**UNITED STATES ENVIRONMENTAL PROTECTION AGENCY**
**REGION 7**
11201 Renner Boulevard
Lenexa, Kansas 66219

JAN 0 6 2015

Ms. Sara Parker Pauley, Director
Missouri Department of Natural Resources
P.O. Box 176
Jefferson City, Missouri 65102

Dear Ms. Pauley:

On December 1, 2011, the Missouri Department of Natural Resources proposed a number of changes to the state's water quality standards (36 MoReg 2521). A public hearing on the proposed changes was held in Jefferson City on January 4, 2012, and written comments were accepted by the MDNR through January 18, 2012. The Missouri Clean Water Commission adopted six new or revised WQS provisions on March 9, 2012, but the final rule, published on May 31, 2012, included only five new or revised provisions. These included (1) an amended compliance schedule authorizing provision at 10 CSR 20-7.031(10), (2) new site-specific dissolved oxygen criteria for the protection of aquatic life in Table K, (3) new and revised phenol criteria for the protection of aquatic life in Table A, (4) new and revised stream recreational use designations in Table H, and (5) new and revised chloride and sulfate criteria for the protection of aquatic life in Table A and related changes to 10 CSR 20-7.031(4)(L).

The revised standards were submitted to the U.S. Environmental Protection Agency under a cover letter dated December 10, 2012.[1] The EPA has acted on the following parts of this submittal, to date:

- On January 25, 2013, the EPA partially approved and partially disapproved the amended compliance schedule authorizing provision.
- On May 10, 2013, the EPA disapproved the new site-specific dissolved oxygen criteria.
- On September 27, 2013, the EPA partially approved and partially disapproved the new and revised aquatic life criteria for phenol.
- On September 27, 2013, in a separate action, the EPA partially approved and partially disapproved most of the new and revised recreational use designations.

Today, the EPA is taking the following additional actions:

- Approving all but one of the remaining recreational use designations. This action does not address the 28.3-mile portion of the Mississippi River designated by the state for secondary

[1] Some supporting electronic files were inadvertently omitted from the original WQS submittal package. These files arrived at the EPA regional office on January 30, 2013.

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contact recreation but not primary contact recreation. The EPA will continue to review the Mississippi River's recreational use designation and will act on this component of the WQS at a later date.

- Disapproving the state's revised aquatic life criteria for chloride, new aquatic life criterion for sulfate and related changes to 10 CSR 20-7.031(4)(L).

## NEW AND REVISED RECREATIONAL USE DESIGNATIONS

Section 101(a)(2) of the Clean Water Act establishes, as an interim national goal, "water quality which provides for the protection and propagation of fish, shellfish, and wildlife and provides for recreation in and on the water" where such uses are attainable. Section 303(c)(2)(A) requires that WQS "protect the public health and welfare, enhance the quality of water, and serve the purposes of [the] Act." The EPA's WQS regulation interprets and implements these provisions by requiring WQS to protect the uses specified in section 101(a)(2) unless these uses have been demonstrated to be unattainable, effectively creating a rebuttable presumption of attainability (40 CFR §§ 131.2; 131.5(a)(4); 131.6(a), (f); 131.10(g), (j), (k)). If a state wishes to remove a section 101(a)(2) use that is not an existing use, or to adopt a use subcategory that requires less stringent criteria, it must demonstrate, through a use attainability analysis (UAA), that the section 101(a)(2) use is unattainable (40 CFR § 131.10(j)(2)).

Federal regulations at 40 CFR § 131.3(g) define a UAA as a "structured, scientific assessment of the factors affecting the attainment of the use which may include physical, chemical, biological, and economic factors as described in 40 CFR § 131.10(g)." A state must provide the information needed to determine whether a section 101(a)(2) use is unattainable and to justify the application of any use subcategory affording a lesser degree of water quality protection. In other words, the administrative record must contain an adequate scientific and technical rationale for changing the use designation (40 CFR §§ 131.5(a)(4); 131.6(f)). In demonstrating that the attainment of a section 101(a)(2) use is not feasible, a state must cite and satisfy at least one of the six regulatory factors described at 40 CFR § 131.10(g).

