Draft Technical Support for Runoff, Erosion, and Spray Drift Mitigation Practices to Protect Non-Target Plants and Wildlife

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1 Abstract

The purpose of this document is to provide information for the mitigation practices EPA identified to date to reduce offsite transport of pesticides in spray drift, aqueous runoff (referred to as runoff), and erosion and to communicate to the public and stakeholders the efficacy of mitigation practices to protect non-target wildlife. It reflects literature reviews, models, and comments from the public[1] to identify potential mitigation practices. As additional information is developed and the science related to mitigation practices evolves, EPA expects to update this document. EPA developed this document to support the draft Herbicide Strategy and Vulnerable Species Pilot project; however, the materials in this document may be useful in understanding the efficacy of mitigation practices in general.

EPA summarizes spray drift mitigation practice recommendations in **Section 6**. EPA uses spray drift models (*e.g.,* AgDRIFT®) to predict deposition of pesticides with distance from the use site. Default modeling assumptions typically consider differences in application equipment, droplet size distributions, and release height. EPA may further refine these models by incorporating additional factors (*e.g.*, wind speed, humidity) that can influence drift.

One of the most common methods to reduce offsite exposure is use of a spray drift buffer (an area between the application and a habitat for listed species). Models can estimate drift exposure out to 2608 feet; however, only a very small fraction of applied would occur at this distance and it is not feasible for most farmers to include a 2608 spray drift buffer. Therefore, EPA used AgDRIFT® to determine a maximum buffer distance for aerial, ground boom, and airblast application equipment beyond which the reduction in exposure is small over a large distance. EPA recommends that these are the maximum buffers that would be recommended for a conventional pesticide. Based on a particular pesticide's application parameters and toxicity data, it may need a smaller buffer or may need the maximum buffer and additional items to reduce offsite exposure.

Often a spray drift buffer is the first item to consider when mitigating spray drift exposure, as it does not change the application method or rate. EPA recommends that spray drift buffers may be utilized to reduce exposure to pesticides in drift (USEPA, 2013). EPA considered options for applicators to reduce the buffer distances, and where EPA found that to be supported, included these in the document. The options for reducing buffers include the following:

- All Application Methods: reduced application rate, coarser droplets, downwind windbreak or hedgerow, high humidity
- Aerial Application: presence of a crop on the field at the time of application[2]
- Ground Boom: hooded sprayer

[1] Comments received on recent pesticide registration actions and in the Endangered Species Act (ESA) Workplan Update (USEPA, 2022b) were considered when developing the evaluation of mitigation practices.
[2] Off-site deposition may be reduced when applications are made when the crop is on the field at the time of application.

EPA evaluated open literature to identify mitigation options that can be used to reduce offsite transport via runoff and erosion in **Section 7**. EPA grouped options that are substantially similar in terms of practice and efficacy (*e.g.*, in-field vegetative filter strips (VFS) group includes alley cropping and strip cropping because these practices all involve in-field VFS). EPA then categorized the efficacy of mitigation practices as high, medium, and low. EPA summarized some field characteristics that are likely to result in lower offsite transport of pesticides as compared to other fields and subsequent exposure of non-target organisms. EPA also considered whether and where exemptions (*e.g.,* fields > 1000 feet from the protection area) from needing to adopt the runoff/erosion mitigation practices are appropriate.

2 Purpose of Document

The purpose of this document is to summarize the options for mitigation practices EPA included in the Herbicide Strategy, Vulnerable Species Pilot, or both related to runoff, erosion, and spray drift and to summarize an evaluation of the efficacy of those mitigation practices. These mitigation practices may be found necessary for inclusion on pesticide labeling to reduce exposure to non-target organisms. The Herbicide Strategy and Vulnerable Species Pilot project relied on information in this document to recommend mitigation practices to reduce exposure to federally listed threatened and endangered species. The mitigation practices described in this document may also be used to support other efforts where the efficacy of spray drift, runoff, and erosion mitigation practices are needed. This document builds upon mitigation options identified in the Federal Insecticide, Fungicide, Rodenticide Act (FIFRA) Interim Ecological Mitigation (IEM) and Other Proposed Language discussed in the *ESA Workplan Update: Nontarget Species Mitigation for Registration Review and Other FIFRA Actions* (USEPA, 2022b).[3]

Section 4 describes some considerations related to understanding mitigation options, and **Section 5** summarizes how habitat for listed species is defined for the purposes of general agricultural use patterns. In **Sections 6** and **7**, there is a discussion of spray drift and runoff/erosion mitigation practices.

3 Overview of Pesticide Fate and Transport Processes

Pesticides are directly applied to agricultural crops to prevent damage from pests such as insects, competing weeds, *etc*. Pesticides may move offsite via drift, aqueous runoff, runoff of sediment-bound residues (erosion), leaching into groundwater and groundwater movement into surface waters (Wagner *et al.*, 2006), wind erosion (Larney, Cessna*, et al.*, 1999; Larney, Leys*, et al.*, 1999), and volatilization.[4] Multiple factors interact to influence the fate and transport of pesticides. How these interact over space and time influences the degree of offsite movement of pesticides and the dominant transport properties, such that, one or two variables

[3] Public comments on the FIFRA IEM have been received and are under review.

[4] The scope of this document is limited to spray drift, aqueous runoff, and runoff of sediment-bound residues (erosion).

cannot be utilized alone to predict exposure. At one location, drift may be a dominant offsite transport pathway, at another transport in aqueous runoff (hereafter referred to as runoff) may be the important transport pathway, and at another location leaching may dominate. While the specific fate and transport pathways vary from site to site, general trends can be identified considering fate and transport across the landscape. EPA utilized these general trends to identify mitigation that reduces offsite movement of pesticides into adjacent areas via runoff and spray drift.

EPA evaluated the efficacy of mitigation practices to reduce offsite movement of pesticides via spray drift, runoff, and erosion, as these are dominant transport pathways for many pesticides (Belles et al., 2019; Commelin et al., 2022; Nahar et al., 2023; Reichenberger et al., 2007; Schönenberger et al., 2022; Sittig et al., 2020). Runoff and spray drift are influenced by factors related to the environment (*e.g.*, precipitation, wind, temperature, elevation, soil type, vegetation) and factors related to the pesticide (application parameters, physical-chemical properties of the pesticide, agronomic practices). Some of these factors can be controlled to reduce pesticide transport, while others cannot be influenced (*e.g.*, precipitation) but can inform decision making. When identifying practices to reduce offsite transport of pesticides (*i.e.*, mitigation practices), only those factors that can be controlled may be considered as options.[5]

Mitigation practices for volatility, wind-blown erosion, and leaching are not covered in this document but are addressed when appropriate for the chemical. Volatility is relevant to some volatile or semi-volatile pesticides (*e.g.*, dicamba and clomazone) and the mitigations needed for this pathway are specific to the pesticide. While wind-blown erosion is a relevant transport pathway, this exposure route is not currently considered in standard exposure models and the mitigation practices that will reduce runoff, erosion, and drift transport (*e.g.*, windbreaks), will also support soil retention on fields and reduce wind-blown erosion. Leaching is relevant for pesticides that are mobile and/or persistent and this pathway is considered when applicable for the pesticide.

4 Considerations Related to Mitigation Practices

Mitigation practices may be needed to reduce exposure to non-target organisms, both to meet the FIFRA standard and EPA's obligations under the Endangered Species Act (ESA). As part of the FIFRA standard for registering a pesticide, the applicant must show, among other things, that using the pesticide according to the specifications on the label "will not generally cause unreasonable adverse effects on the environment." FIFRA section 2(bb) defines "unreasonable adverse effects on the environment" as:

- Any unreasonable risk to man or the environment, taking into account the economic, social, and environmental costs and benefits of the use of any pesticide, or

[5] While the weather (precipitation and windspeed) cannot be controlled, the timing of applications can be moved to a time when the weather conditions will result in reduced offsite transport.

- A human dietary risk from residues that result from use of a pesticide in or on any food inconsistent with the standard under section 408 of the Federal Food, Drug, and Cosmetic Act.

When a proposed pesticide use pattern has a potential for unreasonable adverse effects on the environment, EPA may determine that certain mitigation practices are necessary to reduce exposure to non-target organisms to address these potential risks of concern.

Under section 7(a)(2) of the Endangered Species Act (ESA), EPA must ensure that any action authorized, funded, or carried out by the Agency (referred to as an "agency action") is not likely to jeopardize the continued existence of federally threatened and endangered (listed) species or destroy or adversely modify designated critical habitat. In fulfilling the requirements of ESA section 7(a)(2), EPA must use the best scientific and commercial data available. When appropriate for the agency action, EPA consults with the Fish and Wildlife Service (FWS) and the National Marine Fisheries Service (NMFS) (hereinafter the Services).

The Herbicide Strategy and/or Vulnerable Species Pilot focus on implementing early protections (before EPA has made effects determinations or completed any necessary consultation) for multiple types of registered pesticides (*e.g.,* insecticides, herbicides) to protect listed species. By incorporating early measures to avoid and minimize exposure, EPA expects to reduce the likelihood of future jeopardy or adverse modification determinations and to minimize potential take[6] for listed species from the ongoing use of registered conventional pesticides. When the mitigation practices are intended to reduce exposure for listed species, they should be consistent with the requirements of ESA related to reasonable and prudent alternatives[7] and reasonable and prudent measures.[8] EPA considered whether the proposed mitigation practices for reducing exposures to listed species would be (1) effective at reducing exposure; (2) economically and technologically feasible; and (3) consistent with the intended action. These considerations are consistent with the definition of reasonable and prudent alternatives in the Services' regulations. While EPA has considered similar factors to support development of mitigation practices for listed species, the Services are responsible for establishing RPAs during consultation on particular actions and have the sole authority to do so.

When applying the proposed mitigation practices to particular pesticides, EPA also expects to consider the impacts of the proposed mitigation practices on the efficacy of the pesticide to

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[6] Take means "to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or to attempt to engage in any such conduct." ESA § 3(19), 16 U.S.C. § 1532(19). Incidental take is a take "that result[s] from, but [is] not the purpose of, carrying out an otherwise lawful activity." *See* 50 C.F.R. § 402.02.

[7] Under 50 CFR § 402.02, reasonable and prudent alternatives (RPAs) are defined as "alternative actions identified during formal consultation that can be implemented in a manner consistent with the intended purpose of the action, that can be implemented consistent with the scope of the Federal agency's legal authority and jurisdiction, that is economically and technologically feasible, and that the Director believes would avoid the likelihood of jeopardizing the continued existence of listed species or resulting in the destruction or adverse modification of critical habitat."

[8] Under 50 CFR § 402.02, reasonable and prudent measures (RPMs) refer to "those actions the Director believes necessary or appropriate to minimize the impacts, *i.e.,* amount or extent, of incidental take."

control target pests (including weeds), the risk to other (non-target) organisms, and the pest pressure on the field. For example, EPA expects to consider whether a proposed mitigation practice that decreases a particular pesticide's efficacy below an efficacious level should be recommended as an option for that pesticide, because doing so could increase pest resistance to pesticides. Additionally, if the reduced rate per the proposed mitigation is not effective at treating the pest, the proposed mitigation essentially cancels the action. Other examples of pesticide efficacy considerations include, but are not limited to, whether watering in may be required to activate some pesticides but may reduce the efficacy of others and whether specific droplet sizes are needed to ensure adequate coverage to control a specific pest. Some contact pesticides require a finer droplet size distribution to ensure full contact with the pest. EPA expects to consider these pesticide efficacy factors when selecting appropriate mitigation practices for particular pesticides. Similarly, EPA expects to consider all potential risks of concern to non-target organisms when identifying appropriate mitigation practices because some mitigation practices may reduce offsite transport and risk to one group of non-target organisms but not another.

Areas where some mitigation practices are employed should not be treated with a pesticide. However, pesticide applications are sometimes required for proper maintenance of the mitigation practice. For example, vegetation is key to the effectiveness (or lack thereof) for a hedgerow, a riparian area, or vegetive filter strip. Registrants include information on labels to avoid damage to non-target organisms and sensitive nearby crops. Applicators should select herbicides used in the area to avoid damage to the vegetation in mitigation buffers and/or where the mitigation buffer is consistent with a registered use site.

Riparian areas, hedgerows, prairie strips, and other mitigation practices may provide habitat to non-target organisms (Wenger, 1999), which can increase the biodiversity in agricultural landscapes (Benton *et al.*, 2003; Kremen, 2020). These may both support wildlife and allow for exposure of wildlife to pesticides by encouraging them to reside in areas adjacent to a pesticide treated field. To understand the tradeoff between increased habitat and increased risk associated with exposure to pesticides, a landscape scale analysis may be considered (Dudley and Alexander, 2017; Grant *et al.*, 2022; Topping *et al.*, 2020; Uhl and Brühl, 2019). EPA acknowledges that some mitigation practices considered may also increase habitat for organisms that are considered pests to the crop under production.

EPA acknowledges that some mitigation practices considered may also take years to establish, and the practice would require alteration of the field. Many agricultural producers rent or lease the land that is farmed and may not be able to develop mitigation practices associated with changes to the land. This may reduce the number of mitigation options available to them. EPA sought to include many options for growers to lessen the impact of this potential issue.

This document recommends mitigation that will reduce offsite transport of pesticides and should be adequate to reduce effects to non-target organisms in most cases; however, additional mitigation may be needed on a case-by-case basis based on the risk assessment. If there is substantial accumulation of the pesticide from year to year in field studies and the pesticide may have toxic effects on organisms, EPA will consider whether additional mitigation is needed. It is possible that residues could build up in the field or buffer from year to year (Bhandari *et al.*, 2020; Riedo *et al.*, 2021; Silva *et al.*, 2019) and EPA will consider whether this is an issue for the pesticide under evaluation on a case-by-case basis.

EPA uses models primarily to calculate estimated environmental concentrations (EEC). Models can also be useful for evaluating the effectiveness of pesticide mitigation efforts. EPA uses a weight of evidence to determine whether a mitigation practice is appropriate for reducing offsite transport. Modeling is one line of evidence in that evaluation.

Although EPA uses several different models to calculate EECs, the models that are relevant to pesticide transport and hence mitigation evaluation are the Pesticide in Water Calculator (PWC) and AgDRIFT® . The PWC contains the erosion and runoff routines and AgDRIFT® contains the drift routine. These models have been vetted through various Federal Insecticide Fungicide Rodenticide Act (FIFRA) Scientific Advisory Panels and have been used to support pesticide risk assessments for decades (USEPA, 2023a). A general description of the PWC and EPA's conceptual model for surface water can be found in Young (2019). AgDRIFT® background is available in (Teske *et al.*, 2000; Teske, 2009; Teske *et al.*, 2002; USEPA, 1997).

5 Defining Habitats for Listed Species and Areas that Can Be Included in Buffer Distances and Setbacks

Spray drift and runoff/erosion mitigation practices to reduce pesticide exposure to non-target species often include a buffer between the pesticide application and an adjacent area where listed species may occur (*i.e.*, protected habitat for listed species). Listed species occur in almost all types of terrestrial and aquatic habitats; however, they are less likely to be located in managed areas (*e.g.*, agricultural fields, buildings, roads, mitigation practices, *etc*.). Therefore, EPA is including habitats for the purpose of mitigation for listed species as all areas within the species range or critical habitat except managed areas. A pesticide user may include managed areas in the buffer because listed species are less likely to be in these areas.

Area descriptions described in the proposed example label language below would be included on labels when either spray drift or runoff/erosion buffers are required. If the buffer needed for terrestrial protected habitat for listed species is greater than the buffer needed for aquatic protected habitat for listed species, it applies to both aquatic and terrestrial areas because the terrestrial area around the aquatic area would need a buffer. If only the aquatic habitat for listed species needs a buffer, the label can point to the aquatic habitat for listed species language only.

Crops that may be damaged by the herbicide application should be considered when identifying application areas. Generally, these crops are identified as sensitive crops on labels and restrictions for protection of these crops are already included on labels outside of the ESA analysis.

EPA defines a field for this purpose as the areas where the crop is grown (including fallow land). The buffer would begin where the application ends and therefore may be an in-field buffer, adjacent to the field, or a combination of both. The immediate area within 10 feet of the field is often a disturbed area that is managed and may be considered part of any buffer. **Figure 5-1** illustrates the terrestrial in-field buffer and an aquatic buffer where part of the buffer is in the field and part is not. In summary for spray drift, the buffer represents areas that are not directly treated with the pesticide. Terrestrial buffers for runoff and erosion need to meet the standards for that type of mitigation practice which often includes specific vegetation and vegetation maintenance. While buffers and some areas associated with mitigation or conservation practices may be attractive to species (as described in Definition Box 1), they are not considered protected habitat for listed species for general agricultural use patterns.

Definition Box 1.
A **buffer** is the area between a pesticide application and a protected habitat for listed species area.

A **protected habitat for listed species** is an area with characteristics consistent with listed species' habitats or that may provide habitat to non-target organisms. For the purposes of agricultural pesticides, areas that are managed (*e.g.*, agricultural fields, roads, *etc*.) are not considered a habitat for listed species for general agricultural use patterns.

The reason EPA assumes that areas associated with some mitigation practices (*e.g.*, riparian buffers, prairie strips) are considered part of buffers is to avoid disincentives for growers to provide such habitats, which may have considerable benefits to species. EPA is focused on mitigating exposure off of the treated field for agricultural use patterns. EPA will develop mitigation needed for the listed plants and animals that occur on the field in a separate effort.[9]

[9] Other areas not covered by the HS, will be considered in other strategies or during consultation with the Services on the pesticide.

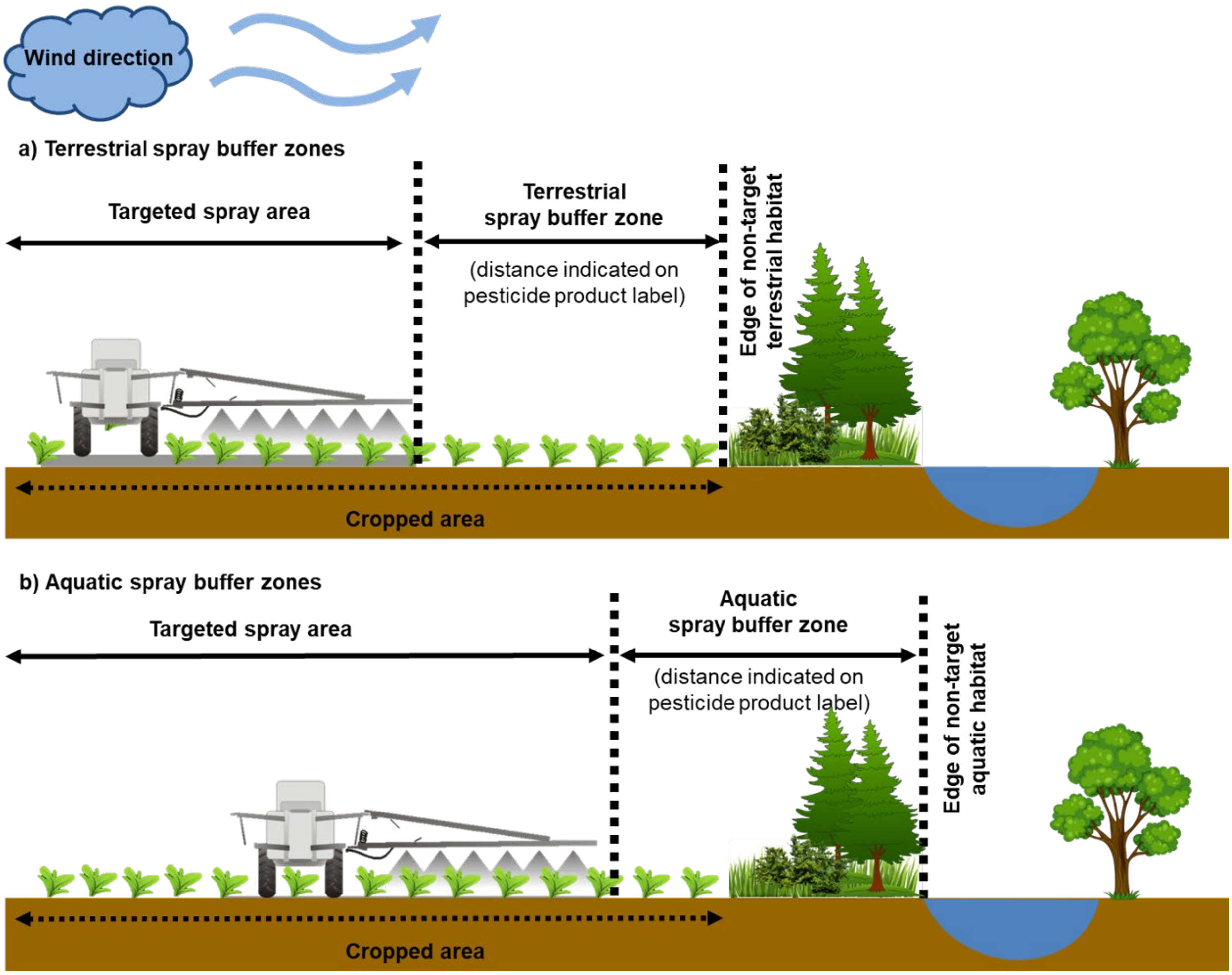

Figure 5-1. Diagram of the Field (Cropped Area) and Terrestrial and Aquatic Buffer Zones[10]
The buffer would begin where the application ends and therefore may be an in-field buffer, adjacent to the field, or a combination of both. The immediate area within 10 feet of the field is often a disturbed area that is managed and may be considered part of any buffer.

