Course Welcome and Introduction

TMDL Academy – Foundations Training

U.S. EPA Office of Wetlands, Oceans, and Watersheds

Welcome to TMDL Foundations!

Mission of the TMDL Academy

- Build participant knowledge and skills needed to develop TMDLs that:
  - include all required elements for EPA approval; and
  - support successful restoration of impaired waters

Objective of the TMDL Foundations Training

- Introduce basic TMDL concepts and enable participants to understand the process for developing TMDLs

Course Activities and Exercises

- **Activities** are spread throughout the course and are designed to:
  - Reinforce key concepts
  - Allow for direct participation
- **Exercises** are included in each module for attendees to:
  - Work through the components of a TMDL in an example scenario
  - Understand best practices and important factors for drafting TMDLs

8-Session Agenda

	Tuesday	Thursday
Week 1	Define TMDL Purpose and Scope	Understand the Impairments and Establish Targets
Week 2	Inventory Pollutant Sources	Plan the Linkage Analysis
Week 3	Execute the Linkage Analysis	Allocate Pollutant Loads
Week 4	Determine Implementation & Monitoring Needs	Prepare and Submit the TMDL Document

Execute the Linkage Analysis

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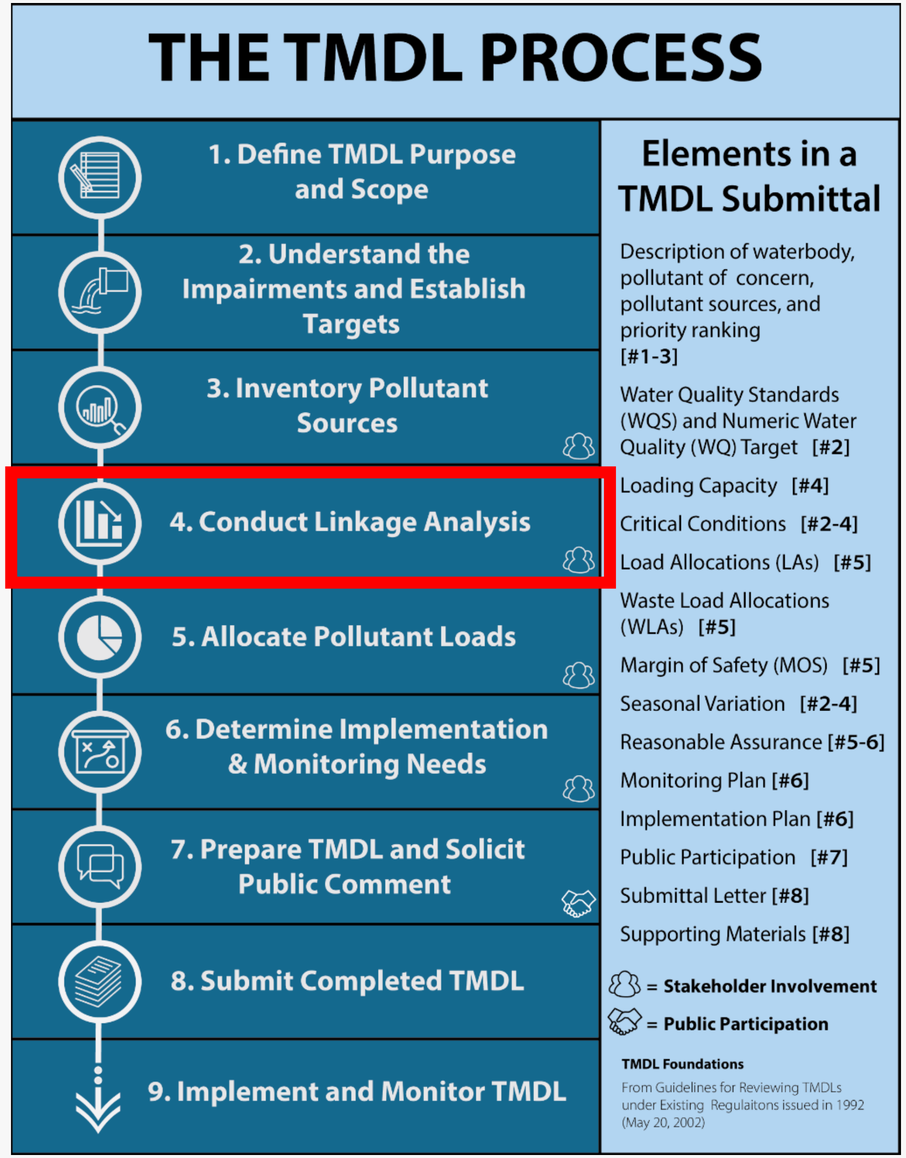
Execute the Linkage Analysis – Session 5

Module Objectives

Provide participants with an understanding of:

- Why and how models can be used for TMDL development and the modeling process
- The Load Duration Curve as an example method for TMDL development and how to prepare a Load Duration Curve



Today's Agenda – Session 5

Training Session #5

Module	Presentations	Exercises/Activities
Execute the Linkage Analysis	Modeling Introduction (20 minutes live; 20 minutes pre-recorded)	Model Selection Activity (20 minutes)
	Load Duration Curve (30 minutes)	Load Duration Curve Exercise (15 minutes)

Modeling Introduction

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Lesson Overview – Modeling Introduction

Introduction

Understand why and how models are used for TMDL development

Process Description

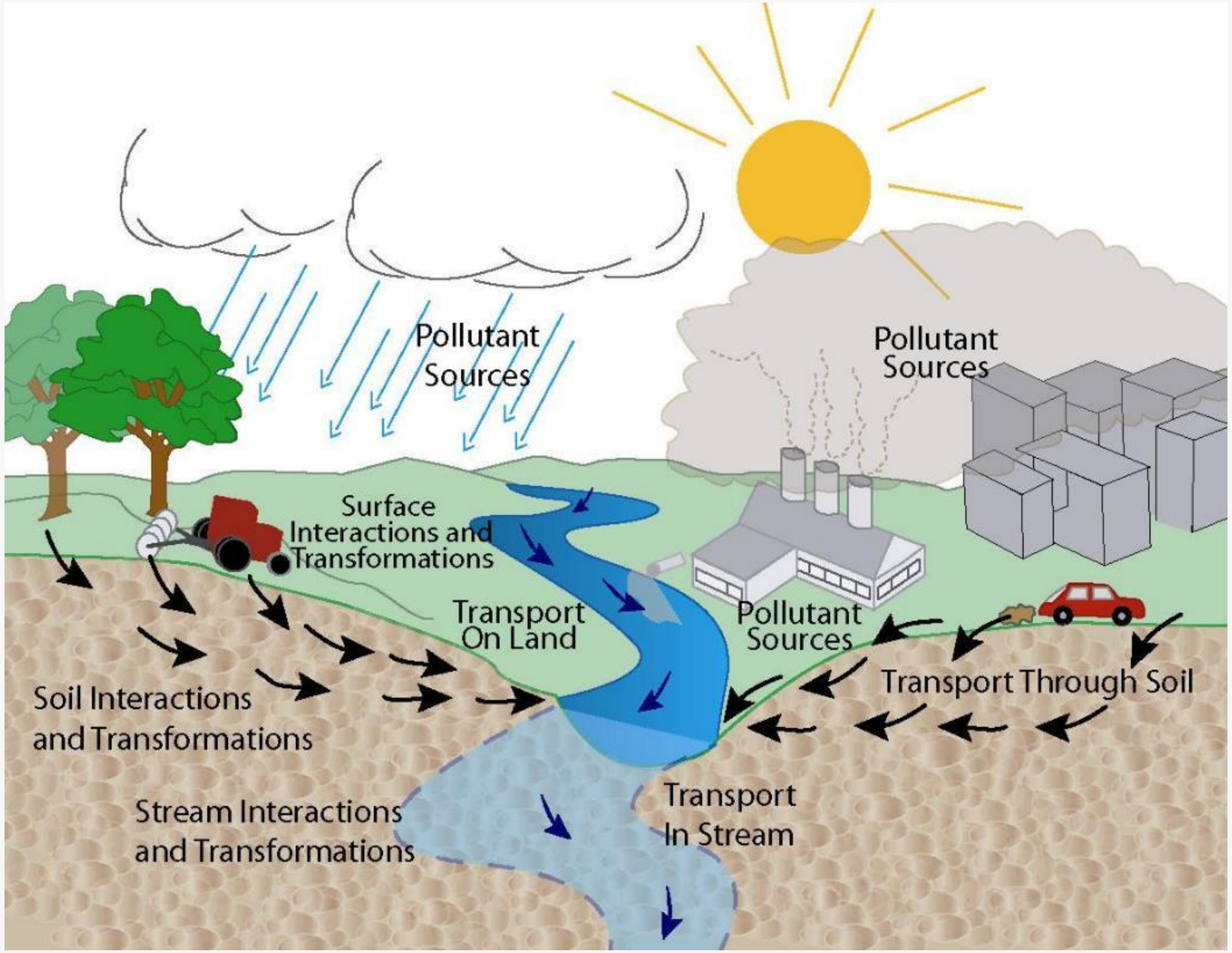
Learn the modeling process

Activity 5.1

Group activity to identify potential modeling methods for TMDL development scenarios

What is a Model?

- A mathematical representation of pollutant fate, transport, and degradation within a watershed and/or waterbody



What is a Model?

