Stormwater Runoff Water Quality Science/Engineering Newsletter Devoted to Urban/Rural Stormwater Runoff Water Quality Management Issues

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This issue of the Stormwater Runoff Water Quality Science/Engineering Newsletter (NL) is a followup to NL6-8, which was devoted to a review of the US EPA Strategy for Water Quality Standards. That Newsletter discussed some of the problems of trying to use the US EPA worst-case-based water quality criteria and state water quality standards based on these criteria to cost-effectively control water pollution associated with urban and rural stormwater runoff. It was concluded that the chemical-concentration-based approach that the US EPA adopted in the early 1980s can readily lead to overregulation of potential pollutants and underregulation of constituents for which there are no water quality criteria/standards. It has been known for some time that there is need for a different regulatory approach, especially for regulating contaminated sediments. This issue of the Newsletter is devoted to a discussion of the **weight-of-evidence** approach for regulating the water quality impacts of contaminated sediments.

Best Professional Judgment Triad Weight-of-Evidence Evaluation of Water/Sediment Quality

There is increasing support for the use of a best professional judgment (BPJ), non-numeric, triad weight-of-evidence (WOE) approach for evaluating the impacts of chemical constituents in aquatic sediments and the water column on water quality. This approach is based on an integrated use of aquatic life toxicity, organism assemblages and chemical information to determine the potential for constituents in sediments to be adverse to the beneficial uses of the waterbody. Included in this evaluation is the determination whether sediments are serving as a source of bioaccumulatable chemicals that are hazardous to higher trophic level organisms including man. While the focus of the use of WOE is aquatic sediments, it is equally applicable to water column impact evaluations. This WOE triad approach is recognized as a far more reliable, cost-effective approach for evaluating whether a chemical constituent(s) associated with a sediment and/or present in the water column is adverse to water quality than the traditionally used regulatory approach of a chemical-specific numeric water quality standard or sediment quality guideline.

Traditionally, water quality regulatory programs have been based on a mechanical application of water quality criteria/water quality standards, as a bright line water quality regulatory limit. If the water quality standard is exceeded, control programs are implemented to control the exceedance of the water quality standard. This chemical-concentration-based approach has "worked," with respect to being able to achieve water quality standards for point sources of pollutants such as domestic and industrial wastewater discharges. However, the success of this approach for point source discharges ignores the cost-effectiveness of the water pollution control programs. To control a chemical to achieve worst-case-based water quality standards ignores that many chemicals exist in a variety of chemical forms, only some of which are toxic/available to impact water quality. Costs for wastewater treatment in excess of those needed to protect the designated beneficial uses have occurred under the chemical-concentration-based approach. These costs have been passed on to the public through higher wastewater management costs. Further, the chemical-concentration-based approach does not adequately evaluate the potential for unmeasured chemical constituents to cause water quality problems. There is need to shift from the chemical-concentration-based approach to a chemical-impact-based approach for implementing water quality management programs. This can be done through a weight-of-evidence approach. Additional information on the need for a weight-of-evidence approach is provided in Appendix A.

The weight-of-evidence approach for regulating water quality is based on the integration of multiple lines of evidence (LOE) to develop an assessment of impacts of a chemical or group of chemicals in a waterbody's water column and/or sediments. Weight of evidence uses multiple LOE to assess the magnitude of the water quality impairment on the waterbody's beneficial uses and the sources of the constituent(s) responsible for the impairment, and becomes the foundation for regulatory action to control the water quality beneficial use impairment. A comprehensive review of the weight-of-evidence approach was published in *Human and Ecological Risk Assessment*, in July 2002. Comprehensive papers reviewing the weight-of-evidence approach were published by Chapman, et al. (2002) and Burton, et al. (2002a,b). As they discuss, there is no standard weight-of-evidence approach. They provide reference to the literature on the various approaches that have been used. The Chapman, et al., and Burton, et al., discussions provide guidance on how a non-numeric, best professional judgment weight-of-evidence approach should be used.

