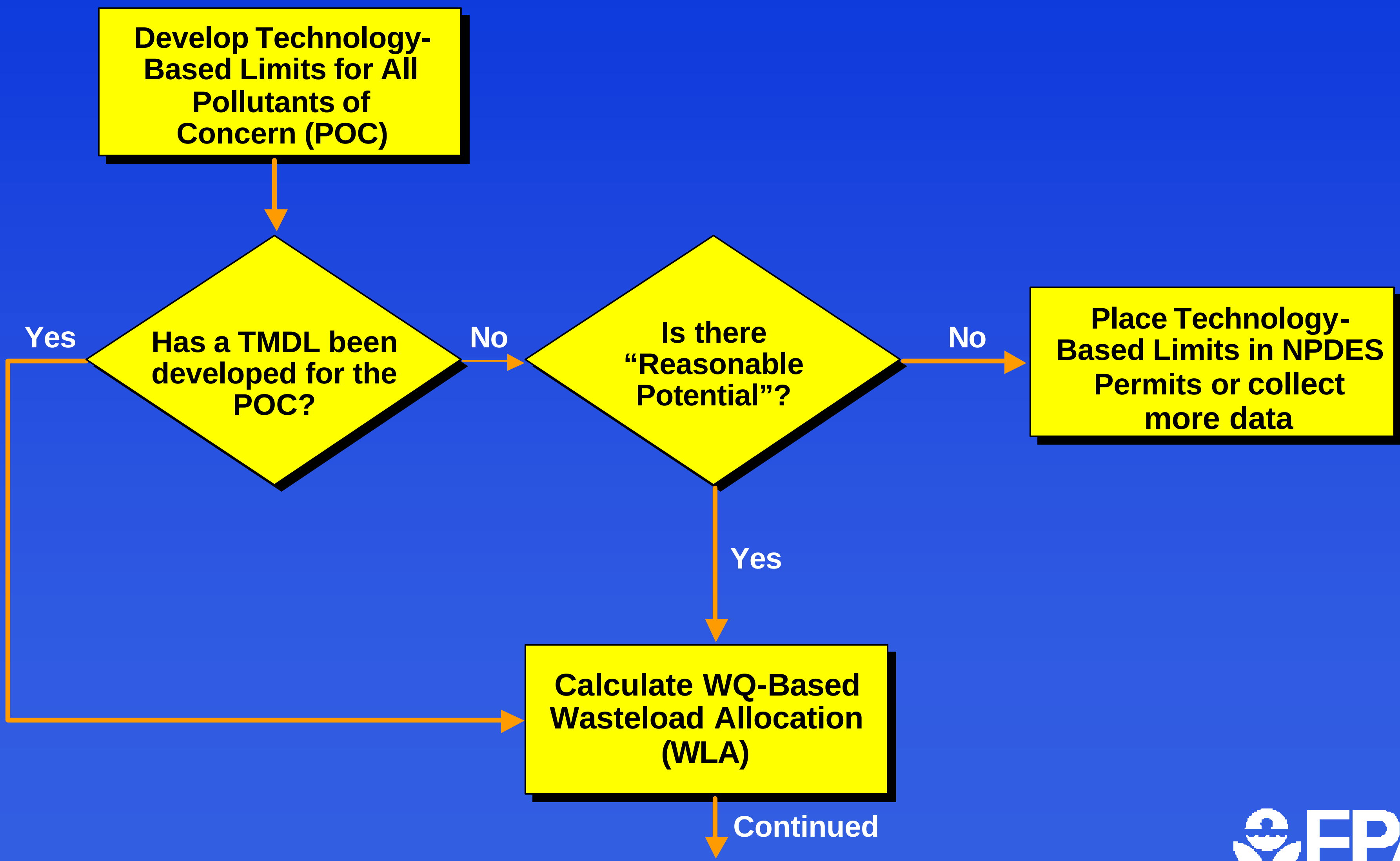
Developing Chemical-Specific Water Quality-Based Effluent Limits

