DEPARTMENT OF ECOLOGY
State of Washington

Calculating Pollutant Loads for Stormwater Discharges

Standard Operating Procedure
Version 1.2

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Washington State Department of Ecology

Standard Operating Procedure for Calculating Pollutant Loads for Stormwater Discharges

Version 1.2

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WQP004

Please note that the Washington State Department of Ecology's Standard Operating Procedures (SOPs) are adapted from published methods, or developed by in-house technical and administrative experts. Published SOPs can be found on Ecology's website http://ecology.wa.gov, search "quality assurance. Their primary purpose is for internal Ecology use, although sampling and administrative SOPs may have a wider utility. Our SOPs do not supplant official published methods. Distribution of these SOPs does not constitute an endorsement of a particular procedure or method.

Any reference to specific equipment, manufacturer, or supplies is for descriptive purposes only and does not constitute an endorsement of a particular product or service by the author or by the Department of Ecology.

Although Ecology follows the SOP in most instances, there may be instances in which Ecology uses an alternative methodology, procedure, or process.

SOP Revision History

Revision Date	Rev number	Summary of changes	Sections	Reviser(s)
6/29/2018	1.1	General updates to dates, references and website throughout. Safety section update.	All	Brandi Lubliner
1/11/2024	1.2	Recertification. Only version number and date changes	All	Brandi Lubliner

1.0 Purpose and Scope

1.1 This document is the Washington State Department of Ecology's Standard Operating Procedure (SOP) for calculating pollutant loads from stormwater discharges. External users that reference this SOP are expected to describe or reference their own agency or jurisdiction safety protocols in their Quality Assurance Project Plan (QAPP), as this document describes Ecology protocols.

1.2 This SOP provides a method for calculating seasonal and annual pollutant loads (contaminant mass loads) from stormwater discharge pipes. The results of the steps in Summary of Procedure are expressed as pounds per year, and pounds per acre per year.

1.3 The annual contaminant mass load (mass/year) is the product of mean contaminant concentration (mass/volume) multiplied by the annual discharge volume (volume/year).

1.4 In an analogous manner, the mass loads may also be broken out on a seasonal basis. In NPDES permits, loads are required to be reported as total annual load and also separately as wet and dry season load.

1.5 While certain types of Best Management Practices (BMPs) can be implemented to reduce stormwater volume and flow, storm flow is fundamentally affected by random, year-to-year changes in weather and runoff hydrology in a drainage area. As a result, contaminant concentrations should be used in time trend analysis, as opposed to estimated event-based, seasonal, or annual contaminant loads, because the large component of random variability in contaminant loads is more likely to confound the interpretation of long-term changes in stormwater quality.

2.0 Applicability

2.1 Data needed for the calculation in this SOP includes continuous flow recordings at the piped monitoring location, continuous rainfall records, stormwater water quality and base flow quality data (if base flow is present), and sampling results collected by use of automated flow-weighted composite samplers. The reported laboratory concentrations for flow-weighted composite samples represent the event mean concentrations (EMCs). Similarly, the calculation of average annual and seasonal mass loads will be performed using flow-weighted averages.

2.2 This SOP applies to calculating pollutant loads from outfall discharge pipes. Literature and research available provides several methods for calculating loads. Some of the available loading methods assume there is an underlying correlation between flow and concentration (i.e., "ratio estimator" methods). While such methods may have some applicability for rivers and streams, compelling evidence of such correlations has not generally been observed in urban stormwater data. As a result, no correlation between flow and concentration is assumed in this procedure. This method was selected from work accomplished by City of Tacoma and Anchor Environmental.

3.0 Definitions

3.1 **Base flow**: Flows occurring in the drainage after 48 hours with no measurable rainfall (i.e., less than 0.02 inches).

3.2 **Continuous Flow Record:** A continuous flow record should consist of hourly measurements throughout the entire water year (24 hr/day x 365 days = 8,760 flow measurements)

3.3 **Dry season:** The dry season in Western Washington occurs between May 1st and September 30th. The dry season in Eastern Washington occurs between July 1st and September 30th (Ecology 2005, 2004).

3.4 **Event Mean Concentration (EMC):** Pollutant concentration of a composite of multiple samples (aliquots) collected during the course of a storm. The EMC accurately determines pollutant loads from a site and is most representative of average pollutant concentrations over an entire runoff event (SSFL, 2008).

