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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION III
1650 Arch Street
Philadelphia, Pennsylvania 19103-2029

December 20, 2017

Environmental Quality Board
P.O. Box 8477
Harrisburg, PA 17105-8477

Dear Sir or Madam:

The U.S. Environmental Protection Agency (EPA), Region III has reviewed the proposed amendments to Chapter 93 of the Commonwealth's environmental regulation. This proposal, which was announced for public review and comment in the Pennsylvania Bulletin on October 21, 2017, constitutes Pennsylvania's current triennial review of its water quality standards, as required by the Clean Water Act (CWA or "the Act") Section 303(c)(1). The purpose of this letter is to provide EPA's comments on the proposal. Please note that the comments and recommendations contained in this letter are strictly for the Environmental Quality Board's (EQB) consideration and do not constitute approval or disapproval decisions under CWA 303(c). Neither are these comments a determination by the EPA Administrator under CWA Section 303(c)(4)(B) that revised or new standards are necessary to meet the requirements of the Act.

Subject to the comments listed below, EPA is fully supportive of Pennsylvania's proposed revisions. Under CWA Section 303(c), it is the responsibility of the Pennsylvania Department of Environmental Protection (PADEP) to protect the existing and designated uses of the surface waters of the Commonwealth by establishing water quality standards. The specific water quality criteria being proposed will help PADEP determine if any particular parameter has the potential to negatively impact water quality and, therefore, uses. Having scientifically defensible numeric criteria also benefits the public: dischargers know what specific standards they will be required to meet, and the general public understands what standards are needed to protect water resources.

In accordance with federal regulation at 40 CFR 131.11, states must adopt water quality criteria based on sound scientific rationale and these criteria must contain sufficient parameters or constituents to protect the designated use. States can adopt numerical criteria based on EPA's national CWA 304(a) recommendations, EPA's national recommendations modified to reflect site-specific conditions, or other scientifically defensible methods. Pennsylvania is proposing to adopt several criteria that are based on EPA's national recommendations, as well as several criteria that are not consistent with EPA's national recommendations or for which there are no national recommendations. EPA reminds PADEP that in

order to support a CWA 303(c) approval, EPA will need to document that Pennsylvania has met the requirements of the 40 CFR 131.11. To that end, please consider the following comments:

Adoption of Ammonia Nitrogen criteria for Protection of Waters Designated for CWF, WWF, TSF, MF

EPA is pleased that Pennsylvania is proposing to adopt ammonia nitrogen criteria based on EPA's recommendations found in "Aquatic Life Ambient Water Quality Criteria for Ammonia – Freshwater, 2013", (EPA-822-R-13-001). However, there appear to be some inconsistencies. In order to be wholly consistent with EPA recommendations, EPA recommends PADEP revise "30-day average Criteria Continuous Concentration (CCC) chronic criterion equation" to "30-day **rolling** average Criteria Continuous Concentration (CCC) chronic criterion equation." Similarly, EPA recommends that "Chronic concentration is not to exceed 2.5 times the CCC as a 4-day average within 30 days…" be revised to "Chronic concentration is not to exceed 2.5 times the CCC as a 4-day average **within the 30-day averaging period**…". As written it appears that Pennsylvania's chronic criteria would be based on any chosen 30-day period, for example, a given month, rather than each possible 30-day period that a rolling average would achieve, regardless of any artificial or implied bracketing such as the set 30-day periods of a given month. For clarity, EPA also recommends rewording "Chronic concentration is not to exceed 2.5 times the CCC as a 4-day average within 30 days (e.g. 2.5 x 1.9 mg TAN/L at pH 7 and 20°C or 4.8 mg TAN/L) more than once in 3 years on average," to "The **highest four-day average within the 30-day averaging period** should not be more than 2.5 times the CCC (e.g., 2.5 x 1.9 mg TAN/L at pH 7 and 20°C or 4.8 mg TAN/L) more than once in three years on average." [Bold text used is only for clarity.]