Components of WOE

The components of a WOE approach are summarized below. Chapman, et al. (2002) stated,

> *"Fully implementing WOE per Burton, et al. (2002b) requires consideration of six main LOE in sediment (or other) assessments (adapted from Chapman, 1990, 1996; Borgmann, et al., 2001; Reynoldson, et al., 2002):*
>
> 1. *Are contaminants present at levels of concern? (sediment chemistry)*
> 2. *Are the contaminants capable of causing toxicity? (laboratory toxicity tests)*
> 3. *Are resident biotic communities altered? (community structure analyses)*
> 4. *Are the contaminants causing the observed toxicity and/or community alterations (manipulative/investigative studies, e.g., TIE [toxicity identification evaluation], CBR determinations)*
> 5. *Are any contaminants of concern capable of and likely to biomagnify? (sediment chemistry and tissue analyses, food chain modeling)*
> 6. *Is the sediment stable or is it liable to erosion resulting in exposure of deeper, more contaminated sediments and/or contamination down-current? (shear stress and cohesion measurements relative to possible and unusual events)"*

Organism Assemblages. Organism assemblage information on the numbers, types and characteristics of aquatic life and, as appropriate, terrestrial organisms, such as fish-eating birds, present at a potentially impacted site is a key component of the information base that needs to be obtained/critically reviewed in assessing the water quality impacts of chemicals on the beneficial uses of a waterbody. It should be understood, however, that a variety of physical (flow, temperature, sunlight, sediment, habitat alteration, etc.), non-potential-pollutant chemical (TDS, TOC, nutrients, organic constituents, hardness, alkalinity, etc.) and biological (reproductive cycles, disease, predation, etc.) factors other than chemicals that are potential pollutants can affect the numbers, types and characteristics of aquatic life in a waterbody's water column or sediments. Organism assemblage information is often evaluated based on a gradient analysis from a polluted area hot spot or from a source of pollutants. This approach helps identify the magnitude of the hot spot of adverse impacts.

Toxicity/Bioaccumulation. Aquatic life toxicity and/or bioaccumulation of potentially hazardous chemicals in aquatic organism tissue that is a threat to human health or higher-trophic-level organisms that use aquatic life as food are key components of a BPJ weight-of-evidence approach. However, as discussed by Lee and Jones-Lee (1996), finding aquatic life toxicity in a water column or in sediments should not be interpreted to mean that this toxicity represents a significant impairment of the beneficial uses of the waterbody that are of concern to the public. It is often not possible to relate laboratory-based sediment toxicity to water quality impairment. Many sediments have "natural" toxicity due to low dissolved oxygen, ammonia and hydrogen sulfide, yet have excellent fisheries and high water quality. This issue needs to be considered in evaluating sediment and water column toxicity.

"Chemistry." There is considerable confusion and misinformation on the appropriate use of chemical information in a BPJ weight-of-evidence water quality evaluation. Because of a general lack of understanding and appreciation of aquatic chemistry, the level of chemical information typically used in a weight-of-evidence evaluation is often based on a 1960s knowledge level of aquatic chemistry, where total concentrations of a few regulated constituents having water quality standards is the chemical information used. However, it has been well-known since the late 1960s that the total concentration of potentially toxic constituents in the water column and/or sediments is an unreliable basis for estimating the water quality impacts on the Clean Water Act designated beneficial uses of a waterbody. The use of total concentrations of constituents and/or the exceedance of a co-occurrence-based so-called "sediment quality guideline" as a regulatory limit is technically invalid. The use of total concentrations as the chemical component of a WOE can distort the triad sediment quality evaluation since it incorporates information into the triad that is not related to the impact of the chemicals on aquatic-life-related and other beneficial uses. It should not be assumed that the toxicity in the water column and sediments is caused by a chemical or group of chemicals that are measured in a typical water quality evaluation. There is need to incorporate toxicity identification evaluations (TIEs) into any evaluation of the cause of toxicity. Without this approach, significant errors can readily be made in assessing the toxic components of the water column and/or sediments.

