# Water Quality Assessment Methods for Toxics

Department of Environmental Quality

**Prepared by:**
The North Carolina Department of Environmental Quality
Division of Water Resources
Water Sciences Section & Planning Section
http://deq.nc.gov/about/divisions/water-resources

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## Introduction to Retrospection of the “>1-in-3” Assessment Method

Waterbody pollutants are often placed into two categories: 1) conventional (i.e. nontoxic) pollutants such as bacteria, turbidity, chlorophyll-a, and pH, and 2) toxic pollutants such as metals and polychlorinated biphenyls (PCBs). Separate assessment methods are typically used to evaluate the data from each group and determine if there is sufficient evidence to classify the body of water as impaired. The methods used to determine impairment for conventional pollutants vary by state, while those used to assess toxic pollutants are generally very similar.

A common method for assessment of conventional pollutants, is to require a minimum sample size (e.g. 10) and then determine a proportion (%) of results exceeding the applicable criterion. An approach determining if more than ten percent exceedance, with a minimum confidence level of 90%, is often used.

The method used to determine impairment for toxic pollutants is quite different than the approach described above and rarely varies by state. This method can be described as ‘if there is more than one exceedance of a standard within a three-year period, the body of water is considered impaired’. This approach (herein referred to as “>1-in-3”) has been applied by the United States Environmental Protection Agency (EPA) for toxic pollutants when states have not developed an alternative scientifically defensible method.

This paper provides a retrospection of the “>1-in-3” assessment method for toxics, and therefore suggests a modernization of water quality assessment and sampling methods for toxics is now appropriate. The “>1-in-3” assessment method is largely based on EPA’s use of: 1) eight studies cited in EPA’s Technical Support Document for Water Quality-based Toxics Control (EPA 1985) and 2) a compilation of papers, including a literature review (Niemi *et al.,* 1990) published in Environmental Management in 1990 (Volume 14, Issue 5).

Below is a review of the studies in EPA (1985) and Niemi *et al.* (1990) that were used to support the “>1-in-3” assessment method. In addition, we summarize two more recent reviews of ecosystem recovery (Jones and Schmitz, 2009; Gergs *et al.,* 2016). The Division advocates that a distinction needs to be acknowledged between: 1) what can be managed (e.g. discharges of metals from point sources and stormwater) and 2) what cannot be managed (e.g. flooding, droughts and accidental chemical spills) in applying appropriate water quality assessment methods for toxics constituents. In addressing the discharges of toxic compounds, particularly the implementation of chronic water quality criteria, a sufficient number of samples is needed to ascertain impacts to aquatic life. Our focus is primarily on toxic compounds discharged, such as metals that can be monitored routinely, and not on toxics associated with unmanageable events.

## Three-year Recovery Period

A primary consideration in the application of “>1-in-3” assessment method is the period of time (i.e. average of three years) it takes for biological communities to recover from the effects of toxic pollutants. Two reviews are commonly cited to support this recovery period, which are listed here and described in further detail below.

1. EPA. 1985 Technical Support Document for Water Quality-based Toxics Control. EPA-440/4-85-032, September 1985
2. Reference to the papers in Environmental Management 1990 Volume 14, Issue 5.

## 1. EPA. 1985 Technical Support Document for Water Quality-based Toxics Control. EPA-440/4-85-032, September 1985

The purpose of this Technical Support Document (TSD) is to provide guidance on "*the task of controlling the discharge of toxic pollutants to the nation's waters" and "each step in the water quality-based toxics control process from screening to compliance monitoring"* (EPA 1985).

This TSD reviewed eight biological recovery studies (Figure 1) to support a three-year recovery time. Most of these eight studies represent catastrophic events that cannot be managed, such as spills or an application of a pesticide, which by of itself is expected to have an adverse impact on biological communities. Only one study (Straight River in Minnesota) included a metal as a toxicant.