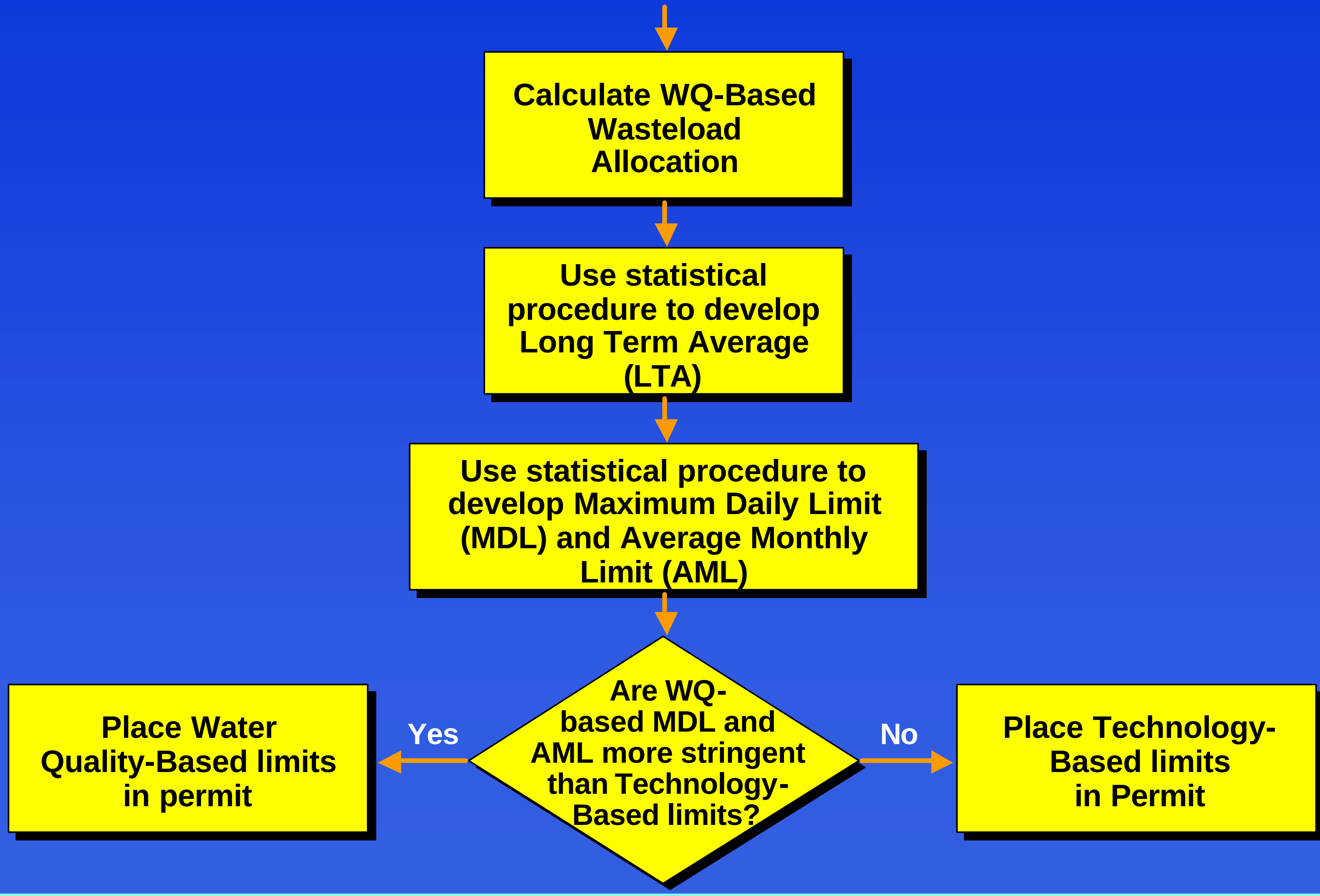
Learning Objectives

- Review process for determining "reasonable potential"
- Discuss procedures for calculating wasteload allocations
- Explain steps for translating a wasteload allocation into water quality-based effluent limits

Standards-to-Permits Process



Standards-to-Permits Process
(Continued)



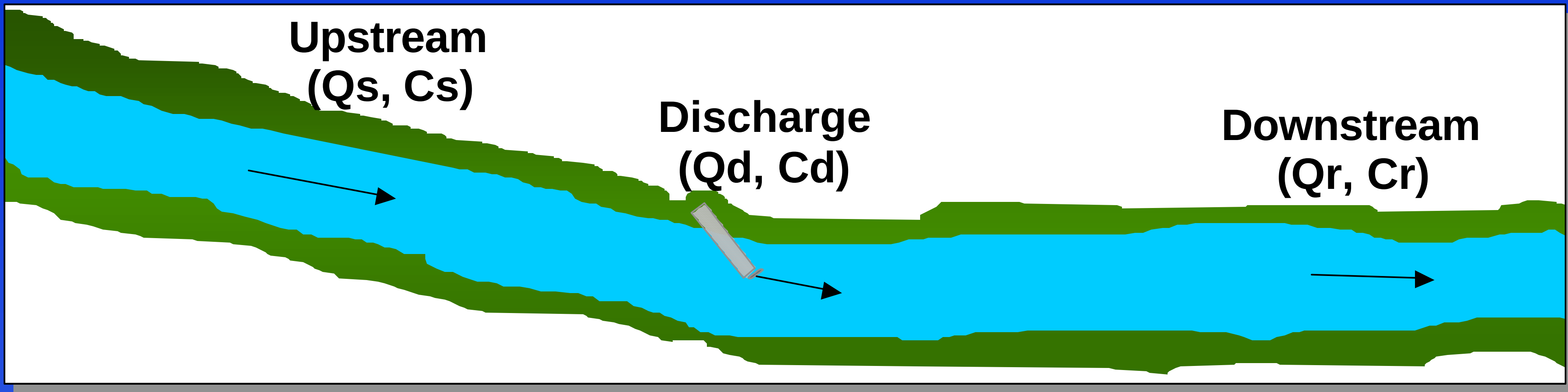
Reasonable Potential 40 CFR §122.44(d)(1)(ii)

- 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

Determining the Need for Water Quality-Based Effluent Limits

Criteria	Type of Limit	Regulatory Cite
Chemical-specific	Chemical-specific	40 CFR §122.44(d)(1)(iii)
WET numeric	WET	40 CFR §122.44(d)(1)(iv)
Narrative	WET or Chemical specific	40 CFR §122.44(d)(1)(v-vi)

Mass-Balance Equation
QdCd + QsCs = QrCr



- Q = Flow (mgd or cfs)
- C = Pollutant concentration (mg/l)
- Mass = [Concentration] [Flow]
- QdCd + QsCs = QrCr
- To determine pollutant concentration in the stream:

$$Cr = \frac{QdCd + QsCs}{Qr}$$

Note: Qr = Qs + Qd

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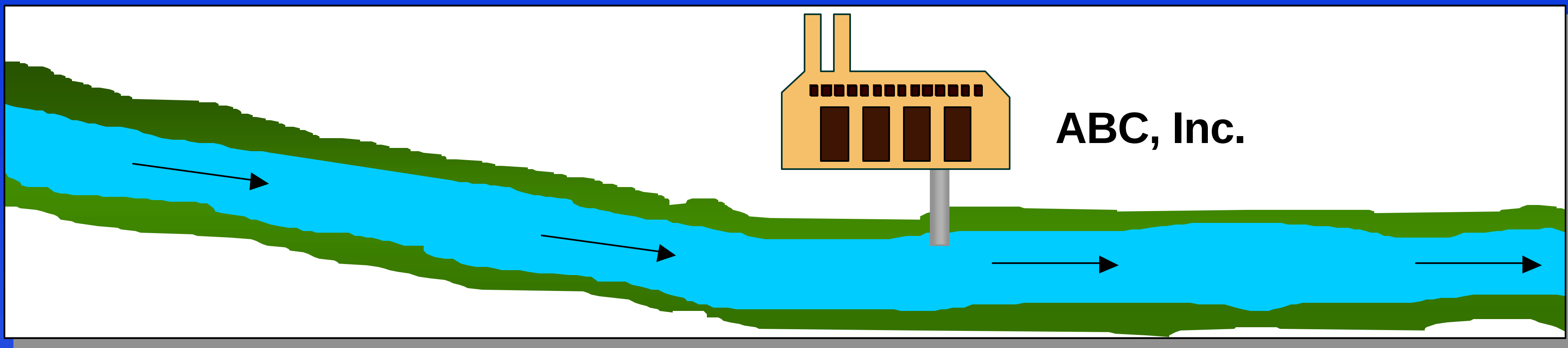
Is There Reasonable Potential to Exceed Water Quality Standards?