In addition, the previous regulation stated that:
"The pH and temperature used to derive the appropriate ammonia criteria shall be determined by one of the following methods:

1) Instream measurements, representative of median pH and temperature—July through September.
2) Estimates of median pH and temperature – July through September – based upon available data or values determined by the Department. For purposes of calculating effluent limitations based on this value the accepted design stream flow shall be the actual or estimated lowest 30-consecutive-day average flow that occurs once in 10 years."

In the proposed revision some of the above descriptive language has been removed. PADEP should clarify what is meant in the proposed revision by "…best estimates, representative of the median pH and temperature of the receiving stream for the applicable time period and design conditions." How will "best estimates" be determined and what will they be based on? How will "design conditions" be considered? Why has the language on calculating effluent limitations been removed? Implementation and assessment is not a reviewable element of a water quality standards submission as determined by 40 CFR §131.21(c), but it could be considered in EPA's review as it relates to the criteria's scientific defensibility and protectiveness of the use.

Adoption of *E. coli* Criteria for Protection of Waters Designated for Water Contact Recreation

EPA is pleased that Pennsylvania is proposing to adopt *E. coli* criteria to protect recreational waters. However, the proposed *E. coli* criteria is not fully consistent with EPA's recommendations

found in "Recreational Water Quality Criteria" (EPA-820-F-12-058). The EPA criteria is comprised of a magnitude, duration, and frequency of excursion for both the geometric mean (GM) and the statistical threshold value (STV). It is important for states to adopt the magnitude, duration, and frequency components of the criteria in order to be consistent with EPA's recommendations and to be fully protective of the primary contact recreation designated use. The magnitudes of Pennsylvania's proposed criteria, and the 30-day duration for the GM and STV, are for the most part consistent with EPA's recommendations. For the criteria to be wholly consistent, EPA has the following recommended revisions:

PADEP should revise the proposed criteria from "*E. coli* level shall be a geometric mean of 126 per 100 milliliters (ml) ..." to "*E. coli* level shall be a geometric mean of 126 **colony forming units (cfu)** per 100 milliliters (ml) ..." to clarify the units of the criterion. Similarly, "410 per 100 ml" should be revised to "410 **colony forming units (cfu)** per 100 ml."

PADEP should remove the provision that the criterion applies "based on consecutive samples, each sample collected on different days during a 30-day period." Data sufficiency (e.g., sampling frequency) is not a reviewable element of a water quality standards submission as determined by 40 CFR §131.21(c), but it could be considered in EPA's review as it relates to the criteria's scientific defensibility and protectiveness of the use. Data sufficiency is more appropriately addressed in the development of the State's assessment methodologies. Further, PADEP should specify that the duration of the criteria is a 30-day interval.

PADEP should revise the language used to describe the frequency of the criteria. In the EPA recommended criteria, the frequency of the criteria, that is, the maximum number of times the pollutant may be present above the magnitude over the specified duration, is expressed differently for the GM and the STV. The GM is a never-to-be-exceeded value, and the STV should be exceeded no more than 10% of the time. Specifically, the EPA recommended criteria states that "The waterbody geometric mean should not be greater than the selected geometric mean magnitude in any 30-day interval. There should not be greater than a ten percent excursion frequency of the selected STV magnitude in the same 30-day interval." PADEP's proposed criteria states that "No more than 10% of the total samples taken during a 30-day period may exceed 410 per 100 ml." PADEP's proposed frequency is expressed as a percentage of samples in the 30-day duration period that can exceed the STV, whereas EPA's language is that the STV should be exceeded no more than 10% of the time. EPA recommends PADEP revise the frequency component of its proposed criteria to be consistent with EPA's recommendation that there should not be greater than a ten percent excursion frequency of the selected STV magnitude in the same 30-day duration interval.

<u>Other Considerations in Proposed Adoption of *E. Coli* Criteria for the Protection of Waters Designated for Water Contact Recreation</u>

EPA recommends PADEP consider whether having recreational criteria that relies on an *E. coli* indicator that would apply only during the swimming season (May 1 through September 30), and a second fecal coliform indicator that would apply "for the remainder of the year," would be difficult for the public to understand. EPA also notes that the data from the different time periods would be difficult to compare.