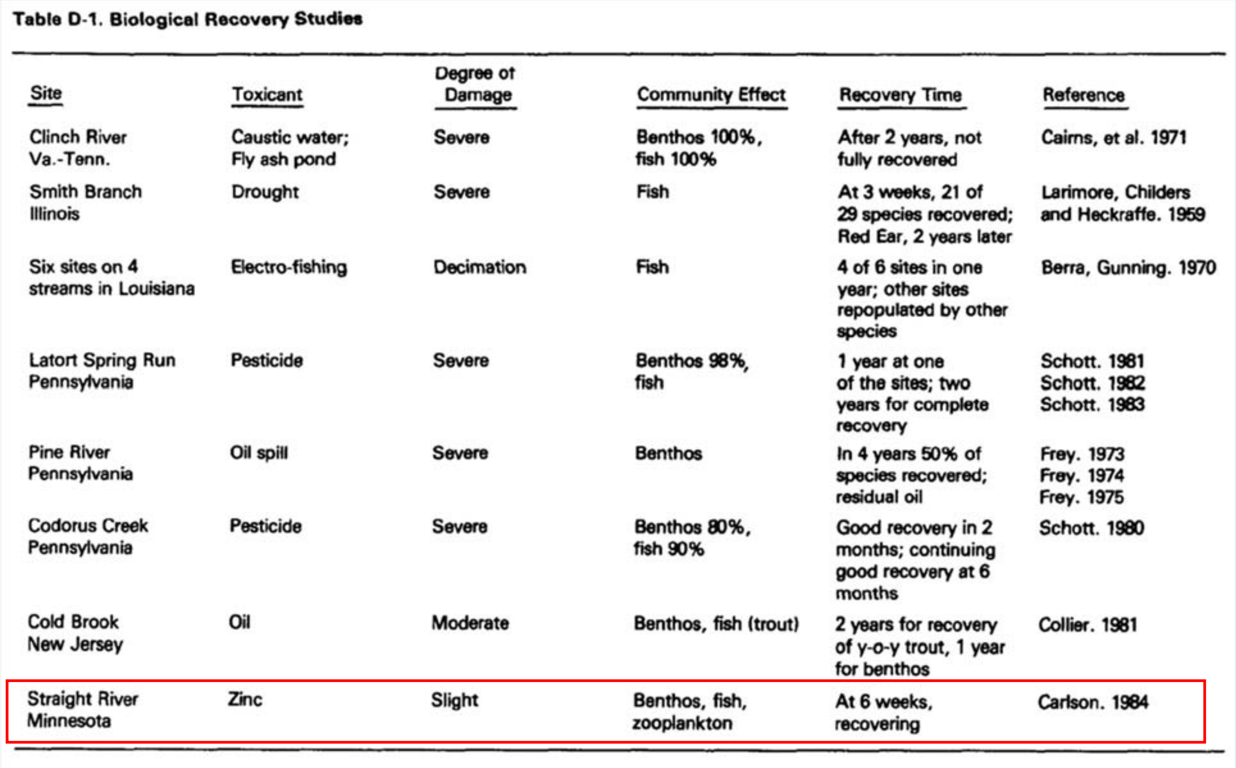


**Table D-1. Biological Recovery Studies**

| Site | Toxicant | Degree of Damage | Community Effect | Recovery Time | Reference |
|---|---|---|---|---|---|
| Clinch River Va.-Tenn. | Caustic water; Fly ash pond | Severe | Benthos 100%, fish 100% | After 2 years, not fully recovered | Cairns, et al. 1971 |
| Smith Branch Illinois | Drought | Severe | Fish | At 3 weeks, 21 of 29 species recovered; Red Ear, 2 years later | Larimore, Childers and Heckraffe. 1959 |
| Six sites on 4 streams in Louisiana | Electro-fishing | Decimation | Fish | 4 of 6 sites in one year; other sites repopulated by other species | Berra, Gunning. 1970 |
| Latort Spring Run Pennsylvania | Pesticide | Severe | Benthos 98%, fish | 1 year at one of the sites; two years for complete recovery | Schott. 1981<br>Schott. 1982<br>Schott. 1983 |
| Pine River Pennsylvania | Oil spill | Severe | Benthos | In 4 years 50% of species recovered; residual oil | Frey. 1973<br>Frey. 1974<br>Frey. 1975 |
| Codorus Creek Pennsylvania | Pesticide | Severe | Benthos 80%, fish 90% | Good recovery in 2 months; continuing good recovery at 6 months | Schott. 1980 |
| Cold Brook New Jersey | Oil | Moderate | Benthos, fish (trout) | 2 years for recovery of y-o-y trout, 1 year for benthos | Collier. 1981 |
| Straight River Minnesota | Zinc | Slight | Benthos, fish, zooplankton | At 6 weeks, recovering | Carlson. 1984 |

Figure 1. Summary of biological recovery studies in *Table D-1* EPA (1985)

Cairns *et al.* (1971) may be the only peer-reviewed reference among the eight studies, since none of the other references could be located. Cairns *et al.* (1971) discusses the recovery of damaged streams from four case studies. This was an important paper in its time, as it began to show that the biological recovery of damaged rivers "*is a function of the physical, chemical and biological characteristics of the receiving stream, the severity and duration of the stress, and the availability of undamaged areas to serve a sources for recolonizing organisms*" (Cairns *et al.* 1971).

