pH Criteria Revision Recommendations for Interstate Waters of the Delaware River Basin

Basis & Background Document

March 22, 2013

Delaware River Basin Commission
DELAWARE · NEW JERSEY
PENNSYLVANIA · NEW YORK
UNITED STATES OF AMERICA

Summary

The stream quality objectives for pH (also referred to as water quality criteria in accordance with Section 4.20) contained within DRBC's Water Quality Regulations have remained unchanged since 1967 despite the development and adoption of national and state criteria and advances in the application of pH criteria over the intervening 45 years. In an effort to update these pH criteria for the interstate waters of the Delaware River, the historic development of pH criteria was reviewed and contrasted across the different criteria promulgated by DRBC and the Basin States as well as the recommended criteria from the federal government. Although small differences among existing criteria and recommendations preclude a unifying set of pH criteria for the Delaware River among all authorities, two primary classes of revisions have been recommended by DRBC staff and unanimously endorsed by DRBC's Water Quality Advisory Committee to minimize the remaining inconsistencies and to best address the natural pH cycles for the Delaware River. The first revision is to set the lower threshold of acceptable pH conditions to 6.5 for all interstate zones of the mainstem Delaware River. Since 1967, the lower threshold has been 6.0 for the freshwater non-tidal Delaware River while both the freshwater and brackish/saltwater zones of the tidal Delaware River have had a 6.5 lower threshold. The second revision is to include a "natural conditions" clause directly into the pH criteria in order to recognize natural and acceptable deviations outside the core 6.5 to 8.5 pH range within the acidic coastal plain tidewaters of the Delaware Estuary, the moderately acidic waters draining the Catskill Mountains and Pocono Plateau, and the high-light and high-productivity zones of the non-tidal Delaware River. This document summarizes the historical background on pH criteria and provides the basis for the proposed revisions to pH criteria.

Introduction

The Delaware River Basin Commission first adopted numeric water quality criteria for the freshwater non-tidal Delaware River and the tidal Delaware Estuary and Bay in 1967, soon after the 1965 amendments to the Federal Water Pollution Control Act authorized the setting of interstate or federal water quality standards (USEPA 1972a). Among the numeric standards established in 1967 by DRBC were pH criteria that differed between the tidal river / bay compared to the non-tidal river above Trenton (DRBC 1967a, DRBC 1967b):

- In the tidal Delaware Estuary and Bay, pH criteria were specified as "**Between 6.5 and 8.5**".
- In the Delaware River above the head-of-tide at Trenton, pH criteria were specified as "**Between 6.0 and 8.5**".

Because the tidal Delaware Estuary includes approximately 50 miles of freshwater tidal river (depending on inflows), the tidal criteria (6.5 to 8.5) applied to a large area of both freshwater and brackish or saltwater conditions. In addition, most interstate tributaries addressed by DRBC's water quality regulations were assigned the broader non-tidal range of 6.0 to 8.5, although a small number of tributaries were assigned the narrower 6.5 to 8.5 pH range. No documentation motivating the difference between the 6.0 and 6.5 lower thresholds first promulgated in 1967 has been identified.

Since 1967, these DRBC pH criteria have remained unchanged while state criteria and USEPA recommendations have evolved. Beginning in 2009, DRBC began an effort to update and revise existing criteria based on inconsistencies and recognized problems in the application of DRBC criteria, and based on revised guidance from USEPA and the Basin States. The pH criteria are one set of criteria that were identified as needing revision. This document serves as a synthesis of the background information upon which DRBC recommendations have been developed, with the following goals for its content:

- Review the history of pH criteria development
- Describe the need for revising DRBC pH criteria
- Synthesize the background material into pH criteria recommendations for the interstate zones of the Delaware River

Historic Development of Water Quality Criteria for pH

The pH of surface waters has long been recognized as both a natural and human-induced constraint to the aquatic life of fresh and salt water bodies, both through direct effects of pH and through indirect effects on the solubility, concentration, and ionic state of other important chemicals (e.g., metals, ammonia). Among natural waters, both highly alkaline waters and highly acidic waters (like the NJ Pinelands) are known to severely restrict the species of plants and animals that can thrive in particular lakes and streams. Likewise, human alteration of the pH regime for a water body can alter both the quality of that water and the aquatic life inhabiting that system, with ocean acidification associated with elevated atmospheric carbon dioxide highlighting the consequences of altered pH regimes.

