**Chapter 3 – Final Carbaryl Exposure Characterization**

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# Environmental Transport and Fate Characterization

Carbaryl will initially enter the environment via direct application (*e.g.*, as liquid sprays, dusts and granular formulations) to use sites (*e.g.*, soil, foliage). It may move off-site via spray drift, dissolved in runoff, and/or as residue sorbed to eroded sediment. Major routes of carbaryl transformation in the environment include alkaline hydrolysis, photolysis in water, and soil and aerobic aquatic metabolism. Carbaryl is known to form the major degradate 1-naphthol via several of these processes.

Physical-chemical properties and known environmental fate and transport-related properties of carbaryl are provided in **Table 3- 1**. Available physical-chemical and fate data on carbaryl degradate 1-naphthol are presented in **Table 3- 2**.

Based on vapor pressure carbaryl is classified as non-volatile under field conditions, while 1-naphthol is classified as having intermediate to high volatility under field conditions ([USEPA, 2010](#_ENREF_27)). While transport in air and precipitation is not a major transport pathway, carbaryl has been detected in precipitation at up to 0.756 µg/L in rain and 4 µg/L in fog ([Foreman *et al.*, 2000](#_ENREF_6); [Mast *et al.*, 2007](#_ENREF_12); [Sanusi *et al.*, 2000](#_ENREF_19); [Vogel *et al.*, 2008](#_ENREF_43); [Waite *et al.*, 1995](#_ENREF_44)). Once in air carbaryl is expected to degrade in hours. Carbaryl is predicted to react with photochemically-generated hydroxyl radicals in the atmosphere, with half-lives on the order of hours (Atmospheric Oxidation Program version 1.70; MRID 48736402).

Potential transport mechanisms of carbaryl in air include spray drift and secondary drift of volatilized or soil-bound residues leading to deposition onto nearby or more distant ecosystems. As with all chemicals applied by aerial or ground spray, spray drift can cause exposure to non-target organisms downwind. With its greater volatility 1-naphthol, once formed, should be less persistent in the environment than carbaryl with a predicted 0.7 hour estimated half-life in air and with complete transformation observed between 3 and 20 days in aerobic systems ([Bunce, 1997](#_ENREF_3); [Kawasaki, 1980](#_ENREF_9); [Pitter, 1976](#_ENREF_17); [Rogers *et al.*, 2002](#_ENREF_18); [USEPA, 2018](#_ENREF_39)).

Degradation kinetic calculations were updated in 2020 to be consistent with the most recent guidance ([USEPA, 2015](#_ENREF_30)). The hydrolysis of carbaryl is pH dependent. At acidic pH (5) the compound is hydrolytically stable, while under neutral (pH 7) and alkaline (pH 9) conditions carbaryl hydrolyzes with half-lives of 12 days and 0.13 days, respectively. The major hydrolytic degradate is 1-naphthol, which was not itself observed to hydrolyze during the course of a 30-day study. Carbaryl photodegrades in water with an observed half-life (at pH 5) of 21 days, adjusted to reflect a 12:12 hourly light-dark cycle. Carbaryl was stable to photolysis in soil.

Degradation rates of carbaryl in studied aerobic soils range from slow to fairly rapid (half-lives of 4-253 days). These half-lives exhibit a monotonic decrease with increasing pH that is consistent with study results showing the chemical to be susceptible to hydrolysis under alkaline, but not acidic, conditions. It seems likely that the wide range in observed aerobic soil half-lives is a consequence of the variability in pH among the tested soils.

Degradation rates for carbaryl have been shown to be relatively slow (half-life: 68.9 days) under anaerobic aquatic conditions. Metabolism in the aerobic aquatic environment is more rapid, with representative half-life values ranging from 2.0 to 18.2 days. In soil and water under both aerobic and anaerobic conditions the major degradate is 1-naphthol.

Data on 1-naphthol are limited; however, 1-naphthol appears to be less mobile than carbaryl, though substantially more volatile. Data from the published literature ([Lamberton and Claeys, 1970](#_ENREF_11)) show, in graphical form (their Figure 4), approximately a 20% loss of 1-naphthol over a period of ~20 days, from combined hydrolysis and photolysis in sterile seawater. Since 1-naphthol can also be generated by a variety of natural and anthropogenic processes, including the breakdown of the polycyclic aromatic hydrocarbon (PAH) naphthalene, its presence in the environment is not necessarily indicative of carbaryl use.

Linear sorption coefficients are calculated and utilized in this assessment to be consistent with current modeling input guidance ([USEPA, 2009b](#_ENREF_25)). Carbaryl is moderately mobile in soils, according to the FAO mobility classification system. Based on batch equilibrium studies, the compound has soil-water distribution coefficients ranging from 1.33 to 2.43 L/kg. Soil sorption of carbaryl is partly a function of soil organic matter content, and increases with increasing organic carbon content, with a mean Koc of 153 mL/goc. The major degradate 1-napthol is also mobile in soil to a degree that apparently varies with soil organic carbon, with reported Kds of 0.396 and 7.73 mL/g, and corresponding Koc values of 75.9 and 240 mL/goc in lower and higher organic matter content soils, respectively ([Burgos *et al.*, 1996](#_ENREF_4)). Terrestrial field dissipation data (MRID 00155759) show dissipation half-lives of 62 to 116 days for carbaryl in the upper 30 cm of the soil profile.

Because of its low octanol/water partition coefficient of 229 ([Windholz *et al.*, 1976](#_ENREF_46)), carbaryl is not expected to bioconcentrate to a significant extent. Bioconcentration data confirm this expectation, with a bioconcentration factor of 45 L/kg-wet weight measured in whole tissues of bluegill sunfish (MRID 00159342).

Table 3- 1. General physical-chemical and environmental fate properties of carbaryl.

| **Parameter** | **Value** | | | **Reference / MRID** |
| --- | --- | --- | --- | --- |
| **Selected Physical/Chemical Parameters** | | | | |
| IUPAC Name | naphthalene-1-yl N-methylcarbamate | | | -- |
| Chemical Abstracts Service (CAS) Registry Number | 63-25-2 | | | -- |
| Chemical Structure |  | | | -- |
| Molecular Weight | 201.22 g/mol | | | Product chemistry |
| Water Solubility | 32 mg∙L-1 at 20o C | | | ([Suntio *et al.*, 1988](#_ENREF_20)) |
| Vapor Pressure | 1.3 x 10-7 torr at 25o C | | | ([Ferreira and Seiber, 1981](#_ENREF_5)) |
| Density | 1.21 kg∙L-1 @ 20o C | | | 42785102 (supplemental) |
| Henry's Law Constant | 1.28 x 10-8 atm∙m3∙mol-1 | | | ([Suntio *et al.*, 1988](#_ENREF_20)) |
| Octanol/Water Partition Coefficient (Kow) | 229 | | | ([Windholz *et al.*, 1976](#_ENREF_46)) |
| Acid Dissociation Constant (pKa) | 10.4 | | | ([Mnif *et al.*, 2011](#_ENREF_13)) |
| **Persistence2** | | | | |
| Hydrolysis (t½ @ 25°C) | stable, pH 3, SFO  stable, pH 5, SFO  >28 days, pH 6, SFO  12 days, pH 7, SFO  3.2 hours, pH 9, SFO | | | 00163847 (supplemental)  44759301 (acceptable)  00163847 (supplemental)  44759301 (acceptable) |
| Aqueous Photolysis (t½ @ 25°C, pH 5) | 21 days, SFO | | | 41982603 (acceptable) |
| Soil Photolysis (t½ @ 20°C, pH 6.2) | stable | | | 48736403 (supplemental) |
| Aerobic Soil metabolism (t½) | 3.81 days (sandy loam, pH 6,7, 25°C, SFO)  19.6 days (sandy loam, pH 6.5, 20.5°C, SFO)  49.1 days (silt loam, pH 6.3, 20.5°C, TIORE)  253 days (silty clay loam, pH 5.8, 20.5°C, TIORE) | | | 42785101 (acceptable)  49468701 (supplemental) |
| Anaerobic Aquatic metabolism (t½ @ 25°C) | 68.9 days (sandy loam system, pH 6.6, SFO) | | | 42785102 (supplemental) |
| Aerobic Aquatic metabolism (t½ @ 25°C) | 2.00 days (clay loam, pH 7.1, TIORE)  5.3 (clay loam, pH 7.98. TIORE)  18.2 (sand, pH 5.77, TIORE) | | | 43143401(supplemental)  46580701 (supplemental) |
| Foliar Degradation (t½) | 3.71 days | | | 45860501  (not classified1) |
| Foliar Washoff Coefficient | 0.91 cm-1 rainfall | | | 45860501  (not classified1) |
| **Mobility/Adsorption-Desorption** | | | | |
| Soil –water distribution coefficients (Kd) in L/kg-soil  Organic-carbon normalized Soil-water distribution coefficients (Koc) L/kg-organic carbon | **Soil** | **Kd** | **KOC** | 43259301 (acceptable)  The CV was lowest for KOC and the KOC is utilized in modeling. There was no relationship with Kd, and pH. Kd values increased with percent OC. |
| Silty clay loam | 2.43 | 122 |
| Sandy loam | 1.33 | 160 |
| sediment | 1.50 | 184 |
| Silt loam | 2.06 | 145 |
| Mean | 1.83 | 153 |
| CV | 0.28 | 0.17 |
| Bioconcentration | Whole fish (bluegill) tissue BCF = 45 L/kg-wet weight | | | 00159342  (not classified) |
| **Field Dissipation** | | | | |
| Terrestrial Field Dissipation (DT50) | 62-116 | | | 00155759  (not classified) |
| Forestry Dissipation (t½) | Foliar, 21 days  Leaf Litter, 75 days  Soil, 65 days | | | 43439801 (supplemental) |

CV = coefficient of variation; SFO=single first order; IORE=indeterminate order rate equation (IORE); SFO DT50=single first order half-life; TIORE=the half-life of a SFO model that passes through a hypothetical DT90 of the IORE fit

1 Foliar dissipation half-life is 90% upper confidence limit on mean half-life from 30 published studies submitted by registrant. Washoff coefficient was obtained from two published studies.

2 The DT50 reported is the representative model input value and is the calculated SFO DT50, TIORE, or the DFOP slow DT50 from the DFOP equation. The model and value chosen is consistent with that recommended using the, *Guidance for Evaluating and Calculating Degradation Kinetics in Environmental Media* ([NAFTA, 2012](#_ENREF_14); [USEPA, 2015](#_ENREF_30)).

Table 3- 2. General physical-chemical and environmental fate properties of carbaryl degradate 1-naphthol.

| **Parameter** | **Value** | **Reference or source** |
| --- | --- | --- |
| **Selected Physical/Chemical Parameters** | | |
| IUPAC Name | naphthalene-1-ol |  |
| Chemical Abstracts Service (CAS) Registry Number | 90-15-3 |  |
| Chemical Structure |  |  |
| Molecular Weight | 144.17 |  |
| Water Solubility | 1126 mg∙L-1 | EPISUITE |
| Vapor Pressure | 2.74 x 10-4 torr at 25o C | EPISUITE |
| Henry's Law Constant | 5.47 x 10-8 atm∙m3∙mol-1 | EPISUITE |
| Log Octanol/Water Partition Coefficient (Kow) | 2.39 | EPISUITE |
| **Persistence** | | |
| Hydrolysis (t½ @ 25°C) | Stable below pH 6.5 | ([Borracino *et al.*, 2001](#_ENREF_2); [Karthikeyen *et al.*, 1999](#_ENREF_8)) |
| Aqueous Photolysis (decay, pH 7.3) | ~20% loss over 20 days | ([Lamberton and Claeys, 1970](#_ENREF_11)) |
| Aerobic Soil metabolism (t½) | No data |  |
| Anaerobic Soil metabolism (t½ @ 25°C) | Stable | ([Karthikeyen *et al.*, 1999](#_ENREF_8)) |
| Aerobic Aquatic metabolism (t½ @ 25°C) | No data |  |
| **Mobility/Adsorption-Desorption** | | |
| Soil –water distribution coefficients | Kd=0.396 mL/g, Koc=75.9 mL/goc (“low OM”)  Kd=7.73 mL/g, Koc=240 mL/goc (“high OM”) | ([Burgos *et al.*, 1996](#_ENREF_4)) |

# Identification of Transformation Products of Concern

Carbaryl is known to form 1-naphthol, which was the primary degradate in all the degradation studies. The only other major degradate was 1, 4-napthoquinone which was found at 17.3% on the third day after study initiation in an aerobic aquatic metabolism study. Data on 1-naphthol are limited; however, 1-naphthol appears to be less mobile than carbaryl and less likely to persist with a predicted 0.7 hour half-life in air and aerobic transformation observed in aquatic and soil systems between 3 and 20 days ([Bunce, 1997](#_ENREF_3); [Kawasaki, 1980](#_ENREF_9); [Pitter, 1976](#_ENREF_17); [Rogers *et al.*, 2002](#_ENREF_18); [USEPA, 2018](#_ENREF_39)). Since 1-naphthol can occur from a variety of natural and anthropogenic processes, including the breakdown of the polycyclic aromatic hydrocarbon (PAH) naphthalene, its presence in the environment is not necessarily indicative of carbaryl usage (**Figure 3- 1**).