The components of a weight of evidence should include chemical concentrations that have the potential to be adverse to the water quality beneficial uses through toxicity to aquatic life and/or excessive bioaccumulation that is a threat to the use of aquatic organisms as a source of food. It is important to note that the co-occurrence-based (coincidence) approaches, such as Long and Morgan or MacDonald so-called "sediment quality guidelines," are not reliable for evaluating the potential for specific chemicals to cause toxicity.

Appendix B provides additional information on aquatic chemistry that is relevant to a weight-of-evidence evaluation.

Numeric versus BPJ WOE

The BPJ weight-of-evidence approach should be based on the consensus of a panel of experts who, in a public, interactive, peer-review process, consider the information available, define what additional information is needed, and then render an opinion as to the integrated assessment of the information available on the significance of a particular chemical constituent in impacting the beneficial uses of a waterbody. While some individuals (such as Menzie, et al., 2002) attempt to establish a quantitative weight of evidence, in which arbitrary ranking scores are added to each line of evidence, Chapman, et al. (2002), Burton, et al. (2002b), and others as referenced therein, as well as Lee and Jones-Lee (2003) support the position that the weight of evidence should be applied based on best professional judgment by experts in the field who are advising the regulatory agencies, the regulated community and the public on the approach that should be followed to develop a technically valid, cost-effective water pollution control program for constituents in the water column and/or sediments. Some of the factors mentioned by Menzie, et al.; Burton, et al.; and Chapman, et al., that are used to evaluate a weight-of-evidence evaluation, should be part of the process. Assigning ranking scores to these lines of evidence, however, could lead to an inappropriate assessment. There is no technical basis for reliably assigning a numeric weighting factor for the weight-of-evidence components.

The BPJ weight-of-evidence approach should be conducted by a panel of experts knowledgeable in the topic areas. If disagreements arise among panel members or between the panel and others, then a full, public interactive peer review should be conducted of the issues in disagreement. Lee (1999) has presented a recommended approach for addressing conflicts on interpretation of information on water quality issues. Adoption of the public, interactive peer review process recommended by Lee (1999) would be a major advance over the typical adversarial approach in incorporating technically reliable science into public policy development.

Water Quality versus Ecological Assessment

One of the issues that needs to be considered in utilizing the weight-of-evidence approach is that many of these approaches are designed for "ecological" risk assessment, where the concern is whether a chemical or group of chemicals is adverse to the functioning of the ecosystem. However, from a water quality regulatory point of view, there is need for a weight-of-evidence approach to be used to regulate water quality beneficial use impairment, which is not necessarily the same as ecological risk assessment. There can be significant adverse impacts on certain species in an ecosystem without adversely impacting the functioning of the ecosystem. However, from a water quality perspective, adverse impacts on game fish, including their food, would have to be controlled, even though it is not necessarily an important component of the ecosystem.

Implementation of WOE

Burton, et al. (2002a,b) and Chapman, et al. (2002) have discussed many of the issues that need to be considered in the development and implementation of the WOE approach. They discuss advantages, limitations, ranking of the LOE and uncertainty in WOE evaluations. These reviews should be reviewed and followed in developing a WOE water quality evaluation.

One of the arguments that is put forth on why not to use the weight-of-evidence approach, in which there is an integration of toxicity, bioaccumulation, aquatic organism assemblages and appropriately developed chemical information into a decision-making process for regulating water quality beneficial use impacts, is the cost. This argument is based on one of the principal problems with water pollution control in the USA – namely, that inadequate funds are being devoted to properly defining real, significant water quality problems, and then controlling them in a technically valid, cost-effective manner. The root of the problem that exists today in 303(d) listing of impaired waterbodies and inappropriate TMDL control programs for the impairment is the result of inadequate funds being made available for monitoring and problem definition evaluation. So long as program administrators will not tell the legislature the true cost of properly conducting water pollution control programs, the programs will always be technically weak, and some efforts will be subject to justified criticism.

