COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF ENVIRONMENTAL PROTECTION
BUREAU OF CLEAN WATER

RATIONALE FOR THE DEVELOPMENT OF AMBIENT WATER QUALITY CRITERIA FOR PROTECTION OF AQUATIC LIFE USE

Carbaryl

May 2022

Executive Summary

Section 303 of the federal Clean Water Act (CWA) requires states to periodically, but at least once every three years, review and revise as necessary their water quality standards. The federal water quality standards regulation at 40 CFR 131.11(b)(1) requires states to adopt numeric water quality criteria that are based on section 304(a) criteria recommendations developed by the United States Environmental Protection Agency (USEPA), section 304(a) criteria recommendations modified to reflect site-specific conditions, or other scientifically-defensible methods. Additionally, the CWA directs states to adopt criteria for toxic pollutants “the presence of which in the affected waters could reasonably be expected to interfere with a state’s designated uses.” 33 U.S.C. § 303(c)(2)(B).

USEPA published nationally recommended ambient water quality criteria for carbaryl to protect aquatic life in April 2012 (USEPA 2012). This USEPA recommendation was developed through its authority under section 304(a) of the CWA. Under the CWA, states and authorized tribes must adopt water quality criteria into their water quality standards to protect designated uses.

The Pennsylvania Department of Environmental Protection (Department) has reviewed USEPA’s 2012 carbaryl aquatic life criteria recommendations and has determined that they will provide an appropriate level of aquatic life protection to surface waters of this Commonwealth. Therefore, the Department is recommending the Environmental Quality Board (Board) adopt a criteria maximum concentration (CMC) of 2.1 ug/L to protect aquatic life from acute exposures to carbaryl and a criterion continuous concentration (CCC) of 2.1 ug/L to protect aquatic life from chronic exposures to carbaryl.

Background

Carbaryl (1-naphthol-N-methylcarbamate; $C_{12}H_{22}NO_2$, CAS #63-25-2), also commonly known as Sevin®, is a broad-spectrum insecticide that is classified with other N-methyl carbamate pesticides. In addition to being a board-spectrum insecticide, carbaryl is also registered for use as a mosquito adulticide, a molluscicide, in pet care products and to thin fruit in orchards to enhance fruit size and repeat bloom (USEPA 2012). It is available for use in the following formulations: baits; dusts; wettable powders; molasses, oil, and water suspensions; pellets; and granules.

Nationally, carbaryl ranked third among the most commonly used conventional pesticides in homes and gardens in 2009. Carbaryl usage was reported to range between 4 and 6 million pounds of active ingredient used annually in 2009. In 2012, carbaryl ranked fifth among the most commonly used conventional pesticides in homes and gardens. Carbaryl usage was reported to range between 2 and 4 million pounds (USEPA 2017b). Since carbaryl is moderately mobile in soils, it enters aquatic environments primarily through stormwater runoff from areas where it has been applied, including agricultural and urbanized areas.

Once in the aquatic environment, carbaryl typically degrades into other substances via hydrolysis or photolysis with the primary degradant being 1-naphthol. Hydrolysis is pH dependent and will occur more rapidly at higher pH. Photolysis occurs in waters that can be penetrated by sunlight and is generally limited to the upper water column of an aquatic system. Degradation of carbaryl and 1-naphthol by photolysis is rapid with half-lives of 1.8 days and less than an hour, respectively. It is important to note that 1-naphthol can result from a variety of natural and anthropogenic processes, so its presence does not indicate usage of carbaryl (USEPA 2012).

The Department reviewed water quality sample data for carbaryl in the national Water Quality Portal. The Water Quality Portal is a cooperative service provided by the United States Geological Survey (USGS), USEPA, and the National Water Quality Monitoring Council (NWQMC). A search of the database generated approximately 2100 sample results for carbaryl in Pennsylvania surface waters that were collected between 1973 and 2022 by USGS. Approximately 600 of the 2100 samples were collected during the past ten years (2012-2022). Most samples were analyzed for dissolved carbaryl, but a small number of samples were analyzed for total recoverable. Approximately 75% of the samples had non-detectable levels of carbaryl. Of the 25% of samples that had detectable amounts, the results ranged from 0.003 ug/L to 0.14 ug/L. If historical sample results are considered, there were three results above the proposed acute and chronic criteria recommendations. The highest values were 335 and 260 µg/L and both of these samples were collected in 1973. The third result was 2.41 ug/L, which only slightly higher than the proposed criteria of 2.1 ug/L. This sample was collected from the Little Neshaminy Creek at Valley Road in 2000.