During the 20th century, the growing recognition of human-induced degradation of streams, lakes, and coastal ecosystems motivated research on the physical and chemical limits tolerated by various species of aquatic life. One of the early comprehensive studies (Ellis 1937) sought to quantify and contrast the natural range of water quality at freshwater sites with healthy fish communities versus sites known to be degraded by human pollution. Among the central parameters examined in this early work was pH. Ellis reported that pH typically ranged from 6.3 to 9.0 in unpolluted streams, with naturally acidic conditions (pH 4.5-6.0) and naturally alkaline conditions (pH to 9.5) noted in special circumstances. He further defined a core pH range of 6.7 to 8.6 as the expected value for most unpolluted streams. Nearly 20 years later, a similar broad summary of freshwater aquatic life needs by a federal investigator recommended a pH range of 6.5 to 8.5 be maintained, the range now commonly seen in water quality regulations (Tarzwell 1957).

Although rudimentary water quality standards date back to the 1700s (McKee and Wolf 1963), various authorities in the United States (and internationally) began to utilize the growing body of research developed on water quality effects during the mid-20th century to set water quality limits for both the discharge of effluents and more broadly for the ambient conditions in surface waters.[1] Water quality and effluent criteria for pH were among these early standards (see NYSWPCB 1950, ORSANCO 1955, McKee and Wolf 1963), with agencies often setting limits between 6.5 and 8.5 (e.g., Connecticut, New York, Soviet Union) but with lower limits ranging down to pH=5.0 depending on the class of water or the state setting the limits (e.g., Maryland, New Jersey, New York) and upper limits as high as pH=9.5 (e.g., Mississippi). In addition, other jurisdictions omitted any reference to pH in their standards during this period or included only narrative statements about acids and alkalis (McKee and Wolf 1963).

In the United States, renewed efforts to delineate acceptable conditions and concentrations for various materials in water followed the 1965 authorization of water quality standards enforceable at the federal level via the 1965 Federal Water Pollution Control Amendments (USEPA 1972a). In a series of reports by and to the Federal government (often referred to by the color of their cover binding: the Green, Blue, Red, and Gold Books), syntheses of prior work and recommendations were compiled for large suites of chemical and physical parameters for water.

The first of these documents, the 1968 "Green Book", provided different criteria recommendations for each parameter based on the "use" to which the water would belong. Thus, the pH criteria varied among recreation (6.5 to 8.3), public water supplies (6.0 to 8.5), freshwater aquatic life (6.0 to 9.0), and other uses (FWPCA 1968). This Technical Advisory Committee report annotated each criteria range with general information about the effects on each use and the limitations beyond the recommended range, but without a detailed review of the varied thresholds identified in the literature.

The subsequent 1972 "Blue Book," written by the National Academies of Sciences and Engineering for the newly created USEPA, provides greater detail on the effect-levels identified in the literature and thus stronger bases for the criteria recommendations (USEPA 1972b; see

[1] *note: such effluent standards were prescribed as early as 1938 for BOD by the precursor to the DRBC, the Interstate Commission on the Delaware River Basin (INCODEL); see INCODEL 1938*

Appendix A for excerpts). Like the 1968 Green Book, the 1972 Blue Book continued to separate the criteria recommendations among the different "uses," with pH recommendations varying from recreation (6.5 to 8.3) to public water supplies (5.0 to 9.0) to aquatic life (6.5 to 8.5 for "maximum protection") and others uses. The Freshwater Aquatic Life recommendations for pH are particularly well-supported, drawing from two comprehensive review publications in 1969 (EIFAC 1969, Katz 1969; see appendices). The findings from these studies are summarized in Table III-6 of the 1972 Blue Book (see Appendix A), describing the organisms affected at different pH ranges. Collectively, the articles suggest no clear thresholds for pH tolerance, with varying degrees of protection at different pH levels depending on the species involved and the environmental setting. As a result, the 1972 Blue Book recommendations for pH criteria span a range of values that are associated with different degrees of protection or risk, as summarized in Table 1 below.