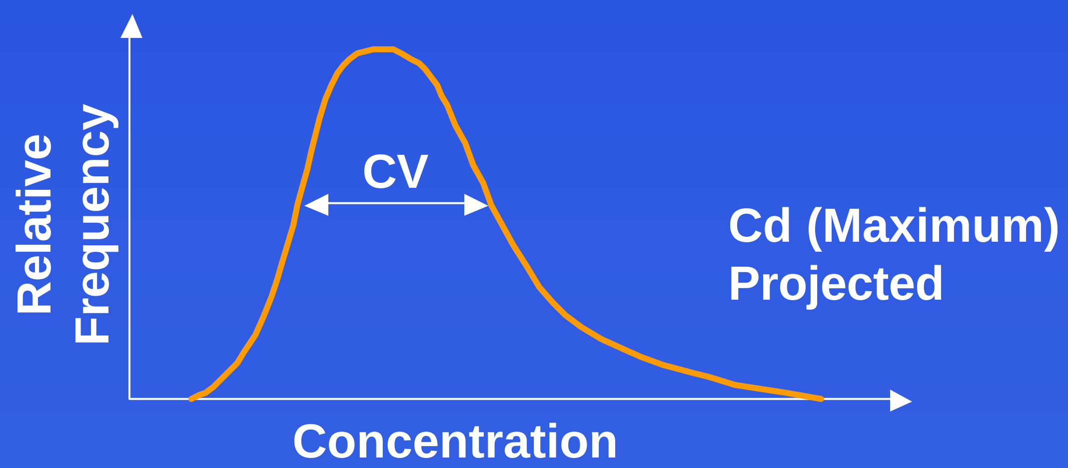
Qs	= Upstream river flow (1Q10)	=	1.2 cfs
Qd	= Discharge flow	=	0.31 cfs
Cs	= Upstream river concentration	=	0.8 mg/l
Cd	= Discharge concentration	=	1.5 mg/l
Water Quality Standard (acute criterion)		=	1.0 mg/l

$$Cr = \frac{QdCd + Qs\,Cs}{Qr} = \frac{(0.31)(1.5) + (1.2)(0.8)}{1.2 + 0.31}$$

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

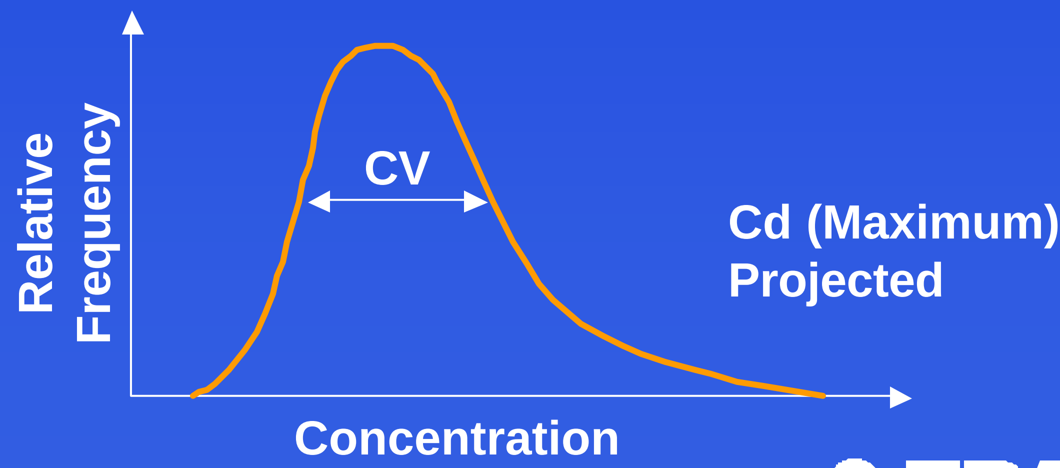
Projecting a Maximum Value for Cd

- 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

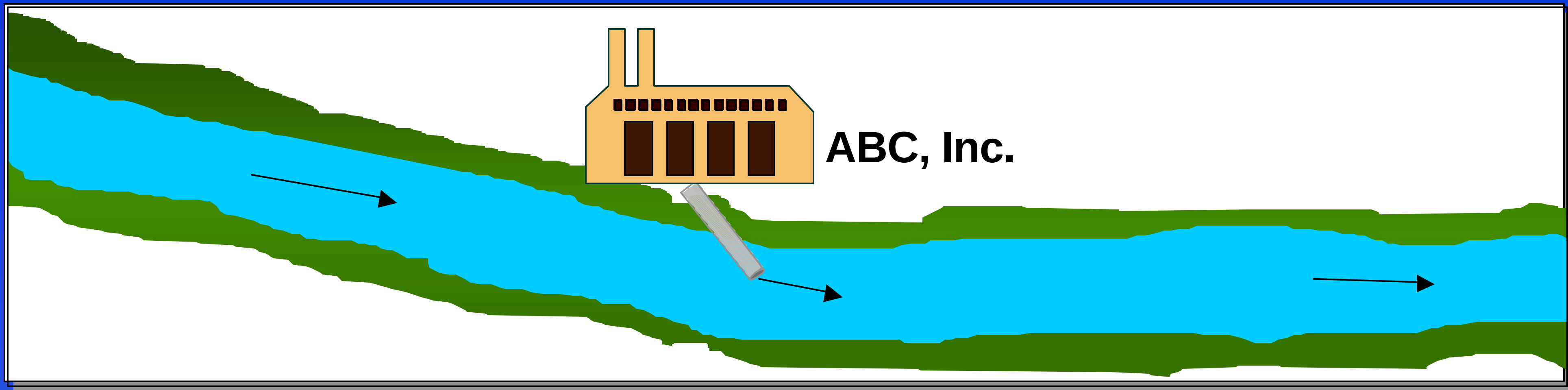
(99% Confidence Level and 99% Probability Basis)

Sample Number	Coefficient of Variation									
N	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0
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	3.7	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?



