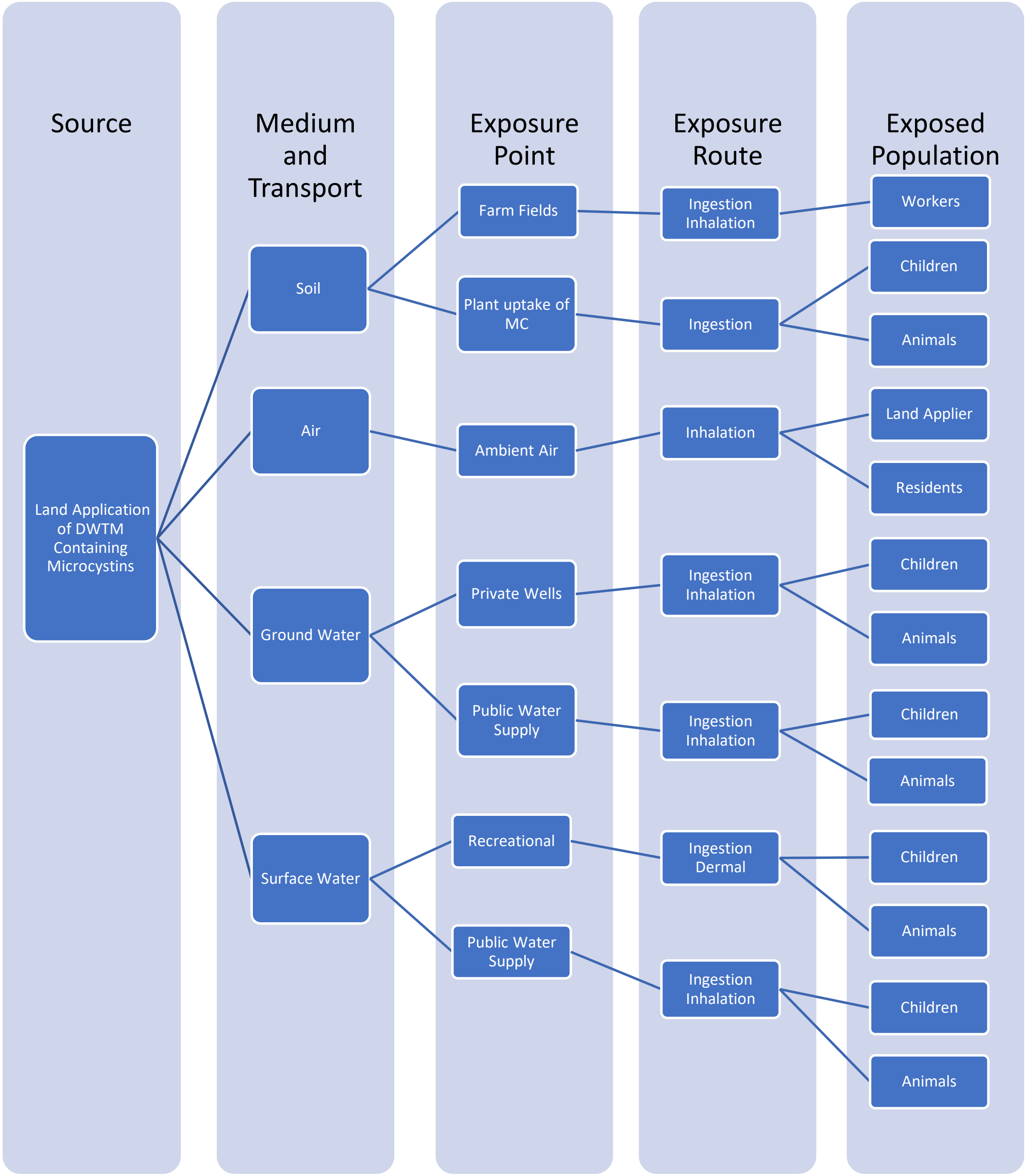
Ohio Environmental Protection Agency

Division of Materials and Waste Management
May 2019

Drinking Water Treatment Material Explanation for Microcystins Limits in Ohio EPA Permit BUGPDWTM001

Conceptual Models for Determining Interim Microcystins Thresholds



Determining the Primary Pathway of Concern

Humans and animals can be exposed directly to microcystins, produced by harmful algal blooms, by ingesting contaminated drinking water or through dermal contact, and indirectly through routes such as eating vegetables that were watered during their growth from surface waters contaminated from microcystins and from eating vegetables that were washed with microcystins contaminated water.

There is data documenting the accumulation of cyanotoxins in plants and crops irrigated with water containing cyanobacterial blooms and evidence that microcystins can accumulate in some food crops. Additionally, microcystins have been found to remain stable in lettuce, carrots, and green beans when cooked, as boiling, frying, or steaming does not degrade toxins prior to consumption.[1] Existing studies show highest accumulation in plant roots and shoots (leaves). Studies have not been conducted on the most common Ohio crops, such as corn, soybean, and wheat.