Table 1. Summary of Primary Freshwater Aquatic Life pH Recommendations from 1972 "Blue Book" (USEPA 1972b) ***{emphases added}***

Protection Level	Recommended Criteria
Nearly Maximum	**"pH not less than 6.5 nor more than 8.5**. No change greater than 0.5 units above the estimated natural seasonal maximum, nor below the estimated natural seasonal minimum."
High	**"pH not less than 6.0 nor more than 9.0**. No change greater than 0.5 units outside the estimated natural seasonal maximum and minimum."
Moderate	**"pH not less than 6.0 nor more than 9.0**. No change greater than 1.0 units outside the estimated natural seasonal maximum and minimum."
Low	**"pH not less than 5.5 nor more than 9.5**. No change greater than 1.5 units outside the estimated natural seasonal maximum and minimum."

The 1976 "Red Book" and the 1986 "Gold Book", written and published by the USEPA, continued to recommend different pH criteria for different "uses" but with fewer use categories identified (USEPA 1976, USEPA 1986). Both the 1976 Red Book and the 1986 Gold Book recommend three pH criteria ranges: 5.0 to 9.0 for Domestic Water Supply, 6.5 to 9.0 for Freshwater Aquatic Life, and 6.5 to 8.5 for Marine Aquatic Life (with an additional caveat for Marine Aquatic Life limiting pH to within 0.2 units of the normally occurring range). The rationale are drawn largely from the 1972 Blue Book and the references therein, with some updates to the literature reviews. These criteria recommendations have remained in place and continue to be the current pH criteria recommended by the USEPA (USEPA 2012; see Appendix D).

Thus, pH criteria and criteria recommendations have varied since the mid-20th century, and there is recognition that different aquatic organisms and different uses of a waterbody require different pH limits. Table 2 below summarizes some of this historical development, focusing on the generally restrictive "use" endpoint of Freshwater Aquatic Life.

Table 2. Summary of Freshwater pH Criteria History with Emphasis on Freshwater Aquatic Life Use Endpoint

Year	Source	pH Criteria		Type of Criteria
		Lower	Upper	
1937	Ellis article	6.3	9.0	Typical range for unpolluted streams
		6.7	8.6	Core range for most unpolluted streams
1950	NY State Water Pollution Control Board	6.5	8.5	WQ Criteria for classes AA, A, B, and C
		6.0	9.0	WQ Criteria for class D
1957	Tarzwell article	6.5	8.5	Recommended criteria
1963	McKee & Wolf summary of criteria	6.5	8.5	Common effluent or ambient criteria
		5.0	9.5	Upper and lower limits of adopted effluent or ambient criteria
1968	FWPCA (Green Book)	6.0	9.0	FW Aquatic Life recommended criteria
1972	USEPA (Blue Book)	6.5	8.5	"Nearly Maximum Level of Protection" recommendation for criteria
1976	USEPA (Red Book)	6.5	9.0	FW Aquatic Life recommended criteria
1986	USEPA (Gold Book)	6.5	9.0	FW Aquatic Life recommended criteria
2012	USEPA (online summary)	6.5	9.0	Freshwater recommended criteria

Proposed Revisions to DRBC pH Criteria

The need for pH criteria revisions within DRBC's Water Quality Regulation stem from both inconsistencies among DRBC criteria, State criteria, and USEPA recommendations, and from exceedances of criteria in the Delaware River attributable to naturally high pH conditions during periods of high primary production. The criteria inconsistencies are problematic because they can result in different Clean Water Act 305(b) and 303(d) assessment decisions for the Delaware River based on the same monitoring data. Similarly, the periods of high pH that result from high primary production can lead to inappropriate assessments of the river where aquatic life use is not impaired yet the inflexible pH criteria suggest an impairment. These issues primarily impact the freshwater zones of the Delaware River. This section therefore reviews the Freshwater Criteria discrepancies in detail before summarizing the Saltwater Criteria among the States and DRBC, and finishes by considering a provision for "natural conditions" in the pH criteria.

Freshwater Criteria

A number of inconsistencies exist between DRBC pH criteria and both USEPA recommendations and the four Basin States' pH criteria for freshwater conditions (see Table 3). The first of these inconsistencies is an internal inconsistency within DRBC's regulations noted earlier. Specifically, the acceptable lower threshold for pH changes from 6.0 in the upper non-tidal Delaware River to 6.5 in the tidal Delaware River & Bay. Because approximately 50 miles of the tidal Delaware River are a freshwater tidal estuary, this change from 6.0 to 6.5 means that different freshwater zones of the Delaware River have different pH criteria depending only on whether they are tidal or not.

