APPENDIX B-2. A New Method to Apply Chronic Water-Quality Standards When Assessing Attainment of Aquatic Life Uses in Illinois Waters

Introduction

The Surface Water Section (SWS; hereafter "we") of the Illinois Environmental Protection Agency, adopt a new way to apply chronic water-quality standards when using physicochemical data (i.e., "water chemistry") to assess attainment of aquatic-life uses in Illinois waters. The new method to apply chronic standards replaces our longstanding old method that fails to properly identify when chronic-concentration thresholds are exceeded during any four-day period.

Although we typically rely primarily on biological data when assessing Aquatic Life Use in streams designated for general use, we rely primarily on water-chemistry data in other situations, e.g., lakes and some non-general-use streams. Whereas evidence that water chemistry does not meet Illinois water-quality standards does not directly indicate aquatic-life impairment, it does indicate the potential for impairment. Our use of water-chemistry data includes determining whether various chronic standards are met.

Chronic standards in Illinois water-quality regulations are designed to protect aquatic life from harm due to excessive pollutant concentrations during extended periods of time. For example, the standards found at 35 Illinois Administrative Code Section 302.208(b) (Illinois Pollution Control Board 2015a) represent chemical-concentration thresholds that are not to be exceeded, as an average, during any period of four days or longer. These standards derive from a method developed by the United States Environmental Protection Agency (Stephan et al. 1985). We apply these chronic standards as one part of assessing attainment of Aquatic Life Use in Illinois waters.

Our longstanding old method to apply chronic standards when assessing attainment of aquatic-life uses has two major limitations. First, although the old method is based on prevailing water-quality standards, the Illinois General Use chronic standards prescribe an averaging period that is inadequate; the Illinois Pollution Control Board recognizes this limitation (see details below). Second, the frequency of our sampling for water conditions typically does not allow us to directly determine a four-day average concentration of any chronic-standard pollutant. The new method reasonably accounts for both limitations and provides reasonable inference of four-day averages based on available observations. We use at least three observations (over at least four days, but typically much longer) to apply the chronic standard with this new method.

Longstanding Flaw in the General Use Chronic Standards

Our guidelines for assessing attainment of aquatic-life uses include using chronic water-quality standards to indicate the potential for impairment. Ideally, we are trying to answer this fundamental question:

During a predetermined period, how often does the four-day average concentration of the pollutant exceed a potentially harmful level, i.e., the threshold concentration for chronic effects? (When using water-chemistry data to indicate the potential for impairment of aquatic-life uses, we typically consider a "*predetermined period*" of three years).

Illinois water-quality regulations at 35 Ill. Admin. Code 302.208(b), 302.212(c)(2), 302.212(c)(3), 302.504(a), 302.504(d), and 302.504(e) for interpreting attainment of chronic standards for metals and other substances do not provide a satisfactory answer to this question. Hereafter, we use the terms,"*chronic standards*", broadly to refer to all of the aforementioned standards, including applicable human-health and wildlife standards. As the Illinois Pollution Control Board now recognizes, our longstanding application of an averaging period of "*at least four days*", as specified in these standards, fails to answer the fundamental question of whether a chronic event has occurred. In a recent rulemaking that pertains to the Chicago Area Waterway System and lower Des Plaines River, the Illinois Pollution Control Board changed the regulatory language that specifies the chronic-averaging period from "*at least four days"* to "~~*at least*~~ *four days*", thus correcting an oversight that has existed since 1990. In the Final Notice Opinion and Order of rulemaking R08-9 (Subdocket D), June 18, 2015, the Illinois Pollution Control Board states (p. 39) "*Although the IEPA proposed an averaging period of 'at least four days' in Section 302.208(b) in R88-21(A), that provision was clearly intended to be consistent with the federal guidance. As noted by USEPA, including the phrase 'at least four days' may not be consistent with the scientific rational* [sic] *behind the proposed standards, i.e., the highest four-day average concentrations that will not produce unacceptable effects over a long-term exposure. As such, the Board revised Section 302.407(b) by removing the phrase 'at least' and requiring that exposure be averaged over any four-day period.* ***The Board notes that similar change will be made to the General Use standards in a future rulemaking when Section 302.208 is open.***" (highlighting added). We also note that this same principle applies to standards at 35 Ill. Admin. Code 302.212(c)(2), 302.212(c)(3), 302.504(a), 302.504(d), and 302.504(e).