The Definition Box 1 provides a general definition of habitat for listed species. More specific definitions for terrestrial and aquatic habitat for listed species are provided below.

The reason EPA assumes that areas associated with some mitigation practices are considered part of buffers is to avoid disincentives for growers to provide such habitats, which may have considerable benefits to species. EPA is focused on mitigation exposure off of the treated field for agricultural use patterns. EPA will develop mitigation needed for the listed plants and animals that occur on the field in a separate effort.

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[10] Terrestrial and aquatic spray drift buffer zones diagram reproduced with permission from the Pest Management Regulatory Agency of Health Canada (2020). 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.

Protected terrestrial habitat for listed species includes any terrestrial area except the following managed areas, which can be included in a mitigation buffer when they are not treated with the pesticide:

a. Agricultural fields, including the treated field or adjacent fields;
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. Areas occupied by a building and its perimeter, silo, or other man-made structure with walls and/or roof;
d. Areas maintained for runoff or drift control, such as vegetative filter strips, field borders, hedgerows, and other areas on the mitigation menu; and
e. Conservation Reserve Program (CRP) and Agricultural Conservation Easement Program (ACEP) areas.[11] CRP and ACEP areas may provide habitat to listed species and movement of pesticides into these areas should be minimized.

Protected terrestrial habitat for listed species includes but is not limited to naturalized areas, parks, wildlife refuges, or wilderness areas and cannot be included in the buffer composition.

All of the habitat exceptions described above may be counted as part of a buffer between the treated field and adjacent habitat for listed species areas. While these areas are not considered protected habitat for listed species, vegetation in the buffer may be damaged by the use of herbicides in adjacent areas.

Protected aquatic habitat for listed species includes all aquatic areas except:

a. On-farm contained irrigation water resources that are not connected to adjacent waters, including on-farm irrigation canals and managed irrigation/runoff retention basins;
b. Vegetated ditches, drainage ditches; and
c. Managed wetlands including constructed wetlands on the farm.

Protected aquatic habitat for listed species includes but is not limited to lakes, reservoirs, rivers, permanent streams, wetlands or ponds, and estuaries.

EPA acknowledges that some listed species may occupy areas that are not listed species protected habitat for agricultural uses of pesticides. For example, the whorled sunflower (*Helianthus verticillatus)* is commonly found on agricultural fields (USFWS, 2023). In this

[11] The CRP is a land conservation program administered by the Farm Service Agency (FSA). In exchange for a yearly rental payment, farmers enrolled in the program agree to remove environmentally sensitive land from agricultural production and plant species that will improve environmental health and quality. Agricultural Conservation Easement Program (ACEP) supports long-term viability of productive farmland from being converted into non-agricultural areas.

situation, EPA and the Services will work to determine if additional mitigation practices are needed for particular species through the consultation process.

6 Spray Drift Mitigation Practices

Spray drift is one of the primary offsite transport pathways for pesticides (Reichenberger *et al.*, 2007). The extent of offsite spray drift transport that will occur is primarily dictated by wind speed and direction, droplet size, and application method in addition to application rate, atmospheric conditions, and any device or barrier that blocks spray droplets from moving offsite. Because spray drift is sometimes confused with volatilization, it should be clearly understood that the data from Spray Drift Task Force (the data underlying EPA's empirical models for estimating spray drift) are intended to address primary deposition which occurs immediately after application. Spray drift does not include movement that occurs after the first time the material lands on the ground followed by re-entering the air (*i.e.,* volatilization and possible deposition), which is often chemical specific, and which may occur over longer periods of time.

The sections below discuss considerations related to EPA's current thinking on how to determine the spray drift buffer distance needed to get to a target[12] concentration, as this is a common spray drift mitigation used with applicability across application methods and droplet spectra. EPA developed maximum buffer distances that provide incremental reductions of exposure associated with offsite deposition for each application method and droplet size distribution. These maximum buffer distances are less than the limit of the model (997 ft for ground boom and airblast applications or 2,608 ft for aerial applications). At the maximum buffer distance, additional spray drift mitigations are not proposed to be necessary if the exposure estimate and toxicity endpoint are within an order of magnitude of each other. Additionally, the sections below discuss alternative or additional mitigation options that can be employed to reduce maximum buffer distances. These include devices or barriers that block droplets from moving offsite (*i.e.*, windbreaks/hedgerows and hooded sprayers) and droplet size and weather conditions that minimize droplets from moving far offsite (*i.e.*, low wind speed, humid conditions, and large droplets). The sections below provide rationales for the current thinking, including references to EPA models, previous EPA work products, and open literature.

EPA's standard models[13] (AgDRIFT® and AGDISP™) are used to quantify and evaluate exposure to spray drift and allow for spray deposition estimates out to 997 ft (304 m) for ground boom and airblast, and out to 2,608 ft (795 m) for aerial applications; these are the limits of the model and may be less depending on model parameterization (Teske *et al.*, 2002). When evaluating exposure for terrestrial species, typically EPA models the deposition fraction to a

[12] The target exposure is based on the application rate, application parameters (application equipment, droplet size distribution, and release height), and the toxicity endpoints for the specific pesticide.
[13] Models for pesticide risk assessment are available at: https://www.epa.gov/pesticide-science-and-assessing-pesticide-risks/models-pesticide-risk-assessment.

specific point or distance away from the pesticide application site. EPA can also use AgDRIFT® to evaluate the amount of deposition to an area downwind from the field where individuals of a species may be located. When evaluating exposure from spray drift to a waterbody, EPA estimates the deposition over the entire surface area of the waterbody and instantaneous mixing with the volume of the water.

Section 6.1 summarizes EPA's standard spray drift modeling assumptions and the underlying data to estimate buffers. **Section 6.2** discusses the establishment of a maximum spray drift buffer distance. If the target exposure occurs at a distance less than the maximum buffer, a buffer can be set at a distance less than the maximum distance. Finally, **Section 6.3** presents options for reducing the buffer distance outside of the standard application considerations (*i.e.*, droplet size distribution, boom height, and application equipment).

6.1 Standard AgDRIFT® Modeling Assumptions

6.1.1 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 bare ground 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: low boom (20 inches) and high boom (50 inches) from the ground or crop canopy (Teske *et al.*, 2000). 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 then uses these two droplet size deposition curves in environmental exposure assessments 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 which correspond to 99.4% and 98.9% application efficiency, respectively. Application efficiency is how much of the pesticide is deposited on field, which is also an indication of how much spray material is available to drift offsite. Use of the 50th percentile subset provides a central estimate of deposition and the 90th percentile provides a high-end estimate of deposition (lower application efficiency yields a higher amount of pesticide available for drift). EPA relies on the 90th percentile exposure estimate as a baseline approach so as to err on the side of protection when it knows that variability in exposures are expected consistent (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 conditions in many parts of the lower 48 states or at many times of day are also not well represented by SDTF data and that conditions less prone to drift are likely in these cases. When available data and supplemental modeling capabilities demonstrate that application or field conditions substantially differ from those represented the 90th percentile deposition curves, spray drift buffer reductions may be considered (further details on buffer reductions are in **Section 6.3**).

6.1.2 Aerial Spray Modeling

EPA utilizes AgDRIFT® and AGDISP™ to model aerial spray. 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 American Society of Agricultural and Biological Engineers (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 a reasonable but high-end estimate of 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 I aerial spray drift modeling results[14] are used as a high-end estimate of spray drift deposition and a baseline approach to determine drift distances that may result in exposure where effects could be observed. 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. For similar reasons, EPA also used the Tier I ground deposition data to estimate exposure and the potential for effects. 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 some advances in aerial application technology. EPA continues to consider those

[14] 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.

comments and may update its input parameters and spray drift modeling prior to implementing spray drift buffers calculated using AgDRIFT® described in this document.

6.1.3 Airblast Spray Modeling

For the current effort, to model airblast spray, EPA utilized the default airblast application parameterization (sparse canopy) in AgDRIFT®. 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 so, to err on the side of protection and when variability in exposures are expected, consistent with EPA exposure assessment guidelines, EPA based this analysis on the default sparse parameterization (USEPA, 1992; USEPA, 2019).

6.1.4 Uncertainties in the Spray Drift Analysis

Increasing crop canopy coverage and vertical vegetation density in grasslands (an important habitat for listed plants proximate to agriculture) have been shown to reduce the extent of spray drift exposure (Goebel *et al.*, 2022). 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 receive a higher deposition than estimated by EPA's models. Listed 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.

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. Default 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[15], 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[16], 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 require 10 flight lines with a 60 ft wide swath (illustrated below in **Figure 6-1**).

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[15] 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.

[16] 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).

With variability in field size established, a field size sensitivity analysis can be conducted to determine field size impact on off-site 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, the difference in point deposition between a 100-foot buffer and a 125-foot buffer for Aerial Medium/Coarse droplets is 1.5% of the application rate. The impact of halving the number of swaths via ground application is similar in that the deposition reduction is small in comparison to the impact of a 25 ft buffer difference. 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; however, the difference in deposition is not large enough to change recommendations for buffer distances because deposition changes in 25 ft buffer increments are larger than deposition changes from field size.

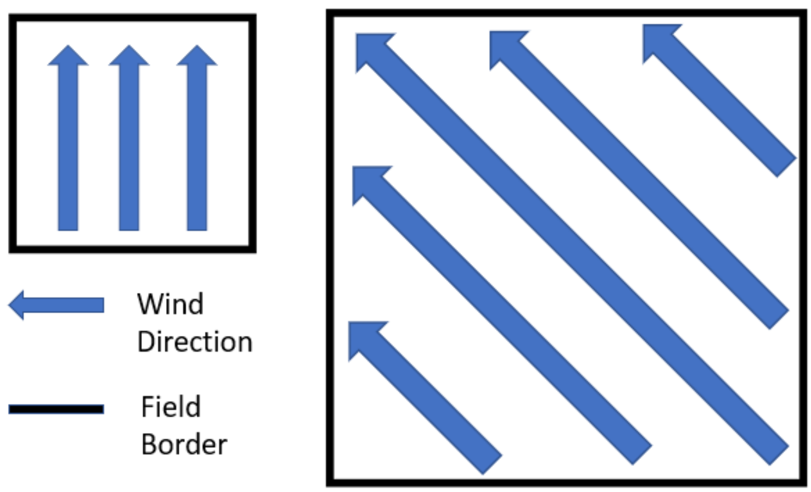

Figure 6-1. Field Size and Wind Direction Scale Comparison for an 8-Acre Field with Parallel Wind (left) and a 32-Acre Field with Wind at 45 Degrees from Parallel (right).

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 (on a sub-field scale) 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 6-1** 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 recommended based on wind orientation to field shape.

Studies evaluating offsite movement that measure wind speed and direction are summarized in previous assessments and speak to field variability associated with these two factors (USEPA, 2020). Though analyses of wind direction over the 21- to 28-day study periods indicate that 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 wind speeds (*e.g.*, <5 mph). However, most studies report a single prevailing wind direction over the course of an application. Though it is acknowledged that wind direction can change over the course of an application, it is expected that wind speeds in these instances are low and are not conditions prone to spray drift. Downwind spray drift buffers should still be maintained in low wind conditions to account for the potential for wind speed increases in the prevailing wind direction (*i.e.*, wind gusts) but spray drift buffers are not necessary in upwind directions.

6.1.5 Assumptions for Estimating Exposure to Drift for Terrestrial and Aquatic Organisms

Potential impacts to adjacent non-target areas may be evaluated based on terrestrial exposure and toxicity or aquatic exposure and toxicity. For terrestrial exposure, a distance is estimated to a point away from the field where exposure will be less than the toxicity threshold. For aquatic exposure, deposition over the surface area of the waterbody used in the conceptual model is instantaneously equilibrated with sediment according to the pesticide's adsorption properties and the resulting water column concentration is as an EEC. Buffer distances for either terrestrial or aquatic organisms can be developed.

6.2 Determination of Maximum Buffer Distance and Off-Sets

When considering mitigations to reduce the off-field transport of spray drift below a target exposure[17], EPA considered whether the proposed mitigation practices for reducing exposures to listed species would be (1) effective at reducing exposure; (2) economically and technologically feasible; and (3) consistent with the intended action. These considerations are consistent with the definition of reasonable and prudent alternatives in the Services' regulations. While EPA has considered similar factors to support development of mitigation practices for listed species, the Services are responsible for establishing RPAs during consultation on particular actions and have the sole authority to do so.

Among other considerations, the establishment of a spray drift buffer must consider whether or not the distance is reasonable for applicators. There are several key factors that EPA and FWS consider when determining a reasonable range of a spray drift buffers, including: field size, application method, release height, and droplet size requirements. One of the major factors is the potential impact at the field level, including when spray buffers take part of the field/orchard out of production or when growers cannot treat a portion of the field/orchard in the same manner as the rest of the field/orchard. This can impact the profitability of the crop

[17] EPA defined the target concentration by the toxicity and level of concern relevant to the ecological risk evaluated. This varies by the types of assessment and level of refinement in the assessment.

(*e.g.*, reduced yield), limit the crops that a grower may be able to plant, and/or result in portions of the field receiving less pesticide treatment and the potential of developing resistance among pests.

Increases in the buffer distance could impact farmers substantially, thus resulting in conservation practices that are not reasonable or prudent in reducing exposures to below a target level. For these instances where pesticide effects on listed species cannot be practically avoided or minimized, EPA proposes considering opportunities to offset the residual effects through habitat restoration and other conservation actions. Doing so can provide greater flexibility for pesticide users and directly further species recovery, especially in response to climate change. Therefore, consistent with prior work supporting Biological Opinions (USEPA 2022a, 2022b), EPA evaluated the drift curves to determine where an exposure reduction is substantial relative to an increase in buffer distance.

6.2.1 Characterization of drift with distance

While AgDRIFT® ground and aerial modules can produce estimates of drift out to 997 ft and 2,608 ft, respectively, the models were developed based on several underlying assumptions, including drift depositing to a bare field, no obstructions to intercept spray droplets that drift off field, and a prevailing wind direction. Given these baseline assumptions, EPA is considering additional lines of evidence with regard to the exposure assumptions, such as interception by plants or structures, wind direction, and how these relate to general reductions in deposition when compared to modeled deposition.

Both the amount of deposition and the rate at which the deposition decreases at greater distances from the edge of the application site. At given distances described below, the change in deposition between buffer increments is small over a large distance and the efficacy of buffers as drift reduction practices 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 the amount of deposition between 200 and 700 ft, the amount of change after 200 ft is less than 0.2% of the amount applied. Although the fraction of applied pesticide is smaller at greater distances, the EECs may still exceed toxicity endpoints where effects are predicted to occur. Additionally, larger particles tend to fall out closer to the field and smaller, finer droplets may travel farther from the application.

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, and as such the likelihood that the model may result in an over-estimation of exposure increases with distance, particularly when obstructions (*e.g.,* vegetation, building) may be present which impede the movement of droplets far afield from the application site. However, for near field deposition close to an application site, in many agricultural areas there are multiple fields with minimal vegetation on the field near planting and emergence. The SDTF position on use of bare ground and low-cut grass canopies has been that it provides a conservative scenario for measuring spray drift and it was not practical to field test a large range of terrain and canopy types (USEPA, 1997). 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. AgDRIFT® assumptions are used to assess exposure in many agriculture 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.

6.2.2 Identifying the Maximum Spray Drift Buffer Distance for Each Deposition Curve

EPA's experience with setting drift buffers indicates that there is a need to identify near-field buffers in increments that are measurable yet far enough apart to be distinguishable. EPA sets the maximum buffer at a distance beyond which exposure does not substantially change. For instances where the distance to an individual effect is within the maximum buffer, toxicity data dictates the buffer distance and any further consideration of a maximum buffer would not be relevant. EPA calculates and considers the maximum buffer distances for mitigation purposes and not for the distance to where an effect may occur. The main reasons for determining a maximum buffer distance include 1) the efficacy of the buffer in reducing exposure decreases with distance, such that a large change in distance has a small change in the fraction of applied at distances far off-site, 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. **Figure 6-2** below depicts one 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. EPA proposes maximum buffer distances be established at distances on each deposition curve where deposition begins to decline more slowly. While the maximum buffer distances set practical exposure reduction limits, potential effects may still be predicted at greater distances and the risk estimates of potential effects are still evaluated using the full deposition curves and standard recommended procedures (USEPA, 2013).

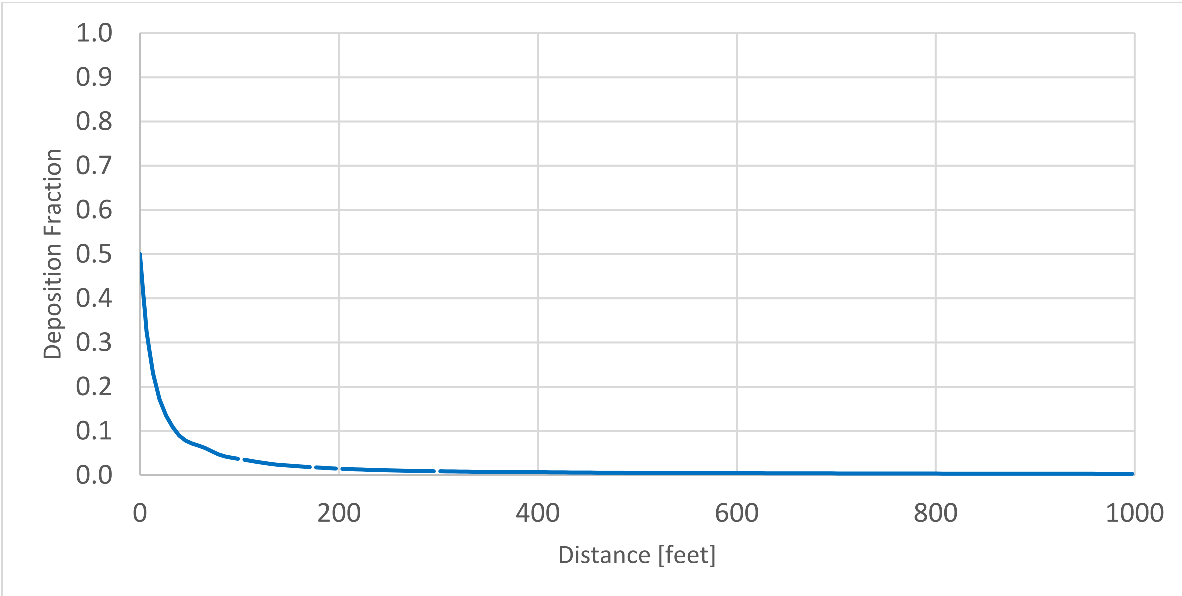

Figure 6-2. Fraction of Applied Pesticide with Distance for Aerial Application with Coarse to Very Coarse Droplets with AgDRIFT® Tier I Aerial Module.

Establishing the maximum buffer distance requires the selection of a distance within which the rate of decline of the spray drift deposition curves can be evaluated. Two approaches, one simple and one more complex, are summarized below and a more detailed analysis can be found in **Appendix E.** The simple approach involves 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 recommended maximum is 100 ft. The more complex approach involves setting maximum spray drift buffer distances where the predicted fraction of deposition declines by <0.5% over 25 ft increments when compared to deposition 5 ft from the field edge. The intent of this more complex approach is to analyze maximum spray drift buffer distances with increments relevant for establishing spray drift buffers (*i.e.*, 25 ft), but the added complexity needed to produce meaningful maximums (*i.e.*, a 5-foot offsite baseline and 0.5% increment) is difficult to justify with available data (see **Appendix E**). Given this, EPA recommends setting maximum buffers based on the simple method (<1% deposition difference over 100 ft). See **Table 6-1** below for a summary of maximum spray drift buffer distances associated with each Tier I deposition curve and **Figure 6-3** for where recommended maximum buffers occur on exponential deposition curves. Note that the y-axis is plotted on an exponential scale in **Figure 6-3** to more clearly show the deposition differences and decline associated with each curve.

Table 6-1. EPA's proposed maximum drift buffer distances established for aerial, ground and airblast applications for agricultural herbicides.