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Appendix A

The Evolution of Water Quality Standards and the Need for Weight-of-Evidence Approach

By the end of the 1960s there was growing recognition that chemical measurements of a potential pollutant were not a reliable indicator of the adverse impacts of the pollutant on the beneficial uses of a waterbody. It was beginning to be recognized then that site-specific evaluation of pollutant impacts are necessary if the constituents of concern (such as a heavy metal, a potentially toxic organic, an organic that tends to bioaccumulate, etc.) are to be regulated, where the funds used for control of the constituent from the various sources are used in the most technically valid, cost-effective manner to control real, significant water quality problems.

The US Congress in 1972, as part of developing the Clean Water Act, required that the US EPA develop national water quality criteria that would be protective of the various beneficial uses of waterbodies. In the early 1970s, the US EPA (which had just been organized) asked the National Academy of Science and the National Academy of Engineering (NAS/NAE) to conduct a review of what is known about the critical concentrations of various potential pollutants, as they may impact various beneficial uses of waters, such as domestic water supply, propagation of fish and aquatic life, industrial and agricultural water supply, transportation, etc. A panel of approximately 150 individuals from across the US worked for about a year to develop what ultimately became the "Blue Book" of Water Quality Criteria 1972. This NAS/NAE (1973) book was published by the US EPA in 1973. It served as the basis for developing the "Red Book" of Water Quality Criteria, which was published by the US EPA (1976). Dr. G. F. Lee was part of the invited peer review panel to the NAS/NAE for review of the "Blue Book" of Water Quality Criteria.

The US EPA supported the NAS/NAE conclusion that it is not possible to regulate many constituents based on exceedance of a measured concentration for a single constituent. It was understood by the early 1970s that many chemical constituents exist in aquatic systems in a variety of chemical forms, only some of which are toxic/available. In order to reliably regulate those forms that can be adverse to aquatic life, it is necessary to conduct site-specific investigations. For heavy metals, the NAS/NAE and the US EPA utilized a toxicity testing procedure to evaluate whether the heavy metals present in a wastewater were in a form that could be toxic to the receiving water aquatic life.

The American Fisheries Society (AFS, 1979) Water Quality Committee panels that developed the critique of the "Red Book" criteria developed reports on the problems with these criteria, which, in many instances (such as with PCBs), further supported the position that exceedance of a single numeric value is not a technically valid approach for regulating water quality. Dr. G. F. Lee was a member of the AFS Water Quality Committee panel that reviewed several of the US EPA "Red Book" criteria.

The 1972 Clean Water Act required that the US EPA develop a list of Priority Pollutants of those chemicals that represent the greatest threat to water quality, and water quality criteria for these chemicals. In the mid-1970s, when the US EPA had not defined the Priority Pollutants or developed water quality criteria for them, an environmental group filed suit against the US EPA for failure to carry out this Clean Water Act requirement. The situation was that Congress did not make funds available to the US EPA to develop the Priority Pollutant list and to develop water quality criteria for them. In order to settle the litigation, the US EPA and the environmental group agreed to develop a list of what are called 129 Priority Pollutants, the majority of which were chlorinated or brominated low molecular weight organic chemicals. The majority of the Priority Pollutants are "rodent" carcinogens – i.e., they have been found to cause tumors in rodents at high concentrations. The Priority Pollutant list was developed in a Consent Decree and adopted without peer review within the US EPA or by experts in the field. The focus of the Priority Pollutant list was drinking water issues and not aquatic life protection. It is recognized by those who are familiar with these issues that development of the Priority Pollutant list was done inappropriately. Further, the Priority Pollutant list has been misused by regulatory agencies and others, where it is assumed that the 129 chemicals that were on this original list represent all of the chemicals of potential concern, and therefore there is little or no need to do any further work to find other hazardous and deleterious chemicals.

In the early 1980s the US EPA, in response to Congress' requirement that water quality criteria be developed for the Priority Pollutants, published a list of criteria based on the information available and announced that the states could use the criteria for the Priority Pollutants as they wished. The US EPA did not require that they be implemented. A couple of years later, the US EPA, under pressure by environmental groups and Congress, announced a new policy of requiring that states adopt water quality criteria for some toxic chemicals as standards. At about that same time, the US EPA (1987) issued the "Gold Book" of Water Quality Criteria, which represented an update of the "Red Book" (US EPA, 1976) of Water Quality Criteria.