The four case studies in Cairns *et al.* (1971) are:

1. <u>Shock Acidification of a Healthy Stream</u>. This was an experimental study in which the pH of a 2.5 mile portion of Mill Creek (Virginia) was lowered by adding "*concentrated technical grade sulfuric acid*" to a portion of Mill Creek. Benthic macroinvertebrate density and diversity were compared between the control and treatment portions of Mill Creek. Assessment of metals was not a component of this study.

2. Recovery from Acid Mine Drainage. This case study examined acid mine drainage from two streams in Pennsylvania. The density and diversity of benthic organisms was measured in addition to a number of water chemistry parameters (pH, specific conductance, acidity, alkalinity, hardness, calcium, and iron). No metals, other than iron, were assessed in this study.
3. Biological damage and Recovery from an Ethyl Benzene – Creosote Spill. This study assessed the effects of an "*abrupt release of acutely toxic material*" on the fish and bottom fauna in a portion of the Roanoke River (Virginia). Metals were not assessed as a component of the study.
4. Biological Damage and Recovery of the Clinch River Following Acute pH Stresses. The Clinch River in southwestern Virginia and northeastern Tennessee was subjected to two major industrial spills, a coal ash spill followed by a spill of sulfuric acid. Metals were not assessed as a component of this study.

Note that three of the four studies represented catastrophic events, such as spills. The remaining case study represented the experimental application of concentrated acid. Metals, with the exception of iron in case study 2, were not measured.

The use of Table D-1 in deriving a three-year recovery period is discussed in EPA's "Technical Support Document for Water Quality-based Toxics Control – Responsiveness Summary" (EPA 1991a):

> "EPA has used Appendix D to set forth information on time periods needed for ecological recovery from severe or catastrophic stresses. EPA's recommended 3-year return interval was set forth in the 1985 "Guidelines for Deriving Numeric National Criteria ... ", and a review or revision of this recommended frequency was not within the scope of the TSD. Nevertheless, EPA intends to address the excursion frequency during the upcoming revision of the Guidelines.
> …
>
> EPA believes that the 3-year return interval can be justified by the Appendix D data if one makes the assumption that the type of ecological impact shown in Appendix D could be caused by fairly small criteria excursions. The concentrations causing the Appendix D impacts were in fact not known. EPA recognizes that the chemical and ecological field data summarized in Chapter 1 suggest that successive excursions well above the criteria would be needed to cause severe impacts. EPA also recognizes that the probability of large excursions can be calculated to be extremely small compared to the probability of marginal excursions."

Most of the studies cited in EPA (1985) represent events that either purposely aim for severe impacts on biological communities (i.e. application of pesticides) or cannot be controlled (i.e. accidental spills and droughts). Therefore, not only is the assumption that "*fairly small excursions*" can result in the impacts summarized in Appendix D extremely conservative, it is also unfounded.

## 2. Reference to the papers in Environmental Management 1990 Volume 14, Issue 5

In April 1987 the National Science Foundation sponsored a workshop "*to analyze unifying concepts in stream ecology and to propose new research directions*" (Yount and Neimi 1990a). Disturbance and recovery of aquatic ecosystems were important but unresolved themes in that workshop that led to further discussions on the recovery of lotic ecosystems from chemical and other disturbances. Discussions from this workshop culminated in a series of papers published in Environmental Management (Volume 14, issue 5).