3.5 **Pollutant Load**: A mass concentration multiplied by the total volume of water passing by a certain point in the conveyance system (generally the stormwater outfall or the point of discharge) over a specified period of time (Wanielista and Yousef, 1992, and Minton, 2005).

3.6 **Wet Season:** The wet season in Western Washington occurs between October 1st and April 30th (Ecology 2005 and 2007). The wet season in Eastern Washington occurs between October 1st and June 30th (Ecology 2004).

4.0 Personnel Qualifications/Responsibilities

Not applicable.

5.0 Equipment, Reagents, and Supplies

5.1 From each monitored station the following data is needed for this calculation:

5.1.1 Continuous flow records (15 minute intervals)

5.1.2 Continuous rainfall records (15 minute intervals)

5.1.3 Stormwater water quality sampling results (EMC) collected by use of automated, flow-weighted composite samplers

5.1.4 Base flow samples (if base flow is present) collected by use of automated, flow-weighted or time-weighted composite samplers.

6.0 Summary of Procedure

6.0.1 Appendix A contains a spreadsheet that can be used for performing this calculation

6.0.2 The total annual load is the sum of base flow and storm flow loads.

6.0.3 At each outfall discharge location where loads are assessed, a base flow analysis is needed, if base flow is present.

6.0.4 If base flow is present at the discharge location, it will have to be taken into consideration for the calculation since the chemical composition of base flow can be different than storm flow (City of Tacoma 2009). Base flow can contain contributions from groundwater intrusion, subsurface flow, seeps and springs. Because of these inherent differences in the nature and quality of their sources, base flow and storm flow loads will be calculated separately.

6.0.5 **Equation 1a**: The equation for calculating total annual mass load [ML] for a particular chemical constituent is:

$$ML = \text{Base Load} + \text{Storm Load}$$

$$ML = [(V_{bd} \times C_b) + (V_{bw} \times C_b)] + [(V_{sd} \times C_s) + (V_{sw} \times C_s)]$$

Where,

- [V_{bd}] is the base flow volume in the dry season,
- [V_{bw}] is the base flow volume in the wet season,
- [C_b] is the average annual flow-weighted base flow concentration,
- [V_{sd}] is the storm flow volume in the dry season,
- [V_{sw}] is the storm flow volume in the wet season, and
- [C_s] is the average annual flow-weighted stormwater concentration.

6.1 Determine Base Flows and Volumes for Wet and Dry Seasons

6.1.1 Install appropriate flow monitoring equipment and automated samplers at the monitoring site (see Ecology ECY 002, 2009 for more details).

6.1.2 Flows occurring in the drainage after 48 hours with no measurable rainfall (i.e., less than 0.02 inches) are defined as base flows.

6.1.3 Collect flow rate data from the site for at least one week to determine presence/absence of base flow. You may be able to make a base flow determination in less than one week if base flow criteria are met during the monitoring period.

6.1.4 Upload information from your flow monitoring equipment to view the storm event(s) hydrograph and distinguish any differences between storm flows and flow stabilization.

6.1.5 If the hydrograph indicates "0" flow between storms, you do <u>not</u> have base flow. If the hydrograph indicates a flow level above "0" that stabilizes between storm events or occurs during dry weather, in accordance with the antecedent precipitation criteria defined in Section 3.0, this is your base flow rate.

6.1.6 If base flow is detected, continue to collect flow rate data on an hourly basis in order to represent each wet and dry season. The measured flow data will include periods of base flow only as well as periods of combined base flow and stormwater.

6.1.6.1 Base flow discharges will need to be estimated during storm events, during which time the total measured flow consists of combination of both base flow and storm flow. Base flow will be estimated during storm events by interpolating from the nearest base flow periods preceding and following the storm(s). Linear interpolation will be used to estimate the base flow contribution during storm events.

6.2 Determine Water Quality from Base Flows from Both Wet and Dry Seasons

6.2.1 Collect water quality samples from your base flow discharge representing both wet and dry seasons. Use an antecedent dry period of equal to or less than 0.02" precipitation in the past 48 hours to ensure you collect a representative base flow sample.

6.2.2 It is recommended that two samples representing the wet season are collected and two samples representing the dry season are collected. This number of samples can be reduced if you find little or no seasonal variation.