Inconsistencies arise in three other comparisons among the criteria. First, New Jersey recently adopted revised criteria for FW2 waters in the coastal plain (excluding the pinelands) that reflect the natural range of slightly acidic conditions experienced in these waters. Because DRBC criteria apply not only to the mainstem Delaware River but also within tributaries up to the head-of-tide, the NJ criteria at 4.5 to 7.5 are in strong contrast to the DRBC criteria in tidal zones at 6.5 to 8.5. Yet because the current criteria proposal recognizes the need for a "natural conditions" clause in the pH criteria (see below), the inconsistency between the acidic coastal plain criteria from New Jersey and the more neutral DRBC criteria can be reconciled by utilizing both the new "natural provisions" clause recommended for DRBC criteria and the documentation from New Jersey on these prevailing natural conditions.

The second inconsistency arises from Pennsylvania's lower pH criterion. As shown in Table 3, both the federal recommendations and the other Basin States have set their lower pH value to 6.5 while Pennsylvania and DRBC (in part) have maintained the older recommended value of 6.0 from the 1968 Green Book. As summarized in the 1972 Blue Book, however, researchers have identified a number of negative effects from pH conditions between 6.0 and 6.5, particularly among invertebrates (USEPA 1972b; see Appendix A excerpts). Raising the lower pH criterion for DRBC Zone 1 from 6.0 to 6.5 would thus align DRBC criteria with the USEPA and all states except Pennsylvania, and would provide a more protective lower threshold for pH conditions.

Recommendation: *Set DRBC lower pH criteria to 6.5 for all mainstem Delaware River zones*

Table 3. DRBC and State pH Numeric Criteria for Relevant Freshwater Interstate Zones *(additional narrative provisions may also apply)*

Jurisdiction	Existing pH Criteria		Applicable Waters
	Lower	Upper	
DRBC	6.0	8.5	Zone 1: non-tidal shared interstate waters
	6.5	8.5	Zones 2 – 6: tidal shared interstate waters
Delaware	6.5	8.5	All waters
New Jersey	6.5	8.5	FW2 in Delaware Basin above Trenton
	4.5	7.5	FW2 in Delaware Basin below Trenton
New York	6.5	8.5	Class A waters (including Delaware River)
Pennsylvania	6.0	9.0	All waters
USEPA	6.5	9.0	Freshwater

The third and final discrepancy among criteria is the difference between an upper pH criterion of 8.5 (DRBC, DE, NJ, NY) and an upper pH criterion of 9.0 (PA, USEPA). Like the lower criterion at 6.0 or 6.5, there has been an evolution in the recommendations for this upper criterion value. As summarized previously, early recommendations suggested upper limits ranging from 8.5 to 9.5. Although the 1976 Red Book and the 1986 Gold Book set pH criteria recommendations at 9.0, the earlier 1972 Blue Book provided mixed information and recommendations. The thorough summary from the 1972 Blue Book outlined little or no effects below a pH of 9.0, but nevertheless recommended an upper pH criterion of 8.5 under "nearly maximum level of protection." This slightly lower recommendation, although apparently not motivated by research on primary producers, is further supported by the inability of certain species of algae and aquatic plants to use bicarbonate (HCO_3^-; the increasingly dominant form of dissolved carbon at increasing pH values) as a viable carbon source for photosynthesis (Pannier 1960, van den Hoek et al. 1995, Wehr and Sneath 2003). Among these primary producers unable to use bicarbonate (and thus negatively affected at pH above 8.5), the red-alga, *Lemanea,* and the flowering plant, *Podostemum ceratophyllum*, are both common in the freshwater non-tidal Delaware River. In particular, *Podostemum* is a state-threatened species in New York with abundant populations in the Delaware River from its headwaters down to the Lehigh River (Munch 1993, TNC 1994). *Podostemum* has also been shown to serve important ecological functions in high-light rivers of eastern North America (Hill and Webster 1982, Hill and Webster 1984, Hutchens et al. 2004, Parker et al. 2007), highlighting the need to set pH criteria protective of this and other primary producer species native to the Delaware River. Retaining the existing DRBC upper criterion value at 8.5 would therefore provide the greatest consistency among the

states (the exception again being Pennsylvania) and would provide a more protective upper threshold for pH conditions.

