EXHIBIT 12

United States Environmental Protection Agency

Office Of Water (EN-336)

EPA/505/2-90-001
PB91-127415
March 1991

EPA

Technical Support Document For Water Quality-based Toxics Control

5. PERMIT REQUIREMENTS

5.1 INTRODUCTION

As the final step in the "standards-to-permits" process, development of permit requirements is often the culmination of the activities discussed in the preceding chapters. This chapter describes the basic principles of effluent variability and permit limit derivation and provides recommendations for deriving limits from various types of wasteload allocation outputs such that water quality standards are protected. It also addresses important considerations in the expression of limits and other types of permit requirements, including toxicity reduction evaluations. The first portion of the chapter deals principally with aquatic life protection. Permitting for protection of human health is found in Section 5.4.4.

5.1.1 Regulatory Requirements

There are both mandatory and discretionary elements associated with the development of water quality-based permit limits to control toxic pollutants and toxicity. The mandatory elements are described in the revisions to the National Pollutant Discharge Elimination System (NPDES) Surface Water Toxics Control Program regulations (54 *FR* 23868, June 2, 1989). The regulations at 40 *CFR* 122.44(d)(1) require that regulatory authorities first determine whether a discharge causes, has the reasonable potential to cause, or contributes to an excursion above water quality standards (narrative or numeric). In making these determinations, regulatory authorities must use a procedure that accounts for effluent variability, existing controls on point and nonpoint sources of pollution, available dilution, and (when using toxicity testing) species sensitivity. Each of these regulations were previously discussed in Chapter 3.

There is a degree of flexibility in the specific procedures a regulatory authority uses in determining whether an excursion occurs or is reasonably expected to occur and in the weight given to the various factors in conducting the evaluation of a specific discharger. The Environmental Protection Agency's (EPA) guidance for making these determinations is contained in the recommendations in Chapter 3.

There are also several EPA policies that reflect these regulatory requirements, including the "National Policy for the Development of Water Quality-Based Limits for Toxic Pollutants" (Appendix B-2) and EPA's "Whole Effluent Toxicity Permitting Principles and Enforcement Strategy," (Appendix B-4). This strategy states that "all major permits and minors of concern must be evaluated for potential or known toxicity (chronic or acute if more limiting)." In addition, the strategy states that "[f]inal whole effluent toxicity limits must be included in permits where necessary to ensure that State Water Quality Standards are met. These limits must properly account for effluent variability, available dilution, and species sensitivity."

There is an element of judgment inherent in the specific permit limit derivation procedures used for an individual discharger once a decision has been made to develop a specific type of limit. Case-specific considerations will usually dictate the most appropriate approach to be taken in individual situations. Nevertheless, the various assumptions used in the permit limit development process should be consistent with the assumptions and principles inherent in the effluent characterization and exposure assessment steps preceding permit limit development. **The permit limit derivation procedure used by the permitting authority should be fully enforceable and should adequately account for effluent variability, consider available receiving water dilution, protect against acute and chronic impacts, account for compliance monitoring sampling frequency, and protect the wasteload allocation (WLA) and ultimately water quality standards. To accomplish these objectives, EPA recommends that permitting authorities use the statistical permit limit derivation procedure discussed in Section 5.4 with the outputs from either steady state or the dynamic wasteload allocation modeling.**

5.2 BASIC PRINCIPLES OF EFFLUENT VARIABILITY

An understanding of the basic principles of effluent variability is central to water quality-based permitting. Many of the concepts are the same as those considered in the development of technology-based limits. However, the process for applying the principles is substantially different, as explained below.

5.2.1 Variations in Effluent Quality

Effluent quality and quantity vary over time in terms of volumes discharged and constituent concentrations. Variations occur due to a number of factors, including changes in human activity over a 24-hour period for publicly owned treatment works (POTWs), changes in production cycles for industries, variation in responses of wastewater treatment systems to influent changes, variation in treatment system performance, and changes in climate. Very few effluents remain constant over long periods of time. Even in industries that operate continuous processes, variations in the quality of raw materials and activities, such as back-washing of filters, cause peaks in effluent constituent concentrations and volumes.

If effluent data for a particular pollutant or pollutant parameter for a typical POTW are plotted against time, the daily concentration variations can be seen (see Figure 5-1, left-hand graphs). This behavior can be described by constructing frequency-concentration plots of the same data (see Figure 5-1, right-hand graphs).

EXHIBIT 12

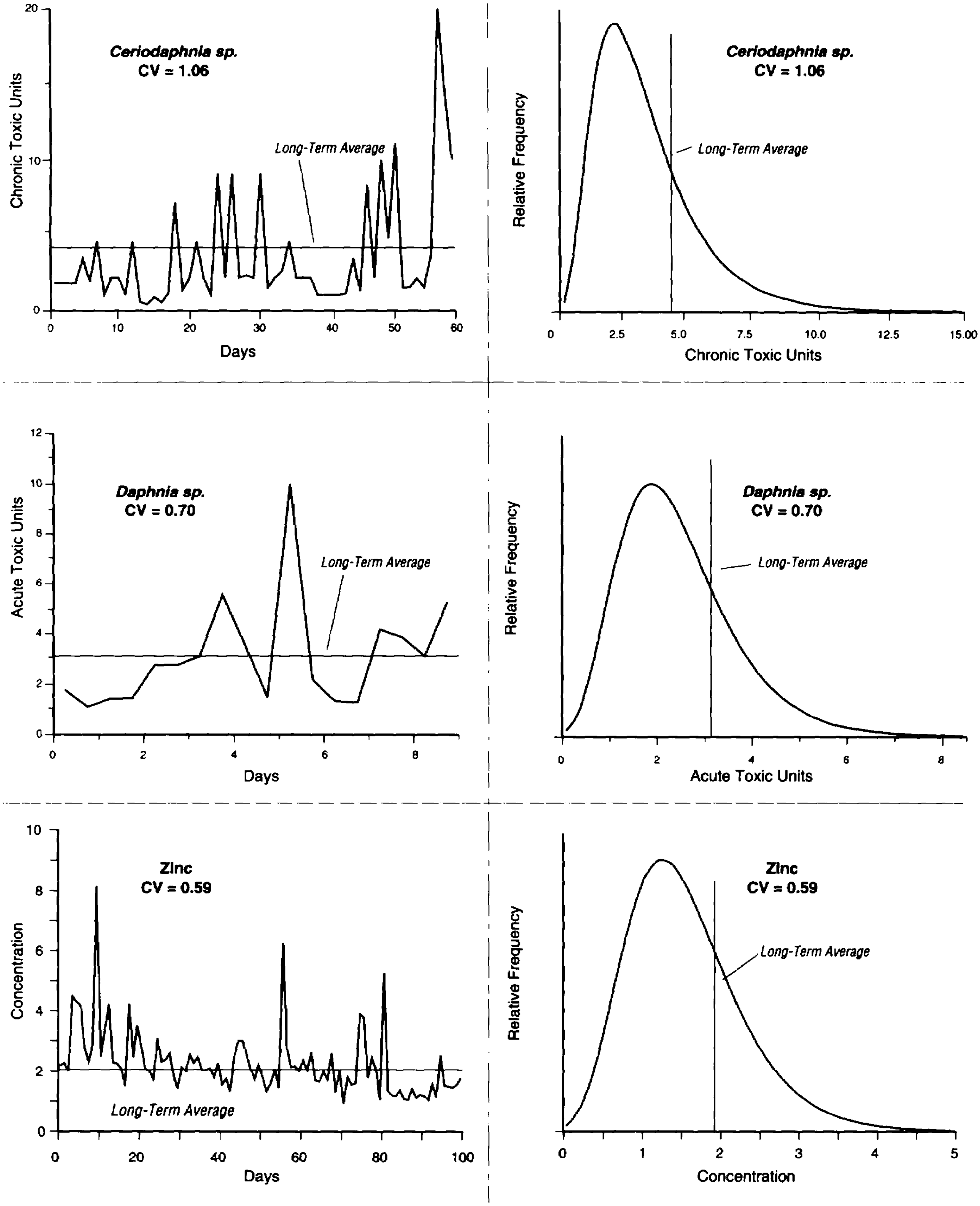

Figure 5-1. Data Relative Frequency Distributions for *Ceriodaphnia* Toxicity, *Daphnia* Toxicity, and Zinc Concentrations for Three Different Effluents

5.2.2 Statistical Parameters and Relationship to Permit Limits

Based upon the shape of the curve of a frequency-concentration plot, the data can be described in terms of a particular type of statistical distribution. The choices for statistical distributions include normal (bell-shaped), lognormal (positively skewed), or other variations on the lognormal distribution. From the vast amount of data that EPA has examined, it is reasonable to assume (unless specific data show otherwise) that treated effluent data follow a **lognormal** distribution. This is because effluent values are non-negative and treatment efficiency at the low end of the concentration scale is limited, while effluent concentrations may vary widely at the high end of the scale, reflecting various degrees of treatment system performance and loadings. These factors combine to produce the characteristically positively skewed appearance of the lognormal curve when data are plotted in a frequency histogram. Appendix E discusses the basis for concluding that effluent data are typically lognormally distributed, as well as recommendations for handling data sets from treatment plants that follow some other type of distribution.

Effluent data from any treatment system may be described using standard descriptive statistics, such as the mean concentration of the pollutant or pollutant parameter (i.e., the long-term average [LTA] and the coefficient of variation [CV]). The CV is a standard statistical measure of the relative variations of a distribution or set of data, defined as the ratio of the standard deviation to the mean. Using a statistical model, such as the lognormal, an entire distribution of values can be projected from limited data, and limits can be set at a specified probability of occurrence. Figure 5-1 shows the frequency-concentration curve and the relative positions of the concentrations corresponding to the mean for the data.

All permit limits, whether technology-based or water quality-based, are set at the upper bounds of acceptable performance. The purpose of a permit limit is to specify an upper bound of acceptable effluent quality. For technology-based requirements, the limits are based on proper operation of a treatment system. For water quality-based requirements, the limits are based on maintaining the effluent quality at a level that will comply with water quality standards, even during critical conditions in the receiving water. These requirements are determined by the WLA. The WLA dictates the required effluent quality which defines the desired level of treatment plant performance or target LTA.

In the development of technology-based effluent limits guidelines, the operating records of various wastewater treatment facilities for a particular category of discharger are examined. Based on the effluent data for the treatment facilities, a composite mean or LTA value for the parameter is determined. This LTA value, with relevant estimates of variability, is then used to derive effluent limit guidelines, which lead directly to permit limits.

In contrast, the process operates in reverse for water quality-based permit limits. The WLA, determined from water quality standards, defines the appropriate discharge level, which in turn determines the requisite target LTA for the treatment facility in order to meet that WLA. Permit limits may then be derived from this targeted LTA and CV. Figure 5-2 illustrates the relationship among the various statistical parameters. As these figures show, highly variable effluents require a much lower targeted LTA to meet the WLA and account for the variability that occurs in effluent concentration above the LTA.

It is extremely important to recognize that the various statistical principles and relationships discussed above operate in any dis-

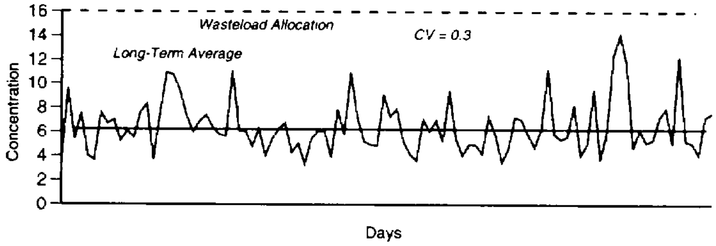

Figure 5-2a. Relationship Between a Single Wasteload Allocation and Two Long-Term Averages for Different Coefficients of Variation

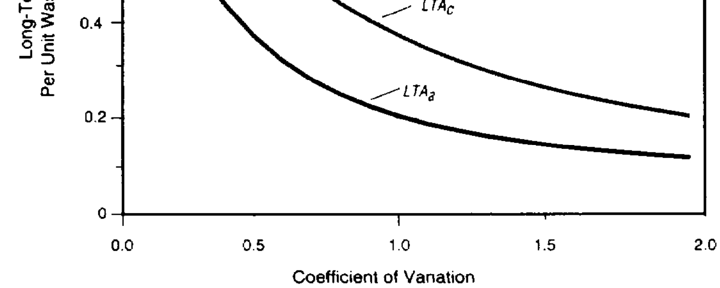

Figure 5-2b. Long-Term Average Per Unit Wasteload Allocation as a Function of the Coefficient of Variation

charge situation—whether or not they are specifically recognized or accounted for. Where a permit limit derivation procedure does not address these principles specifically, the permit writer will be implicitly assuming that there are enough conservative assumptions built into other steps in the process (e.g., water quality models, "buffer" between permit limits and actual operating conditions) to ensure that there will be no reasonable potential for excursions above water quality standards.

5.2.3 Expression of Permit Limits

The NPDES regulations at 40 *CFR* 122.45(d) require that all permit limits be expressed, unless impracticable, as both average monthly and maximum daily values for all discharges other than POTWs and as average weekly and average monthly limits for POTWs. The **maximum daily** permit limit (MDL) is the highest allowable discharge measured during a calendar day or 24-hour period representing a calendar day. The **average monthly** permit limit (AML) is the highest allowable value for the average of daily discharges obtained over a calendar month. The **average weekly** permit limit (AWL) is the highest allowable value for the average of daily discharges obtained over a calendar week.

EPA believes that a maximum daily permit limit can be directly used to express an effluent limit for all toxic pollutants or pollutant parameters except chronic whole effluent toxicity. The typical toxicity test used to measure chronic toxicity consists of samples collected from at least 3 different days over a 7-day period. Therefore, the test does not measure toxicity in any given 24-hour period or calendar day, but rather measures toxicity over a 7-day period. The toxicity could be caused by any one sample or a combination of samples. To address this situation, **EPA recommends that the permit contain a notation indicating that when chronic toxicity tests are required in a permit, the MDL should be interpreted as signifying the maximum test result for the month.**

Additionally, in lieu of an AWL for POTWs, EPA recommends establishing an MDL (or a maximum test result for chronic toxicity) for toxic pollutants and pollutant parameters in water quality permitting. This is appropriate for at least two reasons. First, the basis for the 7-day average for POTWs derives from the secondary treatment requirements. This basis is not related to the need for assuring achievement of water quality standards. Second, a 7-day average, which could comprise up to seven or more daily samples, could average out peak toxic concentrations and therefore the discharge's potential for causing acute toxic effects would be missed. A MDL, which is measured by a grab sample, would be toxicologically protective of potential acute toxicity impacts.

5.3 ENSURING CONSISTENCY WITH THE WASTELOAD ALLOCATION

The WLA provides a definition of effluent quality that is necessary to meet the water quality standards of the receiving water. The WLA is based on ambient criteria and the exposure of the resident aquatic community or humans to toxic conditions. Once a WLA has been developed, accounting for all appropriate considerations, a water quality-based permit limit may be derived to enforce the WLA. The method used to derive the permit limits must be consistent with the nature of the WLA.