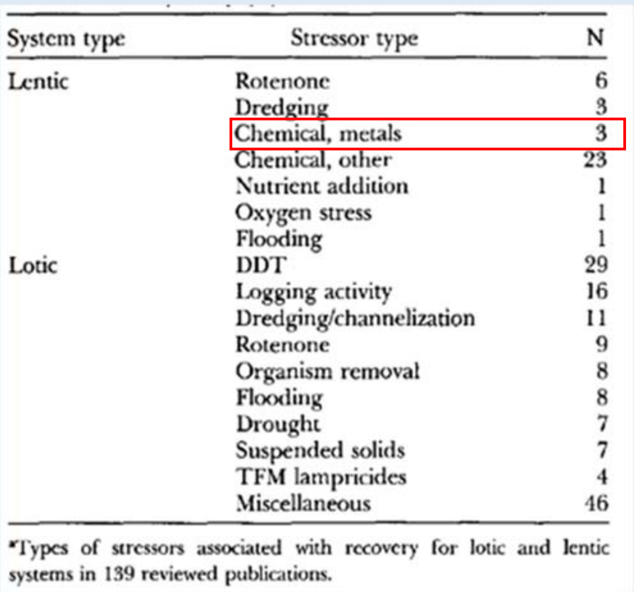
There are two important items in the Preface to the papers in this issue of Environmental Management. First, there is the recognition that research on risk assessment, which focuses on the probabilities of exposure and effects, does not address the relative rates of recovery of impacted ecosystems. Second, the authors stated that the EPA Technical Support Document (EPA 1985) needed additional information on recovery times: “*In that report only a handful of case studies were cited, and most did not come from the peer-reviewed literature. In part, motivation for this symposium [was the] recovery of lotic communities and ecosystem following disturbance: theory and application also arises from the need to place these guidelines on a firmer scientific basis”* (Yount and Niemi 1990a).

In order to put the EPA (1985) guidelines on a “firmer scientific basis”, a literature review was conducted to more thoroughly examine the time required for ecosystem recovery following disturbances. This literature review (Niemi *et al.* 1990) was conducted based on the following keywords: “*ecosystems, communities, stress, perturbations, damage, wind, volcano, storms, disturbance, pollution, mining, logging, flood, recovery, restoration, and resilience*” (Niemi *et al.* 1990). The literature review identified over 150 case studies that reported on some aspect of aquatic life resilience in freshwater ecosystems

Niemi *et al.* (1990) summarized the stressors found in their literature review (Figure 2). This figure shows that most of the studies summarized reflect stressors such as DDT, chemicals (other than metals), logging, and dredging, which are more accurately described as catastrophic events. The review of metals as a stressor was only reflected three times.

Complementing the literature review (Niemi *et al.* 1990) is the narrative review of the recovery of lotic ecosystems from disturbance (Yount and Niemi 1990b). Noteworthy in Yount and Niemi (1990)b is the recognition that a majority of systems recovered fairly quickly. In those systems with longer recovery times, the factors contributing to this included the “availability and accessibility of unaffected up-stream and downstream areas and internal refugia to serve as sources of organisms for repopulation.”

Metals were mentioned once in Yount and Niemi (1990b) and pertained to a study of mining operations in Montana conducted by Chadwick *et al.* (1986) in which a prolonged recovery time may have been the result of the lack of an undisturbed headwater source of colonizers.



| System type | Stressor type | N |
|---|---|---|
| Lentic | Rotenone | 6 |
| | Dredging | 3 |
| | Chemical, metals | 3 |
| | Chemical, other | 23 |
| | Nutrient addition | 1 |
| | Oxygen stress | 1 |
| | Flooding | 1 |
| Lotic | DDT | 29 |
| | Logging activity | 16 |
| | Dredging/channelization | 11 |
| | Rotenone | 9 |
| | Organism removal | 8 |
| | Flooding | 8 |
| | Drought | 7 |
| | Suspended solids | 7 |
| | TFM lampricides | 4 |
| | Miscellaneous | 46 |

*Types of stressors associated with recovery for lotic and lentic systems in 139 reviewed publications.

Figure 2. Frequency of stressors (N) listed in the literature review conducted by Niemi *et al.* (1990)

## Studies on Recovery since 1990

Since Niemi *et al.* (1990), two other literature reviews (Jones and Schmitz 2009, Gergs *et al.* 2016) have addressed disturbance and recovery of biological communities. Jones and Schmitz (2009) reviewed 240 studies based on the following perturbation-type keywords: agriculture, deforestation, eutrophication, hurricane, cyclone, invasive species, logging, oil spill, power plant, and trawling. Both terrestrial and aquatic ecosystems were included in their study. The study did not review any literature on catastrophic or routine discharges of toxics (e.g. metals) into aquatic ecosystems.