Recommendation: *Retain existing upper DRBC pH criteria of 8.5 for all mainstem Delaware River zones*

Saltwater Criteria

DRBC's existing pH criteria for the Delaware River & Bay brackish and saltwater zones ("between 6.5 and 8.5") provide fewer inconsistencies and issues than the freshwater pH criteria. The federal recommendations for saltwater have consistently remained at or near 6.5 to 8.5 since the 1968 "Green Book." Similarly, of the Basin States with estuarine or saltwater criteria (Pennsylvania being unique[2]), the State of Delaware maintains a standard pH criterion of 6.5 to 8.5 for all waters of the state, including estuaries, while New Jersey designated pH criteria of 6.5 to 8.5 for SE waters (saline waters of estuaries) and a narrative pH criterion of "Natural pH conditions will prevail" for SC water (saline coastal waters).

The extent pH is allowed to change is also contained within many (primarily saltwater) criteria statements, with New York State utilizing only a pH change criterion for all saltwater classes: "The normal range shall not be extended by more than one-tenth (0.1) of a pH unit" (6 NYCRR Part 703.3). The State of Delaware also uses pH change provisions for all waters of the state, ranging from an 0.3 unit change to an 0.5 unit change depending on the prevailing pH conditions. Neither New Jersey nor Pennsylvania utilize such a pH change provision, either for saltwater (NJ) or for freshwater (NJ, PA). The USEPA also includes a limit of pH changes of 0.2 units or less for open ocean areas of saltwater.

Thus, other than the change provision, there is broad agreement among DRBC and the Basin States pH criteria, and the USEPA pH criteria recommendations. In addition, these criteria at 6.5 to 8.5 for brackish and saltwater portions of the Delaware River have long been accepted as reasonable and appropriate criteria for the zones with appreciable salinity. As a result, no need has been identified for a pH criteria modification within the brackish and saltwater zones of the Delaware River (all or parts of Zones 4, 5, and 6).

Recommendation: *Retain existing DRBC pH criteria limits of 6.5 to 8.5 for brackish and saltwater zones (oligohaline to polyhaline)*

[2] Pennsylvania has no explicit criteria for brackish or saltwater conditions as the Pennsylvania border with Delaware delimits the approximate extent of oligohaline conditions in the Delaware Estuary. Nevertheless, to the extent that Delaware Estuary criteria can be consider brackish or saltwater criteria, the applicable pH criteria would remain as "From 6.0 to 9.0 inclusive" as with all other surface water bodies.

Natural Exceedances of Criteria

Although ambient and effluent criteria in the range of 6.5 to 8.5 have been advocated for over 50 years, there has likewise been a long recognition of the naturally variable pattern of surface water pH conditions. On short time scales, periods of naturally high photosynthesis (even in pristine settings) can produce pH conditions greater than 8.5 during mid to late-afternoon which then subside at night with the reduction in photosynthetic activity and associated need for CO_2 (Tarzwell 1957, USEPA 1972b). More broadly, naturally acidic and naturally alkaline waterbodies have long been included in considerations of pH requirements and criteria (Ellis 1937, Tarzwell 1957, Kunz and Mallepalle 2008).

As a result of such natural extremes in water quality, and pH specifically, many states have included exemptions to the strict numerical standards if deviations constitute "natural conditions." Within the Delaware River Basin, all four states have some provisions for modifying their water quality criteria, assessment, or effluent requirements based on natural conditions. For pH, Delaware's water quality criteria provide the most explicit exemptions: "pH, measured in standard units, in all waters of the state... Shall be between 6.5 and 8.5 unless outside this range due solely to natural conditions" (Delaware 2004, §4.5.3 and §4.5.3.1). The qualifiers in New Jersey, New York, and Pennsylvania regulations are broader and address the natural conditions generally (not specifically pH) in setting water quality and effluent limits (NJAC 7:9B-1.5(c)1, 6 NYCRR 702.16(b)(1), PA Chapter 93).