Based on this analysis of available water quality data, the current levels of carbaryl found in Pennsylvania's surface waters are low when compared to USEPA's ambient water quality criteria recommendations for the protection of aquatic life. It is important to recognize there is potential for concentrations of carbaryl to become elevated if its use becomes more widespread and common. This potential increase in concentration could be further exacerbated if some exotic pests become ubiquitous, as in the case of the spotted lanternfly (*Lycorma delicatula*). Carbaryl is an effective suppression agent against the spotted lanternfly, so as local populations of invasive spotted lanternfly surge, there would be an expected rise in the amount of carbaryl released into the environment (Penn State Extension 2021). A search of National Pollutant Discharge Elimination System (NPDES) permits issued under the Department's Clean Water Program generated zero permits with discharge effluent limitations or monitor and report requirements for carbaryl.

Aquatic Life Toxicity and Carbaryl

Carbamate insecticides inhibit acetylcholinesterase in animals, which leads to a buildup of the neurotransmitter acetylcholine within the nervous system. This accumulation of acetylcholine triggers the nerve pulses to continue firing throughout the nervous system leading to uncontrolled movement, paralysis, convulsions, tetany and possibly death. Without proper neurological function, respiratory, circulatory, and other bodily functions fail. Most acetylcholinesterase inhibition effects are reversible upon removal of the exposure (USEPA, 2012).

Increases in water temperature, pH and hardness can increase carbaryl toxicity in the aquatic environment. However, there is generally a lack of sufficient trend data to warrant the need to adjust the carbaryl water quality criteria for these parameters.

It is also important to consider whether the degradants of carbaryl, such as 1-naphthol, are inimical to aquatic life. The primary effect of 1-naphthol exposure is thought to be narcosis which is a reversible anesthetic effect. It is caused by chemicals partitioning into cell membranes and nervous tissue which results in disruption of cell functions including those in the central nervous system. Toxicity test results indicate that 1-naphthol is toxic to aquatic life with the most sensitive endpoint being larval growth and development of fathead minnows when chronic exposure exceeds 100 µg/L (USEPA 2012). With that in mind, the highest estimated sample result for 1-naphthol found in the Water Quality Portal for Pennsylvania surface waters was more than 2,000 times lower than the levels that seem to have any effect on aquatic life. The observed low levels of 1-napthol are likely because of its rapid degradation. USEPA indicated that the available aquatic life toxicity data for 1-naphthol is inconclusive and recommended additional studies involving fish and invertebrates to address uncertainties surrounding toxicity and effects from 1-naphthol (USEPA 2012).

Acute toxicity tests generally determine the amount of a substance it takes to kill 50% of the test organisms, but tests may also include determination of the amount of substance it takes to negatively affect or inhibit an organism. These values are often referred to as a lethal concentration (LC50), an effective concentration (EC50), or an inhibitory concentration (IC50). Depending upon the organism, acute toxicity tests are most often conducted over a 48- or 96-hour period. During USEPA's review of carbaryl, toxicity test data was available for 47 freshwater genera (60 species). The first, second, third, fourth, and seventh most sensitive tested species were stoneflies with SMAVs ranging from 3.175 ug/L to 9.163 ug/L. The species included *Isogenus sp*., *Skwala sp., Pteronarcys californica, Claassenia sabulosa*, and *Pteronarcella badia.* Cladocerans (*Daphnia carinata* and *Ceriodaphnia dubia*) were the next most sensitive taxon followed by amphipods (*Gammarus pseudolimnaeus, Gammarus lacustris,* and *Hyalella azteca*). The ten most sensitive freshwater genera are in the classes Insecta and Crustacea, which is expected given that carbaryl is an insecticide (USEPA 2012).