Thus far, all microcystins studies have been focused on growing plants and watering them with contaminated water. There are no studies available describing the fate and transport of microcystins in natural soils. There are also no standardized analytical procedures for determining the concentration of microcystins in soils or sediment. To go a step further, currently there are no studies available documenting fate and transport of microcystins in drinking water treatment material (DWTM) that has been land applied to farm fields.

Ohio EPA has worked with Drs. Nick Basta, Elizabeth Dayton, and Jiyoung Lee to identify potential pathways of concern and environmental impacts of microcystins applied to farm fields through land application of DWTM, based upon ingestion, direct contact, inhalation, plant uptake, leaching to ground water, and run-off to surface waters. Through this collaboration, Ohio EPA has evaluated the pathways of DWTM containing microcystins. Ohio EPA has developed a theoretical concentration of microcystins that can be land applied without adversely impacting human health, safety, or the environment. In collaboration with the researches at OSU, Ohio EPA has determined that the primary pathways of concern are through leaching to ground water and run-off to surface waters. The following is a synopsis of this collaborative effort.

Plant Uptake[1]

Assumptions:

- World Health Organization (WHO) Total Daily Intake: 0.04 μg/kg of body weight
- Average adult weight: 60 kg (WHO)

---

[1] Lee, S., Jiang, X., Manubolu, M., Riedl, K., Ludsin, S. A., Martin, J. F., & Lee, J. (2017). Fresh produce and their soils accumulate cyanotoxins from irrigation water: Implications for public health and food security. Food Research International, 102, 234-245.

- Daily lettuce consumption: 80 g (FDA)
- Allowable microcystin (MC): 30 µg microcystin/kg of lettuce
- Water absorption rate from soil for lettuce: 64%
- Allowable MC concentration in soil for lettuce production: 47 µg/kg

DWTM screening level = critical MC level in soil X (1,000 tons of soil/acre/4 tons of DWTM applied to soil/acre)

This model assumes that when DWTM is applied to soil, it will be mixed with the top six inches of soil. Using Dr. Lee's most conservative MC level in soil of 47 µg/kg (based upon uptake into lettuce), **the DWTM screening level would be 11,750 µg/kg**.

Ohio EPA does not believe at this point, based upon the current research available, that plant uptake of microcystin is the primary pathway of concern. Dr. Lee's calculations are included here to demonstrate that plant uptake is not the driving risk factor for protecting human health. The WHO values used in Dr. Lee's published paper[1] were based on a 13-week mouse study using 0.04 µg/kg/day exposure. When developing the drinking water health advisory (1.6 µg/L MC LR), U.S. EPA used the lowest observed adverse effect level (LOAEL) of 50 µg/kg/day and an uncertainty factor of 1,000 (which brings the LOAEL down to 0.05 µg/kg/day). As you continue to read through the remainder of the risk explanation of this document, you will see that the LOAEL of 0.05 µg/kg/day was used for all calculations. The LOAEL will continue to be used as further research is conducted.

Incidental Ingestion, Direct Contact, and Inhalation

The Division of Materials and Waste Management's (DMWM) beneficial use program asked the Division of Environmental Response and Revitalization to develop a direct contact soil screening level for microcystins. The human health direct contact soil exposure pathway generally includes incidental ingestion, dermal contact, and inhalation of particulates as routes of exposure. However, for the microcystins soil screening level, dermal contact was not quantitatively assessed due to the lack of data supporting significant dermal absorption. There is inadequate evidence at this time to determine the carcinogenicity of microcystins, therefore, no estimate of carcinogenic risk based on exposure to microcystins in soil or DWTM can be made. A reference dose (RFD) of 0.05 µg/kg-bw/day for microcystin-LR was applied as the toxicity criterion. Generic residential exposure assumptions were combined with the microcystin-LR RFD using the Risk Assessment Information System Preliminary Remediation Goal Calculator to develop the draft soil screening level. Draft soil screening levels were developed using a noncancer hazard quotient of 0.1 and 1.

Hazard Quotient = 0.1:
Residential Noncancer Child Soil Ingestion screening level: 0.39 mg/kg
Residential Noncancer Adult Soil Ingestion screening level: 4.17 mg/kg
Residential Age Adjusted Noncancer Soil Ingestion screening level: 1.29 mg/kg

Hazard Quotient = 1:
Residential Noncancer Child Soil Ingestion screening level: 3.91 mg/kg
Residential Noncancer Adult Soil Ingestion screening level: 41.7 mg/kg
Residential Age Adjusted Noncancer Soil Ingestion screening level: 12.9 mg/kg

The age adjusted values are currently supported by U.S. EPA. Current research on the toxicity and exposure to microcystins could support revisions to these draft values in the future.

