

# REPORT TO THE GENERAL ASSEMBLY: TOXICITY OF SELENIUM TO AQUATIC LIFE

## Purpose of this Report:

During the General Assembly's 2014 Session, two resolutions were passed (SJ35 and HJ57), which requested that the Department of Environmental Quality (DEQ) review the toxicity of selenium to aquatic life. The terms of the study and reporting requirements were specified as:

- Examine the most recent scientific information regarding the toxic effects of selenium on aquatic life and account for the chemical speciation of selenium, as well as actual exposure and uptake between and within different aquatic species. The analysis shall consider related studies and revisions in selenium criteria undertaken by other States, including Kentucky.
- Complete its meetings by November 30, 2014, and submit to the Governor and the General Assembly an executive summary and a report of its findings and recommendations for publication as a House or Senate document. The executive summary and report shall be submitted as provided in the procedures of the Division of Legislative Automated Systems for the processing of legislative documents and reports no later than the first day of the 2015 Regular Session of the General Assembly and shall be posted on the General Assembly's website.

## Executive Summary:

Selenium is a naturally occurring element present in soils in varying amounts depending on local geology. Although selenium is a micronutrient needed by animals in small amounts for proper cellular function, excess levels can cause toxic effects, with fish being especially sensitive. Selenium toxicity in contaminated aquatic ecosystems is especially complex and it can cause adverse impacts in a different manner than most other toxic substances.

Under the Federal Clean Water Act, section 304(a) requires the U.S. Environmental Protection Agency (EPA) to develop water quality criteria based on available scientific information. EPA requires States to consider EPA's recommendations (40 CFR Part 131) when adopting water quality criteria into their water quality standards. For toxic substances, water quality criteria are the numerical concentrations that if not exceeded should protect aquatic life. EPA develops water quality criteria based on available scientific information and publishes their recommended criteria for States to use in adopting criteria. Once a State adopts water quality criteria into their water quality standards, EPA must approve them before they become effective.

The science of selenium toxicity has been developing and evolving over several decades, with EPA first issuing recommended water quality criteria for selenium in 1980, with revised criteria issued in 1987. These 1987 recommendations were adopted into Virginia's Water Quality Standards Regulation (9 VAC 25-5 through -550) and are still in force:

1. 20 µg/L (micrograms per liter; parts per billion) for the acute criterion (short term exposures), and
2. 5 µg/L for the chronic criterion (long term exposures)

After EPA issued their 1987 selenium criteria, toxicologists continued to discover additional complexities in the way selenium causes adverse affects in the environment and EPA has been actively studying the toxicity of selenium since the mid 1990s, with the intent to revise their 1987 recommended criteria. Most recently, in May 2014 EPA announced the availability of a new draft Aquatic Life Criteria Document for Selenium in Freshwater, prepared for public review as well as an external peer review. In addition, some States have been considering revisions to their selenium water quality criteria, notably Kentucky, which proposed revisions over the last couple of years that have been partially approved by EPA and contested by environmental groups through lawsuits.

EPA's latest recommendations are for chronic criterion concentrations, intended to protect against long term exposures because of the fact that selenium acts in a bioaccumulative manner. EPA is not recommending an acute criterion. EPA's recommended criteria include four different elements:

1. A fish egg-ovary dry weight concentration of 15.2 mg/kg (milligrams per kilogram; parts per million).
2. Fish-tissue dry weight concentration of 8.1 mg/kg in whole fish, or 11.8 mg/kg dry weight in fish filet.
3. A water concentration – either 4.8 µg/L in lotic water (running water in streams and rivers) or 1.3 µg/L in lentic waters (still waters in lakes and impoundments).
4. A formula for calculating a water criterion for short term or intermittent exposures.

EPA recommends that States adopt all four elements and that the egg-ovary element takes primacy over all other elements and the whole body or filet tissue element takes precedence over the water column elements. This will allow for some flexibility in monitoring and assessment.

Because of the controversy over Kentucky's proposed revisions to their selenium criteria and the preliminary nature of EPA's most recent recommendations, DEQ recommended (with State Water Control Board approval in March 2014) that revisions to Virginia's selenium criteria not be included as part of DEQ's 2014 Triennial Review of water quality standards. However, as directed by SJ35 and HJ57, DEQ has reviewed the current state of the science on selenium toxicity to aquatic life and recommends that once EPA finalizes their recently proposed criteria for selenium, DEQ should consider initiating a rulemaking to amend Virginia's current water quality criteria for selenium.