The Gergs *et al.* (2016) literature review is described below;(2009):

> “Taking a previously published review of case studies as a starting point (Niemi et al. 1990), the emphasis of our literature search was drawn to studies published in the period 1990 – 2010. On the

> basis of title and abstract, a total of 471 and 152 publications were collected for lotic and lentic systems, respectively. Out of these publications, case studies that included recovery and colonization information for freshwater populations or communities were selected on the basis of four criteria: (1) Appropriate description of the system or site characteristics available; (2) disturbance caused by a stressor of which the exposure is described clearly; (3) description and quantification of a pronounced effect that can be related to the described stressor; (4) data on recovery times are available, including pre-disturbance or reference data, or data indicating stable population establishment in newly constructed freshwater ecosystems. By applying these criteria, 397 publications were rejected. Finally, the selection included 150 articles for lotic systems and 76 articles for lentic systems, resulting in a total of 148 case studies and 908 recovery endpoints, i.e., records of recovery or colonization times for populations, functional groups or communities."

Disturbances identified in Gergs *et al.* (2016) included metals, floods, drought, physical disturbance, non-pesticides and pesticides. Results for metals showed a median time to recovery of one year (Figure 3). Although this was the second longest median recovery time among stressor types, the sources of metals were primarily coal/fly ash spills and mining activities (Gergs 2016 personal communication[1] citing the use of: Arnekleiv *et al.* 1995, Chadwick *et al.* 1986, Cherry *et al.* 1979a, Cherry *et al.* 1979b, Cherry *et al.* 1984, Diamond 1993, Hoiland 1992, Hoiland and Rabe. 1992, Nelson *et al.* 1996, Nelson *et al.* 1999, Roline 1998, Ryon 1992, Smith 2003, Valdes 1996, Watanabe *et al.* 2000).

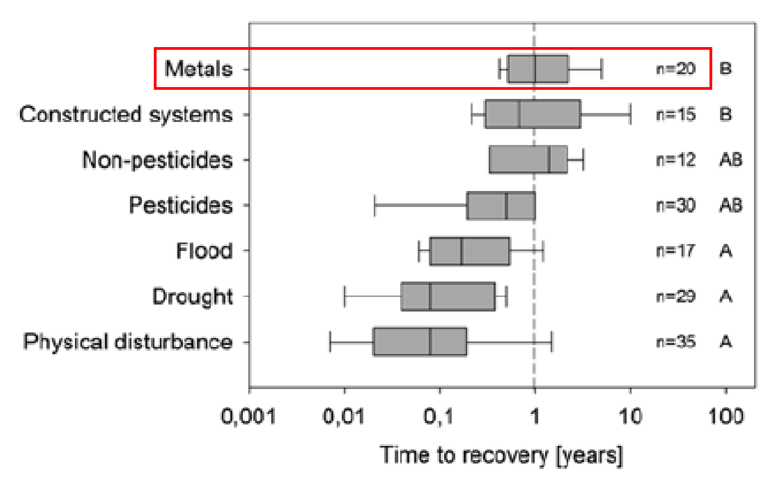


Figure 3. Recovery times in lotic macro-invertebrates separated by stressor type. *Boxes* represent quartiles and whisker symbolize 95% confidence intervals. *Capital letters* indicate significant difference ($p < 0.0001$) in the Kruskal–Wallis test followed by a Dunn's post-hoc comparison; *n* number of recovery endpoints. **(This is figure 5 in Gergs *et al.* 2016)**

None of the studies reviewed in EPA (1985), Niemi et al (1990), Jones and Schmitz (2009) and Gergs *et al.* (2016) represent studies of the effects of metals discharged to the nation's waters. This greatly limits the applicability of the ">1-in-3" assessment method to address the effects of acute and chronic metal discharges. Much of the literature reviewed by EPA (1985), Niemi et al (1990), Jones and Schmitz (2009) and Gergs *et al.* (2016) can be classified as "pulse" perturbations, whereas the discharge of toxics by point sources can be classified as "press" perturbations. The terms "pulse" and "press" originated with Bender (1984) and are used extensively in the scientific literature pertaining to ecosystem disturbances and recovery periods. Glasby and Underwood (1996) define these terms as:

> <u>Pulse perturbation</u> – "*short-term and causing a sudden change in number of species from which the assemblage recovers once the disturbance has ceased.*"

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[1] Email to Steve Kroeger, NC Division of Water Resources on March 16, 2016: "*Dear Steve, thank you very much for your e-mail. In Figure 5 of the review we refer to 20 recordings of recovery times for different taxa of which several are derived from the same study (thus, unfortunately less than 20 studies). Please find the reviewed papers in the attachment. Best regards, André*"

Press perturbation – "*continuous disturbance causing the abundance or density of species to be permanently changed*."