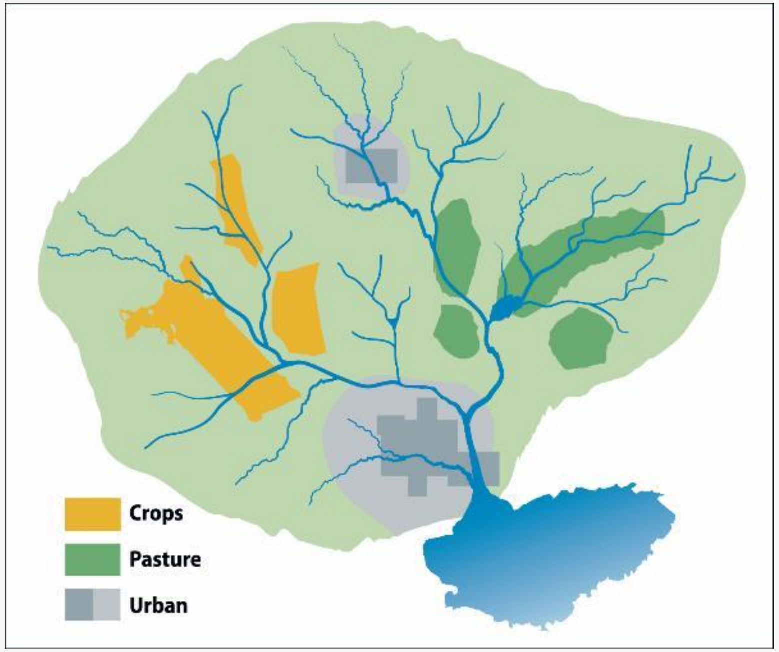
- A model can consist of a single equation or series of equations to approximate one or more environmental conditions
- Run with a spreadsheet or computer program

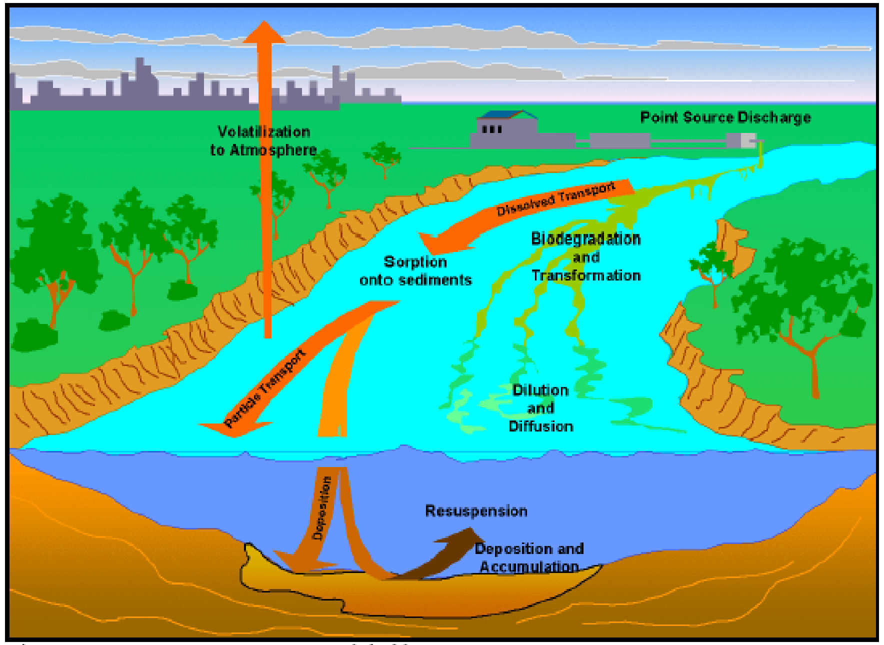
- Land Use Export Coefficients
- Event Mean Concentrations
- Empirical Equations
    - Universal Soil Loss Equation, USLE

- Mechanistic/Process Models
    - HSPF, SWAT, SWMM
    - WASP, CE-QUAL-W2, EFDC
- Advanced Statistical Models
    - SPARROW

Types of Models

- Watershed Models
  - Simulate runoff and pollutant loading from the landscape (loads into a waterbody)
  - May include a basic representation of waterbody conditions
- Waterbody Models
  - Detailed representation of water quality in rivers, lakes, embayments, etc. (response to loading)

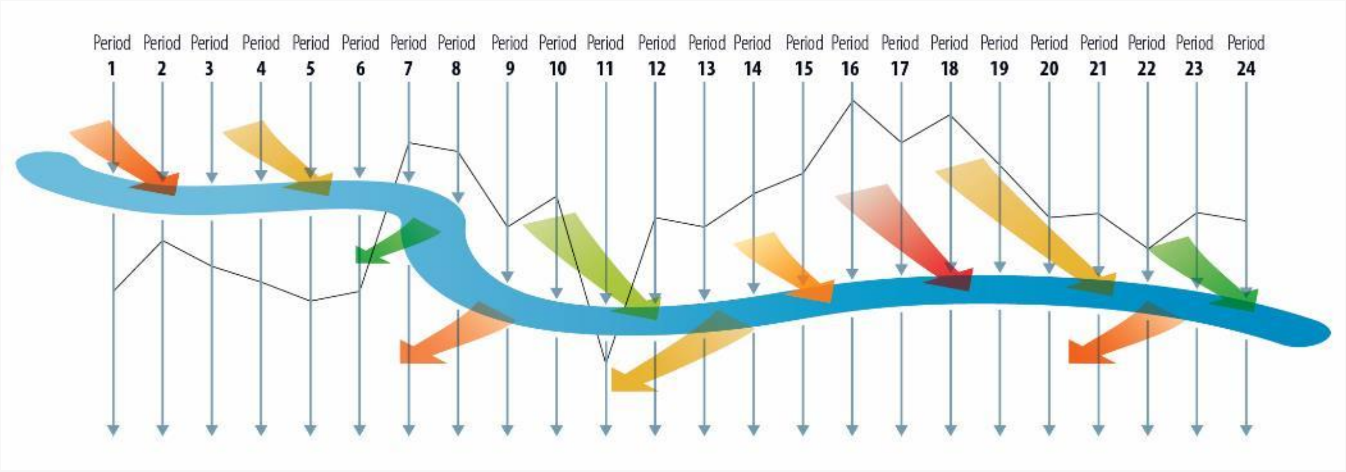




Types of Models

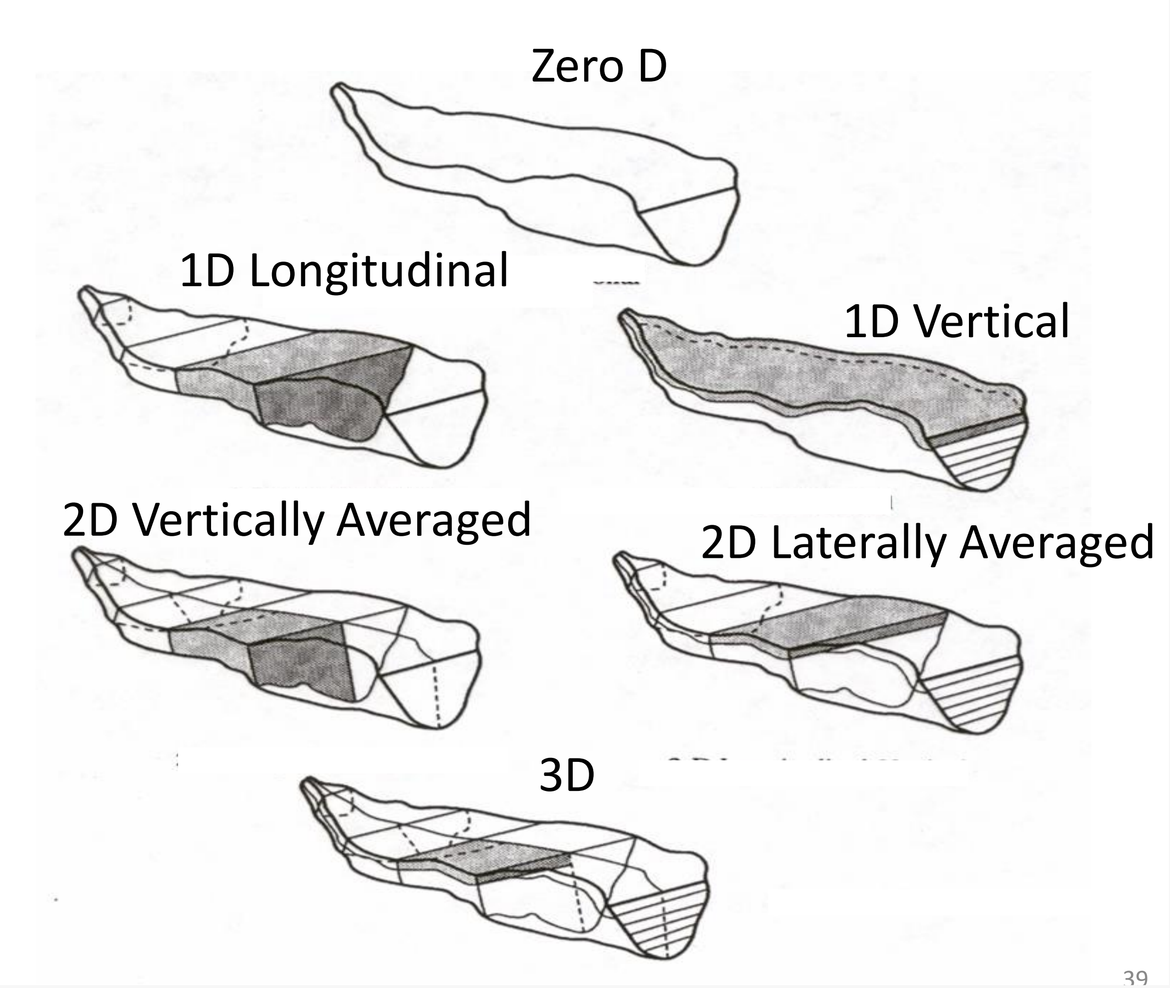
- Static
  - Depict a snapshot in time
  - Steady-state conditions with constant inputs and outputs

- Time-Variable (Dynamic)
  - Simulate changing conditions across months, seasons, years, etc.
  - Variable inputs and outputs



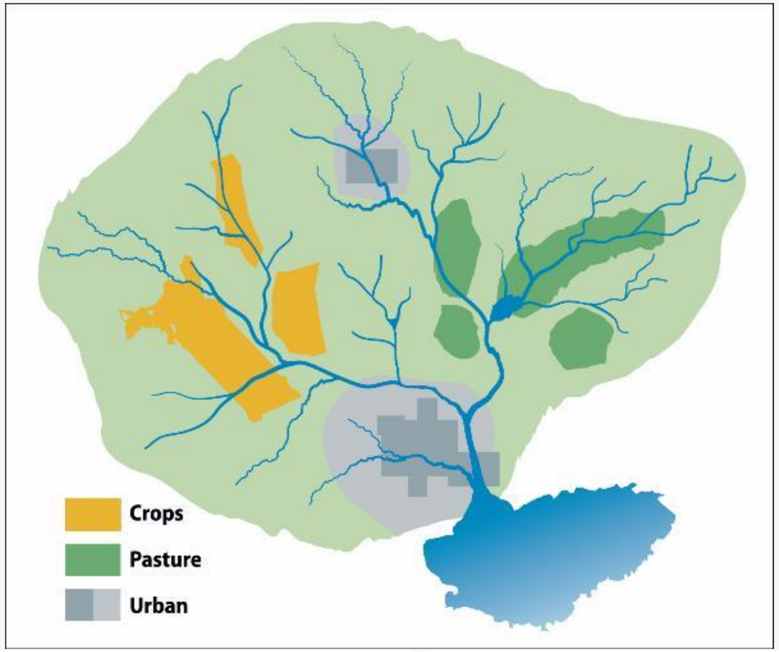
Types of Models

- Waterbody models can be classified according to the spatial representation of a waterbody, ranging from:
  - Zero-Dimensional (Zero D) – entire waterbody is simulated as a single unit with no variability
  - Three-Dimensional (3D) – waterbody is divided into segments that capture longitudinal, lateral, and vertical variability