## Background:

Selenium is a naturally occurring element found in soil. Toxic effects of selenium in the environment have mostly been observed in waterbodies associated with runoff from mining operations where the disturbed soils are high in selenium, discharges from coal fired power plant ash ponds, petroleum refinery effluents, and runoff from irrigation in areas where soils contain high levels of selenium.

Selenium is a micro-nutrient, necessary for proper cellular function of structural proteins and cellular defenses against oxidative damage. While small amounts of selenium are essential for proper cellular functioning, excess amounts can be toxic. The narrow range between the essential dietary needs and toxicity is a key factor in assessing selenium toxicity.

A great deal of interest has been generated regarding the toxicity of selenium and two expert workshops were held in 1998 and 2009, specifically devoted to investigating selenium toxicity in aquatic ecosystems. The current scientific understanding is that selenium is taken up in the tissues of animals and plants living in water bodies polluted with excess amounts and as these are eaten by other animals the selenium bioaccumulates in animals higher in the food chain. The most sensitive adverse effects in polluted waters appear to be on fish reproduction, due to selenium accumulating in the ovaries and eggs. If the concentrations are high enough they can cause deformities and death in the embryos, leading to reproductive failure in the fish population. The complexities of bioaccumulation, which can vary in differing waterbodies depending on the food chains present and the type of water flow (e.g., free flowing rivers and streams vs. still or slow moving lakes and impoundments), makes it difficult to predict with accuracy a specific water concentration of selenium that can be expected to cause toxicity in all waterbodies. For many years EPA has attempted to deal with these complexities and provide updated recommendations for selenium criteria that States can consider for revising their water quality standards.

## Water Quality Criteria:

The Clean Water Act, section 304(a) requires the U.S. Environmental Protection Agency (EPA) to develop water quality criteria based on available scientific information. States must consider the recommended criteria when adopting water quality criteria into their water quality standards (40 CFR Part 131). The Code of Federal Regulations, Title 40: Protection of the Environment, Chapter 1, Subchapter D, §131.11.(a) (2) (b) (1) requires that in establishing water quality criteria for toxic substances States should:

- (1) Establish numerical values based on:
  - (i) 304(a) Guidance; or
  - (ii) 304(a) Guidance modified to reflect site-specific conditions; or
  - (iii) Other scientifically defensible methods”.

For toxic substances, water quality criteria are numerical concentrations that if not exceeded should protect aquatic life. EPA develops water quality criteria based on available scientific information and publishes their recommendations for States to use in

adopting criteria. Once a State adopts water quality criteria into their water quality standards, EPA must approve them before they become effective.

Acute and Chronic Toxicity and Corresponding Criteria:

Typically, EPA develops recommended water quality criteria for toxic pollutants for both an acute and a chronic criterion. An acute criterion is designed to protect against short-term exposures, usually based on laboratory toxicity tests with a duration of 48 to 96 hours and implemented as a one hour average. Acute criteria are designed to prevent lethality and the concentration is typically much higher than the chronic criterion.

Chronic criteria are based on longer term exposures and can be based on lethality, reduced reproduction or reduced growth. The adverse effects of long term or chronic exposures to selenium can occur at much lower concentrations than those that can cause acute toxicity. It is recognized that selenium is more toxic to aquatic life when ingested in their food, compared to just being exposed to selenium dissolved in the water. This mode of action is different from the normal pattern of toxicity usually seen with other toxic pollutants, where contaminated water is the key route of exposure and toxicity. This is the main reason that developing water quality criteria for selenium has proven so difficult.

Selenium accumulates in the adult fish and affects their eggs and larvae. The most sensitive toxic effects appear to include reduced growth and survival of newly hatched fish, skeletal deformities, mutations, deformities and death of fish embryos, resulting in reproductive failures. In some cases, fish-eating birds may also be subject to risk if the fish they consume regularly contain elevated selenium levels.

