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Technical Support Document For Water Quality-based Toxics Control

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TECHNICAL SUPPORT DOCUMENT FOR WATER QUALITY-BASED TOXICS CONTROL

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Office of Water Enforcement and Permits
Office of Water Regulations and Standards
U.S. Environmental Protection Agency
Washington, DC 20460

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

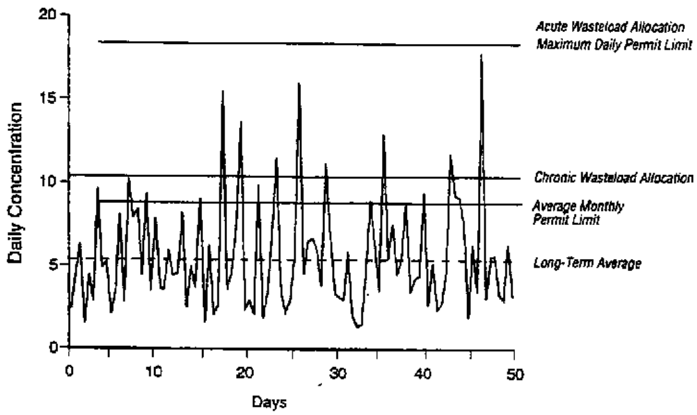

Figure 5-3. Relationship Between Daily Concnetrations, Long-Term Average, Wasteload Allocations, and Permit Limits

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.

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

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

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

$LTA_{a,c}$ $= WLA_{a,c} \bullet e\,[0.5\sigma_4^2 - 2.326\sigma_4] = 12.0 \bullet 0.249$

(from Table 5-1) $= 2.99$

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

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

From dynamic model output

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

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

From single wasteload allocation

Option 1

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

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

$AML = LTA \bullet e\,[2.326\sigma_n - 0.5\sigma_n^2]$ $= 6.29 \bullet 2.27$ (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.

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

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

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

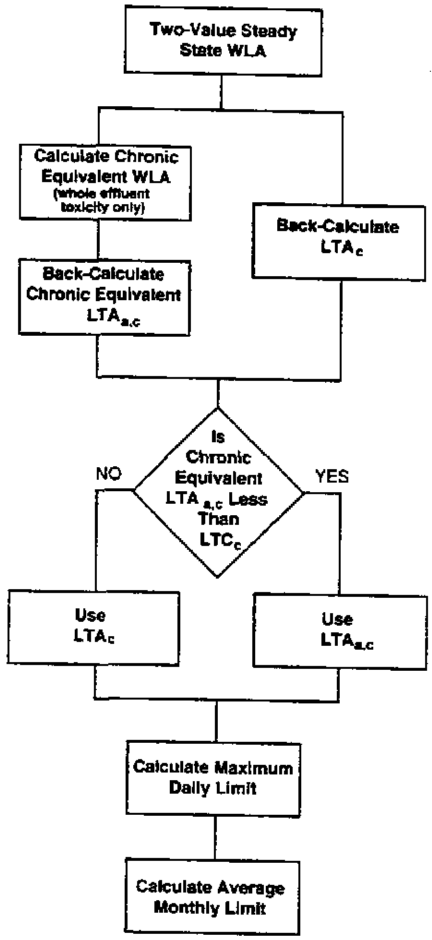

Figure 5-4. Flowchart for Calculating Permit Limits From Two-Value, Steady-State Wasteload Allocation for Aquatic Life Protection

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

CV	WLA Multipliers $e^{[0.5\sigma^2 - z\sigma]}$ 95th Percentile	WLA Multipliers $e^{[0.5\sigma^2 - z\sigma]}$ 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

Acute

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

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	WLA Multipliers $e^{[0.5\sigma_4^2 - z\sigma_4]}$ 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.