Chronic toxicity tests measure longer-term effects associated with exposures to lower concentrations of a pollutant over an extended period of time. Chronic toxicity tests measure lethal and sublethal effects, which include growth, development, behavior and reproduction. The typical endpoint for chronic exposure is the EC20, which is the concentration that it takes to affect 20% of the test organisms, but endpoints may include a no-observed-effect-concentration (NOEC) or a lowest-observed-effect-concentration (LOEC). Carbaryl has been shown to negatively affect survival, growth and reproduction in Fathead Minnows (*Pimephales promelas).* Negative effects on reproduction were observed in a waterflea (*Daphnia magna)*, and negative effects on growth were observed in Colorado Pikeminnow (*Ptychochelius lucius*) and Bonytail Chub (*Gila elegans*).

No acceptable data on bioaccumulation of carbaryl in freshwater are available, but due to its low octanol/water partition coefficient, carbaryl is not expected to bioconcentrate to a significant extent (USEPA 2012).

Guidelines for Carbaryl

Current USEPA 304(a) Water Quality Criteria Recommendations for Carbaryl

The current federal recommendations are designed to protect aquatic life in freshwater from the acute and chronic effects of carbaryl (USEPA 2012). Table 1 below provides the final calculated values for the magnitude of both the CMC, or acute criterion and the CCC, or chronic criterion. Duration and frequency are also given in Table 1. USEPA typically recommends average durations of one hour for the CMC and four days for the CCC for aquatic life criteria based on standard laboratory toxicity tests. These recommendations can be found in USEPA's Water Quality Standards Handbook (USEPA 2017a).

Table 1. Summary of Freshwater Aquatic Life Criteria for Carbaryl.

	Magnitude	**Duration**	**Frequency**
Acute	2.1 µg/L	One-hour average	Once every 3 years on average
Chronic	2.1 µg/L	Four-day average	Once every 3 years on average

Complete details regarding the specific derivation for both the acute and chronic components of the carbaryl aquatic life criteria are described in USEPA's *2012 Ambient Aquatic Life Water Quality Criteria for Carbaryl* (USEPA 2012).

The criteria recommendations were derived using the peer-reviewed procedures defined in EPA's *Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses* (the 1985 guidelines, Stephan et al. 1985). Therefore, comprehension of these guidelines will be necessary to understand the process used by the USEPA to derive this aquatic life criterion recommendation. Ambient water quality criteria derived using these guidelines will protect the aquatic organisms and aquatic life uses specified by states in their water quality standards regulations.

The 1985 guidelines require that a minimum of eight phylogenetically different families are represented in the toxicity data set that is used to derive criteria values for aquatic life and describe which eight phylogenetically different families are required to be in the dataset. The CMC was developed by first assembling available acute test data and it was determined that the minimum data requirements prescribed in the 1985 guidelines were met.

There were 47 genera (60 species) included in the dataset for the derivation of the nationally recommended acute freshwater criteria (see Appendix – Table A-1). The Species Mean Acute Values (SMAVs) were calculated by taking the geometric mean of the acute data for each species in the data set. Genus Mean Acute Values (GMAVs) are either (1) the calculated geometric mean for all of the SMAVs included in that genera; or (2) if there is only one SMAV in that genera, then the GMAV was set equal to the SMAV. The Final Acute Value (FAV) was derived through regression analysis on the four most sensitive GMAVs. The CMC was calculated by dividing the FAV by 2. The four most sensitive genera were within a factor of 1.8 of one another. The freshwater FAV (the 5^{th} percentile of the species sensitivity distribution) for carbaryl is 4.219 ug/L. The CMC is derived by dividing the FAV by 2 and results in a recommendation of 2.1 ug/L.

