controlling both. In the context of the discussion provided in this document, the term *runoff* will refer to water-only runoff, and the term *erosion* will refer to only the solid portion (*i.e.,* eroded solids, sediment, soil) that is picked up by the runoff and transported offsite. Pesticides with high sorption coefficients (*i.e.,* high K_d or K_{OC}, organic carbon-normalized sorption coefficient) will tend to attach to the eroded solids while those with lower sorption coefficients will tend towards the water runoff. For this reason, vulnerability to runoff or erosion is examined separately. This analysis focused only on vulnerability to runoff, however, the areas vulnerable to runoff and erosion should be similar because of the strong dependence of erosion on runoff.

Vulnerability is defined here as the potential of the land area to result in high surface water concentrations of pesticide if the pesticide were to be applied to the land. This vulnerability can be quantified with the Pesticide in Water Calculator (PWC)[36], an EPA tool used in the standard pesticide risk assessment process, which estimates surface water concentrations after application of a pesticide to an adjacent field. Note that the quantification of vulnerability is a hypothetical assessment: it does not consider whether a pesticide is actually used in the area and does not consider local hydrological characteristics, such as drainage areas or actual waterbody types, or the impact of local management practices (*e.g.* tile drains).

The watershed area to receiving waterbody volume, which varies across the landscape, is another important factor related to vulnerability that is not considered in this analysis. With all other things being equal, the watershed area to receiving waterbody ratio is directly proportional to the pesticide concentration in the waterbody – doubling the area-to-volume ratio will double the estimated environmental concentration (EEC). Nevertheless, the vulnerability assessment is an effective tool for estimating the potential for a pesticide to leave an area by runoff and/or erosion if the pesticide were applied there.

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[36] https://www.epa.gov/pesticide-science-and-assessing-pesticide-risks/models-pesticide-risk-assessment#PWC; See Young (2019) for details on the PWC.

G.1.2 Methods

Previous work (USEPA, 2020a; USEPA, 2020c) resulted in the creation of a comprehensive (about 3 million) set of scenarios that covered the United States for use in the PWC. *Scenarios* are inputs to the PWC that describe the crop, land, and weather characteristics and thus are fundamentally runoff and erosion descriptors. EPA has recently developed a systematic method to create scenarios by overlaying the USDA Soil Survey Geographic (SSURGO) database (USDA, 2018b), the latest five years of land cover/crop groups from the USDA Cropland Data Layer (CDL) (USDA, 2018a), and meteorological files/weather station grids generated from NOAA data (Fry *et al.*, 2016). This overlay yields all possible soil-land-crop-weather combinations for the conterminous 48 U.S. states, resulting in the creation of approximately 3 million scenarios.

For this evaluation, the chemical parameters and pesticide application inputs were selected to best capture the overall runoff potential of pesticides (USEPA, 2020a). To minimize the effect of application timing on the results, pesticide applications of 0.1 kg/ha were applied daily for 50 days, starting with the day of emergence (USEPA, 2020a). Additionally, a hypothetical aerobic soil half-life of 180 days was used to prevent excessive accumulation in the top few centimeters of soil (where runoff occurs) (USEPA, 2020a). As with the previous efforts described in USEPA (2020a), chemical sorption properties were selected to best capture and differentiate runoff from other transport pathways. This was achieved by simulating a hypothetical chemical with a low K_{OC} (10 mL/g). The estimated environmental concentrations (EECs) for the low K_{OC} chemical are driven primarily by runoff and therefore the results are indicative of pesticide runoff vulnerability.

Using a hypothetical chemical allows this analysis to cover all pesticides, define the results as pesticide runoff vulnerability, and use all 3 million PWC scenarios to account for geographic variability in weather and soils. As this analysis uses a hypothetical chemical, this EEC is not a concentration expected to be seen on a field, rather, it is an indicator of an area's vulnerability to pesticides occurring in surface water runoff as compared to other regions across the United States.

Because the current effort is aimed at ecological assessments, the EPA Farm Pond (Young, 2019) was used. EPA uses the Farm Pond for ecological assessments, and thus it is appropriate for evaluating the vulnerability of listed species considered in these assessments. The average daily concentration of the entire simulation (54 years) was used as the exposure endpoint for these vulnerability evaluations (Young, 2019). This concentration is proportional to, and therefore can be used as an indicator of, the total pesticide mass transported off the field with runoff (USEPA, 2020a).

Typically, a 1-in-10 year EEC is used in ecological risk assessments to define exposure concentrations. This value comes from ranking the maximum of each duration of interest (*e.g.* 1-day average, 60-day average) for each year of the simulation and estimating the 90th percentile. In comparison to the indicator used, the 54 year average EEC, a 1-in-10 year EEC is more conservative. The 54-year average EEC is more indicative of long-term trends and is therefore less influenced by abnormal weather events (*e.g.* unusual precipitation events) and is more representative of typical conditions on the field.

PWC-generated outputs were linked to each soil-land-crop-weather grid combination. With this analysis, 16 general crop classes were considered. Each crop class is linked to one or more CDL categories and crop group tables described at 40 CFR 180.41. Outputs from scenarios representing the pasture/forage crop class were not included, ensuring only agricultural scenarios were considered.

Scenario location was estimated by the longitude and latitude of the centroid of the weather grid associated with the scenario. Because several scenarios may use the same weather location, the median EEC value for each weather grid was selected for creating the vulnerability maps using in ArcGIS Pro 3.0. This median value is designated as the “pesticide runoff vulnerability score”, and results in about one point for every 17 miles (the approximate size of the weather grid) (**Figure G-1**). Additionally, EPA’s 2017 Cultivated Land Use Data Layer (UDL), which is derived from the 2013 to 2017 Crop Data Layer (CDL), was used to mask out areas where agriculture is not occurring. This ensured the analysis only focused on areas where agriculture was occurring. 2-digit Hydrological Unit Code (HUC2)[37] watershed boundaries, which are used to determine 90th percentile scenarios, were overlaid to assess the variability within these boundaries.

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[37] The United States Geological Survey (USGS) divides the United States into a series of successively smaller watershed boundaries, otherwise known as hydrological units. The hydrological units are nested within each other, from the largest geographic areas (regions) to the smallest (cataloging units) and are each identified by a unique hydrological unit code (HUC). At the HUC2 level, the nation is divided into major geographic areas that contain either the drainage area of a river, such as the Missouri river, or the combined drainage areas of a series of rivers, such as the Texas-Gulf region. (USGS, 2024)

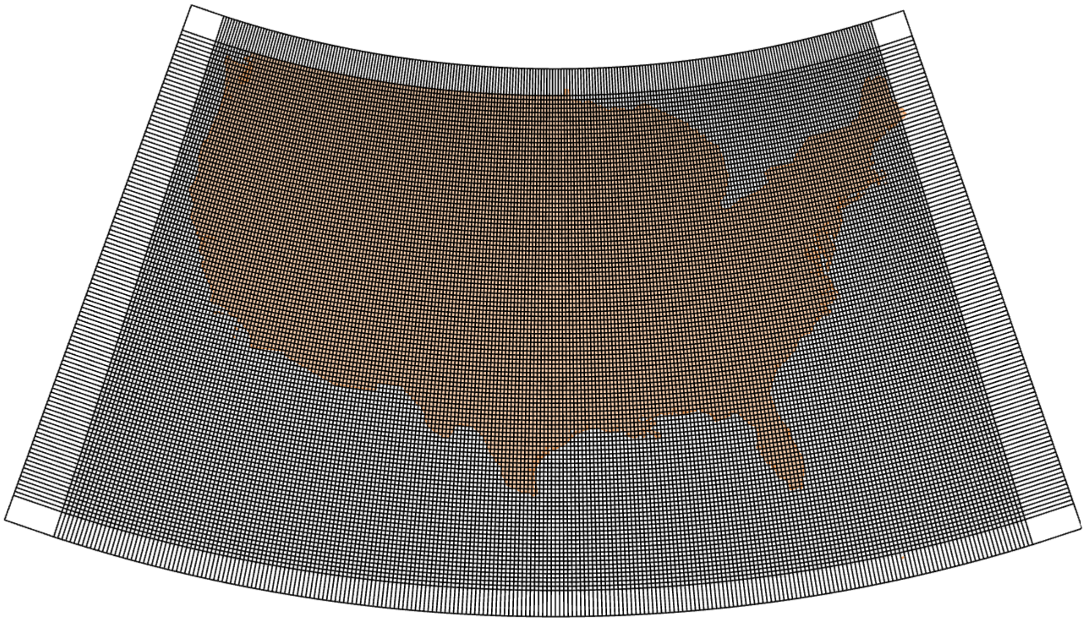

Figure G-1. Weather grid locations overlaid on the contiguous United States. Weather grid locations are evenly distributed, occurring approximately every 17 miles (0.25 x 0.25 - degree resolution)**.**

G.1.3 Results

As shown in **Figure G-2**, western HUC2s were found to have consistently lower vulnerability to pesticide runoff than what was seen nationwide. Central HUC2s (HUC10U, HUC10L, HUC11, HUC23) showed high levels of variability within the watershed, with the western portion having much lower vulnerability to pesticide runoff than the easter portion. Lastly, eastern HUCs typically had higher levels of vulnerability to pesticide runoff, but still some variability was seen within HUC5 and HUC3S. Variability seen within each HUC2 reflects area where mitigation needs based on the 90th percentile scenarios could potentially be over or underestimated.

A deeper look was taken into HUC3S and HUC5 where pesticide runoff vulnerability was lower than expected. It was determined that these areas have higher amounts of soil hydrologic groups A and B. Therefore, precipitation events are more likely to cause more infiltration (and therefore less runoff) in these areas.

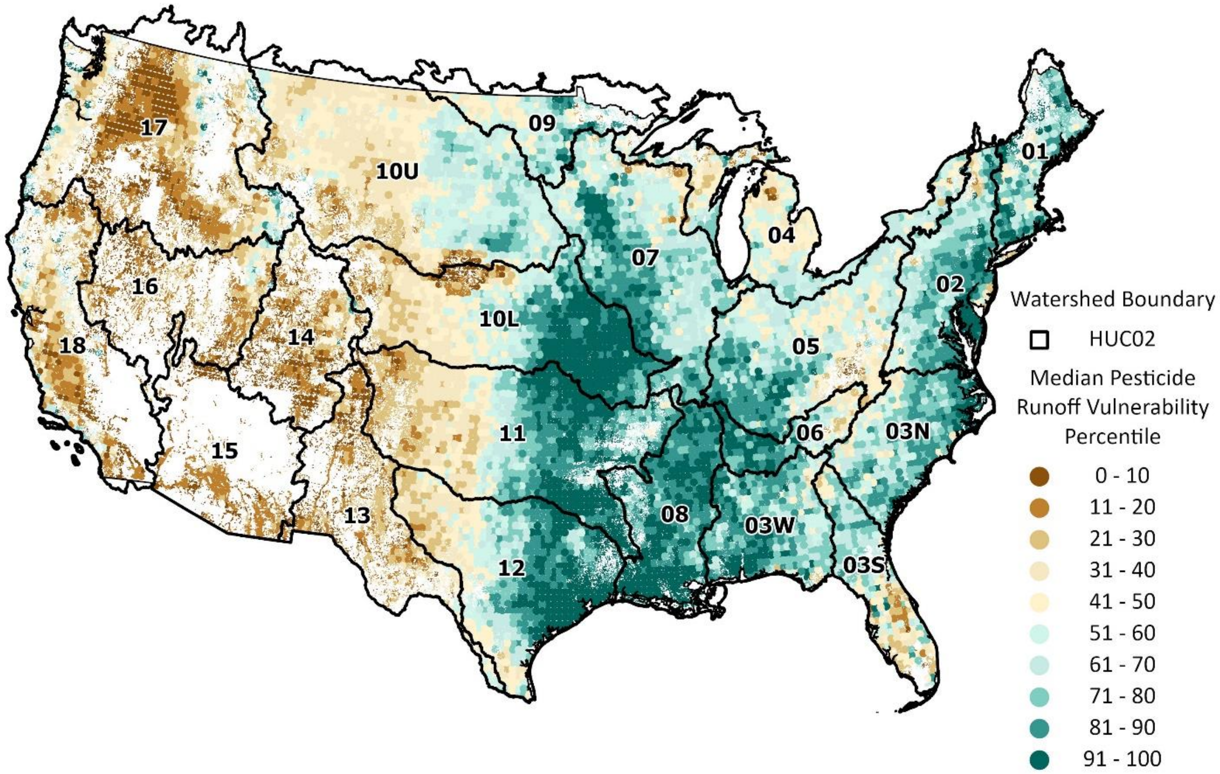

Figure G-2. Median pesticide runoff vulnerability at each weather grid station, divided into 10 quantiles with respective percentile ranges for each quantile. HUC2 watershed boundaries are overlaid and labeled. The Cultivated UDL masks areas where agriculture is not occurring, as shown in white.

G.2 Additional Lines of Evidence

In addition to the pesticide runoff vulnerability maps, several other lines of evidence were included in this analysis. These included observing how the fraction of offsite movement due to runoff changes spatially across the county and mapping pesticide relevant surface runoff and total annual precipitation.

G.2.1 Offsite Movement Runoff Fraction

During the development of scenarios for PWC in 2019, an analysis was completed using the 90th percentile risk assessment scenarios (n = 200) that looked at the fraction of offsite movement transport for a variety of different pesticides. Offsite movement fractions reflect yearly averages and divide offsite movement into three categories: drift, erosion, and runoff. In total, 24 pesticides were considered, which included a mix of herbicides, fungicides, and insecticides. The K_{oc} of these chemicals ranged from 2.7 to 17,975, with 20 of the chemicals having a K_{oc} less than 1,000, corresponding to a FAO mobility classification of moderately to highly mobile.

This analysis used EPA's Farm Pond, 54 years of weather data, accounted for each chemical’s specific degradation parameters, any chemical specific buffer restrictions, and did not include an application date window. Results from each chemical were compiled for every HUC2 and mapped (USEPA, 2006) (**Figure G-3**).

These results show that offsite movement in the western HUC2s has a consistently lower fraction due to runoff, while HUC2s in the east and Gulf regions have consistently higher runoff fractions (**Figure G-3**). This is consistent with precipitation and surface water runoff patterns seen across the country (see **Section G.2.2, Figure G-4**). An important caveat with this analysis is that since it was conducted on a HUC2 scale, variability previously seen within HUC2s in the middle of the country is likely lost.

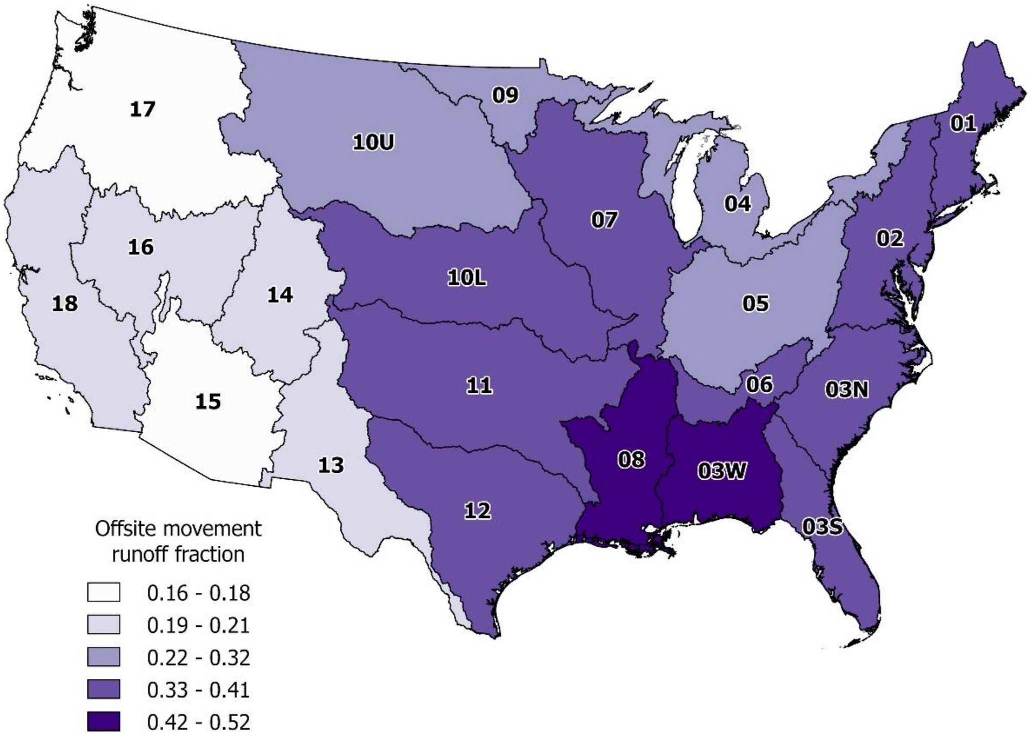

Figure G-3. Fraction of offsite movement due to runoff across HUC2s, as simulated by the 90th percentile scenarios for 20 individual pesticides.

G.2.2 Pesticide Relevant Total Annual Precipitation & Surface Runoff

A review of total annual precipitation from 1950 to 2000 was completed using the WorldClim dataset. This dataset is derived from the means of monthly precipitation readings (Cooperation, 2011). Additionally, EPA completed a review of quick flow surface runoff from EnviroAtlas, which summarizes several U.S. Geological Survey water budget and surficial groundwater datasets by HUC12s (USEPA, 2023b).

With both analyses, the Cultivated Land UDL was used to mask areas where agriculture is not occurring (**Figure G-3**). This masking converts these maps from general precipitation and surface runoff maps to pesticide relevant precipitation and surface runoff maps.

Pesticide relevant precipitation and surface runoff follow similar patterns to what was previously seen in the pesticide runoff vulnerability maps, with lower precipitation and runoff occurring in the western HUC2s (HUC13, HUC14, HUC15, HUC16, HUC17, HUC18, HUC10U) and higher precipitation and runoff occurring in the eastern and Gulf HUC2s (HUC1, HUC2, HUC03N, HUC03S, HUC03W, HUC08). HUC2s in the middle of the country showed a high level of variability (HUC07, HUC10L, HUC11, HUC12), with western portions having less precipitation and runoff than eastern portions.

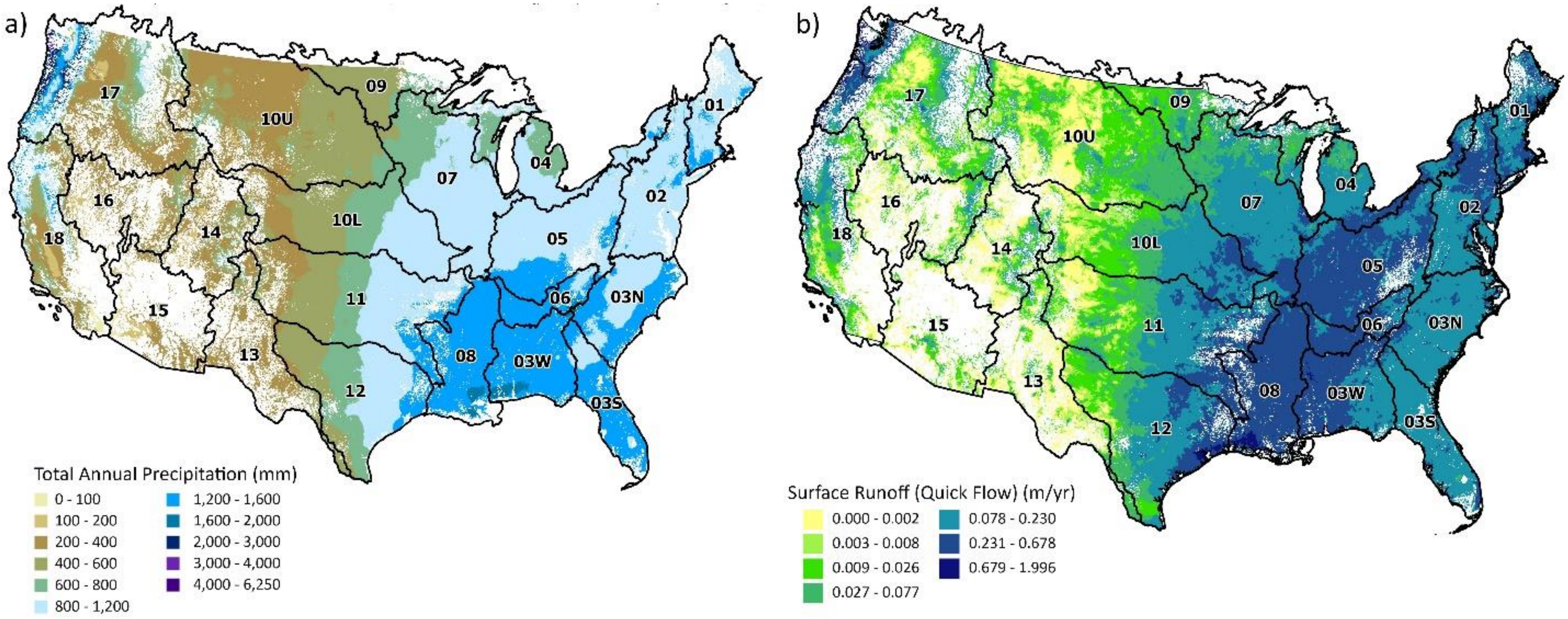

Figure G-4. **a) Pesticide relevant total annual precipitation (mm) for the continental United States, with HUC2 watershed boundaries overlaid and labeled.** The Cultivated UDL masks areas where agriculture is not occurring, as shown in white. **b) Pesticide relevant surface water runoff (m/yr) for the continental United States, with HUC2 watershed boundaries overlaid and labeled.** The Cultivated UDL masks areas where agriculture is not occurring, as shown in white.