From 1999 until recently, EPA had been investigating the possibility of basing acute criteria on a combination of acute toxicity tests with two different chemical forms of selenium; selenite ( $\text{SeO}_3^{2-}$ ) and selenate ( $\text{SeO}_4^{2-}$ ). However, as discussed in EPA's November 15, 2013 decision letter on Kentucky's recently adopted selenium criteria, EPA concluded that it is inappropriate to base an acute criterion on water-only exposure toxicity data. Because the current scientific consensus is that diet is the primary pathway of selenium exposure, an acute criterion that is based on water-only exposure, without accounting for any associated dietary exposure, will not be considered by EPA to be adequately protective of aquatic life. This effectively eliminates the usefulness of previous attempts to develop selenium criteria based on acute water-exposure toxicity data for selenite and selenate. However, this may have little practical effect because the chronic criterion, being lower in concentration and more stringent, is likely to be the principal driving value under most assessment or permitting scenarios.

The 1987 EPA criteria document recommended an acute criterion concentration of 20  $\mu\text{g}/\text{L}$ , which is unusual in that it was back-calculated from the recommended chronic criterion. Because the corresponding chronic criterion of 5  $\mu\text{g}/\text{L}$  was based on field observations, this acute criterion can be considered to partially account for dietary exposure to selenium, and retaining this as an acute criterion was one option EPA offered to Kentucky.

### History of EPA Criteria for Selenium:

EPA issued basic guidance about selenium in 1973, issued an individual criteria document for selenium in 1980 and a revised water quality criteria document in 1987. In the 1987 criteria document, EPA reported on investigations of selenium contamination in several waterbodies; it appeared that selenium caused more toxic effects in the field than laboratory chronic toxicity experiments would suggest. EPA concluded that selenium was entering the food chain and adversely affecting the aquatic life via consumption of contaminated food. This was different than most other toxic substances where contaminated water is the main route of exposure and toxicity.

Experiments showed that fish and mallard ducks were adversely affected when they ate food that contained selenium in the range of 10 to 13 µg/gm (micrograms per gram; parts per million) and that contamination of the food chain appeared to cause toxic effects in waterbodies contaminated with selenium. This was seen in a number of lakes around the country. Of particular importance, studies in a lake contaminated with fly ash (Belews Lake in North Carolina in the Dan River watershed, about 15 miles south of the Virginia border) indicated that in areas where selenium was at or below 5 µg/L, the fish population appeared unaffected, but in areas where selenium was 10 µg/L and higher, the fish community was adversely affected. Based on all the available information, EPA concluded that selenium was capable of causing adverse toxic effects through food chain contamination. It appeared that water concentrations of selenium greater than 5 µg/L caused observable toxic effects in the field. Based on the available information, EPA recommended an acute criterion of 20 µg/L and a chronic criterion of 5 µg/L in their 1987 criteria document. These EPA recommended selenium criteria (20 µg/L acute and 5 µg/L chronic) were the only recommended criteria available for many years and were adopted by Virginia and most other States.

Since 1995, DEQ staff has followed EPA's evolving efforts to update their recommendations for selenium water quality criteria. The understanding of how selenium can have adverse impacts has been developing over the past two decades as more is learned about the complex science behind the testing of its toxicity to freshwater aquatic life and setting water quality criteria that are protective against both acute (short term) and chronic (long term) impacts.

In 1998, EPA held a national workshop with experts on selenium and aquatic life toxicity to investigate the current knowledge of selenium toxicity in aquatic environments. The expert workshop recommended that instead of a water column criterion for selenium, a fish-tissue criterion was a more reliable approach.

In 1999, EPA published draft selenium criteria that reaffirmed the 1987 chronic criterion recommendation. In 2004, EPA published new draft criteria for selenium that recommended a chronic criterion expressed as a fish-selenium concentration applied to fish-whole-body analysis and acute criteria expressed as water concentrations for selenite and selenate. Public comments on this draft criteria document identified further research needs and resulted in additional investigations by EPA; therefore, these criteria were never finalized.

### Kentucky's Development and Adoption of Revised Aquatic life Criteria for Selenium

Recently, Kentucky developed and adopted new, updated water quality criteria for selenium. Kentucky used the EPA 2004 draft criteria recommendations as a starting point, added some new toxicity data and made some adjustments to the toxicity dataset to address only aquatic life species native to Kentucky. After public comments were reviewed and addressed, Kentucky adopted new acute and chronic criteria in 2013. The acute criteria adopted were water concentrations of selenite and selenate and were identical to what was recommended in EPA's 2004 draft criteria document. EPA disapproved Kentucky's acute criteria, stating that EPA has concluded that it is inappropriate to base an acute criterion on water-only exposure toxicity data. Because the current scientific consensus is that diet is the primary pathway of selenium exposure, an acute criterion that is based on water-only exposure, without accounting for any associated dietary exposure, will not be considered by EPA to be adequately protective of aquatic life.