Qs	=	Upstream river flow	1Q10	=	1.2 cfs
Qd	=	Discharge flow		=	0.31 cfs
Cs	=	Upstream river concentration		=	0.8 mg/l
Cd	=	*Maximum observed* discharge concentration		=	1.5 mg/l
		Water Quality Standard (Acute Criterion)		=	1.0 mg/l

$$Cr = \frac{QdCd + QsCs}{Qr}$$

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

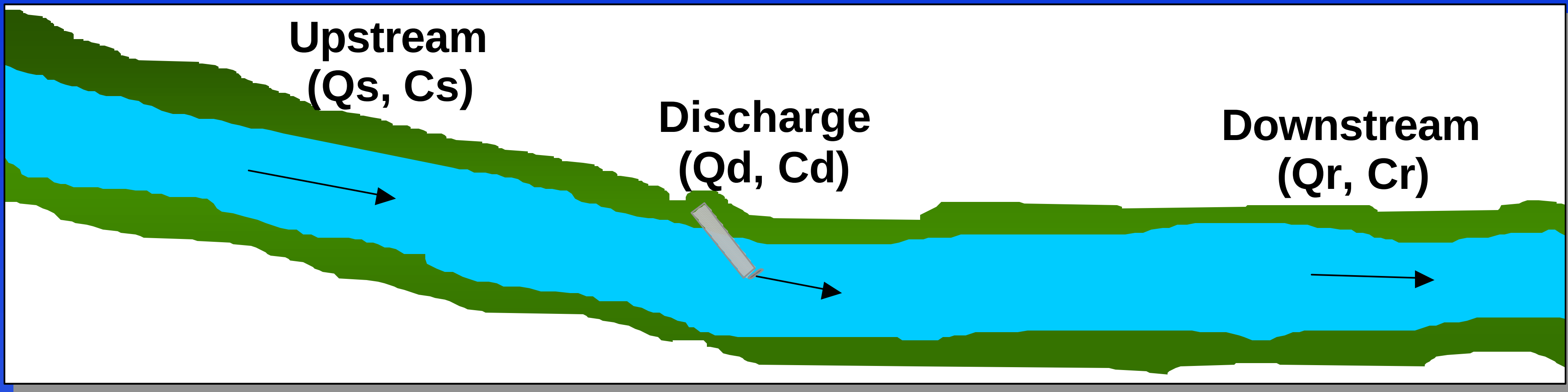
↓

Step 2: Select Lowest LTA

↓

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

Mass-Balance Equation
QdCd + QsCs = QrCr

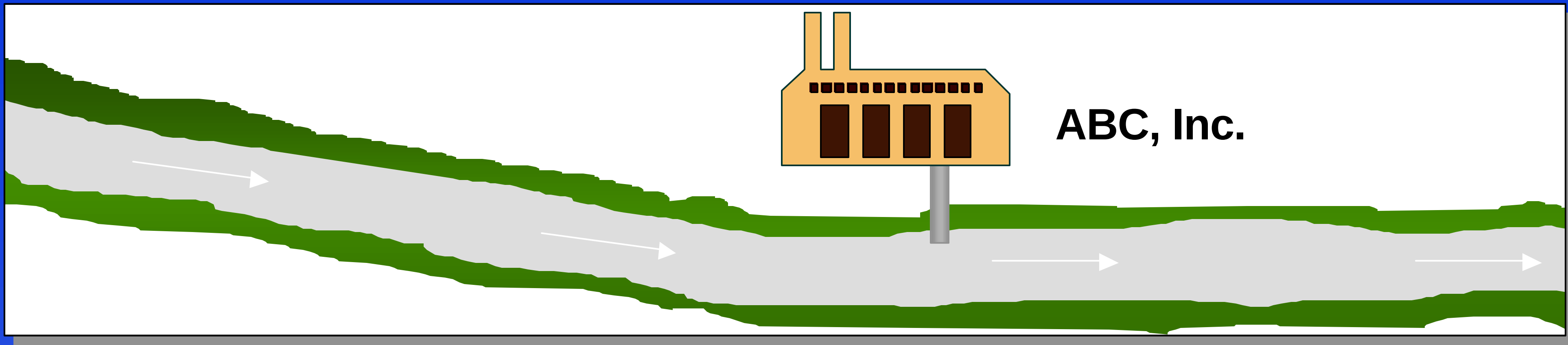


- Q = Flow (mgd or cfs)
- C = Pollutant concentration (mg/l)
- Mass = [Concentration] [Flow]
- QdCd + QsCs = QrCr
- Determine allowable discharge concentration (WLA):

$$Cd = \frac{QrCr - QsCs}{Qd}$$

Note: Qr = Qs + Qd

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



Qs	= Upstream river flow	1Q10	= 1.2 cfs
		7Q10	= 3.6 cfs
Qd	= Discharge flow		= 0.31 cfs
Cs	= Upstream river conc.		= 0.8 mg/l
Cr	= Water Quality Criterion		
	Acute		= 1.0 mg/l (applied at 1Q10)
	Chronic		= 0.9 mg/l (applied at 7Q10)