G.3 These are pesticide vulnerability categories….Mitigation Relief

The lines of evidence discussed above demonstrate that certain areas of the country reliably have a lower vulnerability to pesticide runoff. To determine where to assign mitigation relief points, the magnitude of difference was calculated between the pesticide runoff vulnerability score of each weather grid station and the nationwide maximum score (*i.e.* the maximum of the median total pesticide mass transported off the field with runoff).

Four categories of mitigation were determined. This allows EPA to differentiate regions that are over one order of magnitude from the maximum (brown & light brown regions), the transitional region in the middle of the country (light green region), and the areas similar to the maximum (green region) (**Figure G-5**). Mitigation relief points will be assigned under the various strategies in accordance with these categorizations.

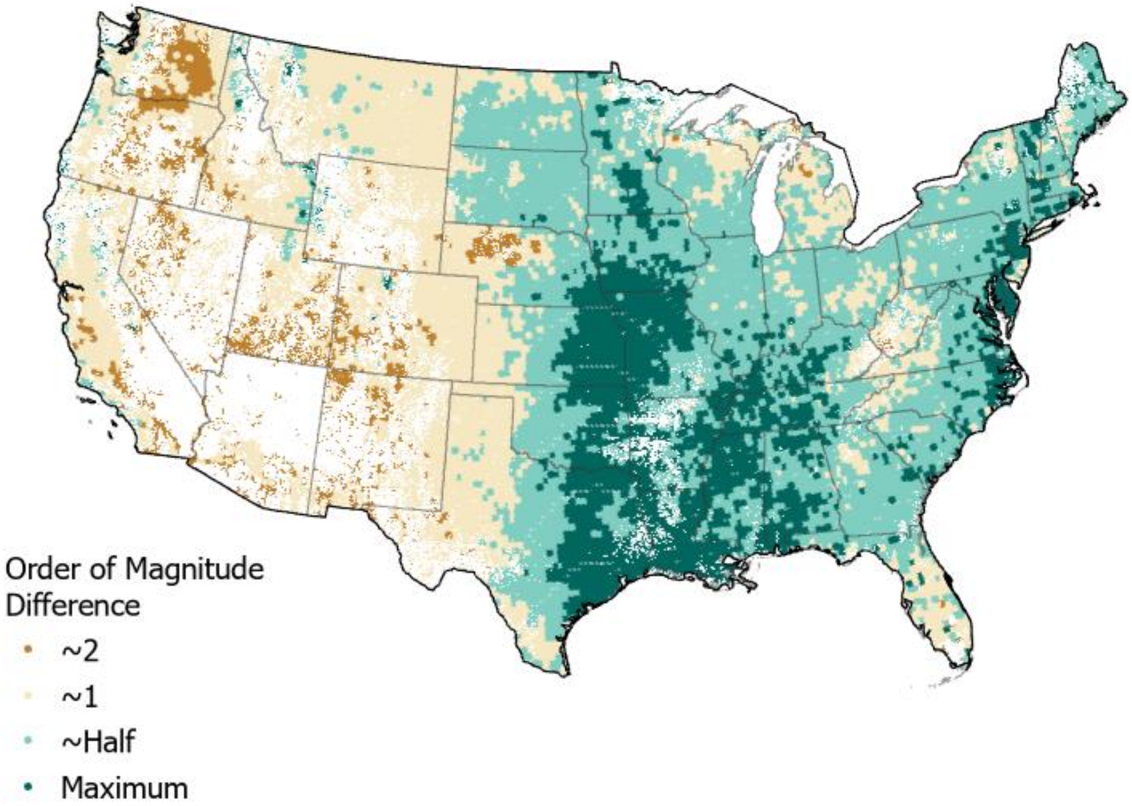

Figure G-5. Median pesticide runoff vulnerability at each weather grid station, divided into four mitigation categories. State boundaries are overlaid and the Cultivated Use Data Layer (UDL) masks areas where agriculture is not occurring, as shown in white.

An empirical cumulative distribution of the pesticide runoff vulnerability scores (*i.e.* the median value at each weather grid) determined the dataset had a lognormal distribution and used to approximate percentiles of the pesticide runoff vulnerability scores in **Table G-1** (Ang, 2007).

Table G-1. Categories of magnitude of difference from nationwide maximum pesticide runoff vulnerability score with corresponding pesticide runoff vulnerability score and mitigation relief. Coloring corresponds to Figure B6.

Order of Magnitude Lower than Max	Pesticide Runoff Vulnerability		
	Indicator Score	**Percentile**	**Classification**
~2	0 – 10.9	0 – 9%	Very low
~1	11 – 109	10 – 49%	Low
~Half	110 – 218	50 – 84%	Medium
Maximum	219 – 1090	85 – 100%	High

A review of how the four mitigation categories break down across several UDLs was conducted. Across the Cultivated Land UDL, approximately 70% of acres fell within the lower categories (green and light green) while 30% fell into the upper mitigation categories (brown and light brown) (**Table G-2**). A review of the Other Crops and Vegetable & Ground Fruit UDLs, which many specialty crops fall within, found that a high amount of the acreage within these UDLs fell within the light brown mitigation category (60-70% of acres; **Table G-2**). While there is a much smaller percentage of these UDLs that fall within the darker brown category, there was still a significant increase from the Cultivated Land UDL representing approximately 1.7 million acres (**Table G-2**).

Table G-2. Categories of mitigation relief determined by the magnitude of difference from the nationwide maximum pesticide runoff vulnerability score with the percentage of acreage per category for several UDLs (Cultivated, Other Crops, and Vegetable & Ground Fruit).

Order of Magnitude Lower than Max	~% of “Cultivated Land” acres (~342 million*)	~% of “Other Crops” acres (~8 million*)	~% of “Vegetable & Ground Fruit” acres (~22 million*)
~2	2% (~7 M acres)	7% (~0.6 M acres)	5% (~1.1 M acres)
~1	28% (~96 M acres)	70% (~5.6 M acres)	60% (~13.2M acres)
Half	51% (~175 M acres)	18% (~1.5 M acres)	31% (~6.8 M acres)
Maximum	19% (~64 M acres)	5% (~0.3 M acres)	4% (~0.9 M acres)

*These acres are not an absolute value. Calculations were done based on EPA's UDLs, which were developed using 5 years of crop data layer (CDL).

In order to be able to efficiently communicate how these mitigation relief points are assigned geographically and recognizing that previously identified boundaries (*i.e.,* I-35 and Route 395) do not account for several regions accurately, mitigation relief points will be assigned based on the median value of each county (**Figure G-6 and Table G-1**). Additionally, the county level is a meaningful scale to stakeholders and preserves much of the variability seen across weather grids (**Figure G-2**). The median value was chosen as the dataset has a lognormal distribution and because it accounts for variations in the number of scenarios across counties. A small number of counties (approximately 11) did not have a weather grid centroid fall directly within their borders; in these instances, a median was taken of the surrounding counties, out to 30 km.

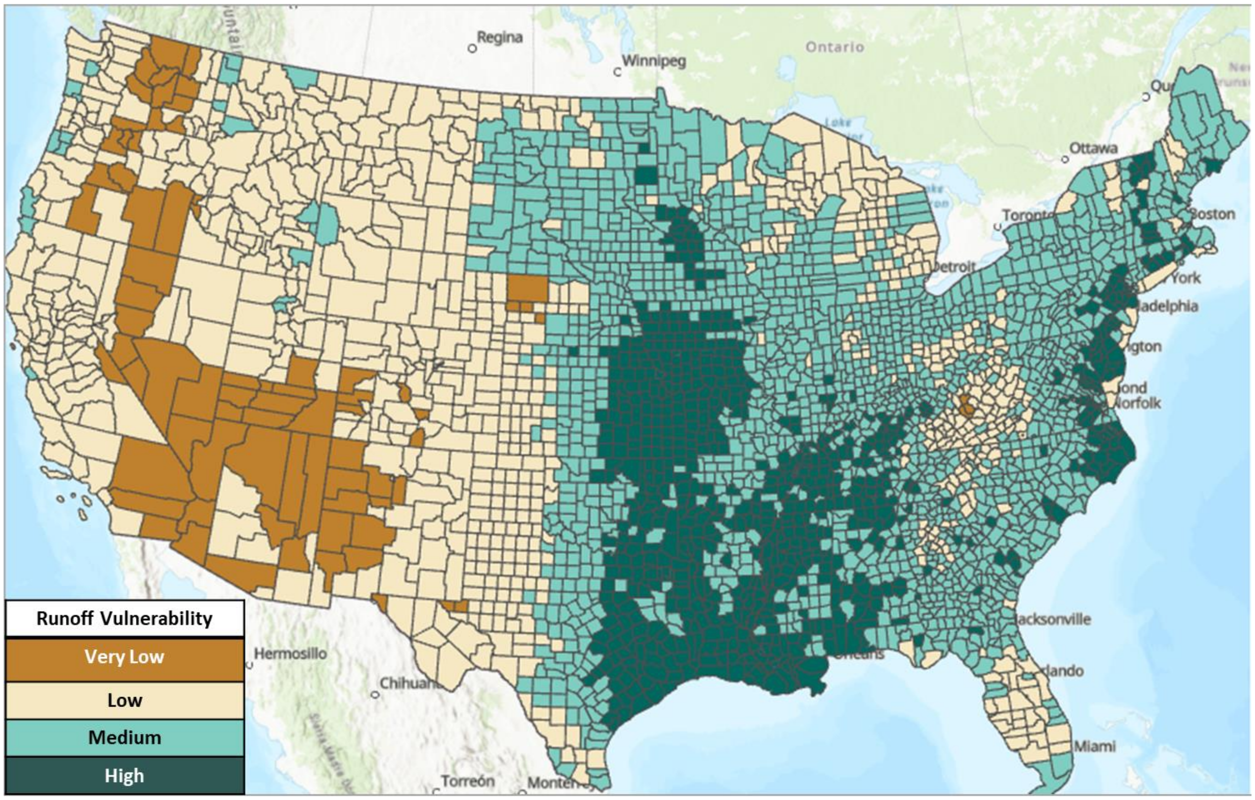

Figure G-6. Assignment of pesticide runoff vulnerability mitigation relief by county. Coloring relates to the magnitude of difference from the maximum pesticide runoff vulnerability score.

G.4 Soil Type Analysis

Over 80% of the current PWC scenarios used for ecological risk assessments are group Hydrologic Group C soils or higher (i.e., not sandy soils). For ecological assessments, these scenarios represent a high-end vulnerability for relatively large HUC-2 regions. Any watershed of field within these regions that are sandy (i.e., A or B soils) would be less vulnerable and give lower EECs from the PWC. **Table G-3** and **Figure G-7** give an example of the EEC differences between sandy (A and B Hydro Group) and the typical standard scenario (typically C Hydro Group). A and B soils could be 14 to 31% of the EEC from the standard scenarios. However, as the graph shows there is considerable variability, and some sandy soils have a higher EECs than some C soils.

Table G. Example of the EEC differences between sandy (A and B Hydro Group) and the typical standard scenario (typically C Hydro Group)

Hydro Group	A	B	C	D
Median	3.8	8.3	26.0	44.2
Min	2.2E-54	2.6E-06	3.2E-09	1.6E-04
Max	113.0	1570.0	431.0	994.0
Average	6.2	30.2	31.4	66.0
25 Quartile	0.9705	2.7	11.4	24.6
75 Quartile	9.32	18	45.4	69.55

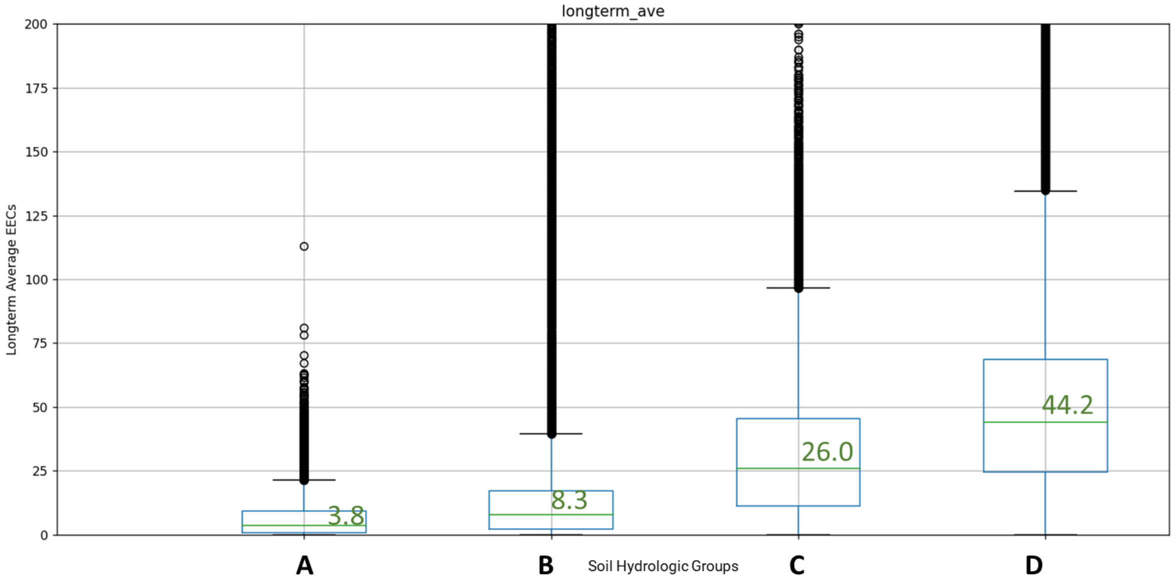

Figure G-7. Distribution of EECs for the same set of conditions used for original scenario vulnerability assessments (USEPA, 2020a). Boxes are the 25 and 75 percentiles, with medians shown inside box. Values are given in the table above.

Appendix H. Relative Humidity

Relative humidity (RH) is a measure of moisture in the air relative to ambient air temperature. The impact of temperature as an independent factor affecting spray drift is discussed in **Section 4.5.1**, while this section discusses the impact of RH. It is generally understood that RH increases the evaporation rate of spray droplets (Sezen and Gungor, 2023), thus making large droplets smaller over time and impacting spray drift. Droplet evaporation is a time-dependent process; RH has a greater impact with longer droplet settling times (caused by a smaller droplet size) or higher release height (*i.e.,* droplets that deposit far from their point of application). For instance, agricultural extension services describe RH <50% as presenting a drift concern and RH >70% as less conducive to drift (Kruger *et al.*, 2019). Victoria (2022) states that RH <40% as having high potential drift, while RH >80% has low drift potential. In a laboratory study, Sezen and Gungor (2023) found 30 µm water droplets (droplets smaller than 'Very Fine' by ASABE definition) in 30% RH lose 95% of mass in less than half the time (1.4 s) than in 50% RH (3.0 s). In the same study, droplets at 70% RH only lost 66% of mass over 4.7 s. The impact of RH increases with distance offsite and is influenced by other variables (*e.g.*, atmospheric conditions, variable windspeed and direction, *etc.*). Therefore, to fully understand the impact of RH on spray drift, EPA conducted a sensitivity analysis for aerial applications using AgDRIFT®.

H.1 Consideration of Relative Humidity for Ground Applications

The data used to develop the AgDRIFT® model (Teske, 2009) were predominately collected in low humidity conditions in western Texas. Of the studies used to collect data for AgDRIFT® development, two studies were conducted in the panhandle of Texas. The first study, conducted during July, was designed to collect data in a hot, dry climate with windspeeds that meet or exceed label maximums, and the second study, conducted at the same site in April, to represent cool season conditions. Another series of trials, designed to collect data in a hot, dry climate, was performed in the Rio Grande Valley of south Texas during July.

The median RH associated with these SDTF trials was 43%, with 3 of the 24 trials having a RH less than 10%. The average humidity values associated with the SDTF ground trials support risk assessment goals by representing conditions that are vulnerable to drift. However, these humidity values are low when compared to average afternoon humidity values across the United States and very low when compared to average morning humidity values (**Table H-1**). Based on national data from January through December 2009, 86% of sites had an afternoon (Noon to 5 PM) RH greater than 45% and 93% had morning RH (4 AM to 9 AM) greater than 60%. Comparatively, the SDTF dataset only had 42% trials with RH greater than 45% and only 25% of trials with greater than 60% RH. Therefore, while the SDTF dataset supports standard modeling for risk assessments and assessments of potential population-level impacts to listed species, these data may not reflect typical atmospheric conditions in some regions or at times of day with higher RH.

Table H-1. Range of relative humidity (RH) values from ground boom trials conducted in Texas, 1992-1993 (Teske, 2009) compared to National Relative Humidity Data (NOAA, 2009)

Relative Humidity (RH) Categories	Percent of SDTF Trials in RH category[1]	Proportion of Sites with Reported Afternoon in RH Category[2]	Proportion of Sites with Reported Morning in RH Category[2]
<25%	21%	3%	<1%
25-45%	38%	11%	1%
45-60%	17%	52%	5%
60+%	25%	34%	93%

[1] Based on 24 trials in the Spray Drift Task Force data set.

[2] Based on 3,168 data points for monthly average relative humidity values according to NOAA. 2009 Jan-Dec; 4 AM to 9 AM for Morning and Noon to 5 PM for Afternoon.

The sensitivity analyses used a RH of 20% and 40% to be representative of conditions relevant to the 90th percentile deposition curves. The 20% RH parameterization is more representative of conditions that are spray drift prone due to low RH. The 40% RH parameterization is more representative of typical conditions in the SDTF trials where low RH is a contributor to spray drift but other atmospheric conditions may have contributed more. The comparison from 40% RH is likely more appropriate considering other atmospheric conditions (*e.g.*, windspeed) are larger determinants of spray drift than RH. The results were compared to analyses conducted assuming a 60% RH, a common condition according to national climate data. The results show 1.2 to 2x (10 to 50%) reduction in the spray fraction deposited at distances relevant to the buffers discussed in **Section 4.2** (between 100 and 500 ft downwind). In terms of estimating the distance of a drift buffer distance, EPA considered how this shift in the deposition fraction curve may impact distance to effect estimates. As an example, for a deposition fraction of 0.02, the distances would be 550 ft for 20% RH, 350 ft for 40% RH, and 250 ft for 60% RH, a 30 to 55% reduction in the necessary buffer. The relative difference in these distances gets smaller the closer to the application site. For example, a deposition fraction of 0.05 would have distances of 145 ft for 20% RH, 120 ft for 40% RH and 100 ft for 60% RH, a 17 to 30% reduction in the necessary buffer. While RH impacts diminish in closer proximity to the field, it is still considered for buffers in close proximity to the field as a buffer is intended to reduce exposure in habitat areas rather than a single point represented by a deposition curve (**Figure H-1**).

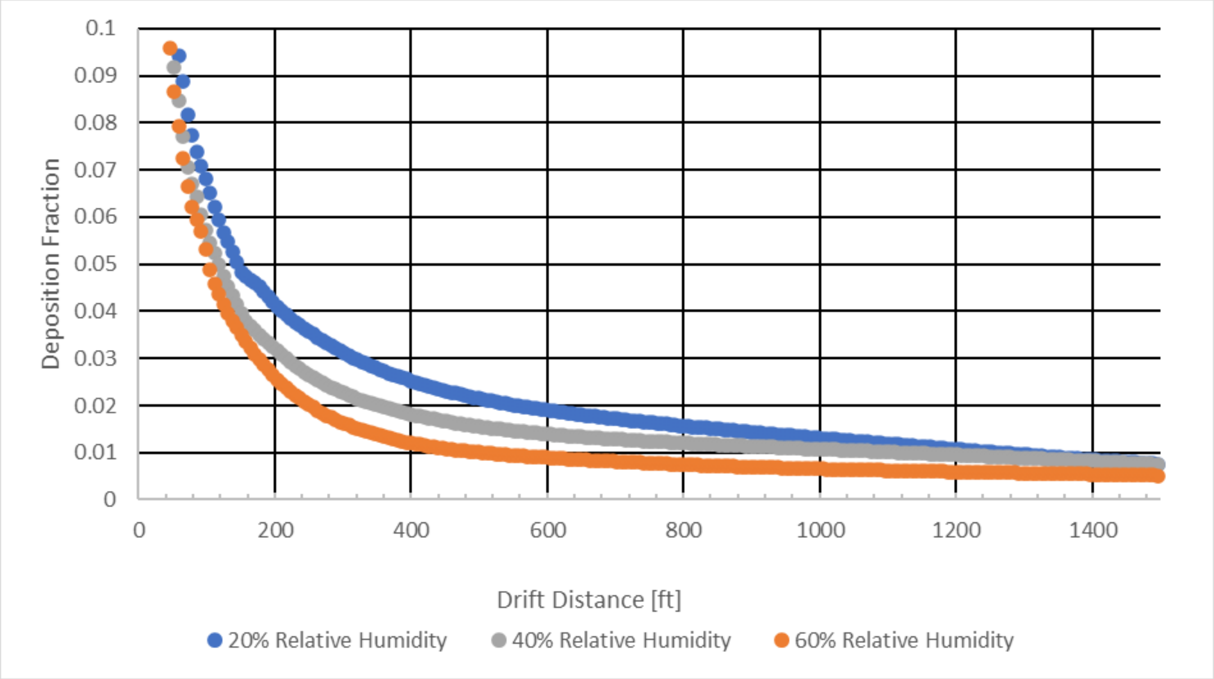

Figure H-1. Variable relative humidity assumptions with medium droplet size distribution for aerial applications (AgDRIFT® v2.1.1).

