User Guide
Combined Sewer Overflow Model for Small Communities

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Disclaimer

The U.S. Environmental Protection Agency (EPA) has designed the Combined Sewer Overflow (CSO) Model for Small Communities as a tool to help small CSO communities reasonably estimate CSO volume and occurrence. EPA is not mandating the use of this model under the 1994 CSO Control Policy or the use of the presumption approach under the 1994 CSO Control Policy. This document is not itself a regulation, nor is it legally enforceable. Rather, it provides a guide to the CSO Model that communities may use in analyzing combined sewer systems and reasonably evaluating the presumption approach criteria to design or estimate sewer overflow volume and/or occurrence. Communities, small or otherwise, might find the model useful and should consult with their National Pollutant Discharge Elimination System permitting authorities to determine whether it is appropriate for them to use the CSO Model for Small Communities. Any mention of trade names, manufacturers, or products in this document does not imply an endorsement by the United States Government or EPA.

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Abbreviations

CSO	combined sewer overflow
CSS	combined sewer system
DCIA	directly connected impervious area
EPA	United States Environmental Protection Agency
GIS	geographic information system
I/I	inflow and infiltration
LTCP	long-term control plan
MG	million gallons
MGD	million gallons per day
MRLC	Multi-Resolution Land Characteristics
NLCD	National Land Cover Database
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
t_c	time of concentration
USGS	United States Geological Survey
WWTP	wastewater treatment plant

CSO Model Overview

The Combined Sewer Overflow (CSO) Model for Small Communities (hereafter referred to as the "CSO Model") is a spreadsheet-based planning tool for small communities that want a simple approach to estimating a CSO occurrence, as well as treated or untreated CSO volume over a 24-hour period, and have limited resources to invest in more advanced CSO monitoring and modeling. The CSO Model may also be used to estimate the CSO controls, either green or gray, needed to meet the presumption approach criteria (i) or (ii) in designing a CSO long-term control plan (LTCP). The CSO Model is designed for small CSO communities that have relatively simple combined sewer systems (CSSs). However, large CSO communities, with populations of greater than 75,000, might find the CSO Model useful if they need to update their existing models, or as a first step before using more expensive models. CSO communities that have many CSO outfalls and complex systems can also use the CSO Model by breaking down their CSS into sub-sewersheds based on receiving waterbodies and sewer infrastructure.

The CSO Model uses physical characteristics of a CSS that are usually well understood by the community (e.g., pipes, pumps, hydraulic control structures, treatment facilities), impervious cover, and observed or estimated rainfall data as inputs to estimate the treated and/or untreated CSO volume at each outfall. CSO communities that have completed the pre-construction monitoring, modeling, and characterization of the CSS while developing their LTCP will have documented these inputs. Communities that have not completed this pre-construction work may still have access to this information through municipal design and construction records, as well as publicly available datasets such as bid tabulations. Unlike other models that use design storm events to estimate CSO volumes, the CSO Model uses actual rainfall data from past storm events and a modified version of the Rational Method.

The model setup and data input requirements have been kept as simple as possible, while still providing a sound approach for modeling CSO events. As with any model, the accuracy of the results depends on the accuracy of data input. The U.S. Environmental Protection Agency (EPA) has provided specific guidance on navigating publicly available data sources and acquiring the necessary data for model input that may be unfamiliar to the user. The CSO Model includes a stormwater runoff component (see the section titled "Runoff Calculations") followed by various routing components (illustrated in the section titled "CSO Model Schematic).

The CSO Model consists of the following tabs:

1. **CSS Input:** General information about the community and its sewer system.
2. **CSO Input:** Characteristics of the community's CSO sub-sewersheds including outfall location, impervious surface area, and hydraulic control capacity.
3. **t_c and Rainfall:** Time of concentration (t_c) and hourly or 15-minute rainfall inputs.
4. **CSO Volume:** Runoff generated, CSO controls, and CSO flow inputs for estimating the CSO volume discharged, treated, stored, or eliminated.
5. **CSO Volume Summary:** Summary of flow volumes across the entire CSS, including flow routed to a wastewater treatment plant (WWTP).