Type of Application	Application Parameters Assumed in Tier 1 AgDRIFT® Modeling	Maximum Buffer Distance in Feet	
		Recommended Method: <1% change over 100 ft	Ancillary Method: <0.5% change over 25 ft Method
Aerial Application	Very fine to fine DSD	500	575
	Fine to medium DSD	300	325
	Medium to coarse DSD	300	275
	Coarse to very coarse DSD	200	225
Ground Boom Application	Very fine to fine DSD; high boom	200	175
	Very fine to fine DSD; low boom	100	175
	Fine to medium-coarse; high boom	100	175
	Fine to medium-coarse; low boom	100	175
Airblast	Sparse	100	150

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

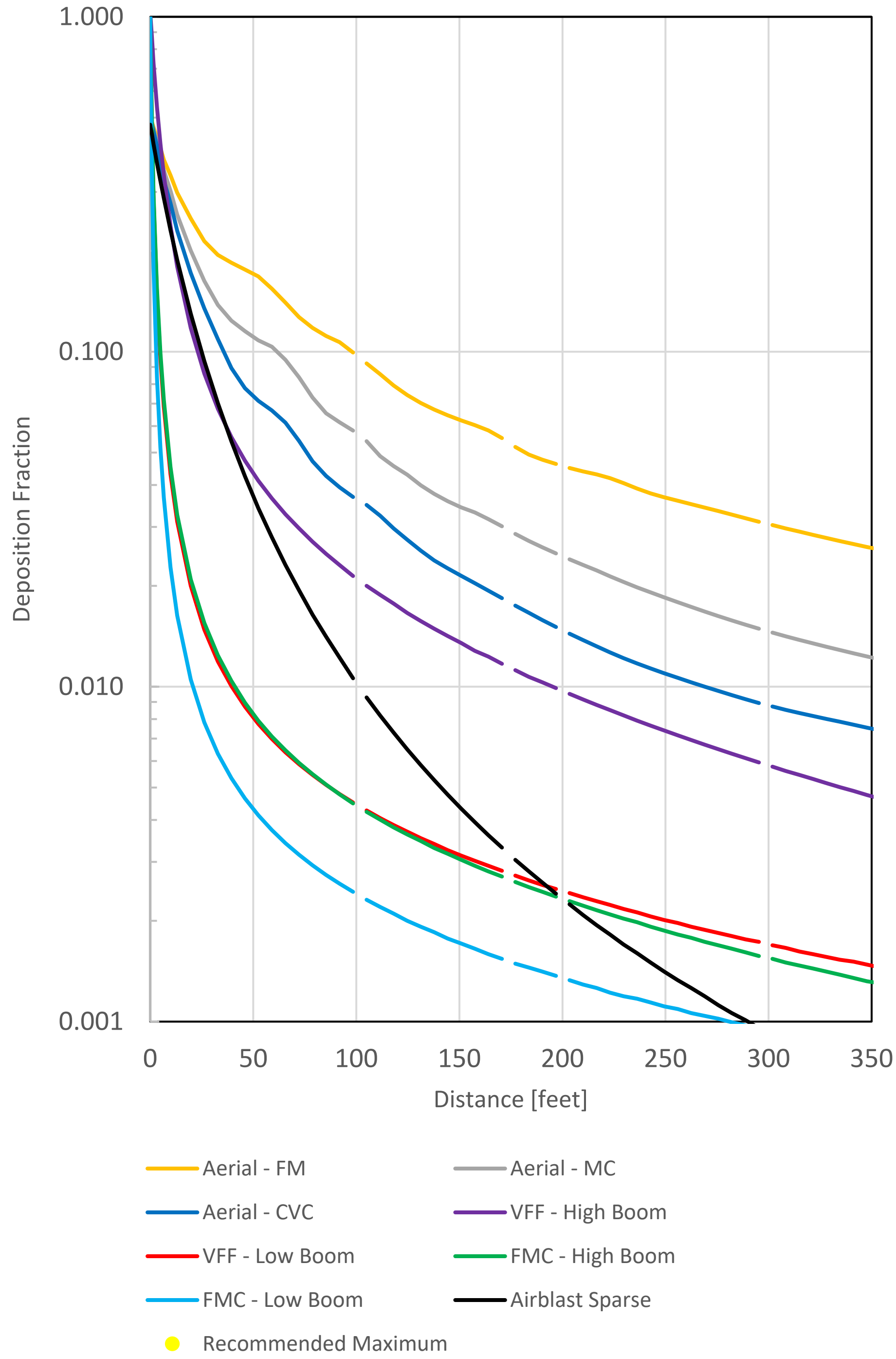

Figure 6-3. Exponential Fraction of Applied Pesticide with Distance for Aerial, Ground and Airblast Applications with Different Droplet Size Distributions based on AgDRIFT® Tier I Modules.

6.3 Options to Reduce Buffer Distances and Efficacy Data

If AgDRIFT® spray drift deposition estimates indicate there is need to reduce exposure relative to the target exposure, mitigation to reduce spray drift in addition to the maximum buffer may be needed. These additional mitigations may also be an option to reduce the maximum buffer size. EPA also considered mitigation practices that may reduce drift exposure but do not translate to recommended mitigations at this time because the impact is not substantial enough to change a spray drift buffer by ≥25 ft . These mitigations and associated options are summarized in **Table 6-2** below and detailed in the following section.

Table 6-2. Summary of proposed spray drift mitigation options

Mitigation Consideration	Application Type		
	Aerial	Ground	Airblast
Downwind Windbreak/Hedgerow	Buffer reduced by 50%	Buffer reduced by 50%	Buffer reduced by 50%
Hooded Sprayer	N/C	Buffer reduced by 50%	N/C
App. Rate Reduction	Dictated by App. Rate	Dictated by App. Rate	Dictated by App. Rate
Temperature	N/A	N/A	N/C
Relative Humidity	25 ft buffer reduction at ≥250 ft with RH >70%*	25 ft buffer reduction at ≥100 ft with RH >60%**	N/C
Change from Fine to Coarse DSD	Buffer derived from available deposition curves	25 ft buffer reduction at ≥75 ft**	N/R
Crop on Field	25 ft buffer reduction at ≥200 ft*	N/A	N/R
Windspeed: 3 to 7 mph	25 ft buffer reduction at 75-175 ft	N/A	N/A

N/A – Not applicable currently because impact is not substantial enough to change spray drift buffer by ≥25 ft; N/C – Not considered in the current effort; N/R – Not relevant; App. – application; mph – miles per hour
*≥275 ft if aerial humidity reduction and crop on field reduction are used together
**≥125 ft if ground humidity reduction and coarse reduction are used together

6.3.1 Accounting for Hedgerow/Windbreak

Data in the open literature show that hedgerows 7 to 8 m (22 to 25 ft) tall result in spray drift reduction of 73% to 98% at wind speeds up to 2.5 miles per hour for ground applications (Lazzaro *et al.*, 2008). De Schampheleire *et al.* (2009) also found reduction in deposition with windbreaks especially when drift reducing structures are at least equal to the height of the spray nozzles. Artificial screens with 36% and 63% open area were tested as drift reducing structures in addition to artificial Christmas trees. When nozzles were 25 cm (10 in.) lower than the height of the windbreaks, deposition was reduced 30 to 70% over a range of conditions at 6 m (20 ft) downwind from release. When nozzles were 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 release. When nozzles were equal to the height of the spray nozzles, deposition was reduced 20 to 50% over a range of conditions at 6 m (20 ft) downwind from release. Finally, Hancock *et al*. (Hancock *et al.*, 2019) studied pesticide deposition to streams and ditches and found a deposition to be 96.1% lower at vegetated sites compared with non-vegetated sites. Vegetated sites had a mean vegetation height and width of 6.6 m (22 ft).

> **Wind directional buffers** can be maintained at half the distance required when windbreaks (*e.g.,* trees or riparian hedgerows) are between the application site and protected habitat for listed species. The windbreak would need to have a row of broad-leaved trees the full length of the treated crop with leaves visible over the entire length, with no significant gaps. The height of the trees or windbreak would need to be at a height greater than the crop to be sprayed.

Due to limited amount of data and likelihood that newly established hedgerows will be less than 7 m (22 ft) tall, EPA assumes a 50% reduction in spray drift when growers utilize a hedgerow or windbreak taller than the spray nozzle release height. This reduction in deposition is consistent with what international regulatory bodies have recommended [*i.e.*, using a 25% reduction for bare trees, a 50% reduction for most trees, and a 90% reduction for full leaf stage (FOCUS, 2007)]. It is also consistent with recent FIFRA decisions that assume a 40% to 50% reduction in deposition with a windbreak (USEPA, 2022b). A 50% reduction will underestimate the effectiveness of hedgerows in the conditions present in Lazzaro et al. 2008, especially for hedgerows with dense vegetation. However, the range of wind speeds evaluated in the study (up to 2.5 mph) does not substantially overlap with the range expected for most pesticide applications (2 to 15 mph). Therefore, a conservative assumption of the effectiveness (*i.e.,* 50%) of the mitigation option is warranted.

6.3.2 Accounting for Hooded Sprayers

For ground applications, Foster *et al.* (2018) shows a 50% reduction in spray drift for application of fine to medium droplet sizes up to 30 m offsite when hooded sprayers are used. 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 (Foster *et al.*, 2018). These reductions were measured considering windspeeds of 5 to 11 mph, which is within the range expected for most pesticide applications. Accordingly, EPA assumed a 50% reduction in deposition when hooded sprayers with demonstrated spray drift reduction are used for ground applications. This 50% reduction is consistent with prior EPA assessment conclusions which allowed for an effects distance reduction from 240 feet to 110 feet (73 to 34 m) when hooded sprayers are utilized (USEPA,

> **Hooded sprayers** are a drift reducing technology that physically blocks driftable droplets at or near the spray nozzle

2020b). For airblast applications, some drift reduction can likely be demonstrated with use of hooded sprayers but that has not yet been quantified (Otto *et al.*, 2015).

6.3.3 Accounting for Application Rate Reduction

For changes in application rate <25%, required buffer distance will change by approximately the same proportion. That is, a 25% reduction in rate results in an 18 to 32% reduction in the needed buffer distance for buffer sizes between 75 and 200 ft. Additionally, a 50% reduction in application rate results in a 41 to 59% reduction in the needed buffer distance for buffer sizes between 100 and 200 ft.

Overall, the relationship between application rate and buffer size varies based on spray drift deposition curves (*i.e.,* application method and droplet size distribution). However, the relationship between application rate and buffer size is not linear and buffer size differences are more sensitive to application rate reductions as buffer sizes increase and the slope of the deposition curve decreases. To understand specific buffer reductions associated with specific application rate reductions, the Tier I modules within AgDRIFT®[18] are generally recommended.

6.3.4 Accounting for Temperature at Application Site

Temperatures in the SDTF data (see **Table 6-3**) are an average of 74 degrees Fahrenheit (°F) and are broadly representative of average high temperatures across the lower 48 states during a high herbicide usage season (*i.e.,* March to May; see **Figure 6-4**).

Table 6-3. 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%

[18] Access the regulatory version of AgDRIFT® at the following link: https://www.epa.gov/pesticide-science-and-assessing-pesticide-risks/models-pesticide-risk-assessment#atmospheric.

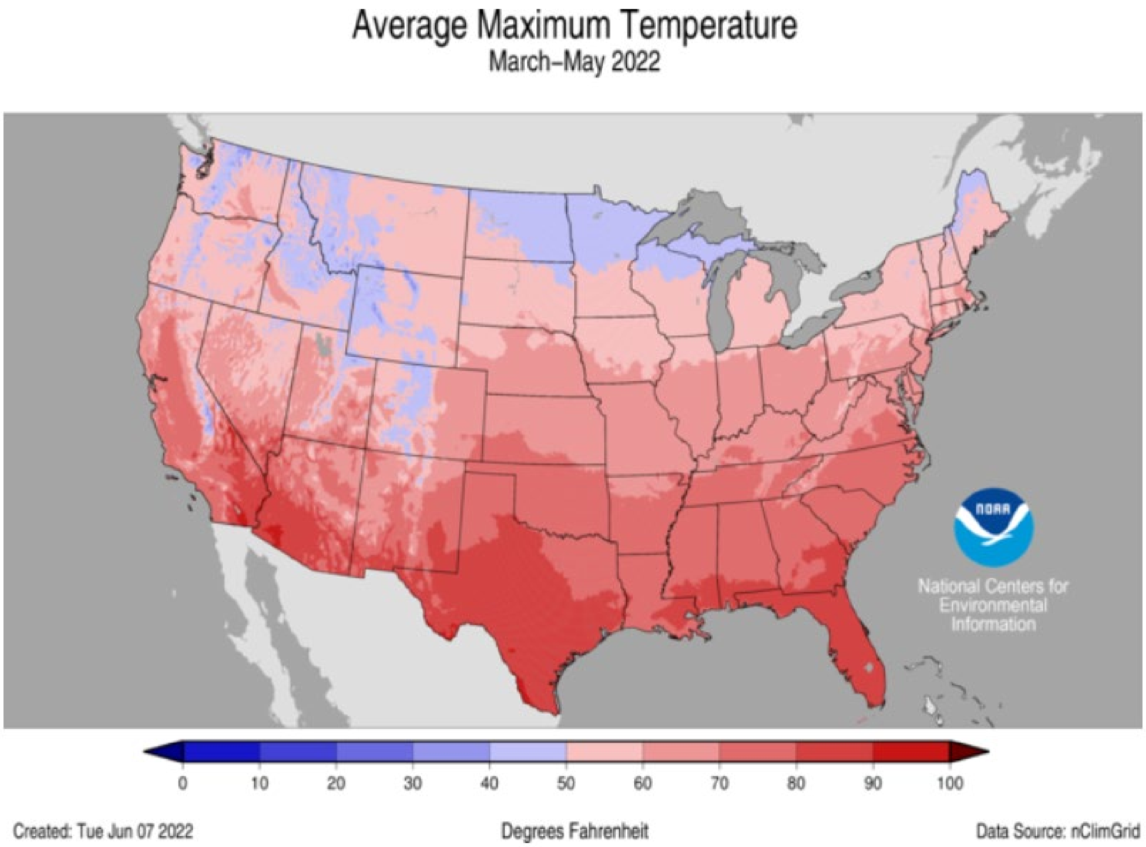

Figure 6-4. Average daily high temperature - March 2022 to May 2022 (NOAA, 2023)

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 (see Tier I aerial parameterization is 86 ^{o}F and 50% RH). This small difference in deposition given a 30^{o} change in the air temperature indicates that temperature (while holding RH constant) is not a sensitive parameter in the model. Given the underlying temperature data associated with spray drift modeling are representative of temperatures across the lower 48 states, and given that the model is not sensitive to temperature, mitigating spray drift based on temperature distinctions is not a recommended path forward at this time. However, temperature has indirect impacts on 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). In summary, temperature is not a sensitive parameter for spray drift modeling, and therefore not directly applicable for spray drift buffer reduction at this time, though there are circumstances where temperature may impact spray drift exposure.

Table 6-4. Aerial deposition differences with temperature for the medium droplet size distribution (AgDRIFT® v2.1.1)

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

6.3.5 Accounting for Humidity at Application Site

Humidity varies across the lower 48 states with regional, seasonal, and daily variation. The variation can be broadly summarized by region or season but should be done so with caution as daily (and sub-daily) variation is substantial. **Figure 6-5** depicts daily and seasonal variation in relative humidity across multiple regions.

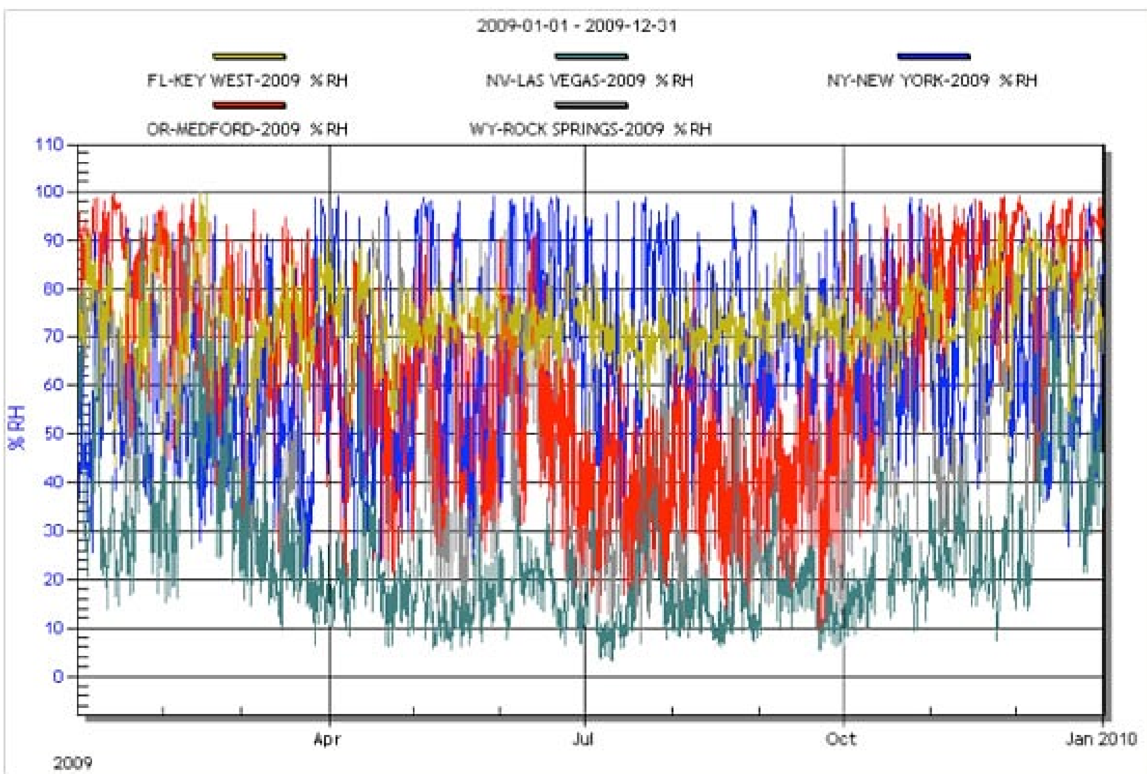

Figure 6-5. Full year of relative humidity data from five regions in the United States[19]

Relative humidity (RH) is a measure of moisture in the air that is relative to ambient air temperature. The impact of temperature as an independent factor affecting drift is discussed in

[19] Figure from Image Permanence Institute, reproduced with permission (Rochester Institute of Technology (RIT), 2023).

Section 6.3.4, while the impact of RH as an independent factor affecting drift is discussed in the following section. Relative humidity is a site characteristic that is generally understood to impact spray drift because lower RH increases the evaporation rate of spray droplets (Sezen and Gungor, 2023). Furthermore, droplet evaporation is a time-dependent process meaning the impact of RH is higher with longer droplet settling times (*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). Another resource cites RH <40% as having high potential drift and RH >80% as low drift potential (Agriculture Victoria, 2022). 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 (1.44 s) as the same droplets in 50% RH (3.01 s) while droplets at 70% RH only lose 66% of mass over 4.74 s.

SDTF data were predominately collected in low humidity conditions that are representative of large agricultural areas in the lower 48 states. The first study conducted during July in the Texas panhandle was selected to collect data in a hot, dry climate with relatively high winds. A cool-season study was conducted at the same site in April. The third series of trials, selected 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 the Spray Drift Task Force trials conducted primarily in a semi-arid climate was 43% and 3 of 24 trials with RH<10%. For context, the default RH associated with aerial modeling in AgDRIFT® is 50%. 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 (see **Table 6-5**). When considering the monthly data below, it is important to also consider the data in **Figure 6-5**above which indicate that monthly averages do not capture the full range of RH values and areas that are generally not arid (*e.g.*, New York) can experience RH <25% while arid areas can experience RH <10% (*e.g.*, Las Vegas).

Table 6-5. Range of relative humidity values from ground boom trials conducted in Texas, 1992-1993 (Teske, 2009) compared to National Relative Humidity Data (NOAA NCEI, Comparative Climatic Data)

Relative Humidity (RH)	Percent of Trials in RH category[1]	Afternoon – Monthly Averages across U.S.[2]	Morning – Monthly Averages across U.S.[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

Though many other site-specific conditions impact offsite deposition (*e.g.,* wind speed, temperature, atmospheric stability), RH has increasing impact at increasing offsite distances and is a more sensitive parameter than temperature (as will be demonstrated below). However, available field data do not directly demonstrate the impact of RH because the impact of RH increasing with distance offsite is complicated by other uncontrolled variables (*e.g.*, atmospheric conditions, variable wind speed and direction, *etc.*). Though the impact of RH on ground applications cannot be directly quantified, the mechanistic modeling capabilities in AgDRIFT® allow for a RH sensitivity analysis for aerial applications. To conduct the sensitivity analyses, EPA selected a RH of 20% to be representative of conditions relevant to the 90th percentile deposition curves considering the underlying data have RH <25% in 5 of 24 trials and RH <10% in 3 of 24 trials. See **Figure 6-6** below for a comparison of offsite deposition from a 20% RH to an RH that is broadly representative of conditions across the lower 48 states (60%).

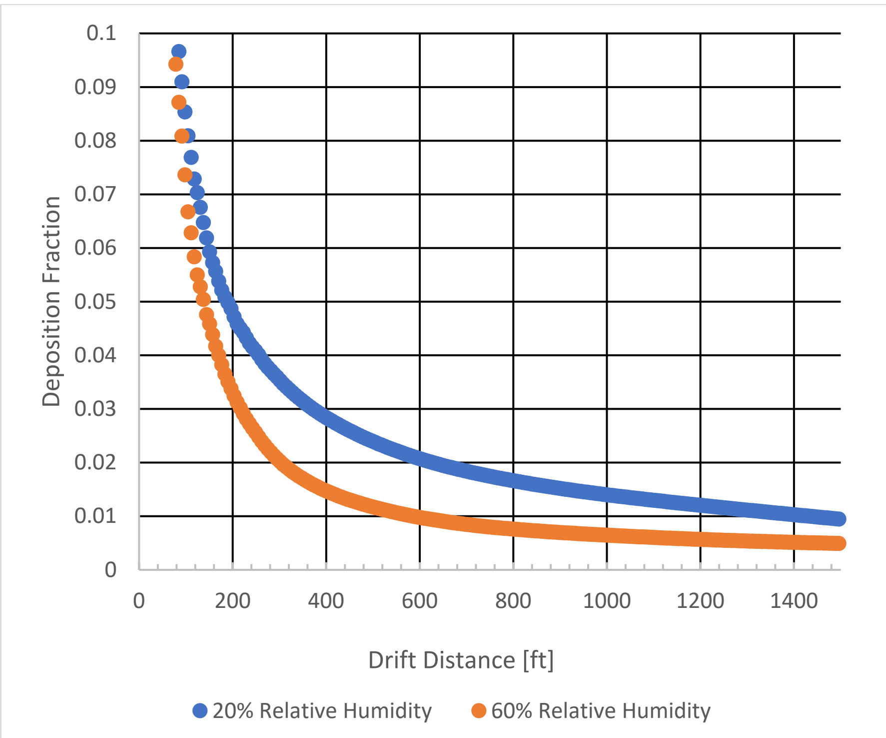

Figure 6-6. Variable relative humidity assumptions with medium droplet size distribution for aerial applications (AgDRIFT® v2.1.1).