It is the press perturbation type that needs to addressed when assessing the effects of discharged toxic compounds (e.g. metals) that may affect aquatic life. Glasby and Underwood (1996) argue that different sampling methods need to be employed to differentiate between pulse and press perturbations.

Although an average of three years for biological communities may be needed to recover from catastrophic events, no evidence was found in Cairns *et al.* (1971), Neimi *et al.* (1990), Jones and Schmitz (2009) or Gregs *et al.* (2016) to suggest community recovery timeframes from occasional exceedances of a chronic criterion for toxic compounds such as metals..

## Independent Application and the Element of Recovery of Biological Communities in the ">1-in-3" Assessment Method

Independent application, aka "independent applicability," represents a 1991 EPA policy developed during discussions on how to integrate biological criteria and assessment methods with traditional chemical/physical methods. This policy (EPA 1991b) states:

> "Because biosurvey, chemical-specific, and toxicity testing methods have unique as well as overlapping attributes, sensitivities, and program applications no single approach for detecting impact should be considered uniformly superior to any other approach. EPA recognizes that each method can provide valid and independently sufficient evidence of aquatic life use impairment, irrespective of any evidence, or lack of it, derived from the other two approaches. The failure of one method to confirm an impact identified by another method would not negate the results of the initial assessment. This policy, therefore, states that appropriate action should be taken when any one of the three types of assessment determines that the standard is not attained."

However, a primary part of the ">1-in-3" assessment method is the determination that it takes an average of three years for biological communities to recover from exceedances of a toxic compound, thereby linking chemical and biological assessments. This three-year period was established through studies examining the recovery of biological communities. Thus, the evaluation of biological communities is indispensable to determine when toxic compounds have impacts on measures such as biological integrity. When biological communities are evaluated during the same assessment period as the collection of metals samples, both sets of data are needed to identify and confirm any impacts.

## Summary and Conclusion

A lack of research during the past 25 years regarding the magnitude, duration and frequency of toxic discharges (e.g. metals) on aquatic life has led to the ">1-in-3" approach becoming the de facto assessment methodology used by many states and the EPA. In this regard, the ">1-in-3" assessment methodology poses a number of specific problems:

1. The effects of metals on aquatic ecosystems and subsequent recovery is not well known. Literature reviews do not address the impacts of point and non-point source discharges (e.g. through permitting mechanisms) of toxic compounds on aquatic ecosystems.
2. The average three-year recovery period cited by the EPA appears to be based on catastrophic (i.e. pulse) events and not routine (press) exposure.

3. The “>1-in-3” method precludes any progress in understanding the resilience of aquatic ecosystems to chronic concentrations of metals through routine monitoring.
4. The “>1-in-3” method greatly increases the chance of a false positive (Type 1) statistical error in water quality assessment.
5. The “>1-in-3” method undermines gaining any knowledge on the magnitude, durational and frequency of toxics on aquatic life.
6. The “>1-in-3” method does not consider an actual assessment of the biological community, when, in fact, the recovery of the biological community is what the ”3” of the “>than 1 in 3” is based upon.

The application of a more robust sample size with a proportion exceedance assessment methodology will lead to understanding magnitude, duration, and frequency of toxin levels over a broader period of time. This is especially relevant for gaining an understanding of the potential for chronic impacts of toxins on aquatic life, which will remain unknown if sampling ends after “more than one exceedance.” Moreover, with a method involving a more robust sample size, any sampling errors can be minimized by the application of confidence levels.

In conclusion, the effects of any toxic discharge (e.g. metals) through permitted mechanisms (e.g. NPDES) on aquatic life needs to be properly assessed to ascertain the potential impact to those uses. When considering impacts to aquatic life in particular, a sufficient number of samples for the toxicant are needed to allow for consideration of possible acute and chronic effects. Additionally, water quality monitoring for both the toxicant (e.g. metals) and biology (benthos and/or fish community) must be completed to fully understand the magnitude of the exposure and its effect.

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