Figure 3- 1. Structures of carbaryl and its degradates

# Measures of Aquatic Exposure

In general, maximum application rates and minimum application retreatment intervals were modeled to estimate the exposure to carbaryl based on the master use summary document (**APPENDIX 1-2**) that was developed for carbaryl.

Carbaryl-specific modeling was conducted to simulate each selected use. This includes the selection of PWC scenarios and agronomic practices (*e.g.*, applications methods, dates). **Tables 3- 7**, **3- 8, and 3- 9** include all pertinent model input parameters as well as the justification for selecting these parameters, and the general approaches used are described below. Insufficient environmental fate data were available to model 1-naphthol. Characterization of the potential exposure to 1-naphthol is described in **Section 2**.

## Aquatic Exposure Models

Aquatic exposures (surface water and benthic sediment pore water) were quantitatively estimated for representative carbaryl uses included in the master use summary document (**APPENDIX 1-2**) by HUC 2 Regions (**Figure 3- 2**) and by aquatic bin (2-7) using the Pesticide Root Zone Model (PRZM5) coupled to the Variable Volume Water Model (VVWM)[[1]](#footnote-2) in the Pesticides in Water Calculator (PWC). The master use summary document for carbaryl includes over 700 use/formulation/application-type combinations. In order to limit simulations to a manageable number, grouping of uses into general categories was performed where possible (**APPENDIX 1-3**). Within these use groups, as well as within non-grouped uses (*e.g*., golf courses), formulations and application methods were selected that were expected to generate maximum Estimated Environmental Concentrations (EECs). Thus use/formulation/application methods that had the highest application rates and/or lowest retreatment intervals were generally chosen. Because even at a given application rate, spray drift and runoff loadings differ between aerial spray, ground spray, and dust applications, both ground and aerial spray (or dust) applications were also modeled, where applicable, for each use/formulation/application method combination. The maximum resulting EECs for each use/bin/HUC combination were then selected (*e.g*., for aerial vs. ground spray), and are assumed to represent exposures for all uses in the grouped category (*e.g*., both aerial and ground spray) for the relevant bin/HUC combination. Ornamental direct applications to trees and spot treatments were not simulated.

As mentioned elsewhere, flowing aquatic bins include bin 2 (low flow), bin 3 (moderate flow), and bin 4 (high flow).  Static aquatic bins include bin 5 (low volume), bin 6 (moderate volume), and bin 7 (high volume).  Additional information on aquatic bins is available in **ATTACHMENT 3-1**.

Aquatic bin 1 represents aquatic habitats associated with terrestrial habitats (e.g., riparian zones, seasonal wetlands) and is simulated using the PRZM5/VVWM and the Plant Assessment Tool (**Section 3.5**). Aquatic bins 8 and 9 are intertidal and subtidal near shore habitats, respectively, and aquatic bin 10 is the offshore marine habitat. EFED does not currently have standard conceptual models designed to estimate EECs for these estuarine/marine systems. EFED and the Services have assigned surrogate freshwater flowing or static systems to evaluate exposure for these estuary and marine bins. Aquatic bin 5 are used as surrogate for pesticide exposure to species in tidal pools; aquatic bins 2 and 3 are used for exposure to species at low and high tide, and aquatic bins 4 and 7 are used to assess exposure to marine species that occasionally inhabit offshore areas.

EFED modeled these flowing and static bins in previous Biological Evaluations (BEs) by using watershed drainage areas develop from flowing waterbody relationships and static bin runoff estimates ([USEPA, 2016a](#_ENREF_31); [USEPA, 2016b](#_ENREF_32); [USEPA, 2016c](#_ENREF_33)). However, the results have not been as expected. In short, one would expect daily concentrations in flowing bins to be lower than those in static bins, given that water, and any pesticide, is flowing out of the system. However, in most of the modeling runs the EECs for the flowing bins were higher, and in many cases an order of magnitude higher, than the static bins. In large part, the higher EECs were the result of modeling a large watershed using assumptions that were designed to simulate a smaller watershed. For example, it was assumed that the watershed was entirely treated on the same day. For a large watershed, it is not expected that this assumption is appropriate. For the static waterbodies, the watershed-to-waterbody ratio was not really known but was derived by determining the watershed size needed to generate runoff sufficient to fill the waterbody. This relationship relies on modeling conducted using topography, surface soil characteristics, and precipitation specific to the PWC model and scenarios considered highly vulnerable to surface water runoff. As a result, there was much uncertainty with the EECs that were being generated from the modeling in the previously completed BEs.

For carbaryl, when using PWC, EFED has relied on two standard waterbodies which have been traditionally used in EFED to estimate EECs for the various bins. The standard farm pond was used to develop EECs for the medium and large static bins (*e.g.*, bins 6 and 7) and the index reservoir for the medium and large flowing bins (*e.g.*, bins 3 and 4). For the smallest flowing and static bins (bin 2 and 5), EFED derived edge of field estimates from the PRZM daily runoff file (*e.g.*, ZTS file). **Table 3- 3** provides a crosswalk of the bins and how they were modeled.

Table 3- 3. Aquatic Bin, Modeled Waterbody Crosswalk

| **Aquatic Bin** | **Description** | **Width (m)** | **Length (m)** | **Depth (m)** | **Flow (m3/s)** | **Waterbody Used for Modeling** |
| --- | --- | --- | --- | --- | --- | --- |
| 1 | Wetland | 64 | 157 | 0.15 | Variable1 | Custom |
| 2 | Low-flowing waterbody | 2 | Field2 | 0.1 | 0.001 | Edge-of-field |
| 3 | Medium-flowing waterbody | 8 | Field2 | 1 | 1 | Index reservoir |
| 4 | High-flowing waterbody | 40 | Field2 | 2 | 100 | Index reservoir |
| 5 | Low-volume, static waterbody | 1 | 1 | 0.1 | N/A | Edge-of-field |
| 6 | Medium-volume, static waterbody | 10 | 10 | 1 | N/A | Farm pond |
| 7 | High-volume, static waterbody | 100 | 100 | 2 | N/A | Farm pond |

1 The depth and flowrate in this waterbody is variable, depending on rainfall.

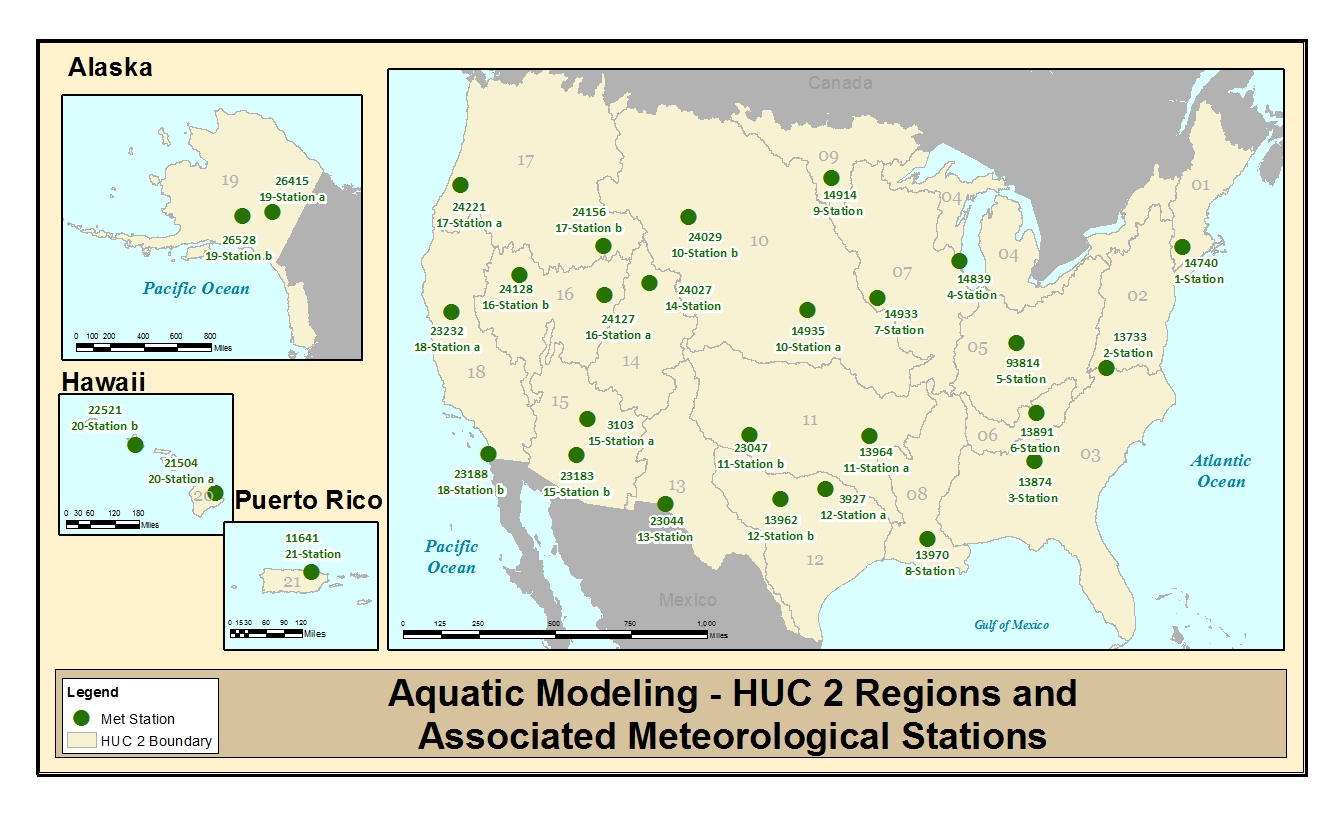
2 The habitat being evaluated is the reach or segment that abuts or is immediately adjacent to the treated field. This habitat is assumed to run the entire length of the treated area.

While the standard farm pond is bigger than bin 6, the EECs estimated for bin 6 in previous BEs were close to those generated for bin 7, and so an economy of modeling was deemed appropriate.

While the index reservoir has a much lower effluent flowrate than bins 3 and 4, it has been used as a vetted flow-through waterbody for EFED for years, with an accepted watershed-to-waterbody ratio developed for an actual vulnerable watershed (Shipman Reservoir, Shipman, IL) and has been reviewed by a previous Federal Insecticide Fungicide Rodenticide Act (FIFRA) Scientific Advisory Panel (SAP) ([USEPA, 1998](#_ENREF_21)). EFED expects the EECs that are generated using the index reservoir to be a conservative surrogate for those observed in bins 3 and 4. The watershed area associated with the index reservoir is roughly an order of magnitude smaller than the average area for a HUC 12 (the smallest areal delineation for an aquatic species range), but within the range of minimum and maximum values.

Lastly, bins 2 and 5 are very small waterbodies and the EECs in them would be reflective of concentrations in a headwater stream or a standing puddle that received runoff at the edge of a treated field. As such, edge-of-field concentrations were estimated and used as a surrogate for EECs in these waterbodies.