The CSO Model also generates graphs for the estimated volume of stormwater runoff for each CSO sub-sewershed (Tab F1, Runoff Volume), CSO volume for each CSO outfall in the CSS (Tab F2, CSO Volume), and total flows throughout the CSS (Tab F3, CSS Flows) during or after a precipitation event.

This document provides step-by-step instructions for using the CSO Model. Each section of this user guide corresponds to the tabs of the CSO Model and describes the inputs necessary to generate volume and event estimations. The user guide discusses calculations and assumptions so that users can adjust the model, as needed, to better fit their specific system and conditions. The accuracy of the CSO Model is dependent on the accuracy of CSO Model inputs, and EPA encourages the user to identify the best available input data.

As part of model development, EPA performed a validation study to evaluate the CSO Model and identify changes that would improve its accuracy and usability. EPA used data from six communities, 28 individual sub-sewersheds with CSSs, and 2,302 CSO events. Results of the validation study demonstrate the level of accuracy the CSO Model can achieve, provide an idea of the type of information needed for model inputs, and show how to interpret the CSO Model results. Highlights from the validation study are below, while the full version can be found on EPA's CSO website at https://www.epa.gov/npdes/combined-sewer-overflows-csos.

EPA carried out the validation study in two phases, each with specific objectives. Because a primary goal of the CSO Model is to remain as simple as possible while still being sufficiently accurate, EPA performed the first round of testing using a preliminary version of the CSO Model to test its major components, such as its timestep and its use of percent imperviousness as a runoff coefficient. Major findings include:

- A 15-minute model timestep, rather than 60 minutes or five minutes, provides the best balance between model accuracy and usability.
- Using hourly rainfall data results in a considerable loss of accuracy; EPA recommends using 15-minute rainfall data or better.
- Total percent imperviousness is a suitable runoff coefficient for smaller sewersheds, but for sewersheds larger than 100 acres, it tends to overpredict peak flows and total volumes. For larger sub-sewersheds, EPA recommends using a directly connected impervious area (DCIA) or applying a reduction factor to total impervious area (additional discussion is provided in the sections below).

The second phase of testing used the current, or final, version of the model that was revised based on the findings of the first phase of testing. The main objectives of the second phase of testing were to provide an evaluation of the level of accuracy that could be expected of this final CSO Model, and to illustrate different ways it could be used. Major findings include:

- The CSO Model predicts runoff volumes and rates better than CSO volumes and rates, owing to inherent complexities in sewer systems and the difficulty in estimating CSO regulator capacity.
- Despite a variable ability to predict CSO volumes and flow rates, the CSO Model performs well in its ability to evaluate the presence or absence of a CSO event.
- The CSO Model can be calibrated and validated using simple, low-cost field monitoring techniques, as described in EPA's 1999 Guidance for Modeling and Monitoring as well as EPA's 2012 CSO Post Construction Compliance Monitoring Guidance. Once calibrated and validated, the CSO Model can serve as a powerful screening-level tool to help communities better understand their CSSs and reduce the need to monitor every rain event.
- More accurate estimations of CSO events occur when using high-quality input data (e.g., high-resolution rainfall data at a maximum timestep of 15 minutes, accurate estimates of inputs like impervious surface area and regulator capacity), as well as only using the CSO Model for smaller (under 100 acres), less complex systems.

CSO Model Results Interpretation and Reporting

The CSO Model is intended to provide an approximation of CSO volumes from actual storm events while requiring minimal effort and input from the user. EPA designed the model as a simpler and less labor-intensive alternative to more complex modeling approaches (e.g., EPA's Storm Water Management Model) and may help reduce the effort and costs associated with preliminary CSO control. In exchange for this simplification, the CSO Model's capabilities are limited when compared to more advanced modeling approaches. It is therefore important to understand these limitations and, wherever possible, calibrate model inputs and validate model results with monitoring data. Once calibrated and validated, the CSO Model can serve as a powerful screening-level tool to help communities better understand their CSSs and focus on more targeted monitoring efforts.