§93.7 Osmotic Pressure

EPA recommends that PADEP take the opportunity of this triennial review of its water quality standards regulations to review its Osmotic Pressure criterion and consider replacing it with a parameter or parameters more appropriately protective of the aquatic life uses in Pennsylvania.

Pennsylvania's in-stream criterion for osmotic pressure in Pa. Code §93.7 allows for a maximum of 50 milliosmoles per kilogram (mOs/kg) for the protection of aquatic life. Pennsylvania's maximum 50 mOs/kg osmotic pressure criterion is equivalent to a specific conductivity (SC) of 3816.8 (µS/cm) based on the equation from Cravotta and Brady (2015[1]) modified under the direction of Cravotta USGS 2017:

Osmotic pressure (mOsm/kg) = 0.0131*SC (µS/cm)

Pennsylvania's criterion appears to come from the 1968 Report of the Committee on Water Quality Criteria for the Federal Water Pollution Control Administration (aka "The Green Book"). That report states that "(d)issolved materials that are relatively innocuous; i.e., their harmful effect is due to osmotic effects at high concentrations, should not be increased by more than one-third of the concentration that is characteristic of the natural condition of the subject water. In no instance should the concentration of total dissolved materials exceed 50 milliosmoles (the equivalent of 1500 mg/l NaCl)." The science for determining the levels of dissolved materials in surface waters as well as what levels are safe for aquatic species has advanced since 1968.

A growing body of science has elucidated that there are low effect-levels on resident aquatic organisms due to mixtures of salts (represented as specific conductance, or ionic compounds) (see examples in citation list in Enclosure 1). For example, a peer-reviewed study in ecoregions that include Pennsylvania found aquatic life use impairment and macroinvertebrate extirpation can occur at levels of specific conductance above 300 to 500 µS/cm (~4 to 6.5 mOsm/kg) (e.g., PADEP unpublished data; Cormier et al. 2012b[2], Cormier et al. in press[2]). A 50 mOsm/kg level can result in extirpation of more than 50% of a stream's macroinvertebrate fauna (EPA unpublished data based on Cormier et al. 2012b[2] and Cormier et al. in press[2]). Recent toxicity studies also reveal aquatic effects at much lower levels of osmotic pressure than Pennsylvania's current maximum 50 mOs/kg osmotic pressure criterion. For example, in the Allegheny River in Pennsylvania, Patnode et al. (2015[2]) observed toxicity with a no adverse effect concentration for specific conductance of 247 µS/cm (~3.2 mOsm/kg) on a federally endangered freshwater mussel (*Epioblasma torulosa rangiana*). In the light of this new science, EPA would recommend that PADEP consider the development of individual ionic parameters, or perhaps adopt specific conductivity criteria for the various ecoregions in Pennsylvania. EPA recommends that PADEP conduct an analysis of Pennsylvania's osmotic pressure and instream aquatic life use (IBI scores) to confirm whether the current osmotic pressure criterion is protecting the narrative aquatic life use standard.

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[1] Cravotta, C.A. and Brady, K.B., 2015. "Priority pollutants and associated constituents in untreated and treated discharges from coal mining or processing facilities in Pennsylvania, USA". *Applied Geochemistry, 62*, pp. 108-130

[2] Full citations can be found in the citation list in Enclosure 1

Updates Consistent with EPA's 2015 Updated Ambient Water Quality Criteria for the Protection of Human Health

EPA commends PADEP for updating or revising most of its criteria consistent with EPA's 2015 ambient water quality criteria for the protection of human health for 94 chemical pollutants including updated scientific recommendations for exposure factors, including body weight, drinking water consumption rate, and fish consumption rate, bioaccumulation factors, and toxicity factors. EPA notes that most of the proposed revisions in Table 5 adopt rounding of the EPA recommended criteria. PADEP should state this in the final rulemaking.