More detailed information can be found in **ATTACHMENT 3-1. Background Document: Aquatic Exposure Estimation for Endangered Species.**

Figure 3- 2. Hydrologic Unit Code (HUC) 2-digit Regions and Associated Metrological Data

## HUC and Use Site Crosswalk

The National Agricultural Statistics Census of Agriculture 2012 (NASS) data along with the Cropland Data Layer (CDL) were used to determine which crops would be modeled within each represented HUC 2. Additionally, specific geographic limitations on how a product may be applied to particular crops were considered when determining what rates would be simulated for different HUC 2 regions. For example, different use rates were simulated for California, Florida, and other states for citrus. If the NASS data indicated any acreage of a crop was grown in a specific HUC 2, it was assumed that the crop was grown in that HUC 2, and aquatic EECs were generated for these HUC2 regions for that crop. If there were no reported NASS cropped acres grown within a particular HUC 2, aquatic EECs for that HUC2 region and use pattern were not determined. A crop use layer-HUC 2 Region matrix for carbaryl is provided in **APPENDIX 3-1**. Limited NASS data are available for Alaska, Hawaii, and Puerto Rico, and some assumptions on which crops would be simulated in those HUC 2 regions were made.

## Scenario Selection

A PWC-scenario was developed for each landcover class and HUC2 where crops in that landcover were grown based on the NASS 2012 census data. A PWC-scenario was not developed for rice because it was simulated using PFAM. **APPENDIX 3-1** provides a crosswalk between the use site and the landcover used to represent the use site as well as which HUC 2 regions were evaluated for each use pattern.  An explanation of how the PWC scenario matrix was developed is provided in **ATTACHMENT 3-1**.

## Application Practices

### Application Method

During application of pesticides, methods of application as well as product formulation used by an applicator can impact the magnitude of off-site transport of the chemical. Label directions (such as application equipment and agronomic practices such as soil incorporation) as well as product formulation are considered as part of the development of the use scenario modeled.

There are several types of carbaryl application types included in the master use summary document (**APPENDIX 1-2**), including for uses that may occur in both agricultural and non-agricultural settings. Application equipment for carbaryl includes fixed and rotary wing aircraft, ground sprayers, chemigation systems, baits, “sprayers”, “shank applicators”, “spreaders”, and dusters. Carbaryl applications may occur at various times throughout the year, and most uses allow multiple applications per year to a given crop. There are several types of carbaryl formulations, however for modeling purposes these formulations are subdivided into liquids [emulsifiable concentrate (EC), water soluble powder (WSP), wettable powder (WP), or flowable concentrate (FLC)] and dry materials (granules, dusts).

### Spray Drift

Carbaryl labels do not include any buffer restrictions. Spray drift fractions for liquid formulations are presented in **Table 3- 4**. For dry material formulations, spray drift is assumed to be zero. Airblast spray drift assumptions were assumed for applications to orchards, grapes, and citrus use patterns that allowed for both ground and airblast applications, as this is the expected application method for carbaryl in orchards.

Table 3- 4. Estimated Spray Drift Fractions for Different Aquatic Bins and Application Methods.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Bin** | | | | | **Default Spray Drift Fraction1**  **(unitless)** | | |
| **Aquatic Bin** | **PWC Bin Number** | **Generic Habitat** | **Depth (m)1** | **Width (m)1** | **Default** | | |
| **Aerial** | **Ground** | **Airblast** |
| 1 | 10 | Wetland | 0.15 | 64 | 0.125 | 0.062 | 0.048 |
| 4 | 4 | Reservoir | 2.74 | 82 | 0.135 | 0.066 | 0.042 |
| 7 | 7 | Pond | 2 | 64 | 0.125 | 0.062 | 0.048 |

1parameters correspond to the input values used in PWC modeling.

Some carbaryl labels specify the use of handheld application equipment (*e.g.*, hose-end sprayers, hand bulb dusters, etc.). Data are not available on the magnitude of spray drift that may result from these types of applications; however, these application methods are not expected to result in substantial drift. Generally, all crops that permit the use of such equipment also permit the use of ground boom or aerial equipment. Such higher-drift (and presumably higher-exposure) application methods were therefore chosen as conservative proxies for all application methods for the relevant crops, for purposes of quantitative exposure estimation.

### Application Timing

Pesticide applications are modeled as occurring on the same Julian days every year over a 30-year time span. Uncertainty in exposure associated with varying weather conditions is represented in the meteorological data files, which reflect variability in measured daily precipitation over the multi-decadal record. The effect of this variability on pesticide concentrations is reflected and conservatively accounted for through the use, as EECs, of concentrations that have a 1-in-10-year or 1-in-15-year return frequency. For detail on application date selection for use of carbaryl, see **APPENDIX 1-3**.

## Special Agricultural Considerations

### Multiple Crop-cycles Per Year

Some labels permit applications on crops that may be planted in rotation (*e.g.*, various vegetables), or that may be grown in multiple crop seasons per year. This phenomenon could result in more carbaryl applied to a given field per year, than would necessarily be expected based upon label instructions. While crop rotations are possible for some carbaryl uses, rotations were not modeled. As the water metabolism half-life for carbaryl 18-days, accumulation of residues over time is not expected.

### Rice and Cranberry Modeling

To determine EECs for the carbaryl cranberry and rice uses, EFED used the Pesticides in Flooded Applications Model (PFAM, version 2.0). PFAM was developed specifically to estimate exposure to pesticides used in flooded agriculture, such as rice paddies and cranberry bogs. The model simulates two linked compartments when the field is flooded: a water column and a sediment zone (benthos). Each compartment is completely mixed and at internal equilibrium with respect to sorption of the chemical ([Young, 2013](#_ENREF_47)). Pesticide moves between the compartments via a time-limited, first-order mass-transfer process. The model accounts for hydrolysis, photolysis, and metabolism in water, sediment, and soil (when no water is present), sorption, and volatilization. The model considers the environmental fate properties of pesticides and allows for the specification of common management practices associated with flooded agriculture, such as scheduled flooding and water releases. Water, sediment, and pesticide may flow out of the flooded field, particularly upon deliberate water release. Changes in water body conditions (temperature, water levels, wind speed, *etc*.) and resulting changes in degradation rates are simulated on a daily time step. Pesticide application and flooding sequences are mapped onto the time series in 1-year cycles for the duration of a 30-year simulation.

Cranberries may be grown in bogs that are temporarily, deliberately flooded to control pests, prevent freezing, and/or to facilitate harvest. After flooding, water may be held on site, recirculated to other cranberry growing areas, or released to adjacent waterbodies (rivers, streams, lakes, *etc*.). For cranberries a 12-inch flood was modeled on October 1, followed by draining of the bog on October 4th. A winter flood was also simulated. The modeled flood date was selected as a plausible date of harvest. Crop stages were estimated.

PFAM was also used to estimate concentrations of carbaryl in a water body that receives flood water released from a rice paddy. Carbaryl use on rice is modeled as a direct application to the flooded rice paddy, and EECs are derived from paddy water concentrations. All available scenarios for both CA and MO were run, but only results from the scenarios that produced the highest EECs are reported. These were “CA mixed no hold” and “MO mixed no winter no hold”. For the former, a value of 29 percent crop treated (PCT) was assumed, in accordance with information presented on another insecticide in the PFAM Input Parameter Guidance ([USEPA, 2016d](#_ENREF_34); [USEPA, 2016e](#_ENREF_35); [USEPA, 2016h](#_ENREF_38)). For the MO scenario, 100 PCT was assumed.

### Plant Assessment Tool (PAT)

The Plant Assessment Tool (PAT) is a mechanistic model that incorporates fate (*e.g*., degradation) and transport (*e.g*., runoff) data that are typically available for conventional pesticides, to estimate pesticide concentrations in terrestrial, wetland, and aquatic plant habitats. For terrestrial plants, runoff and erosion are modeled using PRZM and spray drift is modeled using AgDRIFT deposition values. The model uses a mixing cell approach to represent water within the active root zone area of soil, and accounts for flow through the terrestrial plant exposure zone (T-PEZ) caused by both treated field runoff and direct precipitation onto the T-PEZ. Pesticide losses from the T-PEZ occur from transport (*i.e*., washout and infiltration below the active root zone) and degradation. Wetlands are modeled using PRZM/VVWM and are then processed in PAT to estimate aquatic (mass per volume of water) and terrestrial (mass per area) concentrations. Aquatic plants exposure is modeled using the PRZM/VVWM models and the standard farm pond.

### Pesticide in Water Calculator

To account for the potential exposure to carbaryl as a result of a runoff event that occurs prior to or after a flooding event (*i.e.*, not directly associated with an intentional flooding event) in a cranberry bog, as well as to represent cranberries grown in a more traditional field setting, PWC version 2.001 was also used to estimate carbaryl concentrations in aquatic bins as result of the use of the chemical’s use on cranberries. Carbaryl is used on a number of types of berries, which were grouped together and considered as a unit for purposes of modeling with PWC (**APPENDIX 1-3**). While the typical surface runoff simulated in the PWC does not apply to cranberries grown in bogs, residues may be transported in runoff from non-impounded cranberry bogs just as they would from fields in which other kinds of berries are grown under non-flooded conditions. Also, some cranberries are dry harvested and may not be grown in low-lying or bog-like areas. Therefore, the PWC simulations of berries are considered to encompass carbaryl applications to cranberries that are dry-harvested.

## Non-Agricultural Uses and Considerations

### Exposure from Urban, Suburban and Homeowner Uses

Carbaryl has a number of registered uses that fit the general description of urban, suburban, or homeowner application. These include commercial/institutional/industrial premises, household/domestic dwellings, non-agricultural outdoor buildings, nuisance pests – perimeter treatment, non-agricultural rights-of-way, ornamental and/or shade trees, paths/patios, residential lawns, gardens, turf, along fences, porches *etc*. When considered together, uses such as these could encompass a substantial fraction of an urban or suburban watershed. **Table 3- 5** summarizes these uses, rates, intervals for different areas.

Table 3- 5. Application information for modeled homeowner scenario based on maximum labeled application rates.

|  |  |
| --- | --- |
| **PWC Scenario** | **Residential** |
| Included uses | Garden, turf  House perimeter, along fences, patios, garbage cans, under porches, shrubbery, firewood piles, ornamentals |
| Application rate | 8.36 lbs a.i./A, 4 x1 |
| Application interval | 7 days |

1 Highest homeowner use rate Reg. No. 9198-146 allows for broadcast to lawns, recreational and ornamental turf areas to control various insect pests; control of nuisance pests in and around ornamentals and outside of buildings; and on home fruit and vegetable gardens.

Example residential application instructions include:

* Make applications to lawns, shrub beds, ornamental plantings, wooded areas and around outside perimeters of homes and other buildings. Treat entire lawn and perimeter wooded areas and property boundaries where exposure to ticks may occur.
* Using a spreader, apply granules in a 6-foot band round the home, to shrub and flowerbeds, foundations, ornamental plantings, lawn, or soil.

EFED modeled the entire residence using the Residential ESA scenarios, with the curve number of 83, as these scenarios were readily available, carbaryl is expected to be mainly applied to pervious surfaces, the curve number is in the range of curve numbers reflected for developed open spaces (**Table 3- 6**), and this simplifies the modeling for residential uses.

**Table 3- 6. Curve Number Guidance based on NRCS TR-55 Methodology**

| **Cover Type** | **Treatment of practice** | **Hydrologic Condition (HC) or Percent Impervious surface** | **Hydrologic Soil Group** | | | |
| --- | --- | --- | --- | --- | --- | --- |
| **A** | **B** | **C** | **D** |
| Developed Open Space | <50% grass cover | Poor HC | 68 | 79 | 86 | 89 |
| 50 – 75% grass cover | Fair HC | 49 | 69 | 79 | 84 |
| >75% grass cover | Good HC | 39 | 61 | 74 | 80 |
| Residential | 1/8 ac lots or less | 65% impervious | 77 | 85 | 90 | 92 |
| ¼ acre lots | 38% impervious | 61 | 75 | **83** | 87 |
| 1/3 acre lots | 30% impervious | 57 | 72 | 81 | 86 |
| ½ acre lots | 25% impervious | 54 | 70 | 80 | 85 |
| 1 acre lots | 20% impervious | 51 | 68 | 79 | 84 |
| 2 acre lots | 12% impervious | 46 | 65 | 77 | 82 |

Table produced from page 42 Appendix D on instructions for determining curve number for developing PWC scenarios ([USEPA, 2019a](#_ENREF_40)). The bold value is the value chosen to parameterize the curve number for the CAresidentialRLF scenario.