Linked Models

- Multiple models may be combined to meet objectives and needs



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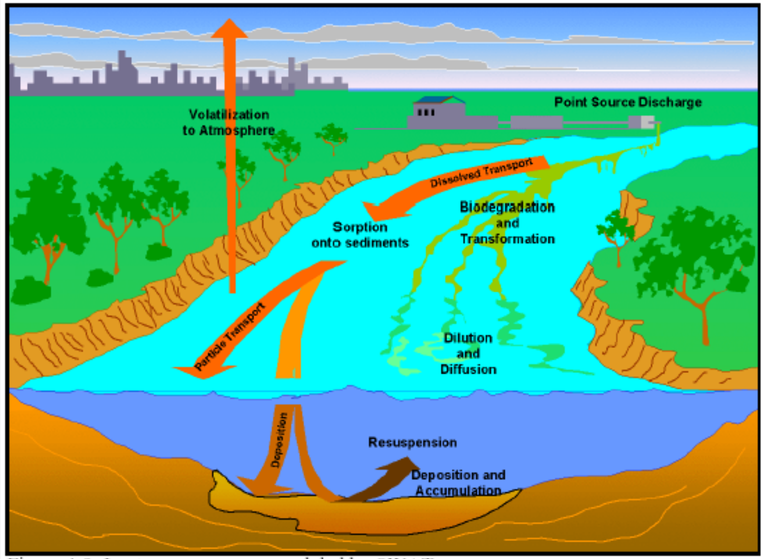

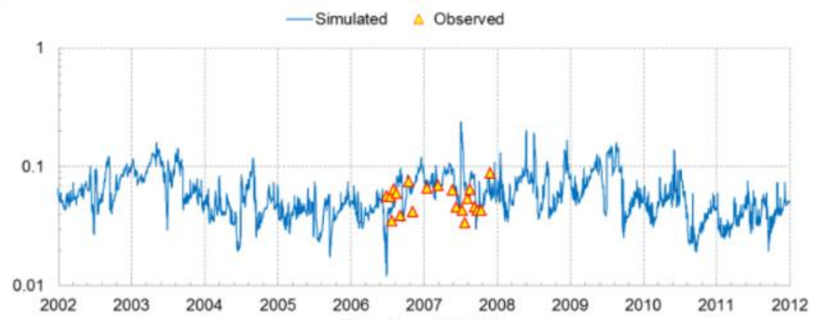

Why are Models Used?

- Help us understand complex systems
- Confirm existing conceptual views or highlight deficiencies in our conceptual understanding
- Afford the opportunity to refine and improve our qualitative and quantitative understanding of a particular system or process
- Can be cheaper and faster than extensive physical testing options

How Can Models be Used for TMDLs?

1. Calculate Loading Capacity

2. Quantify Pollutant Sources

3. Evaluate Load Reduction Scenarios

How Can Models be Used for TMDLs?

1. Calculate Loading Capacity

2. Quantify Pollutant Sources

3. Evaluate Load Reduction Scenarios

- Models can simulate pollutant concentrations and/or values of response parameters under alternative pollutant loads
- Models can estimate the pollutant load that results in attainment of the numeric water quality target

How Can Models be Used for TMDLs?

1. Calculate Loading Capacity

2. Quantify Pollutant Sources

3. Evaluate Load Reduction Scenarios

- Models can simulate existing pollutant loads from nonpoint sources, regulated stormwater sources (e.g., MS4s), and CAFOs
- Models can inform pollutant allocations and TMDL implementation planning

How Can Models be Used for TMDLs?

1. Calculate Loading Capacity

2. Quantify and Compare Pollutant Sources

3. Evaluate Load Reduction Scenarios

- Models can simulate the effects of reduced point source discharge and nonpoint source management practices on water quality
- Modeled scenarios can further guide allocations, TMDL implementation planning, and support reasonable assurance

Limitations of Models

- Example limitations of models:
  - Models can be constrained by data availability, computational limits, assumptions, and knowledge gaps
  - Models will never be a perfect representation of reality
- Despite such limitations, models can still capture key elements of a system and serve as useful tools to inform decision-making

Water Quality Modeling

- **To develop a water quality model:**

Step 1. Prepare Quality Assurance Project Plan

Step 2. Compile Data & Configure Model

Step 3. Calibrate & Evaluate Model

Step 4. Accept & Apply Model

Step 5. Document the Model

Activity 5.1: Choose a Model (Resources)

The following websites contain resources for water quality modeling and analysis:

1. *EPA Surface Water Quality Modeling Training*
   https://www.epa.gov/waterdata/surface-water-quality-modeling-training
2. *EPA Assessment of Surface Water Model Maintenance and Support Status*
   https://cfpub.epa.gov/si/si_public_record_report.cfm?Lab=NHEERL&dirEntryId=342391

Links to other resources:

EPA Surface Water Models to Assess Exposures https://www.epa.gov/ceam/surface-water-models-assess-exposures

EPA Review of Watershed and Water Quality Tools for Nutrient Fate and Transport
https://cfpub.epa.gov/si/si_public_record_report.cfm?Lab=CESER&dirEntryId=348257

Load Duration Curve

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Lesson Overview – Load Duration Curve

Introduction

Describe the Load Duration Curve and how it is used

Process Description

Learn the process for developing a Load Duration Curve

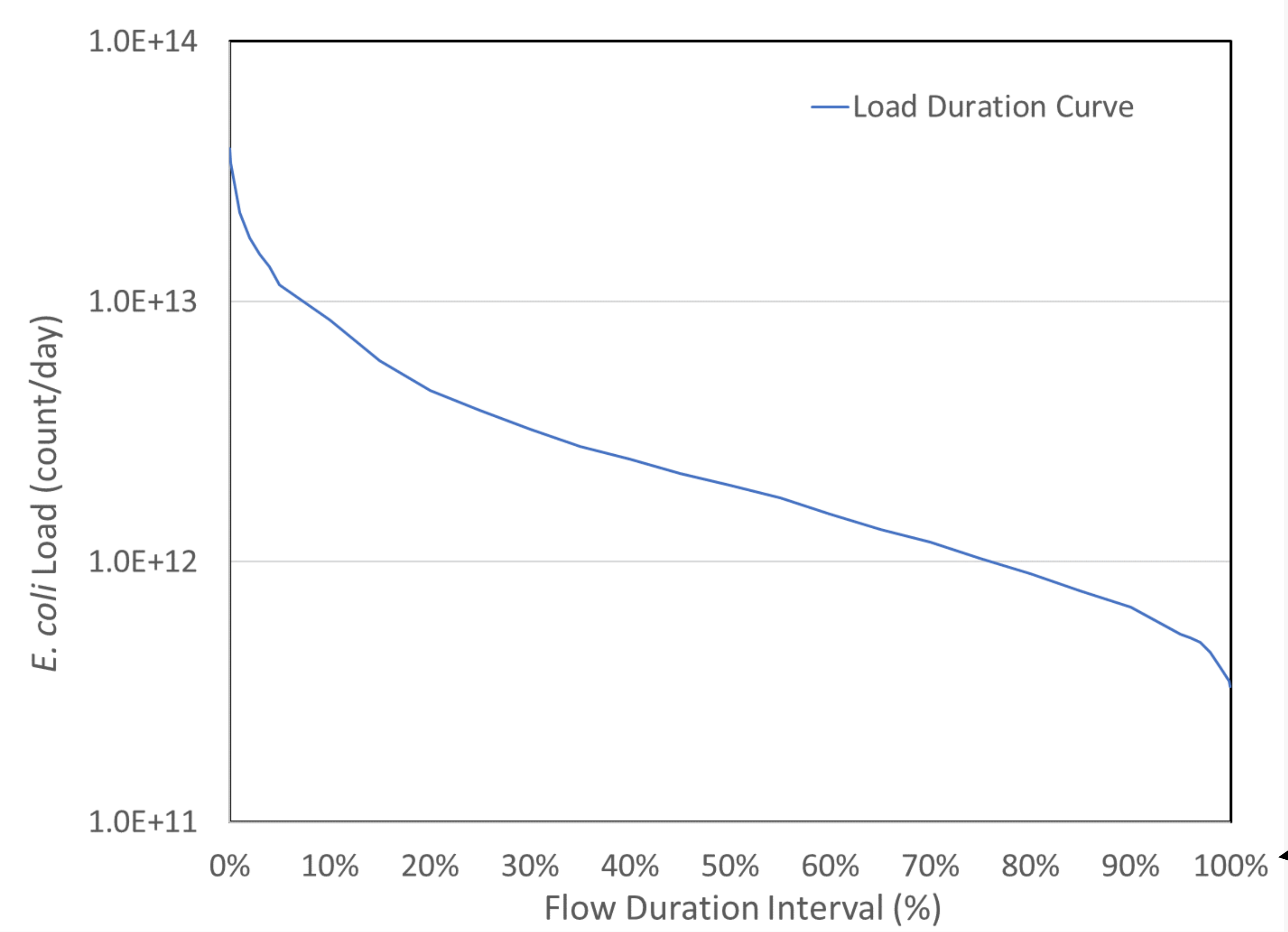
Exercise 5.1

Prepare a Load Duration Curve for the example Opal River TMDL

What is a Load Duration Curve?