PADEP's proposed revisions to human health criteria listed in Table 5 of the state's water quality standards regulations include 78 criteria revisions (of which 75 are consistent with the 2015 EPA update while three (3) appear to be inconsistent), 13 criteria additions, two (2) criteria that show no change (as they are already consistent with the 2015 EPA update), and one (1) criterion that shows a small change in numerical criterion as result of recalculation but should be revised to be consistent with EPA updated criteria.

The three criteria revisions that are inconsistent with EPA's 2015 updated criteria recommendations are: chloroform; chlorophenoxy herbicide (2,4 – D); and 1,1-dichloroethylene. For chloroform EPA recommends a criterion of 60 µg/L while PADEP proposes to revise the current criterion (5.7 µg/L) to 6.5 µg/L. For chlorophenoxy herbicide (2,4 – D) EPA recommends 1300 µg/L while PADEP proposes to add a criterion of 1000 µg/L. For 1,1-dichloroethylene EPA recommends a criterion of 300 µg/L while PADEP proposes to revise the existing criterion (33 µg/L) to 30 µg/L. EPA requests that PADEP explain that these differences are intentional and describe their basis.

EPA notes that in addition to the proposed new criteria for 11 chemical pollutants listed in the Pennsylvania Bulletin, Table 5 also includes adoption of new proposed criteria for Bis(chloromethyl)ether and Endosulfan Sulfate, which are consistent with EPA recommended criteria. EPA is pleased that PADEP is proposing the addition of criteria for these 13 pollutants.

The 1,2-Diphenylhydrazine criterion does change slightly under recalculation from 0.036 to 0.03 µg/L and should be revised to be consistent with EPA recommendations (0.03 µg/L). If PADEP does not propose to revise this criterion, EPA recommends that PADEP provide justification for the higher value of 0.036 µg/L.

PADEP has proposed revised criteria values for the following pollutants which differ from EPA's 304(a) recommendations: cyanide; 2 methyl-4,6-dinitrophenol; Acrolein; 1,3-dichlorobenzene; Hexachlorocyclopentadiene; Endrin Aldehyde. The criteria for each of these pollutants is proposed with 2 significant digits, while the EPA recommended criteria for each of these pollutants includes only 1 significant digits. For example, for cyanide PADEP has proposed a revised criterion of 4.0 µg/L while EPA has recommended a criterion value of 4 µg/L. PADEP may want to consider revising these criteria to be consistent with EPA recommendations (i.e. to include 1 significant digit instead of 2). This would be consistent with PADEP's proposed revisions of other human health criteria which have been rounded to one significant digit, and would allow the State some flexibility since PADEP's proposed revisions for the listed pollutants are more precise than EPA's recommendations, for example for cyanide, 4.0 µg/L is more precise than 4 µg/L.

EPA also notes 2 typographical errors in the proposed Table 5. The chemical pollutant "methoxychlor" is spelled "metoxychlor" though the CAS number and criterion are consistent with EPA updates. The chemical pollutant "1,3-dichloropropene" is spelled "1,3-dichloropropylene" though the CAS number and criterion are consistent with EPA updates.

Other Criteria Updates and Revisions for the Protection of Human Health

Nickel

EPA asks PADEP to clarify why the human health criterion for nickel is proposed to be revised from 610 to 600 µg/L, and the scientific basis for revision. 610 µg/L is the EPA recommended value.

Pennsylvania Department of Environmental Protection developed criteria in Table 5

PADEP is proposing revisions to human health criteria for several chemical pollutants in Table 5 for which there currently are no EPA recommended criteria. These chemical pollutants include: 1,2 cis-dichloroethylene; acetone; boron; formaldehyde; methyl ethyl ketone; metolachlor; resorcinol; 1,2,3-trichloropropane; 1,2,4-trimethylbenzene; 1,3,5-trimethylbenzene; xylene. All revisions result in more stringent criteria. EPA requests PADEP clarify why these criteria are being revised and the scientific basis for revision.