Though changes in RH can be modeled for aerial applications and can help inform changes in RH for ground applications, there are caveats associated with applying model results in this way. Spray drift deposition of aerial and ground applications cannot be directly compared, especially in the near field and with finer droplets, as air turbulence created by the airplane (*i.e.,* wingtip vortices) impact deposition (Teske *et al.,* 2003). However, wingtip vortices dissipate with distance from the application site and wingtip vortices have less impact on larger droplets. **Figure 6-7** depicts the trajectories of droplets with the highest spray volume associated with the median droplets from medium (320 µm), and coarse droplet size distribution (DSD) (500 µm). This figure shows concentrated deposition at 15 to 20 ft (4.6 to 6.1 m) offsite associated with wingtip vortices but the coarser droplets are much less influenced by the wingtip vortices at points beyond this initial concentrated deposition than the medium droplets. It should be noted that a coarse DSD includes a range of droplet sizes with 2% of the spray volume being the median droplets from very fine (100 µm) or finer and 8% of the spray volume being between fine (175 µm) and very fine.

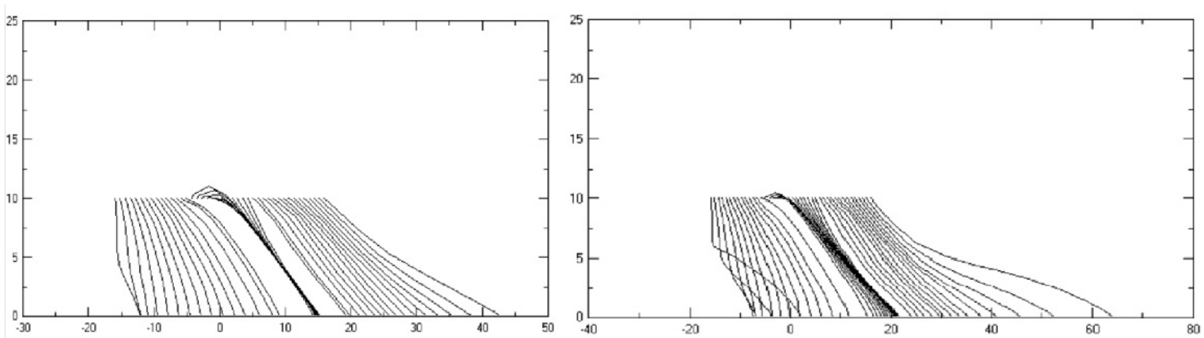

Figure 6-7. Trajectory details associated with highest spray volume droplets for coarse (left) and medium (right) median droplet sizes (AgDISP™ v8.26)

Given this, EPA conducted a humidity sensitivity analysis with AGDISP™ with coarse droplets and results are most relevant at farther distances offsite. EPA held AGDISP™ parameters constant aside from changing RH from 60% to 20% to approximate the difference between typical conditions across the lower 48 states and the conditions represented by the 90th percentile of SDTF ground trials. EPA estimated equivalent point deposition at 105 ft (20% RH) and 59 ft (60% RH) resulting in a 46 ft (14 m) difference associated with differing humidity conditions. Buffer distances closer to the field result in smaller deposition differences between different humidity conditions but interpreting results may be confounded by the effects of wingtip vortices. Given this, a buffer reduction of approximately 60 ft (18 m) at buffer distances >100 ft (>30 m) is demonstrated for aerial applications and may have implications for ground buffer reductions as well. Though there is uncertainty associated with wingtip vortices on applying aerial modeling to ground applications, no deposition difference is observed between medium and coarse DSDs at 175 ft (53 m) offsite.

Another uncertainty is higher release heights of aerial application allowing greater time for droplet evaporation to occur. A 10 ft release height is the maximum recommended release height for aerial applications on current pesticide labels, however, changes are made to address model sensitivity as it relates to application methods with lower release heights (*i.e.*, ground applications). EPA estimated equivalent point deposition at 177 ft (54 m) at 20% RH and 105 ft (32 mg) at 60% RH resulting in a 62 ft (19 m) difference associated with differing humidity conditions with a 10 ft release height. The same 62 ft difference is found at a 30 ft release height. Differences were more pronounced with a lower release height of 7.55 ft (2.3 m; AgDISP™ lower limit) with equivalent point depositions at 200 ft (61 m) at 20% RH and 105 ft (32 m) at 60% RH, indicating that interaction between the ground and wingtip vortices have relatively higher impact on deposition than the additional evaporation time for larger droplets afforded by the higher release height.

Given the uncertainties stated above, the 60 ft (18 m) difference is not taken at face value for ground applications and a 25 ft (7.6 m) buffer reduction for ground buffers greater than or equal to 100 ft (30 m) is considered for uses where RH is 60% or greater at the time of application. As demonstrated in **Table 6-5**, large parts of the country are expected to have RH >60% in the morning but 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. EPA proposes that applicators measure and record RH (>60%) at the time of application if they intend to leverage a high humidity buffer reduction for ground application.

Buffer reductions are most impactful for ground applications as the justification for applying a buffer reduction hinges on a comparison of default model assumptions to what occurs in field conditions. The default model assumption for RH for aerial applications is 50%. A 50% value is broadly representative of humidity across the lower 48 states but is relatively low for many parts of the country, especially when considering morning weather conditions. When RH is changed from 50% to 70% in the AgDRIFT® Tier III aerial module with medium to coarse DSD, a 25 ft reduction in the spray drift buffer is estimated at 246 ft (given that equivalent deposition is estimated at 221 ft with 70% RH). A similar reduction in spray drift buffer is observed for fine to medium DSD but the 25 ft difference occurs at a distance approximately 25 ft farther offsite. Given the direct association between the modeling and the use conditions, deposition differences can be taken at face value. Aerial buffers with medium to coarse DSD can be reduced by 25 ft for buffers ≥250 ft and aerial buffers with fine to medium DSD can be reduced by 25 ft for buffers ≥275 ft. Buffer reductions are not recommended for coarse to very coarse DSD as RH sensitivity is only observed near the maximum recommended buffer (225 ft). EPA proposes that applicators measure and record RH (>70%) at the time of application if they intend to leverage a high humidity buffer reduction for aerial application.

6.3.6 Accounting for Coarser Droplets in Ground Applications

To account for coarser droplets in ground applications, aerial modeling capabilities and available ground deposition data are compared and analyzed to identify a recommended buffer reduction. Aerial modeling indicates a 2X difference between off-field deposition between medium and coarse droplets starting at approximately 75 ft (23 m) offsite and continuing to far field (997 ft or 300 m). There are caveats associated with comparing aerial modeling to ground applications (see discussion within humidity **Section 6.3.5**). EPA estimated equivalent point deposition at 100 ft (medium DSD) and 59 ft (coarse DSD), resulting in a 41 ft difference associated with differing droplet sizes. Equivalent point deposition was estimated at 151 ft (medium DSD) and 92 ft (coarse DSD), resulting in a 59 ft difference associated with the different droplet sizes. For the same reasons stated in the humidity discussion (**Section 6.3.5**), this 59 ft difference is not taken at face value for ground applications and a 25 ft buffer reduction for spray drift buffers greater than or equal to 75 ft is considered for ground application that use coarse or coarser droplets.

EPA has completed a data evaluation review of available data to directly compare the offsite deposition fraction between medium and coarse DSDs for ground applications with a low boom (2 ft) (Wolf, 2016; EPA, 2022d). Deposition at 33 ft offsite was very similar between the DSDs with a 3% average difference. At 66 ft (20 m), 131 ft (40 m), and 262 ft (80 m) offsite the difference 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 66 ft and 131 ft produce similar deposition differences of 40% and 43%, respectively. This again demonstrates that substantial exposure reduction can be expected for spray drift buffer distances of 75 to 175 ft when using coarser droplets and supports a spray drift buffer reduction when coarse droplets are used. Though EPA has conducted a data evaluation review, the underlying data is still under statistical review which may result in a modified coarse droplet mitigation credit in the future.

EPA does not propose that the coarse buffer droplet buffer reduction be used in conjunction with the high humidity buffer reduction if the initial buffer is <125 ft because the final buffer (after all mitigation is accounted) should not be <75 ft. The reason for the recommendation is that the coarse buffer reduction is most relevant at distances >75 ft.

6.3.7 Accounting for Crop on Field

To investigate the impact of on-field crop on reducing offsite spray drift, a sensitivity analysis of on-field surface roughness is performed. Changing AgDRIFT® Tier III parameterization of surface roughness from bare ground default (0.0246 ft) to an average crop value (0.32 ft given an AgDISP™ User Manual recommended range of 0.13 ft to 0.66 ft) reduces downwind deposition by 9 to 11% at 100 ft (30 m) and 24% at 300 ft (91 m) offsite (across droplet sizes from “fine to medium” to “coarse”). The minimum crop value (0.13 ft) produces similar results to the average value (see **Table 6-6**). 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 relative impact of crop on field increases with distance, the absolute difference in deposition is 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 (as indicated in the final two columns in **Table 6-6**). Given the direct association between the modeling and the use conditions, deposition differences can be taken at face value and aerial buffers ≥200 ft (≥61 m) can be reduced by 25 ft (7.6 m) when crop is on the field (a minimum 1 foot tall at time of application). The crop on field buffer reduction recommendation is most relevant for off-field distances greater than the maximum spray drift buffer recommended for ground applications (100-200 ft), this mitigation option is not available for ground applications.

Table 6-6. 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**
*Triggers 0.1601 ft warning within AgDRIFT® Tier III Aerial module but results are produced.

6.3.8 Accounting for Lower Wind Speeds

Reducing the wind speed parameter from 10 mph to 5 mph results in a similar deposition reduction for aerial applications 50 to 150 ft (15 to 46 m) offsite as changing the DSD from medium to coarse and as increasing the buffer by 50 ft (15 m). A smaller change in wind speed from 10 mph to 7 mph results in a similar deposition reduction for aerial applications 75 to 175 ft offsite when compared to increasing the buffer by 25 ft. At offsite distances <75ft and >175 ft, deposition differences from 10 mph to 7 mph model runs result in buffer differences less than 25 ft. At greater distances from the site of application, differences in deposition based on wind speed continue to occur but the relative impact diminishes with distance.

However, the assumption implicit within the model parameterization is that wind speed remains constant across 20 flight lines. Compared to a wind speed of 5 mph, wind speeds slightly higher (*e.g.,* 7 mph) would result in more drift. Although lower wind speeds generally result in less drift, application at lower wind speeds can coincide with conditions that are more prone to drift (*i.e.,* temperature inversion at <2 mph). Though reduced wind speeds generally result in less drift, it is not realistic to assume that wind speed remains constant throughout an application to an agricultural field .[20] Therefore, spray drift buffer reduction associated with reduced wind speed is recommended for a range of wind speeds low enough to reduce offsite deposition, high enough to avoid temperature inversion conditions, and broad enough to allow for changing wind conditions during the course of an application. Given this, a buffer reduction of 25 ft is only relevant for wind speeds from 3 to 7 mph and for buffers between 75 and 175 ft. This buffer reduction can be considered when the boom length is 75% or less of the wingspan for fixed-wing aircraft and a ½ swath displacement upwind is used at the downwind edge of the

[20] As an example, wind speed measured in April 2023 in Lincoln, Nebraska changed 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 windspeeds during the study period are 3.3 mph and 7.2 mph, respectively. Source: NOAA NCEI. Quality Controlled Datasets

field. These boom length and swath displacement restrictions are consistent with current label mitigations for applications with windspeeds up to 10 mph thus limiting complications for applicators when applying this buffer reduction.

Spray Drift Mitigation Summary

Table 6-7 below summarizes proposed spray drift mitigations presented in **Section 6.**

Table 6-7. Summary of Proposed Spray Drift Mitigation Options including Buffer Maximums

Mitigation Consideration	Application Type		
	Aerial	**Ground**	**Airblast**
Recommended Maximum Buffer Distance in Feet (Droplet Size and Release Height)	500 (Very Fine to Fine)	200 (Very Fine to Fine – High Boom)	100 (Sparse)
	300 (Fine to Medium)	100 (Very Fine to Fine – Low Boom)	
	300 (Medium to Coarse)	100 (Fine to Medium/Coarse – High Boom)	
	200 (Coarse to Very Coarse)	100 (Fine to Medium/Coarse – Low Boom)	
Downwind Windbreak/Hedgerow	Buffer reduced by 50%	Buffer reduced by 50%	Buffer reduced by 50%
Hooded Sprayer	N/C	Buffer reduced by 50%	N/C
App. Rate Reduction	Dictated by App. Rate	Dictated by App. Rate	Dictated by App. Rate
Temperature	N/A	N/A	N/C
Relative Humidity	25 ft buffer reduction at ≥250 ft with RH >70%*	25 ft buffer reduction at ≥100 ft with RH >60%**	N/C
Change from Fine to Coarse DSD	Buffer derived from available deposition curves	25 ft buffer reduction at ≥75 ft**	N/R
Crop on Field	25 ft buffer reduction at ≥200 ft*	N/A	N/R
Windspeed: 3 to 7 mph	25 ft buffer reduction at 75-175 ft	N/A	N/A

N/A – Not applicable currently because impact is not substantial enough to change spray drift buffer by ≥25 ft; N/C – Not considered in the current effort; N/R – Not relevant; App. – application; mph – miles per hour
*≥275 ft if aerial humidity reduction and crop on field reduction are used together
**≥125 ft if ground humidity reduction and coarse reduction are used together

7 Runoff/Erosion Mitigation Practices

7.1 Background Information and Considerations for Runoff and Erosion

Selection of effective mitigation options depends on a good understanding of the mechanisms of runoff/erosion and pesticide transport. Pesticides move offsite by the runoff flow of soil and water generally caused by rain events, and losses of 1 to 10% of applied pesticide are commonly observed (Zhang and Goh, 2015). Water runoff tends to carry soluble pesticides while eroding soil may also carry sorbing pesticides. In addition to precipitation, irrigation may also cause runoff and erosion and contribute to offsite transport (Zhang and Goh, 2015).

Runoff and erosion occur when the amount of precipitation or irrigation exceeds the capacity of the land to take in the water. This occurs when 1) the intensity (rate and volume) of rain is greater than the soil infiltration rate, or 2) when the volume of water exceeds the water holding capacity of the soil (*e.g.*, when the soil is saturated). Runoff may occur as sheet flow (a thin layer of water on the surface) or concentrated flow (accumulation of water in rills[21], gullies[22], or swales[23]), which is important for identifying problematic erosion areas. Areas prone to higher runoff may have soil types that restrict movement of water (such as an impermeable layer or high groundwater table) or may experience rates of precipitation that exceed infiltration rates (Alix *et al.*, 2017; Reichenberger *et al.*, 2007). Many runoff mitigation practices slow the overland movement of pesticides and facilitate downward infiltration. The delayed movement may provide time for degradation. EPA has found that other employed practices capture the water, erosion, and pesticide coming off the field and manage the flow of that material.

While the focus of the mitigation practices in this document are related to runoff, erosion, and spray drift, leaching is another transport pathway of pesticides. Movement of residues into groundwater and subsequent movement into adjacent areas (such as lakes, rivers, streams, and wetlands) or into caves can also result in exposure to listed species or other non-target organisms. Additionally, listed species may be exposed to residues in groundwater or surface water used as irrigation water. When subsurface transport is an important consideration for a pesticide (*i.e.*, persistent and/or mobile pesticides) mitigation of that transport pathway is addressed using mitigation practices specific to subsurface transport. These are outside of the scope of this document. EPA acknowledges that reducing runoff and erosion may increase movement of residues into groundwater.

7.2 Efficacy of Runoff and Erosion Mitigations Summary

Pesticide mass transported offsite tends to correlate with the amount of runoff and erosion, but not necessarily in a readily predictable manner. In addition, an evaluation of the existing

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[21] A rill is a small shallow channel.

[22] A gully is a ravine formed by the action of water.

[23] A swale is a low or sunken area or a depression between ridges or a shallow channel with gently sloping sides.

data demonstrates that the efficacy of mitigations is highly variable from one site to the next and often dependent on the study conditions. For any given mitigation practice, a range of efficacy is expected depending on the specific implementation of the practice, the environmental conditions of the treated field, and the chemical/physical properties of the pesticide. Therefore, EPA categorized the efficacy of mitigation measures as high, medium, and low; recognizing a precise percent reduction in exposure is not appropriate given the best available data.

EPA categorized mitigation practice efficacy at reducing exposure estimates and offsite transport into adjacent areas considering 1) the number of scientific studies available to support that the practice, on average, reduces runoff or erosion transport; 2) the range and average percent reductions across studies (when available in a review) and/or modeling results; and 3) best professional judgement.

Two major considerations in evaluating available literature on the effectiveness of a particular mitigation practice is the number of available studies and whether those studies show, on average, a percent reduction in offsite transport (Alix *et al.*, 2017; FOCUS, 2007; Reichenberger *et al.*, 2007; Yuan *et al.*, 2022). This is particularly important for many of the runoff/erosion mitigation practices as efficacy can vary considerably from site to site and within a site. For example, for some practices, the range of the efficacy from the studies is from 0% to 100%. EPA refers to the number of the available efficacy studies as the strength of evidence. This is a key factor because as the number of sites/studies increases, EPA can gain a better understanding of the efficacy of the practice in different environmental conditions. As multiple scientific studies confirm previous research, there is greater confidence in the efficacy of the practice across different environments and pesticides.

EPA employed the same strength of evidence approach as was used in a workshop where a group of experts reviewed efficacy data for runoff and erosion mitigation practices for pesticides titled: *Mitigating the Risks of Plant Protection Products in the Environment. Proceedings of the MAgPIE Workshop* (Alix et al., 2017). The practices were scored as follows: + few scientific publications existing; ++ many scientific publications existing; and +++ abundant scientific publications existing. For the evaluation described in this document, EPA's default for a specific practice was to use the MAgPIE score unless additional literature is now available that the workshop did not consider. When a score for a practice was not available from MAgPIE, EPA relied on other studies and reviews, as available, and scored the strength of evidence relying on the number of studies as described in **Table 7-1.** EPA acknowledges that one study may cover multiple sites and another only a few sites and that the quality of the studies also influences the reliability of the study results. These factors all need to be considered when evaluating the reliability of a practice at reducing offsite transport. EPA may update the efficacy analysis as additional information related to the efficacy becomes available.

Table 7-1. Strength of evidence categories[1] for runoff/erosion mitigation practice efficacy score

Strength of Evidence Category	Criteria	# of Studies
+	Few scientific publications existing	1 - 10
++	Many scientific publications existing	10-20
+++	Abundant scientific publications existing	>20

[1] The number of studies evaluated is one consideration for evaluating the efficacy of mitigation practices.

The second main consideration is the percent reduction in offsite transport or percent reduction in exposure observed in available studies or from modeling (either conducted by EPA or results reported in a scientific publication). For a particular practice, EPA scored the efficacy of a practice as high, medium, or low. To do so, EPA used a combination of: 1) the efficacy based on the totality of the available data; and 2) the strength of evidence score as shown in **Table 7-2** below.

Table 7-2. Summary of efficacy rating for runoff/erosion mitigation practices

Mitigation Practice Efficacy Rating	Lines of Evidence Score, Average Percent Reduction from Field or Modeling
Low	+, at least 10% reduction on average ++ or +++, about 25% reduction
Medium	++ ; >25 - 50% reduction on average
High	+++, about 50% or more average reduction

In this effort, EPA considered targeted field data as well as model estimates when evaluating efficacy of mitigation practices and the percent reduction in exposure that could occur from a practice. Modeling was conducted to support the potential reduction in exposure for the 48-hour rain restriction, for defining areas less vulnerable to runoff and erosion, and to support the vegetative filter strip efficacy. EPA also considered modeling assumptions for the field characteristics in the selection of efficacy category because the field characteristics are reflected in the exposure estimates. Due to the limitations of the model, sometimes modeling does not capture the reduction in offsite transport or exposure that may occur with a mitigation practice (see discussion in **Appendix A**); however, the mitigation practice may still be effective in the field when considering targeted field study results. The target for incorporation of the mitigation practice on labels is whether the practice is likely to be effective at reducing offsite transport of pesticides, not whether the result would influence the ecological risk assessment results and exposure estimates.