$$Cd = WLA = \frac{Cr(Qd + Qs) - CsQs}{Qd}$$

$Cd_{(acute)} = WLA_a = 1.8$ mg/l

$Cd_{(chronic)} = WLA_c = 2.1$ mg/l

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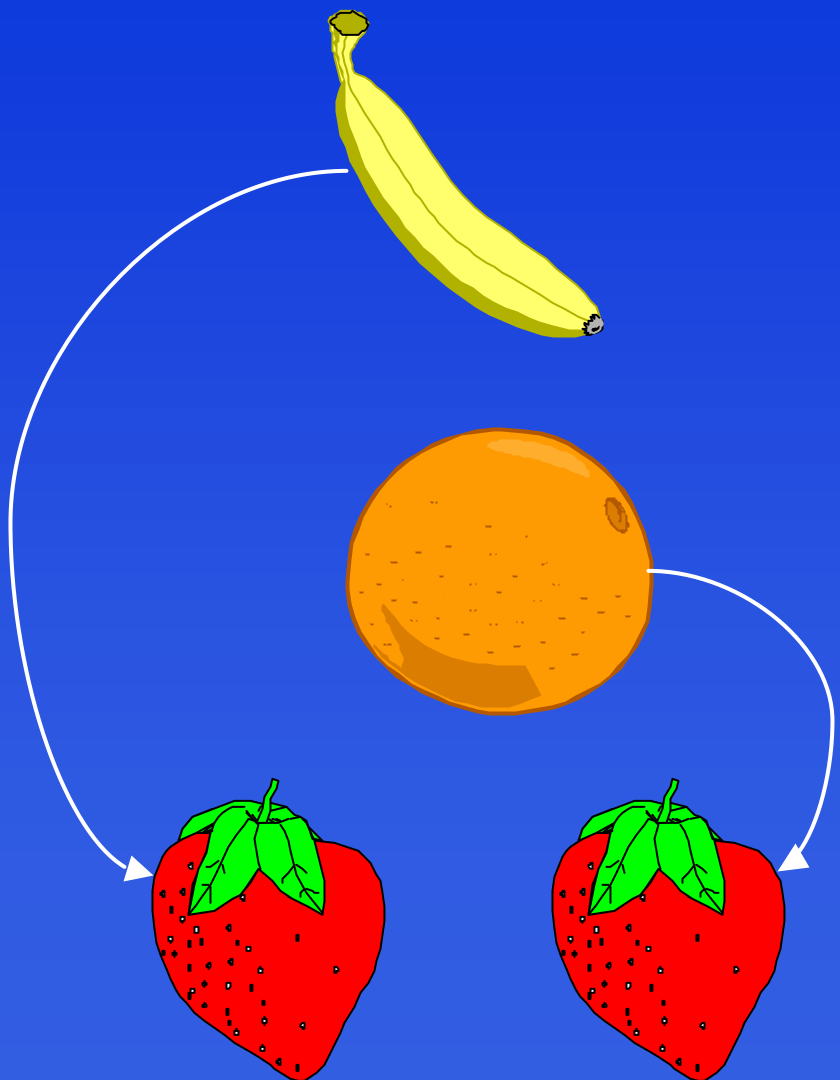
We All Want to Use the Same Fruit