Associated with the Gold Book criteria was the requirement that the criteria be implemented as standards based on "total recoverable" metals and other constituents. Dr. G. Fred Lee was part of the US EPA peer review panel that established the criteria development approach that became the Gold Book criteria and was a member of several US EPA panels for criteria documents. It was understood in the mid-1980s that "total recoverable" was overprotective, but the US EPA claimed that it did not have analytical methods that could be used to define toxic available forms. The US EPA was also provided unreliable verbal information by the Agency's Corvallis laboratory staff on how mild acid soluble fractions of some heavy metals were toxic to aquatic life. When a request was made for data to support this position, the data were not forthcoming, and they have never been made available.

Finally, in the mid-1990s, after it had been well known for over 20 years that particulate forms of heavy metals in the water column are, in general, nontoxic, the US EPA (1995) adopted ambient water soluble heavy metals as the forms to be regulated. Further, Delos (2003) of the US EPA headquarters recently reviewed the approach that the Agency is considering for regulating soluble copper based on its complexation with dissolved organic carbon (DOC).

By the late 1980s/early 1990s, the US EPA announced the "Independent Applicability" policy, which was adopted without public review, which required that water quality standards be met, even though other lines of evidence, such as aquatic life toxicity and organism assemblage information, showed that the water quality standard violation was an "administrative" violation and did not represent an impairment of beneficial uses of the waterbody in which the standard violation was occurring. In the 1980s the US EPA adopted a number of arbitrary approaches for implementation of the US EPA water quality criteria, such as defining the acute criterion as a one-hour average value and the chronic criterion as a four-day average value. The technical rationale for these definitions did not exist then and still does not exist.

During the 1980s and 1990s, the Water Environment Federation organized a water quality criteria/standards committee, of which G. Fred Lee was a member. The committee attempted to address a number of what were recognized to be inappropriate approaches that were adopted in the mid-1980s in implementing the water quality criteria into ambient water quality standards and NPDES permit discharge limits. Such issues as the "independent applicability" policy, the one-day and four-day average acute and chronic criteria implementation, the recurrence period of an exceedance of a standard by any amount more than once every three years representing a violation of the standard, etc., were addressed by the committee. In the mid-1990s the US EPA announced A Notice of Proposed Rule-Making (ANPRM) for water quality standards in which a number of these technically invalid approaches were to be addressed. That effort died under both the Clinton administrations. Recently the US EPA (2003) has announced a new effort to develop a water quality criteria strategy. This issue was discussed in Newsletter 6-8.

In the mid-1980s, and then again in the mid-1990s, the US EPA (1994) provided a Water Quality Standards Handbook, which provides guidance on how to convert US EPA worst-case-based national water quality criteria into site-specific water quality standards. The problem with this approach is that it requires a study program costing several hundred thousand dollars to approximately a half million dollars for each site-specific criterion in order to enable the Agency to continue to use a chemical-concentration-based approach. It is believed that if the US EPA would abandon the chemical concentration approach and focus on chemical impacts, a far more reliable, cost-effective approach could be developed for water pollution control than is in place today. It is for this reason that many of those who are familiar with these issues support the development of the weight-of-evidence approach for water quality evaluation and management.