An estimate of the number of residential lots in a 10-ha watershed has been previously evaluated for California Red Legged Frog (CRLF) and other endangered species assessments [*i.e.*, Appendix G of “Potential Risks of Alachlor Use to Federally Threatened California Red-legged Frog (Rana aurora draytonii) and Delta Smelt (*Hypomesus transpacificus*)”, USEPA 2009]. The assumption previously made was 58 lots arranged in 10 lot blocks([USEPA, 2009c](#_ENREF_26)). There are 10,890 ft2/lot x 58 lots in 10 ha = 631,620 ft2 out of a total of 1,076,391 ft2/ watershed (*i.e.*, 10 ha), resulting in an adjustment factor of 0.587. As a result, EECs for residential uses were adjusted by a factor of 0.587.

## Aquatic Modeling Input Parameters

The following sections discuss methods used for aquatic modeling.  Summaries of the environmental fate model input parameters used in the PWC and PFAM for the modeling of carbaryl are presented in **Tables 3- 7** and **3- 8** and **3- 9**, respectively. Input parameters are selected in accordance with the following EPA guidance documents:

* Guidance for *Selecting Input Parameters in Modeling the Environmental Fate and Transport of Pesticides*, Version 2.1[[2]](#footnote-3) ([USEPA, 2009a](#_ENREF_24)),
* Guidance for Evaluating and Calculating Degradation Kinetics in Environmental Media[[3]](#footnote-4) ([NAFTA, 2012](#_ENREF_14); [USEPA, 2012](#_ENREF_28)), and
* *Guidance on Modeling Offsite Deposition of Pesticides Via Spray Drift for Ecological and Drinking Water Assessment*[[4]](#footnote-5) ([USEPA, 2013](#_ENREF_29))

Table 3- 7. Input values used for tier II surface water modeling using the PWC and PFAM.

| **Parameter (units)** | **Value** | **Source** | **Comments** |
| --- | --- | --- | --- |
| Organic-carbon Normalized Soil-water Distribution Coefficient (KOC (L/kg-OC)) | 153 | MRID 45860501 | Mean of %OC-normalized Freundlich adsorption coefficient for three soils and one sediment. |
| Water Column Metabolism Half-life or Aerobic Aquatic Metabolism Half-life (days) 25 ˚C | 18 | MRID 43143401/ 46580701/ 46580702 | The 90 percent upper confidence limit on the mean of 3 aerobic aquatic metabolism half-life values. The hydrolysis half-life at pH 7 was 12-days and >28-days at pH 6. |
| Benthic Metabolism Half-life or Anaerobic Aquatic Metabolism Half-life (days) 25°C | 207 | MRID 42785102 | Only one half-life value is available, so this value (68.9 days) is multiplied by 3 to arrive at 207 days. |
| Aqueous Photolysis Half-life at pH 5 (days) and 40° Latitude, 25oC | 21 | MRID 41982603 | Compound is stable to hydrolysis at pH 5. Half-life is corrected to reflect a 12 hr:12 hr light:dark irradiation regime. |
| Hydrolysis Half-life (days) | 0 | MRIDs 00163847  44759301  00163847 | The aerobic aquatic metabolism half-life value was not corrected for hydrolysis. Therefore, hydrolysis is set to 0 (stable) here as it is already accounted for in the aerobic aquatic metabolism input parameter. |
| Soil Half-life or Aerobic Soil Metabolism Half-life (days), 20.5 ˚C | 176 | MRID 42785101 49468701 | The 90 percent upper confidence limit on the mean of four aerobic soil metabolism half-life values. |
| Molecular Weight (g/mol) | 201.22 | product chemistry | -- |
| Vapor Pressure (Torr) at 25 oC | 1.3 x 10-7 torr | product chemistry  BC 2062713 | ([Ferreira and Seiber, 1981](#_ENREF_5)) |
| Solubility in Water at 20 oC(mg/L) | 32 | MRID 41829006 | ([Suntio *et al.*, 1988](#_ENREF_20)) |
| Foliar Degradation Half-life (days) | 3.71 | MRID 45860501 | The 90 percent upper confidence limit on the mean of 30 published values. |
| Application Efficiency | 0.99 (ground; air-blast))  0.95 (aerial)  1.0 (granulars, dusts) | Default Values | -- |
| Application Drift | See **Table 3- 4** | -- | -- |
| Heat of Henry J/mol | 58,000 | -- | See Appendix B of PFAM input parameter guidance ([USEPA, 2016e](#_ENREF_35)) |

The pesticide in flooded applications model (PFAM) version 2 was used to estimate concentrations of carbaryl in flood water in cranberry bogs and rice paddies ([USEPA, 2016f](#_ENREF_36)). The reported concentrations represent water introduced to the field and not mixed with any additional water (*i.e.*, receiving waters). These concentrations are expected to exceed those that would be found in adjacent water bodies, due to additional degradation and dilution that would occur upon, and subsequent to, flood water release. The EECs in the rice paddy were used for surrogates for aquatic bins 2, 3, 4, 5, 6, and 7.

For cranberries, a 12-inch flood was modeled on October 1, followed by draining the bog on October 4th. A winter flood was also simulated. The modeled flood date was selected as a plausible date of harvest. Crop stages were estimated. **Table 3- 8** summarizes the PFAM inputs assumed for setting up the cranberry modeling. The EECs for the cranberry bog were compared to the EECs calculated for other berries. If the EECs were similar, the EECs calculated for the cranberry bog were characterized but not utilized in the MAGtool.

For rice all available “eco STD with turnover” scenarios were run, but only results from the scenarios that produced the highest EECs are reported ([USEPA, 2016f](#_ENREF_36)). **Table 3- 9** summarizes the PFAM inputs assumed for setting up the rice modeling.

Table 3- 8. PFAM specific input values used for tier II surface water modeling for cranberries.

| **Input Parameter** | **Value** | **Source** | **Comment** |
| --- | --- | --- | --- |
| **Chemical Tab, see Table 3-7** | | | |
| **Applications Tab** | | | |
| Application rate | 2.04 a.i./A  2.28 kg a.i./ha | Carbaryl Use Summary Table (**APPENDIX 1-2**) | -- |
| Number of Applications | 5 | --- | --- |
| Application dates | 05/07  05/14  05/21  05/28  06/04 | --- | 7-day minimum retreatment interval |
| Slow Release 1/day | 0 | -- | Not applicable |
| Drift Application | 0 | -- | Drift to an adjacent water body or mixing cell was not modeled. |
| **Flood Tab** | | | |
| Number of Flood Events | 4 | -- | Harvest occurs between September and November. Field is flooded just prior to harvest. Field may also be flooded over the winter from December through March 15 (Cape Cod Cranberry Growers Association, 2001). The winter flood height was assumed to be the harvest flood height. In some areas, there is also a late water flood to control spring frost where the bog is flooded in late April for one month. This was not simulated. |
| Date of Event 1 (Month-Day) | 10-01 | -- |
| Turn Over (1/day) | 0 | Assumed |
| Days After (Month-day) | Fill Level, Min Level (m) | Weir (m) |
| 0 (Oct-1) | 0.305 | 0.458 |
| 3 (Oct-4) | 0 | 0 |
| 61 (Dec-1) | 0.305 | 0.458 |
| 105 (March-15) | 0 | 0 |
| **Crop Tab** | | | |
| Zero Height Reference | 05/01 | Information from Maine Cooperative Extension (Armstrong, 2015) | |
| Days from Zero Height to Full Height | 120 (08/29) | Assumed | |
| Days from Zero Height to Removal | 153 (10/1) | Assumed | |
| Maximum Fractional Areal Coverage | 0.2 | Value from OR berries PE scenario | |
| **Physical Tab** | | | |
| Meteorological files | CT W14740  NJ W14734  WI\_2 W14839  WI W14920  OR W24221 | Weather stations from cranberry growing areas | |
| Latitude | 42.3 | Latitudes are 41.6 in CT, 40.0 in NJ, 44.5 in WI, and 44.0 in OR. These are close enough that a default latitude was chosen. | |
| Weir Leakage (m/d) | 0 | PFAM default | |
| Benthic Leakage (m/d) | 0 | PFAM default | |
| Water-sediment mass transfer coefficient (m/s) | 1x10-8 | PFAM default | |
| Reference depth (m) | 0.458 | Set to same depth as weir height. | |
| Benthic depth (m) | 0.05 | PFAM default | |
| Benthic porosity | 0.50 | PFAM default | |
| Dry bulk density (g/cm3) | 1.35 | PFAM default | |
| FOC Water Column on SS | 0.04 | PFAM default | |
| FOC benthic | 0.01 | PFAM default | |
| Suspended Sediment (mg/L) | 30 | PFAM default | |
| Water column DOC (mg/L) | 5.0 | PFAM default | |
| Chlorophyll CHL (mg/L) | 0.005 | PFAM default | |
| Dfac | 1.19 | PFAM default | |
| Q10 | 2 | PFAM default | |

Table 3- 9. PFAM specific input values used for tier II surface water modeling for rice.

| **Input Parameter** | **Value** | **Source** | **Comment** |
| --- | --- | --- | --- |
| **Chemical Tab, see Table 3.7** | | | |
| **Applications Tab** | | | |
| Application rate | 1.53 lbs a.i./A  1.71 kg a.i./ha | Carbaryl Use Summary Table (**APPENDIX 1-2**) | --- |
| Number of Applications | 2 | --- | --- |
| Application dates | 05/07  05/14 | --- | 7-day minimum retreatment interval |
| Slow Release 1/day | 0 | -- | Not applicable |
| Drift Application | 0 | -- | Drift to an adjacent water body or mixing cell was not modeled. |

## Aquatic Modeling Results

The estimated environmental concentrations (EECs) derived from the PWC modeling based on maximum labeled rates included in the master use summary document, by HUC 2, are summarized for the various aquatic bins in **Table 3- 10** and **Table 3- 11**, for water column and pore water, respectively. The complete set of modeling results is available in **APPENDIX 3-1**. PWC model runs and post-processed results are provided in **APPENDIX 3-2**. The range of EECs reflects the various application rates and timings for the various crops and scenarios modeled in the HUC 2 regions. Note that **Table 3- 10** and **Table 3- 11** include EECs generated for the urban use scenario developed for carbaryl.

Table 3- 10. The range of PWC daily average water column EECs for carbaryl.