6.2.3 Since base flow is expected to be relatively steady within an individual sampling event, water quality samples may be collected using either flow-weighted or time-weighted sampling schemes. Automated sampling methods are recommended, however grab sampling techniques may be acceptable (see Ecology ECY001, 2009 for more details). It is recommended that base flow composite samples be collected over a 24-hour period, unless the sampling time is limited by periods of tidal intrusion (see below).

6.2.4 Continue to collect flow rate data for at least one year at each monitoring site since base flows can change gradually over time as a result of seasonal changes in water table elevations, perched underflows, and seepage rates.

6.2.5 When collecting base flow water quality samples in tidally influenced drains (i.e. subject to seawater intrusion and flow reversal), ancillary monitoring information such as flow direction and salinity should be collected and carefully reviewed to detect periods of tidal influence that would result in unrepresentative base flow samples. As a result of this analysis, some of the sample aliquots may need to be excluded from the composite sample.

6.3 Determine Base Flow Volumes for Wet and Dry Season

6.3.1 Determine the seasonal base flow volumes for wet season [V_{bw}] and dry season [V_{bd}]. This is done by integrating the base flow record over time for the wet and dry seasons, as defined in Section 3.0 (i.e., volume/time x time = volume). If the base flow monitoring record consists of systematic measurements at regular intervals (e.g., hourly measurements), this is equivalent to calculating an average base flow discharge rate during the wet and dry seasons, then multiplying by the total duration of the wet and dry seasons, respectively (i.e., 212 and 153 days, respectively).

6.3.2 Calculate the annual base flow volume by summing the wet season and dry season base flow volumes:

$$\text{Total Annual Base flow} = ([V_{bw}] + [V_{bd}]).$$

6.4 Determine Flow Weighted Mean Base Flow Concentration

6.4.1 Use the water quality data collected from your dry and wet season base flow samples to tabulate the chemical concentrations for the monitoring year.

6.4.2 Initially, a flow-weighted mean concentration will be calculated for the entire monitoring year. However, if seasonal differences in base flow quality are evident, mean base flow concentrations may be calculated separately for the wet and dry seasons (see Step 6.12).

6.4.3 Calculate a flow-weighted mean base flow concentration [C_b]. First, calculate the mean base flow rate for each sampling event [BF_i]. This is obtained by dividing the total base flow discharge volume by the total time (duration) of the base flow sampling event:

$$BF_i = V_i / t_i \quad \text{(for each base flow event } i\text{)}$$

Alternatively, if the base flow monitoring record consists of systematic measurements at regular intervals (e.g., hourly measurements), then simply calculate an average base flow discharge rate during the sampling period.

Then, the annualized flow-weighted mean base flow concentration is:

$$C_b = \Sigma\,(C_{bi} \text{ x } BF_i) / \Sigma\, BF_i \; (I = 1 \text{ to n})$$

Where [C_{bi}] is the analytical concentration for base flow event *I*, and [n] = number of base flow sampling events.

6.5 Estimate Base Flow Mass Load

6.5.1 Calculate a contaminant mass load associated with base flow derived from the results of Steps 6.1 and 6.3 using the first two products in Equation 1a.

$$(V_{bd} \text{ x } C_b) + (V_{bw} \text{ x } C_b)$$

6.6 Determine Total Storm Flows and Volumes on a Seasonal and Annual Basis

6.6.1 The record of continuous flow measurements at the monitoring site is the sum of the base flow and storm flow, i.e., the total combined flow. This should be collected for at least one year to capture seasonal variation.

6.6.2 Subtract the continuous base flow record, as developed in Step 6.1.5, from the continuous record of total flow to derive a continuous record of storm flow. During base flow periods, the storm flow should drop to zero.

6.6.3 Integrate the total storm flow volume over the wet season and dry season (volume/time x time = volume). If the monitoring record consists of systematic measurements at regular intervals (e.g., hourly measurements), this is equivalent to calculating an average storm flow discharge rate during the wet and dry seasons (after subtracting the base flow component), then multiplying by the total duration of the wet and dry seasons, respectively (i.e., 212 and 153 days, respectively).