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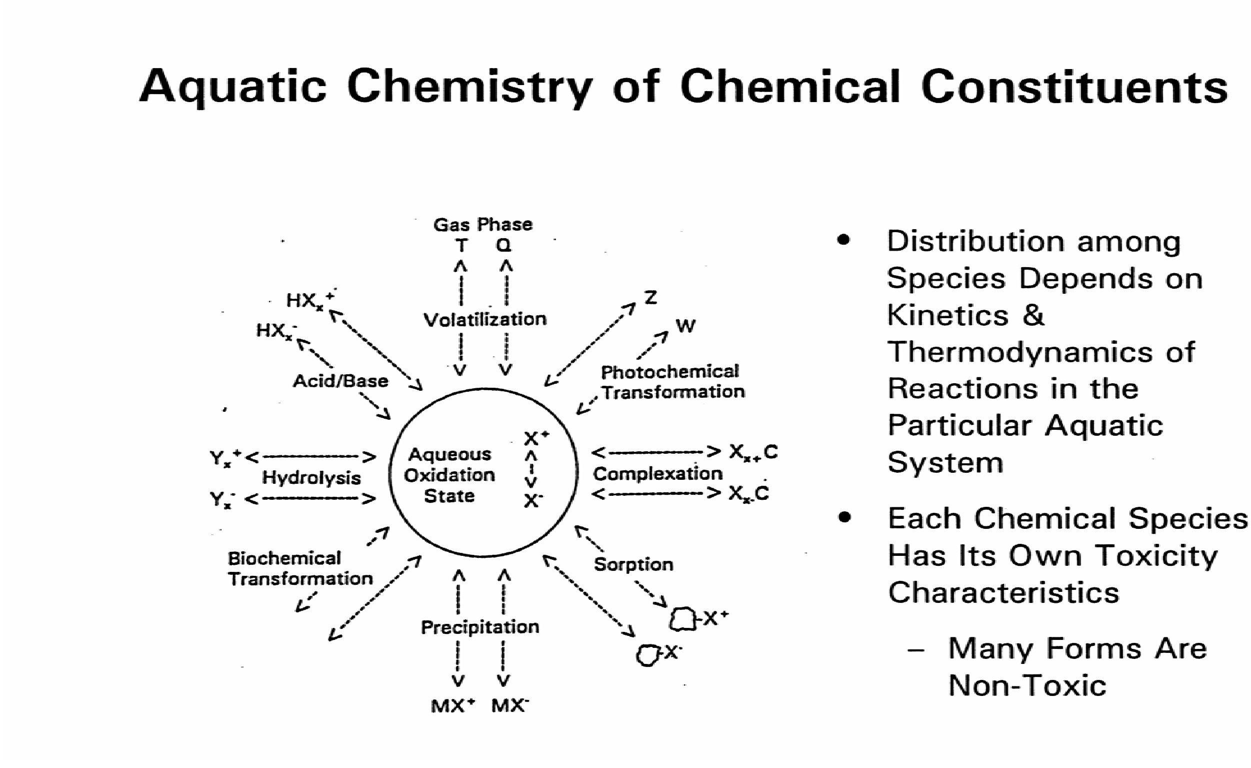
Appendix B
Chemical Issues in WOE[1]

This appendix contains additional information on aquatic chemistry and related topics pertinent to implementation of a water quality WOE.

Aquatic Chemistry. The reason that total concentrations of a selected chemical are unreliable in assessing water quality use impairments is that many chemical constituents exist in aquatic systems in a variety of chemical forms, only some of which are toxic/available. This relationship is shown in the aquatic chemistry "wheel" presented in Figure B1. The forms of a chemical, and therefore their impact on the beneficial uses of a waterbody, such as aquatic life propagation or wholesomeness of aquatic life used as food, depend on the concentrations of detoxification chemicals in the water or sediments. Toxic/available forms of chemicals depend on such factors as redox conditions, complexation, precipitation conditions and, in sediments, organic carbon, sulfides, carbonates, hydrous oxides, clay minerals, etc., that react with potentially toxic forms of potential pollutants to detoxify or make unavailable the potentially toxic constituents.

Figure B1



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[1] Derived from : Lee, G. F. and Jones-Lee, A., "Appropriate Use of Chemical Information in a Best Professional Judgment Triad Weight of Evidence Evaluation of Sediment Quality," Report of G. Fred Lee & Associates, El Macero, CA (2002), published in part in Lee, G. F. and Jones-Lee, A., "Appropriate Use of Chemical Information in a Best Professional Judgment Triad Weight of Evidence Evaluation of Sediment Quality," in Proceedings of Sediment Quality Assessment (SQA5), Aquatic Ecosystem Health and Management Society, Chicago, IL. (in press). Available from http://www.gfredlee.com/BPJWOEpaper.pdf