Based upon the information available at this time, Ohio EPA does not believe that direct contact (incidental ingestion, dermal contact and inhalation) with soil is a primary pathway of concern when protecting human health, safety and the environment from exposure to microcystins.

Leaching to Ground Water

Ohio EPA worked with Drs. Nick Basta and Elizabeth Dayton, using the concepts outlined in U.S. EPA's ***Soil Screening Guidance**: User's Guide* (U.S. EPA, 1996) to develop the human exposure assumptions and consider multiple pathways of exposure to the microcystins through agricultural land use of DWTM containing microcystins, including migration through soil to an underlying aquifer whose water is used for potable purposes. To further explain this concept, let's use arsenic as an example. While ground water transport continues in the saturated zone, further reduction of the concentration of arsenic may occur by means of attenuation and dilution. By the time arsenic arrives at a receptor point in the saturated zone (e.g., a domestic drinking water well), the arsenic concentration is generally lower than the original arsenic concentration in the soil leachate.

There have been no studies thus far to determine if microcystins migrate through soil in a manner similar to arsenic or any other constituent. To derive an interim microcystins limit for land application, an assumption was made that microcystins' migration through the unsaturated zone to the water table may generally reduce the soil leachate concentration of microcystins. The reduction in microcystins concentration can be expressed in a Dilution-Attenuation Factor (DAF) defined as the ratio of original soil leachate microcystins concentration to the receptor point microcystins concentration. The DAF depends on the interaction of a multitude of factors and physical and biogeochemical processes. The DAF also depends on the nature of the microcystins itself; i.e., whether or not the microcystins degrades or sorbs.

For the migration of microcystins to ground water pathway, the Soil Screening Level (SSL) equations in U.S. EPA's *Soil Screening Guidance* assume an infinite source, contamination extending to the water table, and no attenuation in the unsaturated zone. At sites with small sources, deep water tables, confining layers in the unsaturated zone that can block contaminant transport, or contaminants that degrade through biological or chemical mechanisms, more complex models should be used to address such site conditions and can be used to calculate higher SSLs that still will be protective of ground water quality. The following section details the assumptions and calculations that were made when determining the potential transport of microcystins to ground water from land application of a DWTM slurry that contains microcystins.

Assumptions:

- Land application of 6 dry tons per acre of DWTM as a 10% slurry
- Protective ground water standard: 1.6 µg/L
- Attenuation factor: 20[2]
- DWTM slurry incorporated into 1 acre-furrow slice (AFS) defined as a volume of 1 acre (43,560 sq. ft.) and a plow layer depth of 6.67 inches
- Worse case: all MC is dissolved in water phase

Calculations:

- Volume of water land applied in DWTM slurry
- 6 dry tons/A = 12,000 lb. DWTM/acre = 120,000 lb. water/acre (assuming 10% solids)
- 120,000 lb. water/acre = 14,379 gallons = 54,430 Liters/acre land applied
- Existing soil water volume as 25% of pore space in 1 AFS
- Water volume in soil = 0.555 x 43,560 sq. ft. x 0.25 (pore space) = 6,044 cu. ft.
  28.3 L/cu. ft. which is 6,044 cu. ft. = 171,045 L of soil water
- Dilution factor of slurry into soil water = (171,045 + 54,430) L/54,430 L = 4.14

Screen level DWTM slurry calculation:

Ground water threshold of 1.6 µg/L x attenuation factor of 20 = 32 µg/L undiluted slurry = 32 µg/L x 4.14 pore water dilution factor = 132.5 µg/L in DWTM slurry. **Rounded to two significant figures would be 130 µg/L.**

A DWTM slurry for total microcystins must not exceed 130 µg/L so that there is less than 1.6 µg/L in ground water. Based on this model, Ohio EPA believes that this is an acceptable interim screening level for land application of microcystins contained in the DWTM. Based on Ohio EPA's limited sampling and analysis of DWTM from a handful of PWSs, we believe most PWSs will be able to beneficially use their DWTM.

---

[2] *U.S. EPA Soil Screening Guidance: Fact Sheet July 1996*

Run-off to Surface Water

DMWM worked with the Division of Surface Water's (DSW) National Pollutant Discharge Elimination System (NPDES) unit to determine best management practices (BMPs) that will reduce runoff of microcystins to surface waters when land applying DWTM that contains microcystins. Freshwater harmful algal blooms (HABs), are driven by nutrient inputs from anthropogenic sources and potentially impact human health and ecological health. A major nutrient contributor is agricultural land use, specifically tile drainage discharge.[3] This is a primary reason that Ohio EPA added BMPs in this general permit to reduce runoff of microcystins to surface waters.