Our new method of applying General Use, Lake Michigan-basin, or Chicago Area Waterway System and lower Des Plaines River chronic standards accommodates the Illinois Pollution Control Board's intent, even though the General Use and Lake Michigan-basin regulations have not yet been corrected. To serve as context for our revised assessment approach, we provide the following overview of chronic standards.

Overview of Chronic Standards

Illinois water-quality regulations include threshold concentrations that represent acute and chronic effects on aquatic life. These acute and chronic thresholds are based on concepts and procedures in Stephan et al. (1985) and a United States Environmental Protection Agency technical-support document (USEPA 1985). Acute and chronic criteria derived and recommended by USEPA and then adopted into Illinois water-quality standards represent average-concentration thresholds of unacceptable effect on aquatic organisms (Stephan et al. 1985). To apply these thresholds meaningfully, one must know the length of time during which each of these average-concentration thresholds apply. For applying acute standards, it is reasonable to assume a one-hour averaging period. Specifically, indication that the average pollutant concentration during any one-hour period exceeds the acute standard represents an

excursion of the criterion. Indication that the average pollutant concentration during any four-day period exceeds the chronic standard represents an excursion of the criterion.

Stephan et al. (1985) provides a template to formulate water-quality criteria:
"*(1) aquatic organisms and their uses should not be affected unacceptably if the four-day average concentration of (2) does not exceed (3) ug/L more than once every three years on the average and if the one-hour average concentration does not exceed (4) ug/L more than once every three years on the average.*
where (1) = insert "freshwater" or "saltwater"
(2) = insert name of material
(3) = insert the Criterion Continuous Concentration [(CCC), chronic criterion]
(4) = insert the Criterion Maximum Concentration [(CMC), acute criterion]"

"*An averaging period of four days seems appropriate for use with the* CCC *for two reasons...*"
"*The considerations applied to interpretation of the CCC also apply to the CMC. For the CMC the averaging period should again be substantially less than the lengths of the tests it is based on, i.e., substantially less than 48 to 96 hours. One hour is probably an appropriate averaging period because high concentrations of some materials can cause death in one to three hours...Thus it is not appropriate to allow concentrations above the CMC to exist for as long as one hour.*"

USEPA (1985) addresses a common misconception about averaging periods for chronic standards: the averaging period is not based on the duration of the toxicity tests from which the chronic threshold derives. *"Many people have erroneously assumed that because many chronic toxicity tests are 28 or 30 days in length, the CCC was meant to be used as a 30-day average. However, the duration of a toxicity test has nothing to do with the critical period of exposure to concentrations greater than the criteria. Many chronic toxicity tests are of a one-year or longer duration, yet this does not lead to the establishment of an averaging period of one year's duration. Obviously, if a one-year averaging period were used, the CCC could theoretically be exceeded for six months, a duration more than long enough to cause an unacceptable chronic effect in a waterbody*."

Additionally, USEPA (1985) clearly presents the one-day and four-day lengths as maximum periods over which averages should be applied. Longer periods are not considered acceptably protective. *"Because concentrations can be above the CCC without causing adverse effects, there is considerable temptation to specify the CCC in terms of average exposure. However, if the period during which exposure is averaged is long, periods of concentrations above the CCC can produce unacceptable toxic effects without the average concentration exceeding the CCC."* This statement clearly counters the current Illinois regulation, 35 Ill. Admin. Code §302.208(b), that allows the chronic averaging period to be *"any period of at least four days."*

The Illinois water-quality regulations, at 35 Ill. Admin. Code 302.208(b) (excerpt below), 302.212(c)(2), 302.212(c)(3), 302.504(a), 302.504(d), and 302.504(e) for determining attainment of a chronic standard are not consistent with the four-day averaging period recommended by Stephan et al. (1985). These regulations place no constraints on the maximum length of time or the maximum number of observations ("*samples*") for which the average concentration of the

pollutant is considered. Therefore, if one considers at least four observations during a period of at least four days, one is applying the chronic standard consistent with the regulations. For example, the regulation allows either of the following ways to compare a pollutant concentration to the chronic standard to determine if the standard is attained:
(1) an average concentration from five observations (one per year) over a five-year period, and
(2) an average concentration from 60 observations (one per every two hours) over a five-day period.

Clearly, the first comparison provides limited evidence of any four-day period in which an average concentration may have exceeded an applicable regulatory chronic threshold.