Depending on the data that are available concerning chronic toxicity to aquatic animals, the final chronic value might be calculated in the same manner as the FAV or by dividing the final acute value by the final acute-chronic ratio (FACR). In some cases, it may not be possible to calculate a final chronic value. When sufficient chronic toxicity data is not available, acute-to-chronic ratios can be calculated using a minimum of three different aquatic life families provided that at least one species is a fish, one species is an invertebrate and one species is an acutely sensitive freshwater species. If this data is not available, a final chronic value cannot be calculated. There were 5 genera (5 species) in the chronic freshwater dataset for carbaryl (see Appendix; Table A-2). The minimum data requirements for eight phylogenetically different families as specified in the 1985 guidelines were not met, so the CCC calculation relied on the acute to chronic ratios (ACRs). There were 4 valid ACRs that were considered in this approach. The difference between the lowest and highest ACR is a factor of 22, and the ACR increases as the SMAV increases. As such, the 1985 guidelines state that the final acute to chronic ratio (FACR) should be calculated from the geometric mean of the ACRs for species whose SMAVs are close to the FAV. Following this recommendation, the FACR would be the geometric mean of 1.094 (*C. dubia*) and 1.581 (*D. magna*), which is 1.315. The guidelines stipulate that if the most appropriate species mean ACRs are less than 2.0 then the FACR should be equal to 2.0. The CCC was given by dividing the FAV by the FACR of 2.0 and results in a recommendation of 2.1 ug/L.

USEPA 304(a) national criteria recommendations developed using the 1985 guidelines are based on the premise that toxicological data for the species used to derive the national criteria recommendations are representative of the sensitivities of other untested species (USEPA 2013). Based on this premise, the national criteria recommendations are designed to protect the various freshwater and saltwater aquatic communities found across the United States.

Development of Carbaryl Water Quality Criteria

The Department has evaluated USEPA's 304(a) acute and chronic freshwater criteria recommendations for carbaryl to determine if the recommendations are appropriate for this Commonwealth. The Department's evaluation included consideration of the toxicological studies and the aquatic organisms used in these studies along with the methodology used to derive the national recommendation (i.e., the 1985 guidelines). These 304(a) criteria recommendations are consistent with the Department's regulations and policies for developing aquatic life criteria found at §§ 93.8a, 93.8c, and 16.21—16.24.

Calculation of Ambient Water Quality Criteria for Carbaryl

Final Acute Value (FAV) = 4.219 µg/L

Criterion Maximum Concentration (CMC) = FAV ÷ 2

= (4.219 µg/L) ÷ 2

= 2.1095 µg/L

= 2.1 µg/L

Final Acute-Chronic Ratio (FACR) = 2.0

Final Chronic Value = FAV ÷ FACR

= (4.219 µg/L) ÷ 2.0

= 2.1095 µg/L

= 2.1 µg/L

Conclusion

The Department recommends the Board adopt USEPA's 304(a) ambient water quality criteria recommendations for carbaryl as described in this rationale document. Statewide application of these nationally-recommended water quality criteria will provide an appropriate level of protection for freshwater aquatic organisms from the toxic effects of carbaryl.

Literature Cited

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APPENDIX

Table A-1. This table was taken from USEPA 2012 and shows the freshwater GMAVs used in the derivation of the current national aquatic life recommendation for carbaryl. They are ranked from most resistant to most sensitive based on Genus Mean Acute Value.

Rank	Genus Mean Acute Value (µg/L)	Species	Species Mean Acute Value (µg/L)
47	27,609	Walking catfish, *Clarias batrachus*	27,609
46	>27,000	Snail, *Aplexa hypnorum*	>27,000
45	24,632	Mussel, *Anodonta imbecillis*	24,632
44	20,000	Black bullhead, *Ameiurus melas*	20,000
43	16,700	Goldfish, *Carassius auratus*	16,700
42	16,296	Green frog, *Rana clamitans*	16,296
41	12,400	Channel catfish, *Ictalurus punctatus*	12,400
40	12,310	Boreal toad, *Bufo boreas*	12,310
39	9,039	Green sunfish, *Lepomis cyanellus*	9,460
	-	Redear sunfish *L. microlophus*	11,200
	-	Bluegill, *L. macrochirus*	6,970
38	8,656	European chub, *Leuciscus cephalus*	8,656
37	8,200	Oligochaete worm, *Lumbriculus variegatus*	8,200
36	8,012	Fathead minnow, *Pimephales promelas*	8,012
35	6,400	Largemouth bass, *Micropterus salmoides*	6,400
34	4,350	Razorback sucker, *Xyrauchen texanus*	4,350
33	4,153	Common carp, *Cyprinus carpio*	4,153
32	>3,000	Gila topminnow, *Poeciliopsis occidentalis*	>3,000