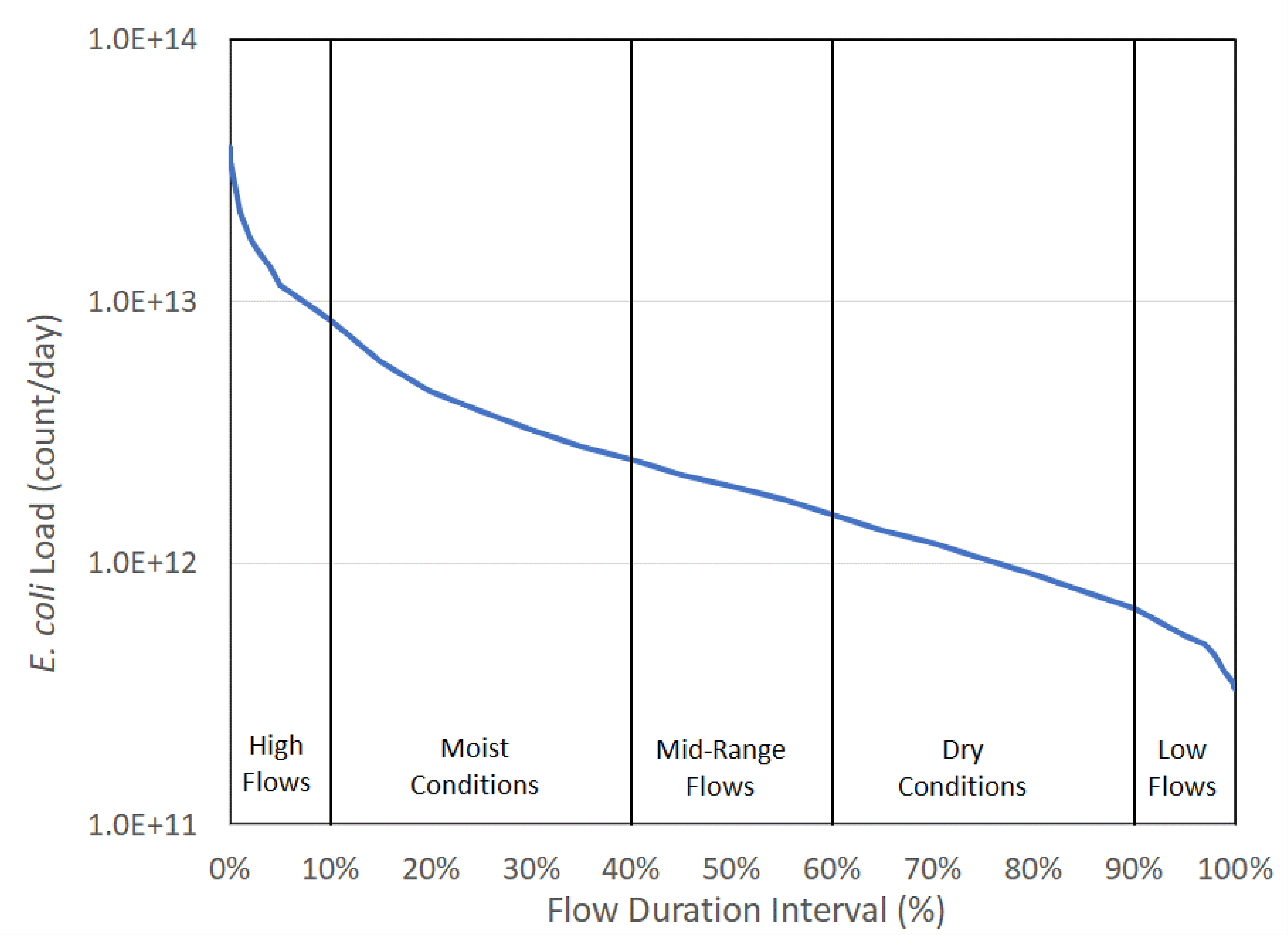
- A graphical representation of the relationship between the water quality target, streamflow, and monitoring data
- A tool used for the development of TMDLs to determine the pollutant loading capacity and inform allocations
- Plots the pollutant load in a stream or river across a range of streamflow values
- Calculated from streamflow data and a target pollutant concentration

Components of a Load Duration Curve

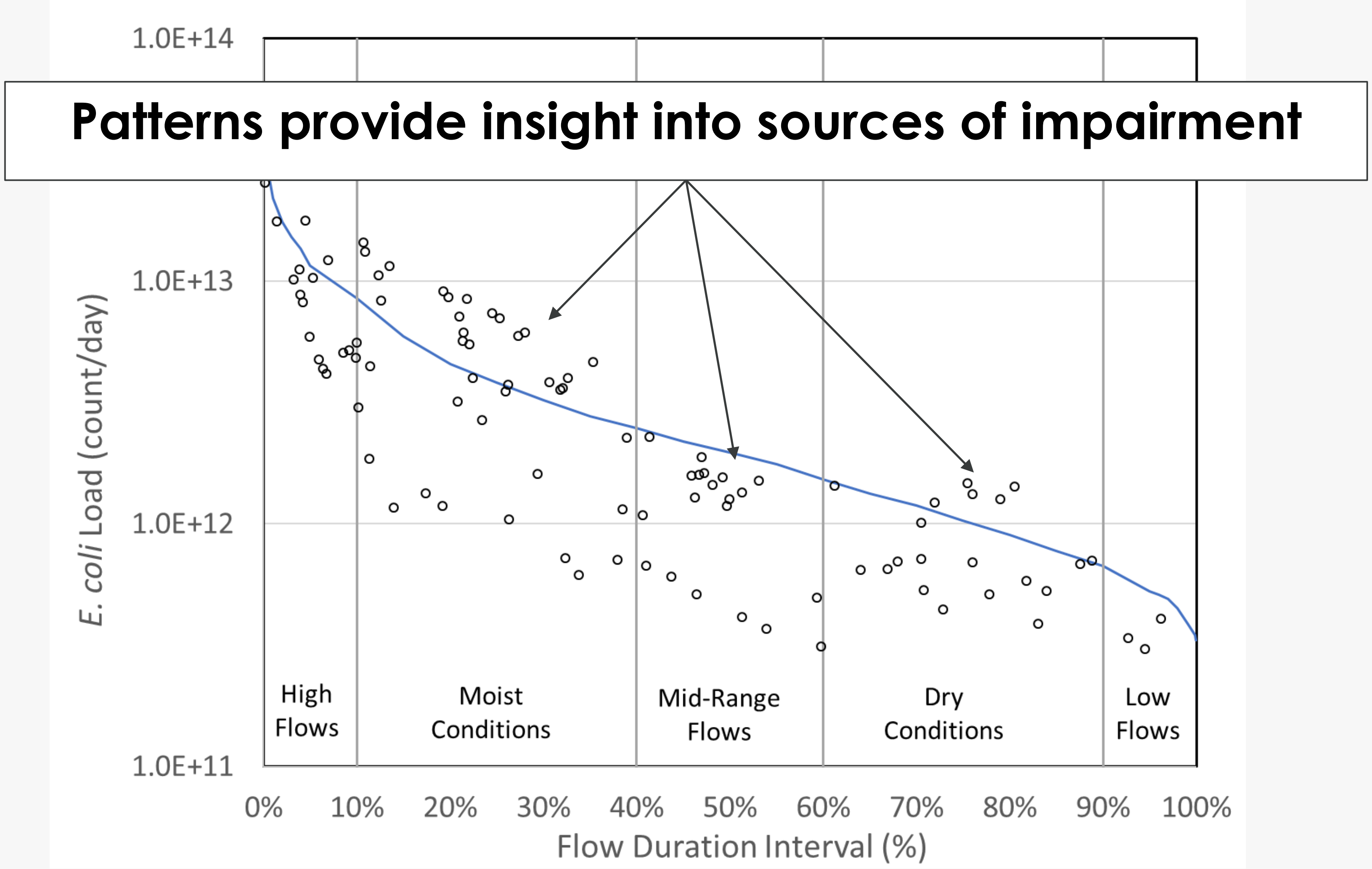


Flow Duration Interval = percent of time each flow and load are equaled or exceeded

Components of a Load Duration Curve



Components of a Load Duration Curve



Load Duration Curve Advantages

- Relatively simple method to determine loading capacity and interpret streamflow and water quality monitoring data
- Only requires streamflow records, samples of pollutant concentrations, and your numeric target value
- Depicts conditions across the entire flow regime
- Includes data from all seasons and can be customized for specific seasons
- Exceedance patterns can guide pollutant allocation, reasonable assurance, and TMDL implementation

Load Duration Curve Limitations

- Does not quantify pollutant sources
- Generally only useful for streams and rivers (other methods may be needed for lakes, embayments, etc.)
- Cannot be used to evaluate response parameters (dissolved oxygen, chlorophyll-a, etc.)
- Assumes fate and transport processes are not significant (sediment dynamics, chemical transformations, biological uptake, etc.)
- Requires long-term daily streamflow measurements or estimates

Develop Load Duration Curve

Develop Load Duration Curve > Step 1 Plan Analysis & Prepare Data > Step 2 Prepare Flow Duration Curve > Step 3 Prepare Load Duration Curve > Step 4 Interpret & Apply > Step 5 Document the Analysis

- **To develop a Load Duration Curve:**

Step 1. Plan Analysis & Prepare Data

Step 2. Prepare Flow Duration Curve

Step 3. Prepare Load Duration Curve

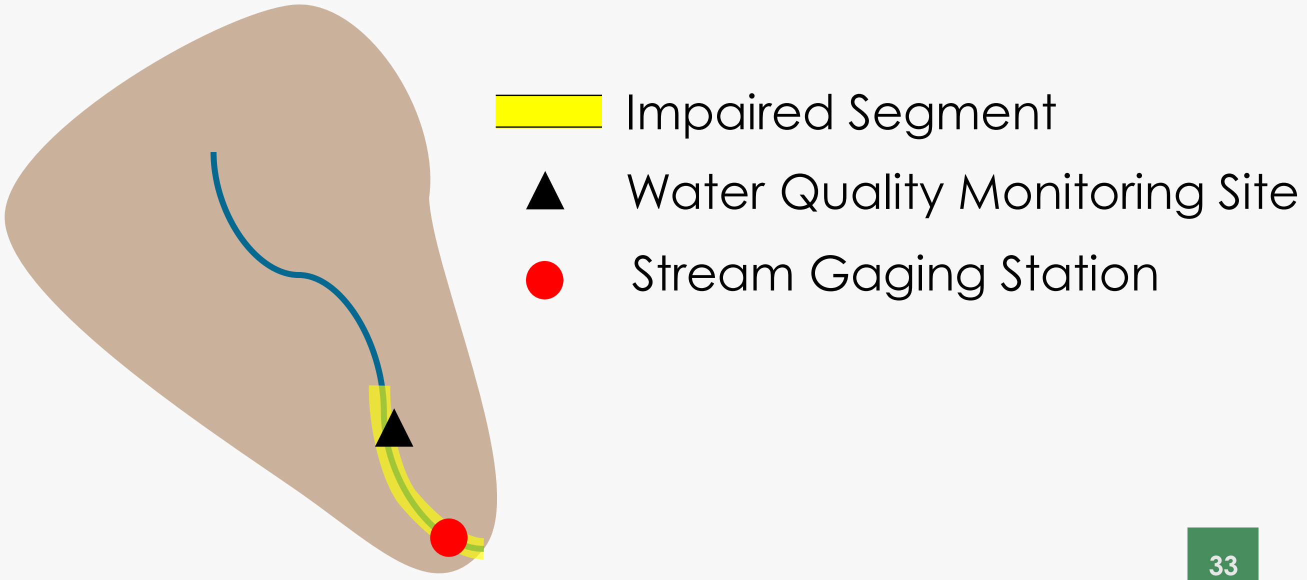
Step 4. Interpret & Apply

Step 5. Document the Analysis

Plan Analysis & Prepare Data

Develop Load Duration Curve → **Step 1 Plan Analysis & Prepare Data** → Step 2 Prepare Flow Duration Curve → Step 3 Prepare Load Duration Curve → Step 4 Interpret & Apply → Step 5 Document the Analysis