As outlined in **Table 7-2**, EPA rated the efficacy of a practice as high when the strength of evidence score was +++ and 50% or greater reduction, on average, was observed or modeled. EPA rated the efficacy of practice as medium when the strength of evidence score was ++ and greater than 25 to 50% reduction, on average, was observed or modeled. EPA rated the efficacy of a practice as low when the strength of evidence score was + and at least a 10% reduction, on average, was observed or when the strength of evidence was ++ or +++ and a 25% reduction, on average, was observed or modeled. In some cases, the data or information available did not fit into this system so EPA placed the practice in an efficacy category based on best professional judgement; those are described in the following sections. When the literature indicated that a practice is efficacious, but this was not captured in modeling, the literature was relied upon for the efficacy rating.

Although runoff and erosion occur together, a distinction is necessary to understand how pesticide mitigation practices can be most effective. 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[24] or K_{OC}[25]) will tend to attach to the eroded solids while those with lower sorption coefficients will tend more towards being within the water phase of the runoff.

The efficacy categories were not associated with a precise amount of reduction in exposure that would be expected to occur with the practice. The actual reduction that would occur is environment and pesticide specific. There is limited evidence supporting the reduction in exposure that may occur when combining practices (Alix *et al.*, 2017; Reichenberger *et al.*, 2007). It is expected that when mitigation practices are not independent of each other, the efficacy reduction will not be additive (Alix *et al.*, 2017; Reichenberger *et al.*, 2007). Mitigation practices that occur in the same area of the field may influence each other and are not independent. The efficacy of mitigation practices that are independent are more likely to be additive (Tomer *et al.*, 2013). For example, using an on-field practice and an adjacent to the field practice is more likely to result in an additive reduction in offsite transport (Reichenberger *et al.*, 2007).

EPA acknowledges that as shown in the various literature studies, the actual percent reduction will be site and pesticide specific. In addition to the variability in the available efficacy data, EPA acknowledges that some of these mitigation practices (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, these 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 will be reduced with these mitigation practices.

The runoff and erosion mitigation practices are categorized as follows:

- **Rain restrictions that generally apply to all herbicides.**
- **Field Characteristics** 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 practices to reduce offsite transport. For example, fields with a low slope or permeable

[24] The Kd is the solid-water distribution coefficient where the solid is typically soil or sediment.
[25] The K_{OC} is the organic-carbon normalized solid-water distribution coefficent where the solid is typically soil or sediment.

soils likely have less runoff. These are similar to considerations used by conservation specialists to determine what mitigations are recommended for a particular field. In general, these factors were given a low efficacy score because these factors are already accounted for in exposure estimates.

- **Pesticide Application Parameters** that users may elect to employ to reduce runoff and erosion such as rate reductions, soil incorporation, and use of certain application technologies that may lead to less concentrated runoff. While changes to the application occur on the field, they are considered separately from the in-field mitigation category, which includes practices related to the field management. The pesticide application parameters consider the change in application related to a single application as it may be a single application that could result in an impact for a pesticide. While reducing the number of applications may also be beneficial considering the overall loading over time, reducing the number of applications may not be adequate to reduce impacts to populations.

- **In-field Management** practices that users may elect to employ to reduce 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 practices. Adjacent to the field mitigation practices are those that generally occur next to the field such as a field border. Some practices may occur on the field and adjacent to the field and they are included in both categories (e.g., VFS).

- **Adjacent to the Field** mitigation practices are those that occur next to the field to which the pesticide application occurs and between an aquatic or terrestrial protected habitat for listed species.

- **Other mitigation practices** are those that may be considered but that do not fit into the categories above.

- **Exemptions** are those practices that EPA and/or the Services have determined are that if followed would not need additional runoff/erosion mitigation.

Within these categories, EPA identified several mitigation practices that are similar and thus grouped them under one name. Several of the proposed mitigation practices are similar in practice and efficacy, so EPA grouped them 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 practice titled in-field VFS. In other words, for this example, if the grower employed alley cropping, then they could not also claim credit for in-field VFS because they are all essentially the same practice, and EPA’s current thinking is that a grower would only receive credit for in-field VFS once. This simplifies the mitigation menu terminology and provides a bridge to common terminology.

The groupings of the mitigation practices can be confusing, particularly for VFS. Vegetative filter strips may occur in the field or adjacent to the field, and thus, they are listed under both the 'in-field' and 'adjacent to the field' categories. To confuse things further, in-field VFS can occur in contoured fields or in fields that are not sloped nor planted with contours. The in-field VFS practice descriptions indicate that many of the practices may occur in flat fields or contoured fields and thus some practices occur in the contour field practice category and the in-field VFS without a contour field. EPA's intent is not to confuse growers and EPA welcomes feedback on ways to simplify this information.

Field data support modeling observations that aqueous runoff is highest when rainfall occurs near the application event (see **Section 7.3.1.1** for details). **Table 7-3** summarizes rain restrictions that EPA expects will be necessary for most pesticides. The rain restrictions in this table are consistent with those proposed for FIFRA interim ecological mitigations (IEMs) (see November 2022 ESA Workplan Update) and reflect updated language based on input from the public comments received.[26] The 48-hour rain restriction may not be needed when the restriction would limit the efficacy of a pesticide.

Table 7-3. Summary of proposed restrictions included on all outdoor terrestrial use site labels

Restriction	Language on the Label
Rain Restrictions	Do not apply during rain.
48-hour rain restriction[1]	Do not apply when soil in the area to be treated is saturated (if there is standing water on the field or if water can be squeezed from soil) or if NOAA/National Weather Service predicts 50% chance or greater of 1 or more inches of rainfall to occur within 48 hours following application. Detailed National Weather Service forecasts for local weather conditions may be obtained on-line at: http://www.nws.noaa.gov, on NOAA weather radio, or by contacting your local National Weather Service Forecasting Office.

NOAA=National Oceanic and Atmospheric Administration

[1] The 48-hour rain restriction may not be required when the restriction would limit the efficacy of a pesticide.

Table 7-4 provides a summary of EPA's current thinking regarding potential mitigations to reduce runoff and erosion with the associated efficacy category (high, medium, low), and a summary of the evidence supporting the efficacy. Detailed descriptions of the practice and the evidence supporting the efficacy are included in **Section 7.3**. **Table 7-5** summarizes EPA's current thinking on situations that could be exempt from implementing runoff and erosion mitigation practices.

[26] The ESA workplan update, comments, are available at www.regulations .gov under docket ID: EPA-HQ-OPP-2022-0908.

Table 7-4. Potential runoff/erosion mitigation practices and associated efficacy at reducing exposure

Mitigation Menu Item[1]	Practices that Qualify[1,3]	Efficacy Score	Justification
Field Characteristics (Multiple Field Characteristics May Apply to an Individual Field)			
Application area is to the west of the I-35 and east of the Sierra Nevada Mountains and Cascade Mountains or highway 395[2]	Not applicable	Low	EPA completed a runoff and erosion vulnerability evaluation to identify regions of the country that have higher propensity for runoff and/or erosion The vulnerability maps show a general division of less vulnerable areas to the west and more vulnerable areas to the east of the I-35 and west of highway 395. Based on the vulnerability analysis these areas have less runoff and erosion as compared to other areas of the country. EPA assigned a low efficacy score because this field characteristic is accounted for in risk estimates.
Application area has predominantly sand, loamy sand, or sandy loam soil[4] without a restrictive layer that impedes the movement of water through soil	Not applicable	Low	Several studies indicate that sand, loamy sand, and sandy loam soils that make up Hydrologic Group A soils and Hydrologic Group B soils have a moderately low runoff potential (USDA and NRCS, 2007). Thus, fewer runoff mitigations are necessary in these areas. There is some uncertainty in the potential for exposure through subsurface transport mechanisms as groundwater exposure is a transport pathway of concern in these areas (Alix *et al.*, 2017). Because soil texture is accounted for in the exposure estimates, EPA assigned a low efficacy score for this field characteristic.
Overall, the application area has a slope of less than 2%	Naturally low slope or flat fields; flat laser leveled fields	Low	Reduction of runoff and erosion with decreased slope is well documented; however, it is also already considered in exposure estimates. EPA assigned a low efficacy score because this field characteristic is accounted for in risk estimates.
Application Parameters			
The maximum single application rate (lbs active ingredient per acre per application) allowed on the label for the specific crop is reduced or only a partial area in the acre is treated. Considered on a per application basis. Do not make applications at a lower rate than that required on the label to avoid resistance issues.	Banded application, spot treatment, partial area treatment, precision agriculture or sprayers	Proportional to rate reduction	Reducing the amount of pesticide applied yields a linear reduction in the amount of pesticide that may occur in runoff or erosion. The rate should not be reduced to a level that reduces the efficacy of the pesticide at treating the pest. Typically, a lower bound on the application rate is included on the label and the label recommendation should be followed. It is possible to still get credit for a reduced application rate if the efficacious rate is utilized only in a portion of the field or only targeted to weeds that need to be controlled and not sprayed over the entire field.
Soil incorporation within a few hours of application. If soil incorporation is required on the label, this is not applicable.	Watering-in or via discing before runoff producing rain event	Medium	Distributing pesticide to greater depths in the soil decreases its availability to interact with runoff/erosion and volatility, reducing offsite transport. Soil incorporation is considered in exposure estimates when it is required on the label; therefore, credit for implementing the practice is not applicable in this case if the modeling indicates that additional mitigation is needed to reduce runoff/erosion.
In-field Mitigation Practices			
Contour Farming	Contour farming, Contour tillage	Medium	There are many studies available evaluating the efficacy of contour farming at reducing offsite transport of pesticides or nutrients. While on average a 45 to 79% reduction in offsite transport was observed in field studies in the United Kingdom, that average score is based on a limited number of studies (Deasy *et al.*, 2010). Therefore, EPA recommends an efficacy score of medium.
	Contour buffer strips, contour	High	The strength of evidence for contour farming with in-field vegetated strips was assumed to be high considering data available for in-field VFS

Mitigation Menu Item[1]	Practices that Qualify[1,3]	Efficacy Score	Justification
	strip cropping, prairie strip, alley cropping (occurring in a contoured field)		and contour VFS. The efficacy score was assumed to be high based on the on average percent reduction in runoff/erosion ranging from 44 to 99% and the vegetated strips are expected to substantially increase the efficacy as compared to contour farming without vegetated strips.
Cover Crop/Continuous Ground Cover	Cover crop, double cropping, relay cropping, vegetative barrier	Low	EPA categorized cover crops as having a low efficacy. There are many scientific studies supporting that cover crops can reduce offsite movement of pesticides (**Table 7-10**). However, there is some uncertainty in the relevance of this mitigation practice in reducing offsite transport of pesticides applied when the main crop is on the field. For example, if the pesticide degrades before the cover crop is installed, there would not be any expected change in offsite exposure. The timing of the mitigation may not result in significant changes in exposure in many cases as the pesticide may already be degraded before the cover crop is in place.
Grassed Waterway	Grassed waterway	Low	There are few scientific studies evaluating the reductions of pesticide moving offsite through grass waterways. At least 10% reduction in offsite transport was observed for some pesticides (Asmussen *et al.*, 1977).
In-field Vegetative Filter Strip (not occuring on a contoured field)	Inter-row vegetated strips, strip cropping, alley cropping, prairie strips	High	EPA expects these practices to have a higher vegetation-to-field ratio than other single-buffer adjacent to the field VFS practices. Abundant studies are available evaluating the percent reduction and on average, reduction of 50% was predicted (Alix *et al.*, 2017).
Irrigation Water Management	Drip tape irrigation, micro-irrigation, precision irrigation	Low	Irrigation practices that are not carefully managed to reduce offsite transport can result in runoff and erosion. Therefore, credit for this practice is provided in order to encourage careful management of water for the field. If irrigation would not otherwise be utilized in the field, this practice cannot be utilized.
Mulching with Natural Materials	Mulching with natural materials	High	Many studies indicate that mulching can be an effective practice at reducing runoff and erosion; the practice reduces offsite transport from 68 to 95%. Therefore, this practice was categorized with an efficacy of medium for both runoff-prone and erosion-prone pesticides.
Residue Tillage Management	No-till, reduced till	Medium	Abundant studies support that tillage management can be an effective practice to reduce runoff, erosion, and movement of pesticides from fields (Alletto *et al.*, 2010; Potter *et al.*, 2015; Seitz *et al.*, 2019). On average the percent reductions observed were reported to be 50 to 75% (Alix *et al.*, 2017), depending on the source (USDA, 2014) and K_{OC} of the pesticide. Therefore, the efficiency rating for no-till or reduced till is medium.
Terrace Farming	Terrace farming, terracing, field terracing	Medium	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 near 25% to 50% depending on the source and pesticide K_{OC} (Alix *et al.*, 2017; Deng *et al.*, 2021; USDA, 2014); therefore, the efficacy category is medium for both runoff-prone and erosion-prone pesticides.
Adjacent to the Field			
Riparian area	Riparian forest buffer, riparian herbaceous cover	High	Abundant studies are available examining the effectiveness of riparian buffers at reducing offsite transport of pesticides (Stutter *et al.*, 2021; Wu *et al.*, 2023). While the efficacy is highly variable, riparian areas on average result in a 61% reduction in offsite transport of pollutants.
30-foot Vegetative Filter Strips - Adjacent to the Field	Vegetative filter strip (VFS), field border	Medium	There are abundant studies and modeling evaluating the effective of VFS adjacent to the field and reducing offsite transport. The evidence indicates that on average VFS reduce pesticide exposure by 25 to 40% for runoff-prone pesticides and 50% for erosion-prone pesticides (Alix *et al.*,

Mitigation Menu Item[1]	Practices that Qualify[1,3]	Efficacy Score	Justification
			2017; Reichenberger *et al.*, 2007; USDA, 2014). The strength of evidence is considered high resulting in an efficacy score of medium.
Vegetated Ditch	Not applicable	Low	Limited data show that vegetated ditches can be effective at reducing offsite transport of pesticides, depending on the shape, distance, and pesticide characteristics.
Other Mitigation Practices			
Water Retention Systems	Constructed wetland, irrigation and drainage tailwater recovery, pond, sediment basins	Medium (runoff-prone). High (erosion-prone)	Abundant studies are available evaluating the efficacy of constructed wetlands to reduce pesticide offsite transport. The efficacy can be high in systems with a long residence time[5] but ineffective in areas with a short residence time. Therefore, runoff-prone pesticides were categorized as having medium efficacy and erosion-prone pesticides high efficacy. Similar practices were included when it was recommended that the system limited connection to off-farm water systems.
Mitigation practices from multiple categories (*i.e.*, in-field, adjacent to the field, or water retention systems) are utilized.[6]	See options in categories above.	Low	Combining mitigations in-field, adjacent to the field, or water retention systems are more likely to result in additive efficacy as they are not occuring in the same area (Reichenberger *et al.*, 2007). Increasing infiltration on the field will reduce the loading to the adjacent area; likely resulting in higher efficacy of that mitigation practice. Multiple frameworks include this consideration (Alix *et al.*, 2017; Tomer *et al.*, 2013). Data are not available to evaluate the efficacy and the efficacy score is based on best professional judgement.

[1] Proposed mitigation practice descriptions specific to pesticides were published with the ESA workplan update: *Nontarget Species Mitigation for Registration Review and Other FIFRA Actions* (USEPA, 2022b). These will be updated based on comments received on the workplan update. If the state has a more restrictive requirement, that may be followed instead. Not all practices are applicable to all fields and crops. If a mitigation practice results in an increase in the amount of pesticides applied to the area, it is recommended that an alternative mitigation practice be selected.

[2] The Sierra Nevada is a major mountain range running along the eastern edge of California. It is between the California Central Valley depression to the Great Basin to the East. The Cascade mountains run from Mount Shasta in northern California to British Columbia.

[3] Only one of the practices that qualify from a 'mitigation menu item' can be used. For example, a user could get credit for contour farming or contour buffer strips but not both. Some of the practices that involve in-field VFS may occur in a contoured field or on a flat field without contours. The practice would only qualify once for the 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] The average time spent in a reservoir or body of water by an individual atom or molecule.

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

Table 7-5. Proposed exemptions from needing to follow the mitigation menu

Exemption	Justification
Follow recommendations from conservation specialist or certified expert to reduce runoff/erosion	Applicators may work with an expert to develop mitigation plans that are designed for their field and are efficacious in reducing offsite transport of pesticides substantially. While conservation programs are not specifically designed for reduction of offsite transport of pesticides, the same types of practices used for reducing offsite transport of nutrients and erosion of soil from the field also reduce offsite transport of pesticides Evaluating a field for the needs of reducing nutrient runoff and erosion are likely to result in similar recommended practices as those recommended in the runoff/erosion mitigation menu. Criteria are being developed so that this option would be considered functionally equivalent to relying on the mitigation menu. Feedback is requested on the types of experts, conservation programs, and appropriate criteria that could be relied upon to ensure that this is an effective practice, including for pesticides that need a high level of reduction of offsite transport to be protective of listed species.
Field is more than 1000 feet away from a terrestrial or aquatic habitat for listed species	Offsite transport adjacent to the field is highest when the field is adjacent to the habitat for listed species. Maximum overland flow distances are commonly assumed to be approximately 1000 to 1200 feet in engineering handbooks (TXDOT, 2019; USDA, 2010; VADEQ, 1992).
Field has subsurface drainage or tile drains installed	If the field has subsurface drainage installed, the mitigation practices are not applicable. The subsurface must release the effluent (water) into controlled drainage (such as release into a retention pond) or saturation buffer[1] zones that do not release water into downstream off-farm aquatic areas. Runoff from the entire field would need to be controlled and directed into a pond or saturation zone.

[1] A saturation buffer (USDA, 2017b) is a "subsurface, perforated distribution pipe used to distribute drainage system discharge beneath a vegetated buffer along its length and discharge channel."

7.3 Summaries of Each Mitigation Practice and Justifications for Efficacy and/or Inclusion as a Mitigation Option

Below is a description of each of the mitigation practice and more detailed information to supplement the summary information in **Table 7-4**. This section also includes additional information on the rain restriction language in **Table 7-3** and the potential exemptions in **Table 7-5.** Note that the descriptions in this section are brief and do not include all of the elements that would need to be in place for the practice to be effective. Proposed mitigation practice descriptions specific to pesticides were published with the ESA workplan update: *Nontarget Species Mitigation for Registration Review and Other FIFRA Actions* (USEPA, 2022b). Where EPA has completed its consideration of comments related to these practice descriptions, EPA has incorporated them into the descriptions presented here.

7.3.1 Restrictions that Would Generally Be Included on All Herbicide Labels

7.3.1.1 Rain and Saturated Soil Restrictions (Not a Menu Item)

Runoff more easily occurs when soils are saturated or when large precipitation events occur. In such cases (high rainfall events or wet soils) rain can lead to offsite transport of on-field pesticide. For this reason, avoiding pesticide applications when runoff is expected will reduce the likelihood of offsite pesticide transport.

EPA is recommending this as a label restriction be included on all pesticide labels as it represents a best management practice (BMP) that should generally apply to all pesticide uses.

7.3.1.2 Restriction of Application 48 hours Before Rain (Not a Menu Item)

Pesticides either dissolved in water or sorbed to soil can move off a treated field due to a runoff-producing rain event. Avoiding pesticide applications just before a runoff-producing rain event can provide additional time for a pesticide to degrade or sorb to soil or foliage before runoff to adjacent areas occurs. Allowance for small, non-runoff-producing rain events may serve to incorporate pesticide into the soil and reduce pesticide runoff. The effectiveness of allowing time for these processes to take place before a runoff event may be influenced partly by the persistence and mobility of the applied pesticide(s) (Commelin *et al.*, 2022; Wauchope, 1978).

The influence of rain restrictions on modeled EECs was evaluated in a recent EPA risk assessment (USEPA, 2022a) with aerobic soil metabolism half-life values of 7 and 29 days. EPA modeled the 48-hour restriction and compared the acute EECs with and without rain restrictions. The modeled reductions in the acute EECs ranged from 10 to 47% for wetland scenarios, with an average reduction of 30%. These wetland results are consistent with the terrestrial runoff EECs (average reduction of acute EECs was 24%). The amount of reduction of the acute wetland EEC varied widely (0-100%) by scenario.

Appendix C summarizes reductions in EECs when simulating the 48-hour rain restriction. The modeling assumed an application every day for an application window.[27] This provides a prediction of how the rain restriction would influence estimated exposure using standard modeling assumptions designed to illustrate the influence of application timing on exposure across a wide range of persistence and sorption assumptions. These results confirm that reductions in EECs do occur; however, the reduction in EECs is generally greater for pesticides with a low K_{OC} or short half-life. However, there is considerable uncertainty regarding the applications date used in the model and whether that date would reflect an actual date chosen by a real applicator, and this analysis did not address that. When the default simulation did not assume a rain event near an application event, there would be little to no change in the EECs. Additionally, modeling assumes instantaneous sorption when in reality sorption may increase over time and the additional time prior to runoff may decrease pesticide availability to runoff. Thus, the modeling may underestimate the effectiveness of limiting applications near rain events.

Rain Restrictions for All Labels:
Do not apply during rain.

Do not apply when soil in the area to be treated is saturated (*i.e.,* if there is standing water on the field or if water can be squeezed from soil,") or if NOAA/National Weather Service predicts 50% chance or greater of 1 or more inches of rainfall to occur within 48 hours following application. Detailed National Weather Service forecasts for local weather conditions may be obtained on-line at: http://www.nws.noaa.gov, on NOAA weather radio, or by contacting your local National Weather Service Forecasting Office.