Beginning with the first numeric water quality criteria promulgated in 1967 and continuing through the currently adopted criteria, DRBC has recognized natural variations in a number of water quality parameters when setting numeric criteria (e.g., temperature, dissolved oxygen, turbidity, phenol). However, at no time has DRBC included a "natural conditions" provision into its criteria for pH. Yet while DRBC criteria have not provided a "natural conditions" provision for pH, intensive evaluations of pH in the past decade have shown numerous pH exceedances that may simply be natural excursions attributable to the short-term effects of photosynthesis or the long-term effects of unique geologic and soil conditions (DRBC 2002, DRBC 2012, Kunz and Mallepalle 2008). As a result, both the substantial scientific record and the recent evaluations of pH conditions in the Delaware Basin indicate that providing flexibility in interpreting pH conditions outside the 6.5 to 8.5 range more completely addresses the complex and variable nature of pH conditions in surface waters. Such language also avoids what statisticians call "Type I" errors where an apparent change is identified when, in reality, no change has occurred.

Recommendation: Include a "natural conditions" clause within the pH criteria for the mainstem Delaware River zones

Summary of Recommendations

As described herein, updates to DRBC pH criteria are warranted for mainstem Delaware River zones within DRBC's regulations, and these recommended revisions have the unanimous support of the state, federal, municipal, industrial, academic, and environmental representatives on DRBC's Water Quality Advisory Committee. The specific revisions to DRBC's Water Quality Regulations presented in Table 4 below are therefore recommended to update the original 1967 pH criteria for Zones 1 thru 6.

Table 4. Existing and Proposed Revisions to DRBC pH Criteria Mainstem Delaware River Zones (revisions indicated with *italicized red text*)

Delaware River Zone	Tidal & Salinity Setting	Existing pH Criteria	Proposed pH Criteria
1A	non-tidal, freshwater	Between 6.0 and 8.5	Between *6.5* and 8.5*, inclusive[a], unless outside this range due to natural conditions*
1B	non-tidal, freshwater	Between 6.0 and 8.5	Between *6.5* and 8.5*, inclusive[a], unless outside this range due to natural conditions*
1C	non-tidal, freshwater	Between 6.0 and 8.5	Between *6.5* and 8.5*, inclusive[a], unless outside this range due to natural conditions*
1D	non-tidal, freshwater	Between 6.0 and 8.5	Between *6.5* and 8.5*, inclusive[a], unless outside this range due to natural conditions*
1E	non-tidal, freshwater	Between 6.0 and 8.5	Between *6.5* and 8.5*, inclusive[a], unless outside this range due to natural conditions*
2	tidal, freshwater	Between 6.5 and 8.5	Between 6.5 and 8.5, *inclusive[a], unless outside this range due to natural conditions*
3	tidal, freshwater	Between 6.5 and 8.5	Between 6.5 and 8.5, *inclusive[a], unless outside this range due to natural conditions*
4	tidal, freshwater to oligohaline	Between 6.5 and 8.5	Between 6.5 and 8.5, *inclusive[a], unless outside this range due to natural conditions*
5	tidal, oligo/mesohaline	Between 6.5 and 8.5	Between 6.5 and 8.5, *inclusive[a], unless outside this range due to natural conditions*
6	tidal, meso/polyhaline	Between 6.5 and 8.5	Between 6.5 and 8.5, *inclusive[a], unless outside this range due to natural conditions*

[a] - additional "inclusive" language added to eliminate any uncertainty whether a 6.0 or 8.5 pH value meets criteria; each would clearly meet criteria under the recommended language

References Cited

Delaware, State of. 2004. Surface Water Quality Standards. As amended, July 11, 2004. (*available at: www.dnrec.state.de.us/DNREC2000/Divisions/Water/WaterQuality/WQStandard.pdf; last accessed 9-July-2012)*

DRBC 1967a. Resolution 1967-2 of the Delaware River Basin Commission, including Water Quality Standards referenced and adopted by this resolution. Adopted March 2, 1967.

DRBC 1967b. Resolution 1967-7 of the Delaware River Basin Commission, including Water Quality Standards for the Delaware River Basin referenced and adopted by this resolution. Adopted April 26, 1967.