The WLA addresses variability in effluent quality. For example, a WLA for human health pollutants is typically expressed as a single level of receiving water quality necessary to provide protection against long-term or chronic effects. On the other hand, a WLA for toxic pollutants affecting aquatic life (with corresponding duration and frequency requirements) should describe levels necessary to provide protection against both short-term and long-term effects.

5.3.1 Statistical Considerations of WLAs

Direct use of a WLA as a permit limit creates a significant risk that the WLA will be enforced incorrectly, since effluent variability and the probability basis for the limit are not considered specifically. For example, the use of a steady state WLA typically establishes a level of effluent quality with the assumption that it is a value never to be exceeded. The same value used directly as a permit limit could allow the WLA to be exceeded without observing permit violations if compliance monitoring was infrequent. Confusion can also result in translating a longer duration WLA requirement (e.g., for chronic protection) into maximum daily and average monthly permit limits. The permit writer must ensure that permit limits are derived to implement a WLA requirement correctly. Potential problem areas are as follows:

- The WLA must be enforced in a regulatory context by translating it into MDLs and AMLs; then and only then, will compliance monitoring associated with permit limits allow the regulatory authority to determine whether or not such permit limits are violated.
- The WLA that assumes that the discharge is steady state (i.e., not changing over time) requires a limit derivation assumption regarding how the effluent may vary.
- MDLs and AMLs average monthly limits must be developed so that they are consistent with each other and mandate the required level of wastewater treatment facility performance.
- If the acute WLA is used alone directly as the MDL, the limit will not necessarily be protective against chronic effects. If the acute WLA is used alone directly as the AML, the limit can allow excursions above the WLA within each month.
- If the chronic WLA is used alone as an MDL, the limit will be protective against acute and chronic effects but at the expense of being overly stringent. If the chronic WLA is used alone as the AML, the limit may be protective against acute and chronic effects depending upon effluent variability.

The objective is to establish permit limits that result in the effluent meeting the WLA under normal operating conditions virtually all the time. It is not possible to guarantee, through permit limits, that a WLA will never be exceeded. It is possible, however, using the recommended permit limit derivation procedures, to account for extreme values and to establish low probabilities of exceedence of the WLA in conformance with the duration and frequency requirements of the water quality standards. This is not to suggest that permit writers should assume a probability of exceedence of the WLA, but rather, that they should develop limits that will make an exceedance a very small likelihood.

Since effluents are variable and permit limits are developed based on a low probability of exceedence, the permit limits should consider effluent variability and ensure that the requisite loading from the WLA is not exceeded under normal conditions. In effect then, the limits must "force" treatment plant performance, which, after considering acceptable effluent variability, will only have a low statistical probability of exceeding the WLA and will achieve the desired loadings.

Figure 5-3 shows a number of important aspects of the relationships among the various statistical parameters. In this illustration, the most limiting LTA (after comparing the LTAs derived from both acute and chronic WLAs) has been chosen for the chronic limiting condition. The more restrictive LTA will automatically meet both WLA requirements. If the effluent "fingerprint" for this LTA (and associated CV) is projected, it can be seen that the distribution of daily effluent values will not exceed the acute or chronic wasteload allocations for unacceptable periods of time. The duration and frequency requirements of the acute and chronic criteria for the pollutant or pollutant parameter will not be exceeded. This figure also illustrates permit limits derived from the more limiting LTA. (Note that for the scenario depicted in Figure 5-3, the MDL is lower than the acute WLA and the average monthly limit is lower than the chronic WLA. This scenario will occur when a 99-percent probability basis is used to calculate the LTA and a 95-percent probability basis is used to calculate the permit limits from the lower of the acute and chronic LTA. For other probability assumptions, these relationships will differ.)

5.3.2 Types of Water Quality Models and Model Outputs

Each of the two major types of water quality models, steady-state and dynamic, and their WLA outputs have specific implications

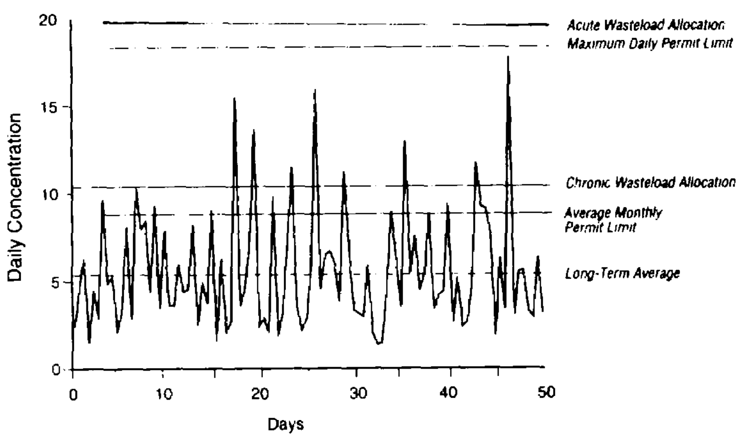

Figure 5-3. Relationship Between Daily Concnetrations, Long-Term Average, Wasteload Allocations, and Permit Limits

for the subsequent permit limit development process. These implications are discussed in detail below. **EPA recommends that steady-state WLA analyses generally be used by permitting authorities in most cases and especially where few or no whole effluent toxicity or specific chemical measurements are available, or where daily receiving water flow records are not available.** Two-value, steady-state models, although potentially more protective than necessary, can provide toxicologically protective results and are relatively simple to use. **If adequate receiving water flow and effluent concentration data are available to estimate frequency distributions, EPA recommends that one of the dynamic WLA modeling techniques be used to derive WLAs that will more exactly maintain water quality standards.**

Steady-State Modeling

Traditional single-value or two-value steady-state WLA models calculate WLAs at critical conditions, which are usually combinations of worst-case assumptions of flow, effluent, and environmental effects. For example, a steady-state model for ammonia considers the maximum effluent discharge to occur on the day of lowest river flow, highest upstream concentration, highest pH, and highest temperature. Each condition by itself has a low probability of occurrence; the combination of conditions may rarely or never occur. Permit limits derived from a steady-state WLA model will be protective of water quality standards at the critical conditions and for all environmental conditions less than critical. However, such permit limits may be more stringent than necessary to meet the return frequency requirements of the water quality criterion for the pollutant of concern.

On the other hand, a steady-state model approach may involve simplifying assumptions for other factors, such as ambient background concentrations of a toxicant, multiple source discharges of a toxicant, number of pollutants causing toxicity, incorrect effluent variability assumptions, and infrequent compliance monitoring. The effect of these types of factors, especially if unaccounted for in the WLA determination, can reduce the level of protectiveness provided by the critical condition assumptions of the steady-state model approach. Therefore, when using a steady-state WLA model, the permitting authority should be aware of the different assumptions and factors involved and should consider these assumptions and factors adequately consideration when developing permit limits.

In general, steady-state analyses tend to be more conservative than dynamic models because they rely on worst case assumptions. Thus, permit limits derived from these outputs will generally be lower than limits derived from dynamic models.

a) Single Value From a Steady-State Analysis

Some single-value, steady-state modeling has been used to calculate only chronic WLAs. These models produce a single effluent loading value and no information about effluent variability. Single value WLAs are typically based upon older State water quality standards that do not specify levels for both acute and chronic protection but only include one level of protection. Such outputs also would be found where a model is based upon protection of human health, since only a single long-term ambient value is of concern.

b) Two Values from Steady-State Analysis

Steady-state modeling for protection of aquatic life can specify two sets of calculations—one for protection against acute effects and one for protection against chronic effects. These models must use water quality criteria specifying two levels of protection. In addition, these models include considerations of mixing zones when developing WLAs to afford two levels of protection. Like the single-value, steady-state models, these models do not produce any information about acceptable effluent variability and may require additional calculations to be translated into permit limits.

For complex discharge situations (i.e., multiple dischargers or complex environmental factors needing consideration), water quality models and associated WLAs are typically developed by specialized water quality analysts in the regulatory authority. However, the permit writer is often required to develop a water quality model and WLA prior to permit limit derivation. In the latter situation, water quality modeling usually consists of simple steady-state dilution models using worst-case assumptions.

Dynamic Modeling

Dynamic models use estimates of effluent variability and the variability of receiving water assimilation factors to develop effluent requirements in terms of concentration and variability. The outputs from dynamic models can be used to base permit limits on probability estimates of receiving water concentrations rather than worst-case conditions. The advantages and disadvantages of various types of dynamic models are provided in Chapter 4.

In general, dynamic models account for the daily variations of and relationships between flow, effluent, and environmental conditions and therefore directly determine the actual probability that a water quality standards exceedence will occur. Because of this, dynamic models can be used to develop WLAs that maintain the water quality standards exactly at the return frequency requirements of the standards. Since this return frequency is usually one event in 3 years, WLAs developed by dynamic models are typically higher than those developed by steady-state models.

A targeted long-term average performance level and coefficient of variation can be derived from each type of dynamic model output, but some of the outputs require some additional manipulation of the data to develop the LTA and the CV. These parameters are also the starting point for the statistical permit limit derivation procedures discussed in the next section. **Continuous Simulation** models offer an array of effluent data that require further manipulation to develop an LTA and a CV. Both **Monte Carlo** and **Lognormal Probabilistic** models produce an LTA and CV, which can be used directly in developing permit limits. Chapter 4 details the different dynamic models. Specific instructions for the use of dynamic models are available in the references listed at the end of Chapter 4.

5.4 PERMIT LIMIT DERIVATION

There are a number of different approaches currently being used by permitting authorities to develop water quality-based limits for toxic pollutants and toxicity. Differences in approaches are often attributable to the need for consistency between permit limit derivation procedures and the assumptions inherent in various types of water quality models and WLA outputs. In addition, permitting authorities also are constrained by legal requirements and policy decisions that may apply to a given permitting situation. In some instances, however, permitting procedures have been adopted without careful consideration of the toxicological principles involved or the advantages and disadvantages of the procedure.

To avoid this problem, EPA recommends that the statistical permit limit derivation procedure described in this chapter be used for the derivation of both chemical-specific and whole effluent toxicity limits for NPDES permits. The type of WLA chosen from which to derive the limits is a matter of case-by-case application, as determined by the permitting authority. Although there are advantages and disadvantages associated with each of the procedures, EPA believes that the statistical derivation procedures will result in the most defensible and protective water quality-based permit limits for both specific chemicals and whole effluent toxicity.

The following section explains EPA's recommended permitting procedures and highlights advantages and disadvantages of various other approaches. With this information, permitting authorities will be better informed when deciding on the most appropriate permit limit derivation approach. For example, permitting authorities may decide to derive water quality-based permit limits for all dischargers using a steady-state WLA model as a baseline limit determination. If time and resources are available or if the discharger itself takes the initiative (after approval by the regulatory authority), dynamic modeling could be conducted to further refine the WLA from which final permit limits would be derived. Box 5-1 presents example permit limit calculations for each of the principal types of WLA outputs discussed in Section 5.4.1. Permit limits derived from dynamic modeling are usually higher than those based upon steady-state modeling. The difference is reflected in Box 5-1 and has been observed in actual applications [1, 2, 3]. In addition, the case studies in Chapter 7 illustrate how water quality-based permit limits are derived and compare the results of limits derived from steady state and dynamic wasteload allocations.

5.4.1 *EPA Recommendations for Permitting for Aquatic Life Protection*

Permit Limit Derivation from Two-Value, Steady-State Outputs for Acute and Chronic Protection

A number of WLAs have two results: acute and chronic requirements. These types of allocations will be developed more often as States begin to adopt water quality standards that provide both acute and chronic protection for aquatic life. These WLA outputs need to be translated into MDLs and AMLs. The following methodology is designed to derive permit limits for specific chemicals as well as whole effluent toxicity to achieve these WLAs.

- A treatment performance level (LTA and CV) that will allow the effluent to meet the WLA requirement is calculated.

EXHIBIT 12

Box 5-1. Sample Calculations of Permit Limits for Whole Effluent Toxicity from Different Wasteload Allocation Data

Available Data	Two Value wasteload allocation	Dynamic model output	Single wasteload allocation
Wasteload Allocation (WLA)	----	----	14.3
Acute Wasteload Allocation (WLAa)	2.60	----	----
Chronic Wasteload Allocation (WLAc)	14.3	----	----
Acute-Chronic Ratio	4.62	----	----
Coefficient of Variation (CV)	0.8	0.8	0.8
Number of Samples per Month (n)	4	4	4
Long Term Average (LTA)	----	9.44	----

From two-value steady state wasteload allocation

$WLA_{a,c} = WLA_a \bullet ACR$ = 2.60•4.62 = 12.0

$LTA_c = WLA_c \bullet e\,[0.5\sigma_4^2 - 2.326\sigma_4]$ = 14.3•0.440 (from Table 5-1) = 6.29

$LTA_{a,c}$ = $WLA_{a,c} \bullet e\,[0.5\sigma^2 - 2.326\sigma]$ = 12.0•0.249 (from Table 5-1) = 2.99

$MDL = LTA_{a,c} \bullet e\,[2.326\sigma - 0.5\sigma^2]$ = 2.99•4.01 (from Table 5-2) = 12.0

$AML = LTA_{a,c} \bullet e\,[2.326\sigma_n - 0.5\sigma_n^2]$ = 2.99•2.27 (from Table 5-2) = 6.79

From dynamic model output

$MDL = LTA_c \bullet e\,[2.326\sigma - 0.5\sigma^2]$ = 9.44•4.01 (from Table 5-2) = 37.9

$AML = LTA_c \bullet e\,[2.326\sigma_n - 0.5\sigma_n^2]$ = 9.44•2.27 (from Table 5-2) = 21.4

From single wasteload allocation

Option 1

$LTA = WLA \bullet e\,[0.5\sigma^2 - 2.326\sigma]$ = 14.3•0.440 (from Table 5-1) = 6.29

$MDL = LTA \bullet e\,[2.326\sigma - 0.5\sigma^2]$ = 6.29•4.01 (from Table 5-2) = 25.2

$AML = LTA \bullet e\,[2.326\sigma_n - 0.5\sigma_n^2]$ = 6.29•2.27 (from Table 5-2) = 14.3

Option 2

MDL = WLA = 14.3

AML = MDL/2 = 7.15

Note: All calculations use the 99th percentile z statistic for calculation of long-term averages and permit limits.

Where two requirements are specified based on different duration periods, two performance levels are calculated (Box 5-2, Step 2).

- For whole effluent toxicity only, the acute WLA is converted into an equivalent chronic WLA by multiplying the acute WLA by an acute-to-chronic ratio (ACR). This ratio should optimally be based on effluent data, but also can be estimated as 10, based on the information presented in Chapter 1 and Appendix A.
- Permit limits are then derived directly from whichever performance level is more protective (Box 5-2, Steps 3 and 4).

Figure 5-4 presents a flow chart summarizing the various steps in this procedure. In addition, the equations used in Box 5-2 are based on the lognormal distribution, which is explained in more detail in Appendix E. The principal advantages of this procedure are described below.

