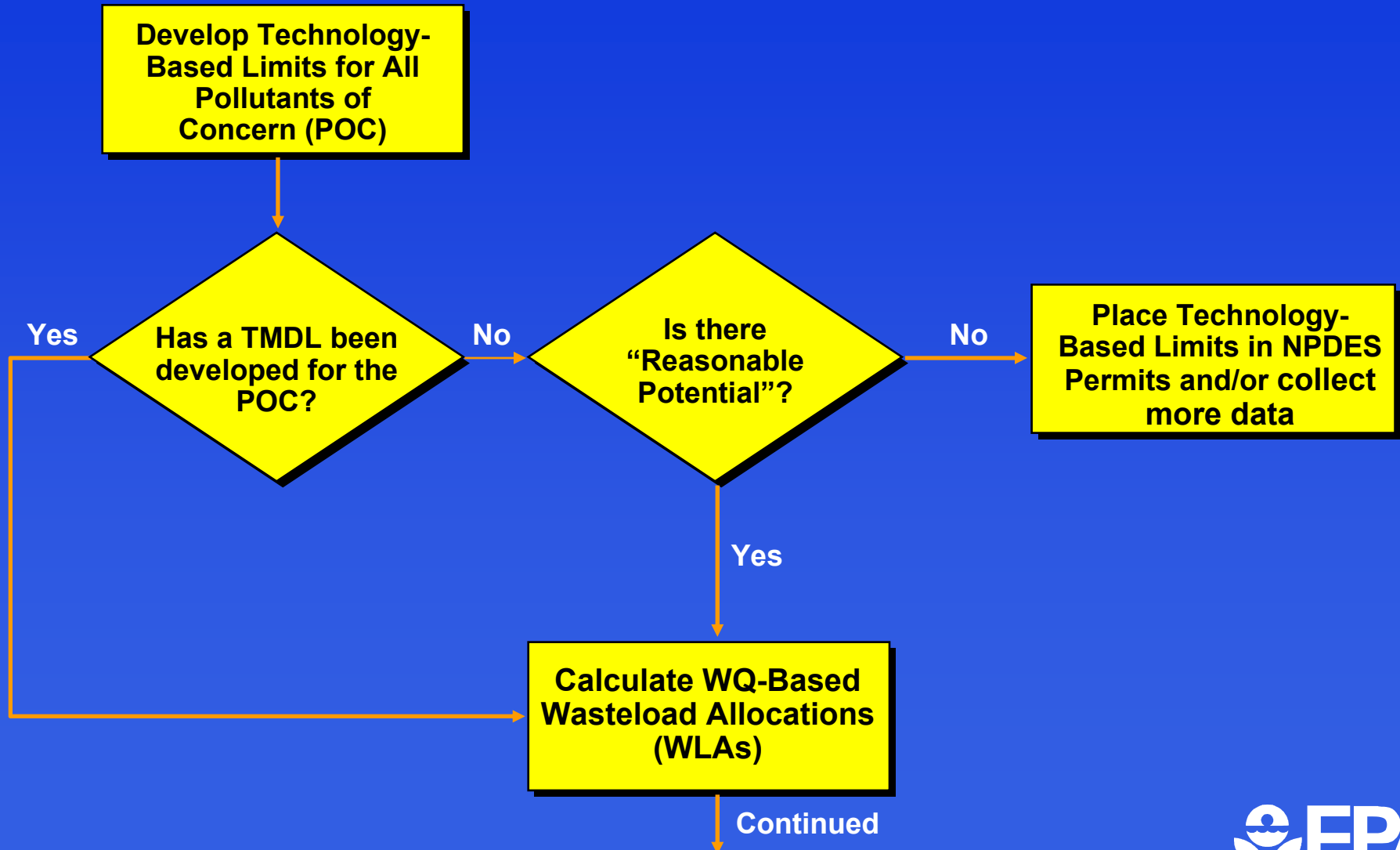


Developing Chemical-Specific Water Quality-Based Effluent Limitations for Toxic Pollutants

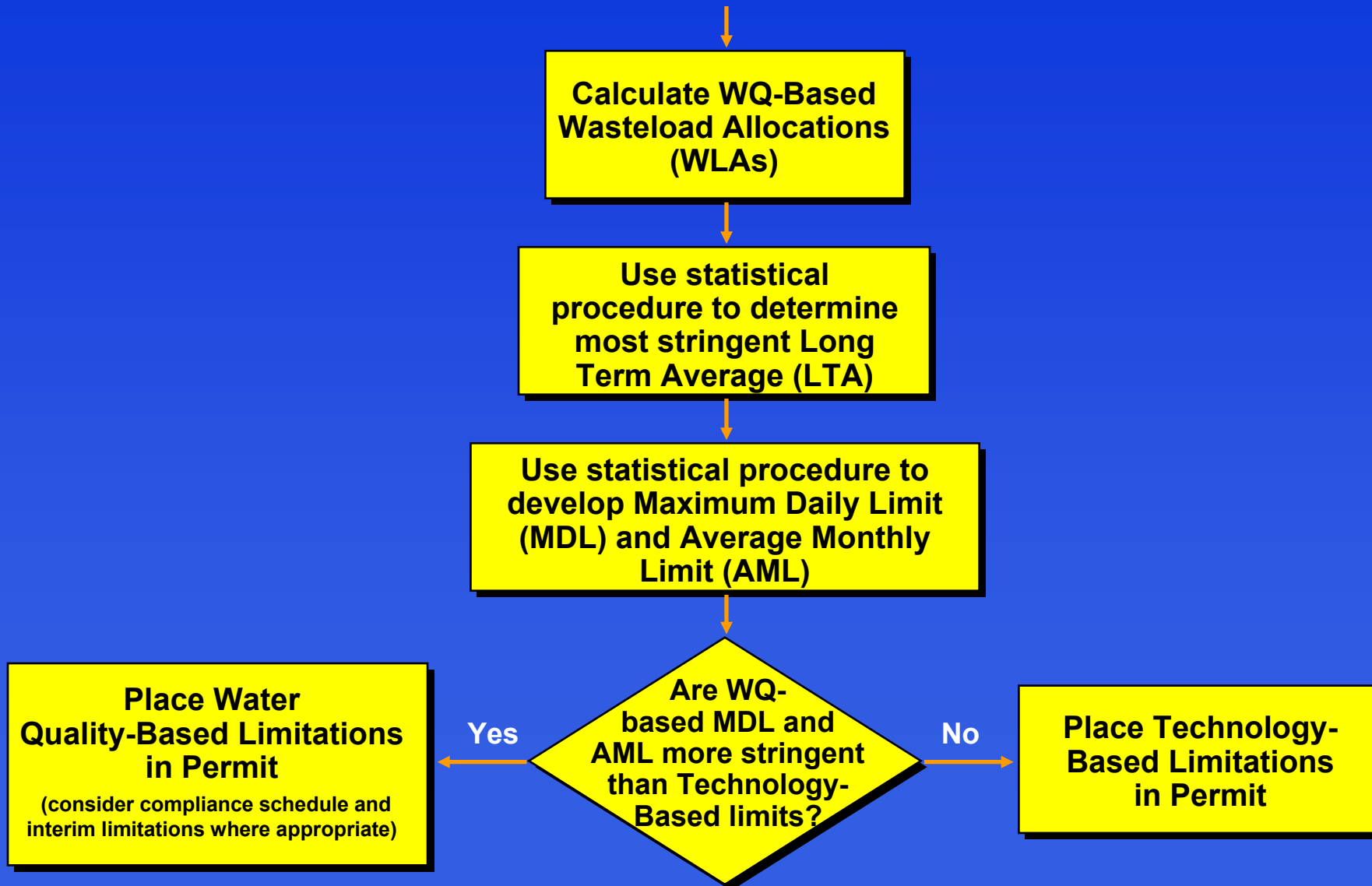
Learning Objectives

- ◆ Review process for determining “reasonable potential” for toxic pollutants
- ◆ Discuss procedures for calculating wasteload allocations
- ◆ Explain steps for translating a wasteload allocation into water quality-based effluent limitations for toxic pollutants