On August 16, 2011, the EPA acted on an earlier (November 2, 2009) WQS submittal from Missouri. That submittal contained a number of use designation changes, some of which involved the removal of a section 101(a)(2) use—whole body contact recreation (WBCR). The revised rule left no recreational use in place for twelve classified stream segments: Bear Creek (WBID 1220), Campbell Creek (WBID 0491), Hickory Creek (WBID 0442), Lindley Creek (WBID 1437), Pike Creek (WBID 2815), Reid Creek (WBID 3410), Rollins Creek (WBID 0382), Scott Branch (WBID 0952), Tributary to Cape La Croix Creek (WBID 1837), Tributary to Clark Fork (WBID 0791), Tributary to Wildcat Creek (WBID 0484) and Truitt Creek (WBID 3175). Upon reviewing the UAAs submitted by the state for these segments, the EPA concluded that each segment could support a less protective recreational use—secondary contact recreation (SCR). The EPA disapproved the state's removal of WBCR in each of these cases, pending the designation of the segments for SCR.

In Missouri's recent (December 10, 2012) WQS submittal, all twelve segments have been designated for SCR but not WBCR. These changes are consistent with the state's earlier conclusion that WBCR is not attainable in the segments owing to insufficient water depth (per 40 CFR 131.10(g)(2)). The state has received no public comments contradicting this finding or otherwise pointing to the historical or current use of the segments for WBCR. The EPA has again reviewed the submitted UAAs, finds that they are



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technically and scientifically defensible, and agrees that SCR currently represents the highest attainable recreational use based on the factors and constraints evaluated as part of the UAAs. The EPA approves the removal of WBCR and assignment of SCR in these twelve instances.[2]

## NEW AND REVISED WATER QUALITY CRITERIA

Revised chloride criteria for the protection of aquatic life

Prior to the Commission's adoption of revised WQS on March 9, 2012, the state's acute criterion for chloride was 860 milligrams per liter (mg/L) and its chronic criterion for chloride was 230 mg/L. These criteria were approved by the EPA on September 8, 2000. Both criteria comported with recommendations published by the EPA under section 304(a) of the Clean Water Act (see *Ambient Water Quality Criteria for Chloride*. 1988. EPA 440/5-88-001).

On December 10, 2012, Missouri submitted revised chloride criteria. These were presented in Table A of the WQS and took the following form:

$$\textit{Acute:} \quad \textit{Chloride} = 287.8 * (\textit{Hardness})^{0.205797} * (\textit{Sulfate})^{-0.07452}$$
$$\textit{Chronic:} \quad \textit{Chloride} = 177.87 * (\textit{Hardness})^{0.205797} * (\textit{Sulfate})^{-0.07452}$$

where chloride and sulfate concentrations were expressed in mg/L and total hardness was expressed in mg/L as calcium carbonate ($CaCO_3$).

The state's WQS submittal package contained no report or general statement explaining and defending the revised chloride criteria. However, the revised criteria equations were identical to those equations adopted by the Iowa Environmental Protection Commission on September 15, 2009, and approved by the EPA on May 19, 2010.

In reviewing Missouri's revised criteria for chloride, the EPA has considered (1) scientific documentation submitted previously by Iowa, and (2) aquatic toxicity data for chloride generated during the past five years and building upon the documentation provided by Iowa. The EPA's review has led to following significant findings:

- *Missouri's revised chloride criteria are not scientifically defensible.*

  The EPA's Office of Research and Development played a prominent role in the development of the chloride criteria adopted by Iowa. Specifically, ORD searched the relevant toxicological literature and databases, identified pertinent studies and data, collaborated with outside laboratories to acquire additional data, and developed alternative water quality criteria for chloride in a manner comporting with federal guidelines (Stephan et al. 1985. *Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses.* PB85-227049).