- This procedure provides a mechanism for setting permit limits that will be toxicologically protective. A steady-state WLA uses a single value to reflect the effluent loading and thus is an inherent assumption that the actual effluent will not exceed the calculated loading value. If the WLA is simply adopted as the permit limit, the possibility exists for exceedance of the WLA due to effluent variability. Clearly, however, effluents are variable. Therefore, permit limits are established using a value corresponding to a percentile of the selected probability distribution of the effluent (e.g., 95th or 99th percentile).
- It allows comparison of two independent WLAs (acute and chronic) to determine which is more limiting for a discharge. The WLA output provides two numbers for protection against two types of toxic effects, each based upon different mixing conditions for different durations. Acute effects are limited based upon 1-hour exposures at critical conditions, close to the point of discharge, or where necessary, at the end of the pipe. Chronic effects are limited based on 4-day exposures after mixing at critical conditions. These requirements yield different effluent treatment requirements that cannot be compared to each other without calculating the LTA performance level the plant would need to maintain in order to meet each requirement. Without this comparison (or in the absence of procedures that address this comparison), the WLA representing the more critical condition cannot be determined. A treatment system will only need to be designed to meet one level of

Box 5-2. Calculating Permit Limits Based on Two-Value Wasteload Allocation

To set maximum daily and average monthly permit limits based on acute and chronic wasteload allocations, use the following four steps:

1	Convert the acute wasteload allocation to chronic toxic units. Skip to Step 2 for chemical-specific limits.
2	Calculate the long-term average wasteload that will satisfy the acute and chronic wasteload allocations.
3	Determine the lower (more limiting) of the two long-term averages.
4	Calculate the maximum daily and average monthly permit limits using the lower (more limiting) long-term average.

Term	Meaning
CV	Coefficient of variation
σ	Standard deviation
$WLA_{a,c}$	Acute wasteload allocation in chronic toxic units
WLA_a	Acute wasteload allocation in acute toxic units
WLA_c	Chronic wasteload allocation in chronic toxic units
LTA_{ac}	Acute long-term average wasteload in chronic units
LTA_c	Chronic long-term average wasteload
TU_a	Acute toxic units
TU_c	Chronic toxic units
ACR	Acute-to-chronic ratio
MDL	Maximum daily limit
AML	Average monthly limit
z	z statistic

Step 1 *(for whole effluent toxicity only)*

$$WLA_{ac}\ (in\ TU_c) = WLA_a\ (in\ TU_a) \bullet ACR$$

Step 2 *(start here for chemical specific limits)*

$$LTA_{a,c} = WLA_{a,c} \bullet e^{[0.5\sigma^2 - z\sigma]}$$

where $\sigma^2 = \ln(CV^2+1)$
$z = 1.645$ for 95th percentile probability basis, and
$z = 2.326$ for 99th percentile probability basis

$$LTA_c = WLA_c \bullet e^{[0.5\sigma_4^2 - z\sigma_4]}$$

where $\sigma_4^2 = \ln(CV^2/4 + 1)$
$z = 1.645$ for 95th percentile probability basis, and
$z = 2.326$ for 99th percentile probability basis

Step 3

$$LTA = \min(LTA_c, LTA_{a,c})$$

Step 4

$$MDL = LTA \bullet e^{[z\sigma - 0.5\sigma^2]}$$

where $\sigma^2 = \ln(CV^2+1)$
$z = 1.645$ for 95th percentile probability basis, and
$z = 2.326$ for 99th percentile probability basis

$$AML = LTA \bullet e^{[z\sigma_n - 0.5\sigma_n^2]}$$

where $\sigma_n^2 = \ln(CV^2/n + 1)$
$z = 1.645$ for 95th percentile probability basis, and
$z = 2.326$ for 99th percentile probability basis

*Full details of this procedure are found in Appendix E.

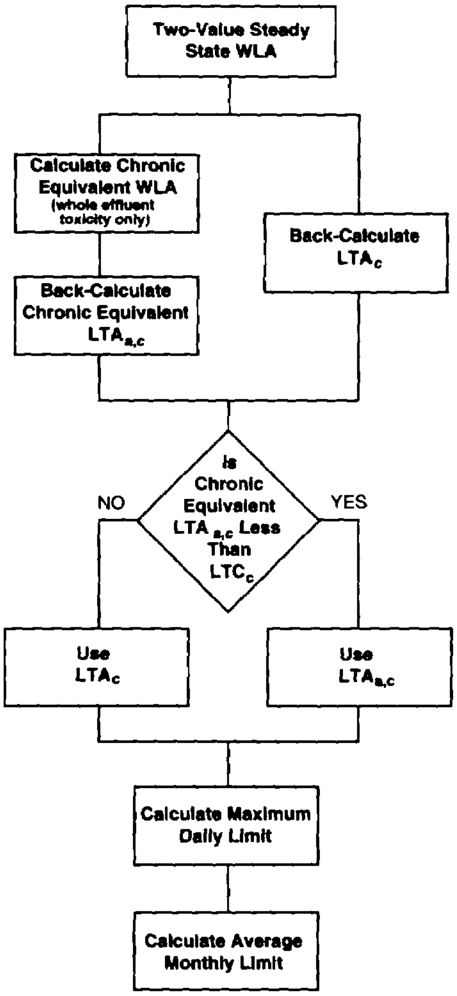

Figure 5-4. Flowchart for Calculating Permit Limits From Two-Value, Steady-State Wasteload Allocation for Aquatic Life Protection

treatment for effluent toxicity—treatment needed to control the most limiting toxic effect.

- The actual number of samples can be factored into permit limit derivation procedures. The procedure provides the means to accurately determine the AML based on the number of observations that will be taken.

The principal disadvantages of this approach are:

- Some permit writers have indicated that additional mathematical calculations associated with these procedures increase the burden for the permit writer and add what is perceived to be an unnecessary step.
- The use of a steady-state WLA may result in permit limits that are more conservative due to the assumption of critical conditions. However, these limits are still protective of water quality criteria. The level of conservatism may be necessary in those instances where limited data prevent a more precise evaluation of a WLA.

This procedure provides a toxicologically sound approach. To help the permit writer, EPA has developed tables (see Tables 5-1 and 5-2) to be used to quickly determine the necessary values. In addition, some permit authorities have developed their own computer programs to readily compute the necessary information from the appropriate inputs.

Permit Limit Derivation From Dynamic Model Outputs

The least ambiguous and most exact way that a WLA for specific chemicals or for whole effluent toxicity can be specified by using dynamic modeling from which the WLA is expressed as a required effluent performance in terms of the LTA and CV of the daily values. When a WLA is expressed as such, there is no confusion about assumptions used and the translation to permit limits. A permit writer can readily design permit limits to achieve the WLA objectives. The types of dynamic exposure analyses that yield a WLA in terms of required performance are the continuous simulation, Monte Carlo, and lognormal probabilities analyses. Chapter 4 provides a general discussion of these models. Guidance manuals for developing WLAs are listed in the references at the end of Chapter 4. Once the WLA is determined, the permit limit derivation procedure which can be used for both whole effluent toxicity and specific chemicals, is as follows:

- The WLA is first developed by iteratively running the dynamic model with successively lower LTAs until the model shows compliance with the water quality standards.
- The effluent LTA and CV must then be calculated from the model effluent inputs used to show compliance with the water quality standards. This step is only necessary for the Monte Carlo and continuous simulation methods.
- The permit limit derivation procedures described in Box 5-2, Step 4 are used to derive MDLs and AMLs from the required effluent LTA and CV. Unlike these procedures for steady-state WLAs, there is only a single LTA that provides both acute and chronic protection, and, therefore, the comparison step indicated in Figure 5-4 and Box 5-2 is unnecessary.

The principal advantages of this procedure are:

- It provides a mechanism for computing permit limits that are toxicologically protective. As with the procedure summarized below for two-value, steady-state WLA outputs, the permit limit derivation procedures used with this type of output consider effluent variability and derive permit limits from a single limiting LTA and CV.
- Actual number of samples is factored into permit limit derivation procedures. This procedure has the same elements as discussed for the statistical procedures in Option 2 below.
- Dynamic modeling determines an LTA that will be adequately protective of the WLA, which relies on actual flow data thereby reducing the need to rely on worst case critical flow condition assumptions.

Table 5-1. Back Calculations of Long-Term Average

Acute

CV	WLA Multipliers $e^{[0.5\sigma^2 - z\sigma]}$ 95th Percentile	99th Percentile
0.1	0.853	0.797
0.2	0.736	0.643
0.3	0.644	0.527
0.4	0.571	0.440
0.5	0.514	0.373
0.6	0.468	0.321
0.7	0.432	0.281
0.8	0.403	0.249
0.9	0.379	0.224
1.0	0.360	0.204
1.1	0.344	0.187
1.2	0.330	0.174
1.3	0.319	0.162
1.4	0.310	0.153
1.5	0.302	0.144
1.6	0.296	0.137
1.7	0.290	0.131
1.8	0.285	0.126
1.9	0.281	0.121
2.0	0.277	0.117

$$LTA_{a,c} = WLA_{a,c} \cdot e^{[0.5\sigma^2 - z\sigma]}$$

where $\sigma^2 = ln[CV^2 + 1]$,
$z = 1.645$ for 95th percentile occurrence probability, and
$z = 2.326$ for 99th percentile occurrence probability

Chronic
(4-day average)

$$LTA_c = WLA_c \cdot e^{[0.5\sigma_4^2 - z\sigma_4]}$$

where $\sigma_4^2 = ln[CV^2/4 + 1]$,
$z = 1.645$ for 95th percentile occurrence probability, and
$z = 2.326$ for 99th percentile occurrence probability

CV	WLA Multipliers $e^{[0.5\sigma_4^2 - z\sigma_4]}$ 95th Percentile	99th Percentile
0.1	0.922	0.891
0.2	0.853	0.797
0.3	0.791	0.715
0.4	0.736	0.643
0.5	0.687	0.581
0.6	0.644	0.527
0.7	0.606	0.481
0.8	0.571	0.440
0.9	0.541	0.404
1.0	0.514	0.373
1.1	0.490	0.345
1.2	0.468	0.321
1.3	0.449	0.300
1.4	0.432	0.281
1.5	0.417	0.264
1.6	0.403	0.249
1.7	0.390	0.236
1.8	0.379	0.224
1.9	0.369	0.214
2.0	0.360	0.204

The principal disadvantages of this procedure are:

- Necessary data for effluent variability and receiving water flows may be unavailable, which prevents the use of this approach.
- The amount of staff resources needed to explain how the limits were developed and to conduct the WLA also is a concern. The permit documentation (i.e., fact sheet) will need to clearly explain the basis for the LTA and CV and this can be resource intensive.

Permit Limit Derivation From Single, Steady-State Model Output

Some State water quality criteria and the corresponding WLAs are reported as a single value from which to define an acceptable level of effluent quality. For example, "copper concentration must not exceed 0.75 milligrams per liter (mg/l) instream." Steady-state analyses assume that the effluent is constant and, therefore, the WLA value will never be exceeded. This presents a problem in deriving permit limits because permit limits need to consider effluent variability.

Table 5-2. Calculation of Permit Limits

CV	LTA multipliers $e^{[z\sigma - 0.5\sigma^2]}$ 95th Percentile	LTA multipliers $e^{[z\sigma - 0.5\sigma^2]}$ 99th Percentile
0.1	1.17	1.25
0.2	1.36	1.55
0.3	1.55	1.90
0.4	1.75	2.27
0.5	1.95	2.68
0.6	2.13	3.11
0.7	2.31	3.56
0.8	2.48	4.01
0.9	2.64	4.46
1.0	2.78	4.90
1.1	2.91	5.34
1.2	3.03	5.76
1.3	3.13	6.17
1.4	3.23	6.56
1.5	3.31	6.93
1.6	3.38	7.29
1.7	3.45	7.63
1.8	3.51	7.95
1.9	3.56	8.26
2.0	3.60	8.55

Maximum Daily Limit

$$MDL = LTA \bullet e^{[z\sigma - 0.5\sigma^2]}$$

where $\sigma^2 = ln[CV^2 + 1]$,
$z = 1.645$ for 95th percentile occurrence probability, and
$z = 2.326$ for 99th percentile occurrence probability

Average Monthly Limit

$$AML = LTA \bullet e^{[z\sigma_n - 0.5\sigma_n^2]}$$

where $\sigma_n^2 = ln[CV^2/n + 1]$,
$z = 1.645$ for 95th percentile,
$z = 2.326$ for 99th percentile, and
n = number of samples/month

CV	LTA Multipliers $e^{[z\sigma_n - 0.5\sigma_n^2]}$ 95th Percentile n=1	n=2	n=4	n=10	n=30	99th Percentile n=1	n=2	n=4	n=10	n=30
0.1	1.17	1.12	1.08	1.06	1.03	1.25	1.18	1.12	1.08	1.04
0.2	1.36	1.25	1.17	1.12	1.06	1.55	1.37	1.25	1.16	1.09
0.3	1.55	1.38	1.26	1.18	1.09	1.90	1.59	1.40	1.24	1.13
0.4	1.75	1.52	1.36	1.25	1.12	2.27	1.83	1.55	1.33	1.18
0.5	1.95	1.66	1.45	1.31	1.16	2.68	2.09	1.72	1.42	1.23
0.6	2.13	1.80	1.55	1.38	1.19	3.11	2.37	1.90	1.52	1.28
0.7	2.31	1.94	1.65	1.45	1.22	3.56	2.66	2.08	1.62	1.33
0.8	2.48	2.07	1.75	1.52	1.26	4.01	2.96	2.27	1.73	1.39
0.9	2.64	2.20	1.85	1.59	1.29	4.46	3.28	2.48	1.84	1.44
1.0	2.78	2.33	1.95	1.66	1.33	4.90	3.59	2.68	1.96	1.50
1.1	2.91	2.45	2.04	1.73	1.36	5.34	3.91	2.90	2.07	1.56
1.2	3.03	2.56	2.13	1.80	1.39	5.76	4.23	3.11	2.19	1.62
1.3	3.13	2.67	2.23	1.87	1.43	6.17	4.55	3.34	2.32	1.68
1.4	3.23	2.77	2.31	1.94	1.47	6.56	4.86	3.56	2.45	1.74
1.5	3.31	2.86	2.40	2.00	1.50	6.93	5.17	3.78	2.58	1.80
1.6	3.38	2.95	2.48	2.07	1.54	7.29	5.47	4.01	2.71	1.87
1.7	3.45	3.03	2.56	2.14	1.57	7.63	5.77	4.23	2.84	1.93
1.8	3.51	3.10	2.64	2.20	1.61	7.95	6.06	4.46	2.98	2.00
1.9	3.56	3.17	2.71	2.27	1.64	8.26	6.34	4.68	3.12	2.07
2.0	3.60	3.23	2.78	2.33	1.68	8.55	6.61	4.90	3.26	2.14

The proper enforcement of this type of WLA depends on the parameter limited. For nutrients and biochemical oxygen demand (BOD), the WLA value generally has been used as the average daily permit limit. However, the impact associated with toxic pollutants is more time dependent, as reflected in the 4-day average duration for the criteria continuous concentration (CCC) (see Chapter 2). Where there is only one water quality criterion and therefore only one WLA, permit limits can be developed using the following procedure:

- Consider the single WLA to be the chronic WLA and derive an chronic LTA for this WLA using the procedures in Box 5-2 (Step 2, Part 2).
- Derive MDLs and AMLs using the procedures in Box 5-2 (Step 4).