$= WLA_a$

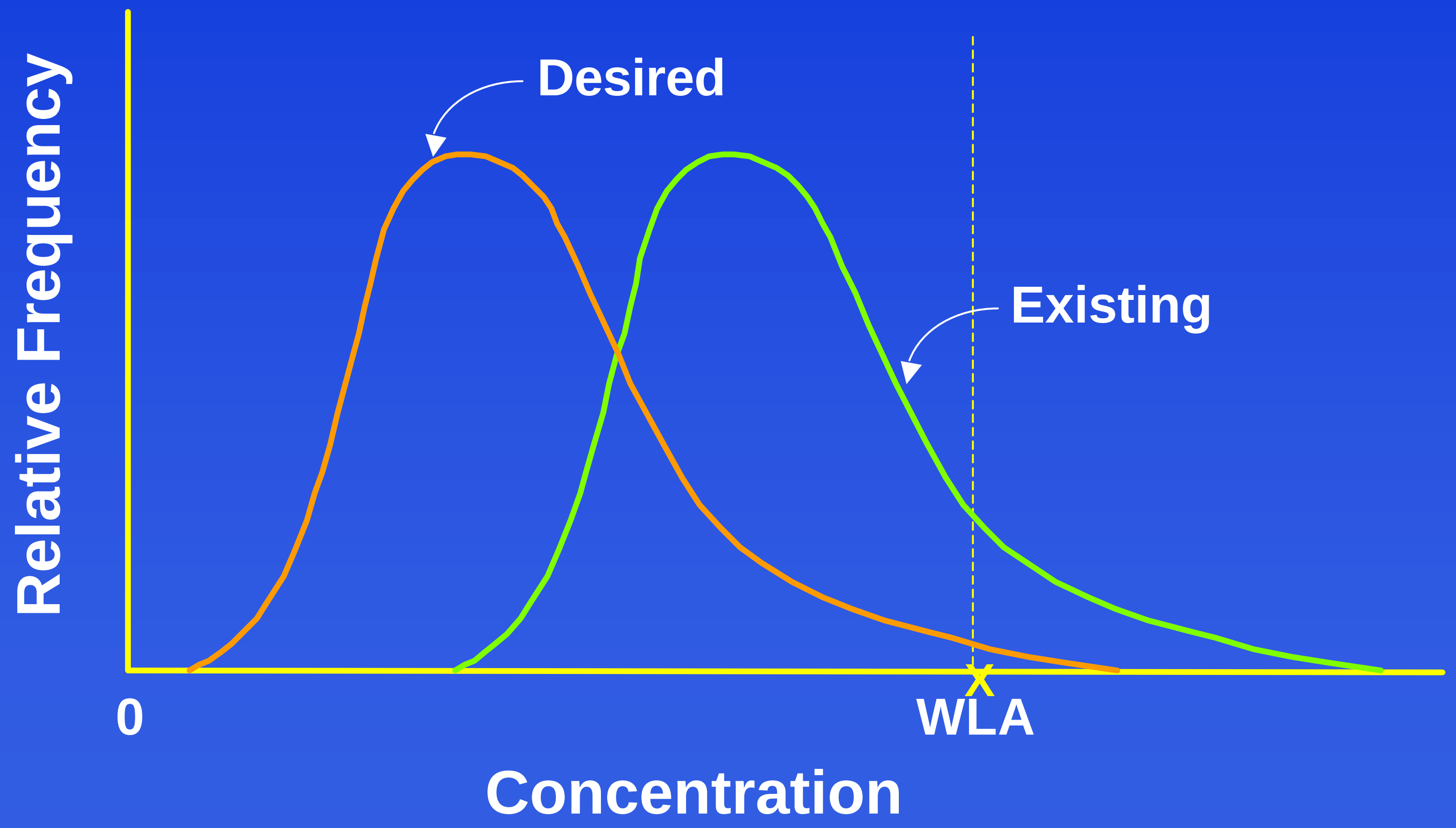
$= WLA_c$

$= LTA$

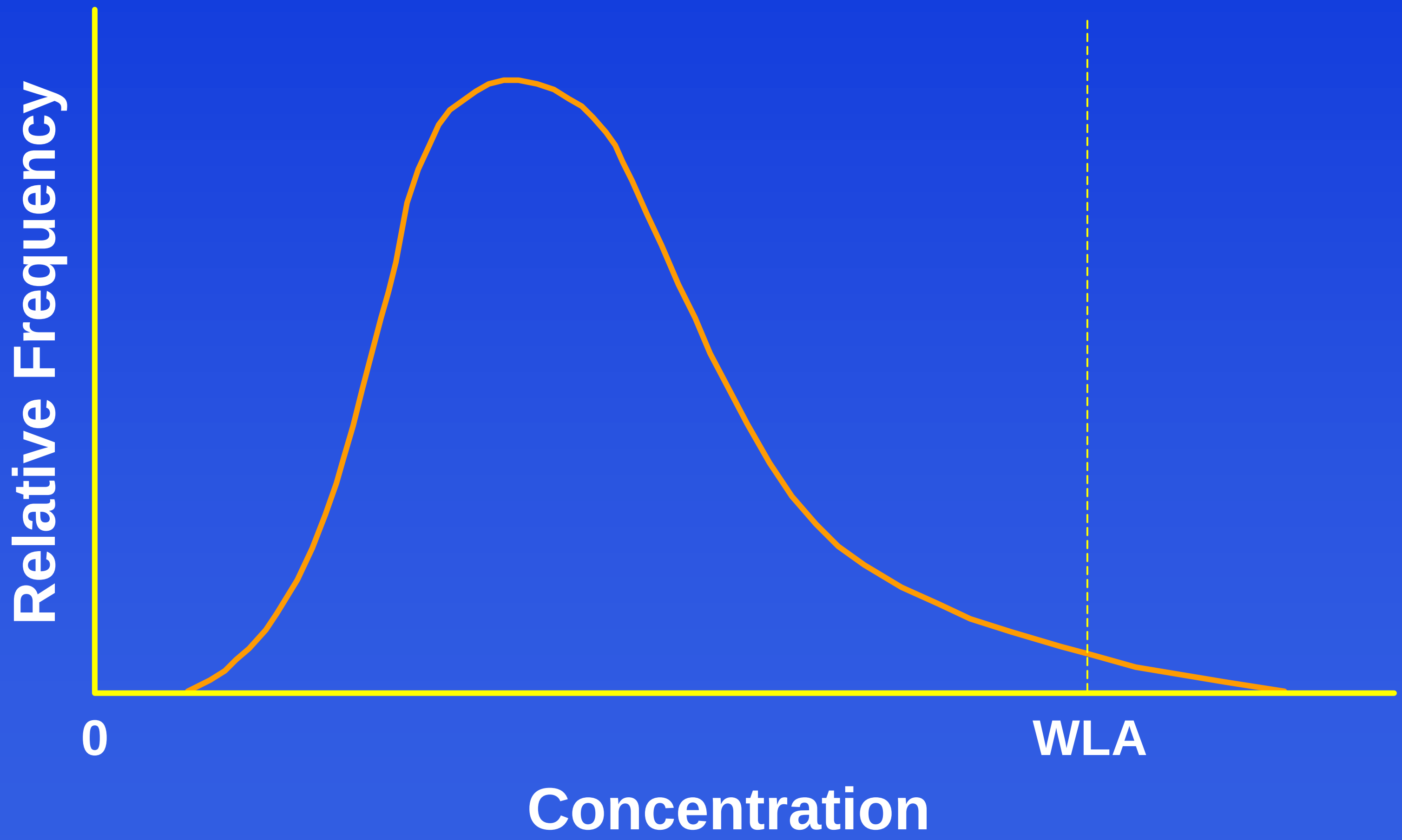
Step 1: Calculate LTAs

- Wasteload allocation (WLA) is "never to be exceeded"
- Assume a log normal effluent distribution
- Characterize "never to be exceeded" by a probability (e.g., WLA is the 99th percentile concentration on the log normal effluent distribution)

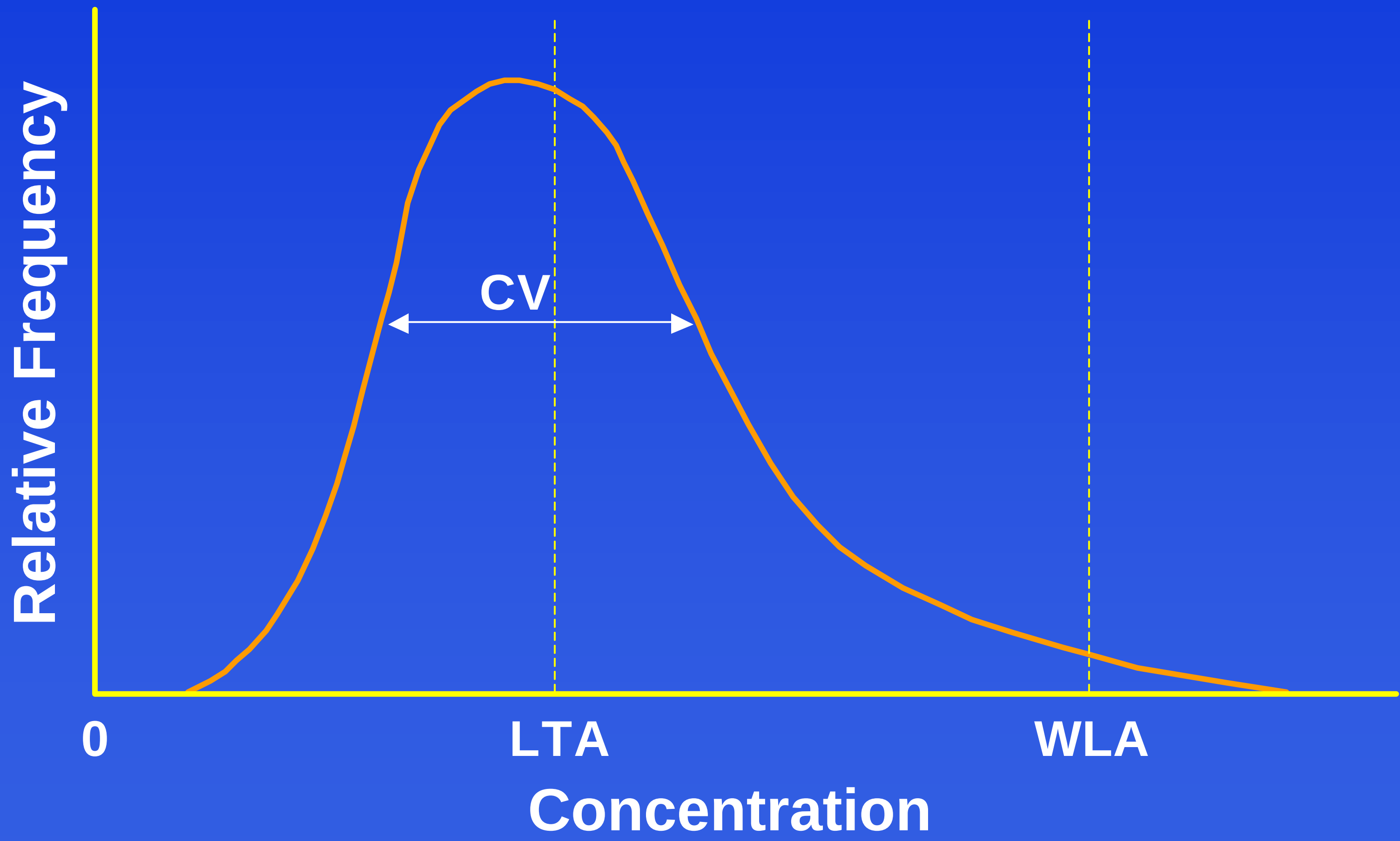
Goal is to Reduce Effluent Concentrations to Below the WLA