[2]Lindley Creek (WBID 1437) represents a special case. The EPA's September 27, 2013, decision letter erroneously indicated that this segment lacked a prior recreational use designation. It approved the segment's designation for SCR but did not approve the removal of WBCR. In today's action, the EPA approves the removal of WBCR and reaffirms that SCR currently represents the highest attainable recreational use for this segment.



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The dataset compiled by ORD contained information on the chloride sensitivities of 29 freshwater genera—17 more genera than represented in the dataset used to derive the acute ambient water quality criterion (AWQC). ORD normalized acute toxicity data (median lethal concentrations; median effective concentrations) against sulfate and total hardness to compensate for differences in the measured concentrations of these parameters among toxicity tests. After sorting the normalized data by taxa, ORD calculated species mean acute values (SMAVs) and genus mean acute values (GMAVs). A final acute value, or FAV, was calculated using the GMAVs and cumulative probabilities for the four most sensitive genera: *Sphaerium*, *Ceriodaphnia*, *Daphnia* and *Lampsilis*. The FAV was divided by two to yield the criterion maximum concentration, pursuant to the 1985 guidelines. Observed statistical relationships between chloride toxicity and total hardness, and between chloride toxicity and sulfate concentration, were used to derive the exponents appearing in the acute criterion equation.

In the derivation of the chronic chloride criterion, acute/chronic ratios (ACRs) for four crustacean species were used to generate a predicted genus mean chronic value (pGMCV) for each invertebrate genus represented in the acute toxicity dataset. An ACR also was available for one vertebrate species (rainbow trout), and this value was used to derive a pGMCV for each vertebrate genus in the acute dataset. Per Stephan et al. (1985), a predicted final chronic value was calculated using the pGMCVs and cumulative probabilities for those four genera with the lowest pGMCVs: *Sphaerium*, *Ceriodaphnia*, *Pseudacris* and *Daphnia*. Exponents for the hardness and sulfate variables in the chronic criterion equation were identical to those applied in the acute criterion equation, based on the assumption that the underlying statistical relationships were robust with respect to differences in duration among toxicity tests.

Shortly after Iowa's adoption of the revised criteria, several additional studies were published that examined the sensitivity of aquatic organisms to chloride exposure (e.g., EPA 2010; Gardner and Royer 2010; Elphick et al. 2011a; Gillis 2011; Soucek et al. 2011; Pandolfo et al. 2012). Test water concentrations of sulfate and total hardness were measured in nearly all of these studies, providing data that could have been used by Missouri to refine the acute and chronic criteria equations developed originally for Iowa. However, Missouri elected to adopt the criteria equations developed for Iowa without modification. In the absence of any report explaining and defending Missouri's decision not to apply the newer scientific studies, the EPA finds that the state's revised criteria for chloride are not scientifically defensible.

- *Missouri's revised chloride criteria are not protective of aquatic life.*

Recent toxicological studies suggest that the AWQC for chloride may not protect certain widely occurring forms of aquatic life (reviewed by Ingersoll and Wang 2014). For example, Wang et al. (2013) reported that median effective concentrations (EC50s) calculated for one cladoceran species and four freshwater mussel species were equal to or less than the FAV used to derive the acute AWQC. They concluded that the acute AWQC may not be protective of certain forms of aquatic life and proposed follow-up studies focusing primarily on freshwater mussels.

Ivey et al. (2013) evaluated ten mussel species for acute sensitivity to chloride and one mussel species for chronic sensitivity to chloride. EC50s calculated for six species were, once again, less than the FAV used to derive the acute AWQC. For the species tested for long-term effects, 20$^{th}$

percentile effective concentrations (EC20s) were consistently at or below the chronic AWQC. Ivey et al. (2013) concluded that (1) chloride sensitivity among freshwater mussels is generally greater than exhibited by other aquatic organisms, and (2) the EPA's recommended criteria for chloride may not be protective of freshwater mussels.