The principal advantages and disadvantages of this procedure are similar to those for the two-value permit limit derivation method discussed previously except that it does not examine two WLAs.

5.4.2 Other Approaches to Permitting for Aquatic Life

Other approaches for translating WLA outputs into permit limits have been used by some permitting authorities. These methods may combine elements of the statistical procedures discussed earlier with specific technical and policy requirements of the permitting authority to derive limits that may be protective of water quality and consistent with the requirements of the WLA. Such approaches may use simplified statistical procedures.

For example, some permitting authorities assume a value for the CV and an acute to chronic ratio above which the chronic WLA will always be more limiting. Where such simplifying assumptions are used, the need to compare LTAs derived from acute and chronic steady-state models is unnecessary. Similarly, for assumed values for n, CV, and exceedence probability, the various equations shown in Box 5-2 can be simplified further, such that the AML will always be a constant fraction of the MDL.

These approaches allow the permit writer to rapidly and easily translate the results of WLAs into permit limits. However, the permit writer clearly should understand the underlying procedures and carefully explain the basis for the chosen assumption. Appropriate State or regional guidance documents also should be referenced.

Another approach used by some permit authorities involves the direct use of the WLA as a permit limit. This approach sometimes involves the following steps:

- The WLA value for toxic pollutants is used as the MDL.
- In the absence of other information, permit writers typically divide the MDL by 1.5 or 2.0 to derive an AML (depending on the expected range of variability).

The principal advantage of this approach is that it is very straightforward to implement and requires minimal resources. The disadvantage of this option is that the average monthly limits must be derived without any information about the variability of the effluent parameter; therefore, the permit writer cannot be sure that these procedures are protective of water quality criteria. Conversely, limits derived from this approach may be overly stringent and subject to challenge.

The direct application of both the acute and chronic WLAs as permit limits is another approach that has been used. The WLA developed for protection against chronic effects becomes the average monthly limit and the acute WLA becomes the MDL. **EPA discourages the use of this approach.** Since effluent variability has not been specifically addressed with this approach, compliance with the monthly average (30-day) effluent limit during critical conditions could exceed the chronic (4-day) WLA. Whether standards are violated with excessive frequency under such conditions would depend upon whether the conditions represented by the worst-case assumptions of the model also were occurring at the same time. By contrast, compliance with limits that were developed using statistical procedures have a low chance of leading to WLA excursions before effluent variability is accounted for in deriving the limits (see Figure 5-3).

Another permitting approach is to use a narrative "no toxicity" limit that is measured using a toxicity testing method that employs only a control and a single exposure at the receiving water concentration (RWC). This is sometimes referred to as a "pass/fail" toxicity test. Although these tests can be less expensive than full dilution series testing, they provide no knowledge as to the extent of toxicity present during the test and therefore no data concerning the seriousness of the impact or the amount of toxicity reduction necessary. The death of a single test animal can occur at any concentration level beyond the lethality threshold for the test organism; therefore, such a test is much less powerful from a statistical standpoint. In addition, it is not possible to determine dose-response relationships for the test organisms without using multiple effluent concentrations. Dose-response curves are useful in determining quality assurance of the tests and in defining threshold dosages for regulatory purposes. Because the drawbacks of the approach generally outweigh the benefits, **EPA recommends that whole effluent toxicity limits be established using a statistical derivation procedure that adequately accounts for effluent variability and that monitoring for compliance with whole effluent toxicity limits be conducted using a full dilution series.**

When setting a whole effluent toxicity limit to protect against acute effects, some permitting authorities use an end-of-pipe approach. Typically, these limits are established as an LC_{50}>100-percent effluent at the end of the pipe. These limits are routinely set without any consideration as to the fate of the effluent and the concentrations of toxicant(s) after the discharge enters the receiving water. Limits derived in this way are not water quality-based limits and suffer from significant deficiencies since the toxicity of a pollutant depends mostly upon concentration, duration of exposure, and repetitiveness of the exposure. This is especially true in effluent dominated waters. For example, an effluent that has an LC_{50}=100 percent contains enough toxicity to be lethal to up to 50 percent of the test organisms. If the effluent is discharged to a low-flow receiving waterbody that provides no more than a three-fold dilution at the critical flow, significant mortality can occur in the receiving water. Furthermore, such a limit could not assure protection against chronic effects in the receiving waterbody. Chronic effects could occur if the dilution in the receiving water multiplied by the acute to chronic ratio is greater than 100 percent. Therefore, in effluent dominated situations, limits set using this approach may be severely underprotective. In contrast, whole effluent toxicity limits set using this approach in very high receiving water flow conditions may be overly restrictive. **Because of these problems, EPA recommends that all whole effluent toxicity limits be set as water quality-based limits and that to do so, the statistical permit limit derivation procedures discussed in Section 5.4.1 be followed.**

5.4.3 Special Permitting Requirements

Water quality-based permit limit development for discharges to marine and estuarine waters follows the same basic steps as the water quality-based approach for freshwater discharges. There are some differences in the water quality criteria used as the basis for protection, the designation of mixing zones, and the water quality models used to develop WLAs; however these differences are addressed in the WLA. (See discussions of these elements in previous chapters.) In addition, there are some special regulatory considerations associated with these types of dischargers, including special reviews of permits with such programs as the Coastal Zone Management Program. Some discharges also require an Ocean Discharge Criteria Evaluation under Section 403(c) of the Clean Water Act (CWA).

5.4.4 EPA Recommendations for Permitting for Human Health Protection

Permit development to protect against certain routes of exposure is another key consideration. Ingesting contaminated fish and shellfish is a toxic chemical exposure route of serious potential human health concern for which there is no intervening treatment process, unlike the drinking water route of exposure. Effluent limits designed to meet aquatic life criteria for individual toxicants and whole effluent toxicity are not necessarily protective of toxic pollutant residue formation in fish or shellfish tissue.

Developing permit limits for pollutants affecting human health is somewhat different from setting limits for other pollutants because the exposure period is generally longer than 1 month, and can be up to 70 years, and the average exposure rather than the maximum exposure is usually of concern. Because compliance with permit limits is normally determined on a daily or monthly basis, it is necessary to set human health permit limits that meet a given WLA for every month. If the procedures described previously for aquatic life protection were used for developing permit limits for human health pollutants, both MDLs and AMLs would exceed the WLA necessary to meet criteria concentrations. Thus, even if a facility was discharging in compliance with permit limits calculated using these procedures, it would be possible to constantly exceed the WLA. This approach clearly is unacceptable. In addition, the statistical derivation procedure is not applicable to exposure periods more than 30 days. Therefore, the recommended approach for setting water quality-based limits for human health protection with statistical procedures is as follows:

- Set the AML equal to the WLA
- Calculate the MDL based on effluent variability and the number of samples per month using the multipliers provided in Table 5-3.

This approach ensures that the instream criteria will be met over the long-term and provides a defensible method for calculating a MDL. Both an MDL (weekly average limit for POTWs) and a monthly average limit are required by EPA regulations, unless impracticable (40 *CFR* 122.45(d)) and are applicable for human health protection. The MDL sets an upper bound on effluent values used to determine the monthly average and provides a measure of effluent compliance during operational periods between monthly sampling.

5.5 SPECIAL CONSIDERATIONS IN USE OF STATISTICAL PERMIT LIMIT DERIVATION TECHNIQUES

The following discussion summarizes the effect of changes in the various statistical parameters on the permit limits that are derived. An understanding of these relationships is important for the permit writer. Additional considerations of each of these parameters with respect to the statistical methods for permit limit derivation also are discussed below.

5.5.1 Effect of Changes of Statistical Parameters on Permit Limits

- **Effect of changes in CV on derivation of LTA from WLA:** As the CV increases, the LTA decreases; and conversely, as the CV decreases, the LTA increases (see Figure 5-5).

  Reason: The LTA must be lower relative to the WLA to account for the extreme values observed with high CVs. An LTA with a zero CV equals the WLA.

- **Effect of changes in CV on derivation of permit limits for a fixed probability basis:** As the CV increases, the permit limits increase (become less stringent); and conversely, as the CV decreases, the permit limits decrease (become more stringent; see Figure 5-6).

  Reason: A higher value for the permit limit is produced for the same LTAs as the CV increases in order to allow for fluctuations about the mean. Following the steps in Box 5-2 to derive the LTA will account for such fluctuations.

- **Effect of changes in number of monthly samples on permit limits:** As the value for "n" (number of observations) increases in the average monthly permit limit derivation equations, the average monthly permit limit decreases to a certain point. The effect on the average monthly limit is minimal for values of n greater than approximately 10. Conversely, as the value for "n" decreases, the AML increases until n=1, at which point the AML equals the MDL (see Figure 5-7).

  Reason: As n increases, the probability distribution of the n-day average values becomes less variable (narrower) around the LTA. Therefore, the 95th or 99th percentile value for an n-day average decreases in absolute value as n increases. (See additional discussion in Section 5.5.3.)

- Effect **of changes in probability basis for permit limits:** As the probability basis for the permit limits expressed in percentiles (e.g., 95 percent and 99 percent) increases, the value for the permit limits increases (becomes less stringent). The converse is true as the probability basis decreases (see Figure 5-6).

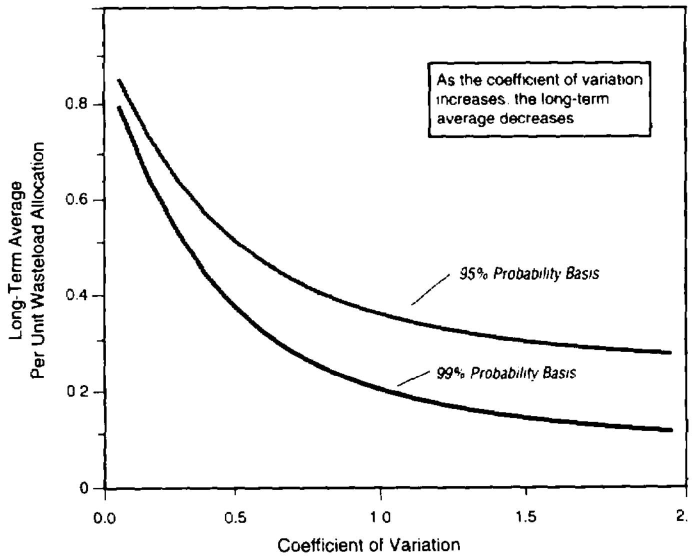

Figure 5-5. Long-Term Average as a Function of the Coefficient of Variation

Reason: There is a higher probability that any randomly chosen effluent sample will be in compliance with its permit limits, if those limits are statistically designed to be greater than a high percentage (e.g., 99 percent) of all possible values for a given LTA and CV.

The overall combination of the coefficient of variation, number of samples, and the assumed probability basis for calculating the LTA from the WLA, and the most limiting LTA, has different effects on the derived limits depending upon the selection made for each. To help illustrate the combined effect of these factors, Figure 5-8 illustrates how the CV, number of samples and probability basis affect the derivation of the AML. Figure 5-9 illustrates the combined effect of the CV and the probability basis on the derivation of the MDL.

5.5.2 Coefficient of Variation

Use of the statistical method of permit limit derivation requires an estimate of the CV of the distribution of the daily measurements of the parameter after the plant complies with the requirements.

Table 5-3. Multipliers for Calculating Maximum Daily Permit Limits From Average Monthly Permit Limits

To obtain the maximum daily permit limit (MDL) for a bioconcentratable pollutant, multiply the average monthly permit limit (AML) (the wasteload allocation) by the appropriate value in the following table.

Each value in the table is the ratio of the MDL to the AML as calculated by the following relationship derived from Step 4 of the statistically based permit limit calculation procedure.

$$\frac{MDL}{AML} = \frac{\exp\,[z_m\sigma - 0.5\sigma^2]}{\exp\,[z_a\sigma_n - 0.5\sigma_n^2]}$$

where

$\sigma_n^2 = \ln\,(CV^2/n + 1)$
$\sigma^2 = \ln\,(CV^2 + 1)$
CV = the coefficient of variation of the effluent concentration
n = the number of samples per month
z_m = the percentile exceedance probability for the MDL
z_a = the percentile exceedance probability for the AML.

Ratio Between Maximum Daily and Average Monthly Permit Limits

	Maximum = 99th percentile Average = 95th percentile					Maximum = 99th percentile Average = 99th percentile				
CV	n=1	n=2	n=4	n=8	n=30	n=1	n=2	n=4	n=8	n=30
0.1	1.07	1.13	1.16	1.18	1.22	1.00	1.07	1.12	1.16	1.20
0.2	1.14	1.25	1.33	1.39	1.46	1.00	1.13	1.24	1.32	1.43
0.3	1.22	1.37	1.50	1.60	1.74	1.00	1.19	1.36	1.49	1.67
0.4	1.30	1.50	1.67	1.82	2.02	1.00	1.24	1.46	1.66	1.92
0.5	1.38	1.622	1.84	2.04	2.32	1.00	1.28	1.56	1.81	2.18
0.6	1.46	1.73	2.01	2.25	2.62	1.00	1.31	1.64	1.95	2.43
0.7	1.54	1.84	2.16	2.45	2.91	1.00	1.34	1.71	2.08	2.67
0.8	1.61	1.94	2.29	2.64	3.19	1.00	1.35	1.76	2.19	2.89
0.9	1.69	2.03	2.41	2.81	3.45	1.00	1.36	1.80	2.27	3.09
1.0	1.76	2.11	2.52	2.96	3.70	1.00	1.37	1.83	2.34	3.27
1.1	1.83	2.18	2.62	3.09	3.93	1.00	1.37	1.84	2.39	3.43
1.2	1.90	2.25	2.70	3.20	4.13	1.00	1.36	1.85	2.43	3.56
1.3	1.97	2.31	2.77	3.30	4.31	1.00	1.36	1.85	2.45	3.68
1.4	2.03	2.37	2.83	3.39	4.47	1.00	1.35	1.84	2.46	3.77
1.5	2.09	2.42	2.89	3.46	4.62	1.00	1.34	1.83	2.46	3.84
1.6	2.15	2.42	2.89	3.46	4.62	1.00	1.33	1.82	2.46	3.90
1.7	2.21	2.52	2.98	3.57	4.85	1.00	1.32	1.80	2.45	3.94
1.8	2.27	2.56	3.01	3.61	4.94	1.00	1.31	1.78	2.43	3.97
1.9	2.32	2.60	3.05	3.65	5.02	1.00	1.30	1.76	2.41	3.99
2.0	2.37	2.64	3.07	3.67	5.09	1.00	1.29	1.74	2.38	4.00