DRBC 2002. 305(b) Water Quality Assessment Report. Published by the Delaware River Basin Commission, September 2002, and revised April 2003. 75 pp. (available at: www.state.nj.us/drbc/library/documents/2002_305breport.pdf; last accessed 9-July-2012)

DRBC 2012. Delaware River and Bay Water Quality Assessment. Published by the Delaware River Basin Commission, March 2012. 92 pp. (available at: www.state.nj.us/drbc/library/documents/WQAssessmentReport2012.pdf; last accessed 9-July-2012)

EIFAC (European Inland Fisheries Advisory Commission, Working Party on Water Quality Criteria for European Inland Fish) 1969. Water quality criteria for European freshwater fish – extreme pH values and inland fisheries. Water Research 3(8): 591-611.

Ellis, M.M. 1937. Detection and measurement of stream pollution. Bulletin of the Bureau of Fisheries Vol. 48 (bulletin #22): 365-437.

FWPCA (Federal Water Pollution Control Administration) 1968. Water Quality Criteria. Report of the National Technical Advisory Committee to the Secretary of the Interior. U.S. Dept. of the Interior, Washington D.C. 215 pp. (*frequently referred to as the "Green Book" based on the cover binding color*)

Hill, B.H. and J.R. Webster. 1982. Aquatic macrophyte breakdown in an Appalachian river. Hydrobiologia 89: 53-59.

Hill, B.H. and J.R. Webster. 1984. Productivity of *Podostemum ceratophyllum* in the New River, Virginia. American J. of Botany 71(1): 130-136.

Hutchens, Jr., J.J., J.B. Wallace, and E.D. Romaniszyn. 2004. Role of *Podostemum ceratophyllum* Michx. in structuring benthic macroinvertebrate assemblages in a southern Appalachian river. J. North American Benthological Society 23(4): 713-727.

INCODEL (Interstate Commission on the Delaware River Basin) 1938. The Delaware River Basin: Water Pollution (with an introductory section devoted to general problems of land and water use). Published by the Interstate Commission on the Delaware River Basin and the Council of State Governments; Philadelphia, PA; series B, no. 1; 19 pp.

Katz, M. 1969. The biological and ecological effects of acid mine drainage. Appendix F *in* Appalachian Regional Commission "Acid Mine Drainage in Appalachia". Contained within U.S. Congress, House Document No. 91-180, 91st Congress, 1st session. (*see Appendix B herein)*

Kunz, C.J. and G. Mallepalle. 2008. Evaluation of surface-water pH levels in New Jersey's coastal plain. Poster presentation at the National Water Quality Monitoring Conference; Atlantic City, NJ.

McKee, J.E. and H.W. Wolf (eds). 1963. Water Quality Criteria (2nd Ed). Publication 3-A of the California State Water Resources Control Board. 548 pp.

Munch, S. 1993. Distribution and condition of populations of *Podostemum ceratophyllum* (riverweed) in Pennsylvania. J. of the Pennsylvania Academy of Science 67(2): 65-72.

NYSWPCB (New York State Water Pollution Control Board) 1950. Rules and Classifications and Standards of Quality and Purity of Waters of New York State. New York State Department of Health publication; Albany, NY; 14 pp.

ORSANCO (Ohio River Valley Water Sanitation Commission) 1955. Stream pollution: aquatic life water quality criteria, first progress report. Sewage and Industrial Wastes 27(3): 321-331.

Pannier, F. 1960. Physiological Responses of Podostemaceae in Their Natural Habitat. Internationale Revue der Gasamten Hydrobiologie 45 (3): 347-354.

Parker, J.D., D.F. Burkepile, D.O. Collins, J. Kubanek, and M.E. Hay. 2007. Stream mosses as chemically-defended refugia for freshwater macroinvertebrates. Oikos 116: 302-312.

Tarzwell, C.M. 1957. "Water quality criteria for aquatic life" pgs. 246-272 *in* Biological Problems in Water Pollution. U.S. Dept. of Health, Education, and Welfare. Cincinatti, OH.

TNC (The Nature Conservancy) 1994. A survey of the aquatic vascular plants of the upper Delaware River. Unpublished report to the U.S. Department of Interior by The Nature Conservancy's Pennsylvania Science Office, Middletown, PA. 322 pp.