| **HUC 2** |  | **Range of 1-in-15 year Daily Average EECs (µg/L)** | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Bin 1** | **Bin 2** | **Bin 3** | **Bin 4** | **Bin 5** | **Bin 6** | **Bin 7** |
| HUC 1 | 125 - 4540 | 241 - 1566 | 29.38 - 460.3 | 29.38 - 460.3 | 241 - 1566 | 17.47 - 346.2 | 17.47 - 346.2 |
| HUC 2 | 90 - 7570 | 84 - 2085 | 7.267 - 365.3 | 7.267 - 365.3 | 84 - 2085 | 4.963 - 265.5 | 4.963 - 265.5 |
| HUC 3 | 130 - 2440 | 261 - 3663 | 44.33 - 633.4 | 44.33 - 633.4 | 261 - 3663 | 28.47 - 445.8 | 28.47 - 445.8 |
| HUC 4 | 81.2 - 7400 | 118 - 2589 | 10.12 - 364 | 10.12 - 364 | 118 - 2589 | 6.713 - 259.4 | 6.713 - 259.4 |
| HUC 5 | 86.7 - 4290 | 232 - 2233 | 33.44 - 480.1 | 33.44 - 480.1 | 232 - 2233 | 19.08 - 342.6 | 19.08 - 342.6 |
| HUC 6 | 66.3 - 3350 | 196 - 2069 | 24.2 - 569 | 24.2 - 569 | 196 - 2069 | 13.06 - 394 | 13.06 - 394 |
| HUC 7 | 82.8 - 6640 | 205 - 2433 | 32.85 - 504.4 | 32.85 - 504.4 | 205 - 2433 | 20.87 - 370.9 | 20.87 - 370.9 |
| HUC 8 | 102 - 6840 | 185 - 1723 | 67.09 - 369.7 | 67.09 - 369.7 | 185 - 1723 | 38.31 - 266 | 38.31 - 266 |
| HUC 9 | 66.3 - 7270 | 114 - 1726 | 14.99 - 314.2 | 14.99 - 314.2 | 114 - 1726 | 9.455 - 224.4 | 9.455 - 224.4 |
| HUC 10a | 66.7 - 10400 | 271 - 4364 | 26.92 - 399.8 | 26.92 - 399.8 | 271 - 4364 | 14 - 277.2 | 14 - 277.2 |
| HUC 10b | 39 - 7870 | 128 - 2693 | 5.547 - 291.6 | 5.547 - 291.6 | 128 - 2693 | 4.521 - 197 | 4.521 - 197 |
| HUC 11a | 117 - 3880 | 109 - 2386 | 7.355 - 432.5 | 7.355 - 432.5 | 109 - 2386 | 4.628 - 317.1 | 4.628 - 317.1 |
| HUC 11b | 122 - 7810 | 245 - 1409 | 29.95 - 374.9 | 29.95 - 374.9 | 245 - 1409 | 18.52 - 289.6 | 18.52 - 289.6 |
| HUC 12a | 46.1 - 7980 | 224 - 1929 | 12.82 - 240.2 | 12.82 - 240.2 | 224 - 1929 | 8.365 - 200.4 | 8.365 - 200.4 |
| HUC 12b | 91.8 - 4870 | 192 - 3076 | 44.2 - 590.7 | 44.2 - 590.7 | 192 - 3076 | 25.75 - 445.3 | 25.75 - 445.3 |
| HUC 13 | 109 - 7850 | 167 - 2819 | 23.67 - 541.3 | 23.67 - 541.3 | 167 - 2819 | 13.07 - 394.7 | 13.07 - 394.7 |
| HUC 14 | 102 - 6060 | 184 - 3156 | 45.82 - 565.8 | 45.82 - 565.8 | 184 - 3156 | 25.19 - 402.7 | 25.19 - 402.7 |
| HUC 15a | 73.1 - 8540 | 181 - 3594 | 36.55 - 436.4 | 36.55 - 436.4 | 181 - 3594 | 20.7 - 253.7 | 20.7 - 253.7 |
| HUC 15b | 71.3 - 5730 | 105 - 5568 | 11.21 - 816.4 | 11.21 - 816.4 | 105 - 5568 | 7.085 - 460 | 7.085 - 460 |
| HUC 16a | 40.1 - 5690 | 262 - 6438 | 9.715 - 604.2 | 9.715 - 604.2 | 262 - 6438 | 6.092 - 325 | 6.092 - 325 |
| HUC 16b | 34.6 - 10300 | 177 - 2967 | 19.56 - 240.8 | 19.56 - 240.8 | 177 - 2967 | 9.547 - 173.9 | 9.547 - 173.9 |
| HUC 17a | 47.8 - 9580 | 101 - 3161 | 2.746 - 169.9 | 2.746 - 169.9 | 101 - 3161 | 1.154 - 154.5 | 1.154 - 154.5 |
| HUC 17b | 58.6 - 2230 | 92 - 2686 | 18.91 - 509.7 | 18.91 - 509.7 | 92 - 2686 | 12.43 - 437.6 | 12.43 - 437.6 |
| HUC 18a | 30.6 - 7410 | 62 - 2660 | 3.687 - 293.9 | 3.687 - 293.9 | 62 - 2660 | 3.816 - 202 | 3.816 - 202 |
| HUC 18b | 31.8 - 5200 | 196 - 3291 | 13.6 - 280 | 13.6 - 280 | 196 - 3291 | 8.208 - 203.2 | 8.208 - 203.2 |
| HUC 19a | 30.7 - 7400 | 201 - 3902 | 25.54 - 311.6 | 25.54 - 311.6 | 201 - 3902 | 13.37 - 197.8 | 13.37 - 197.8 |
| HUC 19b | 40 - 10800 | 120 - 2869 | 24.3 - 368.9 | 24.3 - 368.9 | 120 - 2869 | 11.28 - 269.6 | 11.28 - 269.6 |
| HUC 20a | 51.9 - 6350 | 118 - 3067 | 26.54 - 483.8 | 26.54 - 483.8 | 118 - 3067 | 15.48 - 395.8 | 15.48 - 395.8 |
| HUC 20b | 133 - 1200 | 126 - 1957 | 42.61 - 417.2 | 42.61 - 417.2 | 126 - 1957 | 28.45 - 640.9 | 28.45 - 640.9 |
| HUC 21 | 146 - 6210 | 161 - 3228 | 16.31 - 859.8 | 16.31 - 859.8 | 161 - 3228 | 21.04 - 580.3 | 21.04 - 580.3 |

Table 3- 11. The range of PWC pore water EECs for carbaryl

| **HUC 2** | **Range of 1-in-15 year EECs (µg/L)** | | | | | |
| --- | --- | --- | --- | --- | --- | --- |
| **Bin 21** | **Bin 3** | **Bin 4** | **Bin 51** | **Bin 6 (7)** | **Bin7** |
| HUC 1 | 243 - 2105 | 9.129 - 2788 | 9.129 - 2788 | 243 - 2105 | 6.398 - 733 | 6.398 - 733 |
| HUC 2 | 84.0 - 2179 | 1.773 - 475.3 | 1.773 - 475.3 | 84.0 - 2179 | 1.63 - 130 | 1.63 - 130 |
| HUC 3 | 261 - 3675 | 12.47 - 1162 | 12.47 - 1162 | 261 - 3675 | 11.12 - 318.3 | 11.12 - 318.3 |
| HUC 4 | 120 - 2673 | 2.56 - 814.3 | 2.56 - 814.3 | 120 - 2673 | 2.317 - 208.8 | 2.317 - 208.8 |
| HUC 5 | 233 - 2293 | 9.389 - 623.7 | 9.389 - 623.7 | 233 - 2293 | 7.715 - 137 | 7.715 - 137 |
| HUC 6 | 196 - 2095 | 6.644 - 415.1 | 6.644 - 415.1 | 196 - 2095 | 3.763 - 142.6 | 3.763 - 142.6 |
| HUC 7 | 205 - 2529 | 7.164 - 1036 | 7.164 - 1036 | 205 - 2529 | 5.852 - 302.4 | 5.852 - 302.4 |
| HUC 8 | 185 - 1729 | 10.89 - 812.1 | 10.89 - 812.1 | 185 - 1729 | 8.205 - 260.4 | 8.205 - 260.4 |
| HUC 9 | 114 - 1870 | 4.272 - 414.7 | 4.272 - 414.7 | 114 - 1870 | 2.969 - 109.5 | 2.969 - 109.5 |
| HUC 10a | 246 - 1430 | 6.914 - 377.9 | 6.914 - 377.9 | 246 - 1430 | 5.644 - 104.2 | 5.644 - 104.2 |
| HUC 10b | 225 - 1953 | 5.012 - 148.9 | 5.012 - 148.9 | 225 - 1953 | 3.33 - 83.16 | 3.33 - 83.16 |
| HUC 11a | 192 - 3109 | 10.32 - 740.2 | 10.32 - 740.2 | 192 - 3109 | 7.351 - 169.9 | 7.351 - 169.9 |
| HUC 11b | 167 - 2849 | 5.346 - 401.4 | 5.346 - 401.4 | 167 - 2849 | 3.539 - 148.1 | 3.539 - 148.1 |
| HUC 12a | 184 - 3193 | 10.89 - 1077 | 10.89 - 1077 | 184 - 3193 | 7.247 - 276.3 | 7.247 - 276.3 |
| HUC 12b | 181 - 3639 | 7.712 - 588 | 7.712 - 588 | 181 - 3639 | 6.655 - 133.8 | 6.655 - 133.8 |
| HUC 13 | 271 - 4382 | 5.756 - 307.6 | 5.756 - 307.6 | 271 - 4382 | 3.448 - 92.91 | 3.448 - 92.91 |
| HUC 14 | 128 - 2698 | 2.464 - 113.5 | 2.464 - 113.5 | 128 - 2698 | 2.027 - 82.38 | 2.027 - 82.38 |
| HUC 15a | 105 - 5660 | 3.8 - 707.4 | 3.8 - 707.4 | 105 - 5660 | 2.619 - 231.7 | 2.619 - 231.7 |
| HUC 15b | 262 - 6489 | 1.689 - 170.2 | 1.689 - 170.2 | 262 - 6489 | 1.152 - 72.23 | 1.152 - 72.23 |
| HUC 16a | 177 - 2998 | 7.762 - 98.02 | 7.762 - 98.02 | 177 - 2998 | 4.684 - 76.07 | 4.684 - 76.07 |
| HUC 16b | 101 - 3195 | 1.079 - 71.66 | 1.079 - 71.66 | 101 - 3195 | 0.4413 - 71.26 | 0.4413 - 71.26 |
| HUC 17a | 98 - 2737 | 7.771 - 240.1 | 7.771 - 240.1 | 98 - 2737 | 5.457 - 201.7 | 5.457 - 201.7 |
| HUC 17b | 63 - 2707 | 1.566 - 114.7 | 1.566 - 114.7 | 63 - 2707 | 1.525 - 81.68 | 1.525 - 81.68 |
| HUC 18a | 196 - 3315 | 4.912 - 119.7 | 4.912 - 119.7 | 196 - 3315 | 3.065 - 88.79 | 3.065 - 88.79 |
| HUC 18b | 202 - 3920 | 8.845 - 98.44 | 8.845 - 98.44 | 202 - 3920 | 4.829 - 67.43 | 4.829 - 67.43 |
| HUC 19a | 123 - 2945 | 8.106 - 195.5 | 8.106 - 195.5 | 123 - 2945 | 4.17 - 145.4 | 4.17 - 145.4 |
| HUC 19b | 120 - 3139 | 10.52 - 271 | 10.52 - 271 | 120 - 3139 | 5.967 - 227.1 | 5.967 - 227.1 |
| HUC 20a | 126 - 1959 | 6.105 - 485.2 | 6.105 - 485.2 | 126 - 1959 | 7.006 - 227.1 | 7.006 - 227.1 |
| HUC 20b | 161 - 3232 | 5.25 - 185 | 5.25 - 185 | 161 - 3232 | 5.619 - 187.5 | 5.619 - 187.5 |
| HUC 21 | 109 - 2389 | 1.883 - 301 | 1.883 - 301 | 109 - 2389 | 1.454 - 104.9 | 1.454 - 104.9 |

1 Pore water concentrations for bins 2 and 5 have been estimated using edge-of-field runoff from the dissolved and eroded soil amounts from the ZTS file.

Simulations using meteorological data for different wet-harvested cranberry growing areas resulted in similar EECs. PFAM results included 1-in-10 year aquatic EECs of 97.6 to 550 µg/L for concentrations of carbaryl in cranberry bogs, and were within (though closer to the lower than the upper end of) the range of EECs generated using PWC for various HUC 2 regions and aquatic bins (1.15 to 10,800 µg/L).

Simulations using meteorological data for different rice growing areas also resulted in similar EECs. PFAM results included 1-in-10 year aquatic EECs of 1,770 to 2,700 µg/L for concentrations of carbaryl in rice paddies, and again were within the range of EECs generated using PWC for various HUC2 regions and aquatic bins 1.15 to 10,800 µg/L).