EPA did approve Kentucky's chronic criteria for selenium which are based on fish-tissue concentrations, and are intended to protect fish reproduction. Using EPA's 2004 draft criteria development methods, Kentucky recalculated fish tissue chronic criteria values. Kentucky's new chronic criteria for selenium are 8.6 µg/g dry weight for a whole-body fish sample and 19.3 µg/g in eggs and ovaries. Kentucky also continues to use 5 µg/L (the old chronic criterion) as a threshold water concentration to trigger analysis of fish tissue.

Kentucky's development and adoption of new criteria for selenium was controversial with several environmental groups expressing concerns that the new criteria may not be protective enough, or difficult to implement. The Sierra Club, the Kentucky Waterways Alliance, Kentuckians for the Commonwealth and Appalachian Voices have jointly filed suit (Kentucky Waterways Alliance et al. v. McCarthy et al., in the U.S. District Court for the Western District of Kentucky, case number 3:2013-cv-01207) against Kentucky for adopting, and EPA for approving the new chronic criteria. The suit alleges that the new criteria, which are based on fish-tissue selenium concentrations, wrongly exempts fishless streams, is based on an averaging of results for several fish species instead of the singular most sensitive species, and fails to protect other aquatic life such as invertebrates and salamanders.

### EPA's Continuing Efforts to revise Selenium Criteria.

EPA's 2004 draft criteria document stimulated national interest in the issues related to selenium environmental toxicity and in 2009, the Society of Environmental Toxicology and Chemistry (SETAC) held an International Expert Workshop on Ecological Assessment of Selenium and the Aquatic Environment. Findings from this workshop (set forth in the document listed as Significant Reference 2) included the following:

- *"Diet is the primary pathway of selenium exposure for both invertebrates and vertebrates."*
- *"Traditional methods for predicting toxicity on the basis of dissolved concentrations in water do not work for selenium because the behavior and toxicity of selenium in*

*aquatic systems are highly dependent upon site-specific factors, including food web structure and hydrology.”*

- *“Selenium toxicity is primarily manifested as reproductive impairment due to maternal transfer, resulting in embryo toxicity (death of embryos) and teratogenicity (mutations and malformations) in egg-laying vertebrates.”*
- *“The most sensitive toxicity endpoints in fish larvae are teratogenic deformities such as skeletal, craniofacial and fin deformities and various forms of edema (swelling).”*
- *“The most sensitive toxicity endpoint in birds is embryo mortality.”*
- *“There is a consensus that birds and fish eggs are the critical media in terms of assessing or predicting selenium toxicity at a given location and measured concentrations in these tissues are most strongly linked to adverse effects.”*
- *“For reliable prediction of effect thresholds across a range of sites, numeric benchmarks for egg concentrations provide the greatest certainty. The more distantly connected a possible measurement medium is to the egg concentrations, the less certainty that the associated numeric benchmark will be appropriate across sites.”*

Although expressing a water quality criterion as a selenium concentration in fish egg-ovary tissue appears to be the most reliable method of assessing potential harm to the exposed aquatic community, this does present significant challenges in implementing such a criterion. Fish ovaries are usually only of significant size, and/or eggs only available during breeding season, which can vary among species and is somewhat uncertain in predictability. Also, many of the streams where selenium contamination may be a concern are small streams and the fish likely to inhabit them may be small species. This would make dissection and collection of adequate amounts of ovaries/eggs difficult without harvesting a significant number of fish, which could impact both the fish community structure and food webs. This makes field monitoring of fish populations difficult to achieve with a certainty of capturing female fish with eggs in their ovaries. These are practical issues related to limited timing and resources needed to correctly assess this type of a criterion.

Based on these and other findings of the 2009 SETAC workshop, EPA collaborated with the U.S. Geological Survey on developing a bioaccumulation model. EPA revised their 2004 draft criteria to include criteria based on egg-ovary tissue concentrations as well as water column concentrations and included these recommendation in their 2014 draft criteria document that was released for public review and comment in May 2014.