Ohio's Harmful Algal Bloom Response Strategy for Recreational Waters uses the threshold value of 20 µg/L for microcystins when posting an elevated recreational public health advisory at beaches to avoid all contact with the water. Inevitably, land application and precipitation dilute any microcystins present and cause run-off. Defining that dilution volume for every soil type and for every soil moisture content is incredibly challenging. Out of an abundance of caution, Ohio EPA assumed that microcystins concentration in the DWTM at 20 µg/L or above must be tilled into the soil within six hours, not applied during precipitation events or too saturated ground, and must not be land applied to subsurface drained fields if the drains are flowing, unless there is an on-site means of stopping the discharge from subsurface drains to waters of the state. Requiring these BMPs for DWTM with microcystins concentration at 20 µg/L or above improves the likelihood that this threshold can be met in runoff to surface waters.

Technical Information — Generating DWTM that Contains Microcystins

While not required at this time in Ohio EPA permit GPBUDWTM001, Ohio EPA recommends that sampling and analysis of DWTM in containment areas not occur for at least four to five weeks after the last detection of microcystins has occurred in the raw water compliance samples. This waiting period will provide time for any viable cyanobacterial cells in the containment areas to decrease and for the metabolites to potentially degrade. The concentration of microcystins will continue to increase until the cyanobacterial cells have stopped replicating in the sludge layers and die off. It is probable that during an ongoing cyanobacteria challenge, in a sludge lagoon or other type of containment area, it may take several weeks for total cell death and for biodegradation of the metabolites to occur, depending on the replenishment of nutrients in the system.

Published studies, listed below, included monitoring lagoon sludge when removing cyanobacteria from raw water in the drinking water treatment process and found that:

---

[3] Mrdjen, I., Fennessy, S., Schaal,A., Dennis,R., Slonczewski,J.L., Lee,S., and Lee, J. (2018) Tile Drainage and Anthropogenic Land Use Contribute to Harmful Algal Blooms and Microbiota Shifts in Inland Water Bodies. Environ. Sci. Technol. 2018, 52, 15, 8215-8223.

- More than 80% of cyanobacteria cells remain viable after seven days in the lagoon
- Some cells remain viable for up to 10 or more days in the sludge blanket
- Cells multiply in the sludge and lagoon water
- Cells increase toxin production due to stress from the treatment process
- Mass balance evaluations suggest that metabolite concentrations may increase the initial concentrations from the raw water to up to five times within the sludge blanket
- The maximum release of toxins (indicative of total cell death and lysis) may take up to several weeks with the possibility that viable cyanobacteria could continue to produce and release metabolites over a longer period than previously proposed
- It is probable that during an ongoing cyanobacteria challenge, in the dynamic system of a sludge lagoon or other treatment facility operations, these timeframes will be significantly longer as cells and metabolites are replenished in the system.

References for studies:

- Carlos J. Pestana, Petra J. Reeve, Emma Sawade, Camille F. Voldoire, Kelly Newton, Radisti Praptiwi, Lea Collingnon, Jennifer Dreyfus, Peter Hobson, Virginie Gaget, Gayle Newcombe, 2016. Fate of cyanobacteria in drinking water treatment plant lagoon supernatant and sludge. *Science of the Total Environment* 565 1192-1200.
- Hangzhou Xu, Haiyan Pei, Yan Jin, Hongdi Xiao, Chunxia Ma, Jiongming Sun, Hongmin Li, 2017. Characteristics of water obtained by dewatering cyanobacteria containing sludge formed during drinking water treatment, including C-, N-disinfection byproduct formation. *Water Research* 111 pp. 382-392.
- Water Research Foundation. Optimizing Conventional Treatment for the Removal of Cyanobacteria and Toxins.
  Prepared by: **Gayle Newcombe, Jennifer Dreyfus, Yannick Monrolin, Carlos Pestana, Petra Reeve, Emma Sawade, Lionel Ho and Chris Chow**
  Australian Water Quality Centre, 250 Victoria Square, Adelaide, South Australia 5000
  Stuart W. Krasner and Richard S. Yates
  Metropolitan Water District of Southern California, 700 Moreno Avenue, La Verne, CA 91750
- Jennifer Dreyfus, Yannick Monrolin, Carlos J. Pestana, Petra J. Reeve, Emma Sawade, Kelly Newton, Lionel Ho, Christopher W. K. Chow and Gayle Newcombe, 2016. Identification and assessment of water quality risks associated with sludge supernatant recycling in the presence of cyanobacteria. Journal of Water Supply: Research and Technology-AQUA 65.6.
- Li, X., Pei, H., Hu, W., Meng, P., Sun, F., Ma, G., Xu, X., Li, Y., 2015. The fate of *Microcystis aeruginosa* cells during the ferric chloride coagulation and flocs storage processes. *Environmental Technology* Vol. 36(7), 920-928.