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: $\sigma_4^2 = \mathit{ln}[CV^2/4 + 1]$

z = 1.645 for 95th percentile occurrence probability, and

z = 2.326 for 99th percentile occurrence probability

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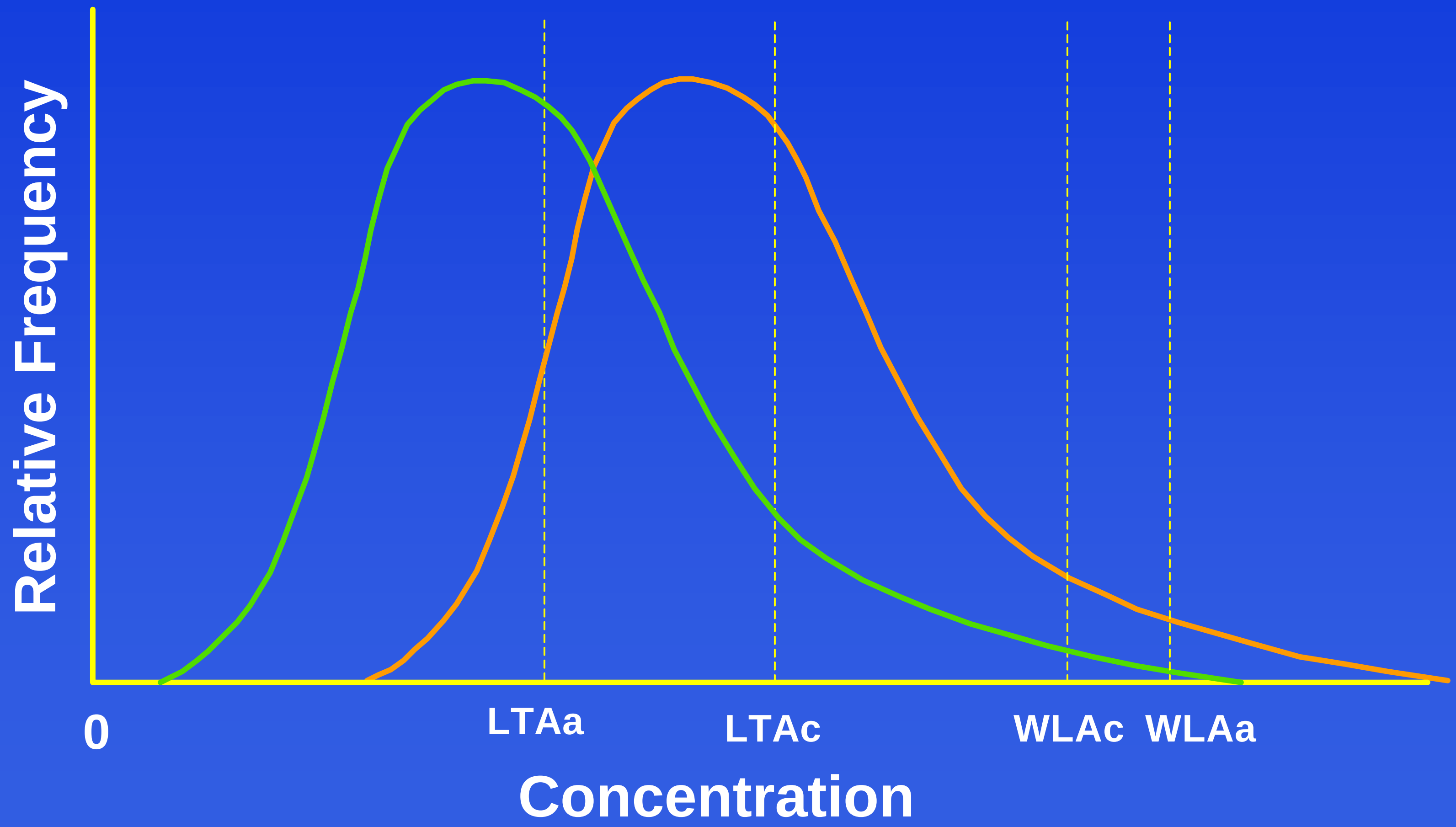
Step 2: Select Lowest LTA