EPA conducted another humidity sensitivity analysis using AGDISP™ with coarse droplets. Similar to the previous analyses, EPA held AGDISP™ parameters constant and varied the RH from 20% to 60%. In this analysis, EPA estimated an equivalent fraction of deposition at 105 ft when assuming 20% RH, which was reduced to 85 ft when assuming 60% RH, a 19% reduction in distance. The analysis also showed that buffer distances closer to the field result in smaller deposition differences between different humidity conditions. Given this analysis, EPA identified a 10% reduction in the spray drift distance for aerial applications for typical RH conditions in the lower 48 states.

Because the impacts of RH on a droplet occur over time, the longer a droplet stays in the air, the more impact RH would have on overall drift deposition. As discussed above, EPA has limited information to evaluate the impact of RH on distance estimates for ground sprays. However, higher release heights of aerial application, which allow greater time for droplet evaporation to occur, should be at minimum reflective of what might occur following a ground spray.

H.2 Consideration of Relative Humidity for Aerial Applications

As discussed in **Appendix A,** EPA estimates spray drift distances for aerial application using the AgDRIFT® model under Tier III assumptions. The current default model assumption for RH in AgDRIFT® Tier III for aerial applications is 50%. While a RH of 50% is broadly representative of humidity across the lower 48 states, it is relatively low for many parts of the country, especially when considering morning weather conditions. In AgDRIFT® Tier III aerial module with medium to coarse DSD, equivalent drift fractions are estimated at 246 ft (50% RH) and 221 ft (70% RH), a 10% reduction in distance. EPA identified a 10% reduction in the spray drift distance for aerial applications with higher efficacy for relatively finer DSD, however, credit is applicable across the full range of DSDs.

H.3 Consideration of Relative Humidity for Airblast Applications

EPA's default airblast modeling (assuming a sparse orchard) is based on spray drift deposition data that was collected in relative humidities ranging from 45% to 63% (dormant apple and grapefruit trials reported in MRID 43925701). These humidity values are representative of typical afternoon humidity across the U.S. EPA's default assumptions for estimating spray drift depositions from airblast applications already accounts for RH. Furthermore, EPA does not have readily available data or data to bridge from empirical studies on airblast applications. Therefore, EPA is not estimating a percent reduction for RH for airblast applications at this time.

Appendix I. Updated Default Spray Drift Modeling Assumptions for Aerial Pesticide Applications for Predicting Exposure in Ecological Risk Assessments

I.1 Introduction: Scope and Purpose

The United States Environmental Protection Agency (EPA) regularly uses AgDRIFT® for estimating offsite deposition from aerial application of pesticides in agriculture to assess risk for terrestrial and aquatic organisms following the recommendations in *Guidance on Modeling Offsite Deposition of Pesticides Via Spray Drift for Ecological and Drinking Water Assessment* (USEPA, 2012a; USEPA, 2012b; USEPA, 2013), referred to as the Offsite Transport Guidance. AgDRIFT® allows aerial drift to be modeled using a tiered approach, with each successive tier employing more parameters and allowing for a more refined spray drift estimate. EPA recommends default assumptions to use in AgDRIFT® that result in upper-bound estimates of the drift fraction consistent with Guidelines for Exposure Assessment (USEPA, 1992; USEPA, 2019).

Over the last several years, the National Agricultural Aviation Association (NAAA[38]) and other stakeholders provided feedback to EPA that some of the standard assumptions previously recommended as default inputs in AgDRIFT® do not reflect the most common agronomic practices for aerial applications, resulting in over predictions of offsite deposition. The most detailed feedback from NAAA is dated June 29, 2020[39]. The NAAA suggested using Tier III Aerial (Agricultural) AgDRIFT® and different input parameters to arrive at aerial drift estimates that they suggest more accurately reflect realistic exposure. Based on this feedback, EPA re-examined some of the input parameters for AgDRIFT® by considering comments made by NAAA as well as other sources of information. The purpose of this document is for EPA to communicate updated recommendations on the use of Tier III aerial modeling in AgDRIFT® with input parameters that reflect current, common aerial application practices. These updates to the Tier III aerial modeling, and resulting deposition curves, are for use in ecological risk assessments at this time.

In this document, updates are provided to some recommendations in the *Offsite Transport Guidance* related for modeling aerial applications and these recommendations would supersede those in the 2013 Offsite Transport Guidance if implemented in standard exposure assessments for ecological risk assessments.

Section I.2 provides an overview of the AgDRIFT® aerial model. **Section I.3** summarizes the recommended updated default assumptions for aerial application modeling with

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[38] National Agricultural Aviation Association. URL: [Home - National Agricultural Aviation Association (agaviation.org)](https://agaviation.org). NAAA represents the aerial application industry and consists of more than 1,700 members in 46 states.

[39] https://www.regulations.gov/comment/EPA-HQ-OPP-2015-0716-0040

justifications for the updated assumptions (with further detail in **Appendix J**). **Section I.4** summarizes the conclusions for this document.

Appendix J provides supporting information. **Section 1** of **Appendix J** contains an example showing how the model was parameterized with the proposed input changes. **Section 2** of **Appendix J** provides additional support for the recommended updated default assumptions.

I.2 AgDRIFT® Model Overview

EPA uses AgDRIFT®, a computer model, for evaluating off-site deposition of pesticides applied by aerial application and for evaluating the potential of buffer zones[40] to protect sensitive aquatic and terrestrial habitat from non-target spray drift exposure and for other spray drift assessment purposes. US EPA's Office of Research and Development (ORD), United States Department of Agriculture (USDA)/Agricultural Research Service (ARS), USDA Forest Service, and the Spray Drift Task Force (SDTF)[41] supported the development of AgDRIFT® under a Cooperative Research and Development Agreement.

AgDRIFT® employs a three-tiered approach for aerial modeling. Results for each assessment tier include an estimate of off-target deposition as a function of distance from the application zone. For aerial assessment, all three tiers are based on a mechanistic model which has been compared to empirical drift data obtained by the Spray Drift Task Force (Johnson, 1995). The ground and orchard airblast sprayer assessments are curve fits based on field data. **Table I-5** contains a summary of variables available for the aerial module for Tiers I, II, and III analysis. In general, higher tiers allow for more refinements in the model inputs which may come from the pesticide label. Additional information on AgDRIFT® is available in the user guide (Teske et al., 2003; Teske et al., 2002).

Table I-5. AgDRIFT® (Version 2.1.1) Model Capabilities and Tiers.

Application Method	**Aerial***
Tier I	Preset model runs: 4 Droplet Size Distributions (DSDs)
Tier II	Limited number of model variables can be changed; DSD library, small aircraft library
Tier III	Many model variables can be changed; DSD library; large aircraft library; atmospheric stability; height for windspeed measurement; spray material properties

* Upper bound estimate generally used in the exposure assessments

I.3 Recommended Default Input Parameters for the Tier III AgDRIFT® Model

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[40] A buffer is the area between the area treated with a pesticide and habitat for non-listed or listed species.

[41] SDTF is a coalition of 39 pesticide registrants formed to develop a comprehensive database of off-target drift information in support of pesticide registration requirements. This protective assessment methodology represents the joint work of industry and EPA researchers working under the above-mentioned agreement as the modeling subcommittee of the SDTF.

The following are updated default parameterization of AgDRIFT® for use in ecological risk assessment. The updated default parameterization utilizes the Tier III option in AgDRIFT® to estimate off-target spray drift deposition that may reach the offsite environment from aerial application. These recommendations do not apply to mosquitocide/adulticide applications where ultra low volume droplet size distributions are utilized and the application height is near 100-ft from the ground. Tier III has many, but not all, of the parameters under evaluation to reflect certain agronomic practices. In this document, the parameter categories considered for updating include: aircraft; swath; atmospheric stability; transport; and terrain because associated preset Tier I parameters may not reflect current, common aerial application practices and also substantially impact modeled deposition. The preset Tier 1 module parameterization and new default model parameters are listed in **Table I-6.**

Table I-6. Comparison between Previous and Current Recommended Default Input Parameters in Tier III AgDRIFT®.

Parameter Group and Parameter		Previous Default Input Parameter	Current Recommended Default Input Parameter
Aircraft > Aircraft	Aircraft Type	Air Tractor AT-401	Air Tractor AT-802A
Aircraft > Nozzles and Droplet Size Distribution (DSD)	Drop Size Distribution	Fine to Medium	Medium*
	Generate Regular Distribution	Extent:76.32% Nozzle Spacing: 0.912 ft	Extent**: 75% Nozzle Spacing: 1 ft
Aircraft	Boom Height	10 ft.	10 ft.
	Flight Lines	20	15
Swath	Swath Width Definition	Fixed Width	Fixed Width
	Swath Width	60	80
	Swath Width Displacement as Fraction of Swath Width	0.3722	0.5
	Half Boom Effect	No entry	No entry
Atmospheric Stability	Stability	Night/Overcast Cloud Cover	Day/Slight Solar Insolation
Advanced Settings	Height for Wind Speed Measurement	6.56 ft	10 ft
Terrain	Surface Roughness	0.0246 ft	0.0246 ft

* AgDRIFT® allows for consideration of many DSDs, a subset of which may appear on labels (*i.e.*, “Fine”, “Coarse”, “Very Coarse”). However, these spray patterns were not selected as the common screening basis since they are used less commonly in aerial applications. Justification for including a given DSD should be included in any assessment based on specific label directions for its use.

** Extent defines the length of the spray boom relative to the airplane wingspan

The sections below summarize the rationale for each recommended default parameter identified above in **Table I-6** while further rationale and supporting information, including comments from NAAA, are available in **Section 2** of **Appendix J**.

I.3.1 Aircraft Type

The following section identifies updates to the aircraft type used in the Tier III Aerial AgDRIFT® model from the Air Tractor 401 (AT-401) to the AT-802A. This is based on consideration of the number of agricultural aircrafts registered with the Federal Aviation Administration (FAA) as well as modeling results across different aircrafts. In 2023, the AT-802A is the most common agricultural aircraft[42] and the only agricultural aircraft that has substantially increased in number over the period that EPA has considered updates to aerial modeling.

Since the time of NAAA's comment in 2020 in which aircraft numbers are discussed, the AT-802A has not only become the dominant aircraft type but also has substantially increased in number[43] compared to other aircrafts. NAAA provided survey data from the 2019 Federal Aviation Administration (FAA) General Aviation and Part 135 Activity Survey (GA Survey) which shows that the AT-502 and AT-802 represent the most common aircrafts registered for agricultural use. Updated survey results in 2023 indicate that, between 2020 and 2023, the AT-802 increased from 488 to 583 (19.5%). Meanwhile, the AT-502 registrations have remained steady (ranging from 506 to 512) during that same time period while the number of all other agricultural aircraft registrations have remained steady or declined (see **Section 2** of **Appendix J** for details).

While NAAA proposed selection of the AT-502B, noting that the loading capacity of 500 gallons is a median between the smaller capacity aircraft (*i.e.,* Piper or Cessna) and the 800-gallon capacity of the large AT-802A, the AT-802A is more commonly used than the smaller AT-502B aircraft. Additionally, the differences in deposition between the AT-502B and AT-802A is relatively small for the majority of the deposition curve (<4% difference in deposition 100 to 500 feet offsite; see **Section 2** of **Appendix J** for details).

EPA conducted AgDRIFT® modeling using the AT-401, AT-502B, and AT-802 to compare off-site deposition between the current default aircraft (AT-401) and the leading agricultural aircrafts (AT-502B and AT-802A). The AT-502B and AT-802A have similar deposition profiles, both producing less offsite deposition than the AT-401, with the AT-502B producing slightly less offsite deposition than the AT-802A at distances <85 ft from the edge of field. At distances >150 ft, the AT-502B and AT-802A are nearly indistinguishable. Additionally, both are less conservative than the AT-401. The offsite distances are more comparable for the AT-502B and the AT-802A, with a maximum difference in fraction of applied of 0.0089 at 20 ft and 0.0002 at 203 ft. At 20 feet from the edge of the field, the AT-802A fraction of applied was 7% lower compared to the AT-502B. That difference decreased to a 1% difference in the fraction of applied at 200 feet from the edge of the field. More information on this analysis can be found in **Section 2** of **Appendix J**.

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[42] Based on Federal Aviation Administration (FAA) Aircraft Inquiry: https://registry.faa.gov/aircraftinquiry

[43] Based on Federal Aviation Administration (FAA) Aircraft Inquiry: https://registry.faa.gov/aircraftinquiry

In recognition of the increasing numbers of the AT-802A and small deposition differences when compared to AT-502B at distances >150 ft from the edge of field, the AT-802A aircraft is recommended for use as a default parameterization executing standard runs of Tier III AgDRIFT®.

I.3.2 Swath Width and Number of Flight Lines

For aerial pesticide applications, a swath is the target area receiving an application during one pass or flight line of an aircraft. The effective swath width is determined by the type of aircraft, flying height, DSD, spray volume, and wind conditions at the time of the application (Barbosa, 2010). Given that swath offset is held constant, larger swath widths function to decrease near field deposition as swath offset is specified as a fraction of swath width (i.e., larger swaths mean larger offsets). With the recommended selection of the AT-802A as the default aircraft, this results in the need to revise swath width and number of flight lines. The current Tier I default swath width (associated with the AT-401) is 60 ft and swath width can be changed as an independent parameter in Tier III. A swath width change from 60 feet to 80 feet is recommended (assuming a 5 gallon per acre application), which is a common and representative swath width for an AT-802A based on recommendations to applicators (Barbosa, 2010)[44,45].

With respect to application spray volume, swath width varies based on spray volume with a width as high as 85 feet for a 2 gal/A spray volume and as low as 72 feet for a 10 gal/A spray volume for the AT-802 (Barbosa, 2010). As an individual parameter, low spray volume functions to increase offsite deposition and is parameterized with a minimal spray volume (2 gal/A) as default in AgDRIFT®. It is not likely that a 2 gal/A spray volume will co-occur with an 80 foot swath for an AT-802, however, the smaller swath width is selected considering it is a more representative swath width.

In the AgDRIFT model, the default number of flight lines for the AT-401 is 20 lines, which with the default 60-foot swath width results in a treated width of 1,200 feet. With a swath width of 80 feet recommended for the AT-802A, only 15 spray lines are needed to treat 1,200 feet typically assumed in AgDRIFT® for aerial applications. Accordingly, the number of flight lines value in the Tier III AgDRIFT model is changed from 20 to 15 when the AT 802A is assumed.

I.3.3 Boom Length

As for boom length, this section recommends updating the standard parameterization of boom length for the AT-802A to be consistent with standard label language of 75% boom

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[44] Common Air Tractor Spray Swath Widths available from WRK of Arkansas, LLC. Available at: https://www.wrkofar.com/assets/airtractor_swathwidth-recommendations.pdf (accessed December 2023).

[45] Typical Air Tractor Swath Widths (Feet) published by Transland: https://www.translandllc.com/wp-content/uploads/2019/02/Typical-Air-Tractor-Swath-Width-Reference.pdf

length[46]. This parameterization is similar to the prior default applied to the AT-401 (approximately 76%). The nozzle spacing should also be updated to 1 ft to reflect commonly used nozzle spacings (prior default is approximately 11 inches). Given these recommendations, a “Regular Distribution” within AgDRIFT is recommended with a 75% extent and 1 foot nozzle spacing (see **Table I-6** above).

I.3.4 Boom Drop

NAAA has stated that the Tier 1 AgDRIFT® model fails to account for the lowered spray boom and nozzles relative to the trailing edge of the wing that may be used by agricultural aircraft today. In order to adjust the boom drop, NAAA proposed adjusting the individual nozzle vertical locations for all of the nozzles in the Nozzles menu. Boom drop is the distance between bottom of the plane and the release height of the pesticide from the spray equipment. The current default assumptions (-1.15 ft for the AT-401 and -0.6601 ft for AT-502B) may not account for drift reduction associated with dropped boom when it is utilized. However, uncertainty exists on whether the 2 ft boom-drop is widely adopted for AT-802A aircraft considering spray boom is not a standard specification on the aircraft but rather a feature that may be retrofitted separately from airplane production. EPA AgDRIFT® modeling found that a boom drop from -0.6601 ft to -2.00 ft may result in drift reduction. EPA AgDRIFT® simulations estimated a deposition reduction of 8% to 15% for the smaller AT-502B and a reduction of 2% to 7% for the larger AT-802A. These modeled differences are not as large as the differences measured on-field in Hoffman and Tom (2000) using a small AT-402B. Differences between the field and modeled values may be explained, in part, by boom drop being a more sensitive parameter for smaller aircraft. The default boom drop of -0.6601 ft may be a conservative parameterization for some users of AT-802A aircraft; however, the parameter does not prove to be sensitive when considering the large size of the aircraft. Considering these factors, changing the boom drop from prior defaults in AgDRIFT® is not recommended.

I.3.5 Swath Displacement

Swath displacement refers to the distance away from a field edge an aerial applicator positions their equipment to account for a crosswind’s impact on the application reaching the target. Swath displacement is a highly sensitive parameter for near field spray drift deposition. For instance, changing the accepted half-swath offset to an assumed quarter swath offset increases deposition at the edge of field and 200 ft offsite by 66% and 11%, respectively. Conversely, changing the accepted half-swath offset to the full swath offset commonly used as a best management practice (Hoffmann et al. 2010) decreases deposition at the edge of field and 200 ft offsite by 70% and 20%, respectively. EPA supports an update to swath displacement parameterization (0.5 swath width) primarily because it is

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[46] Standard recommended spray drift label recommends that the boom length must be 75% or less of the wingspan for fixed-wing aircraft for windspeeds of 10 miles per hour or less (https://www.regulations.gov/document/EPA-HQ-OPP-2016-0114-0094).

reflective of typical label language (USEPA, 2022); however, best management practice includes offsetting the application by 0.5 to 1 swath width (Hoffmann et al., 2010). Best management practices provide additional support for increasing swath displacement from the prior default of 0.3702.

I.3.6 Atmospheric Stability

A temperature inversion is a stable atmospheric condition that is most likely to occur at or near nighttime and/or in low wind conditions. Recent pesticide labels restrict aerial broadcast applications when temperature inversions are present. The preset default parameter for atmospheric stability is night/overcast which is not a common time for application when the target of the application is a crop. Because of the correlation between atmospheric stability and temperature inversions, most aerial applications are expected to occur outside periods where the atmosphere is stable. Choosing a "day with slight solar insolation" is an appropriate parameterization because stable atmospheric conditions with calm winds (0- 3 mph) are avoided eliminating the possibility of the presence of temperature inversion. Furthermore, wind speed is parameterized at 10 mph which is expected to correspond with slightly to moderately unstable conditions during daytime.

I.3.7 Droplet Size Distribution

It is understood that aerial applicators routinely use droplet size spectrums larger than the American Society of Agricultural and Biological Engineers (ASABE) "Fine to Medium"[47] when conducting applications with the field or crop as the application target. EPA will continue to use label specifications as the primary source for model parameterization of DSD and anticipates that ASABE "Medium" droplets or coarser will be modeled in most assessments. However, some labels may require droplets finer than "Medium". To account for a range of assessment needs, a range of droplet size distributions defined by ASABE and available in AgDRIFT ("Fine", "Medium", "Coarse", and "Very Coarse") will be available for risk assessment of aerial applications to fields and crops.