Excerpt of 35 Ill. Admin Code 302.208(b) [highlighting added]:
"…b) The chronic standard (CS) for the chemical constituents listed in subsection (e) shall not be exceeded by the arithmetic average of at least four consecutive samples collected over ***any period of at least four days****, except for those waters in which the Agency has approved a mixing zone or in which mixing is allowed pursuant to Section 302.102. The samples used to demonstrate attainment or lack of attainment with a CS must be collected in a manner that assures an average representative of the sampling period. For the chemical constituents that have water quality based standards dependent upon hardness, the chronic water quality standard will be calculated according to subsection (e) using the hardness of the water body at the time the sample was collected. To calculate attainment status of chronic standards, the concentration of the chemical constituent in each sample is divided by the calculated water quality standard for the sample to determine a quotient. The water quality standard is attained if the mean of the sample quotients is less than or equal to one for the duration of the averaging period."*

Comparison of Old and New Methods

We base the following comparison on a typical dataset from the Ambient Water Quality Monitoring Network: twenty-five paired zinc (Zn) and hardness observations at a stream site, collected at intervals of about six weeks during a three-year period.

Old Method

Our old method (Table 1) erroneously assumes that average (i.e., arithmetic mean) quotients, derived from consecutive sets of four observations, each representing a six-month period, can accurately represent concentrations over one or more four-day periods. The inability of this method to meaningfully represent four-day-average concentrations likely results in underestimation of the actual frequency of chronic-standard exceedances.

Limitations of the Old Method

With the old method, although the averaging period is reduced from three years to a minimum of 4.5 months (i.e., four sampling events that occur once every six weeks), an estimate of the average Zn concentration during a 4.5-month period still provides limited relevant information.

As a result, it remains unclear how often during the predetermined three-year period of observation the four-day average concentration of Zn was at a potentially harmful level.

New Method

The new method uses linear interpolation to determine the duration of chronic events. The new method considers each chronic quotient plotted through time and interpolates a continuum of chronic quotients (Figure 1). This represents the most parsimonious model of quotients through time given the frequency of sampling. Along this continuum, a quotient that remains greater than one over a period of four or more days indicates violation of the chronic standard and consequently represents potential impairment of aquatic life.

Advantages of New Method

Although the new method is computationally more difficult than the old method, it can be automated in an R script. By assuming a linear relationship between observations, it is possible to estimate the duration of chronic events. This assumption is parsimonious and thus reasonable. Unlike the old method, the new method reasonably infers four-day-average concentrations and therefore represents a better way to answer the fundamental question of whether any four-day average exceeds the chronic-standard threshold.

Conclusion

The new method of applying chronic standards provides an important update to our assessment methodology by estimating the duration of each chronic event, i.e., the period in which the chronic quotient is greater than one. The old method is inadequate for estimating chronic exceedances because it cannot determine if an exceedance occurred over the relevant period (four days). Furthermore, our new method represents a proactive step to protect the waters of Illinois consistent with the Illinois Pollution Control Board's recognition of a change (to a four-day averaging period) needed in the General Use standards. Analogous change is needed for chronic standards of the Lake Michigan basin.

Below, we compare the new method to the old method. In the following examples, we use zinc concentrations collected at a site of the Ambient Water Quality Monitoring Network over a three-year period. For the 2020/2022 assessment cycle, we use the new method to apply chronic standards when assessing attainment of aquatic-life uses in Illinois waters.

Table 1. Old Method of Applying Chronic Water-Quality Standards for Dissolved Zinc to Assess Attainment of Aquatic Life Use in Illinois Streams. The column, "Average of Four Quotients," represents averages of chronic quotients in sets of four, i.e., the quotient in each row averaged with those in the immediately preceding three rows.