- 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

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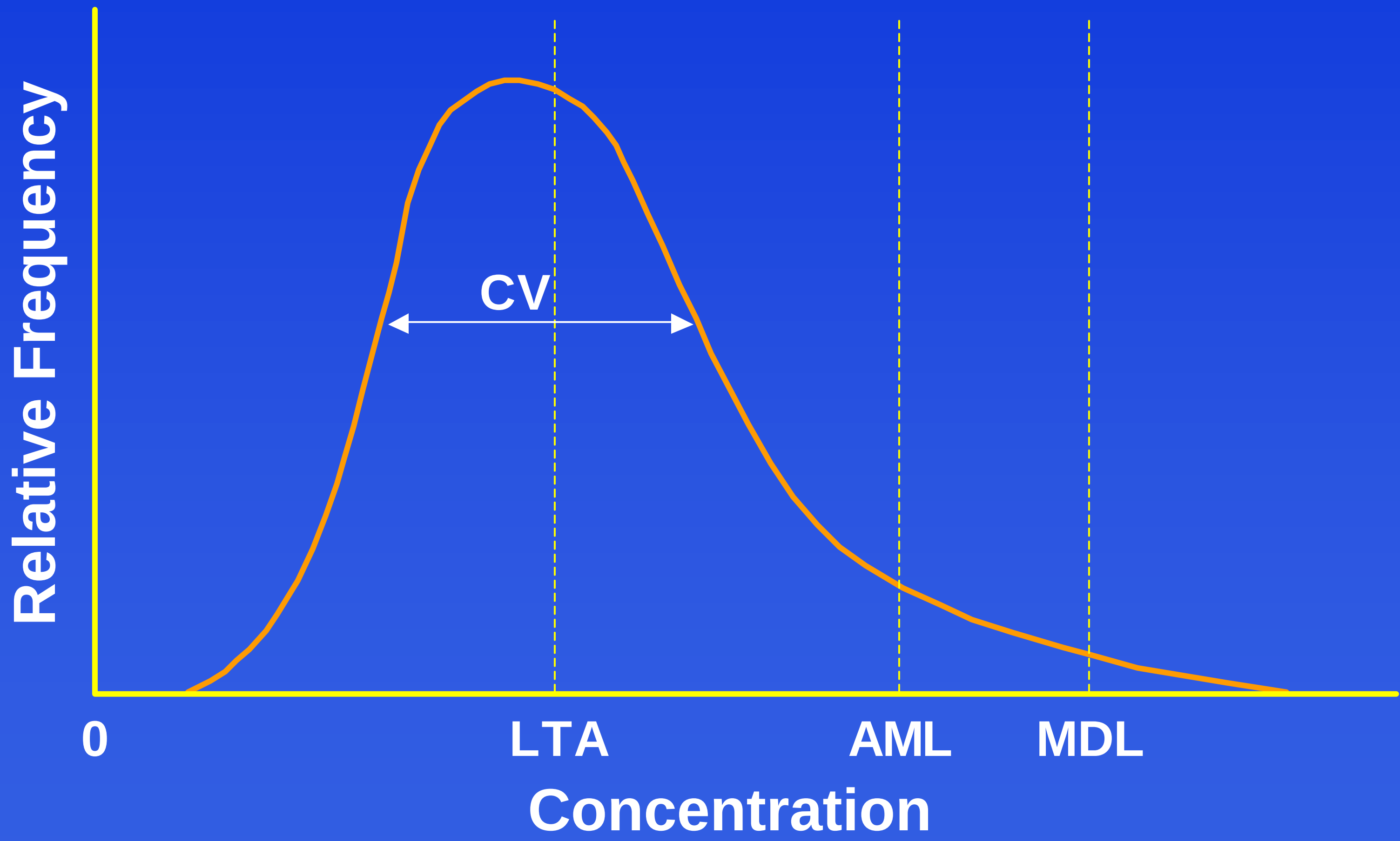
We Can Characterize the Upper Bounds of the Effluent from the LTA and CV



Daily LTA Multiplier

Maximum Daily Limit (MDL)

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

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

z = 1.645 for 95th percentile occurrence probability, and

z = 2.326 for 99th percentile occurrence probability

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

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

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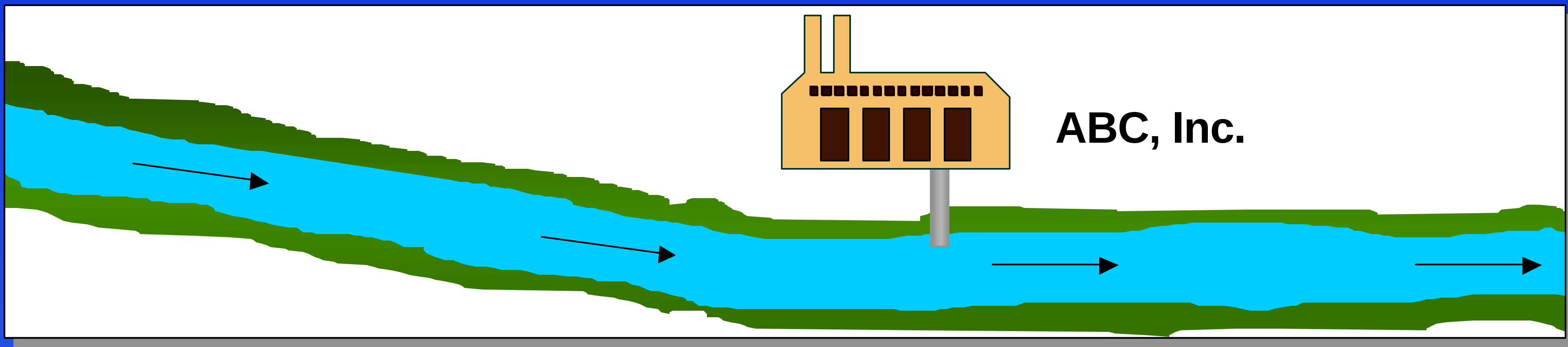
Example



Recall that we calculated the following WLAs:

Cd(acute)	=	1.8 mg/l
Cd(chronic)	=	2.1 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(acute) = 1.8 mg/l
= 99th percentile value

LTA(acute) = 1.8 mg/l x 0.321
= 0.58 mg/l

Step 1: Calculate LTAs

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

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

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Step 3: Calculate MDL and AML
(Continued)

LTA multipliers

$$e^{[z\sigma_n - 0.5\sigma_n^2]}$$

CV	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