**Table 3- 12** summarizes the 1-in-10-year daily average EECs from PFAM modeling.

Table 3- 12. Estimated Environmental Concentration from PFAM Modeling for Cranberry and Rice Use Patterns.

|  |  |  |  |
| --- | --- | --- | --- |
| **Scenario**  **Application Date**  **(App Date and Rate lb a.i./A)** | **HUC 2** | **State** | **Daily Average EECs (µg/L)** |
| **Rice** | | | |
| ECO AR noWinter  5/7, 5/14 at 1.5 lbs a.i./A | 11, 08, 07 | Arkansas | 2610 |
| ECO CA Winter  5/7, 5/14 at 1.5 lbs a.i./A | 16, 17, 18 | California | 2700 |
| ECO LA Winter  4/17, 4/24 at 1.5 lbs a.i./A | 08 | Louisiana | 2640 |
| ECO MO noWinter  5/7, 5/14 at 1.5 lbs a.i./A | 05, 06, 07, 08, 11 | Missouri | 1770 |
| ECO MS noWinter (winter)  5/7, 5/14 at 1.5 lbs a.i./A | 03, 08 | Mississippi | 1770 |
| ECO TX Winter  4/11, 4/14 at 1.5 lbs a.i./A | 12 | Texas | 2650 |
| **Cranberry** | | | |
| MA\_Cranberry\_Winter Flood  5/7, 5/14, 5/21, 5/28, 6/04 with 2.03 lbs ai/A | 02 | Massachusetts | 550 |
| OR\_Cranberry\_No Flood  5/7, 5/14, 5/21, 5/28, 6/04 with 2.03 lbs ai/A | 17 | Oregon | 97.6 |
| OR\_Cranberry\_Winter Flood  5/7, 5/14, 5/21, 5/28, 6/04 with 2.03 lbs ai/A | 17 | Oregon | 473 |
| WI\_Cranberry\_Winter Flood  5/7, 5/14, 5/21, 5/28, 6/04 with 2.03 lbs ai/A | 07 | Wisconsin | 711 |

## Available Monitoring Data

Some important regulatory changes occurred from 2005 to 2008 with implementation of the re-registration mitigations. Applications to wheat were cancelled, aerial applications of some formulations were no longer allowed, broadcast applications of liquid formulations were cancelled in residential settings, and dust applications in agricultural settings were cancelled ([USEPA, 2007](#_ENREF_22); [USEPA, 2008](#_ENREF_23)). Because these registration changes have the potential to impact concentrations that may be observed in monitoring, Water Quality Portal data are summarized for before and after 2006 and were used in the weight of evidence analysis in the MAGtool (discussed in **Chapter 4**).  Monitoring data used in the downstream transport were not updated from the draft BE as it did not impact any of the effects calls.

### Field Studies

Walters *et al* ([2003](#_ENREF_45)) measured residues of carbaryl in surface water after application of carbaryl to trees, shrubs, and herbaceous plants in residential areas to control the glassy-winged sharpshooter (*Homaladosica coagulata*) in Porterverille, Fresno, Rancho Cordova, Brentwood, and Chico, California. Applications of carbaryl were made with a truck mounted sprayer following rates recommended on labels to areas ranging from 24 to 2,300 hectares. Surface water samples were collected from various waters near applications or adjacent to treated areas. No detections of carbaryl were observed in pretreatment samples collected from the same sites. Carbaryl was detected at 0.125 µg/L in a water treatment basin, at 6.94 µg/L in a goldfish pond, and 1,737 µg/L in a rain runoff sample collected from a drain adjacent to a sprayed site.

### General Monitoring Data

Examination of the EPA 303(d) list of impaired waters on December 2, 2019[[5]](#footnote-6) indicates that carbaryl was the cause of impairment for 88 river and stream miles ([USEPA, 2019b](#_ENREF_41)).

Water monitoring data were obtained from the National Water Quality Monitoring Council’s Water Quality Data Portal ([USEPA and USGS, 2021](#_ENREF_42)) in February 2021, which is supplied by the USGS NWIS and EPA STORET databases of monitoring data collected across the United States by numerous federal, state, tribal and local agencies. Prominent contributors to this database include the USGS National Water-Quality Assessment Program (NAWQA) and various state and local agencies including California’s Department of Water Resources and State Water Resources Control Board; Minnesota’s Pollution Control Agency and Department of Agriculture; and Collier and Dade counties in Florida, along with the South Florida Water Management District. Data were also specifically obtained from the Washington State Department of Ecology and Agriculture (WSDE/WSDA) Cooperative Surface Water Monitoring Program, the Oregon Department of Environmental Quality’s (DEQ) Laboratory Analytical Storage and Retrieval (LASAR) database, and the California Department of Pesticide Regulation SURF database. Some of the data may occur in more than one database.

In general, the surface water monitoring data include sampling sites that represent a range of aquatic environments including small and large water bodies, rivers, reservoirs, and urban and agricultural locations, but are limited for some areas of the United States where carbaryl use occurs. Also, the sampling sites, as well as the number of samples, vary by year. The vulnerability of the sampling site to carbaryl contamination varies substantially due to use, soil characteristics, weather and agronomic practices. For the studies that did not specifically target carbaryl use, peak concentrations of carbaryl likely went undetected in these programs. The various monitoring programs did not detect carbaryl with high frequency, but carbaryl detections ranged from <0.01 µg/L up to 335 µg/L (surface water sample from 1973 from a creek in Pennsylvania). Many of the high detections were historical and were reported in the late 1980s, but several more recent detections exceeded 1 ug/L. The extent to which historical values represent current agronomic or labeled use instructions is uncertain and data collected after 2006 are more likely reflective of current use patterns.

Therefore, while there are many individual samples collected and analyzed for carbaryl across the United States, it would not be appropriate to combine these data sources to generate exposure estimates or to use these datasets to represent exposure on a national or even regional basis. While these data demonstrate potential exposure, using the measured concentrations as an upper bound exposure estimate would not be a reasonable approach for the reasons given above, including limited sample frequency, limited use information, and sampling site variability, on a national or even a regional basis. Therefore, model estimated concentrations are considered a suitable upper bound concentration for carbaryl.

#### Water Quality Portal

Surface water and groundwater carbaryl data were obtained in February 2021 in a download of data from the Water Quality Data Portal (<http://www.waterqualitydata.us/>). **Table 3-13** provides a summary of the results by HUC 2 region, with sampling occurring from 2007 to 2021 at over 4,452 sites with a maximum detected concentration of 14.1 µg/L. **Table 3-14** provides a summary of the results by HUC 2 region, with sampling occurring from 1973 to 2006 at over 6,367 sites with sampling in every HUC 2 region with a maximum detected concentration of 335 µg/L.

Table 3- 13. Water Quality Portal Monitoring Data Summarized by 2-digit HUC for Samples Collected After 2006

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **HUC-2** | **Years** | **Number of Sites** | **Number of Samples** | **Number of Detections** | **Measured Detection Range (µg/L)** |
| 01 | 2007 - 2020 | 64 | 728 | 88 | 0.00051 - 0.361 |
| 02 | 2007 - 2020 | 755 | 3476 | 550 | 0.00085 - 1.44 |
| 03 | 2007 - 2020 | 324 | 3854 | 1094 | 0.0006 - 2.18 |
| 04 | 2007 - 2020 | 405 | 2944 | 237 | 0.00039 - 0.99 |
| 05 | 2007 - 2020 | 59 | 1334 | 85 | 0.00038 - 0.038 |
| 06 | 2007 - 2020 | 15 | 340 | 13 | 0.004 - 0.033 |
| 07 | 2007 - 2020 | 724 | 7208 | 192 | 0.00106 - 2 |
| 08 | 2007 - 2020 | 37 | 2006 | 73 | 0.00112 - 0.096 |
| 09 | 2007 - 2020 | 130 | 562 | 12 | - |
| 10 | 2007 - 2020 | 332 | 4162 | 723 | 0.00059 - 0.67 |
| 11 | 2007 - 2020 | 92 | 1679 | 179 | 0.00101 - 3.13 |
| 12 | 2007 - 2020 | 94 | 1758 | 234 | 0.00111 - 0.351 |
| 13 | 2007 - 2021 | 61 | 677 | 9 | 0.004 - 0.034 |
| 14 | 2007 - 2020 | 82 | 777 | 14 | 0.00144 - 0.4 |
| 15 | 2007 - 2020 | 92 | 759 | 19 | 0.00038 - 0.208 |
| 16 | 2007 - 2020 | 16 | 653 | 133 | 0.00116 - 0.317 |
| 17 | 2007 - 2020 | 670 | 9220 | 1512 | 0.00071 - 14.1 |
| 18 | 2007 - 2020 | 385 | 2675 | 402 | 0.00053 - 13 |
| 19 | 2008 - 2019 | 1 | 25 | 0 | - |
| 20 | 2007 - 2019 | 98 | 134 | 15 | 0.00463 - 0.14 |
| 21 | 2009 - 2020 | 16 | 61 | 9 | 0.013 - 0.1 |

Table 3- 14. Water Quality Portal Monitoring Data Summarized by 2-digit HUC for Samples Collected Before 2007

| **HUC-2** | **Years** | **Number of Sites** | **Number of Samples** | **Number of Detections** | **Measured Detection Range (µg/L)** |
| --- | --- | --- | --- | --- | --- |
| 01 | 1993 - 2006 | 114 | 959 | 244 | 0.001 - 3.2 |
| 02 | 1973 - 2006 | 1080 | 6984 | 1894 | 0.001 - 335 |
| 03 | 1975 - 2006 | 908 | 7608 | 1378 | 0.001 - 50 |
| 04 | 1981 - 2006 | 343 | 2836 | 276 | 0.002 - 0.434 |
| 05 | 1989 - 2006 | 217 | 3287 | 531 | 0.001 - 0.672 |
| 06 | 1988 - 2006 | 96 | 1098 | 87 | 0.002 - 0.921 |
| 07 | 1988 - 2006 | 686 | 6395 | 239 | 0.002 - 0.71 |
| 08 | 1977 - 2006 | 152 | 2117 | 268 | 0.002 - 0.482 |
| 09 | 1988 - 2006 | 134 | 641 | 87 | 0.004 - 0.037 |
| 10 | 1983 - 2006 | 617 | 4881 | 518 | 0.002 - 16.5 |
| 11 | 1974 - 2006 | 179 | 1315 | 157 | 0.002 - 1.61 |
| 12 | 1981 - 2006 | 338 | 3330 | 575 | 0.001 - 5.18 |
| 13 | 1986 - 2006 | 82 | 804 | 40 | 0.001 - 4.18 |
| 14 | 1988 - 2006 | 103 | 522 | 42 | 0.002 - 1.42 |
| 15 | 1991 - 2006 | 36 | 809 | 99 | 0.002 - 1.06 |
| 16 | 1977 - 2006 | 205 | 815 | 173 | 0.002 - 0.411 |
| 17 | 1988 - 2006 | 521 | 4481 | 718 | 0.001 - 33.5 |
| 18 | 1981 - 2006 | 524 | 4081 | 1115 | 0.001 - 6 |
| 19 | 1996 - 2003 | 18 | 56 | 18 | 0.002 - 0.332 |
| 20 | 1990 - 2006 | 14 | 86 | 18 | 0.007 - 0.37 |

Historical data may not reflect exposure based on current use patterns.

#### Pilot Reservoir Monitoring Study

In the 2003 assessment, EFED summarized a study ([Blomquist *et al.*, 2001](#_ENREF_1)) that was conducted jointly by the USGS and EPA to increase understanding of pesticide presence and fate in reservoirs. Twelve drinking water supply reservoirs across the country were sampled quarterly throughout the year, and at bi-weekly to weekly intervals following the “primary pesticide application periods”. Site selection emphasized reservoirs having watersheds that were expected to make them susceptible to pesticide contamination, but without emphasis on any particular pesticide. Samples were collected at the locations of drinking water intakes (312 total samples), reservoir outflows (73 samples), and in finished water at the tap (225 total samples). Not all sites had samples collected at the reservoir outflow location. Carbaryl was detected at a total of seven sites, including five intakes, one outflow location, and the finished water of two supplies. Three samples, all collected from intakes, contained 1-naphthol. The highest carbaryl concentration detected was 0.047 µg/L, at Blue Marsh Reservoir in Pennsylvania. Degradate 1-naphthol was found at a maximum of 0.228 µg/L, at Higginsville Reservoir, Missouri. It is worth noting that 1-naphthol has other sources in the environment, including some that are natural. It is also worth noting that all detections of carbaryl were “qualified”, meaning that the reported concentrations were above method detection limits, but below method quantitation limits.