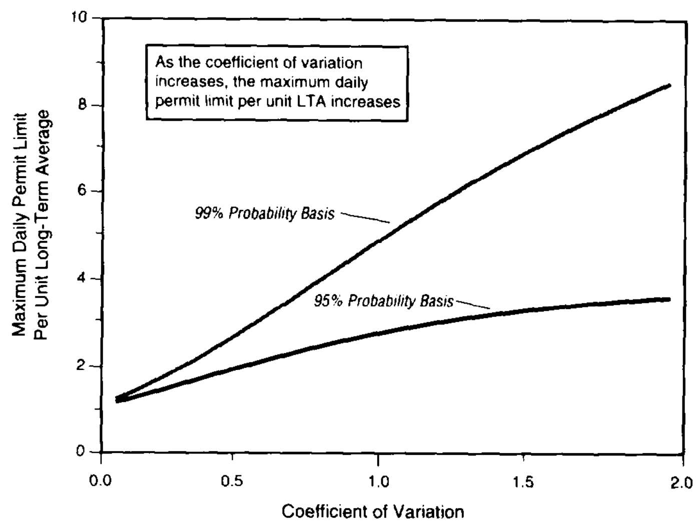

Figure 5-6. Maximum Daily Permit Limit as a Function of the Coefficient of Variation

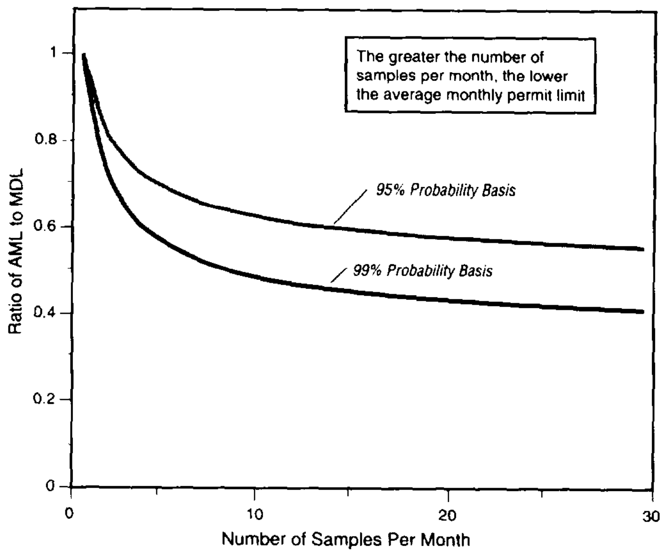

Figure 5-7. Relationship Between Average Monthly Permit Limits and Number of Samples Per Month

If variability is mostly related to production, current data may be used to estimate the CV. If future variability is expected to be substantially different, the CV must be estimated. Discharges of toxic pollutants are generally more variable than discharges of conventional pollutants. It is important to use the best estimate of the CV that can be reasonably achieved. As explained in Chapter 3, EPA's review of the uncertainty associated with effluent variability suggests that a minimum of 10 samples is needed to reasonably quantify the CV.

One concern with respect to using an appropriate CV in the statistical limit derivation procedures is that CVs of regulated systems may be quite different from nonregulated systems. In other words, after permit limits are in place and the permittee is operating to achieve the requisite limits, the variability associated with the parameter of concern may change considerably. Where the permit writer has reason to believe that the CV of the regulated system may behave differently from the nonregulated system (e.g., where changes in the treatment facility are planned), information concerning effluent concentration means and variability can be obtained from effluent guideline documents for individual chemical parameters.

Variability associated with effluent levels of both individual chemicals and whole effluent toxicity is difficult to predict for any individual situation. However, it is important to recognize that failure to assign any CV to an individual toxicant or the parameter toxicity involves an implicit assumption that there is no effluent variability present. Based upon analyses of a wide variety of data from various types of plants, **EPA recommends a value of 0.6 as a default CV, if the regulatory authority does not have more accurate information on the CV for the pollutant or pollutant parameter.** Permit limits are usually not extremely sensitive to small changes in the CV. The value of 0.6 is typical of the range of variability of effluents measured by EPA (see Appendix A) and represents a reasonable degree of relative variability. However, wherever possible, it is recommended that data on effluent variability for the pollutant of concern be collected to define a CV rather than selecting a default value.

5.5.3 Number of Samples

The statistically based method for permit limit derivation results in an MDL that does not depend on monitoring frequency. However, the AML decreases as the monitoring frequency increases, and a greater number for "n" is inserted in the relevant equations. Some permit writers are concerned with this outcome because facilities with more frequent sampling requirements appear to receive more stringent permit limits than those with less frequent monthly sampling requirements.

The AML decreases as the number of monthly samples increases because an average of 10 samples, for example, is closer to the LTA than an average based on 4 samples. This phenomenon makes AMLs based on 10 samples appear to be more stringent than the monthly limit based on 4 samples. However, the stringency of these procedures is constant across monitoring frequencies because the probability basis and the targeted LTA performance are the same regardless of the number of samples taken. Thus, a permittee performing according to the LTA and variability associated with the wasteload allocation will, in fact, meet either of these AMLs when taking the corresponding number of monthly samples.

For water quality-based permitting, effluent quality is determined by the underlying distribution of daily values, which is determined by the LTA associated with a particular WLA and by the CV of the effluent concentrations. Increasing or decreasing monitoring frequency does not affect this underlying distribution or treatment performance, which should, at a minimum, be targeted to comply with the values dictated by the WLA. **Therefore, it is recommended that the actual planned frequency of monitoring normally be used to determine the value of n for calculating the AML. However, in situations where monitoring frequency is once per month or less, a higher value for n must be assumed for AML derivation purposes.** This is particularly applicable for addressing situations such as where a single criterion is applied at the end of the pipe and a single monthly sample

EXHIBIT 12

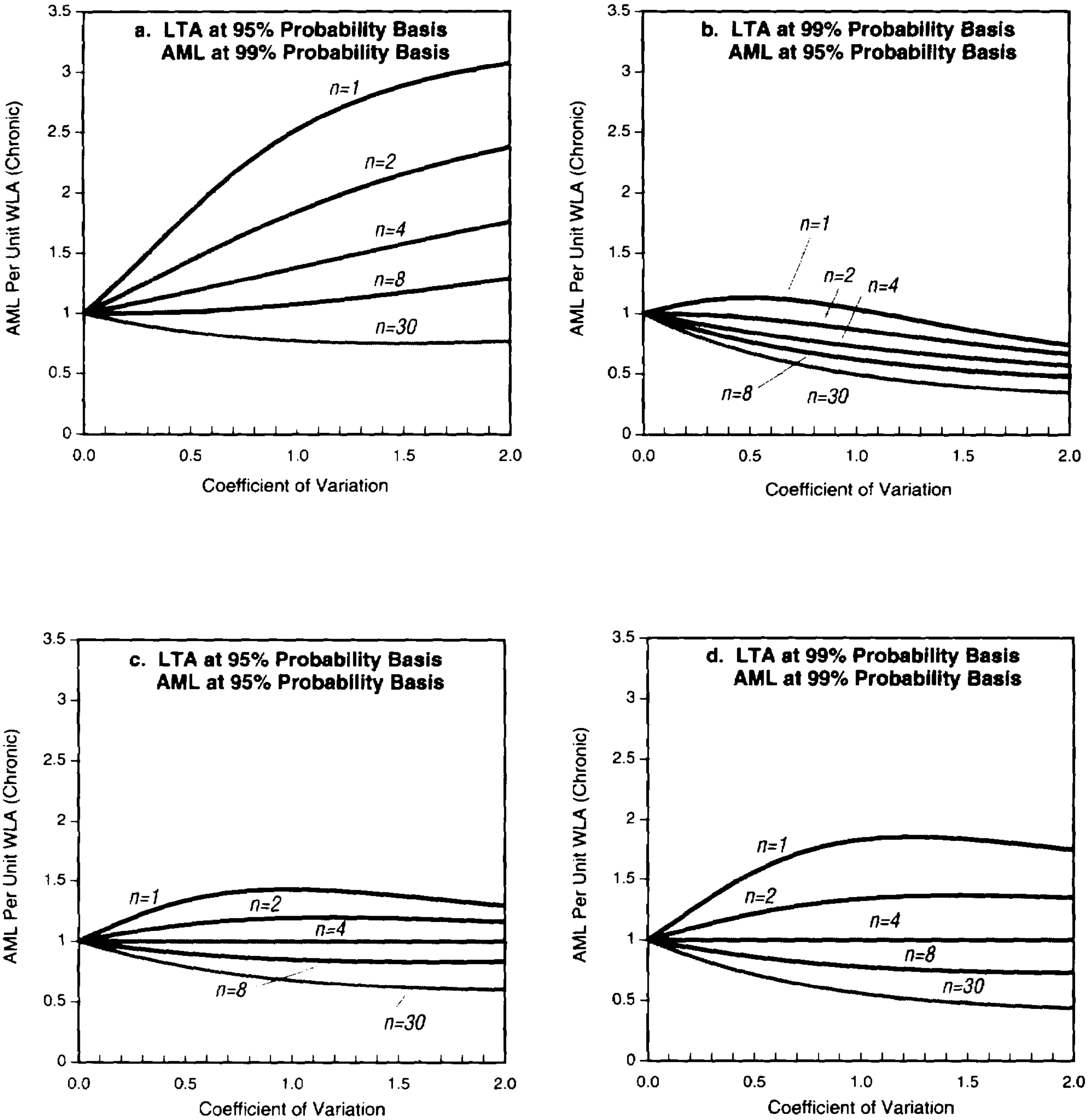

Figure 5-8. Effect of Coefficient of Variation on Average Monthly Limits

EXHIBIT 12

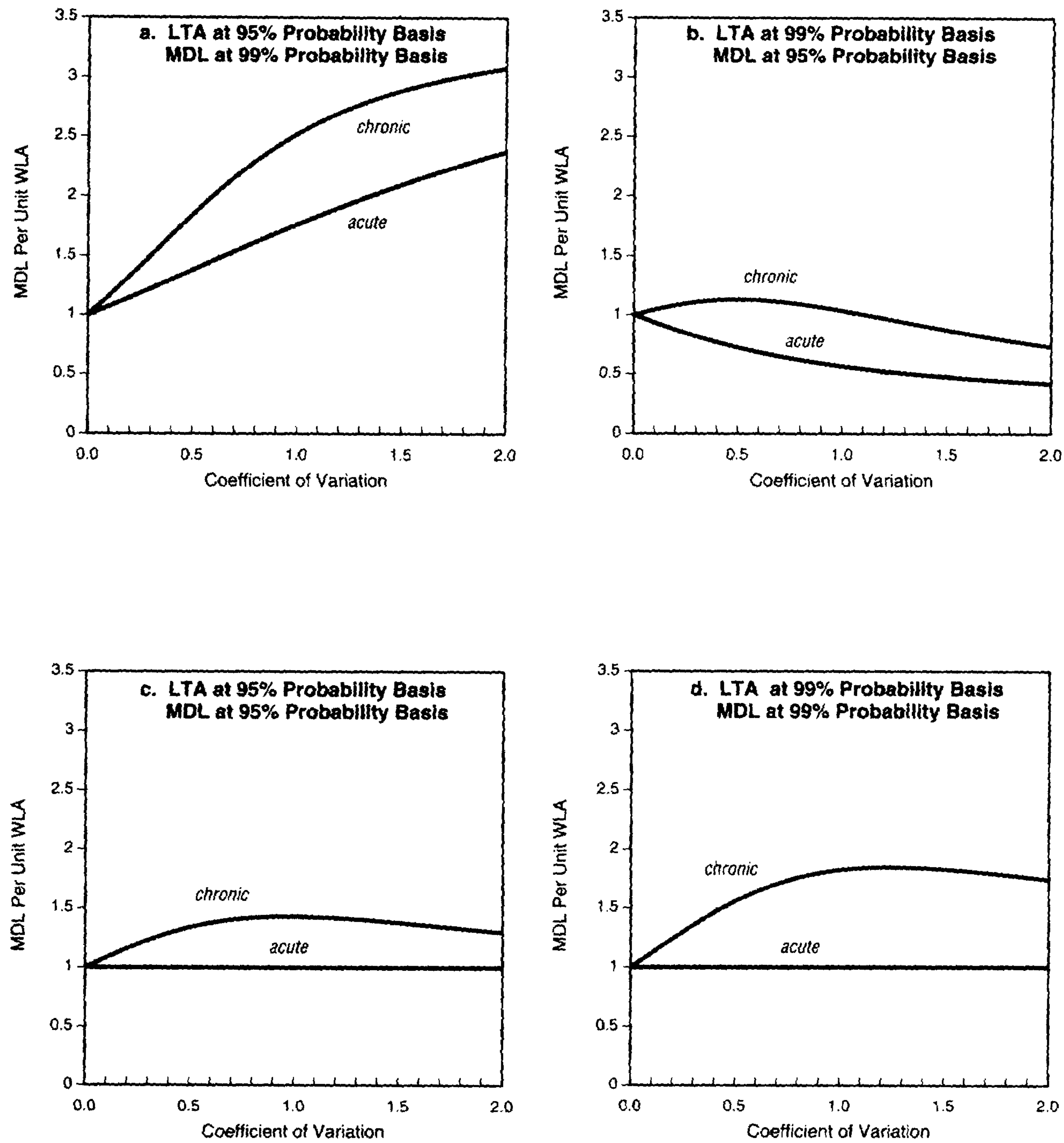

Figure 5-9. Effect of Coefficient of Variation on Maximum Daily Limits

is contemplated for compliance monitoring purposes, or where monitoring frequency is only quarterly. In this case, both the average monthly and the MDL would exceed the criterion. (For example, for a CCC of 1.0 chronic toxic unit [TU_C] applied as a WLA at the end of the pipe, both the MDL and AML would be 1.6 TU_C; assuming CV=0.6, n=1, and a 99-percent probability basis.) A discharger could thus comply with the permit limit but routinely exceed the criterion. **Under these circumstances, the statistical procedure should be employed using an assumed number of samples of at least <u>four</u> for the AML derivation.**

5.5.4 Probability Basis

Selection of the probability basis for use in the equations in Boxes 5-1 and 5-2 is a permitting authority decision necessary for establishing statistically derived permit limits. **Where a permitting authority does not have specific guidance for the probability basis, EPA recommends the following:**

For calculation of the LTAs from the WLAs (Box 5-2):

- Both acute and chronic WLA—.01 probability (99th percentile level).

For calculation of permit limits from the most limiting LTA (Box 5-1):

- MDL—.01 probability basis (99th percentile level)
- AML—.05 probability basis (95th percentile level).

The probability levels for deriving permit limits have been used historically in connection with development of the effluent limits guidelines and have been upheld in legal challenges to the guidelines [4]. It is important to note that these levels are statistical probabilities used as the basis for developing limits. The goal in establishing these levels is to allow the regulatory agency to distinguish between adequately operated wastewater treatment plants with normal variability from poorly operated treatment plants and to protect water quality criteria.

The level for the calculation of the LTA from the WLA is based upon EPA's interpretation of the steady state model used to develop the WLA. EPA considers the WLA to produce an effluent condition that should never be exceeded whenever the critical design conditions occur. To characterize this effluent condition, EPA uses the 99th percentile concentration from the upper tail of the effluent probabilistic distribution curve. The selection of this value is one which can have a significant influence on the level of conservatism in the permit limits. Permit authorities should consider Figures 5-8 and 5-9 to understand the effect of this decision along with other decisions on the AMLs and MDLs.