I.3.8 Maximum Wind Speed

EPA acknowledges the need for flexibility to allow applications in a range of wind speeds. One way to allow for this flexibility is to reduce spray boom length in higher wind speeds, resulting in drift similar to what would occur with standard 10 mph wind speeds and has been reflected on many current labels. This label language has been supported with an analysis using the AT-401 airplane, showing that spray drift with default wind speed and boom length (10 mph and boom that is 76.32% the length of the wingspan; AgDRIFT default) results in similar spray drift to 15 mph (when boom is 65% of the length of the wingspan) at 200 ft offsite when all other parameters are held constant. For this current

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[47] As described in ANSI/ASAE S572.3 FEB2020

effort, the same analysis is conducted with the AT-502B and AT-802A, comparing the default boom 10 mph wind speed with the boom length 75% of the length of the wingspan to 15 mph wind speeds with the boom length 65% of the length of the wingspan. Again, EPA found similar deposition at 200 ft offsite distance with the 65%/15 mph parameterization producing less deposition than the 75%/10 mph parameterization at 50 ft and 500 ft offsite (see **Section 2** of **Appendix J**). Based on this analysis, EPA continues to consider the use of label language that allows for applications in wind speeds up to 15 mph when boom length is reduced to 65% of the wingspan (USEPA, 2022). For AgDRIFT® modeling assumptions, EPA recommends maintaining the current default assumption of the maximum wind speed of 10 mph as the current recommended default boom length (75% the length of the wingspan) is specific to this wind speed. This recommendation is consistent with current spray drift label language[48] and is recommended for modeling aerial applications using Tier III AgDRIFT®.

I.3.9 Height of Wind Speed Measurement

This section recommends updating the height of wind speed measurement from 6.56 feet to 10 feet because a 2019 NAAA survey of applicators indicated that ~80% of applicators measured wind speed from the aircraft where the pesticide is released using smoke (NAAA 2019). Additionally, this is consistent with the current recommended label language for spray drift, indicating that wind speed should be measured at the release height or higher[11].

NAAA's suggestion on increasing the default AgDRIFT® Tier III Aerial wind speed height measurement value to 12 feet is based on the ability of most modern aerial applicators to measure and monitor weather conditions (including wind speed) in the cockpit. However, a wind speed measurement height of 10 feet is more consistent and conservative with current practices, based on a recommended minimum release height of 10 feet above the crop canopy. Therefore, an update of the default wind speed height from 6.56 feet to 10 feet instead of 12 feet is recommended.

I.3.10 Surface Roughness

This section does not recommend changing the default surface roughness parameter reported in Tier 1 when using the Tier III module. An increased surface roughness value will lead to less offsite deposition estimates. NAAA proposed a surface roughness of 0.32 ft as the AgDRIFT® Tier III Aerial default value, an increase from the current 0.0246 ft bare ground assumption, citing a study by Hoffmann *et al*. The Hoffman *et al*. (2007) study compared offsite drift of applications occurring at different growing stages of a cotton crop. Results showed that when the cotton canopy closure is >80%, the canopy is effectively closed and has similar deposition to bare ground. Open literature supports that offsite deposition varies by crop. Different crops will have different canopy densities at different growth stages, making canopy density, and therefore an ideal surface roughness value, difficult to predict. NAAA's assumption that most aerial applications are applied post-

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[48] https://www.regulations.gov/document/EPA-HQ-OPP-2016-0114-0094

emergence is reasonable; however, post-emergence includes many applications that are also made early in the season where the crop has limited growth and release height increases as the crop increases, which is not modeled. When applications are made, while crops are not always present, some amount of vegetation is likely present adjacent to the field. However, because the amount of vegetation will vary and the influence on drift is not consistent, EPA did not identify changing the previous value.

I.4 Conclusion

The sections above provide the most salient points for updating AgDRIFT® Tier III aerial input parameters. Lines of evidence for determining recommendations include open literature, modeling sensitivity analysis, and stakeholder comments. The recommended change for aerial modeling from Tier I AgDRIFT® to Tier III AgDRIFT® with the seven parameter changes described above are captured below in **Figure I-1**. At distances of 25ft from edge of field, the Tier III deposition for Fine DSD is greater compared to current Tier I outputs. The Tier III deposition for Medium DSD is lower compared to both the Tier I or Tier III Fine DSD.

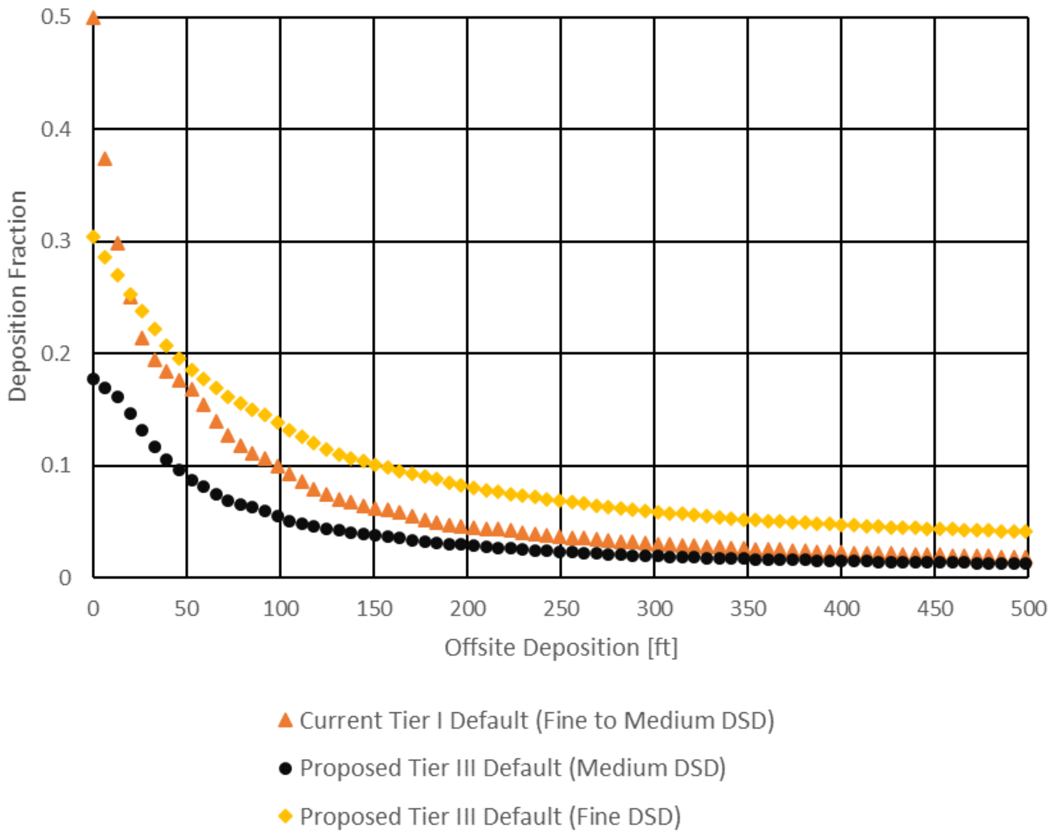


Figure I-1. Comparison of point deposition between current Tier I AgDRIFT® default and recommended Tier III AgDRIFT® default with varying droplet size distribution (DSD) parameterization.

Tier III AgDRIFT® is utilized with certain parameters as new defaults whereas some parameters will not be revised from the Tier I defaults. Other parameters are available in Tier III AgDRIFT® but they are not explored here and could be on a case-by-case basis but would require additional information on product specification comparability to model parameterization. Further characterization and/or supporting material for each parameter can be found in **Section 2** of **Appendix J**.

I-5 Literature Cited

MRID 43803501. Johnson, D.R. (1995) Drift from Applications with Aerial Sprayers: Integration and Summary of 1992 and 1993 Field Studies. Spray Drift Task Force. Sponsor Report Number: 194-002

Barbosa, R. 2010. Equipment Setup for Aerial Application of Liquid Pesticides. July 2010. Louisiana State University AgCenter. Available at: https://www.lsuagcenter.com/~/media/system/6/0/a/d/60ad7c66df006c9949b583471c5ec5f4/pub3160liquidpesticideslowres.pdf.

FOCUS. 2007. Landscape and Mitigation Factors in Aquatic Risk Asessment. Volume 2. Detailed Technical Reviews. Report of the FOCUS Working Group on Landscape 35 and Mitigation Factors in Ecological Risk Assessment. EC Document Reference SANCO/10422/2005.

Hoffmann, C., Fritz, B., Thornburg, J., Bagley, W., Birchfield, N., & Ellenberger, J. 2010. Spray Drift Reduction Evaluations of Spray Nozzles Using a Standardized Testing Protocol. Journal of Astm International, 7, 10.

Hoffmann, W. C., Fritz, B. K., & Martin, D. E. 2007. AGDISP Sensitivity to Crop Canopy Characterization. Transactions of the ASABE, 50(4), 1117-1122.

Hoffmann, W. C., & Tom, H. H. 2000. Effects of Lowering Spray Boom in Flight on Swath Width and Drift. Applied Engineering in Agriculture, 16(3), 217-220.

Huang, Y., & Thomson, S. 2016. Atmospheric Stability Evaluation at Different Time Intervals for Determination of Aerial Spray Application Timing. Journal of Biosystems Engineering, 41, 337-341.

1995. Drift from Applications with Aerial Sprayer: Integration and Summary of 1992 and 1993 Field Studies. . Report Number: 194-002, MRID 43803501. Spray Drift Task Force.

Teske, M., Bird, S. L., & Esterly, D. M. 2003. A User's Guide for AgDRIFT(R) 2.0.07: A Tiered Approach for the Assessment of Spray Drift of Pesticides. C.D.I. Report No. 01-02. February 2003. Available at: https://www.epa.gov/pesticide-science-and-assessing-pesticide-risks/models-pesticide-risk-assessment.

Teske, M. E., Bird, S. L., Esterly, D. M., Curbishley, T. B., Ray, S. L., & Perry, S. G. 2002. AgDrift®: A model for estimating near-field spray drift from aerial applications. Environmental Toxicology and Chemistry, 21(3), 659-671.

Teske, M. E., & Curbishley, T. B. 2011. Continuum Dynamics, Inc. AGDISP Version 8.25 User Manual. July 2011. Available at: https://www.epa.gov/pesticide-science-and-assessing-pesticide-risks/models-pesticide-risk-assessment#atmospheric.

USEPA. 1992. Guidelines for Exposure Assessment. EPA/600/Z-92/001. May 1992. United States Environmental Protection Agency. Available at:

https://www.epa.gov/sites/default/files/2014-11/documents/guidelines_exp_assessment.pdf.

USEPA. 2012a. Distribution of Guidance for Using AgDRIFT/AGDISP in Ecological Risk Assessments for use in the Environmental Fate and Effects Division. October 12, 2012. Environmental Fate and Effects Division. U.S. Environmental Protection Agency.

USEPA. 2012b. Implementation of Spray Drift Exposure Model Versions of AgDRIFT v.2.1.1 and AGDISP v. 8.26 For Use in the Environmental Fate and Effects Division. May 22, 2012. Environmental Fate and Effects Division. U.S. Environmental Protection Agency.

USEPA. 2013. Guidance on Modeling Offsite Deposition of Pesticides Via Spray Drift for Ecological and Drinking Water Assessment. U.S. Environmental Protection Agency. Office of Chemical Safety and Pollution Prevention. Office of Pesticide Programs. Environmental Fate and Effects Division.

USEPA. 2019. Guidelines for Human Exposure Assessment. EPA/100/B-19/001. October 2019. Risk Assessment Forum. United States Environmental Protection Agency. Available at: https://www.epa.gov/sites/default/files/2020-01/documents/guidelines_for_human_exposure_assessment_final2019.pdf.

USEPA. 2022. ESA Workplan Update: Nontarget Species Mitigation for Registration Review and Other FIFRA Actions. Docket ID EPA-HQ-OPP-2022-0908. November 2022. United States Environmental Protection Agency. Office of Chemical Safety and Pollution Prevention. Office of Pesticide Programs. Available at: https://www.epa.gov/system/files/documents/2022-11/esa-workplan-update.pdf.

Appendix J. Supporting Materials for Updated Default Spray Drift Modeling Assumptions

J.1. Guidance for parametrization of Tier III AgDRIFT® in case of aerial application of pesticides on agricultural crops for Terrestrial assessment and Aquatic Assessments

J.1.1 Procedure Used to Create EFED Tier III AgDRIFT® Input File

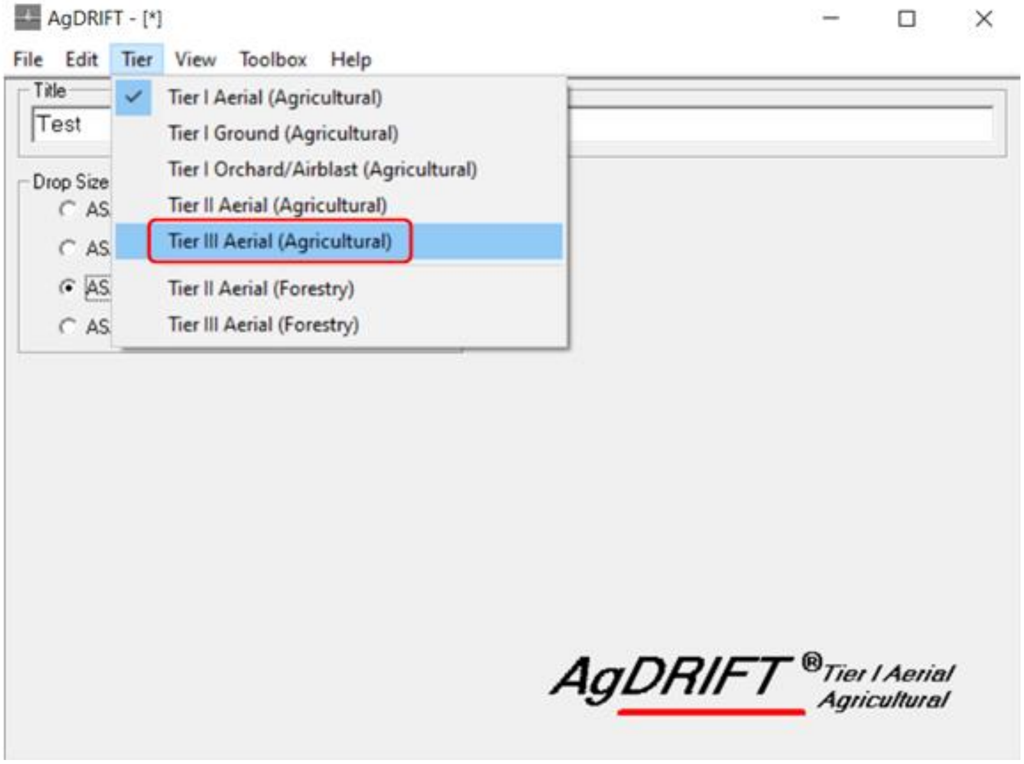
EFED reviewed stakeholders suggested changes to current default values in Tier III AgDRIFT® model. **Table J-1** contains a list of previous Tier III defaults along with recommended changes to these values.

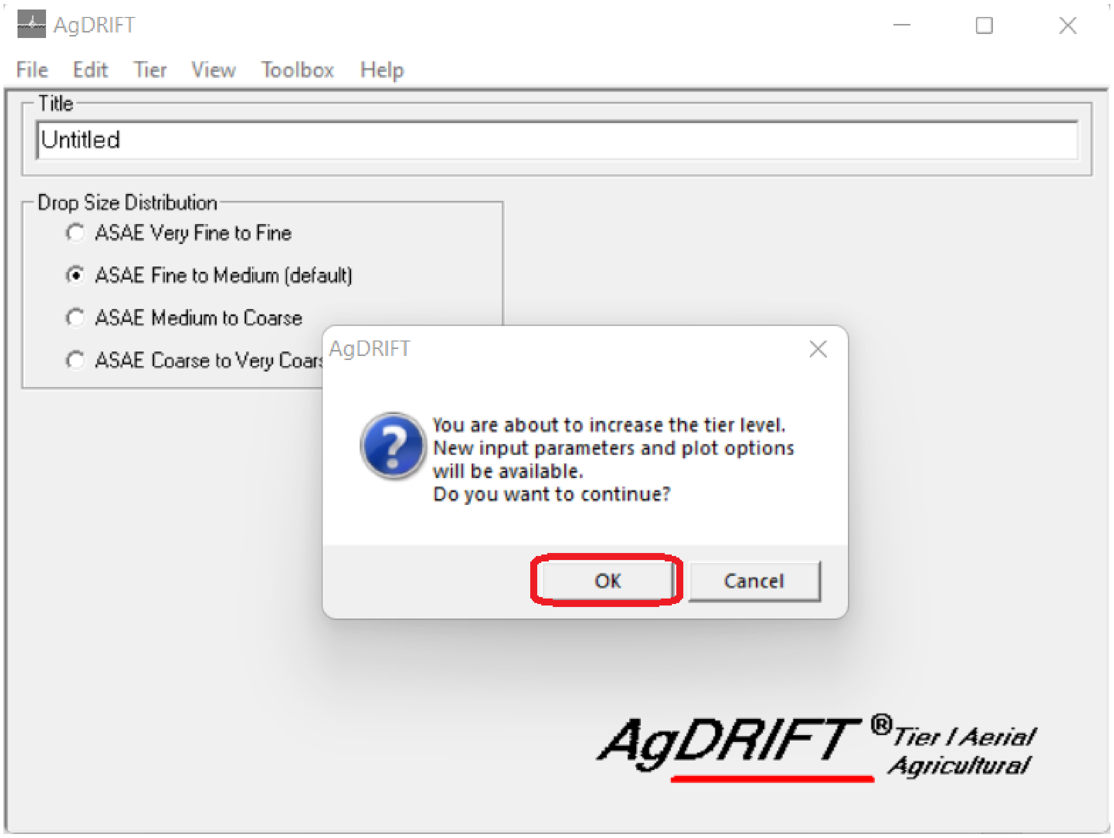
Table J-1. Tier III AgDRIFT® current and EFED accepted defaults.

Entry Section	**Entry Sub-section**	**AgDRIFT® Tier III Default**	**Current recommended Default**
Aircraft	Aircraft button	AT-401	AT-802A
	Flight lines	20	15
	Nozzles and DSD: Generate Regular Distribution	Nozzles: Blank	Nozzles: Blank
		Extant: Blank	Extant: 75%
		Spacing: Blank	Spacing: 1.00 ft.
Swath	Swath Width Definition	60 ft.	80 ft.
	Swath Displacement Definition: Fraction	0.3722	0.5
Atmospheric Stability	Stability button	Night and overcast	Day with slight solar insolation
Advance Setting	Edit button: Height of wind speed measurement	6.56 ft.	10 ft.

Hereunder, screen shots showing the procedure used to change the default value which results in the creation of **EFED Standard Tier III AgDRIFT® Input File** (EFED Standard Tier III run file.agd). This standard input file is to be used, by EFED, to run **Tier III AgDRIFT®** model to predict offsite deposition.

(1) Choose Tier III Aerial (Agriculture). A warning will appear stating that Tier III aerial (Agriculture) is chosen. For that press OK. After pressing OK the main parameters window will appear.



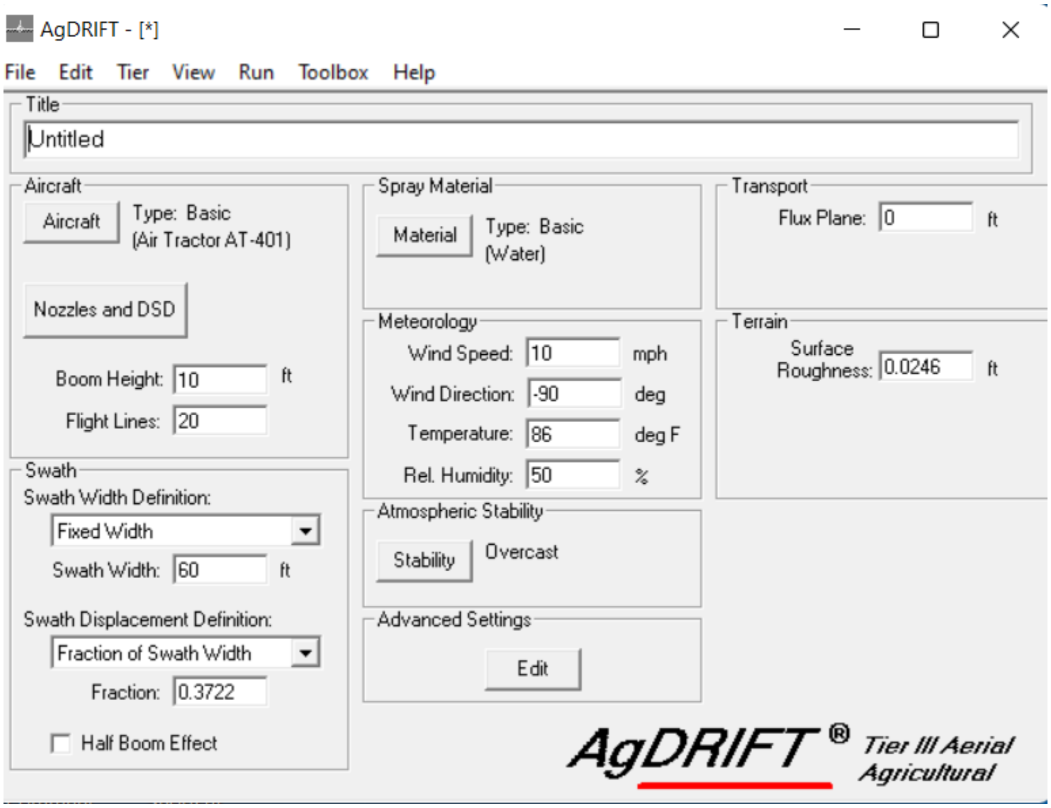


Title: Untitled

Drop Size Distribution
○ ASAE Very Fine to Fine
● ASAE Fine to Medium (default)
○ ASAE Medium to Coarse
○ ASAE Coarse to Very Coar

AgDRIFT

You are about to increase the tier level.
New input parameters and plot options will be available.
Do you want to continue?