#### Community Water Systems Study

In the first phase of this study ([Kingsbury *et al.*, 2008](#_ENREF_10)) water was sampled approximately monthly over roughly one-year time periods between 2002 and 2004, from nine community water supplies in the U.S. that draw from flowing waters (eight rivers and one “brook”). Community water systems serve as both a source water for human health drinking water and are waters that serve as an ecological resource. The systems serve populations that range in size from about 3,000 to two million people. At each site samples in phase one were collected only from source water (*i.e.*, water prior to treatment). In the second phase of the study both source and finished water (*i.e*., water that has passed through the treatment process but not yet been sent through the distribution system) were sampled repeatedly between 2004 and 2005, from eight of the nine locations studied in phase one. Samples in both phases were analyzed for 258 anthropogenic contaminants, including both carbaryl and 1-naphthol. In phase one carbaryl was detected at six of the nine sites, at frequencies that ranged from 6% to 47% of samples (*i.e.*, of 12 to 17 samples collected per site). In phase two carbaryl was detected at five of the eight sites in source water (at detection frequencies ranging from 15.4 to 46.7%), and at three of the eight sites in finished water (at detection frequencies ranging from 6.7 to 30.8%). The maximum carbaryl concentrations detected in source and finished water were 0.25 and 0.012 µg/L (estimated) respectively. Though the samples in question were collected roughly three months apart from each other and so were not paired, they were both found in water obtained from the Chattahoochie River, Georgia, in 2004. The study authors noted that although carbaryl was detected more frequently in source than in finished water, spike data did “not indicate that concentrations are affected by chlorination”. They concluded that concentrations may be reduced as a result of water treatment in general, but that additional information was needed.

In phase one, 1-naphthol was detected in source water at four of the nine sites, at frequencies that ranged from 5.9 to 29.4%. In phase two, 1-naphthol was also detected in source water at four of the nine sites, at frequencies that ranged from 6.7 to 15.4%. The maximum 1-naphthol concentration detected in source water was 0.015 µg/L. In finished water 1-naphthol was detected only one time and at one site (one out of 13 samples), at 0.013 µg/L. This sample was also found (in 2005) in water obtained from the Chattahoochie River, Georgia.

#### Oregon DEQ Water Quality Monitoring

Surface and ground water carbaryl data were obtained on September 19, 2016 in a download of data from the state of Oregon’s AWQMS database (<http://www.oregon.gov/deq/Data-and-Reports/Pages/default.aspx>) ([Oregon Department of Environmental Quality, 2018](#_ENREF_16)). According to the download a total of 2,443 water samples (of which, excluding blanks and duplicates, 1,258 were surface water of various kinds including industrial waste, municipal effluent, “non-potable water” and samples collected from rivers and streams, and 957 were ground water) were analyzed by the State of Oregon for carbaryl between 1986 and 2012. Surface water samples were collected at a total of 205 sites, and ground water samples were collected at 510 sites. There were 113 quantifiable detections (9.0% of samples) of carbaryl in surface water, at concentrations up to 51.4 µg/L (this in an “industrial waste” sample). The highest concentration in a river or stream sample was 1.1 µg/L, in a sample collected from a creek in 2009. By way of comparison, the USGS NAWQA program reported a maximum carbaryl detection of 23.5 µg/L in Oregon, in a sample collected from a creek in 2006. There were no quantifiable detections of carbaryl in ground water (quantitation limit variable) reported by the state of Oregon. Note that the USGS also reported no detections of carbaryl in Oregon groundwater.

According to the LASAR download a total of 29 water samples (excluding blanks and duplicates) were analyzed by the State of Oregon for 1-naphthol in groundwater, all in 1999. There were no quantified detections of 1-naphthol in any of these samples (quantitation limit apparently 1 µg/L). According to the download no surface water samples were analyzed for 1-naphthol by the state of Oregon. By way of comparison, as previously mentioned the download from the Water Quality Data Portal reports the highest 1-naphthol concentration detected in surface water nationally as 1.6 µg/L, found in a 2006 sample from an Oregon stream. Similar to the state of Oregon, the USGS reported no detections of 1-naphthol in 109 groundwater samples collected between 1993 and 2012.

#### California Department of Pesticide Regulation

The California Department of Pesticide Regulation (CDPR) maintains a surface water database of pesticide detections in surface waters (large and small water bodies) for the entire state. This is an ambient water monitoring program. In general, sample frequencies are sporadic and range from once per year to twice per month depending on the site and year. The sampling frequency and timing represented in the dataset do not specifically target carbaryl applications; however, there are some sampling sites located within areas known to have high carbaryl use. Because the sampling was not designed in relation to carbaryl usage and precipitation events, it is expected that the CDPR data underestimate carbaryl concentrations. The magnitude of this underestimation is unknown.

The maximum detection was 13 µg/L in 2011 from a sample taken from Prairie Flower Drain at Crows Landing. Overall, 26 samples had concentrations greater than 1 µg/L ranging from 1991 to 2015. There are 4 samples greater than 1 µg/L were collected post 2011. The samples with the highest concentrations occurred throughout the year. CDPR data for carbaryl in surface water are highlighted in **Table 3- 15**.

Table 3- 15. CDPR surface water monitoring data for carbaryl

| **Parameter** | **Carbaryl** |
| --- | --- |
| Sampling Years | 1991-2017 |
| Number of Samples | 15198 |
| Sample Frequency | varied |
| Qualified Detections | 306 |
| Frequency of Detections | 2% |
| Maximum Detection | 13 µg/L  2011  Stanislaus County, CA  Prairie Flower Drain at Crows Landing Rd |
| Limit of Quantitation | 0.002 to 10 µg/L |

#### Washington State Department of Agriculture

The Washington State Department of Agriculture provided monitoring data collected between 2003 and 2019 on carbaryl during the comment period of the draft Biological Evaluation. More than 5,000 surface water samples were collected from 36 distinct sites in Washington State. The limit of quantitation was between 10 and 20 ng/L for most samples. There were 217 samples detections with a maximum concentration of 10 µg/L detected in 2003 and 0.38 µg/L after 2006 (in 2013). These data were utilized in the MAGtool analysis and downstream monitoring analysis.

## Aquatic Exposure Summary

Model-derived EECs represent an upper bound on potential exposure as a result of the use of carbaryl. Comparing the concentrations in the medium and high flowing and static bins (3, 4, 6, and 7) to the highest measured concentrations, the modeled values are roughly an order of magnitude greater than the measured concentrations. The medium and high flowing and static bins were used for comparison purposes as these would seem to represent typical waterbodies considered for ambient water monitoring, as they typically have flow and water present all year. As recommended by the National Research Council (NRC) in the 2013 National Academy of Science (NAS) report ([NRC, 2013](#_ENREF_15)), general monitoring data are not recommended to be used to estimate pesticide concentrations after a pesticide application or to evaluate the performance of EPA’s fate and transport models. However, EPA believes monitoring data can be used as part of the weight-of-evidence evaluation in characterizing potential exposure.

## Uncertainties in Aquatic Modeling and Monitoring Estimates

There are various sources of uncertainty in this assessment. With respect to model results, uncertainty exists regarding some model inputs. For example, data are available only from a single anaerobic aquatic system. Perhaps more importantly, the range in aerobic soil metabolism half-lives is quite large (4 – 253 days), which is likely to be a consequence of differences among the pH of the studied soils, and of carbaryl’s susceptibility to hydrolysis under alkaline, but not acidic conditions. Because this half-life range is so wide, the representative aerobic soil half-life calculated for use as a model input (90% upper confidence limit on the mean) is relatively large: at 176 days, its value is within the range of hydrolytic decay rates expected in acidic soils, *i.e.,* those with pH less than 6, which is more acidic than most agricultural soils. For uses on soils that are not acidic, use of this half-life may substantially overestimate the persistence of carbaryl in soil.

Exposure to aquatic organisms from pesticide applications is estimated using PWC EECs. Regional differences in exposure are assessed using regionally-specific PWC scenarios (*e.g.*, information on crop growth and soil conditions) and meteorological conditions at the HUC 2 level (**Section 3.3. Scenario Selection**). The information used in these scenarios is designed to reflect conditions conducive to runoff. In instances where PWC scenarios do not exist in a HUC 2, surrogate scenarios from other HUCs are used. For fields where agricultural practices that result in less conservative scenario parameters are employed (*i.e.*, conditions less conducive to runoff and pesticide loading of waterbodies), the potential for lower EECs would be expected.

The static waterbodies modeled with VVWM are fixed volume systems with no outlet, resulting in the potential for accumulation of pesticide over time. Effects due to the increase and/or decrease of the water level in the waterbody and thus the concentration of pesticide in the waterbody are not modeled.

Flowing waterbodies are modeled in the VVWM using the constant volume and flow through custom waterbody option. Effects due to the increase and/or decrease of the water level and flowrate in the waterbody and thus the concentration of pesticide in the waterbody are not modeled.

The assessment relies on maximum use patterns (**Section 3. Measures of Aquatic Exposure**). In situations where use patterns are less than the labeled maximums, environmental exposures will be lower.

The aquatic modeling conservatively assumes that the waterbody abuts the treated area. As such, any reduction in loading from runoff that could occur as the result of managed vegetative filter strips or unmanaged naturally-occurring interfaces between treated areas and waterbodies are not taken into account.

The aquatic modeling assumes a constant wind of 10 mph blowing directly toward the waterbody (**Section 3.4.2. Spray Drift**). These assumptions are conducive to drift transport and result in maximum potential loading to the waterbody. However, in many situations the wind will not be blowing constantly and directly toward the water body at this speed; therefore, aquatic deposition will likely be less than predicted. Additionally, many labels and applicator best management practices encourage not applying pesticides when the wind is blowing in the direction of sensitive areas (*i.e.*, listed species habitat). Lastly, reductions in spray drift deposition due to air turbulence, interception of spray drift on nearby plant canopy, and applications during low wind speeds are not taken into account in the spray drift estimates; therefore, loading due to spray drift may be over-estimated.

There is uncertainty associated with the selection of PWC input parameters. In this regard, one of the important parameters that can impact concentration estimates is the selection of application dates (**Section 3.4.3. Application Timing**); runoff and potential pesticide loading are greatest when applications immediately precede major precipitation events. Although the pesticide application dates are selected to be appropriate and protective (*i.e.*, selected with consideration for label restrictions and simulated cropping dates, pest pressures, and high precipitation meteorological conditions), uncertainty nevertheless results because the application window (the time span during a season that a pesticide may likely be applied) for a pesticide may be wide and actual application dates may vary over the landscape. While data sources exist that allow for determination of historical application dates (*e.g.*, California’s Pesticide Use Report and pesticide use surveys), it is uncertain how these dates reflect future application events. Additionally, the PWC models use the same application dates for the 30-year simulation. While it is unlikely that an application would occur on the same dates every year for 30 years, this modeling process allows for a distribution of EECs to be developed that captures the peak loading events.

PRZM/VVWM are field-scale models. Flowing water bodies such as streams and rivers with physical parameters consistent with aquatic bins 3 and 4 have watershed areas well beyond those of typical agricultural fields. Watershed sizes estimated for bin 3 habitats exceeded 10,000 acres and bin 4 watersheds were assumed to be greater than 4 million acres. Initial modeling efforts in previous BEs, applying the field-scale model to these large watersheds and using the same scenario parameters as those used for the other bins, resulted in extremely high EECs which have not been observed in the environment, nor would be expected to occur due to fluid dynamic processes such as advective dispersion (**Figure 3- 3**), where the peak concentration is dampened as it moves from a low flowing stream (bin 2) to a higher flowing river (bins 3 and 4). It is acknowledged that a watershed/basin-scale model capable of evaluating the impact of pesticide and water transport at the field-scale and aggregating these loadings to waterbodies at the larger watershed-scale is needed to evaluate these flowing aquatic systems.

Other sources of uncertainty result from ambiguous or incomplete information regarding timing of application for various uses on the label. EFED based its modeled application timing assumptions on use information provided by BEAD. For most uses only limited information on specific target pests and/or timing were provided, therefore EFED made the conservative assumption that initial applications take place during relatively wet periods, *e.g*., during months that are (or are nearly), the rainiest of the year on average, for the location represented by each scenario. EFED assumed maximum single application rates for all uses, which may overstate typical application rates. Maximum annual application rates were also not provided for many use/formulation/label combinations, suggesting that this information may be missing from some labels. In such cases EFED made the assumption that maximum annual rates would be the same as maximum annual rates for analogous or identical uses specified on other labels.