#### Latest EPA Draft Criteria:

In May 2014, U.S. EPA issued another draft criteria document with recommendations for selenium criteria in freshwater to replace their 2004 draft. This draft document is titled “External Peer Review Draft Aquatic Life Ambient Water Quality Criterion for Selenium – Freshwater 2014”, and was subjected to a public comment period from May 14 through July 28, 2014. This draft document was also subjected to an independent, contractor-led external peer review by seven experts in aquatic toxicology. The peer reviewers considered both the 2014 draft criteria document as well as the public comments on this draft. As of October 2014, the peer review was completed and EPA is now revising their

draft criteria, taking into account the comments of the peer reviewers and the public. EPA will next publish in the Federal Register a new Draft Selenium Criterion and will solicit additional scientific reviews through a second 60 day comment period. EPA plans on proposing the draft criterion in early 2015 and hopes to finalize the selenium criterion document by the end of 2015 (personal communication, Kathryn Gallagher, Branch Chief, Ecological Risk Assessment Branch, EPA). Of course, the ultimate timing of finalizing the criteria document is dependent on the extent of the technical revisions needed in response to the public comments and the peer review. DEQ is closely following the progress of this EPA criteria development activity.

Criterion Recommendation contained in EPA's "External Peer Review Draft Aquatic Life Ambient Water Quality Criterion for Selenium – Freshwater 2014":

The 2014 draft criteria document does not recommend an acute criterion but instead recommends focusing on preventing chronic adverse effects of selenium caused by bioaccumulation and the exposure to aquatic animals through their food rather than directly through the water. The adverse effects of selenium occur primarily due to transfer of selenium to eggs and embryos, causing harmful reproductive effects. The chronic criterion recommended by EPA is intended to protect the reproductive success of fish. This EPA 2014 recommended criterion is expected to also protect aquatic insects and plants because the available evidence indicates that these are less sensitive to selenium than fish.

EPA also noted that their recommendations for water quality criteria typically focus directly on aquatic life, not on aquatic-dependent wildlife such as birds. EPA recognizes the concerns for aquatic-dependent wildlife, including birds, but considers this issue to be beyond the scope of this national criteria update. EPA plans to consider this issue in the future. EPA notes that available evidence suggest that selenium is not significantly biomagnified moving up the food chain except in specific ecosystems where the food-web is heavily based on mollusks. Mollusks accumulate selenium to a greater extent than do insects and crustaceans. In waters where mollusks form the basis of the food-web and for species of wildlife and birds that primarily feed on mollusks, it could be expected that a water column concentration of selenium might need to be lower than the water concentrations recommended in the 2014 draft criteria.

A summary fact sheet on EPA's May 2014 Draft selenium water quality criterion is available at this EPA website:

<http://water.epa.gov/scitech/swguidance/standards/criteria/aqlife/selenium/upload/External-Peer-Review-Draft-Aquatic-Life-Ambient-Water-Quality-Criterion-For-Selenium-Freshwater-2014.pdf>

EPA's 2014 Draft Selenium Criteria recommendations are summarized in the following table:

2014 EPA Draft External Peer Review Selenium Criteria Recommendations

Media Sample	Magnitude	Duration
Fish eggs or ovaries	15.2 mg/kg dry weight	Instantaneous (not to be exceeded)
Fish whole-body, or Fish muscle (skinless, boneless fillet)	8.1 mg/kg dry weight 11.8 mg/kg dry weight	Instantaneous (not to be exceeded)
Water (running streams)	4.8 µg/L	30 day average
Water (ponds, reservoirs lakes)	1.3 µg/L	
Water; Intermittent Exposure and Discharges	See Below*	See Below*

**\* Water: Intermittent Exposure and Discharges:**

The fourth element of EPA's draft criteria recommendations is applicable to situations where the exposure to selenium may be intermittent rather than continuous. This element of the draft criteria is intended to prevent short-term or intermittent water column exposures to selenium from causing chronic effects. It uses a combination of the water-criterion concentration and a fraction of the time the water concentration may be at these threshold values.

For running waters, the intermittent exposure criterion used the chronic, 30-day average concentration for flowing waters (4.8 µg/L) and the water quality criterion equation is:

$$WQC \text{ intermittent } (int) = \frac{4.8 \mu\text{g/L} - \text{average background concentration}}{f_{int}} (1-f_{int})$$

where  $f_{int}$  is the fraction of any 30 day period during which elevated selenium concentrations occur, with  $f_{int}$  assigned the value of  $\geq 0.033$  (corresponding to 1 day).

For still waters, ponds, reservoirs and lakes, the equation is the same with the appropriate water chronic criterion concentration of 1.3 µg/L for still waters used instead of 4.8 µg/L used for flowing waters.