Missouri's revised chloride criteria are, under certain environmental conditions, even less protective than the AWQC. For example, at a hardness level of 150 mg/L and a sulfate level of 15 mg/L, the state's applicable acute criterion for chloride is 637 mg/L and its applicable chronic criterion is 393 mg/L. As hardness increases to 500 mg/L, the applicable acute and chronic criteria become 816 and 504 mg/L, respectively. As hardness increases to 1,000 mg/L, the applicable acute and chronic criteria become 941 and 581 mg/L, respectively.

Chloride toxicity in some aquatic species can be mitigated by an increase in total hardness but potentially exacerbated by an increase in sulfate concentration (Soucek et al. 2011). Although the criteria adopted by Missouri attempt to capture these relationships, they do not reflect the toxicity data and water quality (hardness, sulfate) data generated during recent scientific studies. It remains unclear, therefore, whether the adopted criteria are protective of certain sensitive groups of aquatic organisms, notably freshwater mussels.

- *Missouri's criteria equations for chloride are vague or silent with respect to the statistical form of the independent variables.*

  As noted previously, Missouri's WQS submittal contains no report or general statement explaining and defending the revised chloride criteria. The state presumably intends to express the acute criterion concentration as an instantaneous value and the chronic criterion concentration as a four-day (96-hour) average, based on the definition for "acute toxicity" given at 10 CSR 20-7.031(1)(A) and the definition for "chronic toxicity" given at 10 CSR 20-7.031(1)(E). Pursuant to 10 CSR 20-7.031(1)(Y), the state also presumably intends to apply hardness values that reflect "the lower quartile... value of a representative number of samples from the water body in question or from a similar water body at the appropriate stream flow conditions."

  However, the WQS do not address the statistical nature of the sulfate variable appearing in the chloride criteria equations. It is unclear whether the state intends to apply a lower quartile value or some other statistical expression for sulfate. This is viewed by the EPA as a major omission, in that values for sulfate applied in the criteria equations will have a material impact on the magnitude of the chloride criteria. Missouri's WQS also do not establish an allowable excursion frequency for the chloride criteria. Numeric water quality criteria for the protection of aquatic life must include magnitude, duration *and* frequency components, because all three components are needed to quantify the allowable level of pollutant exposure (see *Water Quality Standards Handbook, Second Edition*. EPA-823-B-93-002).

In summary, Missouri's revised criteria for chloride are not scientifically defensible, may not be protective of the aquatic life use, are vague or silent with respect to the statistical form of the independent variables, and fail to specify allowable criteria excursion frequencies. Given these considerations, the EPA hereby disapproves these criteria. The state's former acute criterion of 860 mg/L



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and former chronic criterion of 230 mg/L remain in effect for Clean Water Act purposes, pursuant to this action.

New sulfate criterion for the protection of aquatic life

On March 9, 2012, the state adopted the following hardness- and chloride-dependent water quality criterion for sulfate (all sulfate values are expressed in mg/L):

| | *Chloride, $Cl^-$ (mg/L)* | | |
|---|---|---|---|
| *Hardness, H (mg/L)* | *$Cl^- < 5$* | *$5 \leq Cl^- < 25$* | *$25 \leq Cl^- < 500$* |
| *$H < 100$* | *500* | *500* | *500* |
| *$100 \leq H \leq 500$* | *500* | *S1* | *S2* |
| *$H > 500$* | *500* | *2,000* | *2,000* |

*S1 = [-57.478 + 5.79 (hardness) + 54.163 (chloride)] * 0.65*
*S2 = [1276.7 + 5.508 (hardness) – 1.457 (chloride)] * 0.65*

In submitting this criterion to the EPA, the state provided no accompanying scientific report or explanatory statement. However, the criterion's table and two equations are identical to those adopted by the Iowa Environmental Protection Commission on September 15, 2009, and approved by the EPA on May 19, 2010. Therefore, in reviewing this criterion, the EPA has considered (1) scientific documentation submitted previously by Iowa and (2) aquatic toxicological data for sulfate generated during the past five years and building upon the documentation provided by Iowa. This review has led to the following significant findings:

- *Missouri's new sulfate criterion is not scientifically defensible.*

  Iowa's acute criterion for sulfate is based on an earlier collaborative effort between ORD, the Illinois Environmental Protection Agency and the Illinois Natural History Survey. During 2005 and 2006, ORD and IEPA reviewed the relevant toxicological literature and related datasets while INHS generated additional acute toxicity data for five species of aquatic invertebrates: *Ceriodaphnia dubia*, *Hyalella azteca*, *Chironomus tentans*, *Sphaerium simile* and *Lampsilis siliquoidea*. Tests for *H. azteca* and *C. dubia* were performed under a range of chloride and total hardness concentrations, providing the data needed to establish statistical relationships between these water chemistry factors and observed toxicity. Using this expanded dataset, ORD calculated an FAV and a criterion maximum concentration for sulfate and developed the table and two equations expressing the criterion as a function of both ambient hardness and chloride level.

  Shortly after the adoption of this criterion by Illinois and Iowa, additional studies were published that examined the sensitivity of aquatic organisms to sulfate exposure (e.g., EPA 2010; Consbrock et al. 2011; Elphick et al. 2011b). Test water concentrations of chloride and total hardness were measured in nearly all of these studies, providing data that could have been used by Missouri to refine the sulfate criterion developed by ORD, IEPA and INHS. However, Missouri elected to adopt the criterion's table and two equations without modification. In the absence of any report explaining and defending Missouri's decision not to apply the newer



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scientific studies, the EPA finds that the state's adopted criterion for sulfate is not scientifically defensible.

- *Missouri's new sulfate criterion is not protective of aquatic life.*

  The state's aquatic life criterion for sulfate is presented in Table A of the WQS. This table does not specify whether the sulfate criterion addresses acute toxicity or chronic toxicity. However, 10 CSR 20-7.031(4)(A) reads, in part, "All Table A and B criteria are chronic toxicity criteria, except those specifically identified as acute criteria." This is problematic, in that the adopted criterion for sulfate is based on acute toxicity data (see preceding paragraphs).

  Pursuant to 10 CSR 20-7.031(1)(A) and (1)(E), Missouri expresses its acute criteria as maximum instantaneous concentrations and its chronic criteria as four-day average concentrations (most parameters) or 30-day average concentrations (ammonia only). Acute criteria must be met at the edge of the zone of initial dilution, whereas chronic criteria must be met at the edge of the mixing zone (see 10 CSR 20-7.031(4)(A)4.A). Application of the adopted sulfate criterion as a chronic criterion (i.e., as a four-day average concentration at the edge of the mixing zone) would potentially (a) subject aquatic organisms within the mixing zone to acutely toxic conditions and (b) subject aquatic organisms outside the mixing zone to chronically toxic conditions.

  Recent studies have shown that the sulfate criterion developed by ORD, IEPA and INHS may not be protective of certain widely occurring forms of aquatic life, even when correctly applied as an acute criterion (reviewed by Ingersoll and Wang 2014). For example, USGS-CERC has generated sulfate toxicity data (EC50s and EC20s) for a number of previously untested species and genera (Consbrock et al. 2011; Wang et al. 2013). Much of this work has focused on freshwater mussels, which are now known to rank among the most sensitive organisms to sulfate exposure. Test results have shown that (a) the acute criterion developed by ORD, IEPA and INHS may not be protective of certain mussel species and (b) a chronic criterion for sulfate is needed to protect mussels and other sensitive aquatic organisms, such as embryonic and newly hatched fathead minnow (*Pimephales promelas*).

  Given the above considerations, the EPA finds that the sulfate criterion adopted by Missouri is not protective of the aquatic life use.