Standards-to-Permits Process



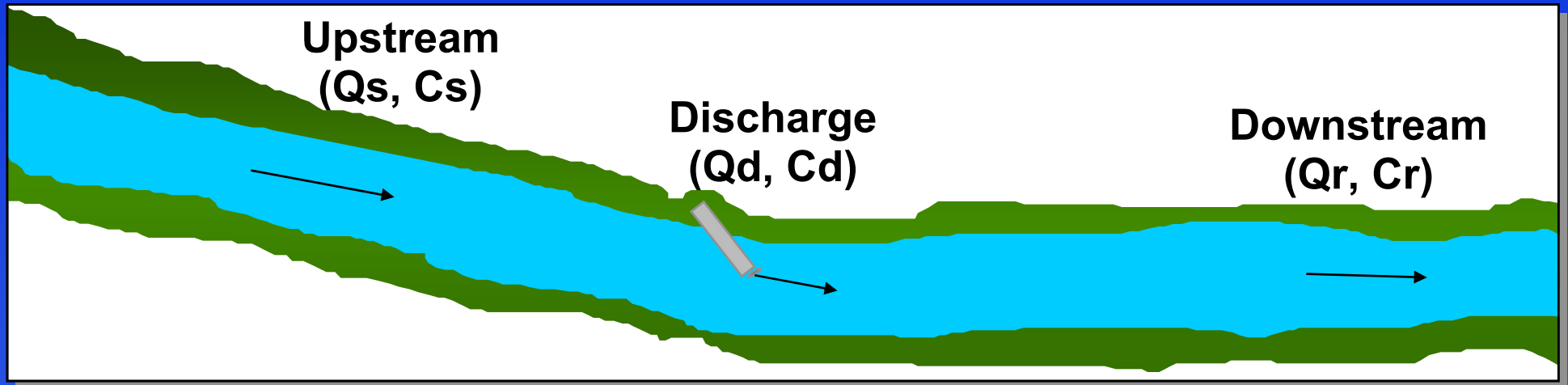
Standards-to-Permits Process (Continued)



Reasonable Potential - 40 CFR 122.44(d)(1)(ii)

- ◆ **The permit writer is required to consider:**
 - Existing controls on point and nonpoint sources
 - Effluent variability
 - Sensitivity of species to toxicity testing and, where appropriate, dilution

Mass-Balance Equation

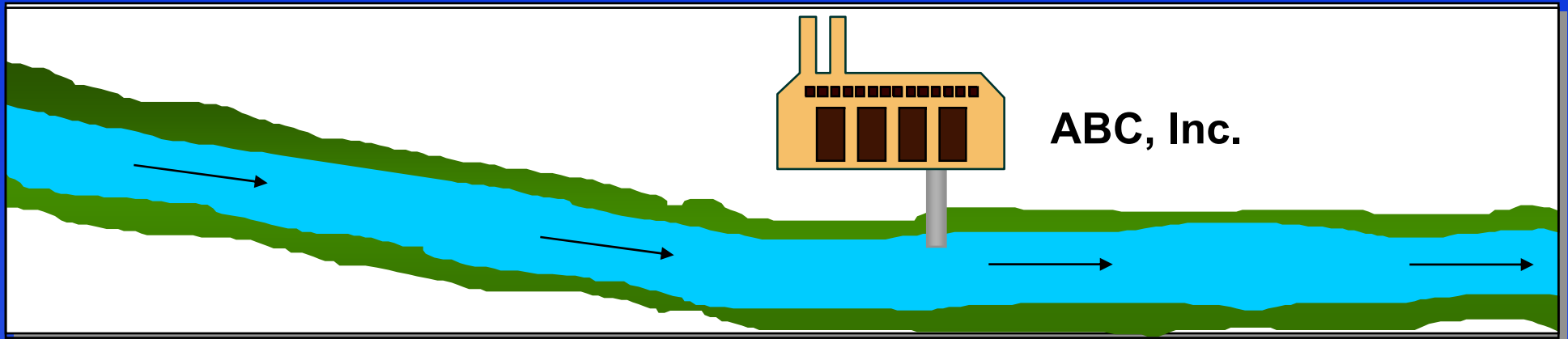
$$Q_d C_d + Q_s C_s = Q_r C_r$$


- ◆ Q = Flow (mgd or cfs)
- ◆ C = Pollutant concentration (mg/l)
- ◆ Mass = [Concentration] [Flow]
- ◆ $Q_d C_d + Q_s C_s = Q_r C_r$
- ◆ To determine pollutant concentration in the stream:

$$C_r = \frac{Q_d C_d + Q_s C_s}{Q_r}$$

Note: $Q_r = Q_s + Q_d$

Is There “Reasonable Potential”?



Assume: Rapid and complete mixing

Qs = Upstream river flow available for dilution = 1.2 cfs

Qd = Discharge flow = 0.31 cfs

Cs = Upstream river concentration = 0.8 mg/l

Cd = Discharge concentration = 1.5 mg/l

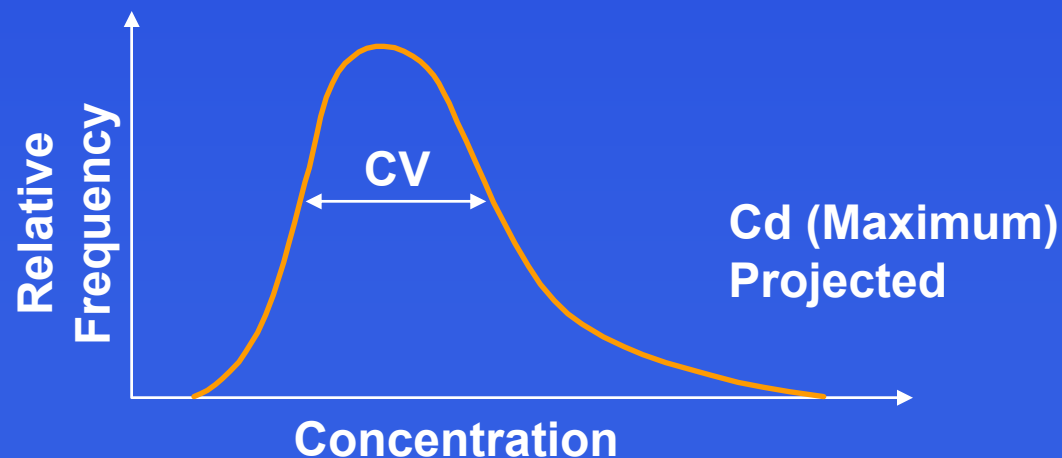
Acute Criterion from WQS = 1.0 mg/l

$$C_r = \frac{Q_d C_d + Q_s C_s}{Q_r} = \frac{(0.31)(1.5) + (1.2)(0.8)}{1.2 + 0.31}$$