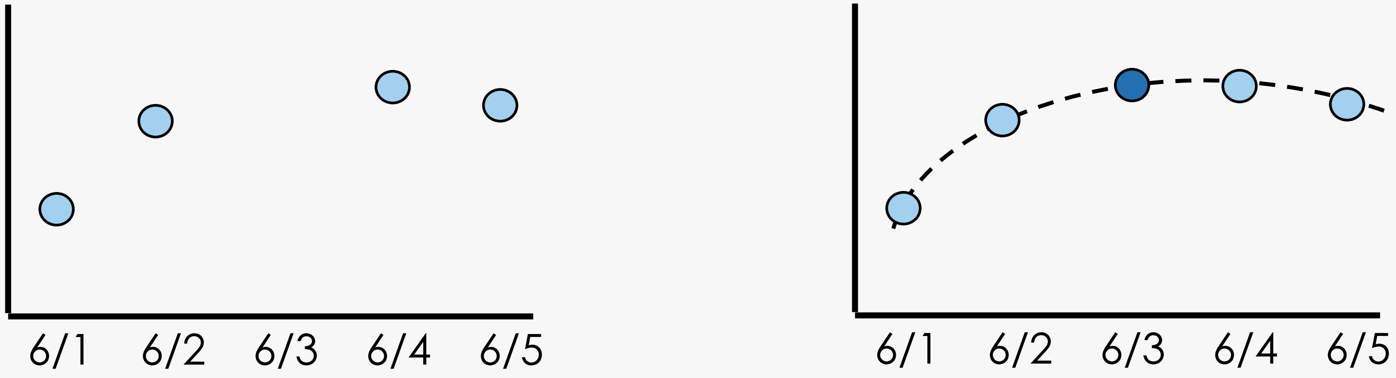
- Planning considerations for Load Duration Curve analysis:
  - Geographic – location of impaired segments vs. stream gaging stations and water quality monitoring sites
  - Temporal – period of record to analyze, seasonal vs. entire year



Plan Analysis & Prepare Data

Develop Load Duration Curve | **Step 1 Plan Analysis & Prepare Data** | Step 2 Prepare Flow Duration Curve | Step 3 Prepare Load Duration Curve | Step 4 Interpret & Apply | Step 5 Document the Analysis

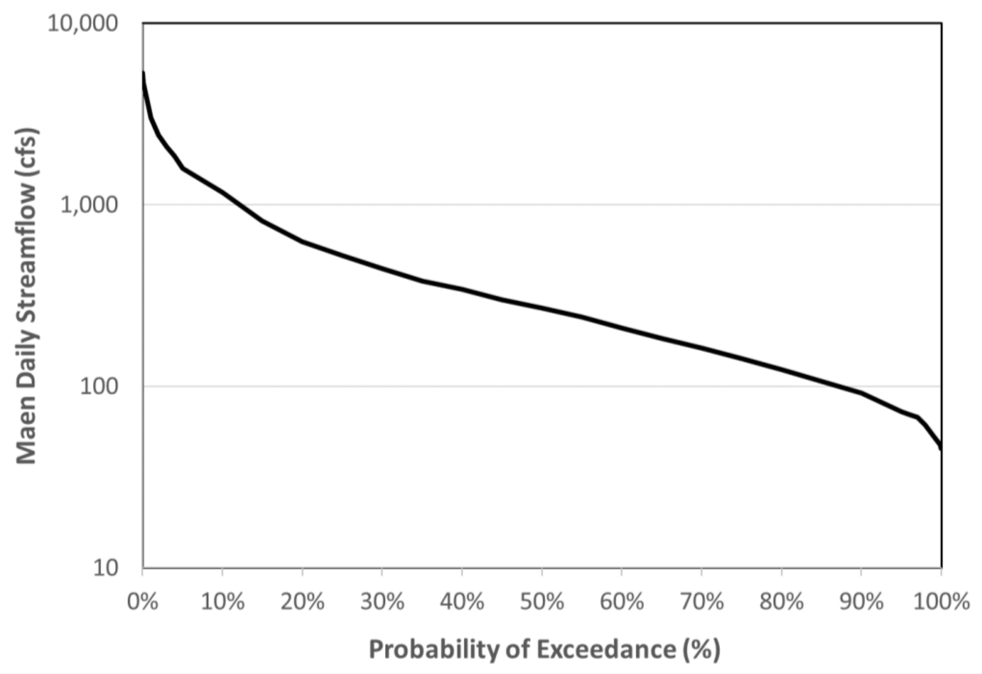
- Compile daily streamflow data from USGS or other sources
- Evaluate the completeness of streamflow records
  - Small gaps (days, weeks) could be filled by interpolating between data points
  - Large gaps (months, years) may require advanced methods for estimating missing data



Prepare Flow Duration Curve

Develop Load Duration Curve → Step 1 Plan Analysis & Prepare Data → **Step 2 Prepare Flow Duration Curve** → Step 3 Prepare Load Duration Curve → Step 4 Interpret & Apply → Step 5 Document the Analysis

- Begin the analysis by generating a Flow Duration Curve
- A Flow Duration Curve plots ***streamflow*** versus the ***percent of time*** each streamflow value is equaled or exceeded



Prepare Flow Duration Curve

Develop Load Duration Curve → Step 1 Plan Analysis & Prepare Data → **Step 2 Prepare Flow Duration Curve** → Step 3 Prepare Load Duration Curve → Step 4 Interpret & Apply → Step 5 Document the Analysis

- To prepare the Flow Duration Curve:
  - Calculate streamflow magnitudes for a series of flow duration intervals
  - Plot results
- Can be completed using spreadsheet software or statistical programming packages (R, Python, Matlab, etc.)

Prepare Flow Duration Curve

Develop Load Duration Curve → Step 1 Plan Analysis & Prepare Data → **Step 2 Prepare Flow Duration Curve** → Step 3 Prepare Load Duration Curve → Step 4 Interpret & Apply → Step 5 Document the Analysis

	Flow Duration Interval	Streamflow (cfs)
Maximum flow →	0%	2,320
	5%	2,290
	…	…
Median flow →	50%	2,045
	…	…
	95%	759
Minimum flow →	100%	642

Prepare Flow Duration Curve

Develop Load Duration Curve → Step 1 Plan Analysis & Prepare Data → **Step 2 Prepare Flow Duration Curve** → Step 3 Prepare Load Duration Curve → Step 4 Interpret & Apply → Step 5 Document the Analysis

Flow Duration Interval	Streamflow (cfs)
0%	2,320
	2,290
	…
	2,045
…	…
95%	759
100%	642

Calculated from observed streamflow data

Date	Streamflow (cfs)
7/4/2009	2,320
7/5/2009	2,318
7/6/2009	2,310
…	…
12/29/2019	1,266
12/30/2019	1,259
12/31/2019	1,255

Prepare Flow Duration Curve

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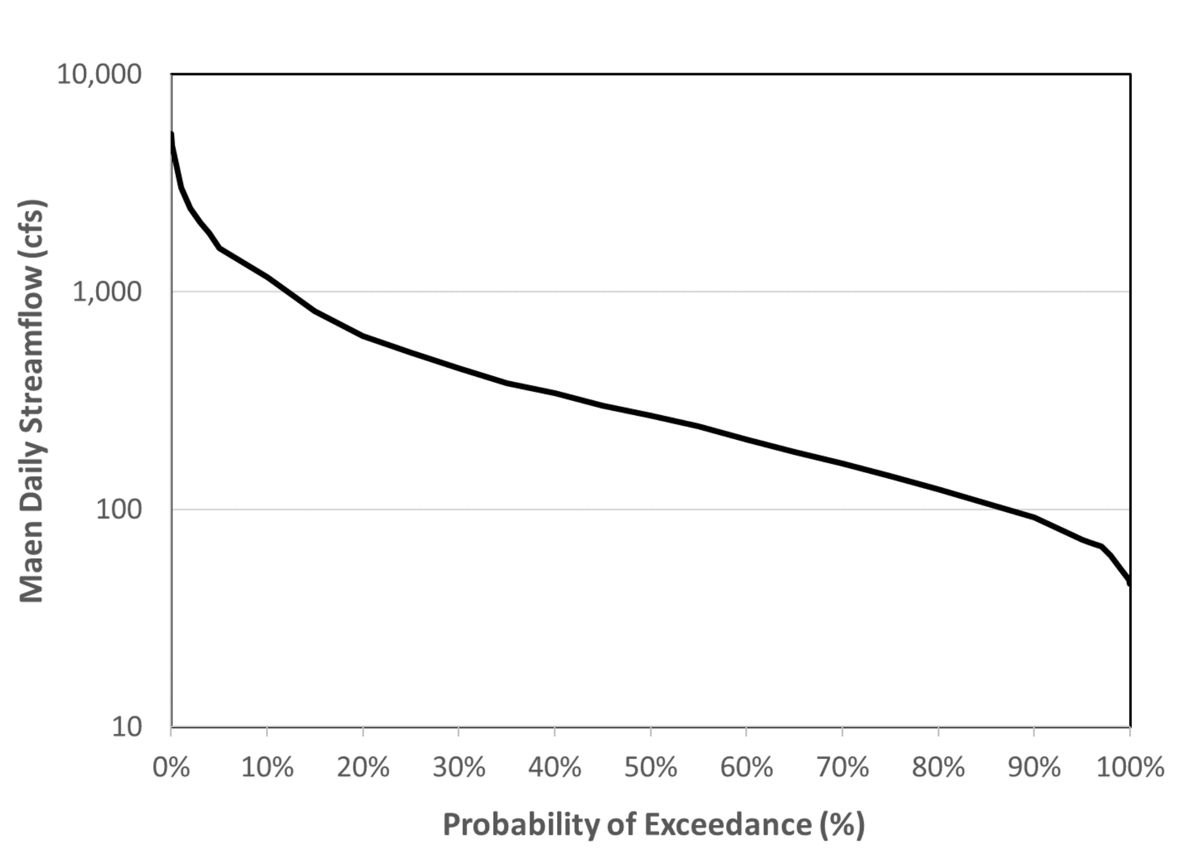
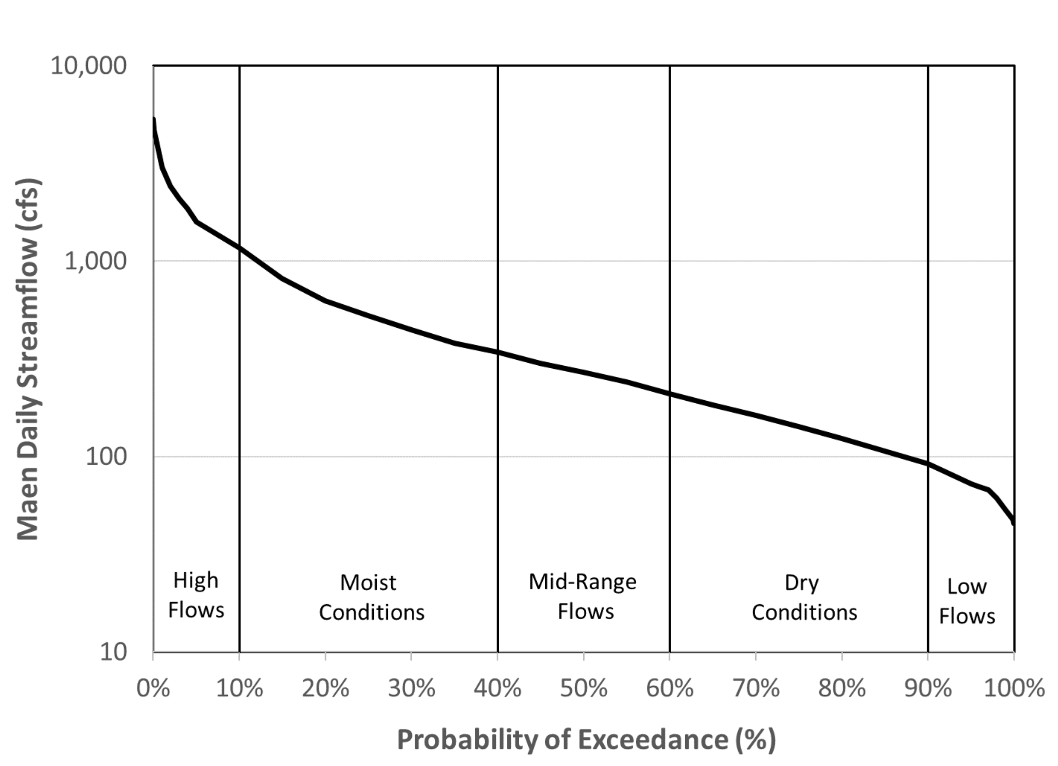