Mitigation Menu Consideration: If the pesticide aerobic soil metabolism half-life is less than 10 days, the number of mitigation practices needed to reduce offsite transport may be reduced on a case-by-case basis. EPA may consider requiring fewer mitigation practices to be required on the label.

Field data support PWC modeling results that aqueous runoff is highest when rainfall occurs near the application event. Commelin *et al.* (2022) measured 30 pesticides in runoff and erosion over two growing seasons (14 rainfall events) and in soil samples taken from agricultural fields. Commelin *et al.* (2022) demonstrated that dissolved-phase transport mainly occurred near the time of application (69% within 10 days of the application versus no transport after 60 days) and particle-phase transport occurred over the longer term (90% was transported within 100 days of the application with significant transport still occuring after 150 days). For pesticides with aerobic soil metabolism half-life values 98 of 203 days, residues were detected for applications that occurred in the previous growing season. Of the 30 pesticides

[27] Application window is when modeling is conducted with simulations assuming applications may occur over an application window to evaluate the influence of application timing on exposure. Starting with the first day of the window (*e.g.*, June 1st) and applying the pesticide on that day for the entire simulation (*e.g.,* 54 years) and then starting with the next simulation run applies the pesticide to the next day of the window (*e.g.,* June 2nd) for the entire simulation and so on until the model gets through the application window set. This is not equivalent to applying the pesticide for every day within the application window.

evaluated, persistence was an important factor in whether residues were detected in runoff or erosion. Pesticides with aerobic soil metabolism half-life values less than 32 days were not detected in any runoff event. In the study, both mobile and immobile pesticides occurred more in the particulate phase than in the dissolved phase. Commelin *et al.* (2021) concluded "*that solubility and adsorption characteristics may not suffice to predict the dominant transport mode and related environmental fate of pesticides*". In addition, several studies anecdotally noted that atrazine (a persistent, mobile chemical) concentrations were highest in runoff when runoff-producing rain events occurred a few days after application (Caron *et al.*, 2012; Fawcett *et al.*, 1994; Gaynor *et al.*, 1995; Krutz *et al.*, 2005).

Some herbicides are more effective if a small amount of irrigation or rain is applied after application (e.g., watering in). Therefore, the restriction was limited to when there is a greater than 50% chance of 1 inch or more of rain within the next 48-hours.

7.3.2 Exemptions

7.3.2.1 Application Area is More than 1000-feet From Protected Habitat for Listed Species

Runoff from use sites will move from a high elevation to a lower elevation within a catchment. Overland flow or sheet flow is flow over plane surfaces usually less than one inch deep and is estimated to occur over a maximum distance of 100 feet for unpaved areas and 300 feet for paved areas but varies considerably according to actual field conditions (USDA, 2010; USEPA, 2023a; VADEQ, 1992). Shallow concentrated flow usually begins as overland flow and converges to form small rills, gullies, and swales. The recommended maximum length for shallow concentrated flow will vary for different watersheds and waterbodies but has been assumed to be 1000 ft to 1200 feet (305 to 366 m) by engineering texts (TXDOT, 2019; USDA, 2010; VADEQ, 1992). Wu and Lane (2017) calculated overland flow path lengths[28] for 41,449 wetlands in the prairie pothole region and the majority had a flow path length of less than 400 m (1,312 ft) with a mean of 138 m (453 ft). The amount of offsite transport decreases as the distance away from the field increases. Thus, terrestrial or aquatic protected habitat for listed species that are farther than 1,000 feet (305 m) from the application site are likely to receive less runoff and erosion, although there is connectivity between wetlands and streams, and residues may move from upstream areas (Wu and Lane, 2017). This 1000 ft proximity is also considered by other countries and NMFS[29] in determining the amount of runoff and erosion mitigation needed at a site (Bauer *et al.*, 2014; NMFS, 2023).

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

[29] 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).

7.3.2.2 Follow Recommendations from a Conservation Specialist

Potential Exemption Language for Label: If the lands are managed with a site-specific runoff and/or erosion plan or pesticide loss mitigation plan implemented according to the recommendations of a recognized conservation program, then the runoff mitigation menu practices are not needed. Recognized conservation or stewardship programs include those established by federal and state agencies; local, county, or municipal government; university extension programs; or independent certification programs. Growers must maintain documentation of their participation in the program, including recommendations, planning, design, implementation, and maintenance of any conservation practices.

Alternatively, growers may implement a site-specific runoff and/or erosion plan designed in conjunction with a qualified professional, independent of an established program. The professional must hold a certification that includes training or expertise in mitigating runoff and erosion from agricultural fields.

The programs would need to have characteristics that would result in reduction in offsite runoff and erosion transport that would be functionally equivalent to the runoff mitigation menu. These characteristics are currently under development.

Applicators may work with an expert to develop mitigation plans that work for their field and that are efficacious in reducing runoff and/or erosion. While conservation programs are not specifically designed for reduction of offsite transport of pesticides, the same types of practices used for reducing offsite transport of nutrients and erosion of soil from the field also reduce offsite transport of pesticides. Evaluating a field for the purpose of reducing nutrient runoff and erosion are likely to result in similar recommended practices as those recommended in the runoff mitigation menu.

EPA (with help from USDA) is developing criteria so that this option would be considered functionally equivalent to relying on the mitigation menu. The runoff mitigation menu provides growers with options for which EPA has efficacy data on the practice’s ability to reduce runoff and/or erosion from agricultural fields. However, these options and others are best selected and implemented with guidance from a professional who can evaluate 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 can account for in the planning process. Feedback is requested on the types of experts, conservation programs, and appropriate criteria that could be relied upon to ensure that this is an effective practice. Information is especially needed to show how following an expert’s recommendations or a conservation programs recommendation would be adequate for a pesticide that would need a high level of reduction of offsite transport to be protective of listed species.

USDA OPMP is conducting a survey about participation in runoff and/or erosion mitigation programs to better understand available programs and their attributes._EPA is collaborating with USDA to identify criteria or characteristics of the programs that would meet this exemption and welcomes potential criteria from stakeholders. Feedback is requested on the types of experts and appropriate criteria that could be relied upon to ensure that this is an effective practice.

The EPA recognizes that an evidence-based conservation plan aimed to reduce runoff/erosion from a grower's lands and developed by an experienced conservation program specialist will likely result in effective implementation of mitigation/conservation practices for that land. EPA's current thinking is that if a grower is following recommendations from a recognized expert to reduce runoff/erosion, then mitigation practices identified on the menu would not need to be followed.

EPA with the help of USDA has been collecting information on such programs that could be considered "functionally equivalent" to the identified mitigation practices. These include federal, state, municipal, and local government programs, a state university extension program, National Alliance of Independent Crop Consultants, or certified agricultural conservation specialists. Some example programs that might be applicable include the following:

- **Federal:** National Resource Conservation Service (NRCS) programs, erosion control plans required for Crop Insurance;
- **State:** California erosion control plans implanted through Water Boards; Colorado voluntary soil health program, Michigan Agricultural Environmental Assurance Program; and
- **Local/municipal:** soil and water health programs run by Conservation districts, watershed districts.

7.3.2.3 Subsurface Tile-drains are Installed

If the field has subsurface drainage installed (*e.g.*, tile drains), runoff will be greatly reduced. Therefore, the mitigation practices are not applicable, and the field would be exempt from any runoff mitigation menu requirements. In order to maintain protection of listed species, the subsurface tile drains must 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. Runoff from the entire field would need to be controlled and directed into a pond/saturation zone. Maintained tile drains are known to reduce erosion and pesticides with a high K_{OC} may have less off-site transport than runoff prone pesticides (Skaggs *et al.*, 1982). If there are tile drains and they are not maintained, erosion could occur from a field due to a clogged drain.

7.3.3 Field Characteristics

The characteristics of the field onto which a pesticide is applied influence the potential for offsite transport. The main factors affecting offsite transport of pesticides from the field include: soil texture and structure, permeability of subsoil and the vadose zone[30], depth to the groundwater table, slope, and weather (Reichenberger *et al.*, 2007). Therefore, these factors may reduce runoff and/or the concentration of pesticide in runoff and are included in the mitigation menu. EPA determined that field characteristics are one consideration for determination of the amount of mitigation needed to reduce runoff and erosion. These factors are considered in modeling, but in a broad way using representative high-end parameter values. Modeled EECs are not spatially explicit exposure estimates for a particular field but are high-end estimates for a Hydrologic Unit Code 2 region[31] or subregion. The factors considered below are also included as factors in determining the amount of runoff or erosions mitigations needed by other regulatory authorities and by conservation specialists (Alix *et al.*, 2017; Bauer *et al.*, 2014; Dyson *et al.*, 2019; NRCS, 2014). As the exposure estimates produced to evaluate the potential for population level effects reflect some of these field characteristics already, EPA gave these field characteristics low efficacy. These factors will likely reduce runoff and erosion from fields; however, additional mitigation would still be needed if ratios of exposure to toxicity endpoint for those areas indicate population level effects may occur.

7.3.3.1 Overall Low Sloping Field with Less than a 2% Slope

Slope can influence soil erosion and the associated offsite transport of soil-sorbed pesticide. Although runoff also generally increases with slope, the effect is not nearly as influential and consistent as it is for erosion (Wischmeier and Smith, 1978). Slope is already a consideration in the calculations of 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 explicitly accounts for slope. EPA PWC model developers selected inputs for slopes in the PWC to represent areas with higher-than-average erosion. So, actual field slopes that are lower than these modeled values should produce less erosion than assumed in the PWC. The recently released PWC scenarios (released in May 2023) generally have low slopes, with 60% of scenarios have slopes of 2% or less and about 50% of the scenarios have slopes of 1% or less. However, the higher-sloped scenarios (up to 48% slope in the newly released scenarios) could drive risk assessments, especially for high K_{OC} chemicals. Therefore, credit should be given for fields with low slopes of 2% or less, but because modeled slopes are also typically low, this

[30] Part of the earth between the land surface and water table. Often referred to as the unsaturated zone.

[31] 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 subwatersheds (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 United States Geological Survey Water-Supply Paper 2294, entitled "Hydrologic Unit Maps" (https://nas.er.usgs.gov/hucs.aspx).

mitigation credit is low. The 2% limit is suggested by USDA (2017a) as the lowest slope for consideration for use of erosion practices like contour farming.

7.3.3.2 Sand, Loamy Sand, or Sandy Loam Soil Without a Restrictive Layer that Impedes the Movement of Water Through Soil

Soils with a sand, loamy sand, or sandy loam soil texture (Hydrologic group[32] 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) resulting in reduced runoff and erosion from these soil types as compare to Hydrologic group C (sandy clay loam soil texture) and D soils (clay loam, silty clay loam, sandy clay, silty clay, or clay soil texture). EPA assigned this low efficacy. Although there are multiple lines of evidence to support that runoff and erosion are reduced in these soil types due to reduced water moving off the field, for the most part these qualities are already considered in the modeled EECs.

> **Soil Texture Determination:** Where labels reference soil type, EPA expects that the label would reference soil texture 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/.

7.3.3.3 Western Agriculture

When a field is located in western agriculture, the lower precipitation amounts create less runoff and erosion. Western agriculture is defined as the area is to the west of the Interstate 35 and east of the Sierra Nevada Mountains and Cascade Mountains or U.S. Route 395. The efficacy category assigned for this item is low because much of the mitigating benefit of these regions is already included in the modeling of the EECs.

7.3.4 Application Parameters

7.3.4.1 Pesticide Application Rate reduction

Using less pesticide (by reducing the application rate) is the most effective means by which growers can reduce the amount of a pesticide in offsite pesticide movement as the amount of pesticide moving offsite is proportional to the amount of pesticide applied. See **Table 7** for the pesticide application rate reduction summary.

[32] Hydrologic soil groups were developed to characterize soils based on measured rainfall, runoff, and infiltometer 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).

Table 7-6. Pesticide application rate reduction or partial application efficacy summary

Mitigation	Practices that Qualify	Efficacy	Strength of Evidence	Average and Range of Percent Reduction
Rate Reduction/ Partial Treatment	Rate reduction, banded application, partial/spot treatment, precision sprayers	Proportional to reduction	+++	Proportional to rate reduction; the percent reduction is calculated as the applied rate in lbs a.i./A divided by the maximum single application rate required on the label in lbs a.i./A.

a.i.=active ingredient

7.3.4.2 Soil Incorporation

> **Soil Incorporation** is when a pesticide is incorporated into the top layer of soil via watering in or mechanically discing in within a few hours after application.

The benefits of incorporating pesticides into the soil at the time of application for reducing the amount of pesticide in runoff events has been recognized for decades (Wauchope, 1978), and was included in early EPA regulatory models like GENEEC (USEPA, 2001), where EEC reductions were proportional to the incorporation depth. Soil incorporation can reduce the accessibility of pesticide to runoff (Young and Fry, 2019) with greater depth being less accessible, resulting in less mass of the pesticide in runoff. The soil depth that is accessible to runoff 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 extracts pesticide located nearer to the surface more easily than pesticide at greater depth, application methods that distribute pesticide to deeper soil depths (*e.g.,* watering-in or by mechanical means) will reduce the mass of the pesticide in runoff. The EECs estimated by the PWC may consider soil incorporation if incorporation is required on the label, but any additional incorporation beyond the label requirement will reduce the amount of pesticide available for runoff in comparison to a "non-incorporated" ground application.[33] Therefore, EPA is including this mitigation as an option when a pesticide is applied such that it is incorporated into the soil beyond that of a surface application. See **Table 7-7**for the soil incorporation efficacy summary.

Table 7-7. Soil incorporation efficacy summary

Mitigation	Practices that Qualify	Efficacy Score	Strength of Evidence	Average and Range of Percent Reduction
Soil Incorporation	Water-in, mechanically incorporated in a manner to distribute pesticide to at least 1 inch depth	Medium	+++	Not available

[33] See the PRZM 5 User Guide for default incorporation assumptions (Young and Fry, 2014).

7.3.5 In-field Management Practices

7.3.5.1 Contour Farming

Contour farming 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.

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. Deasy (2010) practiced 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.

Contour farming may reduce the field's curve number (a runoff indicator) by 6 to 12 units (USDA and NRCS, 2004). 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 or nutrients. Although on average a 45 to 79% reduction in offsite transport was observed in field studies in the United Kingdom, that average score is based on a limited number of studies (Deasy *et al.*, 2010). Therefore, EPA recommends an efficacy score of medium. See **Table 7-8** for the efficacy summary for contour farming with vegetated field strips.

Table 7-8. Contour farming without vegetation in field strips efficacy summary

Mitigation	Practices that Qualify	Efficacy Score	Strength of Evidence	Average and Range of Percent Reduction
Contour Farming	Contour farming, contour tillage	Medium	++ (Alix *et al.*, 2017)	On Average: 45 to 79% (Deasy *et al.*, 2010) Range: 0 to 92%

7.3.5.2 Contour Farming with Vegetated Strips

> **<u>Contour Buffers Strips</u>** 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.

Contour buffer strips are strips of permanent herbaceous vegetation planted along the field contour alternated with wider cultivated strips. The strips reduce runoff and trap sediment. Contour buffer strips typically consist primarily of perennial plants such as grass, whereas prairie strips are planted with native plant species.[34] Because the VFS is established on the contour, runoff flows more evenly across the entire surface of the strip, reducing erosion. The vegetation also slows runoff, increasing infiltration. Sediment and pesticides are filtered from the runoff as it flows through the strip thereby improving surface water quality. Arora *et. al*. (2010) summarized two studies where edge-of-field contour strips were evaluated and on average 44 to 47% 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. Prairie strips would result in similar reduction but are not required to be planted on contours and typically consist of native grasses.

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 can be planted across the entire field while that is not required for contour farming.

See **Table 7-9** for the contour farming with in-field vegetation efficacy summary. The strength of evidence for contour farming with in-field vegetated strips was assumed to be high considering data available for in-field VFS and contour VFS. The efficacy score was assumed to be medium based on the on average percent reduction ranging from 44 to 59% and the vegetated strips are expected to substantially increase the efficacy as compared to contour farming without vegetated strips.

Table 7-9. Contour farming with vegetated strips efficacy summary

Mitigation	Practices that Qualify	Efficacy Score	Strength of Evidence	Average and Range of Percent Reduction
Contour Farming with In-Field Vegetation	Contour buffer strips, contour strip cropping, vegetative barrier, prairie strip if on a contour, alley cropping	High	+++ Based on in-field VFS data	Average: 44 to 59% (Arora *et al.*, 2010) Range: 8 to 96%

[34] Iowa State University of Science and Technology. Prairie Strips in the Conservation Reserve Program. https://www.nrem.iastate.edu/research/STRIPS/content/what-are-prairie-strips

Vegetative Barrier (sub category of a type of contour farming with vegetated strips)

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, typically comprised of grasses, is established on the contour, runoff is restricted, reducing sheet and concentrated flow-based erosion. The grass slows runoff, helping the water soak into the soil and reducing erosion.

Vegetative barriers are similar to VFS but are an in-field practice and are planted along the contour. Therefore, this practice is similar in mechanism to both VFS and contour farming. EPA expects similar factors contribute to the efficacy of contour buffer strips as VFS and this is confirmed by field studies (Arora *et al.*, 2010). In vegetative barriers, more specific vegetation requirements (*e.g.*, stiff, dense vegetation) are necessary than for contour buffer strips. Both vegetation type and density impact the efficacy of VFS; therefore, the vegetation requirements for the vegetative barrier may improve the efficacy of vegetative barriers compared to contour buffer strips. As vegetative barriers are a subcategory of contour farming with vegetated strips an efficacy score specific to vegetative barriers was not developed.

7.3.5.3 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 those crops. Cover crops are most often recommended when low residue-producing crops are grown on erodible land. Cover crops may be used as a successive crop after one crop is harvested or relay-planted (similar to double cropping) where the second crop is planted into the first crop before harvest.

Cover crops increase water infiltration, consequently reducing aqueous runoff, by reducing soil bulk density[35] and increasing the number of macropores (Blanco-Canqui and Ruis, 2020; Haruna *et al.*, 2018). Cover crops also improve soil structure by increasing soil organic matter, and the canopy of cover crops intercepts rain drops, decreasing rainfall impact and thereby decreasing and erosion (Haruna *et al.*, 2018; Kaspar and Singer, 2011). Quantity, duration, and distribution of residues and plant canopies impact the effectiveness of a cover crop in reducing erosion, runoff, and pesticide concentrations (Kaspar and Singer, 2011). Using cover crops in conjunction with reduced tillage practices may further reduce surface runoff from fields (Haruna *et al.*, 2018; Langdale *et al.*, 1991). In addition to reducing sediment transport and aqueous runoff, cover crops may increase

[35] Mass of particles making up soil divided by total volume occupied by the soil.

sorption of pesticides to organic matter and promote microbial degradation (Cassigneul *et al.*, 2015; Cassigneul *et al.*, 2016).

Use of a cover crop resulted in an 11 to 99% reduction in soil losses for different tillage systems, cover crops, and spring crops across different southern U.S. locations (Langdale *et al.*, 1991), and an 86% reduction in soil loss in olive groves in Spain (Gómez *et al.*, 2018). When combined with no-till residue management, cover crops resulted in a 95 to 100% reduction in cyanazine or 99% reduction in atrazine loss associated with sediment and an 87 to 95% reduction in cyanazine or 67% reduction in atrazine loss associated with the aqueous phase (Hartwig and Ammon, 2002); however, these percentages reflect a combination of cover crop and no-till mitigation practices. Yuan *et al.* (2022) summarized reviews on conservation practices including cover crops and reported a mean load reduction of 73% for sediment. Blanco-Canqui and Ruis (2020) conducted a literature review evaluating cover crop influence on water quality considering field and laboratory studies. Cover crops increased infiltration in 82% of 17 studies but the infiltration rates ranged between 5 to 462% and cumulative infiltration on average was 43% (Blanco-Canqui and Ruis, 2020).

Cover cropping may result in a curve number reduction of 5 to 19 (USDA and NRCS, 2004), which is higher than the reduction expected for contour farming (rated low efficacy for runoff reduction). EPA categorized cover crops as having a low efficacy. There are many scientific studies supporting that cover crops can reduce offsite movement of pesticides (**Table 7-10**). However, there is some uncertainty in the relevance of this mitigation practice in reducing offsite transport of pesticides applied when the main crop is on the field. For example, if the pesticide degrades before the cover crop is installed, there would not be any expected change in offsite transport. The timing of the mitigation may not result in significant changes in exposure if the pesticide has already degraded before the cover crop is in place.

Table 7-10. Cover Crop/ Continuous Ground Cover efficacy summary

Mitigation	Practices that Qualify	Efficacy	Strength of Evidence	Average and Range of Percent Reduction
Cover Crop/ Continuous Ground Cover	Cover crop, double cropping, relay cropping	Low[1]	++ (Alix *et al.*, 2017)	Average: 50% (Alix *et al.*, 2017) Range: 11 to 100%

[1] An efficacy of low was assigned using best professional judgement. If the pesticide degrades before the cover crop is installed, there would not be any expected change in offsite exposure.

7.3.5.4 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, an 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 within the cultivated field, grassed waterways filter sediment and slow the flow of water, increasing infiltration of aqueous runoff (Asmussen *et al.*, 1977). 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). Asmussen *et al*. (1977) evaluated offsite transport of 2,4-D through surface runoff on 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 through grass waterways. While the literature suggests that grassed waterways may be an effective mitigation practice (*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). Therefore, grassed waterways were rated low efficacy (**Table 7-11**). 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 practice when this occurs.