- *Missouri's criterion equations for sulfate are vague or silent with respect to the statistical form of the independent variables.*

  In the application of the sulfate criterion, Missouri presumably intends to use "lower quartile" values for total hardness pursuant to 10 CSR 20-7.031(1)(Y). However, the statistical nature of the chloride variable is not addressed in the state's WQS. This is viewed by the EPA as a major omission, in that chloride values applied by the state will materially impact the magnitude of the sulfate criterion. Missouri's WQS also do not establish an allowable excursion frequency for the sulfate criterion. As noted previously, numeric water quality criteria for the protection of aquatic life must include magnitude, duration *and* frequency components, because all three components are needed to quantify the allowable level of pollutant exposure.



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In summary, Missouri's new sulfate criterion is not scientifically defensible, is not protective of the aquatic life use, is vague or silent with respect to the statistical form of the independent variables, and fails to specify an allowable excursion frequency. The EPA disapproves this criterion.

Removal of criteria limiting combined concentrations of chloride and sulfate

Prior to the Commission's March 9, 2012, rulemaking, Missouri's WQS contained the following language at 10 CSR 20-7.031(4)(L):

> *(L) Sulfate and Chloride Limit for Protection of Aquatic Life.*
>
> 1. *Streams with 7Q10 low flow of less than one (1) cubic foot per second. The concentration of chloride plus sulfate shall not exceed one thousand milligrams per liter (1,000 mg/L). Table A includes additional chloride criteria.*
>
> 2. *Class P1, L1, L2, and L3 waters and streams with 7Q10 low flow of more than one (1) cubic foot per second. The total chloride plus sulfate concentration shall not exceed the estimated natural background concentration by more than twenty percent (20%) at the 60Q10 low flow.*

The above restrictions on combined concentrations of chloride and sulfate were removed from the revised WQS. As shown below, 10 CSR 20-7.031(4)(L) now references only the state's new sulfate criterion and newly revised chloride criteria:

> *(L) Sulfate and Chloride Limit for Protection of Aquatic Life. Water contaminants shall not cause sulfate or chloride criteria to exceed the levels described in Table A.*

The position of two words in this provision ("criteria" and "levels") may have been inadvertently reversed at some point in the state's rulemaking process. Additionally, the revised rule fails to define the term "water contaminants." This term potentially could be interpreted to refer to chloride and sulfate derived from anthropogenic sources rather than all sources. Such an interpretation would not be protective of the aquatic life use, because toxicological risk is a function of ambient pollutant concentration rather than pollutant source.

The earlier language at 10 CSR 20-7.031(4)(L) was approved by the EPA on September 8, 2000. It reflects a realization that the toxicological effects of chloride and sulfate may be additive (see Soucek 2007; Soucek et al. 2011). In the absence of an approved criterion for sulfate in Table A of the WQS, the earlier language affords the state's aquatic life some measure of protection against the potential additive effects of chloride and sulfate. Given these considerations, and the concerns noted in the preceding paragraph, the EPA disapproves the revised language found at 10 CSR 20-7.031(4)(L). The original wording of this provision, approved by the EPA on September 8, 2000, and reproduced above, remains in effect for Clean Water Act purposes.

## CONCLUDING REMARKS

To remedy the above disapproval actions, Missouri may wish to (a) comprehensively review the relevant toxicological literature and databases, including the recent articles, reports, posters and



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presentations listed in the Enclosure, (b) develop appropriate acute and chronic criteria for chloride and sulfate following EPA-recommended procedures or other scientifically defensible procedures, (c) formally adopt these criteria and (d) include them in a future WQS submittal, along with a report that clearly explains and defends the criteria derivation procedures followed by the state. As emphasized previously, all aquatic life criteria submitted by the state must include magnitude, duration and frequency components. The EPA stands ready to assist the state in its efforts to develop criteria for chloride and sulfate that are scientifically defensible and protective of the aquatic life use.