$$C_r = 0.94 \text{ mg/l}$$

Projecting a Maximum Value for Cd

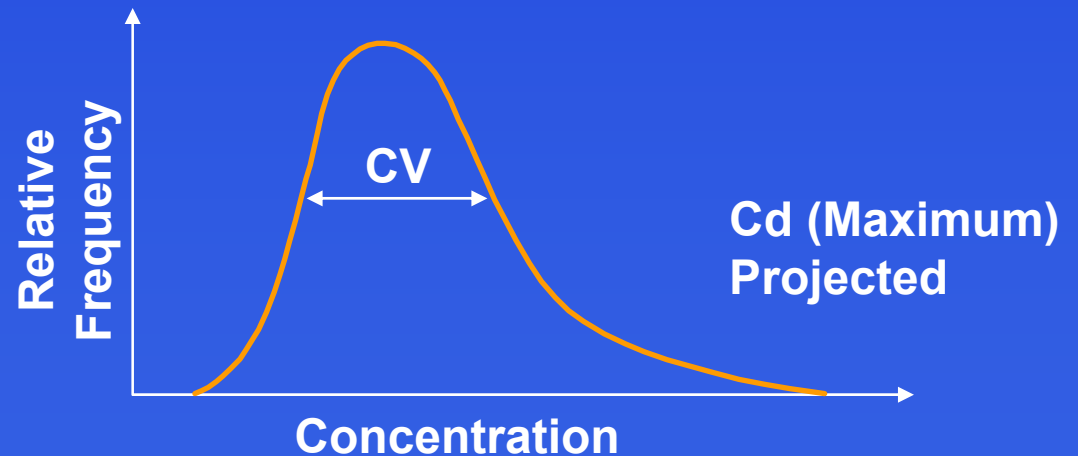
- ◆ We must consider
 - Effluent variability - defined by the coefficient of variation (CV)
 - Uncertainty due to a limited number of data points
 - Desired upper-bound of the expected lognormal distribution



Statistical Approach

◆ Selected Percentile

- What is the upper bound value of the discharge pollutant concentration that we want to determine?
 - 99th percentile?
 - 95th percentile?
 - Other?



Statistical Approach

◆ Confidence Level

- What confidence level do we want for our upper bound value?
 - 99% confidence?
 - 95% confidence?
 - Other?
- At the 99% confidence level:
 - the largest value of 5 samples is greater than the 40th percentile
 - the largest value of 330 samples is greater than the 99th percentile

Projecting a Maximum Value for Cd

- ◆ How do you determine Cd with a 99% confidence level at the 99% upper bound?
 - Options:
 - 1) Take the maximum value of 330 or more samples
 - 2) Project a maximum value from existing data using a multiplier

Reasonable Potential Multiplying Factors

(99% Confidence Level and 99% Probability Basis)

Sample Number	Coefficient of Variation									
	N	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8
1	2.5	6.0	13.2	26.5	48.3	81.4	128.0	190.3	269.9	368.3
2	2.0	4.0	7.4	12.7	20.2	30.3	43.0	58.4	76.6	97.5
3	1.9	3.3	5.6	8.9	13.4	19.0	25.7	33.5	42.3	52.0
4	1.7	2.9	4.7	7.2	10.3	14.2	18.6	23.6	29.1	35.1
5	1.7	2.7	4.2	6.2	8.6	11.5	14.8	18.4	22.4	26.5
6	1.6	2.5	3.8	5.5	7.5	9.8	12.4	15.3	18.3	21.5
7	1.6	2.4	3.6	5.0	6.7	8.7	10.8	13.1	15.6	18.2
8	1.5	2.3	3.3	4.6	6.1	7.8	9.6	11.6	13.6	15.8
9	1.5	2.2	3.2	4.3	5.7	7.1	8.7	10.4	12.2	14.0
10	1.5	2.2	3.0	4.1	5.3	6.6	8.0	9.5	11.0	12.6
11	1.4	2.1	2.9	3.9	5.0	6.2	7.4	8.8	10.1	11.5
12	1.4	2.0	2.8	3.7	4.7	5.8	7.0	8.1	9.4	10.6
13	1.4	2.0	2.7	3.6	4.5	5.5	6.5	7.6	8.7	9.9
14	1.4	2.0	2.6	3.4	4.3	5.2	6.2	7.2	8.2	9.2
15	1.4	1.9	2.6	3.3	4.1	5.0	5.9	6.8	7.7	8.7
16	1.4	1.9	2.5	3.2	4.0	4.8	5.6	6.5	7.3	8.2
17	1.4	1.9	2.5	3.1	3.8	4.6	5.4	6.2	7.0	7.8
18	1.4	1.9	2.4	3.0	3.7	4.4	5.2	5.9	6.7	7.4
19	1.4	1.8	2.4	3.0	3.6	4.3	5.0	5.7	6.4	7.1
20	1.3	1.8	2.3	2.9	3.5	4.2	4.8	5.5	6.1	6.8

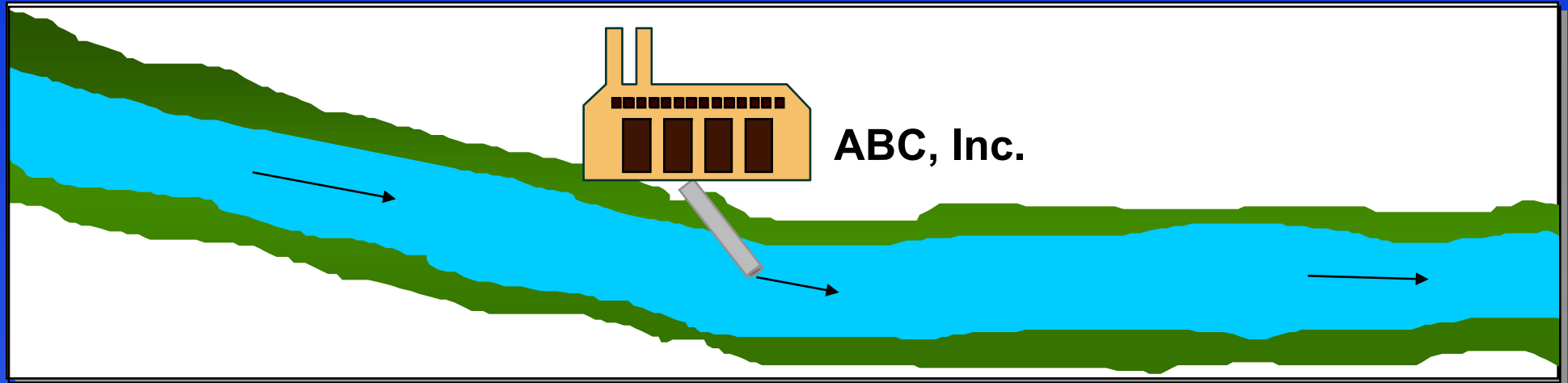


Projecting a Maximum Value for Cd

◆ Re-examine data for ABC, Inc.