The primary criterion element that EPA has the most confidence in is 15.2 mg/kg dry weight measured in fish eggs and/or ovaries. If selenium levels are below this concentration in eggs or ovaries, adverse reproductive effects are considered unlikely.

The second element of the fish-tissue criterion is 8.1 mg/kg dry weight as measured in a whole-body fish sample, or 11.8 mg/kg dry weight measured in a skinless, boneless fillet. There is less confidence in this "non egg-ovary" criterion, but it will allow more flexibility in monitoring and sampling fish, because eggs are only present in fish for a brief time period each year.

A third element of the criterion is a water criterion of 4.8 µg/L in lotic water (running water in streams and rivers) or 1.3 µg/L in lentic waters (still waters in lakes and impoundments). The two concentrations differ because selenium bioaccumulates

differently in the food webs typically found in streams/rivers compared to food webs in impoundments and lakes.

A fourth element is an equation that can be used to assess short term exposures based on the water-concentration in the water body and using either the 4.8 or 1.3 µg/L concentration, depending on the water body type (e.g., stream or lake) in situations where the selenium in the water may be influenced by intermittent flows.

EPA recommends that all four elements be adopted as a State's criterion and a hierarchy established listing the most important/reliable criterion being the egg/ovary concentration, followed by the whole body-concentration or the filet concentration, and finally the water concentration. Following this established hierarchy, the best available monitoring data will be used to assess selenium in an aquatic setting.

### DEQ Recommendations:

DEQ Water Quality Standards staff recommends that any decision on how to amend Virginia's current criteria for selenium should be made after EPA issues their final recommended criteria for selenium in freshwater. Since 1998, EPA has engaged in a long and thorough investigation of the toxicity and potential ecological risks that selenium can pose to freshwater aquatic life. The EPA process for revising their criteria for selenium in freshwater has generated considerable interest from the public and other interested parties. The understanding of selenium toxicity and possible adverse effects on aquatic life has evolved significantly during the process and it appears that EPA is in the final stages of finalizing their recommendations.

Once EPA issues their final criteria recommendation for selenium, DEQ will decide how best to proceed with amending Virginia's water quality criteria which will require a formal rulemaking following the Administrative Process Act. This process typically takes 18 to 24 months (at the earliest) to complete and can be very time-consuming and staff-intensive.

When EPA makes their final determinations and finalizes their recommended selenium criteria, it will be the result of more than a decade of investigations and debate involving the public and the scientific community. EPA will consider their new criteria recommendations to represent the latest scientifically defensible approach to providing protection to aquatic life from the adverse effects of selenium. It is unlikely that EPA would approve any State's new criteria that do not closely follow their latest recommendations. If Virginia attempts to adopt selenium criteria before EPA finalizes their recommendations, and those criteria differ from whatever EPA finally recommends, then it is unlikely that EPA would approve the proposed criteria.

Alternately, if Virginia were to proceed with the criteria amendment process before EPA's recommendations are finalized, it is possible that the time and effort expended on the rulemaking could be wasted. EPA has the authority under the Clean Water Act and federal regulations (33 U.S.C. 1251 et seq., 40 CFR §131.5 (b)) to disapprove a State's water quality

standards and promulgate Federal standards (under section 303(c)(4)), and may also promulgate a new or revised standard when necessary to meet the requirements of the Act.

If EPA disapproved Virginia-proposed selenium criteria because they differ from EPA's proposed recommendations, notification of that action would be accompanied by specific changes that the State must adopt for the proposal to be acceptable. Per 40 CFR §131.22 (EPA promulgation of water quality standards):

(a) If the State does not adopt the changes specified by the Regional Administrator within 90 days after notification of the Regional Administrator's disapproval, the Administrator shall promptly propose and promulgate such standard.

At the time any proposed amendment is presented that is judged unacceptable by EPA, they would also likely rule that Virginia's current selenium standards are outdated and inadequate to protect the aquatic life designated use. In any case, until either Virginia or EPA adopts new and approved criteria, the "current criteria" will remain in effect. By waiting until EPA has finalized their guidance before Virginia begins the process of amending criteria for selenium, we can craft our updated criteria to address EPA's recommended guidance. This will save time, effort and resources and will help ensure the final Virginia updated criteria will be more likely to receive EPA approval.

## List of Significant References for Selenium Aquatic Life Toxicity:

A list of references that includes the more important sources of information that have been reviewed over time and were used in conducting the study called for by the General Assembly.