New or Updated Section 304(a) Criteria Recommendations

In August 2015, EPA revised the WQS regulations at 40 CFR Part 131. As part of that revision, states are now required to provide an explanation if not adopting new or revised criteria for parameters for which EPA has published new or updated CWA Section 304(a) criteria recommendations. 40 CFR §131.20(a). This change was made to foster meaningful and transparent involvement of the public and intergovernmental coordination with local, state, and federal entities in light of recent science provided by EPA through its criteria recommendations. EPA will not approve or disapprove this explanation. For Pennsylvania's triennial review, the state will need to provide explanations where new or revised criteria are not adopted for parameters where EPA has published new or updated CWA Section 304(a) criteria recommendations since May 30, 2000. These would include:

- Human health criteria for 1,2-Diphenylhydrazine if the state does not adopt suggestions in above section on "Updates Consistent with EPA's 2015 Updated Ambient Water Quality Criteria for the Protection of Human Health"
- Human health criteria for methylmercury for consumption of organism only
- Human health criteria for N-nitrosodibutylamine, N-nitrosodiethylamine, N-nitrosopyrrolidine
- Human health criteria for selenium
- Human health criteria for zinc
- Acute and chronic criteria for carbaryl and tributyl for the protection of aquatic life
- Application, statewide, of the Aquatic Life Ambient Freshwater Quality Criteria – Copper (EPA-822-R-07-001, February 2007).
- Nutrient criteria for the protection of aquatic life. See EPA's Ecoregional criteria for Total Phosphorus, Total Nitrogen, Chlorophyll *a*, and Water Clarity (Secchi depth for lakes; turbidity for streams and rivers) (& Level III Ecoregional criteria) (2003)

- Selenium criterion for the protection of aquatic life (Aquatic Life Ambient Water Quality Criteria for Selenium – Freshwater, EPA-822-R-16-006, June 2016).

PADEP can link to additional information on all of these parameters through EPA's Water Quality Criteria website at: https://www.epa.gov/wqc

§ 93.8d Development of site-specific water quality criteria

EPA commends PADEP on the proposal to include the Biotic Ligand Model (BLM) as an option for developing site-specific copper criteria. However, EPA notes that while use of the model for the development of site-specific criteria is a step forward, PADEP should consider adopting statewide freshwater copper criteria based on the biotic ligand model.

EPA also believes that PADEP needs to formalize the establishment of site-specific criteria as revisions to its water quality standards regulations. PADEP should clarify Pennsylvania regulation at 93.8d(f)(3) to indicate that the submission of site-specific criteria to EPA for review and approval is to obtain EPA approval under CWA Section 303(c).

In order for EPA to take a CWA 303(c) action on site-specific criteria, those criteria must be in state law or regulation. See 40 C.F.R. Section 131.4(i). EPA recommends that PADEP maintains Table 1A, §16 Appendix A, Site-Specific Water Quality Criteria for Toxic Substances (that PADEP is proposing to delete in this triennial review; refer to Department of Environmental Protection (PA DEP) Notice: Chapter 16 Water Quality Toxics Management Strategy – Statement of Policy at 47 Pa.B. 6703: https://www.pabulletin.com/secure/data/vol47/47-42/1767.html) for this purpose. EPA also recommends that PADEP continue to maintain the publicly available online table of site-specific criteria.

93.9a – 93.9z – Corrections to drainage lists

PADEP is making a number of corrections to its drainage lists, as well as proposing to consolidate and reformat several drainage lists. PADEP must be cautious that in the process of these revisions they do not inadvertently change the designated use of any streams, especially if the change of designated use is to a use that is less protective. EPA has reviewed the revisions and finds that several revisions need to be clarified. These include:

- In Drainage List D, confirm that the GIS coordinates represent the original location of the PA 903 bridge and not the GIS coordinates of the relocated bridge.
- In Drainage List G, PADEP indicates that they are restoring the correct designated use to the Chester Creek/Goose Creek basin from TSF to WWF. PADEP needs to provide additional documentation to support this revision, as it is unclear from the information in the public notice that this is the correct designation.
- In Drainage List G, in clarifying the zone descriptions for the tributaries to East Branch Brandywine Creek, it appears that PADEP revised the designated uses as well and resulting in a protected use with lesser protection for unnamed tributary 00322 to Beaver Creek. Provide additional information

to confirm if this was an intended revision and if so, provide additional documentation to support this revision.