Title: Untitled

Aircraft
Type: Basic (Air Tractor AT-401)
Boom Height: 10 ft
Flight Lines: 20

Swath
Swath Width Definition: Fixed Width
Swath Width: 60 ft
Swath Displacement Definition: Fraction of Swath Width
Fraction: 0.3722
☐ Half Boom Effect

Spray Material
Type: Basic (Water)

Meteorology
Wind Speed: 10 mph
Wind Direction: -90 deg
Temperature: 86 deg F
Rel. Humidity: 50 %

Atmospheric Stability
Overcast

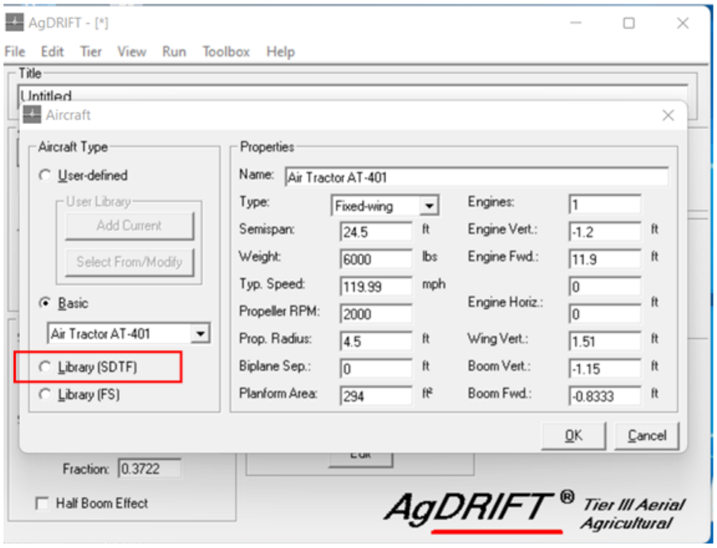
Advanced Settings

Transport
Flux Plane: 0 ft

Terrain
Surface Roughness: 0.0246 ft

(2) Change Aircraft default from AT-401 to the new default AT-802A from Library (SDTF)

- Push the Aircraft button and choose the library (SDTF)



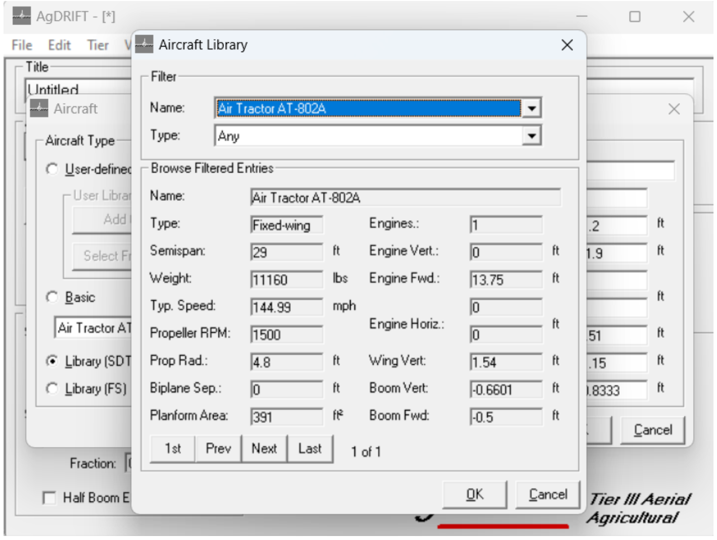
Aircraft Type
○ User-defined
● Basic
Air Tractor AT-401
○ Library (SDTF)
○ Library (FS)

Properties
Name: Air Tractor AT-401

Type:	Fixed-wing		Engines:	1	
Semispan:	24.5	ft	Engine Vert.:	-1.2	ft
Weight:	6000	lbs	Engine Fwd.:	11.9	ft
Typ. Speed:	119.99	mph		0	
Propeller RPM:	2000		Engine Horiz.:	0	ft
Prop. Radius:	4.5	ft	Wing Vert.:	1.51	ft
Biplane Sep.:	0	ft	Boom Vert.:	-1.15	ft
Planform Area:	294	ft²	Boom Fwd.:	-0.8333	ft

Fraction: 0.3722
☐ Half Boom Effect

- Choose aircraft AT-802A From the drop-down menu and push OK.



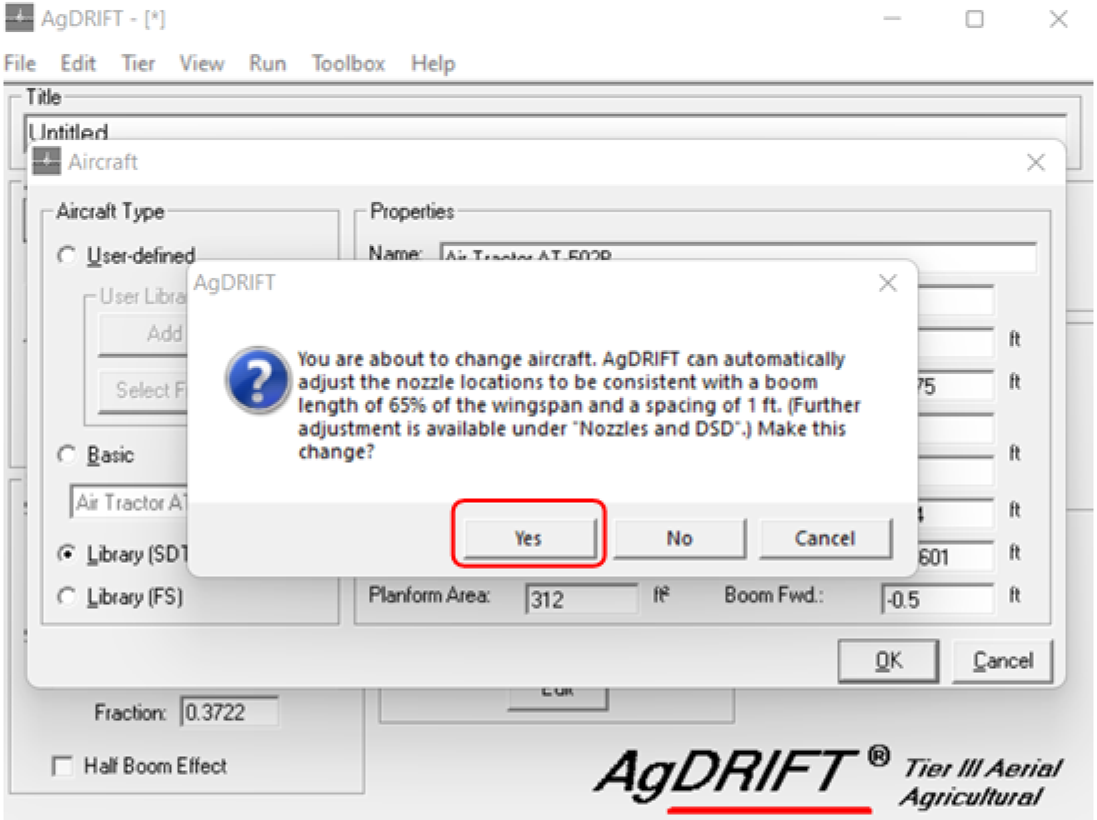
Filter
Name: Air Tractor AT-802A
Type: Any

Browse Filtered Entries
Name: Air Tractor AT-802A

Type:	Fixed-wing		Engines.:	1	
Semispan:	29	ft	Engine Vert.:	0	ft
Weight:	11160	lbs	Engine Fwd.:	13.75	ft
Typ. Speed:	144.99	mph		0	
Propeller RPM:	1500		Engine Horiz.:	0	ft
Prop Rad.:	4.8	ft	Wing Vert:	1.54	ft
Biplane Sep.:	0	ft	Boom Vert:	-0.6601	ft
Planform Area:	391	ft²	Boom Fwd:	-0.5	ft

1 of 1

A window will appear confirming the chosen aircraft and its properties. Make sure that the chosen aircraft is “Air Tractor-AT-802A” and if that is the case press OK. A warning will appear to confirm the aircraft change. Choose YES



Untitled

Name: Air Tractor AT-502B

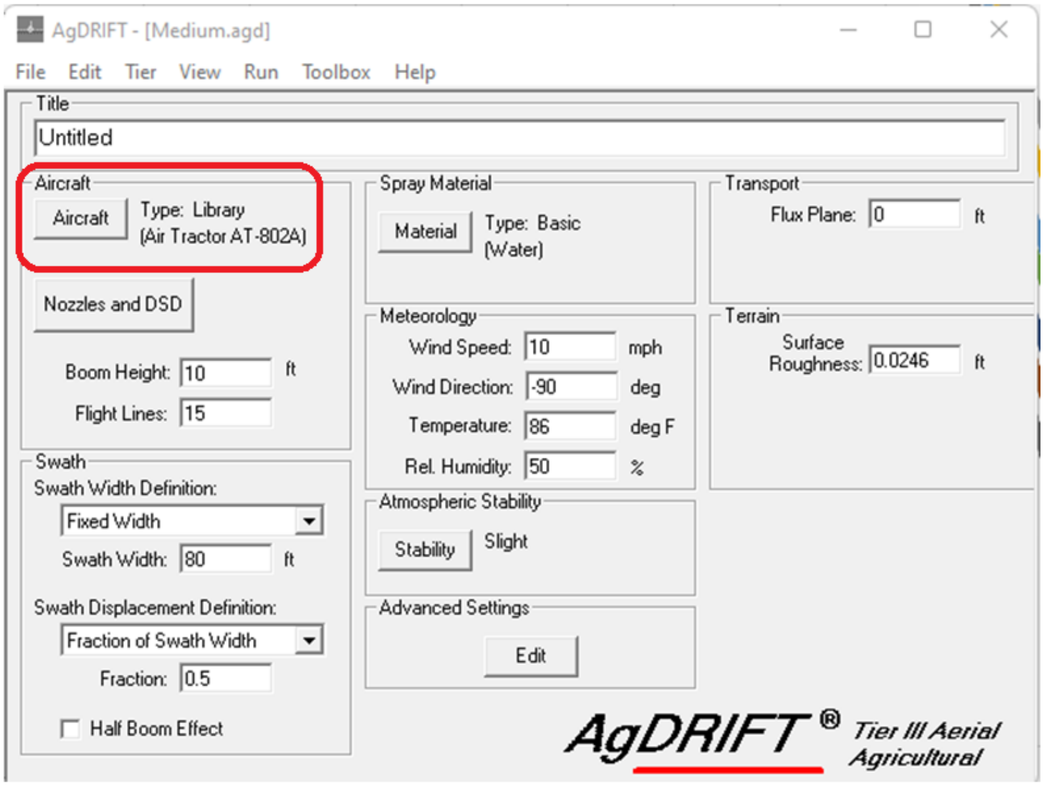
Planform Area: 312 ft²

Boom Fwd.: -0.5 ft

AgDRIFT

You are about to change aircraft. AgDRIFT can automatically adjust the nozzle locations to be consistent with a boom length of 65% of the wingspan and a spacing of 1 ft. (Further adjustment is available under "Nozzles and DSD".) Make this change?

Note that the aircraft is changed to AT-802A as shown below



Title: Untitled

Aircraft Type: Library (Air Tractor AT-802A)

Boom Height: 10 ft

Flight Lines: 15

Spray Material Type: Basic (Water)

Flux Plane: 0 ft

Wind Speed: 10 mph

Wind Direction: -90 deg

Temperature: 86 deg F

Rel. Humidity: 50 %

Surface Roughness: 0.0246 ft

Stability: Slight

Swath Width Definition: Fixed Width

Swath Width: 80 ft

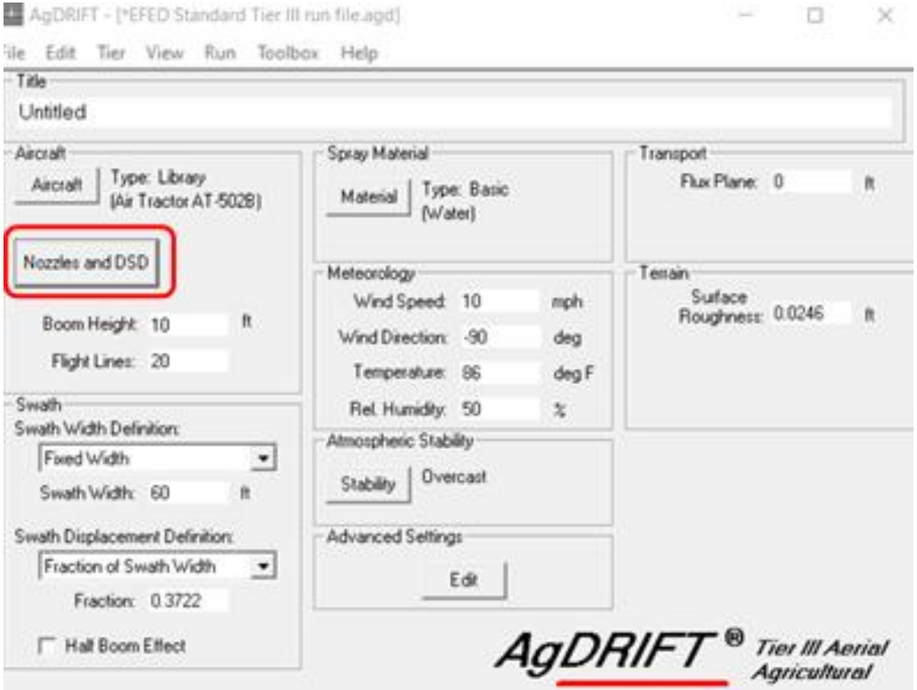
Swath Displacement Definition: Fraction of Swath Width

Fraction: 0.5

☐ Half Boom Effect

(3) Change the Nozzles General Regular Distribution

- Push Nozzles and DSD button in the aircraft parameter. This will take you to another screen (Nozzle Installation Properties) as shown, below



Title: Untitled

Aircraft
Type: Library (Air Tractor AT-502B)
Boom Height: 10 ft
Flight Lines: 20

Swath
Swath Width Definition: Fixed Width
Swath Width: 60 ft
Swath Displacement Definition: Fraction of Swath Width
Fraction: 0.3722
☐ Half Boom Effect

Spray Material
Type: Basic (Water)

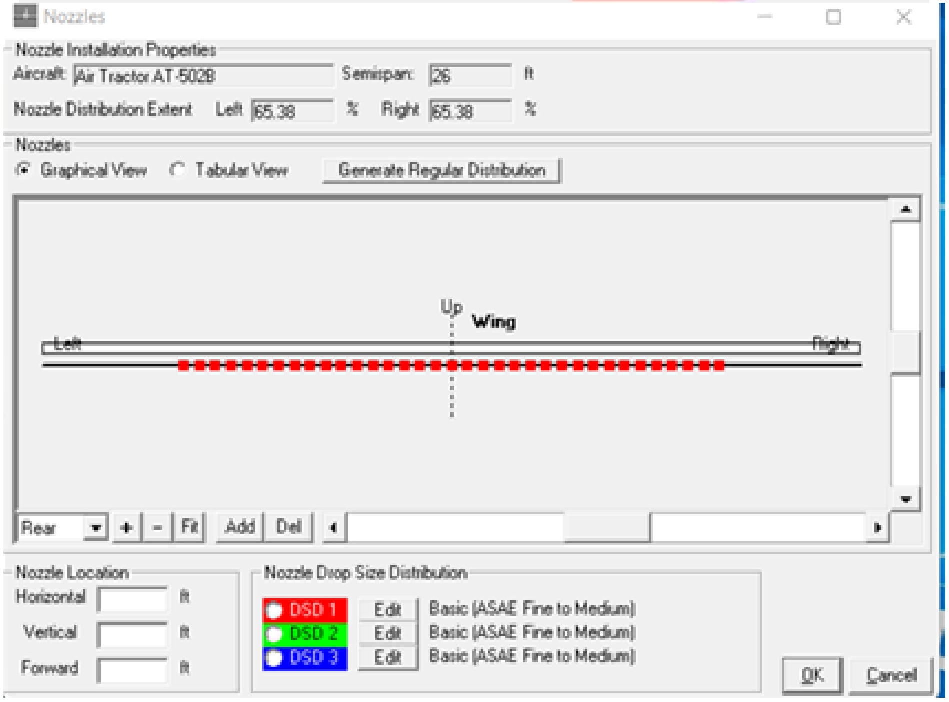
Meteorology
Wind Speed: 10 mph
Wind Direction: -90 deg
Temperature: 86 deg F
Rel. Humidity: 50 %

Atmospheric Stability: Overcast

Advanced Settings

Transport
Flux Plane: 0 ft

Terrain
Surface Roughness: 0.0246 ft



Nozzle Installation Properties
Aircraft: Air Tractor AT-502B
Semispan: 26 ft
Nozzle Distribution Extent Left 65.38 % Right 65.38 %

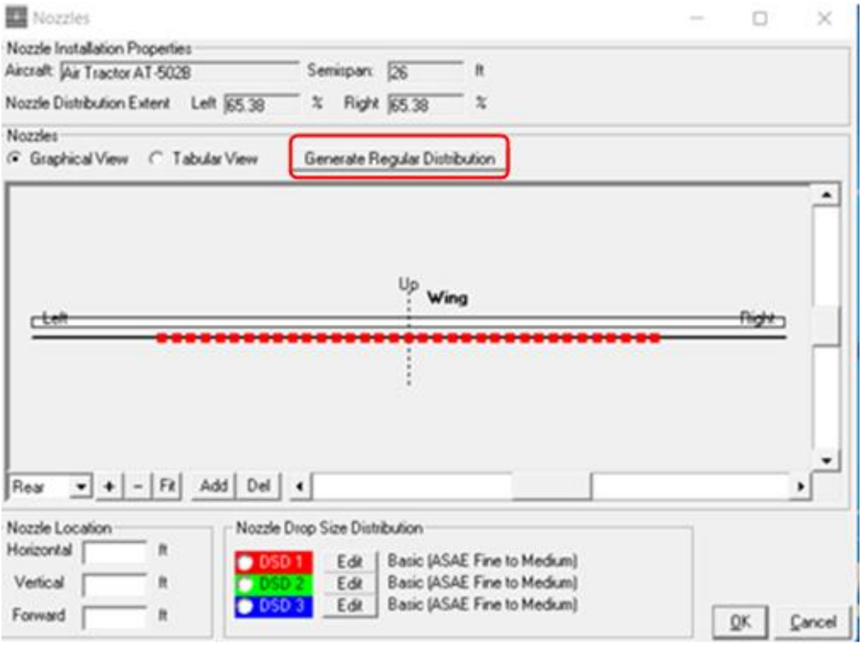
Nozzles
● Graphical View ○ Tabular View

Nozzle Location
Horizontal ft
Vertical ft
Forward ft

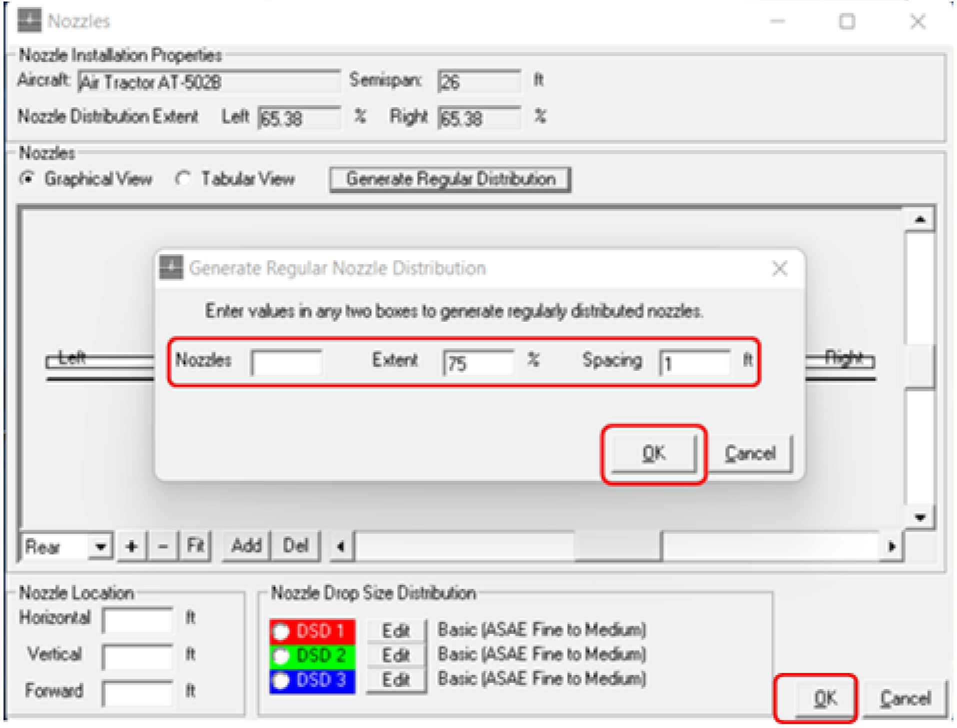
Nozzle Drop Size Distribution
○ DSD 1 Basic (ASAE Fine to Medium)
○ DSD 2 Basic (ASAE Fine to Medium)
○ DSD 3 Basic (ASAE Fine to Medium)

- Push the Generate Regular Distribution button. And enter the following as shown below:
  - Nozzles: leave blank.
  - Extent: enter 75%
  - Spacing: enter 1 ft.