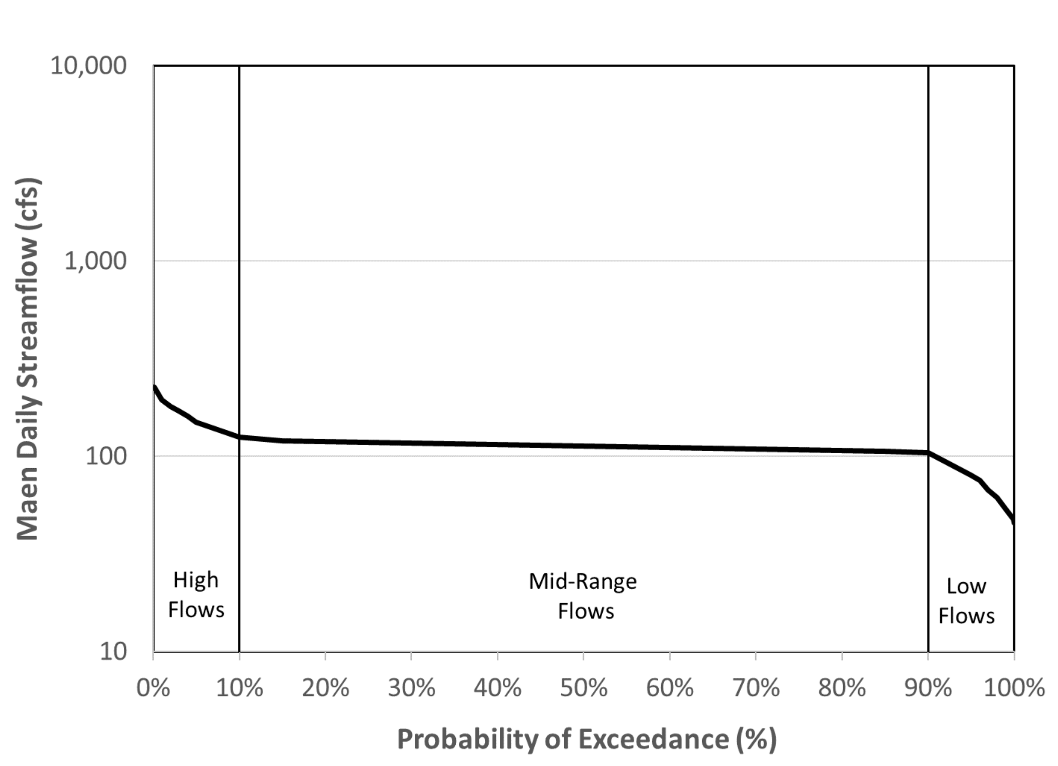
Flow Duration Interval	Streamflow (cfs)
0%	2,320
5%	2,290
...	...
50%	2,045
...	...
95%	759
100%	642

Prepare Flow Duration Curve

Develop Load Duration Curve | Step 1 Plan Analysis & Prepare Data | **Step 2 Prepare Flow Duration Curve** | Step 3 Prepare Load Duration Curve | Step 4 Interpret & Apply | Step 5 Document the Analysis

- Divide the curve into flow regime zones





Prepare Load Duration Curve

Develop Load Duration Curve | Step 1 Plan Analysis & Prepare Data | Step 2 Prepare Flow Duration Curve | **Step 3 Prepare Load Duration Curve** | Step 4 Interpret & Apply | Step 5 Document the Analysis

- To prepare the Load Duration Curve:
  - Calculate the pollutant load that results in water quality target attainment for each point on the flow duration curve using the general loading equation

General Loading Equation

Load = Target Concentration x Flow x Unit Conversion Factor

Prepare Load Duration Curve

Develop Load Duration Curve → Step 1 Plan Analysis & Prepare Data → Step 2 Prepare Flow Duration Curve → **Step 3 Prepare Load Duration Curve** → Step 4 Interpret & Apply → Step 5 Document the Analysis

Flow Duration Interval	Streamflow (cfs)	Target Pollutant Concentration
0%	2,320	1 mg/L
5%	2,290	
...	...	
50%	2,045	
...	...	
95%	759	
100%	642	

Determined during the *Establish Targets* step of TMDL development

Prepare Load Duration Curve

Develop Load Duration Curve → Step 1 Plan Analysis & Prepare Data → Step 2 Prepare Flow Duration Curve → **Step 3 Prepare Load Duration Curve** → Step 4 Interpret & Apply → Step 5 Document the Analysis

Flow Duration Interval	Streamflow (cfs)	Target Pollutant Concentration	Pollutant Load (lbs/day)
0%	2,320	1 mg/L	12,514
5%	2,290		12,352
…	…		
50%	2,045		11,030
…	…		
95%	759		4,094
100%	642		3,463

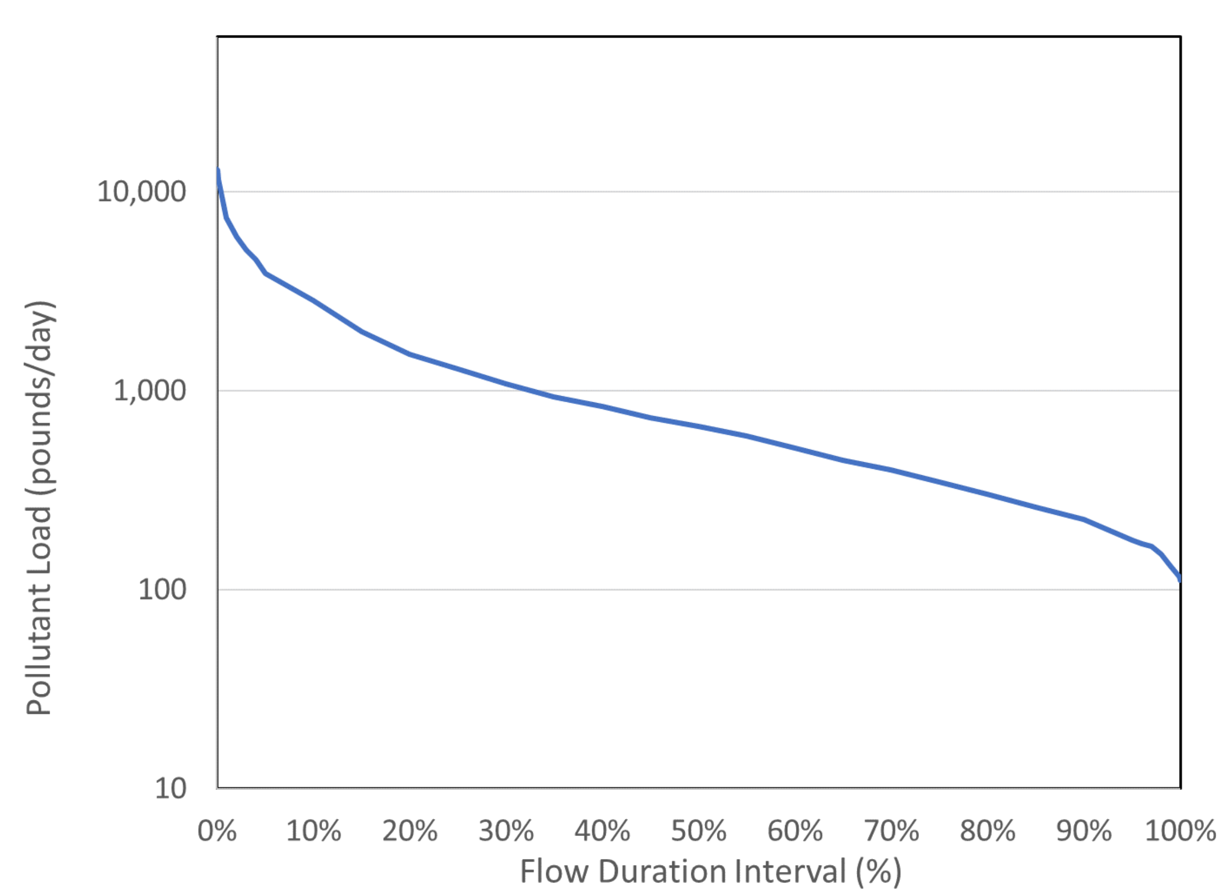
General Loading Equation

Load = Target Concentration x Flow x Unit Conversion Factor

Prepare Load Duration Curve

Develop Load Duration Curve | Step 1 Plan Analysis & Prepare Data | Step 2 Prepare Flow Duration Curve | **Step 3 Prepare Load Duration Curve** | Step 4 Interpret & Apply | Step 5 Document the Analysis