6.6.4 Calculate the total annual storm flow volume by summing the dry season and wet season storm flow volumes.

$$\text{Total Annual Storm flow} = ([V_{sw}] + [V_{sd}]).$$

6.7 Separate Storm Flow and Base Flow Volumes in Sampled Storm Events

6.7.1 For outfalls with base flow contributions, the sampled storm events represent a mixture of storm flow and base flow:

6.7.2 Subtract the base flow contribution volume from total combined flow (measured flow) to give the storm flow contribution for each sampled storm event (see also Section 6.6.2).

6.7.3 Integrate the storm flow and base flow volumes over the sampling event period, then calculate the fractional volumetric contributions of storm flow and base flow for each sampling event.

6.7.4 Note: The fraction of storm flow volume [f_s] plus the fraction of base flow volume [f_b] should be equal to one. These fractions are storm event-specific and are expected to change from one storm to the next.

6.8 Calculate Storm Flow EMC for each Sampled Storm Event

6.8.1 The total stormwater EMC [EMC_{tot}], derived from laboratory analysis of a flow-weighted composite water quality sample, is a mixture of storm flow and base flow components. As a result, the base flow volume must be "unmixed" from the EMC_{tot} using the principles of mass balance to calculate the EMC for the storm flow concentration alone [EMC_s].

6.8.2 Perform this calculation using the volumetric fractions from Step 6.7.2 [f_s and f_b] and the mean base flow concentration from Step 6.4.2 [C_b]:

$$EMC_s = [EMC_{tot} - (C_b \times f_b)] / f_s \qquad \text{[Equation 1b]}$$

6.8.3 In most situations, EMC_s will be greater than EMC_{tot} because more contaminated stormwater runoff is generally diluted by less contaminated base flow.

6.9 Determine Annualized Flow-Weighted Mean Storm Flow Concentration

6.9.1 Total stormwater EMCs for sampled storm events during the monitoring year will be converted to storm flow EMCs as described in Step (6.8). Then, a flow-weighted mean storm flow concentration will be calculated for the entire monitoring year.

6.9.2 First, calculate the mean storm flow rate for each sampling event [SF_i], which is obtained by dividing the total storm flow discharge volume by the total time (duration) of the storm flow sampling event:

$$SF_i = V_i / t_i \quad \text{(for each storm flow event } i\text{)}$$

6.9.3 Alternatively, if the monitoring record consists of systematic flow measurements at regular intervals (e.g., hourly measurements), then simply calculate an average storm flow discharge rate for each sampling event (after subtracting the base flow contribution).

6.9.4 Then, the annualized flow-weighted mean storm flow concentration is:

$$C_s = \Sigma\,(EMC_{si} \times SF_i) / \Sigma\, SF_i \; (I = 1 \text{ to } n)$$

Where [EMC_{si}] is the event mean concentration for storm flow event *I*, and [n] = number of storm flow sampling events.

6.9.5 Initially, a flow-weighted mean storm flow concentration will be calculated for the entire monitoring year. However, if seasonal differences in stormwater quality are evident, mean storm flow concentrations may be calculated separately for the wet and dry seasons (see Step 6.12).

6.10 Estimate Storm Flow Mass Load

6.10.1 Estimate a contaminant mass load associated with storm flow from the results of Steps 6.6 and 6.9.

6.10.2 Calculate the storm flow mass load from the last two products in Equation 1a:

$$(V_{sd} \text{ x } C_s) + (V_{sw} \text{ x } C_s)$$

6.11 Estimating Flow to Fill Data Gaps (i.e. Incomplete Flow Monitoring Records)

6.11.1 Although it is expected that a continuous flow monitoring record will be collected in the first year or two of data collection to characterize the hydrologic response in a particular drainage basin, it is also expected that the flow monitoring intensity may be reduced in subsequent years. Therefore it becomes necessary to estimate flows, based on observed rainfall-runoff relationships, during periods when active flow monitoring is not being conducted.

6.11.2 Determine a rainfall-runoff relationship for each monitoring site using continuous flow record and rainfall records. Avoid series of overlapping storms with poorly defined separations between storm events.

6.11.3 Use a number of discrete storm events of varying magnitude for determining the runoff volumes associated with incident rain depths.

6.11.4 Create a regression model to fit to this relationship so that runoff volumes may be predicted from rainfall records when there are gaps in the flow monitoring record or in future years when flow meters are not collecting continuous measurements over the entire monitoring year.