Table 7-11. Grassed waterway efficacy summary

Mitigation	Practices that Qualify	Efficacy Score	Strength of Evidence	Average and Range of Percent Reduction
Grassed Waterway	Grassed waterway	Low	+	Average: not available Range: 0 to 100%

7.3.5.5 In-field Vegetative Filter Strip

In-field vegetative filter strips include 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. Based on the recommended efficacy score criteria, these were given a high efficacy score as EPA expects these practices to have a higher vegetation-to-field ratio than other single-buffer VFS practices as there will be multiple strips per field. Abundant studies are available evaluating the percent reduction and on average a reduction of 50% was predicted (Alix *et al.*, 2017).

Table 7-12. In-field vegetative filter strip efficacy summary

Mitigation	Practices that Qualify	Efficacy Score	Strength of Evidence	Average and Range of Percent Reduction
In-Field Vegetative Filter Strip	Inter-row vegetated strips, strip cropping, alley cropping, prairie strips	High	+++	Average: 50% (Alix *et al.*, 2017) Range: 11 to 94%

Alley Cropping (a type of in-field vegetative filter strip)

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). In addition to the benefits garnered by strip cropping, alley cropping also provides benefits due to the depth tree roots reach 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).

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

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, an efficacy score specific to alley cropping was not developed.

Strip Cropping or Intercropping (a type of in-field vegetative filter strip)

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.

Strip cropping has similar properties to contour farming for sloped fields but alternates various crop types with different plant spacing (*i.e.*, densities) in strips. The strips of erosion-resistant crops (*e.g.*, grasses) decrease the velocity of aqueous runoff and allow for trapping of sediments.

A meta-analysis of soil conservation literature in the Mediterranean countries demonstrated that soil loss reduction is slightly higher than runoff reduction using strip cropping. Based on Soil and Water Assessment Tool modeling of pesticide runoff, simulated strip cropping was the most effective technique for reducing atrazine loading compared with contour farming and 5-m buffer strips, with a 37% decrease in dissolved and 81% decrease in sorbed atrazine (Holvoet *et al.*, 2007). Strip-cropping of cowpea in maize in India reduced runoff by 11% and erosion by 8.3% (Khokhar *et al.*, 2021). As strip cropping is a subcategory of in-field VFS, an efficacy score specific to strip cropping was not developed.

7.3.5.6 Irrigation Water Management (Reduced Runoff from Irrigation)

Excessive irrigation can lead to runoff and offsite transport of pesticides. Irrigation water management works to control the volume and frequency of irrigation water applied to crops, while meeting crop needs, conserving water resources, and reducing runoff. Furthermore, controlled irrigation can serve to incorporate ground applied pesticides and reduce pesticide concentrations in runoff. With irrigation water management, a grower knowing the water needs of the crop and the water-holding capacity of the soil can apply the correct amount of water and avoid excessive runoff. 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, 2023b). 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 can infiltrate the soil so that runoff does not occur (Hansen and Trimmer, 1986). Other simple practices that prevent runoff are turning water off in a timely manner when irrigating and using soil moisture sensors, surge valves for furrow irrigation, or computer programs/apps that calculate pressure in irrigation tubing and hole size to ensure even water flow on all rows (Schwankl *et al.*, 2007; Smith, 2016; Yonts and Eisenhauer, 2008).

For the reasons identified above, fields under irrigation water management likely have reduced pesticide runoff compared to unmanaged fields, and thus EPA included this as a runoff mitigation option with a low efficacy score since it is not specifically aimed at pesticide runoff reduction and it likely is not as effective at reducing runoff as not irrigating at all (**Table 7-13**).

Table 7-13. Irrigation water management efficacy summary

Mitigation	Practices that Qualify	Efficacy Score	Strength of Evidence	Average and Range of Percent Reduction
Irrigation Management	Controlling irrigation water to minimize runoff; micro irrigation	Low	+	Not available

7.3.5.7 Mulching with Natural 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 natural materials to the land surface. Natural mulches must be applied such that mulch provides a minimum of 70% ground cover. The minimum depth of mulch must be 2 inches such that the mulch will remain during heavy rain or winds. If mulch needs to be held in place, appropriate practices must be used so that the mulch remains on the field.

Jiang et al. (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 (Chalker-Scott, 2007) aligned with results Jiang et al. (Jiang *et al.*, 2011), with Chalker-Scott reporting that straw mulch reduced erosion by 86%. Many mulching 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).

Many studies indicate that mulching can be an effective practice at reducing runoff and erosion; the practice reduces offsite transport from 68 to 95% (**Table 7-14**). Therefore, this practice was categorized with an efficacy of medium for both runoff-prone and erosion-prone pesticides.

Table 7-14. Mulching efficacy summary

Mitigation	Practices that Qualify	Efficacy Score	Strength of Evidence	Average and Range of Percent Reduction
Mulching with Natural Materials	Mulching with natural materials	High	++	Average not available Range: 68 to 95%

7.3.5.8 Residue Tillage Management

Residue and Tillage Management involves 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.

This category of practices includes conservation tillage practices 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.

No/reduced tillage or residue tillage management promotes soil macroporosity and maintains the structure of soil aggregates; increasing infiltration of runoff water and decreasing erosion (Fawcett *et al.*, 1994). No/reduced till 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 with suitable K_{OC} values (Fawcett *et al.*, 1994).

The benefits of no/reduced tillage on runoff and erosion are highly variable in the literature. Some studies have found that no/reduced tillage does not impact (Gaynor *et al.*, 1992; Glenn and Angle, 1987; Shipitalo and Owens, 2003) or increases atrazine concentrations/loads in runoff water (Gaynor *et al.*, 1995). Other studies found that no/reduced tillage decreased atrazine loads in runoff by 42% in no-till treatments (Pantone *et al.*, 1996) or by as much as 100% when infiltration of runoff water into soil 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% by some reports (Fawcett *et al.*, 1994).

Abundant studies support that tillage management can be an effective practice to reduce runoff, erosion, and movement of pesticides from fields (Alletto *et al.*, 2010; Potter *et al.*, 2015; Seitz *et al.*, 2019), on average the percent reductions observed were reported to be 50 to 75% (Alix *et al.*, 2017), depending on the source (USDA, 2014) and K_{OC} of the pesticide. Therefore, the efficiency rating for no-till or reduced till is medium (**Table 7-15).**

Table 7-15. Residue tillage management efficacy summary

Mitigation	Practices that Qualify	Efficacy Score	Strength of Evidence	Average and Range of Percent Reduction
Residue Tillage Management	No till, reduced till	Medium	+++	Average: 50 to 75% (Alix *et al.*, 2017) Range: 0 to 100%

7.3.5.9 Terrace Farming

> **<u>Terraces</u>** are described as a stair stepping technique of creating flat or nearly flat crop areas along a gradient. They can be constructed as earth embankments or a combination of ridge and channel systems. A terrace is an earthen embankment that is built across a slope to intercept and store water runoff. 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 reduces runoff water from 5 to 87%, on average by over 42% (Deng *et al.*, 2021) or 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) or 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); therefore, the efficacy category is low for both runoff-prone and erosion-prone pesticides (**Table 7-16**).

Table 7-16. Terracing efficacy summary

Mitigation	Practices that Qualify	Efficacy Score	Strength of Evidence	Average and Range of Percent Reduction
Terrace Farming	Terrace farming, terracing, field terracing	Medium	++	Average: 25 to 42% for runoff-prone; 50% for erosion-prone (Alix *et al.*, 2017) Range: 5 to 95%

7.3.6 Adjacent to the Field Mitigations

7.3.6.1 Riparian Area

> **<u>Riparian buffer zone (herbaceous or forest)</u>** 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 must be tolerant to intermittent flooding and saturated soil and be managed until established in the transitional zone between a field and an aquatic habitat. Herbaceous buffers must consist of non-woody vegetation and must have a minimum width of 2.5 times the width of the stream or 35 feet if adjacent to a larger water body. Forest buffers must be planted trees and shrubs and must have a minimum width of 35 if adjacent to a larger 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. The vegetation requirements typically are not as effective at reducing channelized flow. Therefore, riparian buffers and VFS share the same mechanisms of reducing aqueous runoff, sediment loading, and pesticide loading, and the same factors will contribute to the efficacy of the riparian buffer.

Runoff is more likely to be channelized in a riparian buffer than in VFS due to the woody vegetation in the riparian buffer (Bereswill *et al.*, 2012). Additionally, because of the proximity of riparian buffers to streams/receiving area, any enhanced infiltration of runoff will have a shorter subsurface route to the stream and therefore may be less effective compared to a buffer farther away (Reichenberger *et al.*, 2007).

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 the 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. However, 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 practice was considered a high reduction rating (NMFS, 2023) when used as a reasonable and prudent alternative. Therefore, riparian buffers were rated as high (**Table 7-17**).

Table 7-17. Riparian areas efficacy summary

Mitigation	Practices that Qualify	Efficacy Score	Strength of Evidence	Average and Range of Percent Reduction
Riparian Area	Riparian forest buffer, riparian herbaceous cover	High	+++	Average: 62% (Stutter *et al.*, 2021) Range: 3 to 100%

7.3.6.2 30-foot Vegetative Filter Strips Adjacent to the Field

Vegetative Filter Strips are managed on-field 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. The effectiveness of filter strips to reduce pesticide loading into an adjacent surface water body 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.

Vegetation in the 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).

Vegetative filter strips have been reported to reduce pesticide loads in aqueous 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 VFS at reducing aqueous 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).

The minimum VFS width should be at least 30 ft (9.1 m) (Reichenberger *et al.*, 2007). 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.

There are abundant studies and modeling evaluating the effective of VFS adjacent to the field for reducing offsite transport. The evidence indicates that on average VFS reduce pesticide exposure by 25 to 40% for runoff-prone pesticides and 50% for erosion-prone pesticides (Alix *et al.*, 2017; Reichenberger *et al.*, 2007; USDA, 2014). The strength of evidence is considered high resulting in an efficacy score of medium (**Table 7-18**). Additional information on VFS is available in **Appendix D**.

Table 7-18. Adjacent to the field vegetative filter strip efficacy summary

Mitigation	Practices that Qualify	Efficacy Score	Strength of Evidence	Average and Range of Percent Reduction
30-ft Vegetative Filter Strip	Field border, vegetative barrier	Medium	+++	Average: 25 to 50% (Alix *et al.*, 2017; Reichenberger *et al.*, 2007; USDA, 2014) Range: 1 to 94%

Field border (a type of adjacent to the field vegetative filter strip)

> A **field border** is a strip of permanent vegetation established at the edge or around the perimeter of a field. A 30-foot border is needed with dense vegetation 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 practices are a vegetated zone immediately adjacent to an agricultural field. Therefore, due to their similarities and a lack of literature specifically addressing field borders, the same efficacy is assumed for field borders as for VFS. The field border would need to be maintained with vegetation and with a width similar to the VFS to be considered substantially equivalent. As field border is a subcategory of adjacent to the field VFS, an efficacy score specific to field borders was not developed.

7.3.6.3 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.

Moore *et al.* (Moore *et al.*, 2008) evaluated the reduction in diazinon and chlorpyrifos 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.

Limited studies are available evaluating the reduction in pesticide offsite transport for vegetated ditches; however, the available data indicate that they can be effective for some pesticides (Alix *et al.*, 2017; Moore *et al.*, 2008; USDA, 2014).

Table 7-19. Vegetated drainage ditch efficacy summary

Mitigation	Practices that qualify	Efficacy Score	Strength of Evidence	Average Percent Reduction
Vegetative Drainage Ditch	Vegetated ditch	Low	+	50% (Moore *et al.*, 2008)

7.3.7 Other Mitigation Practices

7.3.7.1 Water and Retention System

Constructed wetlands and other water retention systems capture agricultural effluent and allow for sedimentation, sorption, and degradation in a constructed environment (Øygarden *et al.*, 1997). For the purposes of this analysis, the water retentions systems should be drained into a catchment basin, such that sediment and runoff are prevented from entering waterways off the farm (Meinen and Robinson, 2020).

Water retention systems promote water infiltration, sedimentation, and degradation and sorption of pesticides (Budd *et al.*, 2009; Rose *et al.*, 2006). 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). Iseyemi *et al*. (2021) previously reported that there was no reduction of nutrients (nitrate/sulfate) when comparing reservoir influent to effluent. Conversely, Budd (2009) observed a 52 to 94% reduction in seasonal pyrethroid concentrations; however, the constructed wetland was less effective at removing diazinon than other chemicals.

Abundant studies are available evaluating the efficacy of constructed wetlands and water retention systems to reduce pesticide offsite transport (Alix *et al.*, 2017). The efficacy can be high in systems with a long residence time[36] but ineffective in systems with a short residence time. Therefore, water retention systems are categorized with a medium efficacy for runoff-prone pesticide and high efficacy for erosion-prone pesticides (**Table 7-20**).

Table 7-20. Constructed wetland efficacy summary

Mitigation	Practices that Qualify	Efficacy Score	Strength of Evidence	Average and Range of Percent Reduction
Water Retention Systems	Constructed wetland, irrigation and drainage tailwater recovery, pond, sediment basins	Medium (runoff-prone); High (erosion-prone)	+++	Average: 75% (Alix *et al.*, 2017) Range: 0 to 94%

[36] Average length of time that water would remain in the wetland or retention pond.

7.3.7.2 *Mitigations from multiple categories (i.e., on-field, adjacent to the field, or controlled drainage)*

Reduction in offsite transport will be increased when multiple practices are combined such as 1) methods to increase infiltration rates and keep runoff on the field, 2) practices at the edge of the field to receive/reduce runoff that does not stay on the field, and 3) practices that retain, disperse, or provide time for dissipation before the runoff enters other waters (Wenger, 1999).

Combining on-field mitigations and adjacent to the field mitigations is more likely to result in additive efficacy as the mitigation practices are not occurring in the same area. Increasing infiltration on the field will reduce the loading to the adjacent area; likely resulting in higher efficacy of that mitigation practice. Multiple frameworks discuss that combining mitigation practice with different mechanisms are more likely to have a higher efficacy (Alix *et al.*, 2017; Tomer *et al.*, 2013). The efficacy score was determined to be low based on best professional judgement and due to limited studies evaluating combinations of practices (**Table 7-21**).

Table 7-21. Mitigation practices from multiple categories efficacy summary

Mitigation	Practices that Qualify	Efficacy Score	Strength of Evidence	Average and Range of Percent Reduction
Mitigation practices from multiple categories (*i.e.*, in-field, adjacent to the field, or water retention systems) are utilized.	Not applicable	Low	+	Not available

7.3.8 Mitigation Practices Not Included in the Current Proposed Mitigation Menu

7.3.8.1 *Polyacrylamide Anionic Erosion Control (PAM)*

PAM reduces erosion from fields by stabilizing soil aggregates, flocculating particles, and reducing surface sealing, crusting, and erosion. PAM reduces aqueous runoff by increasing infiltration. EPA needs additional data on the efficacy of PAM to consider it as a mitigation menu item.

8 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
^{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 coefficent
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

VFSMOD: Vegetative Filter Strip Modeling System

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Appendix A. Consideration of Modeling and Efficacy

EPA uses models primarily to estimate environmental concentrations (EEC). Models can also be useful for evaluating the effectiveness of pesticide mitigation efforts. EPA uses a weight of evidence to determine whether a mitigation practice is appropriate for reducing offsite transport. Modeling is one line of evidence in that evaluation.

Although EPA uses several different models to estimate EECs, the models that are relevant to pesticide transport and hence mitigation evaluation are the Pesticide in Water Calculator (PWC) and AgDRIFT® . The PWC contains the erosion and runoff routines and AgDRIFT® contains the drift routine. These models have been vetted through various Federal Insecticide Fungicide Rodenticide Act (FIFRA) Scientific Advisory Panels and have been used to support pesticide risk assessments for decades (USEPA, 2023a). A general description of the PWC and EPA's conceptual model for surface water can be found in Young (2019). AgDRIFT® background is available in (Teske *et al.*, 2000; Teske, 2009; Teske *et al.*, 2002; USEPA, 1997).

These models are valuable tools for providing general EECs suitable for regulation, but care must be exercised when using models more mechanistically, like for mitigation evaluation, and one should not necessarily expect a mitigation practice that performs well in the model to also perform on the field and vice versa. One example is the modeling of a vegetated filter strip on the EPA's standard 10-ha model field where a 10-m buffer may show 90% removal of pesticide. But on a larger, not atypical U.S. field, that same effectiveness is unlikely due to the greater runoff volumes from larger fields. Another example of processes that may not scale linearly from model to reality include the amount of erosion produced on the field, which in turn will impact mitigation efficiency aimed at reducing erosion; the small model field is likely to produce more erosion per area than larger fields that are not uncommon in the U.S. (Wischmeier and Smith, 1978).

Besides scaling issues, it is important not to confuse purely model behavior (*i.e.*, model artifacts) with what actually occurs. In other words, a model (in particular the PWC) can exhibit mitigation behavior that does not exist, or it may be unresponsive to a process that should clearly benefit mitigation. One example is that the PWC will give noticeably lower concentrations if a pesticide is applied after emergence rather than before emergence, even if the two application dates vary by a single day. This does not mean that limiting applications to post emergence is a viable mitigation practice. Rather, this effect is strictly a function of a simplifying assumption in the model in which the model's curve number (a runoff indicator) abruptly changes to a lower value on emergence day. In reality, curve numbers would change more subtly and gradually over an extended period of time such that there would be no difference in pesticide transport if the pesticide were applied the day before or the day after emergence but would only be realized after crop size changes significantly enough to impact runoff, unlike the model predictions. Other potential misinterpretations are pointed out where appropriate in the work that follows. Model simulations, however, can be quite effective for mitigation evaluation and provide a line of evidence to support mitigation decisions as demonstrated below.

EPA uses a weight of evidence to determine whether a mitigation practice is appropriate for reducing offsite transport. Modeling is one line of evidence in that evaluation.

Appendix B. Vulnerability Maps for Pesticide Transport Offsite by Runoff and Erosion

Pesticide movement away from areas of application occur primarily by runoff, erosion, and aerial drift. 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 best areas to employ runoff/erosion mitigation.

Runoff and erosion often occur together, therefore a distinction is necessary to understand how pesticide mitigation practices 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}) will tend to attach to the eroded solids while those with lower sorption coefficients will tend more towards being in the water phase of the runoff. For this reason, vulnerability to runoff or erosion is examined separately, although 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)[37], a USEPA 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 drainage areas or actual waterbody types or waterbody sizes in an actual location[38]. 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.

Methods

Previous work (USEPA, 2020a; USEPA, 2020c) resulted in the creation of a comprehensive 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, 2018a), the latest five

[37] https://www.epa.gov/pesticide-science-and-assessing-pesticide-risks/models-pesticide-risk-assessment#PWC; See Young (2019) for details on the PWC.

[38] 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).

years of land cover/crop groups from the USDA Cropland Data Layer (CDL) (USDA, 2018b), 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 as well as pesticide application inputs for PWC simulations were the same as used in USEPA OPP (2020a). The application patterns and chemical degradation rates were selected to best capture the overall runoff and erosion potential of pesticides, as described in USEPA OPP (2020a). As with the previous efforts, chemical sorption properties were selected to best capture and differentiate runoff and erosion. In the present analysis two chemicals were simulated: one with a low K_{OC} (10 mL/g) and one high K_{OC} (10,000 mL/g). The EECs for the low K_{OC} chemical are driven primarily by runoff and thus results are indicative of runoff vulnerability, while EECs for the high K_{OC} chemical are driven primarily by erosion and is indicative of erosion vulnerability.

Because the current effort is aimed at ecological assessments, the EPA farm pond (Young, 2019) was used instead of the human drinking water reservoir, which was used in the previous work (USEPA OPP, 2020b). The USEPA uses the farm pond for ecological assessments, and thus it is more appropriate for evaluating the vulnerability of communities considered in ecological risk assessments. The overall average concentration of the entire simulation (54 years) was used as the exposure endpoint for these vulnerability evaluations (Young, 2019). This concentration is a good indicator of the total pesticide mass transported off the field with runoff and/or erosion (USEPA, 2020a).

PWC-generated outputs were linked to each soil-land-crop-weather grid combination. 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, only the median EEC value for each weather grid was used for creating the vulnerability maps using ArcGIS Pro 3.0. This results in about one point for every 16 miles (the approximate size of the weather grid). Therefore, inverse distance weighted (IDW) interpolation technique was used to derive a continuous vulnerability map that aggregates local vulnerabilities to reduce the impact of any one locality and improves visual presentation at large geographic scales (ESRI, 2022)[39]. The IDW technique computes an average value for unsampled locations using values from nearby weighted locations. The IDW method assumes that each measured point has a local influence that diminishes with distance and weights the points closer to the interpolated location greater than those farther away. The IDW method was selected over other methods as it keeps the interpolated values within the measured range. It is also the commonly reported method in processing of various spatial data, such as soil moisture distribution (Srivastava *et al.*,

[39] Environmental Systems Research Institute (ESRI).2022. ArcGIS Pro 3.1 Help. IDW (Spatial Analyst) https://pro.arcgis.com/en/pro-app/latest/tool-reference/spatial-analyst/idw.htm

2019) and surface water volume estimation (Fuentes *et al.*, 2019), and in creating digital elevation models (Salekin *et al.*, 2018), air pollution models (Su *et al.*, 2018), and many others.