5.6 PERMIT DOCUMENTATION

The fact sheet and supporting documentation accompanying the permit must clearly explain the basis and the rationale for the permit limits. When the permit is in the draft stage, the supporting documentation will serve to explain the rationale and assumptions used in deriving the limits to the permittee and the general public in order to allow public comment on the draft permit. When the permit is issued, the administrative record for the facility (particularly the fact sheet) will be the primary support for defending the permit in administrative appeals including evidentiary hearings. This information also will serve to alert compliance/enforcement personnel to any special considerations that were addressed at the time of permit issuance. In addition, the accompanying documentation will be extremely important during permit reissuance and will assist the permit writer in developing a revised permit.

In 40 *CFR* Part 124.56, a fact sheet containing "[a]ny calculations or other necessary explanation of the derivation of specific effluent limitations" for many draft permits is required. Accordingly, the WLAs along with the required LTA and CV used and the calculations deriving them must be included or referenced in the fact sheet. The permit limit derivation method used must also be explained in the permit documentation. Where a permitting authority develops a standardized and simplified method for permit limit development as discussed in Section 5.4.2, the permitting authority may not need to document all of the underlying assumptions in the fact sheet, provided that the fact sheet references a written permit limit development protocol. Any other guidance used must also be cited.

5.7 EXPRESSING LIMITS AND DEVELOPING MONITORING REQUIREMENTS

Limits must be expressed clearly in the NPDES permit so that they clearly are enforceable and unambiguous. Chapter 6 discusses compliance monitoring and enforcement problems that can result from improperly expressed limits. All limits, both chemical-specific and whole effluent, should appear in Part 1 of the permit. Special considerations in the use of both chemical-specific and whole effluent toxicity limits are discussed below.

5.7.1 Mass-based Effluent Limits

Mass-based effluent limits are required by NPDES regulations at 40 *CFR* 122.45(f). The regulation requires that all pollutants limited in NPDES permits have limits, standards, or prohibitions expressed in terms of mass with three exceptions, including one for pollutants that cannot be expressed appropriately by mass. Examples of such pollutants are pH, temperature, radiation, and whole effluent toxicity. Mass limitations in terms of pounds per day or kilograms per day can be calculated for all chemical-specific toxics such as chlorine or chromium. Mass-based limits should be calculated using concentration limits at critical flows. For example, a permit limit of 10 mg/l of cadmium discharged at an average rate of 1 million gallons per day also would contain a limit of 38 kilograms/day of cadmium.

Mass-based limits are particularly important for control of bioconcentratable pollutants. Concentration-based limits will not adequately control discharges of these pollutants if the effluent concentrations are below detection levels. For these pollutants, controlling mass loadings to the receiving water is critical for preventing adverse environmental impacts.

However, mass-based effluent limits alone may not assure attainment of water quality standards in waters with low dilution. In these waters, the quantity of effluent discharged has a strong effect on the instream dilution and therefore upon the RWC. At the extreme case of a stream that is 100 percent effluent, it is the effluent concentration rather than the effluent mass discharge that dictates the instream concentration. Therefore, **EPA recommends that permit limits on both mass and concentration be specified for effluents discharging into waters with less than 100 fold dilution to ensure attainment of water quality standards.**

5.7.2 Energy Conservation

Water quality-based permit limits by themselves do not provide any incentive to dischargers to reduce wastewater flows. The reverse is true; a more dilute effluent means water quality-based limits are more easily achieved. However, increased flow translates into increased power consumption for treatment facilities. Significant power usage stems from pumping and mixing of volumes of wastewater in treatment systems. If the volume of wastewater can be reduced, power consumption can be reduced and less fossil fuel burned. Such reductions can be expected to result in concomitant decreases in air pollution.

Therefore, EPA recommends that flow reductions and energy savings be specifically encouraged where appropriate (usually in dilutions greater than 100:1) by allowing water quality-based permit limits to be mass-based and by allowing concentration-based limits to vary in accordance with flow reduction requirements. The permit also could include an energy savings analysis subject to approval by the permitting authority.

5.7.3 Considerations in the Use of Chemical-specific Limits

Metals

Another common problem encountered in expressing permit limits occurs for metals. Some water quality standards express numeric criteria for metals in terms of the dissolved or acid soluble phase of the metal. NPDES regulations at 40 *CFR* 122.45(c) require permit limitations for metals to be expressed in terms of total recoverable metal unless (1) an effluent guideline requires the use of another form, (2) technology-based limits are established on a case-by-case basis, or (3) the approved analytical method measures only the dissolved form.

Where State water quality standards are expressed directly as total or total recoverable metals, the permit limit can be established directly. Where the water quality standards are expressed as dissolved or acid soluble metal, the permit writer will need to reconcile the different expressions of metals when establishing the permit limits. Some State water quality standards implementation policies or procedures provide the requirements for this conversion. In instances where a State has no policy or procedure, the permit writer can take one of four approaches. First, the permit writer could assume no difference between the dissolved or acid soluble phases and the total recoverable phase. This is the most stringent approach and would be most appropriate in waters with low solids, where the discharged form of the metal was mostly in the dissolved phase, or where data to use the other options are unavailable. Second, the permit writer could develop a site-specific relationship between the phases of metals by developing a relationship through review of information on instream metal concentrations. This approach requires concurrent sampling of both metal phases during periods reflective of the environmental conditions used to determine the WLA. Third, the permit writer could use a relationship developed by EPA from national data; this relationship is described in the national guidance for determining WLAs for toxic metals in rivers. This relationship requires knowledge of instream concentrations of total suspended solids at the environmental conditions used to determine the WLA. Fourth, the permit writer could use a geochemical model, such as the equilibrium metal speciation model MINTEQA2 (see Chapter 4). However, the input data requirement of this model are equivalent to collecting site-specific data under Option 2. These options will be expressed in more detail in subsequent guidance issued by EPA.

Update: The Agency has issued "Interim Guidance on Interpretation and Implementation Aquatic Life Criteria for Metals." See the update notice in front of this document for availability.

Detection Level Limits

A commonly encountered problem is the expression of calculated limits for specific chemicals where the concentration of the limit is below the analytical detection level for the pollutant of concern. This is particularly true for pollutants that are toxic in extremely low concentrations or that bioaccumulate.

The recommended approach for these situations is to include in Part 1 of the permit the appropriate permit limit derived from the water quality model and the WLA for the parameter of concern, regardless of the proximity of the limit to the analytical detection level. The limit also should contain an accompanying requirement indicating the specific analytical method that should be used for purposes of compliance monitoring. The requirement should indicate that any sample is analyzed in accordance with the specified method and found to be below the compliance level will be deemed to be in compliance with the permit limit unless other monitoring information (as discussed below) indicates a violation. Sample results reported at or above the compliance level should be reported as observed whereas samples below the compliance level should be reported as less than this level.

The level of compliance cited in the permit must be clearly defined and quantified. **For most NPDES permitting situations, EPA recommends that the compliance level be defined in the permit as the <u>minimum level</u> (ML). The ML is the level at which the entire analytical system gives recognizable mass spectra and acceptable calibration points.** This level corresponds to the lowest point at which the calibration curve is determined based on analyses for the pollutant of concern in a reagent water. The ML has been applied in determinations of pollutant measurements by gas chromatography combined with mass spectrometry. The concept of a minimum level recently was used in developing the Organic Chemicals, Plastics, and Synthetic Fibers effluent guidelines [5].

The minimum level is not equivalent to the method detection level, which is defined in 40 *CFR* Part 136 Appendix B as the minimum concentration of a substance that can be measured and reported with 99-percent confidence that the analyte concentration is greater than zero and is determined from the analysis of a sample in a given matrix containing the analyte. EPA is not recommending use of the method detection level because quantitation at the method detection level is not as precise as at the ML. It is not similar to the practical quantitation limit (PQL), which is typically set as a specific (and sometimes arbitrary) multiple of the method detection level. Because the PQL has no one definition, EPA is not recommending its use in NPDES permitting. Nor is it similar to other terms such as the limit of detection, limit of quantitation, estimated quantitation limit , or instrument detection limit.

The permitting authority may choose to specify another level at which compliance determinations are made. Where the permitting authority so chooses, the authority must be assured that the level is quantifiable, defensible, and close as possible to the permit level.

Where water quality-based limits below analytical detection levels are placed in permits, EPA recommends that special conditions also be included in the permit to help ensure that the limits are being met and that excursions above water quality standards are not occurring. Examples of such special conditions include fish tissue collection and analyses, limits and/or monitoring requirements on internal waste streams, and limits and/or monitoring for surrogate parameters. This information can be used to help support reopening the permit to establish more stringent effluent limits if necessary.

5.7.4 Considerations in the Use of Whole Effluent Toxicity Limits

Test Methods

NPDES regulations at 40 *CFR* 122.44(i)(1)(iv) require that methods approved under 40 *CFR* Part 136 be used for compliance monitoring, and in the absence of an approved method, the permit must specify the method to be used. The permit should also carefully consider any other case-specific aspects of the whole effluent toxicity test method that should be designated in the permit. Such aspects as the dilutions at which testing will be conducted, the different species to be used, the specific endpoints, the statistical procedures for analyzing the data, quality assurance, and other factors should be clearly stated as a permit condition to assure that the whole effluent toxicity testing that is performed to ascertain compliance with a limit or monitoring requirement is the test procedure the regulatory authority desires. In some instances, promulgated methodologies allow significant flexibility and choice in how the method is actually conducted. A simple reference to the methodology in the permit may not result in the test being conducted as intended.

Units of Expression and Detection Levels

The permit limit for toxicity itself and the detection levels, or sensitivity levels, associated with the various types of toxicity tests determine the type of monitoring requirement, which should be specified with the limit. It is a misconception to think, for example, that only acute toxicity tests should be used where the WLA for acute protection is used to derive the more limiting LTA or should always be used to monitor for the MDL. It is a similar misconception to think that only chronic tests should be used where chronic LTA is limiting or should always be used to monitor for the average monthly limit. The MDLs and AMLs are derived from the more limiting of the two LTAs. Therefore, either acute or chronic tests might apply to a given situation depending upon the test detection levels or test sensitivity.

For example, a limit of 5 TU_c (no observed effect concentration [NOEC] of 20 percent or greater) would require chronic toxicity testing where the ACR is 20 for that effluent. An acute test would not be sensitive enough to measure effluent toxicity in this instance, since 5 TU_c would be equivalent to 0.25 TU_a. Conversely, if the ACR was 2, then an acute test could be used because 5 TU_c would be equal to 2.5 TUa. Generally, there is no reason to mix two types of monitoring requirements for the same limit when limits are derived from the most limiting LTA. Doing so will confuse the results and complicate assessments of average monthly limits where sampling frequency is greater than once per month.

The acute toxicity test, when using an LC_{50} as the test endpoint, has an upper sensitivity level of 100-percent effluent, or 1.0 TU_a. If less than 50 percent of the test organisms die at 100-percent effluent an LC_{50} cannot be determined from the test data, and the true LC_{50} value for the effluent cannot be measured. In this situation, an acute test could still be used for compliance monitoring purposes but the endpoint would need to be changed to a greater level of sensitivity. The endpoint could be specified in terms of "no statistically significant difference in acute toxicity between 100 percent effluent sample and the control." This is the most sensitive application of an acute test and could be used for monitoring compliance with a limit that, because of lack of available dilution, applies the EPA recommended acute criterion of 0.3 TU_a at the end of the pipe.

However, these tests would not accurately quantify any level of chronic toxicity present. For chronic testing, an effluent with an NOEC of greater than 100 percent presents a similar test sensitivity problem. An effluent with an NOEC of greater than 100 percent contains less than 1.0 TU_c and would meet the EPA recommended chronic criterion for toxicity at the edge of the mixing zone, if dilution were available, as well as at the end of the pipe if no dilution were available.

Description of Limits

When toxicity limits are used, additional description of the limit is required. The limit should be stated in Part 1 as "effluent toxicity" in the parameter column with "maximum TUs," "minimum ATE [acute toxicity endpoint]," or "minimum NOEC" in parentheses underneath. The numerical values should be placed in the appropriate concentration column followed by TU or a percent sign. A footnote should direct the reader to Part 3 for specific requirements on how to conduct the tests. The description in Part 3 should accomplish the following:

- Explain how the limit is expressed (e.g., the limit is the minimum ATE expressed as percent effluent or the limit is the maximum TU_a)
- Specify the test species and the test methods for compliance monitoring purposes
- Describe any special reporting or followup requirements (e.g., requirements to conduct a toxicity reduction evaluation).

The language in Part 3 should be modified as needed to suit the situation. The following example language is provided only for purposes of illustration:

- "The effluent toxicity limit contained in Part 1 is the allowable chronic toxicity to the most sensitive of three test species. It is expressed as the allowable NOEC in percent effluent. The required test species and the procedures to follow are described in *Short Term Methods for Estimating the Chronic Toxicity of Effluents and Receiving Waters to Freshwater Organisms*, EPA/600/4-89/001, March 1989."
- "The permittee shall conduct monitoring of effluent toxicity once per month. One 24-hour composite sample shall be collected and tested within 24 hours of collection. Results shall be reported as the NOEC. Any test that does not meet quality control requirements as described in the above referenced methods shall be repeated using a freshly collected sample as soon as practicable."

5.7.5 Selection of Monitoring Frequencies

There is no fixed guidance on establishment of monitoring frequencies. The decision on the monitoring frequency is case-specific and needs to consider a number of factors, including those listed below:

- Type of treatment process, including retention time
- Environmental significance and nature of the pollutant or pollutant parameter
- Cost of monitoring relative to the discharger's capabilities and benefit obtained
- Compliance history
- Number of monthly samples used in developing the permit limit
- Effluent variability.

Based upon an array of data analyzed for both individual chemicals and whole effluent toxicity, and independent of other considerations, EPA has observed that ideally 10 or more samples per month provides the greatest statistical likelihood that the average of the various monthly values will approach the true monthly LTA value. In practice, however, selection of monitoring frequencies will need to consider the previously mentioned factors and arrive at a reasonable compromise of the appropriate considerations.

5.7.6 Analytical Variability

Permits require monitoring to establish whether a facility is discharging at a level that complies with the permit limits. All monitoring includes analytical variability. The true concentration in a sample can be higher or lower than the measured one due to this variability; however, there is no way to predict which way it will go.

Historically, EPA has not directly considered analytical variability from monitoring methods when establishing permit limits. If the upper bound of the analytical variability was added to the limit, there would be a higher potential that the permit limit would fail to protect the wasteload allocation. This would not be consistent with 40 *CFR* 122.44(d)(1). On the other hand, if the lower bound of the analytical uncertainty was subtracted from the limit, there would be better assurance that the limit achieved the WLA. This approach could be overly conservative given the other factors used to develop permit limits. EPA believes that its recommended approach provides a balance between these two extremes.

5.7.7 Antibacksliding

CWA Section 402(o) establishes express statutory language prohibiting the relaxation of permit limits based on water quality. Under the statute, relaxation of water quality-based limits is permissible only if either the requirements of Sections 402(o)(2) or 303(d)(4) are met. These two provisions constitute independent exceptions to the prohibition against relaxation of permit limits. If either is met, relaxation is permissible.