Collection Date	Dissolved Zinc, ug/l	Hardness, Ca Mg, ug/l	Chronic Standard, Dissolved Zinc, ug/l	Chronic Quotient, Dissolved Zinc	Average of Four Quotients
1/21/2015	38.3	320,000	83.75	0.46	
3/19/2015	6.38	183,000	52.16	0.12	
4/6/2015	3.39	143,000	42.32	0.08	
5/26/2015	34.9	450,000	111.79	0.31	0.24
6/25/2015	0	190,000	53.84	0.00	0.13
8/20/2015	77.3	462,000	114.32	0.68	0.27
9/1/2015	42.9	545,000	131.49	0.33	0.33
10/20/2015	305	842,000	190.10	1.60	0.65
12/10/2015	26.5	260,000	70.24	0.38	0.75
1/5/2016	48	243,000	66.33	0.72	0.76
2/22/2016	10.3	204,000	57.19	0.18	0.72
4/7/2016	24.3	250,000	67.94	0.36	0.41
5/24/2016	55	276,000	73.88	0.74	0.50
6/16/2016	72.6	389,000	98.81	0.73	0.50
8/22/2016	18.3	173,000	49.73	0.37	0.55
9/19/2016	38.2	399,000	100.96	0.38	0.56
10/13/2016	194	637,000	150.07	1.29	0.69
12/7/2016	61.5	371,000	94.93	0.65	0.67
3/9/2017	2.97	141,000	41.82	0.07	0.60
5/18/2017	76	266,000	71.61	1.06	0.77
6/20/2017	102	461,000	114.11	0.89	0.67
7/31/2017	5.9	344000	89.04	0.07	0.52
9/11/2017	14.1	550,000	132.51	0.11	0.53
10/19/2017	186	446,000	110.95	1.68	0.69
12/13/2017	29.8	379,000	96.66	0.31	0.54

1. For each pair of dissolved Zn and hardness observations (Table 1), we calculate a chronic-threshold concentration of Zn by using the equation from 35 Ill. Adm. Code 302.208(e).

Chronic-threshold concentration of Zn (ug/l) $= e^{A+B\ln(H)} \times 0.986$, where e = base of natural logarithm, ln(H) = natural logarithm of hardness in milligrams per liter, A = -0.4456 and B = 0.8473

2. For each pair of Zn and hardness observations, we calculate a quotient:

Concentration of Zn (ug/l) / Chronic-threshold concentration of Zn (ug/l)

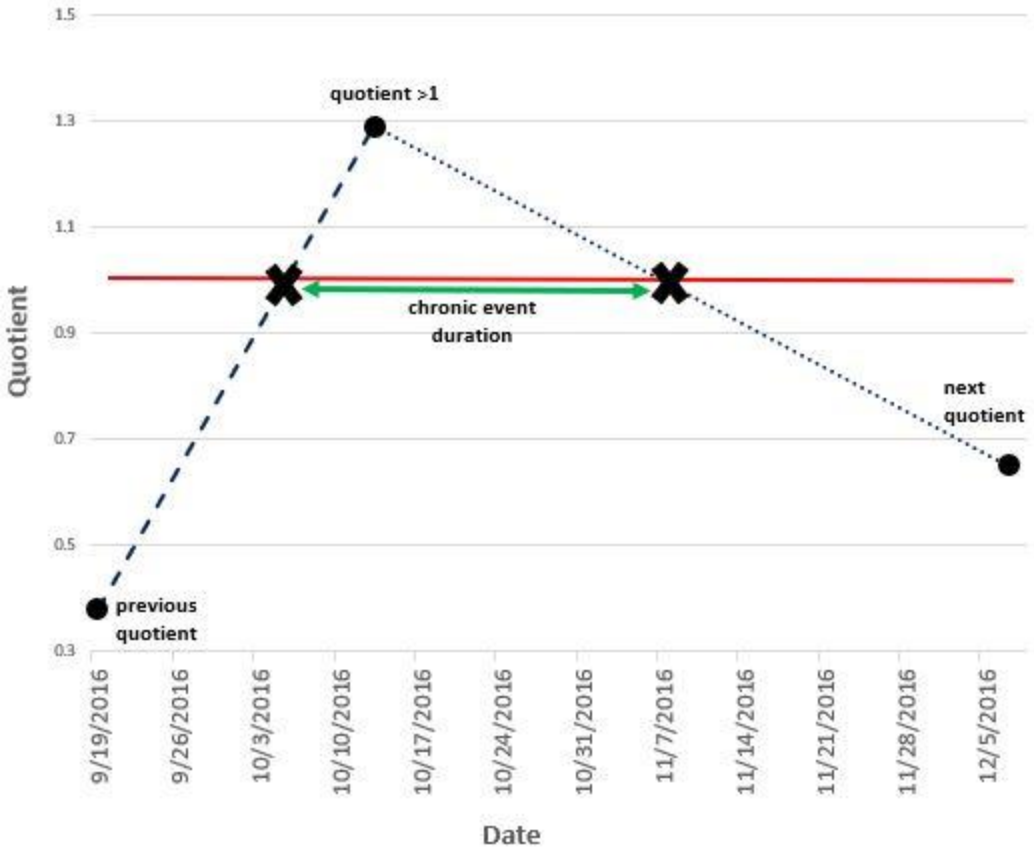
3. In total, we calculate 25 quotients for a typical three-year ambient cycle. Among these quotients, there are 22 sets of four consecutive quotients. We compare the mean value of each group of four consecutive quotients to a value of 1. If this mean value is larger than 1, then the chronic standard is exceeded. General Use regulations allow us to use four or more consecutive observations up to the maximum number of available observations.