Typically the water quality evaluation/management field operates at the "hub" of the wheel shown in Figure B1, where little or no consideration is given to the toxic/available forms of the chemical, which are controlled by the kinetics (rates) and thermodynamics (positions of equilibrium) of the reactions that lead to the chemical species that are present at the "rim." Rarely is information available on the amounts of the active forms of detoxification components of water and/or sediments and the characteristics of the reactions that occur with the potentially toxic/available forms. Because of this situation, it is not possible to predict, based on typical chemical analyses, the toxic/available forms of potential pollutants such as heavy metals, selected organics, nutrients, etc., that impact the beneficial uses of a waterbody which are of concern to the public.

Repeatedly, it has been found that when the significant technical deficiencies in the chemical information used in a weight-of-evidence evaluation are discussed with those who are proceeding to conduct the evaluation using unreliable or inadequate chemical information, such as total concentration of a chemical, those responsible claim that more appropriate chemical information is too complex to understand and difficult to obtain. The chemical total concentration approach can be characterized as an unreliable, "cheap" chemical investigation that, while providing some chemical information, is obviously unreliable for use in a weight-of-evidence approach.

Chemical Composition versus Water Quality. A fundamental problem exists in the water quality field with many of its practitioners using chemical concentrations, as typically measured in US EPA or "Standard Methods" analytical procedures, as "water quality." Water quality, by Clean Water Act requirements, is tied to the beneficial uses of a waterbody. Since it is not possible to translate chemical concentrations in either a discharge to a waterbody or within a waterbody to a real impairment of beneficial uses, it is not appropriate to characterize a set of chemical analysis data as an assessment of water quality. Such data should be characterized as "water quality characteristics" that, when appropriately combined with other information, can provide inference on the relationship between a constituent(s) and the water quality characteristics of a waterbody which are of concern to the public.

A similar problem exists with respect to the term "chemistry" when referring to chemical data. Chemistry involves the evaluation of the thermodynamics and kinetics of the reactions that govern the distribution of chemical species in a waterbody (see Figure B1). A set of data on chemical concentrations is not "chemistry," but provides information on the chemical characteristics of a waterbody.

Basically, the problem is that those who use total concentrations of a potentially toxic chemical, knowingly or through ignorance, use the presence of chemical constituents, regardless of impacts, as synonymous with pollutants -- i.e., constituents which adversely impact the beneficial use of waterbodies. This is an inappropriate approach which ignores the aquatic chemistry of constituents of concern, and can readily cause substantial waste of public and private funds in unnecessary chemical constituent control. This approach is also a significant deterrent to obtaining the information needed for a reliable assessment of the beneficial use impacts of the unregulated constituents -- i.e., those without water quality criteria/standards -- since the focus is on chemical concentrations rather than chemical impacts.

Association of Chemical Concentrations with Impacts. As long as individuals continue to use unreliable chemical information in a weight-of-evidence triad, such as total concentrations of a few chemicals, to "associate" the presence of a measured chemical constituent to a water quality impact (such as toxicity, bioaccumulatable chemicals, changes in organism assemblages, etc.), the BPJ weight-of-evidence approach is not a reliable tool, since one of the key components of the triad is fundamentally flawed. While toxicity and excessive bioaccumulation are readily measurable characteristics of an aquatic ecosystem, as are the numbers, types and characteristics of aquatic life in a particular system of concern, as well as the total concentrations of chemical constituents present in this system, the total concentration measurements often have no relationship to the impact of potential pollutants on beneficial uses.

The duration of exposure of an organism to a toxic form of a chemical is an important characteristic that must be considered in evaluating the potential water quality significance of pulses of toxic chemicals. Figure B2 shows the relationship between duration of exposure and toxicity that typically occurs, where high concentrations of standard laboratory-measured toxicity can be tolerated by some forms of aquatic life, provided that the duration of exposure of this toxicity is short, compared to the critical toxicity/duration of exposure relationships that exist in ambient waters for aquatic life.

Figure B2
Critical Concentration/Duration of Exposure Relationship