- Number of samples (n) = 8
- CV = 0.6 (default value if $n < 10$)
- Maximum Observed Value of Effluent Concentration (Cd) = 1.5 mg/l
- Projected Maximum Value of Cd = 1.5 mg/l x multiplier
= 1.5 mg/l x 3.3
= 5.0 mg/l

Is There Reasonable Potential to Exceed Water Quality Standards?



Q_s	=	Upstream river flow available for dilution	=	1.2 cfs
Q_d	=	Discharge flow	=	0.31 cfs
C_s	=	Upstream river concentration	=	0.8 mg/l
C_d	=	<i>Maximum observed</i> discharge concentration	=	1.5 mg/l
		Acute criterion from WQS	=	1.0 mg/l
C_r	=	$\frac{Q_d C_d + Q_s C_s}{Q_r}$		

Is There Reasonable Potential to Exceed Water Quality Standards? (Continued)

◆ Projected maximum Cd = 1.5 mg/l x 3.3
= 5.0 mg/l

◆ Cr = $\frac{(0.31)(5.0) + (1.2)(0.8)}{1.2 + 0.31}$

= 1.7 mg/l

1.7 mg/l > 1.0 mg/l (WQS - Acute criterion)



Steps in Developing Chemical-Specific Water Quality-Based Effluent Limits

Acute and Chronic Wasteload Allocations (WLAs)

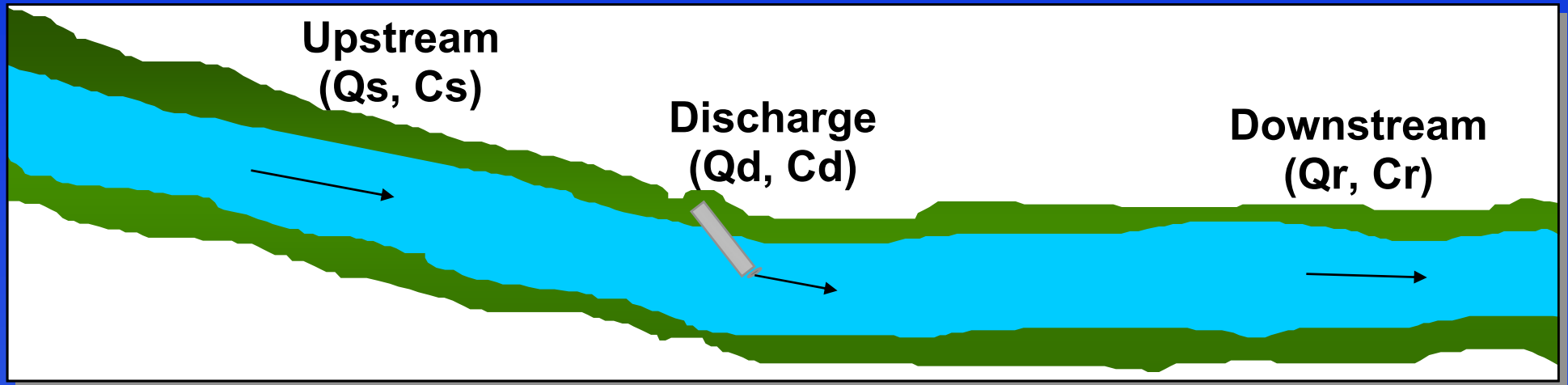
Step 1: Calculate Long-Term Average (LTA) for Both WLAs

Step 2: Select Lowest LTA

Step 3: Calculate Maximum Daily Limit (MDL) and Average Monthly Limit (AML)



Mass-Balance Equation

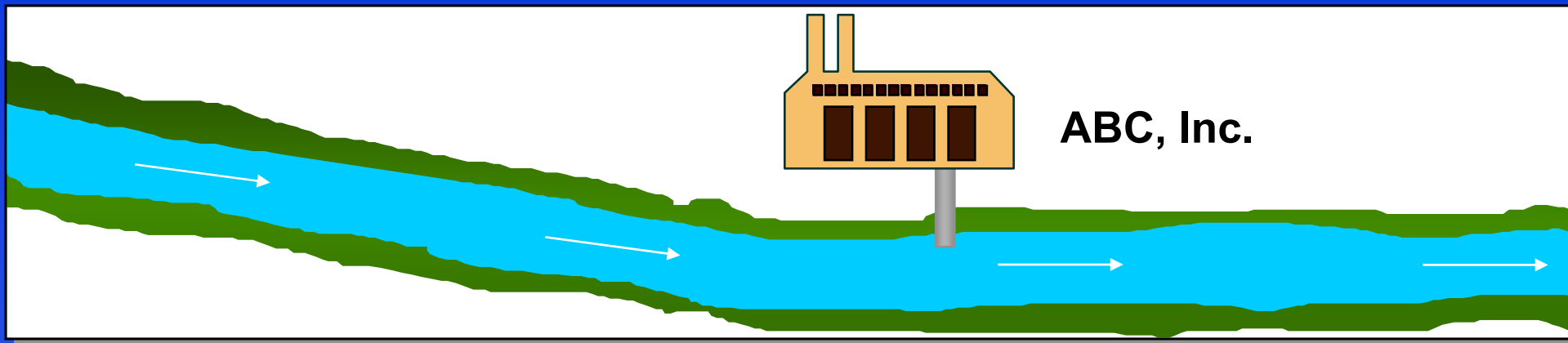
$$Q_d C_d + Q_s C_s = Q_r C_r$$


- ◆ Q = Flow (mgd or cfs)
- ◆ C = Pollutant concentration (mg/l)
- ◆ Mass = [Concentration] [Flow]
- ◆ $Q_d C_d + Q_s C_s = Q_r C_r$
- ◆ Determine allowable discharge concentration (WLA):

$$C_d = \frac{Q_r C_r - Q_s C_s}{Q_d}$$

Note: $Q_r = Q_s + Q_d$

What is the maximum allowable pollutant concentration in the ABC, Inc. effluent assuming complete mixing?



Q_s = Upstream river flow

$1Q_{10}$ = 1.2 cfs

Q_d = Discharge flow

$7Q_{10}$ = 3.6 cfs

C_s = Upstream river conc.