- In Drainage List J, provide documentation that inclusion of the downstream limit of Roaring Brook did not inadvertently result in a protected use with lesser protection being assigned to a portion of the stream.
- In Drainage List L, in making corrections to Logan Branch, it appears that PADEP revised the designated uses as well and resulting in a protected use with lesser protection for a tributary to Logan Branch . Provide additional information to confirm if this was an intended revision and if so, provide additional documentation to support this revision.
- In Drainage List L, Horse Thief Run is proposed to be deleted, and it is unclear to which basin it has been assigned. Confirm that its designated use of CWF, MF has been maintained.
- In Drainage List L, there are a number of streams that are proposed to be deleted, and it appears that they are being assigned to be included in a basin with a designated use with lesser protection. Please confirm that the designated uses have been maintained for the following streams: Bender Run, Mosquito Creek, Lycoming Creek (source to Long Run), unnamed tributaries to Lycoming Creek, Cascade Run, Sugar Works Run, Mill Creek, Roaring Branch, Abbott Run, Red Run, Rock Run, Frozen Run, Heylmun Run, Pleasant Stream, Slacks Run, Shoemakers Run, Grays Run, Hagermans Run, Gendenen Run, Trout Run, Wolf Run, Daugherty Run, Hoagland Run, and Long Run.
- In Drainage List M, PADEP is proposing to add UNT 17823 and UNT 17821, both below Federal Aid Secondary Highway (FAS) 690, as those portions of the streams had been missing from the list. Although upstream of FAS 690 the streams are designated HQ-CWF, MF, downstream has been assigned CWF, MF. PADEP needs to provide additional documentation to support this revision, as it is unclear from the information in the public notice that this is the correct designation.
- In Drainage List O, PADEP is proposing to add the Trout Run basin from the water supply dam to mouth, as it was missing from the list. Above the water supply dam, Trout Run is designated EV, this segment of the stream is being added as HQ-CWF, MF. PADEP needs to provide additional documentation to support this revision, as it is unclear from the information in the public notice that this is the correct designation.
- In Drainage List O, PADEP is proposing to correct the designated use of Reynolds Run from HQ-CWF, MF to HQ-TSF, MF. PADEP needs to provide additional documentation to support this correction as it is unclear from the information in the public notice that this correction is warranted.
- In Drainage List R, PADEP indicates that the erroneous stream listing for Mill Run is being deleted, but provides no indication as to why the listing is erroneous.

<u>Exceptions for fishable/swimmable waters</u>

As part of this triennial review, PADEP reexamines water body segments that do not meet the fishable and/or swimmable goals specified in Clean Water Act Section 101(a)(2). In the Delaware River in Zones 3, 4, and upper Zone 5 of the Delaware Estuary basin uses are limited to WWF (Maintenance Only) and MF (Passage Only) for tidal portions of the basin from river mile 108.4 to the PA-DE State Border and do not include propagation. In the public notice of the triennial review, PADEP notes that recent Delaware River Basin Commission (DRBC) review has found successful reproduction demonstrated in the compromised estuary zones. EPA understands that PADEP continues to work with DRBC and other stakeholders in determining the appropriate criteria that should apply in the lower Delaware River and Delaware Estuary. However, EPA also notes that this public notice recognizes that

propagation is occurring, and is therefore an existing use. Per Pennsylvania's antidegradation regulation at 93.4c(a)(1)(i), existing use protection shall be provided when the Department's evaluation of information indicates that a surface water attains or has attained an existing use. In addition, the public notice acknowledges the presence of the Federally-listed endangered species Atlantic sturgeon. Pennsylvania regulation at 93.4c(a)(2) states that the confirmed presence of such a species requires that PADEP ensure the protection of the species. Based upon these Pennsylvania regulations, EPA believes PADEP should be implementing water quality standards to protect for the existing use. For example, NPDES permits could be written using dissolved oxygen criteria that protects Atlantic sturgeon, rather than the current criteria, which is widely acknowledged to be under protective of that species.