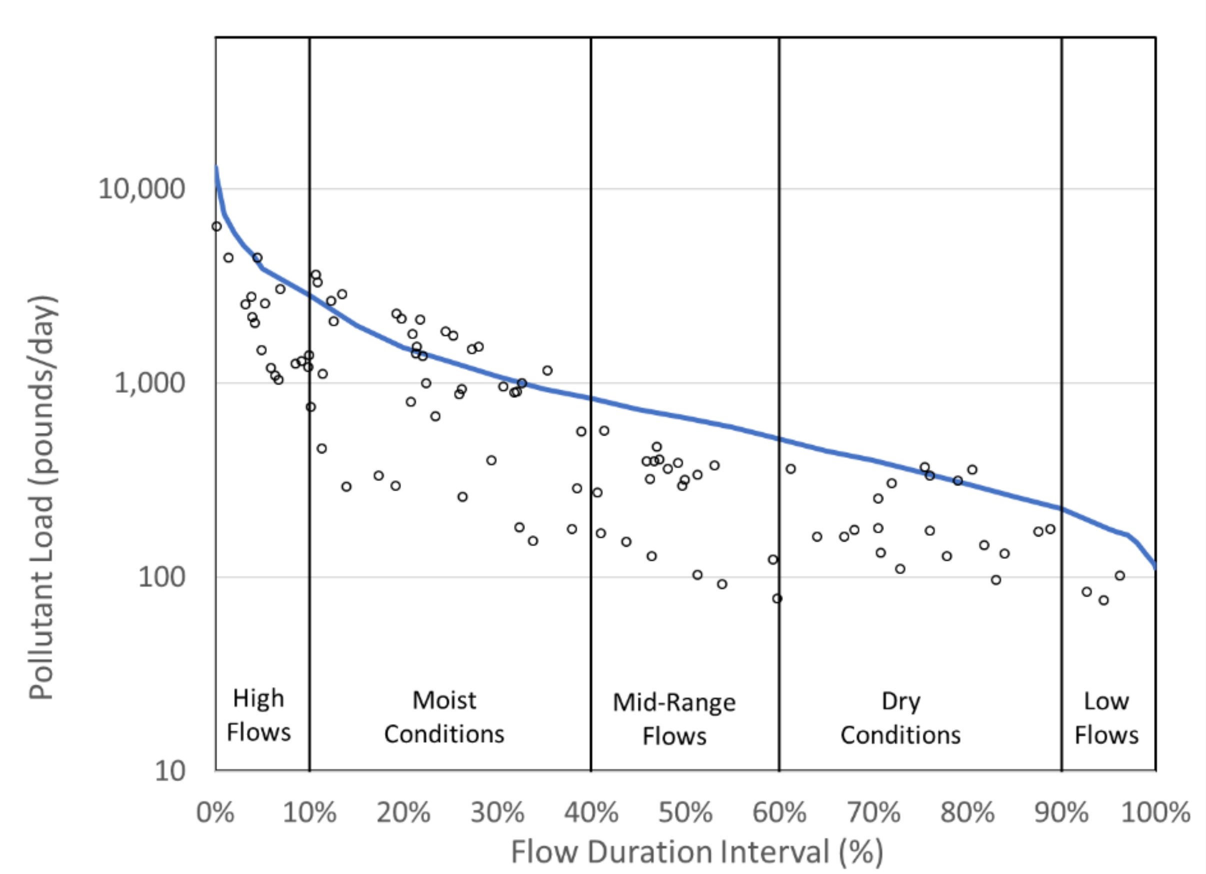
Flow Duration Interval	Pollutant Load (lbs/day)
0%	12,514
5%	12,352
...	
50%	11,030
...	
95%	4,094
100%	3,463



Prepare Load Duration Curve

Develop Load Duration Curve | Step 1 Plan Analysis & Prepare Data | Step 2 Prepare Flow Duration Curve | **Step 3 Prepare Load Duration Curve** | Step 4 Interpret & Apply | Step 5 Document the Analysis

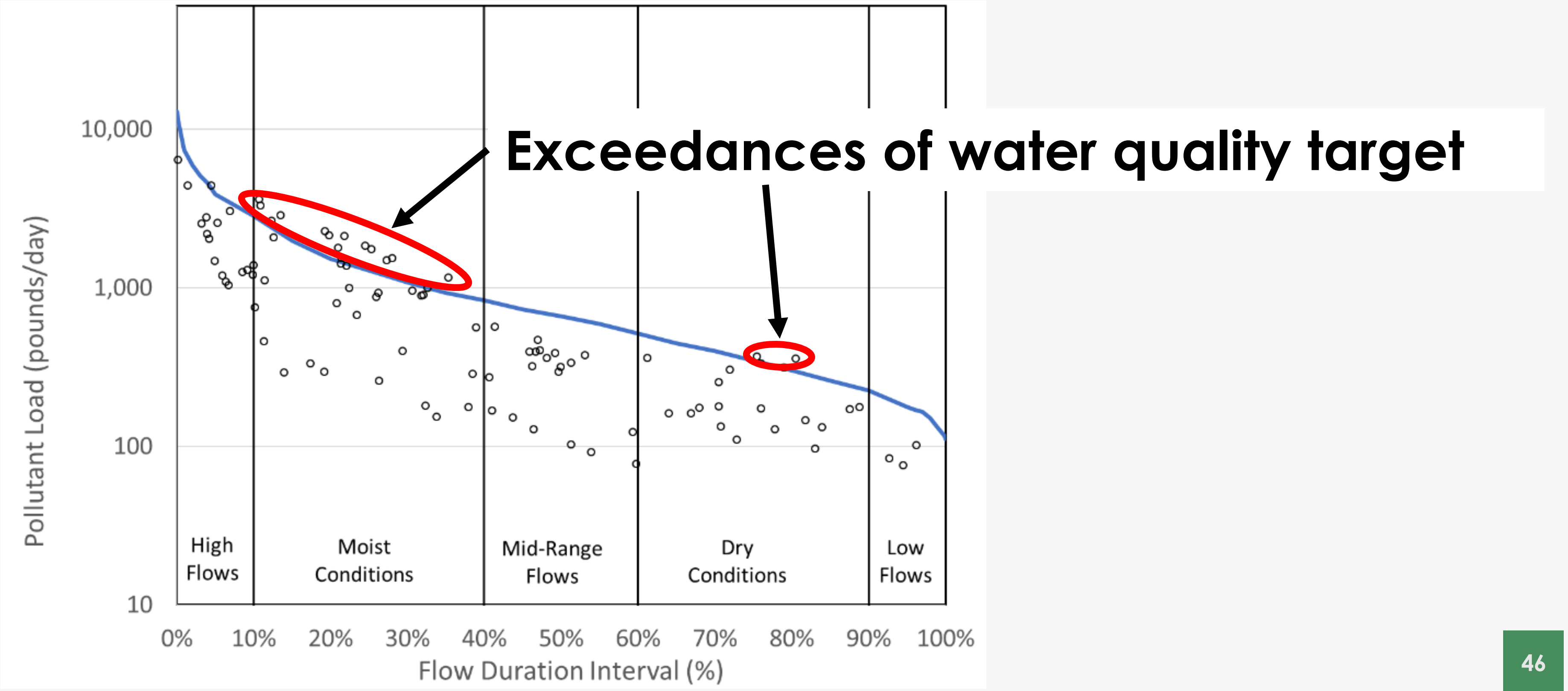
- Add water quality monitoring data and flow regime zones



Interpret & Apply

Develop Load Duration Curve | Step 1 Plan Analysis & Prepare Data | Step 2 Prepare Flow Duration Curve | Step 3 Prepare Load Duration Curve | **Step 4 Interpret & Apply** | Step 5 Document the Analysis

- Use the Load Duration Curve to evaluate the relationship between flow conditions and sampled water quality



Interpret & Apply

Develop Load Duration Curve

Step 1 Plan Analysis & Prepare Data

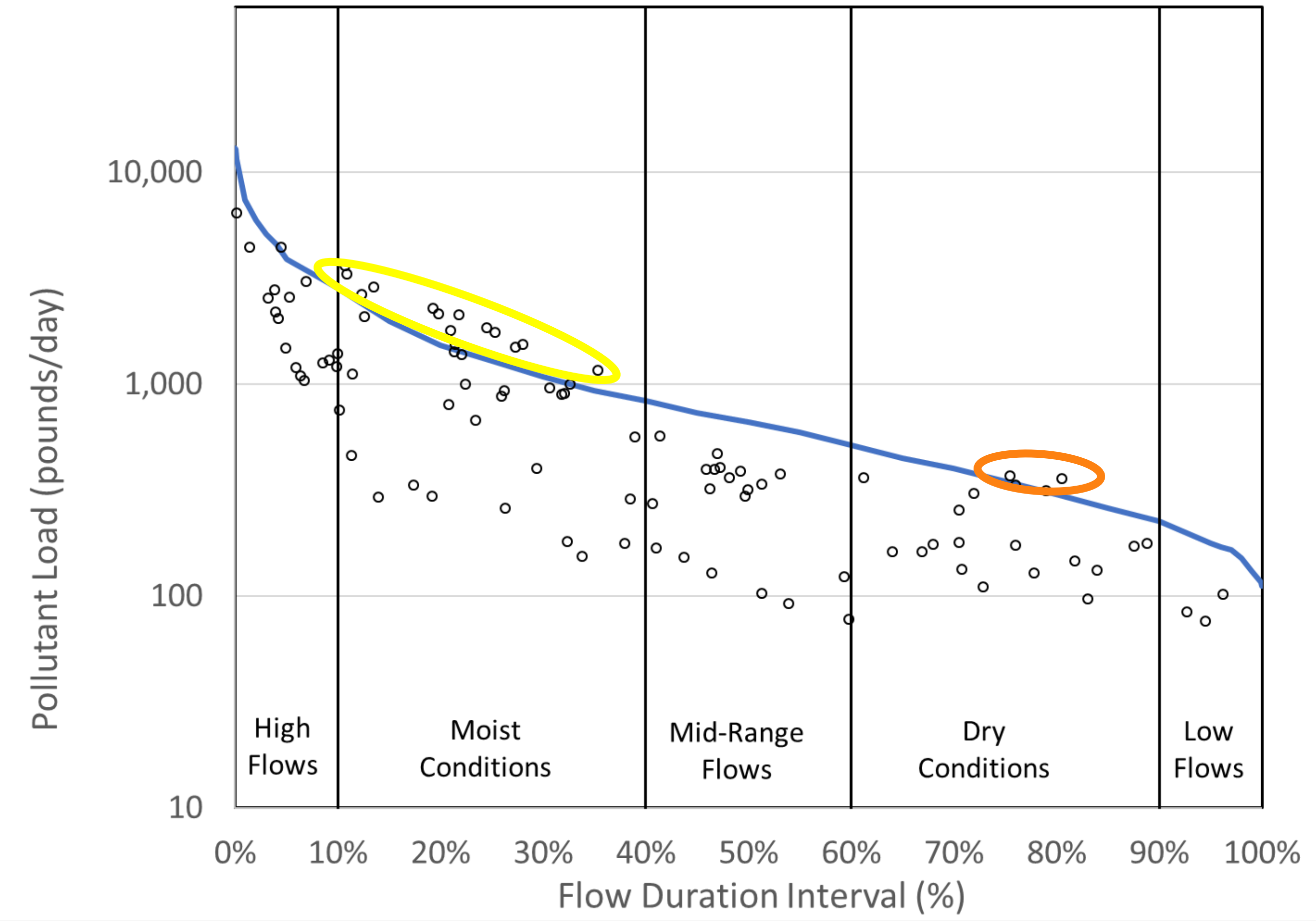
Step 2 Prepare Flow Duration Curve

Step 3 Prepare Load Duration Curve

Step 4 Interpret & Apply

Step 5 Document the Analysis

Exceedances are generally runoff-driven (agriculture, stormwater, CSOs, etc.)