Then push OK for the selected nozzles distribution and for the nozzles screen, as shown below.



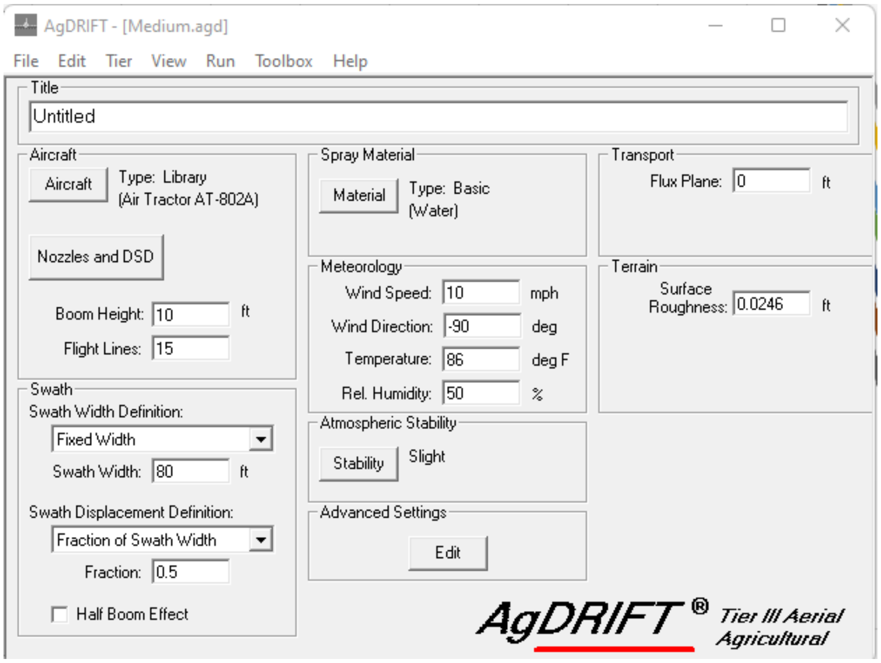
Aircraft: Air Tractor AT-502B
Semispan: 26 ft
Nozzle Distribution Extent Left 65.38 % Right 65.38 %
● Graphical View ○ Tabular View
DSD 1 Basic (ASAE Fine to Medium)
DSD 2 Basic (ASAE Fine to Medium)
DSD 3 Basic (ASAE Fine to Medium)



Aircraft: Air Tractor AT-502B
Semispan: 26 ft
Nozzle Distribution Extent Left 65.38 % Right 65.38 %
● Graphical View ○ Tabular View
Enter values in any two boxes to generate regularly distributed nozzles.
Nozzles Extent 75 % Spacing 1 ft
DSD 1 Basic (ASAE Fine to Medium)
DSD 2 Basic (ASAE Fine to Medium)
DSD 3 Basic (ASAE Fine to Medium)

(4) Swath: Change swath width definition from 60 ft to 80 ft (More appropriate value to AT-802A aircraft) and change the Swath Displacement Definition: Fraction to 0.5 instead of 0.3722 (To account for label language requiring a half-swath offset upwind) as shown below.

(5) Flight Lines: Change ‘Flight Lines’ (in ‘Aircraft’ section) from 20 to 15 to account for the increase in swath width from 60 ft to 80 ft.



Title: Untitled

Aircraft: Type: Library (Air Tractor AT-802A)

Boom Height: 10 ft

Flight Lines: 15

Swath Width Definition: Fixed Width

Swath Width: 80 ft

Swath Displacement Definition: Fraction of Swath Width

Fraction: 0.5

☐ Half Boom Effect

Spray Material: Type: Basic (Water)

Meteorology: Wind Speed: 10 mph; Wind Direction: -90 deg; Temperature: 86 deg F; Rel. Humidity: 50 %

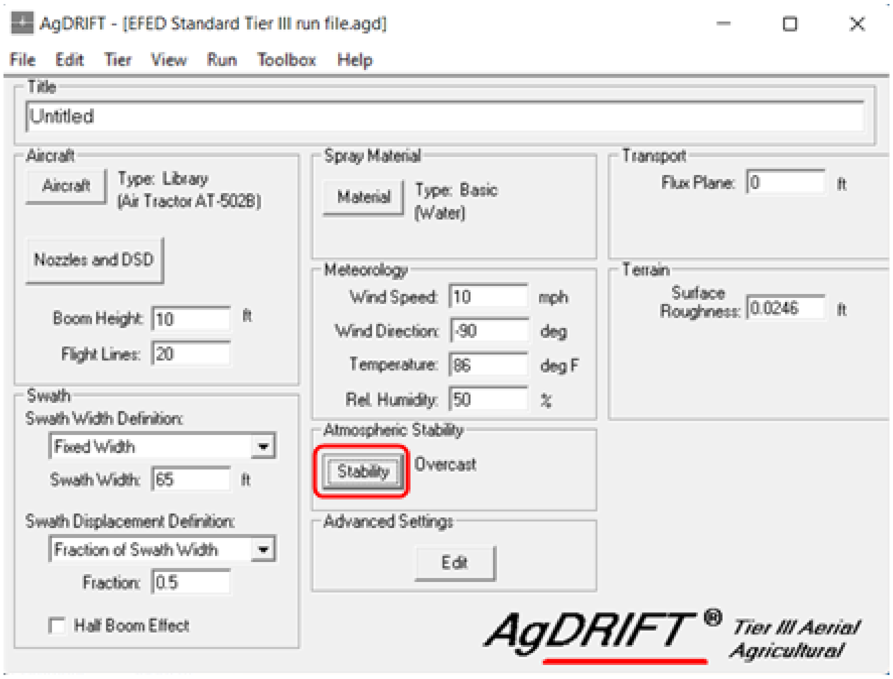
Atmospheric Stability: Slight

Transport: Flux Plane: 0 ft

Terrain: Surface Roughness: 0.0246 ft

(6) Atmospheric Stability:

- Push Stability button and change data in the new window to “Day with slight solar insolation” and push OK and OK again for the warning that appears as shown below.



Title: Untitled

Aircraft: Type: Library (Air Tractor AT-502B)

Boom Height: 10 ft

Flight Lines: 20

Swath Width Definition: Fixed Width

Swath Width: 65 ft

Swath Displacement Definition: Fraction of Swath Width

Fraction: 0.5

☐ Half Boom Effect

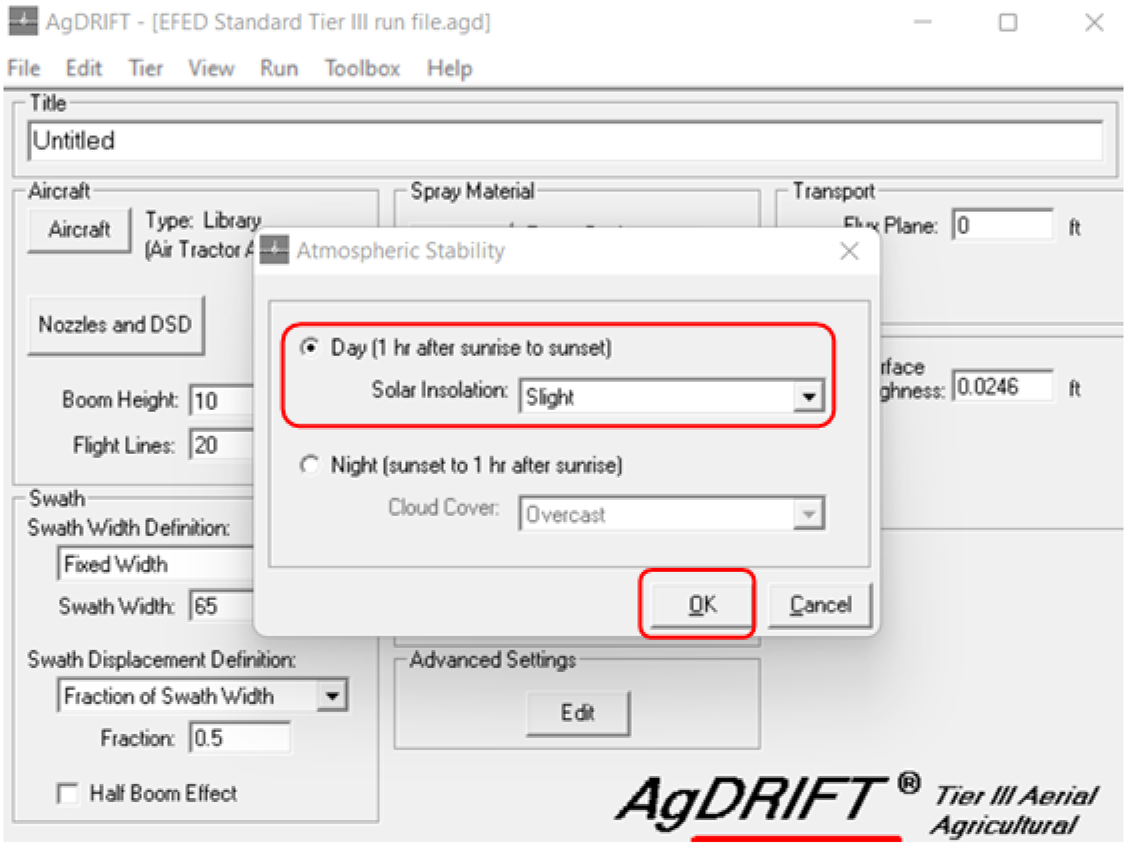
Spray Material: Type: Basic (Water)

Meteorology: Wind Speed: 10 mph; Wind Direction: -90 deg; Temperature: 86 deg F; Rel. Humidity: 50 %

Atmospheric Stability: Overcast

Transport: Flux Plane: 0 ft

Terrain: Surface Roughness: 0.0246 ft



Title: Untitled

Aircraft Type: Library (Air Tractor A

Boom Height: 10

Flight Lines: 20

Swath Width Definition: Fixed Width

Swath Width: 65

Swath Displacement Definition: Fraction of Swath Width

Fraction: 0.5

☐ Half Boom Effect

Transport Flux Plane: 0 ft

Surface Roughness: 0.0246 ft

Atmospheric Stability

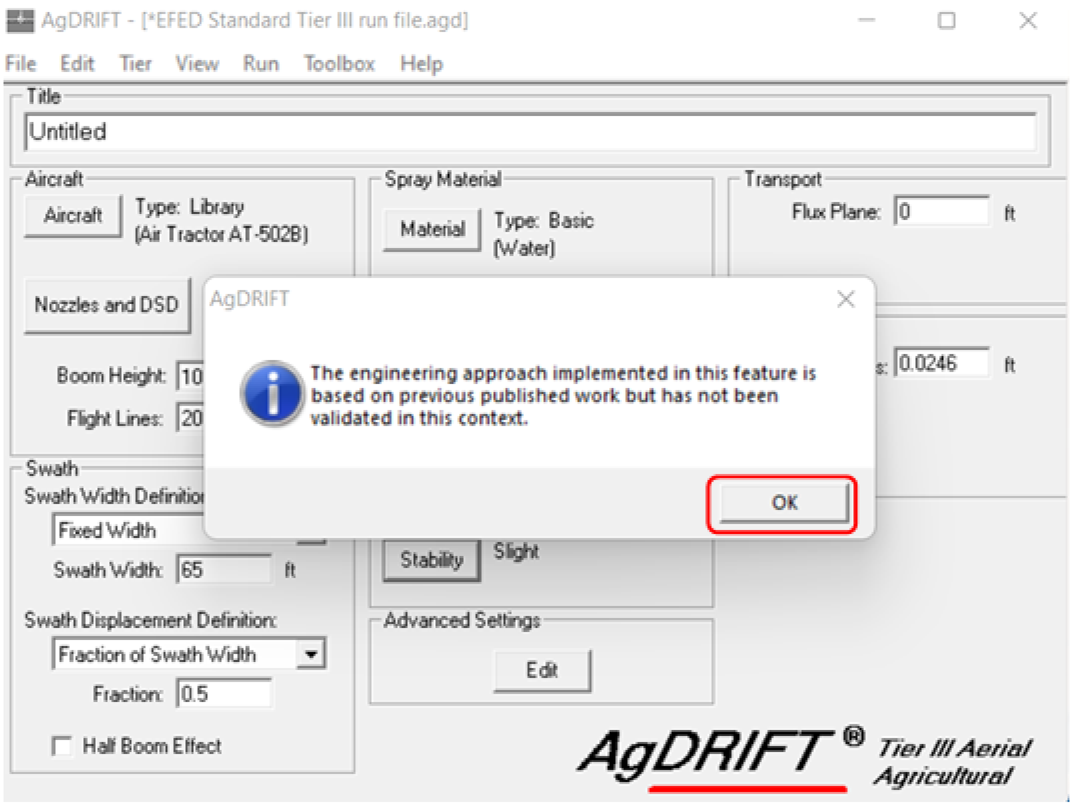
● Day (1 hr after sunrise to sunset)

Solar Insolation: Slight

○ Night (sunset to 1 hr after sunrise)

Cloud Cover: Overcast

OK Cancel



Title: Untitled

Aircraft Type: Library (Air Tractor AT-502B)

Spray Material Type: Basic (Water)

Transport Flux Plane: 0 ft

Boom Height: 10

Flight Lines: 20

Swath Width Definition: Fixed Width

Swath Width: 65 ft

Swath Displacement Definition: Fraction of Swath Width

Fraction: 0.5

☐ Half Boom Effect

Stability: Slight

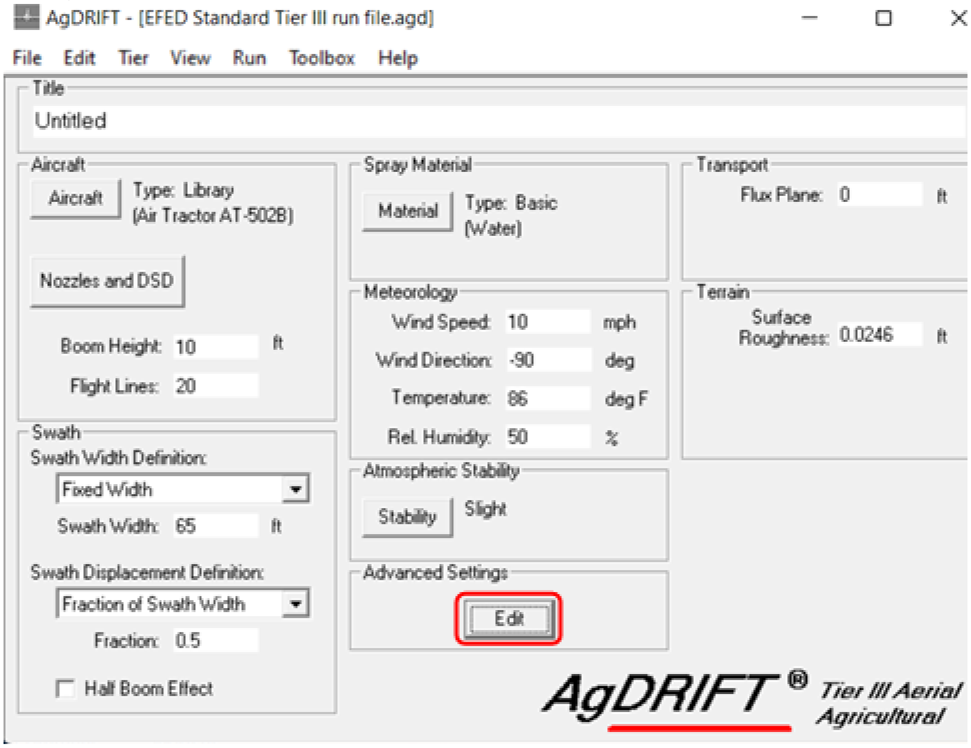
0.0246 ft

AgDRIFT

The engineering approach implemented in this feature is based on previous published work but has not been validated in this context.

OK

(7) Advanced Setting: Push the edit button to change the height for wind speed measurement (the 1st item in the window) to 10 ft. instead of 6.56 ft., then push OK, as shown below.



Title: Untitled

Aircraft Type: Library (Air Tractor AT-502B)

Boom Height: 10 ft

Flight Lines: 20

Swath Width Definition: Fixed Width

Swath Width: 65 ft

Swath Displacement Definition: Fraction of Swath Width

Fraction: 0.5

☐ Half Boom Effect

Spray Material Type: Basic (Water)

Meteorology

Wind Speed: 10 mph

Wind Direction: -90 deg

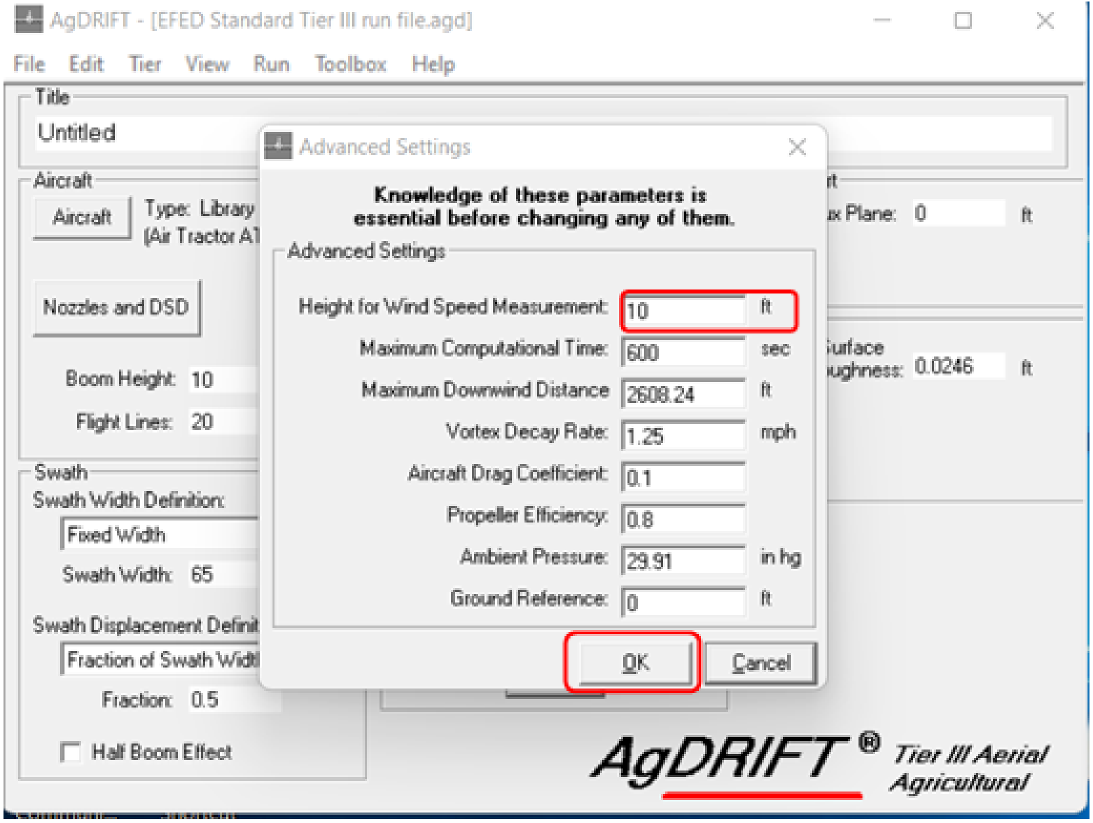
Temperature: 86 deg F

Rel. Humidity: 50 %

Atmospheric Stability: Slight

Transport Flux Plane: 0 ft

Terrain Surface Roughness: 0.0246 ft



Knowledge of these parameters is essential before changing any of them.