PADEP also reexamined the removal of the water contact use from the Delaware River between River Miles 108.4 to 81.8. In the proposed rulemaking, PADEP states that the WC use remains excluded from the designated uses in this portion of the Delaware River because of impacts from combined sewer overflows (CSO) and hazards associated with commercial shipping and navigation. EPA believes that this conclusion needs to be reconsidered since EPA's Combined Sewer Overflow Policy was issued in 1994 and incorporated into the Clean Water Act in 2000. Long Term Control Plans are now under development or in place for the CSOs in this portion of the river. In addition, recreation which results in contact with the water is occurring in this portion of the river. PADEP should initiate an effort with the Delaware River Basin Commission (DRBC) and the other member states to revise the applicable standards to include designated use protection for water contact/swimming.

Thank you for this opportunity to provide comments on Pennsylvania's triennial review of its water quality standards regulation. EPA would be happy to assist the Commonwealth as necessary to complete this triennial review. If you have any questions concerning this letter, please contact me at (215)814-5452, or have you staff contact Katherine Bentley at (215)814-5762.

Sincerely,

Evelyn S. MacKnight

Evelyn S. MacKnight, Associate Director
Office of Standards, Assessment & TMDLs
Water Protection Division

cc: Thomas Barron (PADEP)

Enclosure 1: Literature that accompanies §93.7 Osmotic Pressure comment

Field-based Effects Literature

Cormier SM, Suter GWII, Pond GJ, Zheng L. 2012a. Assessing causation of the extirpation of stream macroinvertebrates by a mixture of ions. Environ Toxicol Chem 32:277–287

Cormier SM, Suter GWII, Zheng L. 2012b. Derivation of a benchmark for freshwater ionic strength. Environ Toxicol Chem 32:263–271

Cormier SM, Suter GW, II., 2012c. A method for deriving water quality benchmarks using field data. Environ Toxicol Chem 32:255–262

Cormier SM, Zheng L, Flaherty, CM, *in press*. A field-based model of the relationship between extirpation of salt-intolerant benthic invertebrates and background conductivity. Science of the Total Environment.

U.S. Environmental Protection Agency. 2011. A field-based aquatic life benchmark for conductivity in Central Appalachian streams. EPA 600/ R-10/023F. Office of Research and Development, National Center for Environmental Assessment, Washington, DC.

Toxic Effects Literature

Canadian Council of Ministers of the Environment. 2011. Canadian Water Quality Guidelines: Chloride Ion. Scientific criteria Document. Winnipeg: Canadian Council of Ministers of the Environment.

Corsi, S.R., Graczyk, D.J., Geis, S.W., Booth, N.L., Richards, K.D., 2010. A fresh look at road salt: aquatic toxicity and water-quality impacts on local, regional, and national scales. Environ. Sci. Technol. 44 (19):7376–7382. http://dx.doi.org/10.1021/es101333u.

Gillis. PL. 2011. Assessing the toxicity of sodium chloride to the glochidia of freshwater mussels: Implications for salinization of surface waters. Environmental Pollution 159:1702-1708.

Iowa Department of Natural Resources. 2009. Water Quality Standards Review: Chloride, Sulfate, and Total Dissolved Solids Consultation Package. Des Moines, Iowa.

Patnode KA, Elizabeth Hittle, Anderson RM, Zimmerman L, Fulton JW. 2015. Effects of high salinity wastewater discharges on unionid mussels in the Allegheny River, Pennsylvania. Journal of Fish and Wildlife Management 6(1):55-70; e1944-687X.

Soucek DJ, Lionton TK, Tarr CD, Dickinson A, Wickramanayake N, Delos CG, Cruz L. 2011. Influence of water hardness and sulfate on the acute toxicity of chloride to sensitive freshwater invertebrates. Environmental Toxicology and Chemistry. 30(4): 930-938.