Relaxation of Water Quality-based Limits Under Section303(d)(4)

Section 402(o)(1) prohibits the establishment of less stringent water quality-based effluent limitations "except in compliance with Section 303(d)(4)." Section 303(d)(4) has two parts: Paragraph (A), which applies to "nonattainment waters" and Paragraph (B), which applies to "attainment waters."

- Nonattainment waters: Section 303(d)(4)(A) allows establishment of less stringent water quality-based effluent limitations in a permit for discharge into a nonattainment water only if (1) the existing permit limitation must have been based on a total maximum daily load (TMDL) or other WLA established under Section 303, and (2) attainment of water quality standards must be assured.
- Attainment waters: Section 303(d)(4)(B) allows establishment of less stringent water quality-based effluent limitations in a permit for discharge into an attained water as long as the revised permit limit is consistent with a State's antidegradation policy. This is not restricted to limits based on a TMDL or WLA.

Relaxation of Water Quality-based Limits Under Section 402

Section 402(o)(2) also outlines exceptions to the general prohibition against establishment of less stringent water quality-based permit limits in a permit. Under Section 402(o)(2), the establishment of less stringent limits based on water quality may be allowed where:

1) There have been material and substantial alterations or additions to the permitted facility which justify this relaxation.
2) Good cause exists due to events beyond the permittee's control (e.g., acts of God) and for which there is no reasonably available remedy.
3) The permittee has installed and properly operated and maintained required treatment facilities but still has been unable to meet the permit limitations (relaxation may only be allowed to the treatment levels actually achieved).

4) New information (other than revised regulations, guidance, or test methods) justifies relaxation of water quality-based permit limitations.

   This last exception applies to water quality-based permit limitations only where the revised limitations result in a net reduction in pollutant loadings and are not the result of another discharger's elimination or substantial reduction of its discharge for reasons unrelated to water quality (e.g., operation termination).

Although Paragraph 402(o)(2) lists two additional exceptions, one for technical mistakes and mistakes of law and one for permit modifications or variances, the statute provides that these exceptions do not apply to water quality-based effluent limitations. As a result, these exceptions do not provide a basis for relaxing water quality-based limitations.

Relaxation of Water Quality-Based Permit Conditions or Standards

The provisions in Section 402(o) discussed previously only address the relaxation of effluent limits based on water quality. The relaxation of other permit conditions or standards based on water quality are governed by EPA's existing antibacksliding regulations at 40 *CFR* 122.44(l)(1). Under these regulations when a permit is renewed or reissued, interim effluent limitations, standards, or conditions must be at least as stringent as the final effluent limitations, standards, or conditions in the previous permit "unless the circumstances on which the previous permit was based have materially and substantially changed since the time the permit was issued and would constitute cause for permit modification...". In other words, unless cause for permit modification is present, relaxed conditions or standards are not permissible. EPA regulations setting forth cause for permit modification can be found at 40 *CFR* 122.62.

Restrictions of Backsliding

Even if any of the backsliding exceptions outlined in the statute or regulations are applicable and met, Section 402(o)(3) acts as a floor and restricts the extent to which water quality-based permit limitations may be relaxed. Paragraph (o)(3) prohibits the relaxation of water quality-based permit limitations in all cases if there will be a violation of applicable effluent limitation guidelines or water quality standards, including antidegradation requirements. This requirement affirms existing provisions of the CWA that require permit limits, standards, and conditions to ensure compliance with applicable technology-based limits and water quality standards.

5.8 TOXICITY REDUCTION EVALUATIONS

Where monitoring indicates unacceptable effluent toxicity, one principal mechanism for bringing a discharger into compliance with a water quality-based whole effluent toxicity requirement is a toxicity reduction evaluation (TRE) [6]. The purpose of a TRE is to investigate the causes and to identify corrective actions for difficult effluent toxicity problems. The permitting authority may require that the permittee conduct a TRE in those cases where the discharger is unable to explain adequately and immediately correct exceedances of a whole effluent toxicity permit limit or requirement.

A TRE is a site-specific study conducted in a stepwise process to narrow the search for effective control measures for effluent toxicity. TREs are designed to identify the causative agents of effluent toxicity, isolate the sources of the toxicity, evaluate the effectiveness of toxicity control options, and then confirm the reduction in effluent toxicity. The ultimate objective of a TRE is for the discharger to achieve the limits or permit requirements for effluent toxicity contained in the permit and thereby attain the water quality standards for receiving waters.

The requirement for a permittee to conduct a TRE may be written into the special conditions section of a permit, which contains whole effluent toxicity limits. In some cases, the permit issuing authority may also use other legally binding mechanisms, including Section 308 letters, Administrative Orders, or Consent Decrees, to require a TRE.

5.8.1 TRE Guidance Documents

To assist permittees in conducting TREs and achieving compliance with whole effluent toxicity limits, EPA has developed a series of three guidance documents [6, 7, 8]:

1) *Generalized Methodology for Conducting Industrial Toxicity Reduction Evaluations* (EPA/600/2-88/070)
2) *Toxicity Reduction Evaluation Protocol for Municipal Wastewater Treatment Plants* (EPA/600/2-88/062)
3) *Methods for Aquatic Toxicity Identification Evaluations:*

   Phase 1 Toxicity Characterization Procedures (EPA/600/3-88/034)

   Phase 2 Toxicity Identification Procedures (EPA/600/3-88/035)

   Phase 3 Toxicity Confirmation Procedures (EPA/600/3-88/036).

These guidance documents describe the methods and procedures for conducting TREs and Toxicity Identification Evaluations (TIEs). They are based on the results of EPA's continuing efforts in TRE methods research and case study applications. Separate TRE guidance has been developed for industrial dischargers and municipal wastewater treatment plants to better address the circumstances of each type of facility. Procedures for the characterization, identification, and confirmation of the causative agents of effluent acute toxicity have been developed and are described in a three-phased TIE methods manual. These TIE methods are applicable to both industrial and municipal effluents and are an integral part of the protocols for TREs described in the industrial and municipal TRE guidance documents. TIE methods using chronic toxicity tests for identifying toxicants will soon be developed and available in a draft guidance document.

5.8.2 Recommended Approach for Conducting TREs

To ensure the successful completion of a TRE, the guidance documents recommend a systematic, stepwise approach that

EXHIBIT 12

eliminates the possible causes or sources of toxicity until a solution or control method is determined. The guidance documents discourage "playing hunches" or implementing extensive control measures solely on the basis of unsubstantiated conclusions (e.g., selecting and implementing a treatment plant upgrade without adequate information). Experience shows that unnecessary delays and expenditures in achieving the objective of the evaluation are avoided by building a sound scientific and engineering basis for selection of a control method. This can best be done by the logical interpretation of the information and data collected in a systematic approach to a TRE. The causes or control methods identified should then go through a confirmation stage. This is especially important in cases where the control method selected requires the construction of additional treatment. A flow chart, generalized from the guidance documents, for this approach to TREs is presented in Figure 5-10. The steps in this flow chart are summarized in the following discussion.

Determination of TRE Objectives and Development of the TRE Plan

Obviously, the success of any study is dependent on a clear understanding of what is to be achieved and how these objectives are to be demonstrated and measured. Typically, TRE objectives are set by the regulatory authority in terms of a toxicity test endpoint (ATE or chronic toxicity endpoint [CTE]) in order to meet a limit or permit condition. TRE plans should be submitted by the discharger as soon as possible. In some cases, this could be 30 to 60 days following notification that a TRE is required. In other instances, this period could be longer. These plans are important for ensuring that the TRE objectives are well understood and that the TRE to be conducted is thorough and represents a reasonable effort to achieve the required reduction in effluent toxicity. An implementation schedule should also be developed describing the timeframe for completion of the specific components of the TRE plan by the required TRE completion date. This schedule should be submitted for review in conjunction with the TRE plan. **EPA recommends that the TRE schedule should be set or approved by the regulatory agency**. Approval of the schedule and the completion date should not imply approval of the TRE plan itself or the procedures and methods outlined in the plan. Instead, the TRE plan should only be reviewed and any comments provided to the permittee as needed.

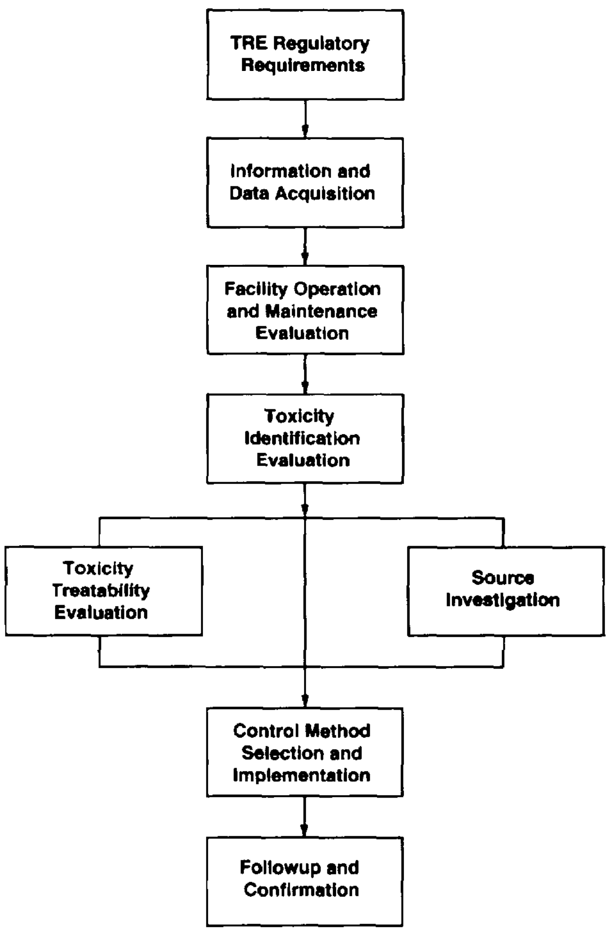

Figure 5-10. Generalized TRE Flow Chart

To assist in this review, Box 5-3 provides evaluation criteria for TRE plans. The permitting authority should review the TRE plan and inform the discharger of any apparent shortcomings or potential problems. The TRE should not be delayed pending completion of the review of the plan. The specified completion date for the TRE must still be met and the permittee should be expected to begin steps to investigate and alleviate the effluent toxicity as soon as possible following notification that a TRE is required. During the course of the TRE, the regulatory agency should provide oversight, as time permits, to make the TRE as effective as possible.

Evaluation of Existing Site-specific Information

The next step involves the collection of any information and analytical data relevant to the effluent toxicity. The permittee should begin collecting and evaluating this information as soon as possible following notification that a TRE is required. In some cases, this step may be conducted concurrently with accelerated toxicity testing as part of the development of a TRE plan. For an industrial discharger, this part of the evaluation would include information such as plant and process information, influent and effluent physical and chemical monitoring data, effluent toxicity data, and material use. For a POTW, additional information, such as industrial waste survey applications, local limits compliance reports, and monitoring data, should be collected. This information is used to supplement the data generated in the later steps of the TRE and may be useful at that stage to point to potential sources or treatment options.

Evaluation of Facility Operations and Maintenance Practices

This part of the evaluation is performed in order to ascertain whether the facility is consistently well operated and whether the effluent toxicity is the result of periodic treatment plant upsets, bypass, or some other operational deficiency that may be causing or contributing to the effluent toxicity. This part of the TRE should be initiated immediately after notification that a TRE is required. Alternatively, the permittee may begin to conduct this step at the same time that any accelerated toxicity testing is required. At both municipal and industrial facilities, this step would involve the evaluation of "housekeeping," treatment system operation, and chemical use. In some cases, best management practices (BMPs) may be identified, which would improve operations and effluent quality. However, the effectiveness of BMPs in reducing effluent toxicity should be carefully confirmed, and it will usually be necessary to test a number of samples and perhaps to conduct Phase 1 of the TIE to develop this level of certainty. The results of this evaluation may lead to preliminary strategies for source reduction and pollution prevention, including spill or leak prevention, improvements in material handling and disposal practices, or substitution or re-use of a compound known to be highly toxic.

Toxicity Identification Evaluation

TIE procedures are performed in three phases: characterization, identification, and confirmation [7]. In each phase, aquatic organism toxicity tests are used to track toxicity at each step of the procedure. In most cases, these are abbreviated or shortened toxicity tests. In the toxicity characterization phase, the general nature of the causative agents of effluent toxicity or toxicants is determined. This is done by conducting a battery of tests to characterize the physical/chemical characteristics of the toxicity: solubility, volatility, decomposability, complexibility, filterability, and sorbability. This information can then be used to decide which chemical analytical methods will to use in Phase 2 or it can be used to design treatability studies.

The results of Phase 1 also may be used to provide additional confirmation of the effectiveness of any BMP that was implemented in the previous step of the TRE to reduce the effluent toxicity. This would require conducting at least one Phase 1 analysis prior to implementation of the BMP (i.e., any source control method implemented as a result of the evaluation of facility operation and maintenance). The results of this analysis would then be compared with Phase 1 results from samples taken after BMP implementation.

Box 5-3. Evaluation Criteria for TRE Plans

- Are the objectives or targets of the TRE stated clearly and accurately?
- Are the schedule and milestones for accomplishing the tasks described in the study plan?
- Are the final TRE report, progress reports, and meetings with the regulatory authority included as part of the schedule?
- Are the approaches or methods to be used described to the extent possible prior to beginning the TRE?
- Has available EPA guidance been used in designing the TRE and developing the TRE plan (or if other methods are proposed, are these sufficiently documented)?
- Does the TRE plan specify what results and data are to be included in the interim and final reports?
- Does the TRE plan provide for arrangements for any inspections or visits to the facility or laboratory that are determined to be necessary by the regulatory authority?
- Are the toxicity test methods and endpoints to be used described or referenced?
- Does the approach described build on previous results and proceed by narrowing down the possibilities in a logical progression?
- Does the plan provide for all test results to be analyzed and used to focus on the most effective approach for any subsequent source investigations, treatability studies, and control method evaluations?
- Are optimization of existing plant/treatment operations and spill control programs part of the initial steps of the TRE?
- Does the TRE plan allow a sufficient amount of time and appropriate level of effort for each of the components of the study plan?
- Does the TIE use broad characterization steps and consider quantitative and qualitative effluent variability?
- Is toxicity tracked with aquatic organism toxicity tests throughout the analyses?
- Is the choice of toxicity tests for the TRE logical and will correlations be conducted if the species used are different from those used for routine biomonitoring?
- Is the laboratory analytical capability and the expertise of the investigator broad enough to conduct the various components of the evaluation?

In Phase 2 of the TIE, the results of Phase 1 are built upon, and the TIE proceeds to chemical analyses designed to identify the specific chemicals causing effluent toxicity. In Phase 3, the identified toxicants are confirmed using a number of procedures, including correlation of toxicity with chemical concentration, spiking experiments, toxicity mass balance, and additional test species and their symptoms.

The current version of the TIE methods uses acute toxicity tests to characterize and identify the toxicants. In some cases, these methods may also be used for TREs where the objective is to reduce chronic toxicity. In order for these methods to be applicable, however, there must be some measurable acute toxicity in the effluent samples that are to be characterized in Phase 1 and analyzed in Phase 2. If this approach is used, the appropriate chronic toxicity test, as specified in the TRE objectives and permit requirements, should then be used in the Phase 3 confirmation procedures. This will confirm that the toxicant(s) identified using acute tests in Phases 1 and 2, are indeed causing the whole effluent chronic toxicity, which must be reduced.