PRZM/VVWM are field-scale models. Flowing water bodies such as streams and rivers with physical parameters consistent with aquatic bins 3 and 4 have watershed areas well beyond those of typical agricultural fields. Watershed sizes estimated for bin 3 habitats exceeded 10,000 acres and bin 4 watersheds were assumed to be greater than 4 million acres. Initial modeling efforts in previous BEs, applying the field-scale model to these large watersheds and using the same scenario parameters as those used for the other bins, resulted in extremely high EECs which have not been observed in the environment, nor would be expected to occur due to fluid dynamic processes such as advective dispersion (**Figure 3- 4**), where the peak concentration is dampened as it moves from a low flowing stream (Bin 2) to a higher flowing river (bins 3 and 4). It is acknowledged that a watershed/basin-scale model capable of evaluating the impact of pesticide and water transport at the field-scale and aggregating these loadings to waterbodies at the larger watershed-scale is needed to evaluate these flowing aquatic systems.

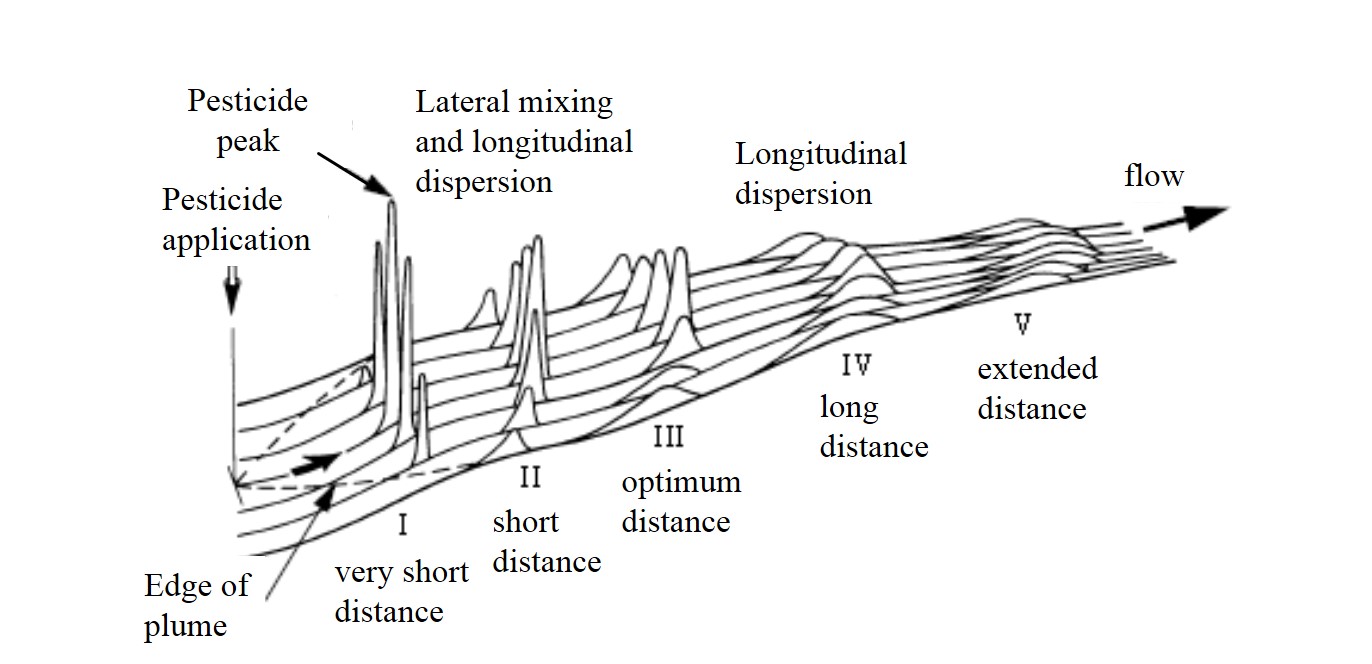


Figure 3- 3. Effect of pesticide concentration via advective dispersion.

As carbaryl has a low level of volatility (vapor pressure of 1.3x10-7 torr and a Henry’s Law Constant of 1.28x 10-8 atm-m3/mol), transport in the air and precipitation via volatilization is not expected to be a significant exposure pathway. Yet carbaryl has been detected in precipitation at up to 0.756 µg/L in rain and 4 µg/L in fog ([Foreman *et al.*, 2000](#_ENREF_6); [Mast *et al.*, 2007](#_ENREF_12); [Sanusi *et al.*, 2000](#_ENREF_19); [Vogel *et al.*, 2008](#_ENREF_43); [Waite *et al.*, 1995](#_ENREF_44)). Based on these data, it is possible that carbaryl can be deposited on land and into waterbodies via precipitation. Estimates of exposure to carbaryl included in this assessment are based only on transport of carbaryl through runoff and spray drift from application sites.

## Uncertainties the Plant Assessment Tool (PAT)

The PAT model does not account for site specific field management and hydrology (*e.g.,* terracing, contour farming, runoff and erosion controls, irrigation/drainage ditches, rills and creeks) which may result in less opportunity for runoff into the T-PEZ. Many different factors (*e.g*., slope; surface roughness; flow path length; etc.) can influence the occurrence, distance of, and prevalence of runoff onto the T-PEZ. These factors may vary greatly between different application sites (*e.g*., corn; wheat; potato; grape; bare field; turf).

The PAT model assumes that the water leaving the field as surface runoff is driven primarily by the amount of rainfall and the curve number, which is a function of the land use (*i.e*. row crops, pasture, fallow), management (*i.e*., straight row cropping, conservation tillage, *etc*.), and hydrologic soil conditions (*i.e*., high runoff potential with very slow infiltration rates)([Young and Fry, 2016](#_ENREF_48)). Runoff leaving the field is assumed to enter the T-PEZ along the downslope field edge and coverage of the T-PEZ area conceptually happens instantaneously as the calculations are on a daily timestep rather than shorter timestep (*e.g*., hourly). As a result, the T-PEZ does not account for differences in the runoff loading (*e.g*., point entry and fan shaped sheet flow vs. uniform sheet flow entry), gradients in concentration due to interception and infiltration (*e.g*., buffering capacity of the T-PEZ), rain intensity and infiltration capacity relationships (*e.g*., pulsed rain events vs. one intense rain event). These natural features of the landscape may result in higher concentrations from runoff at the edge of the T-PEZ nearer the treated field than estimated in the model.

There are many different types of wetlands (*e.g*., depressional, groundwater fed, flow through, permanently flooded, and ephemeral) that may be present in landscapes receiving runoff from pesticide use sites. The default WPEZ model was selected to be representative and conservative (in terms of final pesticide concentrations) and acts as a surrogate for other types of wetlands. This assumption may result in overestimation of pesticide loading and fate than would be observed in some wetland systems.

# Measures of Terrestrial Exposure

Terrestrial animals may be exposed to carbaryl through multiple routes of exposure, including diet, drinking water, dermal and inhalation exposure. Terrestrial dietary items may consist of plants, invertebrates, or vertebrates (amphibians, reptiles, birds or mammals) that inhabit terrestrial areas or aquatic dietary items (fish, invertebrates or plants). However, due to carbaryl’s low log kOW value (2.36), significant bioaccumulation in aquatic food items is not expected and potential risk from this route of exposure is considered low. A bioconcentration factor (BCF) value of 45 L/kg-wet weight in whole fish tissue (MRID 159342), as well as BCF values of 34-38 L/kg-wet weight in aquatic plants (E15807) were reported for carbaryl ([Kanazawa *et al.*, 1975](#_ENREF_7)). While empirical BCF values were not available for aquatic invertebrates, the KABAM-derived BCF value is 9 L/kg-wet weight. These low BCF values provide further evidence that carbaryl has a low potential to bioaccumulate. Therefore, estimates of exposure through consumption of aquatic food items using KABAM or BCF values are not calculated. A detailed discussion of the conceptual framework for estimating terrestrial exposure concentrations is provided in **ATTACHMENT 1-1**.

Two major parameters are used in terrestrial exposure modeling to characterize a species: body weight and diet. Estimates of body weights are necessary to estimate dose-based exposures through diet, drinking water, inhalation and dermal exposure routes. Information on the dietary requirements of listed species are necessary to determine relevant exposures through consumption of contaminated prey. Species-specific assumptions related to diet and body weight are provided within the model. The foliar dissipation half-life of the chemical can also impact the duration of exposure to predicted terrestrial EECs. A foliar dissipation half-life of 3.2 days is used for carbaryl, based on 90% upper confidence limit on mean half-life from 30 published studies submitted by registrant (MRID 45857901).

To improve efficiency and expand EFED’s modeling capabilities to other, non-dietary routes of exposure for terrestrial organisms, models have been developed to integrate the relevant exposure pathways and allow for batch processing of multiple analyses. For use in the pilot BEs ([USEPA, 2016g](#_ENREF_37)), the Terrestrial Effects Determination (TED) tool was developed, which integrated T-REX, T-HERPS, the earthworm fugacity model, components of KABAM and AgDRIFT into one model platform. As part of the development of the draft biological opinion for chlorpyrifos, diazinon and malathion, the TED tool was converted to the terrestrial MAGtool, which further expanded the TED tool to predict the magnitude of effect at a population scale and incorporate the degree of overlap of a species range with potential use sites for a chemical (and associated off site transport areas) into the effects determination. The MAGtool has replaced the TED tool for modeling terrestrial exposure in the biological evaluations. Additional technical information on the MAGtool, can be found in the Revised Methods and the model documentation.[[6]](#footnote-7)

When the MAGtool is run for each species, terrestrial exposure concentrations are uniquely calculated for each species depending on relevant use overlap with the species range, available usage data, application rates associated with these relevant uses and the dietary items, habitat and obligate relationships for that species. As EECs will vary for each species, they are determined for each species in the individual effects determinations (**APPENDIX 4-1**).

To provide a bounding of potential terrestrial EECs used in the effects determinations, EECS were calculated for the range of single application rates for carbaryl (a minimum single application rate of 0.415 lb a.i./A and a maximum single application rate of 12.24 lb a.i./A) and are provided below in **Table 3- 16**. How the EECs will be applied will vary with each step of the analysis (*e.g.,* use of upper bound EECs in Step 1 vs. distribution of EECs in Step 2) and could be slightly higher with mid-range application rates applied multiple times. Additionally, other information considered in Step 2 (*e.g.,* typical use rates, use rates based on maximum usage in a species range, distribution of EECs, etc.), could alter the EECs used to assess a species exposure. All uses for carbaryl and associated application rates are provided in **APPENDIX 1-3**.  **Table 3- 16** summarizes the mean and upper bound dietary-based EECs and the associated base model that is used in the MAGtool to predict the EECs. Carbaryl uses also include granular and dust formulations; these are analyzed separately and are discussed in **APPENDIX 4-5**.

Table 3- 16. Mean and upper bound dietary based EECs calculated for food items consumed by listed mammals, birds, terrestrial-phase amphibians or reptiles based on foliar applications. Values represent potential exposures for animals feeding on the treated field or in adjacent habitat directly adjacent to the field.

| **Food Item** | **Model** | **Min. single app. rate**  **(0.415 lb a.i./A)** | | **Max. single app. rate**  **(1 app. of 12.24 lb a.i./A)** | |
| --- | --- | --- | --- | --- | --- |
| **Upper Bound** | **Mean** | **Upper Bound** | **Mean** |
| Short Grass | T-REX | 100 | 35 | 2938 | 1040 |
| Tall Grass, nectar and pollen | T-REX | 46 | 15 | 1346 | 441 |
| Broadleaf plants | T-REX | 56 | 19 | 1652 | 551 |
| Seeds, fruit and pods | T-REX | 6 | 3 | 184 | 86 |
| Arthropods (above ground) | T-REX | 39 | 27 | 1151 | 796 |
| Soil-dwelling invertebrates (earthworms) | Earthworm fugacity | 0.8 | NA1 | 25 | NA1 |
| Small mammals (15 g, short grass diet) | T-HERPS | 95 | 34 | 2801 | 992 |
| Large mammals (1000 g, short grass diet)2 | T-HERPS | 15 | 5 | 449 | 159 |
| Small birds (20 g, insect diet)2 | T-HERPS | 44 | 31 | 1310 | 906 |
| Small terrestrial phase amphibians or reptiles (2 g; insect diet) | T-HERPS | 2 | 1 | 64 | 44 |
| Fish, aquatic invertebrates and aquatic plants | NA3 |  | | | |

1 NA as upper bound and mean residues only applicable to items dependent on residues on foliage

2 Also represent residues in carrion.

3 NA due to lack of bioaccumulation of carbaryl in aquatic dietary items

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