6.11.5 Different relationships may need to be modeled for the wet and dry seasons if the hydrologic response is significantly different.

6.12 Evaluate Seasonal Differences in Base Flow and Stormwater Quality

6.12.1 After two years of monitoring data are collected (i.e., 4 base flow events per year [8 total] at 11 to 14 events per year [22 to 28 total]), perform statistical tests to determine whether statistically significant differences in base flow or stormwater quality are evident between wet and dry seasons.

6.12.2 Tests for significant difference may be performed using a parametric statistical test (i.e., t-test) or an equivalent nonparametric test (i.e., Mann-Whitney-Wilcoxon rank sum test). The nonparametric test is preferable if data are highly censored.

6.12.3 If statistically significant seasonal differences are observed in base flow, stormwater, or both, the mass loading equation is modified as appropriate:

$$ML = (V_{bd} \text{ x } C_{bd}) + (V_{bw} \text{ x } C_{bw}) + (V_{sd} \text{ x } C_{sd}) + (V_{sw} \text{ x } C_{sw}) \quad \text{[Equation 1c]}$$

Where,

- $[C_{bd}]$ is the flow-weighted mean base flow concentration during the dry season.
- $[C_{bw}]$ is the flow-weighted mean base flow concentration during the wet season.
- $[C_{sd}]$ is the flow-weighted mean stormwater concentration during the dry season.
- $[C_{sw}]$ is the flow-weighted mean stormwater concentration during the wet season.

7.0 Records Management

7.1 Records with calculations, rainfall data records, continuous flow records and water quality data records should be maintained on site for up to 3 years.

8.0 Quality Control and Quality Assurance Section

8.1 Check calculations during the Data Verification and Data Validation procedure for each project. Any errors should be addressed and indicated in the records.

9.0 Safety

Not Applicable

10.0 References

10.1 City of Tacoma, *Quality Assurance Project Plan for Stormwater Monitoring,* (2008)

10.2 City of Tacoma, *Stormwater Monitoring Report for Thea Foss and Wheeler-Osgood Waterways*, 2001-2008, prepared for Washington Department of Ecology, March 2009.

10.3 Minton, G, *Stormwater Treatment: Biological, Chemical, and Engineering Principles,* Sheridan Books, Ann Arbor, Michigan, 2005

10.4 SSFL CDO Expert Panel, *Sample Collection Methods for Runoff Characterization at Santa Susana Field Laboratory*, October 20, 2008

10.5 Wanielista, M.P. and Yousef, Y.A., *Stormwater Management*, New York: John Wiley and Sons, 528 p, 1992.

10.6 Washington State Department of Ecology, *Phase I Municipal Stormwater Permit,* January 2007 and August 2016.

10.7 Washington State Department of Ecology, *Stormwater Management Manual for Western Washington*, Publication No. 05-10-033, 2005.

10.8 Washington State Department of Ecology, *Stormwater Management Manual for Eastern Washington*, Publication No. 04-10-076, 2004.

10.9 Washington State Department of Ecology, *Standard Operating Procedure for Automatic Sampling for Stormwater Monitoring,* ECY 002, 2009.

10.10 Washington State Department of Ecology, *Standard Operating Procedure for Collecting Grab Samples from Stormwater Discharges,* ECY001, 2009.

Appendix A Instructions for Pollutant Loading Workbook

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MEMORANDUM

To:	Julie Lowe, Department of Ecology Dana DeLeon, City of Tacoma	**Date:**	August 19, 2009
From:	Todd Thornburg, AnchorQEA	**Project:**	080195-01
Re:	Pollutant Loading Workbook Instructions		

GENERAL

This memo provides user instructions for the Pollutant Loading Workbook which has been developed to provide automated pollutant loading calculations according to the procedures described in Ecology's *Standard Operating Procedure for Calculating Pollutant Loads for Stormwater Discharges* (ECY004; 2009). The Pollutant Loading Workbook contains five separate worksheets:

1. Flow Interpolation
2. Event Flow Data
3. Annualized Mean Concentrations
4. Pollutant Loadings
5. Hydrographs

Cells requiring user input data are highlighted in yellow. A majority of the output calculations are summarized in Worksheet Nos. 3 and 4, which are formatted for printing on 11" x 17" paper (in landscape). The worksheets are described in more detail below.