It is possible to use the methods and procedures described in the other components of the overall TRE with either acute or chronic toxicity tests. The fact that the previous version of the EPA TIE methods use acute toxicity tests should not be construed to mean that TREs cannot be required or conducted for the reduction of chronic toxicity. These methods provide additional tools to assist permittees in the reduction of whole effluent chronic toxicity. Phase 1 procedures that use chronic toxicity tests will soon be available in draft EPA guidance. These TIE methods are applicable to freshwater discharges to either saltwater or freshwater receiving waters. The use of these methods for saltwater receiving waters may require their adaption for use with marine test species or, preferably, an initial correlation of the recommended freshwater TIE test species to the marine species used for monitoring.

Source Investigation

Based on the results of the TIE, a decision is made on whether to conduct treatability studies on the final effluent and/or conduct a source investigation. A source investigation is most readily performed when the specific toxicants have been identified and influent samples can be analyzed for the presence of these compounds or when potential source streams can be selected for chemical analysis (based on the results of the initial data acquisition step). However, in some cases where the specific causative agents of effluent toxicity have not been identified in the TIE, it may be possible to conduct a source investigation by "treating" influent samples in bench-scale models of the facility treatment plant, measuring the toxicity of the treated sample and then tracking this toxicity to its source.

Source investigations will lead to control methods, such as chemical substitution, process modification, treatment of process or influent streams (pretreatment), and possible elimination of the process. For POTWs, source investigations may lead to the development of local limits or to the requirement that an indirect discharger evaluate and control their effluent so as to reduce its toxicity and prevent passthrough at the POTW. The implementation of source control methods can effectively reduce effluent toxicity and also can avoid any cross-media transfer of pollutants to air or sludge, which may occur as a result of end of pipe treatment. Types of source control methods that have proven to be effective in reducing effluent toxicity are improvements in facility housekeeping, chemical substitution, process optimization, reclamation/re-use, and pretreatment.

Toxicity Treatability Evaluation

Toxicity treatability evaluations are conducted to identify possible treatment methods that can effectively reduce effluent toxicity and may involve modifications or additions to the existing system. Treatability studies generally use the same type of information on the nature of the chemicals to be removed as is generated by Phase 1 of the TIE. These treatability tests should be conducted on a bench-scale initially and then a pilot scale prior to construction of additional treatment or substantial modification of the existing plant. The use of these bench- and pilot-scale tests, coupled with aquatic organism toxicity tests, should be used to confirm the effectiveness of the treatment option. Confirmation of the results of treatability studies is equally important as it is for the TIE. Skipping this confirmation step is an invitation for unwarranted expense.

Toxicity Control Method Selection and Implementation

After the investigative steps of the TRE are completed, it is not unusual for a number of possible control options to have been identified. At this point, a site specific selection must be made by the discharger based on the technical and economic feasibility of the various alternatives. Following this selection, the toxicity control method is implemented or a compliance plan is submitted if construction of additional treatment requires a substantial amount of time.

Followup and Confirmation

After the control method is implemented and the final TRE report is submitted, the permitting agency should direct the permittee to conduct followup monitoring to confirm that the reduction in effluent toxicity is attained and maintained. Normally, this monitoring should follow an accelerated schedule, weekly or biweekly toxicity tests, for a period of 2 to 3 months to confirm the effectiveness of the controls implemented and the continued attainment of the TRE objective. This followup monitoring should use the same species as were specified for routine toxicity testing in the permit. The test endpoints of these toxicity tests should be the same as those which were calculated by the water quality-based permit limit derivation procedure used when the permit was issued. Once the discharger has demonstrated the successful completion of the TRE, the permitting agency should direct the discharger to return to the routine permit monitoring schedule.

5.8.3 Circumstances Warranting a TRE

It is the responsibility of the permitting authority to determine if the permit limits and/or the State water quality criteria have been threatened or violated and to notify the permittee if a TRE is required. It is appropriate for the permitting authority to require additional toxicity testing following the initial exceedance or violation. This additional testing may precede notification that a TRE will be required or it may be considered as the initial part of the

TRE and be conducted simultaneously with TRE plan development and the evaluation of other existing site-specific information.

It is important to recognize that the purpose of this additional toxicity testing is to determine the continued presence or absence of effluent toxicity and the magnitude of that toxicity. This information can then be used to determine the continued compliance or noncompliance with the limit or permit conditions for effluent toxicity. These tests do not serve to verify or confirm the initial test results from an earlier sample. Instead, the permit authority shall use the results of these tests to determine if a TRE or some other action is the appropriate response to the initial occurrence of toxicity.

If the permit has a limit for whole effluent toxicity, then generally, the permit should not include any specific conditions for accelerated toxicity testing or for triggering a TRE or some other action (e.g., exceedances in two consecutive tests or exceedances in any three out of five tests). CWA Section 309 requires that any single violation of a permit limit may be subject to enforcement. The EPA *Compliance Monitoring and Enforcement Strategy for Toxics Control* (January 19, 1989, Appendix B-4) states that, "Each exceedance of a directly enforceable whole effluent toxicity limit is of concern to the regulatory agency and therefore qualifies as meeting the VRAC [violation review action criterion] requiring professional review." Accelerated monitoring should only be used to assist in this professional review to determine what, if any, enforcement response is necessary, including the need for the permittee to conduct a TRE. It will be necessary for the Region or State regulatory authority to determine this on a case-by-case basis. This must be done in a manner consistent with the priorities established in their respective toxics control strategies and permitting procedures.

In situations where it is determined that accelerated testing is appropriate, a maximum of weekly tests for a minimum period of 2 months is recommended. This would result in eight tests, plus the routine monitoring toxicity test that initially indicated the exceedence or violation, for a total of nine tests in the series. As a practical approach for determining if a TRE is an appropriate response, **EPA recommends if toxicity is repeatedly or periodically present at levels above the effluent limits more than 20 percent of the time, a TRE should be required.** With toxicity present at this rate, the TRE protocols will be useful.

In most cases, any one additional exceedance (beyond the initial routine monitoring toxicity test result) in the accelerated toxicity tests could result in notification of the permittee that a TRE is required. Exceptions to this guideline might include cases where the permittee is able to adequately demonstrate that the cause of the exceedances is known and corrective actions have been immediately implemented or cases where additional test quality assurance/quality control (QA/QC) is necessary or desirable. The submittal of QC fact sheets for self-biomonitoring (e.g., Appendix B-2) should always be recommended to avoid QA/QC problems.

If the test results indicate that toxicity is not consistently or repeatedly present in the test series, previous discharge monitoring reports (DMRs) should be examined to ascertain if a recurrent problem exists. If the problem is recurrent, a TRE should be required, and the TRE plan should explain how the design of the evaluation will address this periodic or recurrent effluent toxicity problem. In these cases, more elaborate sampling design and influent or process stream monitoring may be needed. It should be expected that TREs conducted under these circumstances will probably require a more flexible schedule and perhaps additional time before the required completion date.

If the accelerated testing and previous DMRs show the continued absence of effluent toxicity, then the initial exceedance would be considered an episodic event and a TRE should not be required. A TRE is not an appropriate response to a single, episodic effluent toxicity event (e.g., a spill or a plant upset). By conducting accelerated testing following a violation or exceedance of a permit condition, unnecessary TREs can be avoided. Similarly, conducting accelerated testing as part of the initial steps of a TRE will allow for the TRE to be ended in its very early stages if the toxicity is immediately controlled or determined to be episodic or nonrecurrent. By following the TRE guidance and incorporating accelerated testing into the TRE, unnecessary analyses and expense can be avoided.

It also is important to note that for the practical purposes of conducting a TRE (as opposed to the purpose of determining if a TRE should be required or not), the magnitude of the effluent toxicity needed to conduct a TRE may be less than the magnitude or level set as the permit limit or permit monitoring condition. This is because if the limit or monitoring condition is water quality-based then some amount of dilution will usually be incorporated in determining the unacceptable level of effluent toxicity. In some cases, it may be possible for the TRE procedures to be carried out even if the toxicity does not actually exceed this permitted level. This will be the case as long as the effluent toxicity is periodically or consistently present in measurable amounts in samples of 100-percent effluent.

It also is reasonable for a discharger to initiate a TRE prior to the establishment of a permit limit for toxicity if unacceptable levels of toxicity are found in the effluent through routine monitoring or through inspection and compliance sampling by the regulatory authority. Under these circumstances the regulatory authority will need to identify what constitutes unacceptable levels of toxicity since this will not be defined by a permit limit (see Chapter 3 on determining the reasonable potential for excursions of water quality standards). It also is not unreasonable for the discharger to voluntarily initiate a TRE under these circumstances.

5.8.4 Mechanisms for Requiring TREs

There are a number of mechanisms that can be used to require a TRE. In most cases, the TRE should be required by a Section 308 letter or by an enforcement action, such as a Section 309 Administrative Order or a Consent Decree. The permittee should receive notification from the permit authority of what response is required. This enables the permit authority to assess whether a TRE is the appropriate action to pursue. If effluent toxicity reappears following the successful completion of a TRE, then the permit authority should be able to review this type of situation to determine if an additional TRE is appropriate or if some other action is required. In general, when the permit is issued with whole effluent toxicity limits in Part 1 of the permit, TRE requirements should be used where necessary to bring the permittee into compliance with those limits. Box 5-4 provides example language for effluent toxicity limits, developed as part of the Whole Effluent Toxicity Basic Permitting Principles and Enforcement Strategy (Appendix B-4).

Box 5-5 presents sample language for use in requiring TREs by a Section 308 letter or a Section 309 Order. This sample language, especially the reporting dates, should be tailored to fit the specific permittee. The completion date should be specified on a case-by-case basis. Factors to consider in setting this completion date include the type of facility, the variability of the effluent, and the previous compliance history. In order to conduct a TRE, reasonable timeframes are 6 to 18 months for an industrial discharger and 12 to 24 months for a municipal wastewater treatment plant. For POTWs, it may take longer to conduct a TRE due to lengthy government contracting procedures, large sewer collection systems, and less influent constituent control. It should be recognized that extensions to these initial timeframes may be granted if the progress reports demonstrate that this is warranted. In situations where reductions in chemical concentrations to meet chemical-specific limits are needed as well as reductions in effluent toxicity, the timeframes may be adjusted to enable those efforts to proceed simultaneously.

Box 5-4. Model Permit Language for Effluent Toxicity Limits

Part 1.A. Final Effluent Limits and Monitoring Requirements

During the period beginning on the effective date of this permit and lasting until the expiration date, the permittee is authorized to discharge in accordance with the following limits and monitoring requirements from the following outfall(s): 001.

Effluent Characteristic		Discharge Limit Concentration		Monitoring Requirement	
Reporting Code/Units	Parameter	Daily Maximum	Monthly Average	Measurement Frequency	Sample Type
—TU_c	Toxicity	10.0	5.0	x/month	composite

The permittee shall use the toxicity testing and data assessment procedures described in Part 3.B of this permit.

Box 5-5. Example Language for Requiring Toxicity Reduction Evaluations

The discharger shall demonstrate that effluent toxicity-based permit limits described in Part 1.A. of the permit are being attained and maintained through the application of all reasonable treatment and/or source control measures. Upon identifying noncompliance with those limits the discharger shall initiate corrective actions according to the following schedule:

	Task	Deadline
1.	Take all reasonable measures necessary to reduce toxicity immediately.	Within 24 hours
2.	Submit a plan and schedule to attain continued compliance with the effluent toxicity-based permit limits in Part I.A.,where source of toxicity is known, if immediate compliance is not attained.	Within 30 days
3.	Submit a TRE study plan detailing the toxicity eduction procedures to be employed where source is unknown and toxicity cannot be immediately controlled through operational changes. EPA's Toxicity Reduction Procedures, Phases 1, 2, and 3 (EPA-600/3-88/034, 035, and 036) and TRE protocol for POTWs (EPA-600/2-88/062) shall be the basis for this plan and schedule.	Within 45 days

Box 5-5. Example Language for Requiring Toxicity Reduction Evaluations (continued)

4.	Initiate TRE plan.	Within 45 days
5.	Comply with approved TRE schedule.	Immediately upon approval
6.	Submit results of the TRE, including summary of findings, corrective actions required, and data generated.	Per approved schedule
7.	Implement TRE controls as described in the final report.	On due date of final report per approved schedule
8.	Complete TRE implementation to meet permit limits and conditions.	Per approved schedule, but in no case later than XX months from initial noncompliance.

CHAPTER 5
REFERENCES

1. Marr, J.K., and R.P. Canale. 1988. Load Allocation for Toxics Using Monte Carlo Techniques. *Journal WPCF* 60(5):659-66.

2. Freedman, P.L., J.F. Pendergast, C. Wilber, and S.C. Chang. 1988. Seasonal Changes and Effluent Limits. *Journal WPCF* 60(3):317-23.

3. Parkerton, T.F., S.M. Stewart, K.L. Dickson, J.H. Rodgers, and F.Y. Saleh. 1989. Derivation of Site-Specific Water Quality Criteria for Zinc: Implications for Wasteload Allocation. *Research Journal WPCF* 61(11,12):1636-44.

4. Shell Chemical Company NPDES Permit Nos. LA0005762, LA0050962, TX00048663, Appeal No. 85-14, 85-15, 85-16 before the Administrator, U.S. EPA. U.S. EPA Judicial Officer decision, October 20, 1987.

5. U.S. EPA. 1987. *Development Document for Effluent Guidelines and Standards for the Organic Chemicals, Plastics and Synthetic Fibers Point Source Category, volumes 1 and 2*; EPA 440/1-87/009.

6. U.S. EPA. 1988. *Toxicity Reductions Evaluation Protocol for Municipal Wastewater Treatment Plants.* EPA/600/2-88/062.

7. U.S. EPA. 1988. *Methods for Aquatic Toxicity Identification Evaluations*: Phase 1, Toxicity Characterization Procedures (EPA/600/3-88/034); *Phase 2, Toxicity Identification Procedures* (EPA/600/3-88/035); and *Phase 3, Toxicity Confirmation Procedures* (EPA/600/3-88/0360.

8. U.S. EPA. 1988. *Generalized Methodology for Conducting Industrial Toxicity Reduction Evaluations.* EPA/600/2-88/070.

ADDITIONAL REFERENCES

Aitchinson, J., and J.A.C Brown. 1963. *The Lognormal Distributions.* London: Cambridge University Press.

Gilliom, R.H., and D.R. Helse. 1986. Estimation of Distributional Parameters for Censored Trace Level Water Quality Data 1 and 2. *Water Resources Research* 22:135-55.

Kahn, H.D., and M.B. Rubin. 1989. Use of Statistical Methods in Industrial Water Pollution Control Regulations in the United States. *Environmental Monitoring and Assessment* 12:129-48.

Shumway, R.H., A.S. Azari, and P. Johnson. 1989. Estimating Mean Concentrations Under Transformation for Environmental Data with Detection Limits. *Technometrics* 31(3):347-56.