1. Brix, K.V. et al (no date). Critical Review of Tissue-Based Selenium Toxicity Thresholds for Fish and Birds. Parametrix Inc and Kennecott Utah Copper.
2. Chapman P.M., W.J. Adams, M.L. Brooks, C.G. Delos, S.N. Luoma, W.A. Maher, H.M. Ohlendorf, T.S. Presser and D.P. Shaw. 2009. Ecological Assessment of Selenium in the Aquatic Environment: Summary of a SETAC Pellston Workshop. Pensacola FL (USA): Society of Environmental Toxicology and Chemistry (SETAC).
3. Formation Environmental, LLC and HabiTech, Inc., January 2012. Proposed Site-Specific Criterion, Sage and Crow Creeks, Idaho.
4. Formation Environmental, LLC and HabiTech, Inc., January 2012. Technical Support Document: Proposed Site-Specific Criterion, Sage and Crow Creeks, Idaho.
5. GE Consultants Inc., December 3, 2012. Draft Technical Memorandum, Recommended updates to Kentucky's selenium aquatic life standards.
6. Geotechnical Environmental Water Resources Ecological Consultants, December 2012. Draft Technical Memorandum, Recommended updates to Kentucky's selenium aquatic life standards.
7. GEI Consultants Inc., October 2013. Updated Freshwater Aquatic Life Criteria for Selenium (produced for Virginia Mining Issues Group).
8. GEI Consultants Inc., Golder Associates, Parametrix and University of Saskatchewan, December 2008. Selenium Tissue Thresholds: Tissue Selection Criteria, Threshold Development Endpoints, and Potential to Predict Population or Community Effects in the Field.
9. Kentucky Department of Environmental Protection, September, 2012. Statement of Consideration Relating to Selenium Criteria proposed changes to 401 KAR 10:031.
10. Kentucky Department of Environmental Protection, April 3, 2013. Letter to Senator Harris and Representative Bell; 401 KAR 10:031 (Amended After Comment). Surface water standards, Agency Amendment to revise Kentucky water quality standards for selenium.
11. Lemly, A.D. and J.P. Skorupa, 2007. Technical Issues Affecting the Implementation of U.S. Environmental Protection Agency's Proposed Fish-Tissue-Based Aquatic

Criterion for Selenium. Integrated Environmental Assessment and Management- Volume 3, Number 4-pp. 552-558.

12. McIntyre, D.O., M.A. Pacheco, M.W. Garton, D. Wallschläger, and C.G. Delos, 2008. Effect of Selenium on Juvenile Bluegill Sunfish at Reduced Temperature. Health and Ecological Criteria Division, Office of Water, U.S. Environmental Protection Agency, Washington, DC. Contract #68-C-04-006. EPA-822-R-08-020.
13. Payne, R.G., Kentucky of Environmental Protection, 2013. Update to the Kentucky Water Quality Standards for the Protection of Aquatic Life: Acute Selenium Criterion and Tissue-Based Chronic Criteria.
14. U.S. EPA. 1980a, Ambient water quality criteria for selenium. EPA-440/5-80-070
15. U.S. EPA. 1987a, Ambient water quality criteria for selenium. EPA-440/5-87-006.
16. U.S. EPA. 1995, Ambient Water Quality Criteria for selenium. EPA-820-B-96-001
17. U.S. EPA, 1998. Report on the Peer Consultation Workshop on Selenium Aquatic Toxicity and Bioaccumulation. Office of Water, EPA-822-R-98-007.
18. U.S. EPA. Draft Aquatic Life Water Quality Criteria for Selenium – 2004, EPA-822-D-04-001
19. U.S. EPA. External Peer Review Draft Aquatic Life Ambient Water Quality Criterion for Selenium – Freshwater 2014. EPA 822-P-14-001 May 2014
20. West Virginia Department of Environmental Protection. Selenium Bioaccumulation Among Select Stream and Lake Fishes in West Virginia. February 2009
21. West Virginia Department of Environmental Protection. Selenium-Induced Developmental Effects Among Fishes in Select West Virginia Waters. January 2010.
22. Summary of the SETAC Pellston Workshop on Ecological Assessment of Selenium in the Aquatic Environment, Selenium <http://www.namc.org/docs/00045009.PDF>
23. Letter dated November 15, 2013 from EPA to Dr. Leonard Peters, Secretary, Energy and Environment Cabinet, Kentucky.