= 0.31 cfs

= 0.8 mg/l

C_r = Water Quality Criterion

Acute

= 1.0 mg/l (applied at $1Q_{10}$)

Chronic

= 0.9 mg/l (applied at $7Q_{10}$)

$$C_d = WLA = \frac{C_r(Q_d + Q_s) - C_s Q_s}{Q_d}$$

$$C_d(\text{acute}) = WLA_a = 1.8 \text{ mg/l}$$

$$C_d(\text{chronic}) = WLA_c = 2.1 \text{ mg/l}$$



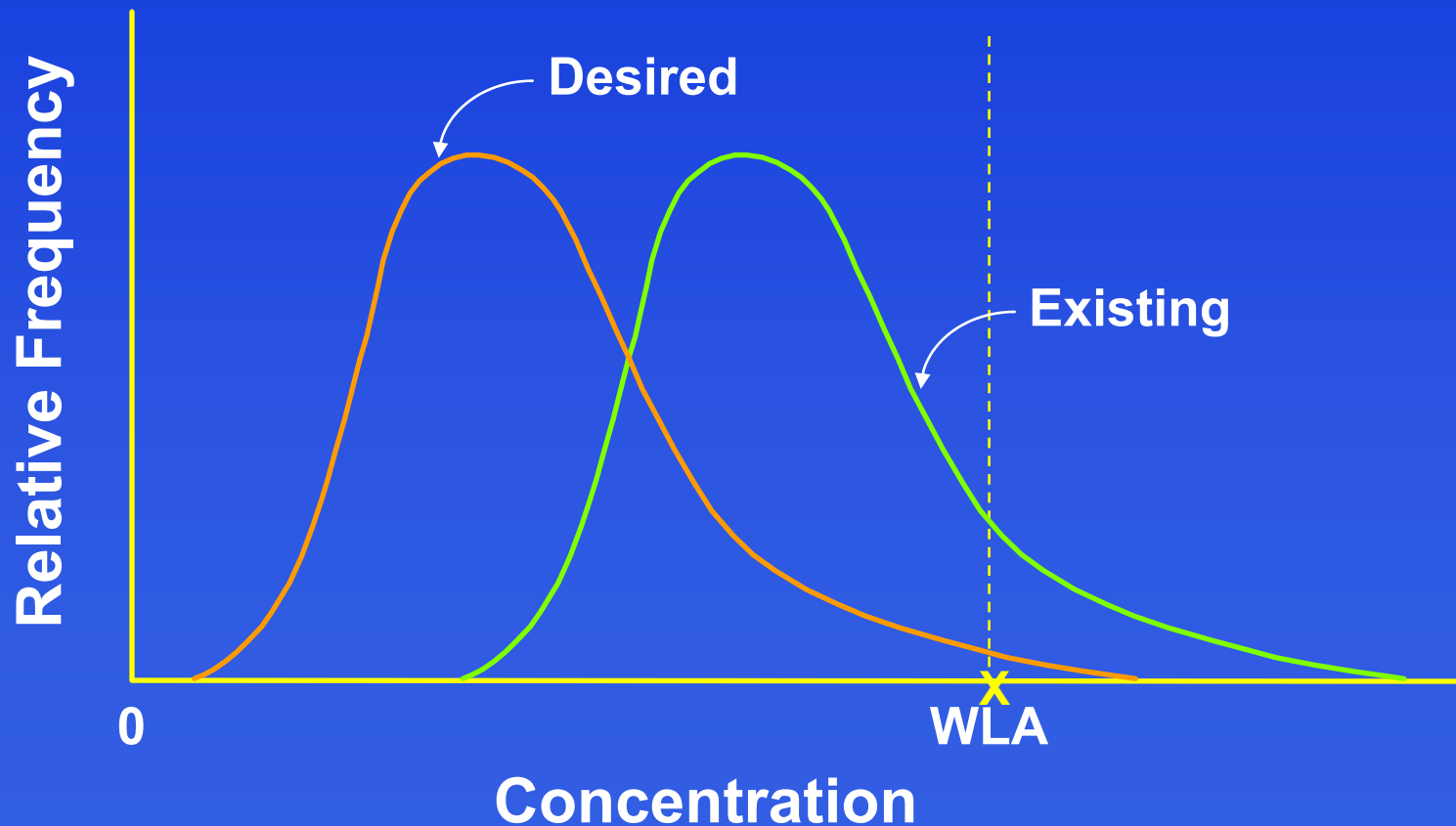
Need a Common Statistical Basis

- ◆ WLA_a typically expressed as 1-day average
- ◆ WLA_c typically expressed as 4-day average
- ◆ LTA establishes common statistical basis and allows direct comparison

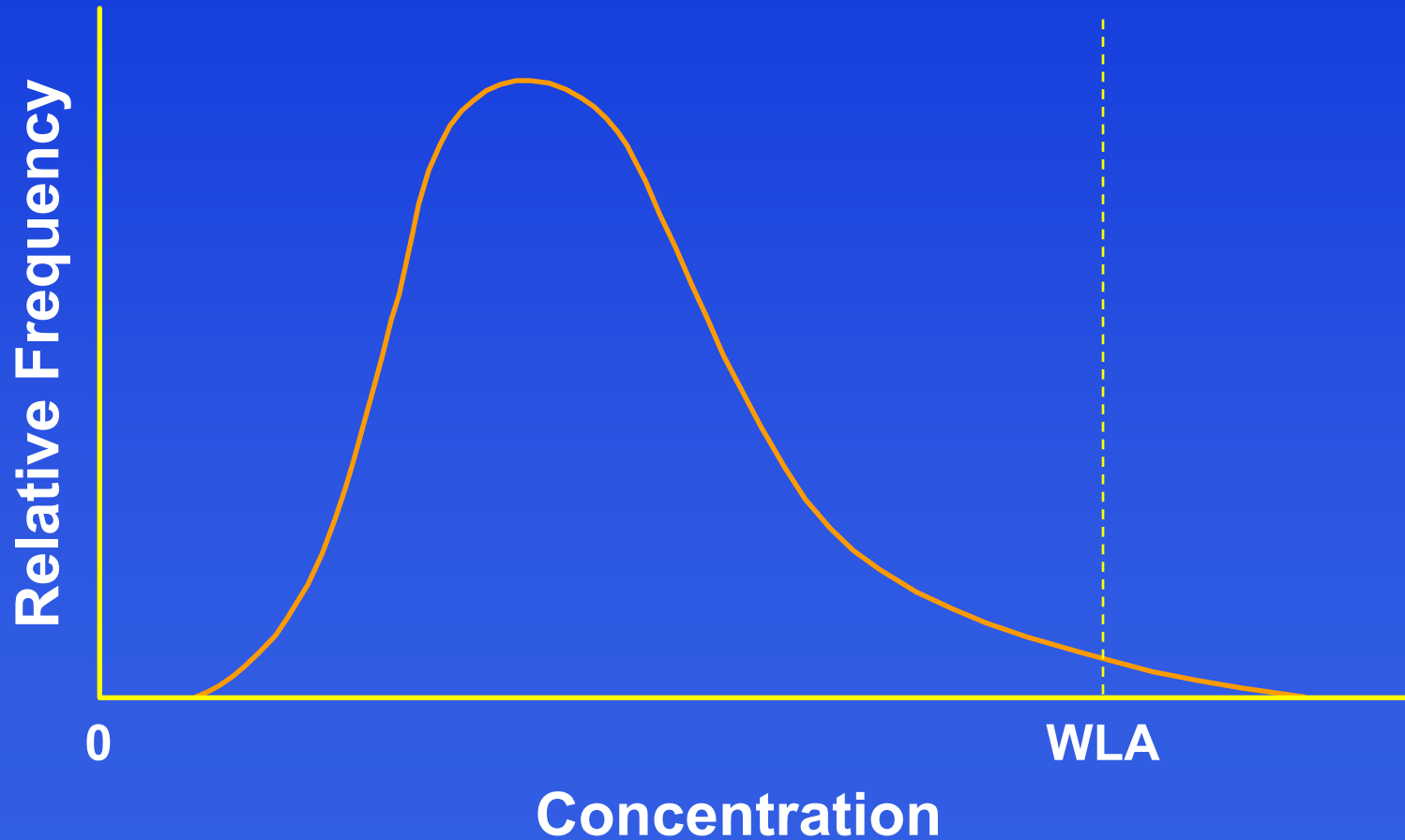
Step 1: Calculate LTAs

- ◆ **Wasteload allocation (WLA) is “never to be exceeded”**
- ◆ **Assume a lognormal effluent distribution**
- ◆ **Characterize “never to be exceeded” by a probability (e.g., WLA is the 99th percentile concentration on the lognormal effluent distribution)**