The EPA appreciates Missouri's continuing efforts to protect and restore water quality and its overall commitment to the triennial WQS review and revision process. My colleagues and I look forward to working with the MDNR, the Commission and interested stakeholders on future WQS revisions. Should you have any questions or comments regarding today's actions, please contact John DeLashmit, Chief, Water Quality Management Branch, at (913) 551-7821.

Sincerely,

Karen A. Flournoy

Karen A. Flournoy
Director
Water, Wetlands and Pesticides Division

cc: John Madras, MDNR
Corey Buffo, EPA HQ



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ENCLOSURE

SCIENTIFIC STUDIES ADDRESSING THE AQUATIC TOXICOLOGY OF CHLORIDE AND SULFATE: SOME RECENT EXAMPLES

Consbrock RA, Hardesty DK, Wang N, Ingersoll CG, Brumbaugh WG. 2011. Acute and chronic sulfate toxicity to select freshwater organisms in water-only exposures. Poster presented at 32nd annual meeting of the Society of Environmental Toxicology and Chemistry, November 14, 2011, Boston, MA.

Elphick JRF, Bergh KD, Bailey HC. 2011a. Chronic toxicity of chloride to freshwater species: effects of hardness and implications for water quality guidelines. Environmental Toxicology and Chemistry 30:239–246.

Elphick JRF, Davies M, Gilron G, Canaria EC, Lo B, Bailey HC. 2011b. An aquatic toxicological evaluation of sulfate: the case for considering hardness as a modifying factor in setting water quality guidelines. Environmental Toxicology and Chemistry 30:247–253.

EPA. 2010. Final report on acute and chronic toxicity of nitrate, nitrite, boron, manganese, fluoride, chloride and sulfate to several aquatic animal species. U.S. Environmental Protection Agency, Region 5. EPA 905-R-10-002.

Gardner KM, Royer TV. 2010. Effect of road salt application on seasonal chloride concentrations and toxicity in south-central Indiana streams. Journal of Environmental Quality 39:1036–1042.

Gillis P. 2011. Assessing the toxicity of sodium chloride to the glochidia of freshwater mussels: implications for salinization of surface waters. Environmental Pollution 159:1702–1708.

Ingersoll CG, Wang N. 2014. Preliminary summary of results from USGS laboratory toxicity testing of major ions with select freshwater fish and invertebrates. Invited presentation delivered to Missouri Water Quality Standards Stakeholders' Workgroup, October 17, 2014, Jefferson City, MO.

Ivey CD, Consbrock RA, Kunz JL, Ingersoll CG, Wang N, Brumbaugh WG, Hammer E, Bauer CR, Barnhart CM. 2013. Sensitivity of freshwater mussels at two life stages to acute or chronic effects of NaCl or KCl. Poster presented at 34th annual meeting of the Society of Environmental Toxicology and Chemistry, November 18, 2013, Nashville, TN.

Pandolfo TJ, Cope WG, Young GB, Jones JW, Hua D, Lingenfelser SF. 2012. Acute effects of road salts and associated cyanide compounds on the early life stages of the unionid mussel *Villosa iris*. Environmental Toxicology and Chemistry 31(8):1801–1806.

Soucek DJ. 2007. Comparison of hardness- and chloride-regulated acute effects of sodium sulfate on two freshwater crustaceans. Environmental Toxicology and Chemistry 26:773–779.

Soucek DJ, Dickinson A, Major KM, McEwen AR. 2013. Effect of test duration and feeding on relative sensitivity of genetically distinct clades of *Hyalella azteca*. Ecotoxicology 22:1359–1366.

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

Wang N, Ingersoll CG, Ivey CD, Besser J, Brumbaugh WG, Alvarez D, Hammer E, Bauer CR, Augspurger T, Raimondo S, Shephard B, Bartoszek J, Barnhart CM, Eckert N. 2013. Acute sensitivity of freshwater mollusks and commonly tested invertebrates to select chemicals with different toxic modes of action. Poster presented at 34th annual meeting of the Society of Environmental Toxicology and Chemistry, November 18, 2013, Nashville, TN.



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