Exceedances are generally effluent-driven (wastewater discharge, illicit discharges, etc.)

Interpret & Apply

Develop Load Duration Curve → Step 1 Plan Analysis & Prepare Data → Step 2 Prepare Flow Duration Curve → Step 3 Prepare Load Duration Curve → **Step 4 Interpret & Apply** → Step 5 Document the Analysis

Pollutant Source	**Load Duration Curve Zone**				
	High Flow	Moist	Mid-Range Flow	Dry	Low Flow
Point Source (Non-Stormwater)				○	●
Septic Systems			●	○	
Stormwater (Impervious Areas)		●	●	○	
Stormwater (Pervious Areas)	●	●	○		
Combined Sewer Overflows	●	●			
Streambank Erosion	●	○			

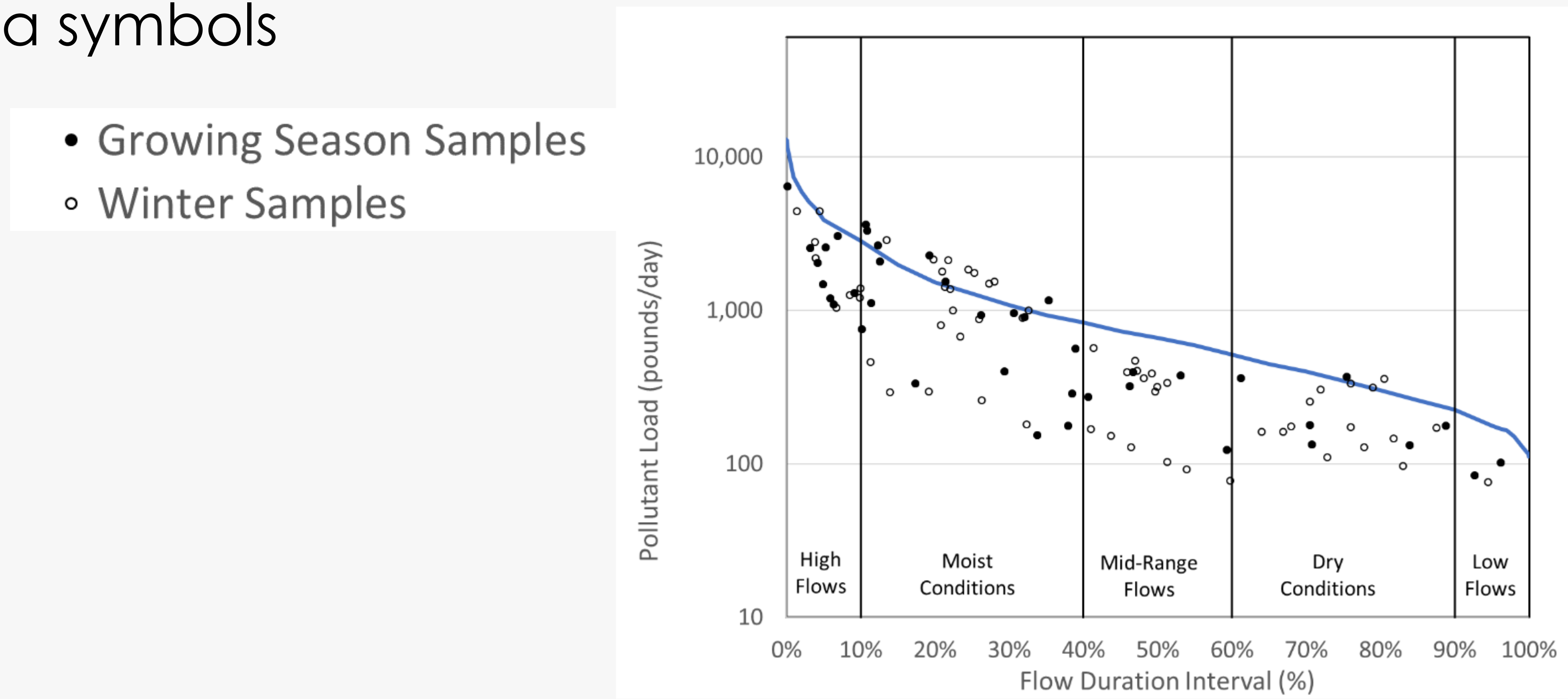
● = High Contribution to Exceedances

○ = Moderate Contribution to Exceedances

Interpret & Apply

- Develop Load Duration Curve
- Step 1 Plan Analysis & Prepare Data
- Step 2 Prepare Flow Duration Curve
- Step 3 Prepare Load Duration Curve
- **Step 4 Interpret & Apply**
- Step 5 Document the Analysis

- Seasonal variation can be evaluated by adjusting sample data symbols



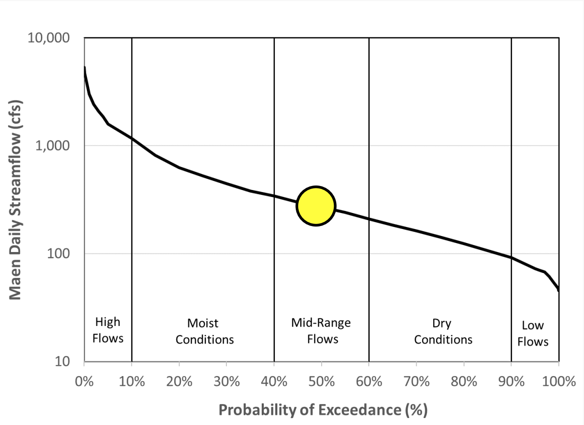
Interpret & Apply

Develop Load Duration Curve → Step 1 Plan Analysis & Prepare Data → Step 2 Prepare Flow Duration Curve → Step 3 Prepare Load Duration Curve → **Step 4 Interpret & Apply** → Step 5 Document the Analysis

- Options for expressing the loading capacity from the Load Duration Curve:

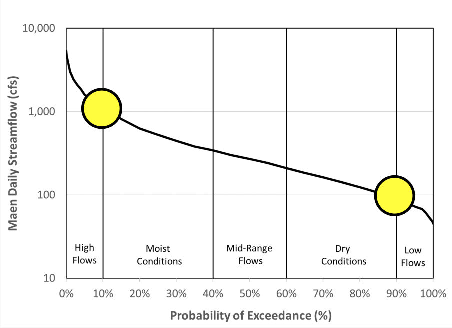
Load for a Critical Flow

Loading Capacity = 500 lbs/day

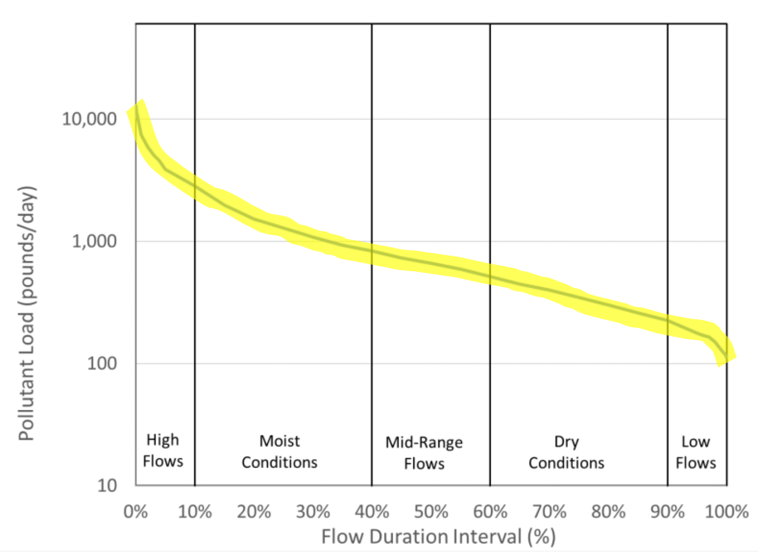


Loads for Multiple Flow Zones

Flow Zone	*Loading Capacity*
Low Flow	*100 lbs/day*
High Flow	*1,000 lbs/day*



Entire Load Duration Curve



Document the Load Duration Curve

Develop Load Duration Curve → Step 1 Plan Analysis & Prepare Data → Step 2 Prepare Flow Duration Curve → Step 3 Prepare Load Duration Curve → Step 4 Interpret & Apply → **Step 5 Document the Analysis**

- The Load Duration Curve data sources, methods, and results can be documented in the TMDL report or in a technical appendix
- TMDL developers can also update strengths and weaknesses for inclusion in the TMDL report, potential topics include:
  - Streamflow and water quality monitoring data quality (completeness, representativeness, etc.)
  - Supporting evidence for Load Duration Curve assumptions (relationship between streamflow and pollutant loading, minimal fate and transport processes, etc.)
  - How are seasonality and critical conditions addressed?

Exercise 5.1: Develop a Load Duration Curve

Learning Assessment

1) Which of the following statements best describe a load duration curve?
    a) A plot of historical and projected pollutant loading from nonpoint sources in a watershed
    b) A visual depiction of the relationship between streamflow and loading capacity
    c) The maximum pollutant load that an NPDES permitted facility is designed to discharge

Exercise 5.1: Develop a Load Duration Curve

Learning Assessment

2) What pieces of data and information are typically used to generate a load duration curve? (select all that apply)
   a) Long-term streamflow monitoring data
   b) Precipitation measurements
   c) The numeric water quality target for the TMDL
   d) Water quality monitoring data for the waterbody
   e) Discharge Monitoring Reports for point sources

Exercise 5.1: Develop a Load Duration Curve

Learning Assessment

3) Which of the following statements is true:

   a) Load duration curves are generally only useful for streams and rivers; other methods may be needed for lakes, embayments, etc.

   b) Load duration curves cannot be used to evaluate response parameters (dissolved oxygen, chlorophyll-a, etc.)

   c) Load duration curves assume that fate and transport processes are not significant (sediment dynamics, chemical transformations, biological uptake, etc.)

   d) All of the above

Exercise 5.1: Develop a Load Duration Curve

Learning Assessment

4) Exceedances of a numeric target that occur in the **low flow** portion of a load duration curve are generally **runoff-driven**
   a) True
   b) False

Exercise 5.1: Develop a Load Duration Curve

- Download the Exercise 5.1 files to your laptop:
  - *Training Session 5 > Activity-Exercise Materials >*
    Exercise 5.1 – Instructions.pdf
    Exercise 5.1 – Load Duration Curve.xslx
- Use the instructions and Excel file to create a load duration curve for the Opal River TMDL
- Answers will be discussed at the beginning of Session 6

Closing Comments

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U.S. EPA Office of Wetlands, Oceans, and Watersheds

Q&A Session