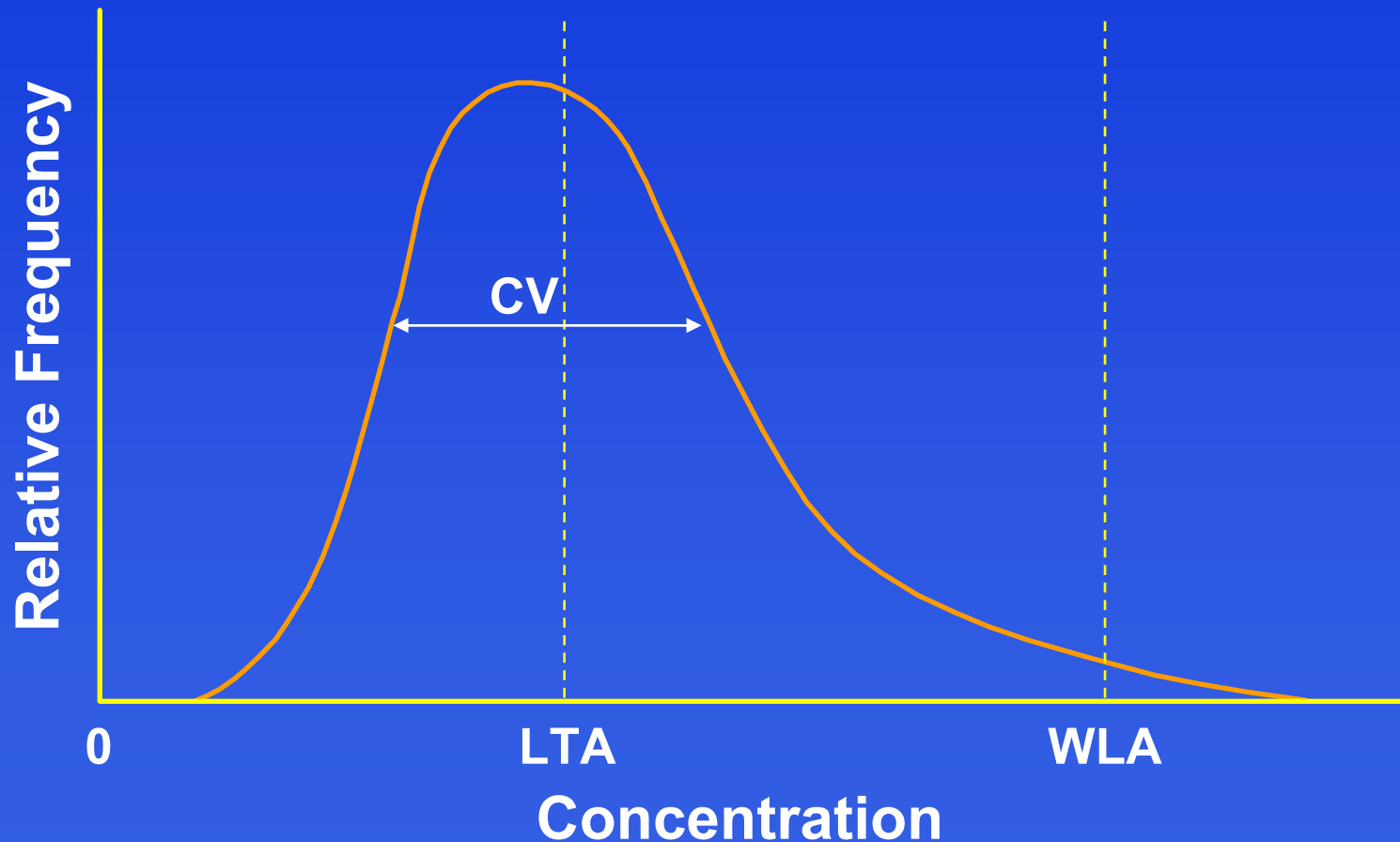
Goal is to Reduce Effluent Concentrations to Below the WLA



This Distribution Achieves the Goal



We Can Characterize the Desired Distribution by LTA and CV



Acute WLA Multiplier

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

Acute

$$LTA_a = WLA_a \cdot e^{[0.5 \sigma^2 - z\sigma]}$$

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 WLA Multiplier

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

**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

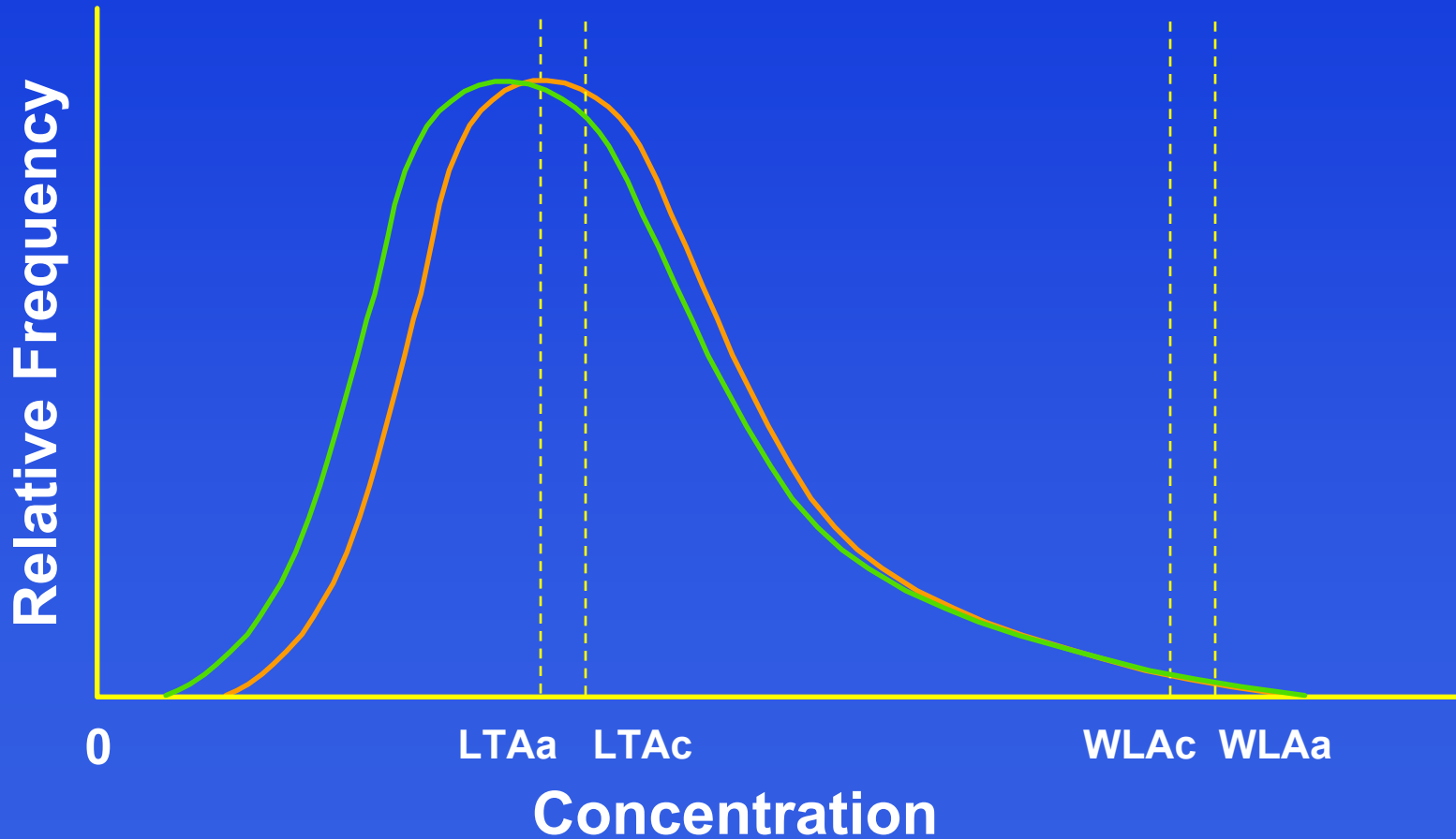
$z = 2.326$ for 99th percentile occurrence probability