Advanced Settings

Height for Wind Speed Measurement: 10 ft

Maximum Computational Time: 600 sec

Maximum Downwind Distance: 2608.24 ft

Vortex Decay Rate: 1.25 mph

Aircraft Drag Coefficient: 0.1

Propeller Efficiency: 0.8

Ambient Pressure: 29.91 in hg

Ground Reference: 0 ft

J.2 Additional Rationale Supporting Recommended Default Parameters

J.2.1 Aircraft Type

Since the time of NAAA's comment in 2020 in which aircraft numbers are discussed, the AT-802A has not only become the dominant aircraft type but also has substantially increased in number[49] compared to other aircrafts. The 2019 Federal Aviation Administration (FAA) General Aviation and Part 135 Activity Survey (GA Survey) indicates that a total of 3,120 agricultural aircraft were used in 2019 to apply pesticides. From this survey, the AT-502 and AT-802 represent the most common aircrafts registered for agriculture use. In 2020, NAAA recommended updating the aircraft used in AgDRIFT® modeling to the AT-502B, noting that the loading capacity of 500 gallons is a median between the smaller capacity aircraft (*i.e.,* Piper or Cessna) and the 800-gallon capacity of the large AT-802A. Larger aircrafts have a larger wingspan and a larger vehicle mass resulting in more droplets landing on-field due to a large swath offset and therefore less droplets available for drift. Since the time of NAAA's initial comment in 2020, the AT-802A is the only agricultural aircraft that has substantially increased in number[50] with AT-502 and AT-602 seeing minor increases and all other aircraft decreasing in number since 2020. The number of registered AT-502 (includes A and B) ranged from 506 to 512 during the period from 2020 to 2023 (when surveys distinguish between the AT-502, AT-502A, and AT-502B, the AT-502B is the leading aircraft). At the same time, the number of registered AT-802 increased from 488 to 583, becoming the dominant agricultural aircraft. Between 2020 and 2023, registered AT-802A increased to 19.5% of registered aircraft, more than any other agricultural aircraft. AT-502, AT-602, AT-802, and Thrush aircraft (*i.e.*, all aircraft with hopper capacities ≥500 gallons) appear to represent 51% of the aircrafts used in the United States agriculture and possibly more treated acres compared to all other aircrafts due to its high loading capacity and wide swath. When normalized for hopper capacity, aircraft with 500-gallon capacity or greater account for 68 to 73% of all aerial application capacity registered with the FAA with a 4% increase in the past four years. See **Table J-2** for information on number of aircraft, associated hopper capacity, and changes in FAA registrations. This analysis assumes that the number of aircraft registrations correlates to the number of acres treated. Since most aircrafts registered have hopper capacities ≥500 gallons, this analysis will focus on medium and large aircrafts, as use of smaller aircraft inputs is not as representative of exposure for the majority of aerial application.

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[49] Based on Federal Aviation Administration (FAA) Aircraft Inquiry: https://registry.faa.gov/aircraftinquiry

[50] Based on Federal Aviation Administration (FAA) Aircraft Inquiry: https://registry.faa.gov/aircraftinquiry

Table J-2. Number of aircraft, associated hopper capacity, and changes in FAA registrations.

Hopper capacity range	Aircraft	Hopper Capacity (gallons)	2020 FAA Number of Registered Aircrafts	2023 FAA Registrations	Change in FAA Registrations ('20 to '23)
Large (510 to 800 gallons)	**AT-802**	**800**	**488**	**583**	+2.9%
	AT-602	630	236	238	
	Thrush	**510 to 710**	**606**	**548**	
Medium (350 to 500 gallons)	**AT-502**	**500**	**506**	**510**	-3.8%
	AT-400	400	53	49	
	AT-401	*400*	*77*	*66*	
	AT-402	400	183	173	
	AT-301	350	113	99	
Small (150 to 280 gallons)	Piper PA-36	275	115	105	-9.3%
	Cessna 188	200 to 280	381	347	
	Piper PA-25	150	477	463	
Other (Small to Medium)	**G-164 (AgCat)**	**247 to 500**	**527**	**478**	-6.0%

Bold values are those that had more than 500 registered aircraft in 2020 or 2023. The default AT-401 and respective registrations are *italicized*.
Source: Federal Aviation Administration (FAA) Aircraft Inquiry: https://registry.faa.gov/aircraftinquiry

The aircraft options in AgDRIFT® Tier III model can be used to choose the type of aircraft from the basic aircraft menu (4 aircraft types: Ag Husky; Air Tractor AT-502; Wasp Helicopter; and Air Tractor AT-401) or from the aircraft library menu (37 fixed-wing aircrafts and 31 helicopters) (Refer to **Section J.1** for guidance). **Table J-3** contains a summary of the characteristics of the previous aircraft selection for AgDRIFT®, AT-401, the NAAA recommended AT-502B, and the AT-802, which had the largest increase in registrations of all agricultural aircrafts between 2020 and 2023.

Table J-3. Characteristics of the most common medium and large aircrafts[1] used in agriculture. (Source: Spray Drift Task Force Library in AgDRIFT®)

Aircraft Name[2]	**AT-401**	**AT-502B**	**AT-802A**	**Ag-Cat Super B**	**Thrush T34**
Type	Fixed-wing	Fixed-wing	Fixed-wing	Fixed-wing	Fixed-wing
Semispan[3] (ft)	24.5	26	29	21.25	23.75
Weight (lbs)	6,000	7,000	11,160	5335	7665
Typical Speed (mph)	119.99	134.99	114.99	114.99	139.99
Propeller RPM	2,000	2,000	1,500	2300	2000
Propeller Radius (ft)	4.5	4.4	4.8	4.4	4.4
Biplane Sep (ft)	0	0	0	6.1	0
Platform Area (ft^2)	294	312	391	392	350
Engine Number	1	1	1	1	1

Aircraft Name[2]	**AT-401**	**AT-502B**	**AT-802A**	**Ag-Cat Super B**	**Thrush T34**
Engine Vert. (ft)	-1.2	0	0	0.3999	0
Engine Fwd. (ft)	11.9	13.75	13.75	11	16.9
Engine Horiz. (ft)	0	0	0	0	0
	0	0	0	0	0
Wing Vert. (ft)	1.51	1.54	1.54	1	1.38
Boom Vert. (ft)	-1.15	-0.6601	-0.6601	-1	-1
Boom Fwd. (ft)	-0.8333	-0.5	-0.5	-0.5	-0.5
Hopper size (gal)	400	500	800	400	510

[1] Thrush and AgCat registration count consists of multiple specific aircraft types (individual aircrafts not specified) that have small parameter differences and are therefore not included in this table.

[2] The most common aircrafts used in agriculture are manufactured by Air Tractor.

[3] Half of wingspan

EPA conducted AgDRIFT® modeling using five aircraft types presented in **Table J-3** to compare off-site deposition between the default aircraft (AT-401), the leading medium agricultural aircraft, AT-502B, and the leading large agricultural aircrafts, AT-802 and Thrush. The input parameters for the runs reflect recommended parameter changes (including Medium DSD) except for aircraft specific changes in swath width and the number of spray lines (**Table J-4**).

Table J-4. Aircraft-dependent parameters.

Parameter	**Aircraft Type**				
	AT-401	**AT-502B**	**AT-802A**	**Ag-Cat Super B**	**Thrush T34**
No. of flight Lines	20	19	15	20	19
Swath Width (ft)	60	65	80	60	65

Output from modeling is presented in **Figure J-1**.

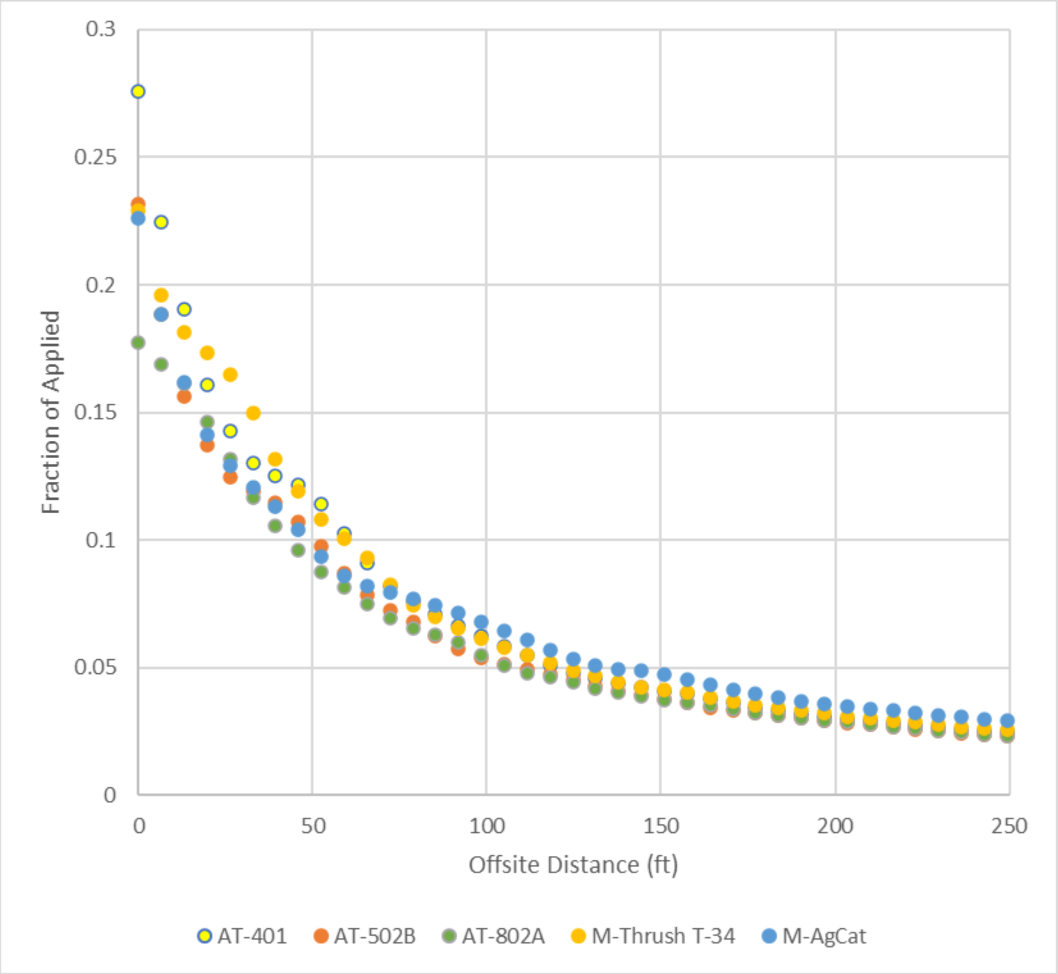

Figure J-1. Fraction of applied with distance from the edge of field using different aircraft

Offsite deposition output in **Figure J-1** indicates varied deposition fractions from 0 to 250 ft from the application. The aircraft-dependent differences in fraction of applied were the highest within 50 ft. from the edge of the field and is nearly indistinguishable as offsite deposition approaches 250 ft. AT-802A and AT-502B are comparable and result in the least offsite deposition. The Thrush T-34 results in slightly more offsite deposition than the AT-401 at <50 ft offsite distance, but after 50 ft, the distances are comparable. The AgCat is comparable to the AT-502B and AT-802A at offsite distances less than 60 ft but is the most conservative aircraft investigated for modeling offsite distances greater than 85 ft. Because the AgCat and the Thrush FAA registrations do not distinguish between individual aircraft types and both aircraft categories are not growing, EPA is focusing the remainder of this analysis on comparing the prior default modeling aircraft selection, the AT-401, with NAAA's recommendation of the AT-502B and the aircraft with the current greatest number of registrations, the AT-802A.

Model runs indicate similar deposition profiles for AT-502B aircraft and AT-802A with slightly more conservative estimates for AT-502B aircraft at offsite distances less than 85 ft.

At offsite distances greater than 150 ft, the AT-502B and AT-802A are nearly indistinguishable. Additionally, both are less conservative than the AT-401. Comparing the AT-401, AT-502B, and the AT-802, at 20 ft offsite, the maximum difference in fraction of applied is 0.024 at 20 ft, and 0.0016 at 203 ft offsite. Alternatively, the offsite distances are more comparable for the AT-502B and the AT-802A, with a maximum difference in fraction of applied of 0.0089 at 20 ft and 0.0002 at 203 ft.

The FAA survey shows that the AT-502B and AT-802A are more commonly registered aircrafts for pesticide application compared to the AT-401. As shown above, the AT-502B and AT-802A have similar deposition profiles, with the AT-502B having only slightly higher deposition around less than 85 ft offsite. However, the AT-802A aircraft is the most commonly utilized aircraft, with registrations increasing by 19.5%[51] between 2020 and 2023. In recognition of the increasing numbers of the AT-802A and small deposition differences when compared to AT-502B, it is recommended that the AT-802A aircraft be used as a default parameterization executing standard runs of Tier III AgDRIFT®.

J.2.2 Boom Length

While a boom length of 75% of the wingspan is standard, changes in boom length can be required to allow for applications in high wind conditions that would otherwise not allow for an aerial application to occur. It is found that comparable modeled offsite deposition occurs with a 75% boom length and 10 mph wind as occurs with a 65% boom length and 15 mph wind. See **Figure J-2** below for a comparison across boom lengths and wind speeds for the AT-502B and AT-802A. Note that the figure below assumes swath displacement as constant across comparisons (0.5 fraction of swath width).

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[51] 95 new 2023 registrations / 488 2020 registrations

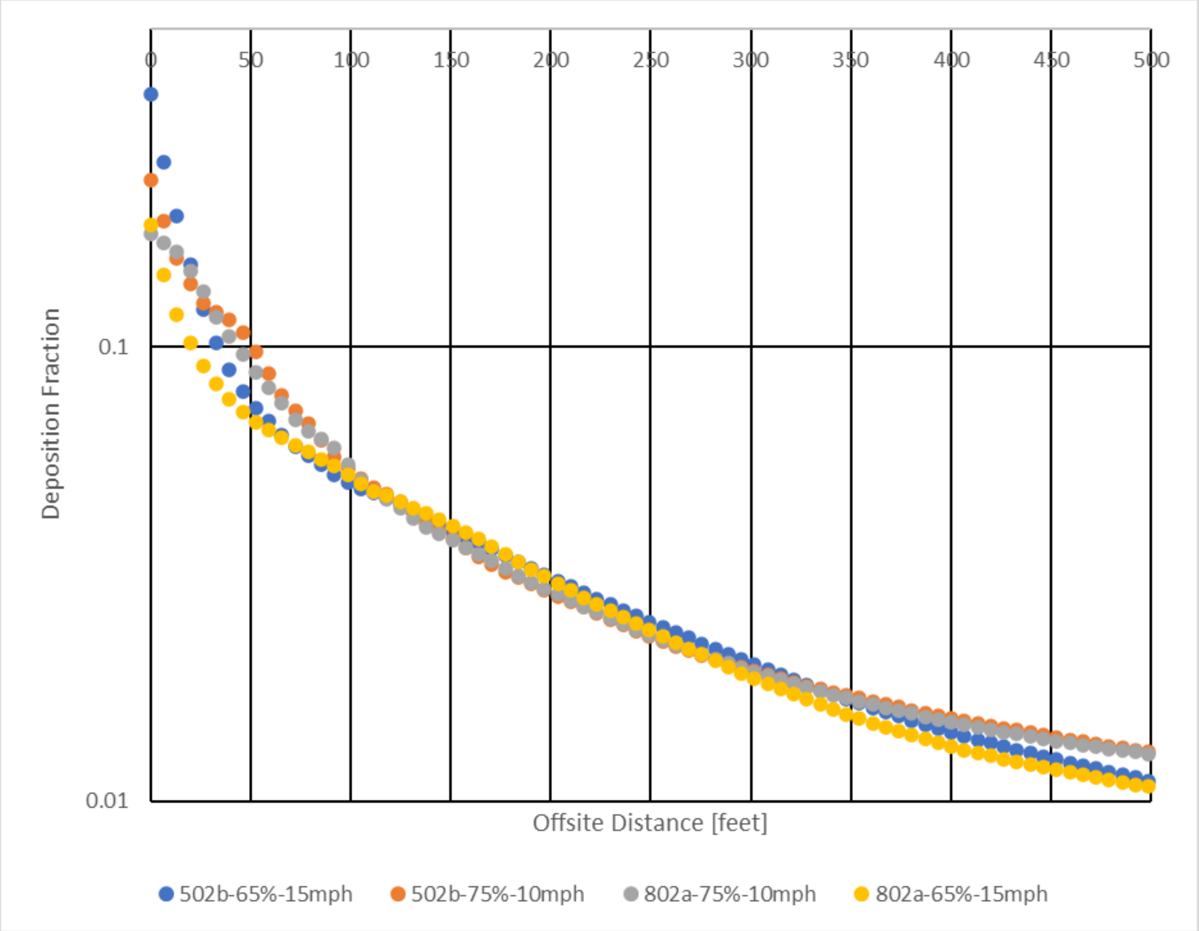

Figure J-2. Comparison of Boom Length and Wind Speed changes with AT-502B and AT-802A Aircraft.

J.2.3 Boom Drop

Boom drop is the distance between bottom of the plane and the release height of the pesticide from the spray drift equipment. Hoffmann and Tom (2000) note that a lowered boom system allows droplets to reach their targets without interference from air turbulence and is thus expected to reduce drift. The boom system is attached to the aircraft and can be lowered to a desired release height once the aircraft is in the air. While AgDRIFT® assigns a certain height to the boom drop based on the aircraft selected, it is understood that spray boom is not standard equipment included in the specifications of aircraft[52].

Use of drop boom equipment is recommended by NAAA[53] as a method to reduce offsite transport and could potentially be used to reduce offsite deposition. It is EPA's current

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[52] AT-802A Air Tractor Specifications (available at: https://airtractor.com/aircraft/at-802a/) https://airtractor.com/aircraft/at-402b/

[53] https://www.regulations.gov/comment/EPA-HQ-OPP-2015-0716-0040

understanding that use of dropped boom occurs but is not necessarily common practice as survey data on the topic is not currently available. Thus, it would not be simulated in default modeling assumptions but could potentially be used to reduce the drift buffer needed when it is utilized. However, additional work is needed before EPA could account for this practice in risk assessments. EPA needs to have evidence that the practice consistently reduces off-site transport and the practice commonly occurs.

The Tier 1 AgDRIFT® model does not account for lowering spray boom and nozzles relative to the trailing edge of the wing. Hoffmann and Tom (2000) demonstrated that lowering the spray boom 1.5 feet relative to the trailing edge of the wing with an AT-402B reduced off-target deposition for near-field and far-field areas with 26% and 56% reduction at 10 meters (32.8 ft.) and 310 meters (1,017 ft), respectively. However, off-target deposition between 15 meters (49.2 ft) and 40 meters (131 ft) are substantially similar between raised and lowered spray boom. This study was conducted using a fine spray at wind speeds between 2.9 and 5.1 miles per hour. Thus, there is uncertainty in the effectiveness of this option in reducing drift as the amount of reduction did not occur at some distances but did at others and how drift reduction is influenced across different aircraft with different airflow dynamics.

EPA simulated the boom-drop by maintaining the default Boom Vertical setting and changing the vertical locations of all nozzles to reflect an appropriate boom height for the aircraft[54]. The differences in deposition fraction resulting from adjusting the boom-drop were the highest within 100 ft from the edge of the field and decreased with distance. Fraction of applied at 33 ft, 200 ft, and 1,017 ft is shown in **Table J-5**.

Table J-5. Summary of Deposition Predicted when Modeling Boom Drop

Aircraft	Parameter and Difference	Distance from edge of field		
		33 ft (10 m)	200 ft (61 m)	1,017 ft (310 m)
		Fraction of Applied		
AT-502B	Default (-0.6601 ft)	0.111	0.0378	0.0099
	Dropped Boom (-2 ft)	0.0949	0.0349	0.0089
	Percent Difference	17%	8%	11%
AT-802A	Default (-0.6601 ft)	0.116	0.0285	0.0859
	Dropped Boom (-2 ft)	0.114	0.0267	0.0831
	Percent Difference	2%	7%	3%

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[54] The procedure was recommended in May 2018 by Harold Thistle of the U.S. Forest Service, and Milt Teske of Continuum Dynamics. The 2 ft boom drop was achieved by changing the individual nozzle vertical locations for all the nozzles in the Nozzles menu to –1.3999 instead of zero. Given that the default Boom Vert. setting is -0.6601 ft below the wing in AgDRIFT® for the AT-502B, the nozzle vertical adjustment is set another -1.3399 ft below the wing (0.6601 + 1.3399= 2.0 ft).

The current default assumptions (-1.15 ft for the AT-401 and -0.6601 ft for AT-502B) do not account for drift reduction associated with dropped boom, as spray boom does not appear to be standard equipment and that differences in boom drop (and nozzle spacing) exist within in the same aircraft type. A boom drop from -0.6601 ft to -2.00 ft may result in drift reduction as AgDRIFT® predicts a deposition reduction of 8% to 15% for the smaller AT-502B and a reduction of 2% to 7% for the larger AT-802A. These modeled differences are not as large as the differences measured by Hoffmann and Tom (2000) with a small AT-402B aircraft. Differences between the field and modeled values may be explained, in part, by boom drop being a more sensitive parameter for smaller aircraft. Uncertainty exists on whether the 2 ft boom-drop is a standard for AT-802A aircraft in the absence of survey data, and the parameter does not prove to be sensitive considering the large size of the aircraft. Considering these factors, EPA does not recommend changing the boom drop from prior defaults in AgDRIFT®.