Rank	Genus Mean Acute Value (µg/L)	Species	Species Mean Acute Value (µg/L)
31	2,930	Nile tilapia, *Oreochromis niloticus*	2,930
30	2,655	Bonytail chub, *Gila elegans*	2,655
29	2,600	Black crappie, *Pomoxis nigromaculatus*	2,600
28	2,515	Guppy, *Poecilia reticulate*	2,515
27	2,480	Yellow perch, *Perca flavescens*	2,480
26	2,470	Gray tree frog, *Hyla versicolor*	2,470
25	2,462	Crayfish, *Orconectes immunis*	2,870
	-	Crayfish, *O. virilis*	2,112
24	2,079	Greenthroat darter, *Etheostoma lepidum*	2,140
	-	Fountain darter, *E. fonticola*	2,020
23	2,005	Colorado pikeminnow (formerly squawfish), *Ptychochelius lucius*	2,005
22	1,810	Apache trout, *Oncorhynchus apache*	1,540
	-	Coho salmon, *O. kisutch*	1,654
	-	Chinook salmon, *O. tshawytscha*	2,690
	-	Cutthroat trout, *O. clarkii*	3,300
	-	Rainbow trout, *O. mykiss*	860
21	1,810	Shortnosed sturgeon, *Acipenser brevirostrum*	1,810
20	1,730	African clawed frog, *Xenopus laevis*	1,730
19	1,322	Striped bass, *Morone saxatilis*	1,322
18	1,269	Brook trout, *Salvelinus fontinalis*	1,629
	-	Lake trout, *S. namaycush*	988.1
17	1,000	Crayfish, *Procambarus clarkia*	1,000

Rank	Genus Mean Acute Value (µg/L)	Species	Species Mean Acute Value (µg/L)
16	889.0	Atlantic salmon, *Salmo salar*	1,129
	-	Brown trout, *S. trutta*	700
15	839.6	Crayfish, *Cambarus bartoni*	839.6
14	280	Aquatic sowbug, *Asellus brevicaudus*	280
13	250	Amphipod, *Pontoporeia hoyi*	250
12	230	Mysid, *Mysis relicta*	230
11	200	Backswimmer, *Notonecta undulate*	200
10	15.2	Amphipod, *Hyalella azteca*	15.2
9	13.78	Amphipod, *Gammarus lacustris*	18.76
	-	Amphipod, *G. pseudolimnaeus*	10.12
8	11.90	Cladoceran, *Daphnia carinata*	35
	-	Cladoceran, *D. magna*	7.521
	-	Cladoceran, *D. pulex*	6.4
7	9.163	Stonefly, *Pteronarcella badia*	9.163
6	8.781	Cladoceran, *Simocephalus serrulatus*	8.781
5	5.958	Cladoceran, *Ceriodaphnia dubia*	5.958
4	5.6	Stonefly, *Claassenia sabulosa*	5.6
3	4.8	Stonefly, *Pteronarcys californica*	4.8
2	3.6	Stonefly, *Skwala sp.*	3.6
1	3.175	Stonefly, *Isogenus sp.*	3.175

Table A-2. This table was taken from USEPA 2012 and shows the freshwater GMCVs used in the derivation of the current national aquatic life recommendation for carbaryl. They are ranked from most resistant to most sensitive based on Genus Mean Chronic Value.

Rank	Genus Mean Chronic Value (µg/L)	Species	Species Mean Chronic Value (µg/L)
5	897.8	Bonytail chub, *Gila elegans*	897. 8
4	636.8	Fathead minnow, *Pimephales promelas*	636. 8
3	620.8	Colorado pikeminnow (formerly squawfish), *Ptychochelius Lucius*	620. 8
2	10.6	Cladoceran, *Ceriodaphnia dubia*	10.6
1	3.770	Cladoceran, *Daphnia magna*	3.77 0