Step 2: Select Lowest LTA

- ◆ Protects both WLAs (acute and chronic)
- ◆ Sets one basis for facility performance

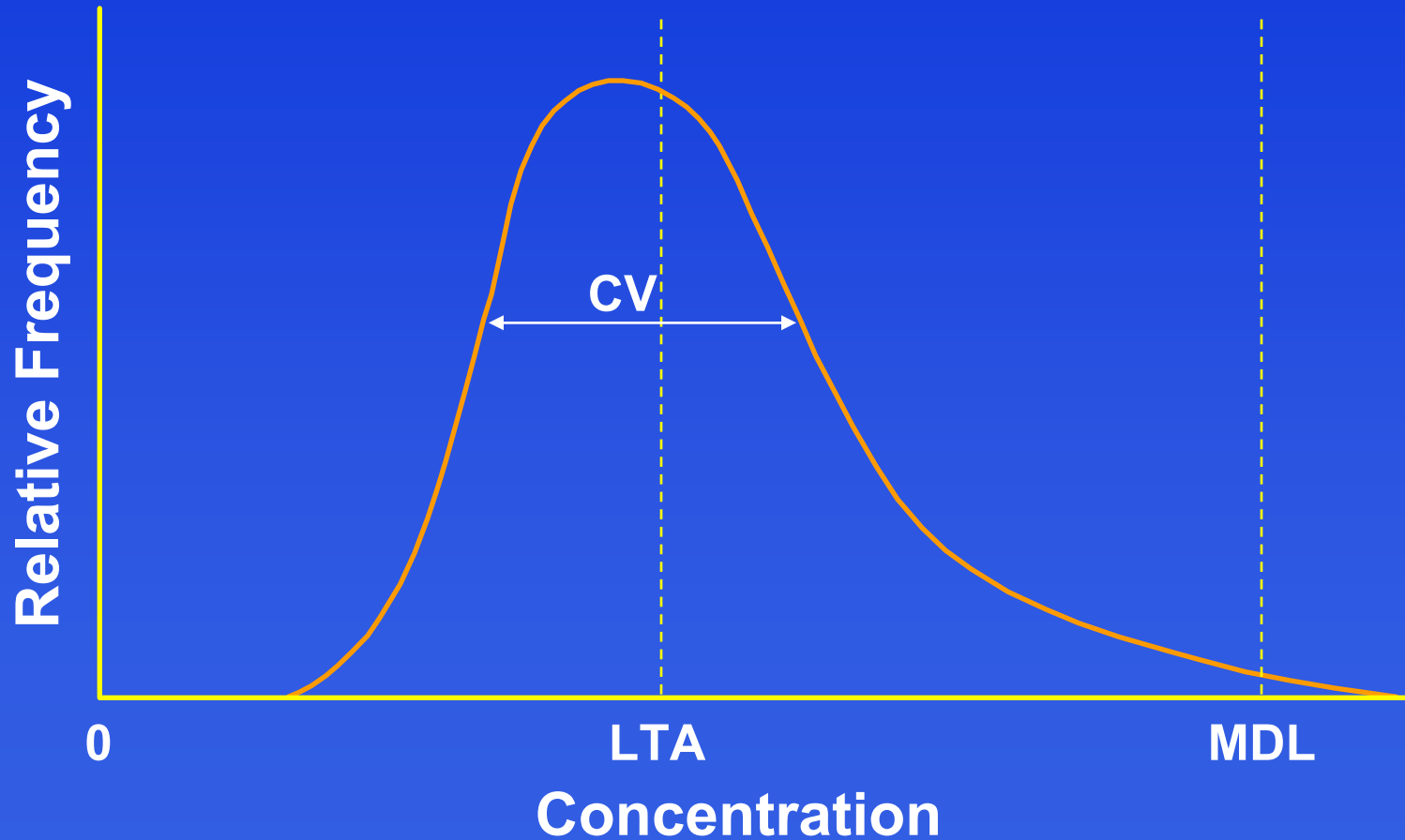
Because There Are Two LTAs, We Need to Use the More Stringent