J.2.4 Atmospheric Stability

The atmospheric stability screen in AgDRIFT® Tier III model can be used to choose the input that describes the stability of the atmosphere during the application. The default AgDRIFT® input in the model is night with overcast cloud cover.

Atmospheric stability is a measure of atmospheric status which determines whether air will rise, sink, or be neutral. In general, stability refers to air tendency to rise or to resist vertical motion. Atmospheric stability, in a specified geographic location, is classified based on wind speed and solar insolation at the site into unstable conditions (extremely, moderately or slightly unstable), Neutral, and stable conditions (slightly or moderately stable) (**Table J-6**)[55].

Table J-6. Atmospheric stability classes based on wind speed and solar insolation.

Ground Wind Speed (m/s)	**Day-time solar insolation**			**Night-time solar insolation**	
	Clear summer day	**Summer days with Few broken clouds**	**Cloudy summer day Or Fall afternoon**	**Thin overcast (>4/8 low cloud)**	**≤4/8 cloudiness**
	Strong	**Moderate**	**Slight**	**Mostly Overcast**	**Mostly Clear**
<2	Extr UNST	Ext to Mod UNST	Mod UNST	Slight ST	Mod ST
2-3	Extr to Mod UNST	Mod UNST	Slight UNST	Slightly ST	Mod ST
3-5	Mod UNST	Mod to Slight UNST	Slight UNST	Neutral	Slight ST
5-6	Slight UNST	Slight UNST/Neutral	Neutral	Neutral	Neutral
>6	Slight UNST	Neutral	Neutral	Neutral	Neutral

Abbreviations: Ext= Extremely; Mod= Moderately; Slight= Slightly; ST= Stable; UNST= Unstable;
4.5 m/s = 10 mph

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[55] NOAA URL: READY Tools - Pasquill Stability Classes (noaa.gov)

Additionally, atmospheric stability can also be classified based on the vertical temperature gradient and wind speed profiles (Huang and Thomson, 2016) which is referred to as the Stability Ratios (SR) (**Table J-7**).

Table J-7. Atmospheric stability classes based on the vertical temperature gradient and wind speed profiles (SR= Stability Ratio).

Atmospheric Stability Class	Stability Ratio (SR)
Unstable	-1.7 to -0.1
Neutral	0.1
Stable	0.1 to 1.2
Very Stable	1.2 to 4.9
[1]***SR***= log scale of	Temperature difference between two heights
	Wind speed at equidistant between these heights

Language that appears on new and updated pesticide labels include: "**Do not** make aerial or ground applications into areas of temperature inversions". Temperature inversion is related to the stability of the atmosphere as it develops when cool air is trapped at the ground under a layer of warm air. It occurs when air near the surface becomes cool during night-time while air just above remained warm (**Figure J-3**). These conditions favor pesticide drift as an application occurring in the warm air aloft does not mix with the cool air below (the application target) allowing the droplets to drift offsite rather than be deposited to the target.

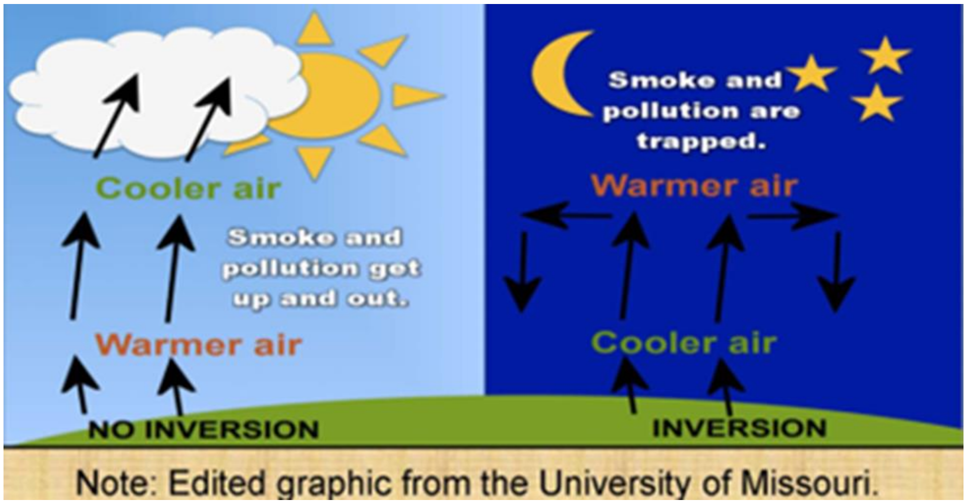

Figure J-3. Atmospheric conditions for temperature inversion and no inversion (Source: Oceanic and Atmospheric Administration (NOAA), National Weather Service, Little Rock, Arkansas[56])

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[56] The Figure is available at: https://www.weather.gov/media/lzk/inversion101.pdf (accessed 12/2023). (shared with permission)

The main conditions that favor the development of temperature inversions are[57]:

- Long nights (long period of time for cooling Earth/air to occur).
- Clear skies (25% or less cloud cover as it increases cooling of earth's surface).
- Light and variable winds with minimal mixing of the lower atmosphere (Calm winds <3 mph). Could happen with winds of 4 to 6 mph.
- Begins in the mid to late afternoon especially 3-5 hours before sunset and intensifies throughout the night until dawn. The inversion will then dissipate into mid-morning approximately 2-3 hours after sunrise.

As shown above, possible timing of occurrence of temperature inversion depends on many factors although it is likely to occur during stable atmospheric conditions. Atmospheric stability can be determined for a geographic location at certain time of the year. For example, daily probability of atmospheric stability was determined during April to October 2004 in Stoneville, Mississippi as shown in **Figure J-4**.

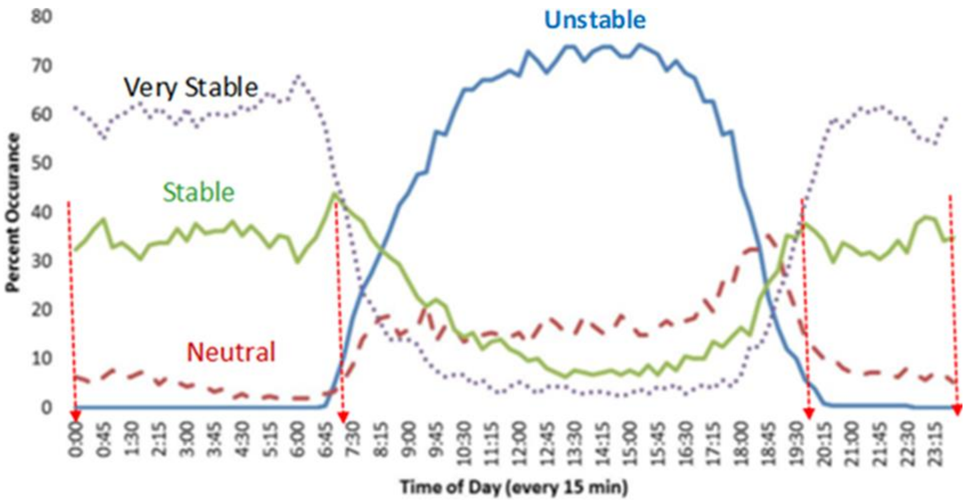

Figure J-4. Daily probability of atmospheric stability from April- October 2004 in Stoneville, Mississippi (Huang and Thomson, 2016). Arrows indicate when inversion occurs.

Figure J-4 indicates that stable atmospheric conditions (*i.e.*, inversion conditions) are likely to occur mid to late afternoon and to intensify through night- time. During this period, the probability of occurrence of temperature inversion is expected to be the highest.

In AgDRIFT® Tier III, the current default inputs for atmospheric stability are night with overcast cloud cover. As shown above, the possibility of occurrence of temperature inversion is higher than any other time within the day. The goal of the applicator is to abide

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[57] MRCC - About Temperature Inversions (purdue.edu)
Temperature inversions: Something to consider before spraying (umn.edu)

by label restriction by applying when conditions are favorable and avoid possible presence of a “temperature inversion”. Therefore, most of the aerial applications are expected to occur outside periods where the atmosphere is stable. Choosing a “day with slight solar insolation” is ideal in this case because stable atmospheric conditions with calm winds (0- 3 mph) are avoided eliminating the possibility of the presence of “temperature inversion”. This is especially important with winds of 4 to 6 mph when “temperature inversion” is difficult to predict. Furthermore, wind speed is parameterized at 10 mph which is expected to correspond with slightly to moderately unstable conditions during daytime.

J.2.5 Height of Wind Speed Measurement

NAAA proposed a wind speed measurement height of 12 feet as the AgDRIFT Tier III Aerial default value. Currently, the FIFRA Interim Ecological Mitigation (IEM) best management practices for wind speed measurements[58] requires wind speed to be measured at release height or higher. However, the AgDRIFT® default value currently assumes a measurement at height 6.56 feet. This default parameter is the approximate height of an average person holding a wind meter in the air above their head when conducting wind speed measurements, which is not typical of current wind speed measurement practices for aerial applications. As wind speed generally increases with height from the ground, the 6.56 feet wind speed height measurement results in a higher predicted deposition as compared to a higher wind speed height measurement because the wind speed at the release height will be higher than that where it is measured.

NAAA’s suggestion on increasing the default AgDRIFT Tier III Aerial wind speed height measurement value to 12 feet is based on the ability of most modern aerial applicators to measure and monitor weather conditions (including wind speed) in the cockpit at the height of application either through a smoker or an Aircraft Integrated Meteorological Measurement System (AIMMS).

Aerial applicators equipped with smokers inject a small amount of vegetable oil into the aircraft exhaust system that creates smoke, allowing the pilot to determine, by observing smoke movement, the wind direction and an estimate of wind speed. Inversions can be detected by observing vertical smoke movement. Additionally, AIMMS provides real-time onboard weather data, including wind speed and direction, temperature, and humidity. The atmospheric data collected by AIMMS is then synchronized with the GPS unit, along with the droplet size data. This enables the pilot to take into account outside wind speed and direction when making every pass, resulting in an even more precise application. The 2019 NAAA Aerial Application Industry survey shows that 81% of all agricultural aircraft have smokers and 8% have AIMMS, which highlights aerial application’s ability to continuously monitor wind speed and direction and adjust applications as needed throughout the actual application process.

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[58] https://www.regulations.gov/document/EPA-HQ-OPP-2016-0114-0094

NAAA notes that the default release height for aerial applications is 10 feet above the crop canopy, which is the location of the boom and is typically around 2 feet below the wing in an agricultural aircraft. The smoke from a smoker is released from the exhaust, which is typically located just above the wing, and the AIMMS probe is mounted directly on the wing. The current default parameter of 6.56 feet is more accurate for ground application methods or wind speeds measurement techniques taken from the ground. For these reasons NAAA recommends the height for wind speed measurement be set to 12 feet when using AgDRIFT® Tier III to model spray drift from aerial applications as that is the actual height the wind speed is measured at.

However, a wind speed measurement height of 10 feet is more consistent with current practices, based on a recommended release height of 10 feet above the crop canopy, and more conservative, taking into account the variability of the aircraft over the field while crops are present. Therefore, we are suggesting that an update of the default wind speed height to 10 feet instead of 12 feet to be more conservative and representative. That said, there is not significant difference in final drift estimations when comparing a default wind speed measurement parameter of 10 and 12 feet (**Table J-8**).

To determine the effect of wind speed height parameter on overall drift, an analysis was conducted by varying this parameter (6.56, 10 and 12 feet) in AgDRIFT under 10 and 15 mph with 0 and 200 ft buffers. These wind speeds are the most common aerial application restrictions required by pesticide labels. This analysis is presented in the table below.

Table J-8. Effects of Wind Speed Measurement Height Default Parameters on Terrestrial Drift Fraction

Wind Speed Measurement Height (ft)	Fraction of Applied[1] and % Decrease	
	No Buffer	200ft Buffer
10 mph Wind speed		
6.56	0.1833	0.0301
10	0.1772 (-3.3%)	0.0290 (-3.7%)
12	0.1773 (-3.3%)	0.0284 (-5.6%)
15 mph Wind speed[2]		
6.56	0.2148	0.0324
10	0.1857 (-13.5%)	0.0307 (-5.2%)
12	0.1752 (-18.4%)	0.0310 (4.3%)

[1] All other AgDRIFT® parameters are with the new recommended default values

[2] Boom length assumption for 15 mph wind speed is adjusted to 65% for consistency with recommended label language.

The effect of increasing the default measurement height parameter in AgDRIFT® has an impact on the predicted offsite drift when buffers are not considered. At 10 and 15 mph wind speed, estimated offsite drift is decreased by 10% (from 0.125 to 0.113 at 10 mph and 0.228 to 0.205 at 15 mph) when the default wind speed measurement height parameter is increased from 6.56 to 10 feet. This difference decreases when higher buffer restrictions are in place. There is a 1-4% difference between a default wind speed measurement height of 10 and 12 feet based on the wind speed.

This increase in estimated drift resulting from increasing the wind speed measurement height parameter is due to the increase in wind speed as height increases. The wind speed at 10-12 feet can be approximately 10-15% greater than the wind speed at 6.56 feet, varying based on surface roughness. Therefore, if wind speed is measured at 10-12 feet, AgDRIFT® will overestimate this wind speed by 10-15% if the wind speed measurement height is assumed to be at 6.56 feet, resulting in an overestimation of pesticide offsite drift during aerial application. Similarly, if wind speed is measured at the currently assumed default measurement height of 6.56 feet, drift predictions would be underestimated by 10-15% if the assumed measurement height is set to 10-12 feet.

Since the current common practice for measuring aerial application wind speed is through smokers or use of an AIMMS at a height of 10-12 feet, it is likely that the 6.56 ft wind speed measure assumption results in an overestimated amount of offsite transport through drift. Because of this, the recommended wind speed measurement height parameter is updated from 6.56 to 10 ft in AgDRIFT® default modeling assumptions.

J.2.6 Surface Roughness

Surface roughness is the effective roughness height of ground cover, and it varies with the crop characteristics (Teske and Curbishley, 2011). In AgDRIFT® modeling, a greater surface roughness value will lead to lower offsite deposition estimates. The current model assumes 0.0246 ft, reflecting a bare ground assumption on field. Given this, NAAA proposed a surface roughness of 0.32 ft as the AgDRIFT® Tier III Aerial default value. While most aerial applications are assumed to be made to fields post-emergence or for burn down[59], millions of acres are also treated with little vegetation on the field. If crop presence were to be accounted for in modeling, it would be based on the label recommendations for the characteristics of the crop when the application was recommended to be made.

To determine what the most appropriate assumption for surface roughness should be, this section discusses an analysis that considered 1) an evaluation of the open literature on the effects of having a crop on field at the time of application, which includes the reference NAAA submitted; 2) the options for surface roughness in modeling; and 3) what the most common practices are for aerial pesticide application.

NAAA's suggestion for a surface roughness of 0.32 ft is based on a study by Hoffmann et al. (2007), in which the authors compared AgDISP^{TM} estimated spray drift deposition and measured deposition for aerial applications of pesticides on cotton crops of varying heights and canopy roughness parameters. AgDISP^{TM} is a spray drift model developed for the USDA

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[59] Conversation with Biological and Economic Analysis Division on October 25, 2023

Forest Service and not typically used for agricultural assessments for EFED. The authors monitored offsite field deposits at 50 m from flight line at four different canopy heights- 0 m (bare ground), 0.3 m, 0.7 m, and 1 m. As canopy height increased, canopy roughness and displacement parameters were also reported to increase. The highest downwind deposition was noted for 0 m (bare ground) and 1 m crop height. The authors note that at the 1 m cotton crop height, the canopy is effectively closed, preventing the spray from penetrating the canopy, and so behaves more like a bare ground application. The two intermediate treatments (0.3 and 0.7 m) have comparable field depositions and AGDISP^{TM} deposition estimates at distances greater than 10 ft from the flight line.

Based on the above study, NAAA's recommended surface roughness parameter is derived from the greater of the two intermediate crop heights, 0.7 m (2.3 ft), and multiplied by 0.14. This 0.14 conversion factor is the AGDISP^{TM} canopy roughness conversion factor (Teske and Curbishley, 2011). Canopy roughness is defined as the effective roughness height of the canopy.[60] Canopy roughness is similar to surface roughness in that is derived from crop height. AGDISP^{TM} defines surface roughness as 1/30 crop height, distinct from the canopy roughness conversion factor.

There are some limitations with the use of this study as the basis for a proposed surface roughness parameter. This study only considers one crop, cotton, and field deposits and AGDISP^{TM} offsite deposition estimates are only considered fully comparable at two intermediate heights. The greater of the two heights was chosen as the basis of the canopy roughness calculation, leading to a less conservative surface roughness value as compared to if the 0.3 m crop height were selected. Additionally, the study authors do not comment on crop maturity. While this surface roughness parameter might be appropriate for a cotton plant during canopy development, this assumption cannot be extended to other crops because crop heights vastly vary during growth and at harvest, and so canopy displacement is also likely to vary. Calculation of canopy roughness is solely based on crop height, not considering canopy displacement.

Additional open literature supports that offsite deposition varies by crop. While canopy closure increases for cotton as it matures, this same pattern is not observed in all crops. A 2007 FOCUS report describes differences in drift between different crops and bare ground, indicating there is not a clear trend between having crop on field and less deposition (FOCUS, 2007). For example, unlike the difference in offsite deposition observed at different cotton canopy heights in the Hoffmann study, wheat crops were shown to have similar offsite deposition at different canopy heights (0.4 m and 0.8 m). There was greater offsite deposition when applications were made to wheat compared to bare ground. Hoffmann *et*

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[60] Teske, M. E., & Curbishley, T. B. 2011. *Continuum Dynamics, Inc. AGDISP Version 8.25 User Manual*. July 2011. Available at: https://www.epa.gov/pesticide-science-and-assessing-pesticide-risks/models-pesticide-risk-assessment#atmospheric.

al. demonstrated that canopy closure in cotton led to comparable drift to bare ground (Hoffmann et al., 2007). Considering this information, modeling with the proposed surface roughness value of 0.32 ft for applications to 0.4 m tall wheat crops would result in an underestimation of offsite deposition.

As mentioned above, the study submitted by NAAA used AGDISP™, not AgDRIFT®, to compare field deposits to deposition estimates. AgDRIFT® Tier III Aerial and AGDISP™ have different inputs for surface roughness. In AgDRIFT®, only a surface roughness parameter can be input into the agricultural model. However, in AGDISP™, inputs are dependent on whether the proposed application is to bare ground or a cropped field. Bare ground applications have a surface roughness parameter only, akin to AgDRIFT® Tier III Aerial. However, when there is crop on field, users are directed to enter crop height, canopy roughness, and canopy displacement parameters.

As AgDRIFT® is EPA's standard exposure model for estimating drift deposition, work was done exploring whether crop presence could be simulated in AgDRIFT® and accurately predict changes in deposition with changes in crop characteristics. The agricultural model in AgDRIFT® could not be used for simulating crops because surface roughness parameters can be altered but canopy characteristics are not an available input parameter; however, canopy characteristics can be simulated in AGDISP™. AGDISP™ was then used to compare predicted deposition from inputing the NAAA proposed surface roughness value as either surface roughness or canopy roughness. When a canopy is indicated on AGDISP™, canopy height, roughness, and displacement inputs are required, and the corresponding values used in the Hoffmann study were selected. However, the resulting deposition curves were not the same. These results indicate that surface roughness and canopy roughness cannot be assumed to be the same and accurately model offsite deposition.

The current AgDRIFT® Tier III Aerial model design does not allow entry of the canopy height and displacement parameters. Thus, the NAAA-proposed surface roughness parameter is not recommended for use in AgDRIFT at this time, as this comparison shows that the canopy roughness from a cropped plot is not equivalent to surface roughness of bare ground.

NAAA included a statement in their recommendations that the majority of aerial applications are made to a standing crop. There is not data readily available to evaluate this claim, but this assumption is reasonable however, applications to bare ground or to areas with emerging and/or little vegetation are also commonly made. Therefore, it is not assumed that vegetation will be present on the field for all applications in modeling.

Overall, the default surface roughness parameter is not being updated at this time. The NAAA suggested replacement value is only representative of cotton crops prior to maturity and cannot be readily extended to other crops. Additionally, the AgDRIFT® model only allows for modeling surface roughness and does not consider canopy density, which, at crop maturity, was shown by Hoffmann *et al.* to result in field deposition comparable to bare ground. Because each crop has different canopy growth, it is difficult to predict at which growing stages this replacement value could be applied to other crops, if at all. For application to crops with a dense canopy, using the proposed replacement value could result in an underestimation of offsite deposition with distance. Additionally, no reduction in offsite deposition was observed for applications to wheat.[61] Therefore, the canopy displacement cannot be incorporated into AgDRIFT® Tier III Aerial without further model development.

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[61] FOCUS. 2007. *Landscape and Mitigation Factors in Aquatic Risk Assessment. Volume 2. Detailed Technical Reviews. Report of the FOCUS Working Group on Landscape and Mitigation Factors in Ecological Risk Assessment*. EC Document Reference SANCO/10422/2005.