6. FLOW INTERPOLATION

Overview

This worksheet analyzes continuous flow data for use in subsequent calculations of flow-weighted concentrations and pollutant loadings. The worksheet defines base flow and storm flow periods based on user-defined specifications for antecedent precipitation requirements. The default definition of base flow is less than 0.02 inches of precipitation in the preceding 48 hours. The worksheet separately estimates stormwater and base flow contributions during storm flow periods by interpolating base flows between base flow periods, then subtracting the base flow contribution from the total flow (combined stormwater and base flow), as directly measured in the field.

User Input Requirements

- Site data (outfall number and water year)

- Hourly cumulative measurements of precipitation for the entire water year (October 1 through September 30). Note that the precipitation record must begin on September 29 to evaluate the antecedent precipitation period for October 1.
- Hourly flow measurements for the entire water year. If flow measurements are collected more frequently (e.g., 15 or 30 minute intervals), average hourly measurements should be calculated and reported. The default flow units are gallons per minute (gpm).

2. EVENT FLOW DATA

Overview

This worksheet calculates event-mean flows during specific sampling periods for use in calculating flow-weighted annualized concentrations of stormwater and base flow. It also calculates the proportional contributions of storm flow and base flow during sampled storm events for use in "unmixing" calculations (see Worksheet No. 3).

User Input Requirements

- Sampling events for base flow (up to 4 events) and stormwater (up to 14 events) are sequentially numbered. Using integers that represent the sampling event number, the user must identify the periods of sampling for each separate base flow and stormwater sampling event, to the nearest hour. If 30 or more minutes are sampled within a given hour, that hour is included in the sampling period; if less than 30 minutes are sampled, the hour is excluded from the sampling period.

3. ANNUALIZED MEAN CONCENTRATIONS

Overview

This worksheet calculates flow-weighted, annualized mean concentrations for stormwater and base flow. In outfalls with significant base flow contributions, it "unmixes" the stormwater and base flow contributions during combined storm events.

Currently, the worksheet is not set up to calculate separate flow-weighted concentrations for the wet season and dry season. In the future, it could be modified to calculate seasonal means if it can be shown that there are statistically significant differences between wet season and dry season pollutant concentrations in stormwater and/or base flow.

User Input Requirements

- Number of valid base flow (up to 4) and stormwater (up to 14) monitoring events. This number should match the number of events used in the preceding Worksheet No. 2. Because of weather, physical or other constraints, the maximum number of monitoring events may not be collected in every outfall and every year. If the "number of valid events" does not match those in Worksheet No. 2, "#DIV/0!" errors will result.

- The user must enter chemical analytical results for NPDES constituents of concern, including index conventionals, metals, and organic constituents, for each sampled event. The analytical results are considered "event-mean concentrations" (EMCs) because they should have been collected as flow-weighted composite samples using automated samplers.

4. POLLUTANT LOADINGS

Overview

This worksheet calculates seasonal and annual pollutant loads (in pounds) for stormwater and base flow for NPDES chemicals of concern.

User Input Requirements

- Specify whether or not the month of February in the water year occurs during a leap year (e.g., Feb-2008, 2012, 2016, 2020, etc.). During a normal year, the wet season will include 212 days, whereas during a leap year, it will include 213 days. This will affect the calculation of mean storm and mean base flows during the wet and dry seasons. However, it will not directly affect pollutant loading calculations. All pollutant loading calculations, regardless of whether or not they occur during a leap year, are based on a normal year's discharge (365 days and 212 wet season days), so as not to impart an artificial bias on loading estimates during leap years.
- An extra cell is provided for unit conversion(s), if needed. For example, if flow measurements are collected in cubic feet per second (cfs) as opposed to gallons per minute (gpm), the unit conversion from cfs to gpm (default units) could be accommodated in this cell.

7. HYDROGRAPHS

Overview

This worksheet provides a chart template for plotting hydrographs of base flow, storm flow, and combined flow. The chart references back to the continuous base flow and storm flow hydrographs developed in Worksheet No. 1.

User Input Requirements

- The primary user input for this chart is the time scale on the X-axis. The time scale will need to be specified in Julian days for the entire water year or for any specific period of interest within the water year.

For Pollutant Loading Workbook, see Excel File associated with publication 18-10-026.