Results

The runoff vulnerability map is shown in **Figure B1**, where runoff vulnerability is divided into high- and low-vulnerability areas. These vulnerability classifications were determined by ranking all scenarios using methods in USEPA (2020a) and segregating them into two equal divisions—top 50% and bottom 50%. High areas in orange represent the upper 50% of areas vulnerable to pesticide runoff in the U.S., and yellow areas represent the lower 50% of areas vulnerable to pesticide runoff. The erosion vulnerability map (**Figure B2**) illustrates the similarity of erosion vulnerability to runoff vulnerability.

The vulnerability maps show a general division of less vulnerable areas to the west and more vulnerable areas to the east of the Interstate 35 (I-35). These lower vulnerability areas extend westward from I-35 to the Sierra Nevada Mountains (California) and Cascade Mountains (Oregon, Washington) or U.S. Route 395. EPA relied upon this vulnerability analysis to propose reduced amounts of runoff and erosion mitigation needed in this less vulnerable regions (shown in yellow). Areas that to the east of I-35 and west of the Sierra Nevada Mountains and Cascade Mountains tend to have more runoff and erosion as compared to other areas of the country. This pattern is not surprising since the main driver for runoff and erosion is precipitation, and runoff is the primary driver of the movement of eroding solids. Differences arise from crop practices and local soil erosion characteristics.

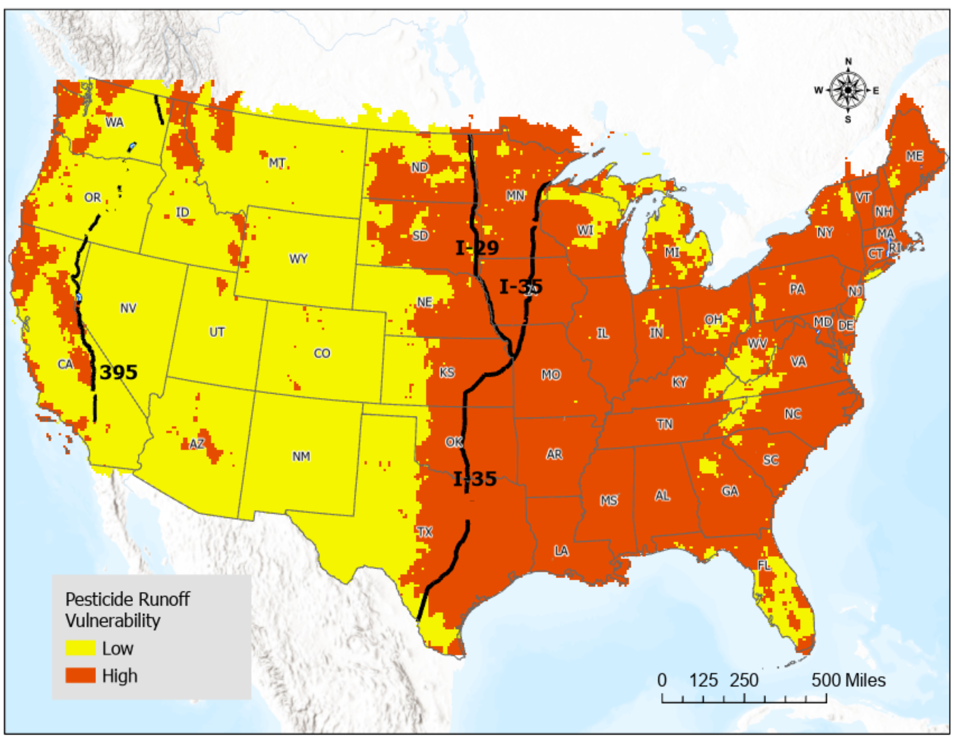

Figure B1. Runoff Vulnerability Map

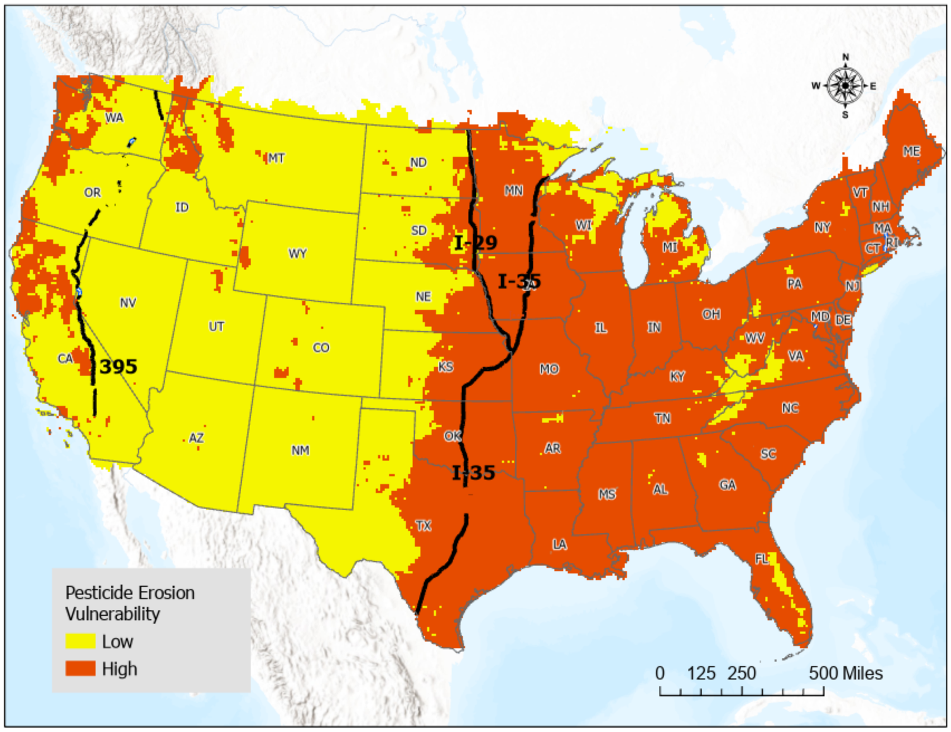

Figure B2. Erosion Vulnerability Map

Appendix C. Modeling to Support Efficacy of Rain Restriction

Summary

Previous work by EPA modeled the average reduction in expected environmental concentrations (EECs) with a 48-hour rain restriction for mock chemicals that were stable to degradation except by aerobic soil metabolism (US EPA, 2022b). EPA applied this approach 1) to expand upon the original rain restriction analysis, and 2) to investigate the impact of soil incorporation and post-emergence applications on EECs (results not presented in this appendix). For the work described herein, a wide variety of scenarios were modeled to understand the impacts of various mitigations across a range of use patterns and locations (**Table C1**). To understand the impact of the mitigations for chemicals across a range of persistence and mobility, we modeled a set of 'mock chemicals' where the sorption coefficient and aerobic soil metabolism (ASM) half-life were varied across runs (**Table C2**). We focused on ASM because ASM and foliar degradation were identified as the most relevant Pesticide in Water Calculator (PWC) degradation parameters prior to a chemical leaving the field as runoff based on the conceptual model of PWC; however, foliar degredation data are rarely received for EPA ecological risk assessments. In addition to ASM and foliar half-life, application date impacts final EECs, so for each chemical, we modeled a 60-day application window (-30 days to +29 days from the original application date) to assess the effects of variability in the application date on the modeling results. Use information such as application date, application rate, and application type were kept constant across all runs, except where noted.

Table C1. Pesticide in Water Calculator Scenarios Modeled for 48-hour Rain Restriction Analysis.

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 C2. Pesticide in Water Calculator (PWC) Modeling Parameters for Mock Chemicals.

PWC Modeling Parameter	Original Chemical	Mock Chemicals
Sorption Coefficient (mL/g)	153	**Varied**[1]
K_{oc} flag	TRUE	TRUE
Water Column Metabolism Half-life (day)	12.6	0
Water Reference Temperature (°C)	25	25
Benthic Metabolism Half-life (day)	207	0
Benthic Reference Temperature (°C)	25	25
Aqueous Photolysis Half-life (day)	21	0
Photolysis Reference Latitude	40	40
Hydrolysis Half-life (days)	0	0
Soil Half-life (days)	176	**Varied**[2]
Soil Reference Temperature (°C)	20.5	20.5
Foliar Half-life (days)	3.71	0
Molecular Weight (g/mol)	201.2	201.2
Vapor Pressure (torr)	1.37E-07	1.37E-07
Solubility (mg/L)	32	32
Henry's Constant (unitless)	4.63E-08	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.

In summary, our results demonstrate that 48-hour rain restrictions are only likely to be efficacious for a small subset of chemicals. In addition, soil incorporation of pesticides may be efficacious at reducing EECs, but the efficacy of soil incorporation is depth dependent. Finally, limiting applications to post-crop emergence did not consistently reduce EECs.

48-hour Rain Restriction

Methods

Previously, to investigate the effectiveness of a 48-hour rain restriction for pesticides across a range of K_{OC} values and persistence, we modeled a range of use patterns that covered a broad set of agricultural and non-agricultural scenarios in PWC (**Table C1**), modifying the K_{OC} (10, 1,000, 10,000 mL/g), aerobic soil metabolism half-lives (1, 10, 100 days), or foliar degradation half-lives (1, 10, 100 days) across model runs, with or without a rain restriction. Here, to expand upon previous results, we modeled additional mock chemical combinations including K_{OC} values of 100 and 20,000 mL/g, and aerobic soil metabolism half-lives of 2, 5, 500, and 3,000 days (modeling parameters in **Table C2**).

To simulate the 48-hour rain restriction, we used the rain restriction modeling option in PWC, set to avoid 1 cm of precipitation for 48 hours, with a 7-day optimum application window and 3-day minimum re-treatment interval. All modeling was conducted by assuming zero drift to only assess the effects of the rain restriction and not variability in the amount of spray drift versus runoff in the different scenarios.

To determine the average percent reduction garnered by the 48-hour rain restriction, we first averaged the yearly maximum 1-day average from each scenario modeled (around 30 years of simulations) and from each application date modeled (30 dates) for the restriction and without the restriction applied. Then the percent difference was calculated according to **Equation 1**.

Equation 1

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

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

Results

These modeling efforts increased the range of K_{OC} values and ASM half-lives that were investigated and increased the granularity of modeling for chemicals in terms of Koc or ASM half-lives. We found that EECs from chemicals with a K_{OC} of 100 mL/g or 20,000 mL/g were not impacted by the 48-hour rain restriction unless they had an ASM half-life of less than 2 days, in which case there was about a 20% reduction in EECs compared to no restriction (**Table C3**). For chemicals with an ASM half-life of 500 days, the 48-hour rain restriction did not impact EECs, but for chemicals with ASM half-lives of 2 or 5 days, the rain-restriction was associated with a 26 to 12% decrease in EECs, with more reduction observed for chemicals with shorter ASM half-lives. EPA concludes that a 48-hour rain restriction will be most effective for chemicals that are mobile and/or non-persistent.

Table C3. Average Rain Restriction Estimated Environmental Concentrations (EECs) and Percent Reduction in EECs Compared to No Restriction.

K_{OC} (g/mL)	ASM half-life (days)	1-day, rain restriction (µg/L)	1-day, no restriction (µg/L)	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

K_{OC} (g/mL)	ASM half-life (days)	1-day, rain restriction (µg/L)	1-day, no restriction (µg/L)	Difference (%)
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 co-efficient; ASM=aerobic soil metabolism half-life
Color coding indicates the four levels of K_{OC} and ASM considered, where green represents the lowest values and red the highest values. For example, chemicals with low K_{OC} and low ASM (green in both columns) would be considered mobile and non-persistent.

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

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). These results were summarized to predict percent pesticide mass reduction by soil class.

The results indicate that soil class is had the most influence on estimated environmental concentrations (EECs). Soil classes with similar pesticide reduction results were grouped for brevity. The sand, clay, and silty clay results had limited interpretive value because the sand had 100% reduction in the EEC[40,] and the silty clay and clay had a 0% reduction in the EEC. VFS are not expected to be commonly used with silty clay and clay soils because tile drains will likely be installed to prevent accumulation of water on the surface of soils. Therefore, VFS were assumed to not be applicable for sand, silty clay, and clay soils.

The results were further summarized for each soil texture by 1) 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 D1 shows the required buffer width to produce several examples of field area to buffer area ratios for the specific case of EFED's regulatory standard pond field size of 10 ha.**

Table D1. Summary of Simulated Vegetative Filter Strip (VFS) Width and Field Area[1] to Strip Area Ratio for the EFED Regulatory 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

Results of these modeling simulations were used to estimate the efficacy category for different VFS assumptions. These results are shown in **Table D2**. These categories or a simplified assumption may be included in the main mitigation menu assuming the lowest category for each soil texture, K_{OC} value, and HUC2 region.

[40] Subsurface transport will be an important transport pathway for sandy soils.

Table D2. Summary of the Categories of Efficacy by Soil Texture for Vegetative Filter Strips (VFS) by Hydrologic Unit Code (HUC) 2 Regions

Soil Texture	Eastern HUC2 regions (01 to 12)		Western HUC2 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	20:1 ratio: Medium 50:1 ratio: Low	High	High	High
Loam	Low	Medium	20:1 ratio: Medium 50:1 ratio: High	High
Silty Loam, sandy loam	Low	Low	20:1 ratio: Low 50:1 ratio: Medium	20:1 ratio: Medium 50:1 ratio: High
Sandy clay loam, clay loam, silty clay loam	None	Low	None	Low

Analysis of Predicted Pesticide Reductions using VFSMOD

Background

Vegetative filter strips (VFS) can be an effective mitigation practice 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 assumes a densely planted turf vegetation occuring immediately in between a treated agricultural field and a receiving waterbody.

Analysis

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[41]. 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. 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 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,

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

and were thus selected for further evaluation and proposed 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 across the PWC scenarios were selected to represent each soil texture. The various groupings are given in **Table D3**.

Table D3. 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
Mid	20:1, 10:1	50 ft, 100 ft

(c)

K_{OC} Class	K_{OC} (L/kg-oc)
Low	1, 10, 100
Mid	1,000 and 10,000

The proposed draft table of pesticide reductions is presented below in **Table D4**. 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 D4. Lower bound Pesticide Reductions from VFSMOD in Runoff and Eroded Sediment

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

[a] Based on 95th percentile starting runoff value, rounded to nearest 10%.
[b] VFS Class: Based on 1) VFS width where low is 20 or 30 ft width, and mid is 50 or 100 ft width; and 2) Field:VFS Area where low is ratios of 50:1 (20 ft VFS width) or 35:1 (30 ft VFS width) and mid is ratios of 20:1 (50 ft VFS width) or 10:1 (98 ft VFS width)
[c] K_{OC} Class: Low is 1, 10, or 100 L/kg-oc; Mid is 1,000 or 10,000 L/kg-oc.

Uncertainties

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 zero percent; however, EPA acknowledges that other mechanisms such as tile drainage would most likely be employed in these runoff-prone soils. Tile drainage a mechanism not modeled in VFSMOD. Therefore, VFSMOD predicted runoff reductions for clay and silty clay soils are not recommended for use in mitigation.

References

Muñoz-Carpena, R. and J.E. Parsons. 2004. A Design Procedure for Vegetative Filter Strips Using VFSMOD-W. *Trans. of ASAE* 47(6):1933-1941. doi: 10.13031/2013.17806.

Muñoz-Carpena, R. and J.E. Parsons. 2021. VFSMOD-W Vegetative Filter Strips Modeling System, Model documentation & user’s manual, (vfsm v4.5). University of Florida. Last updated: November 24, 2021.

Appendix E. Supporting Material for Maximum Spray Drift Buffer Distances

Establishing the maximum buffer distance requires the selection of a distance within which the slope of the spray drift deposition curves can be evaluated. A simple/recommended method for evaluating this distance is presented in **Section 6** above. The following ancillary method is also presented for consideration but EPA is not currently proposing this method.

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[42]). 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.[43] A point is selected at five feet from edge of field as a point of deposition 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). Furthermore, areas less than five feet from the edge of field may not be easily distinguished from the field edge and may be considered managed land (*e.g.,* for runoff or drift control). Five feet from the field edge allows for a comparison more consistent with offsite deposition, because it can be understood as a transition point between on-site and off-site exposure. A 25-foot distance is selected as this is an increment at which label-required spray drift buffer distinctions are measurable and far enough apart to be distinguishable. This process is applied to each application method (aerial, ground boom, airblast) and all droplet size assumptions. As described earlier, exposure may still occur beyond EPA's proposed maximum buffer distances. To determine if the maximum buffer distance is sufficient to meet a given mitigation need, EPA compares the maximum buffer distance to the distance at which a target exposure causing effects may occur. If exposure above the target is still expected after maximum buffers are applied, additional mitigations other than spray drift buffers are required. See **Figure E1** below indicating the distances at which deposition is no longer substantially changing with distance according to this ancillary 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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[42] 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.

[43] 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.

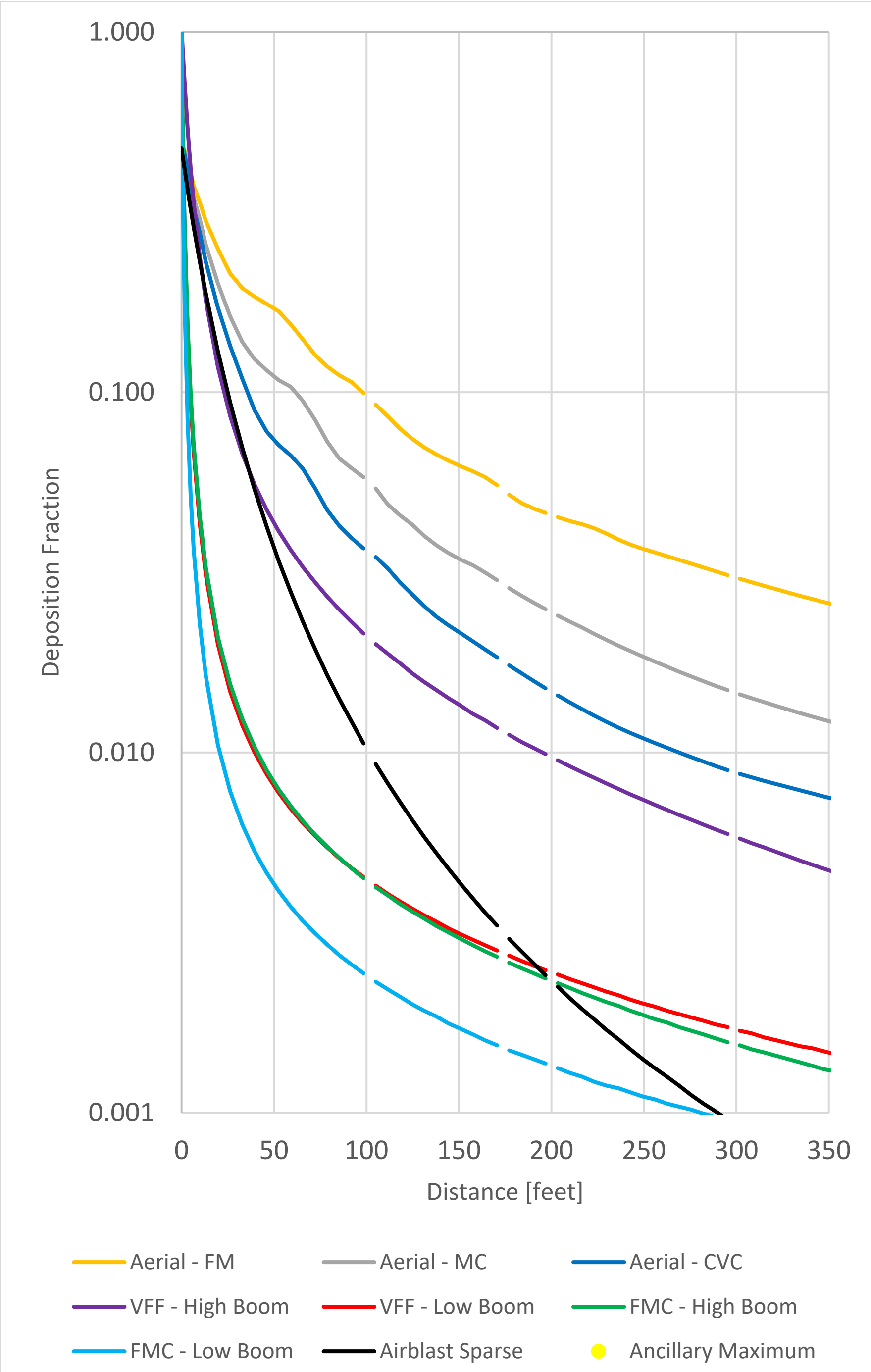

Figure E1. Fraction of Applied Pesticide with Distance for Aerial, Ground, and Airblast Applications with Different Droplet Size Distributions based on AgDRIFT® Tier I Modules. The maximum buffers show where deposition change over 25 feet is <0.5% when compared to deposition 5 feet off field.

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 E1** above depicts the maximum buffer extents for eight representative drift curves while **Table E1** and **Table E2** below provide a more complete numerical representation of all 13 relevant drift curves.

Table E1. 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 E2. 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**								

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

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.