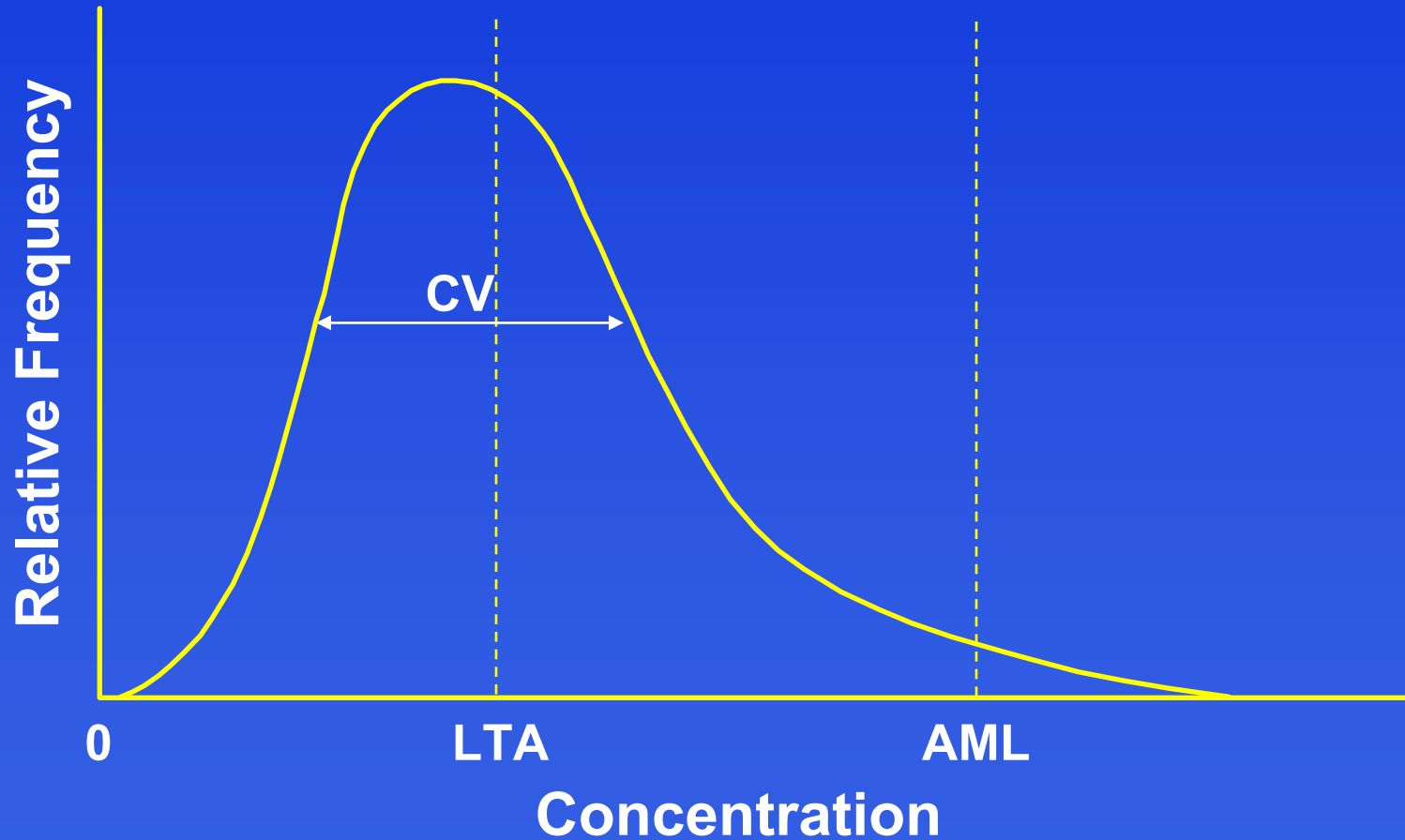
Step 3: Calculate MDL and AML

- ◆ **Allows comparison to technology-based limits**
- ◆ **Uses upper-bound estimates for both MDL and AML**
- ◆ **Ties AML to planned frequency of monitoring**

We Can Characterize the Upper Bounds of the Effluent from the LTA and CV



We Can Characterize the Upper Bounds of the Effluent from the LTA and CV



Daily LTA Multiplier

Maximum Daily Limit (MDL)

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

where: $\sigma^2 = \ln[\text{CV}^2 + 1]$

$z = 1.645$ for 95th percentile occurrence probability, and

$z = 2.326$ for 99th percentile occurrence probability

CV	LTA multipliers	
	$e^{[z\sigma - 0.5\sigma^2]}$	
	95th percentile	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



Monthly LTA Multiplier

Average Monthly Limit

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

where: $\sigma_n^2 = \ln[CV^2/n + 1]$.

z = 1.645 for 95th percentile occurrence probability, and

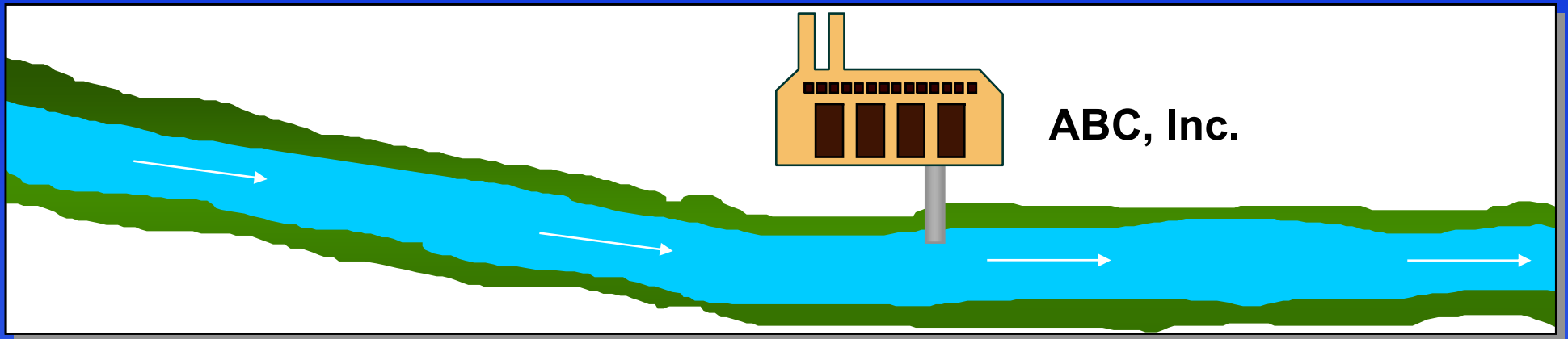
z = 2.326 for 99th percentile occurrence probability

n = number of samples/month

CV	LTA multipliers									
	$e^{[z\sigma_n - 0.5\sigma_n^2]}$									
	95th percentile					99th percentile				
	n=1	n=2	n=4	n=8	n=30	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	1.56	1.37	1.25	1.16	1.08
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	1.96	1.66	1.45	1.31	1.16	2.68	2.09	1.72	1.42	1.23
0.6	2.13	1.90	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



Example



Recall that we calculated the following WLAs:

$\text{Cd}(\text{acute}) = 1.8 \text{ mg/l}$

$\text{Cd}(\text{chronic}) = 2.1 \text{ mg/l}$

Step 1: Calculate LTAs

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

Acute

$$CV = 0.6$$

$$WLA(\text{acute}) = 1.8 \text{ mg/l}$$

$$= 99\text{th percentile value}$$

$$LTA(\text{acute}) = 1.8 \text{ mg/l} \times 0.321$$

$$= 0.58 \text{ mg/l}$$



Step 1: Calculate LTAs

CV	WLA multipliers	
	$e^{[0.5 \frac{\sigma^2}{4} - z\sigma_4]}$	
	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

Chronic

CV = 0.6
WLA(chronic) = 2.1 mg/l
 = 99th percentile value
LTA(chronic) = 2.1 mg/l x 0.527
 = 1.1 mg/l



Step 2: Select Lowest LTA

- ◆ **LTA(acute) = 0.58 mg/l**
- ◆ **LTA(chronic) = 1.1 mg/l**
- ◆ **Select LTA(acute) = 0.58 mg/l**

Step 3: Calculate MDL and AML

CV	LTA multipliers	
	$e^{[z\sigma - 0.5\sigma^2]}$	
	95th percentile	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

MDL

CV = 0.6

MDL = 99th percentile value

**MDL = 0.58 mg/l x 3.11
= 1.8 mg/l**



Step 3: Calculate MDL and AML (Continued)

CV	LTA multipliers									
	$e^{[z\sigma_n - 0.5\sigma_n^2]}$									
	95th percentile					99th percentile				
	n=1	n=2	n=4	n=8	n=30	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	1.56	1.37	1.25	1.16	1.08
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	1.96	1.66	1.45	1.31	1.16	2.68	2.09	1.72	1.42	1.23
0.6	2.13	1.90	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

AML

Number of Samples = 8 (assume twice-weekly sampling)

CV = 0.6

AML = 95th percentile value

AML = 0.58 mg/l x 1.38
= 0.80 mg/l