USEPA 1972a. The Challenge of the Environment: A Primer on EPA's Statutory Authority. United States Environmental Protection Agency publication; Washington, D.C.. 43 pp. (reprinted portion available at www.epa.gov/aboutepa/history/topics/fwpca/05.html; last accessed 9-July-2012) *(complete document may be available at nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=2000RRST.txt; last accessed on 9-July-2012)*

USEPA 1972b. "Water Quality Criteria 1972." Report to the Committee on Water Quality Criteria, Environmental Studies Board, by the National Academy of Science & National Academy of Engineering. EPA/R3-73-033, Washington, D.C. 594 pp. (*see Appendix A herein for relevant excerpts*; *frequently referred to as the "Blue Book" based on the cover binding color*)

USEPA 1976. "Quality Criteria for Water" United States Environmental Protection Agency publication EPA 440/9-76-023; Washington DC; 501 pp. (*frequently referred to as the "Red Book" based on the cover binding color*)

USEPA 1986. "Quality Criteria for Water 1986" United States Environmental Protection Agency publication EPA 440/5-86-001; Washington DC; 477 pp. (*frequently referred to as the "Gold Book" based on the cover binding color*)

USEPA 2012. National Recommended Water Quality Criteria. Published online by the United States Environmental Protection Agency at water.epa.gov/scitech/swguidance/standards/criteria/current/index.cfm *(last accessed 10-July-2012; see Appendix D for a printed copy of the July 2012 version)*

Acknowledgements

This document was prepared by Delaware River Basin Commission staff: Carol R. Collier, Executive Director. Erik L. Silldorff was the principle author with the cooperation and assistance of John R. Yagecic and Thomas J. Fikslin. Final criteria recommendations were discussed with DRBC's Water Quality Advisory Committee in March 2009, with useful feedback and insightful suggestions that have been incorporated into both the criteria and this Basis and Background document. Members in attendance and/or who contributed to this work were Al Pagano – chair, DuPont; Al Ambler – NPS; Bart Ruiter – DuPont; Dave Wolanski – DNREC; Debra Hammond – NJDEP; Denise Hakowski – USEPA; Izabela Wojtenko – USEPA; Jason Cruz – PWD; John Jackson – Stroud WRC; Mary Neutz – Wilmington; Tom Barron – PADEP; Tracy Carluccio – Del. Riverkeeper.

APPENDICES

Appendix A. ***Excerpts from*** USEPA's 1972 "Blue Book": USEPA 1972. "Water Quality Criteria 1972." Report to the Committee on Water Quality Criteria, Environmental Studies Board, by the National Academy of Science & National Academy of Engineering. EPA/R3-73-033, Washington, D.C. 594 pp.

Appendix B. ***Copy of*** Katz, M. 1969. The biological and ecological effects of acid mine drainage. Appendix F in Appalachian Regional Commission "Acid Mine Drainage in Appalachia". Contained within U.S. Congress, House Document No. 91-180, 91st Congress, 1st session.

Appendix C. ***Copy of*** EIFAC (European Inland Fisheries Advisory Commission, Working Party on Water Quality Criteria for European Inland Fish) 1969. Water quality criteria for European freshwater fish – extreme pH values and inland fisheries. Water Research 3(8): 591-611.

Appendix D. ***Printed copy of*** USEPA 2012. National Recommended Water Quality Criteria. Published online by the United States Environmental Protection Agency at water.epa.gov/scitech/swguidance/standards/criteria/current/index.cfm (printed 10-July-2012)

Appendix A. ***Excerpts from*** USEPA's 1972 "Blue Book": USEPA 1972. "Water Quality Criteria 1972." Report to the Committee on Water Quality Criteria, Environmental Studies Board, by the National Academy of Science & National Academy of Engineering. EPA/R3-73-033, Washington, D.C. 594 pp.

Appendix B. ***Copy of*** Katz, M. 1969. The biological and ecological effects of acid mine drainage. Appendix F in Appalachian Regional Commission "Acid Mine Drainage in Appalachia". Contained within U.S. Congress, House Document No. 91-180, 91st Congress, 1st session.

Appendix C. ***Copy of*** EIFAC (European Inland Fisheries Advisory Commission, Working Party on Water Quality Criteria for European Inland Fish) 1969. Water quality criteria for European freshwater fish – extreme pH values and inland fisheries. Water Research 3(8): 591-611.

Appendix D. ***Printed copy of*** USEPA 2012. National Recommended Water Quality Criteria. Published online by the United States Environmental Protection Agency at water.epa.gov/scitech/swguidance/standards/criteria/current/index.cfm (printed 10-July-2012)