4. One or more quotients exceeding a value of 1 indicates potential impairment of Aquatic Life Use.

This method can also be used for pollutants with chronic thresholds that are not hardness based. The quotient would be calculated by dividing each observation's concentration by the chronic-threshold concentration.

In this example, 0% (0/22) of the calculated average quotients are >1. When applying our old method, Zn concentrations in this stream do not indicate potential impairment of Aquatic Life Use.

Figure 1. New Method: Chronic Quotient Interpolated through Time. Black circles represent quotients calculated from concentrations in three actual observations. Dashed (ascending) and dotted (descending) lines represent linear interpolation (through time) of the chronic quotient among the three fixed-point calculated quotients. The X symbols indicate where the ascending and descending interpolated quotients equal one (red line). Distance along the x-axis (time) between the two "X"s represents the duration of a chronic event, i.e., duration of chronic quotient greater than one.



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2. For each pair of Zn and hardness observations, we calculate a quotient (Table 1):
Concentration of Zn (ug/l) / Chronic-threshold concentration of Zn (ug/l)

3. We identify quotients >1 as well as the quotients that immediately precede and follow them (Table 2).

4. For each quotient > 1, we calculate the slope of each ascending and descending line, based on the standard formula for determining the slope (m) of a line where: $m = (Y_2 - Y_1)/(X_2 - X_1)$, where X is sampling date and Y is the quotient of each observation.

5. For each line, we use the calculated slope (m) and a y value (Y) of 1 to determine the y-intercept (b), based on the standard equation of a line, $Y = mX+b$, where b is the y-intercept. This equation rearranges to $b = Y/mX$.

6. For each line, we solve the equation X = (Y-*b*)/*m* where Y is a quotient = 1, *m* is the slope calculated at step 4, and *b* is the y-intercept calculated at step 5. For each line, X is the chronic start date (ascending line) or the chronic end date (descending line). The simplified equation is X = (1-*b*)/*m*.

7. We determine the duration of each chronic event (i.e., time that the quotient remains above 1) as the difference between the chronic start and end dates. A chronic duration of greater than or equal to four days indicates an exceedance of the chronic standard and indicates the potential for impairment of aquatic life.

Table 2. New Method to Apply Chronic Water-Quality Standards for Dissolved Zinc to Assess Attainment of Aquatic Life Use in Illinois Streams.

Date	Chronic Quotient	Ascend-ing Slope	Ascend-ing Intercept	Chronic Start Date	Descend-ing Slope	Descend-ing Intercept	Chronic End Date	Chronic Duration (Days)
1/21/2015	0.46							
3/19/2015	0.12							
4/6/2015	0.08							
5/26/2015	0.31							
6/25/2015	0							
8/20/2015	0.68							
9/1/2015	0.33							
10/20/2015	1.6	0.03	-1094.67	9/26/2015	-0.02	1013.41	11/14/2015	48.2
12/10/2015	0.38							
1/5/2016	0.72							
2/22/2016	0.18							
4/7/2016	0.36							
5/24/2016	0.74							
6/16/2016	0.73							
8/22/2016	0.37							
9/19/2016	0.38							
10/13/2016	1.29	0.04	-1616.08	10/5/2016	-0.01	497.65	11/6/2016	32.6
12/7/2016	0.65							
3/9/2017	0.07							
5/18/2017	1.06	0.01	-605.29	5/13/2017	-0.01	221.92	5/29/2017	15.9
6/20/2017	0.89							
7/31/2017	0.07							
9/11/2017	0.11							
10/19/2017	1.68	0.04	-1776.01	10/2/2017	-0.02	1073.44	11/15/2017	43.8
12/13/2017	0.31							

Each chronic quotient that is greater than one has a chronic-event duration (Table 2). A duration greater than four days indicates an exceedance of the chronic standard. In this example, each chronic event lasted 48.2, 32.6, 15.9, and 43.8 days, respectively. The sampling occurred at regular intervals between January 2015 and December 2017, and at least one chronic event occurred during each calendar year. Compared to the old method, which detected no exceedances (Table 1), the new method indicates four separate chronic events.

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