Model Limitations

The CSO Model treats each CSO sub-sewershed as a single, homogenous surface with a single conveyance capacity. While this approach greatly reduces data requirements by not requiring definition of complex, heterogeneous, and distributed land surface types and pipe networks, it also reduces the model's ability to capture complex runoff and routing processes, which can put more emphasis on the limited user inputs that apply uniformly to each CSO sub-sewershed and directly influence model results. These inputs include rainfall data, definition of sub-sewershed area and the associated impervious surface percentage, and time of concentration (t_c) inputs that determine the timing of the runoff response.

Based on extensive model testing, EPA identified the following specific limitations:

- The CSO Model is most suitable for sub-sewersheds that are less than 100 acres. For larger sub-sewersheds, the model tends to overpredict runoff flow rates and volumes (and CSO volumes, by extension). For larger sub-sewersheds, EPA recommends percent impervious surface be used as a calibration parameter.
- The CSO Model is most accurate when users input rainfall data that are based on a 15-minute timestep or shorter. If hourly rainfall data are used instead, the model's accuracy can be greatly reduced due to the importance of short-term rainfall intensity.
- The CSO Model cannot capture tailwater effects such as the influence of high tide on CSOs. If permittees are evaluating a tidally influenced system, EPA encourages a thorough review of tailwater stage data to ensure tidal effects are not inhibiting overflow behavior.

Model Input Calibration and Results Validation

Although guidance on how to obtain these data inputs is provided throughout this document, the user is encouraged to calibrate and validate these inputs as best as possible. For example, if users determine percent impervious surface based on digital land cover data, but the CSO Model consistently overpredicts overflow volumes, this input (along with other inputs that affect overflow volume, such as regulator capacity) should be adjusted until the overprediction reduces. Similarly, if a local rain gauge is the source of rainfall input, the user should also compare this input to other rainfall data sources either within the community or in nearby communities. The main text of this document recommends data sources, while additional resources are listed in Appendix A.

The CSO Model is designed to calculate the amount of CSO volume generated from a given storm event. Users can therefore calibrate model inputs and validate model results with monitoring data that record the presence or absence of a CSO, or that record CSO volume. Users can obtain such data using a range of approaches, from the simple and low-cost to highly automated. For example, a strategically placed chalk line on the inside of a CSO outfall or a small piece of woody debris placed atop a diversion structure are simple and low-cost approaches that can indicate whether a CSO occurred. Conversely, a variety of electronic sensors are available that can measure flow depth and velocity within a range of conveyance configurations. Both types of results can be directly compared to CSO Model output and used to determine whether model results are reasonable. If the CSO Model consistently overpredicts or underpredicts overflows when compared to observed data, users can refine or calibrate model inputs such as percent impervious surface, initial abstraction, and regulator capacity so CSO Model outputs better match observed conditions, on average.

Several guidance documents are available to help the user determine which type of monitoring is appropriate. EPA's Combined Sewer Overflows Guidance for Monitoring and Modeling and CSO Post Construction Compliance Monitoring Guidance both provide useful information for how to design a monitoring protocol, compare observations to model results, and maintain permit compliance. For guidance on how to implement "smart data infrastructure," see EPA's Smart Data Infrastructure for Wet Weather Control and Decision Support.

Reporting

For reporting purposes, the CSO permittee should work with their National Pollutant Discharge Elimination System (NPDES) permitting authority to get the proper approval before submitting the estimates generated by the CSO Model. EPA recommends that CSO permittees verify CSO Model estimates through monitoring at critical locations in their CSS, which may include the following:

- CSO outfall locations that discharge the most volume.
- CSO outfall locations that discharge the most often.
- CSO outfall locations that discharge to sensitive areas.
- Locations in the CSS that are known to bottleneck.
- Other specific locations mentioned in the NPDES permit.

Sensitive Areas

EPA expects a CSO permittee's LTCP to give the highest priority to controlling overflows to sensitive areas. Sensitive areas, as determined by the NPDES permitting authority in coordination with state and federal agencies as appropriate, include designated ***Outstanding National Resource Waters, National Marine Sanctuaries, waters with threatened or endangered species and their habitat, water with primary contact recreation, public drinking water intakes or their designated protection areas, and shellfish beds.***

The CSO Model and the Presumption Approach

The CSO Model can be used by CSO communities that have chosen the presumption approach criteria (i) or (ii), as described in the CSO Control Policy,[1] to quantify the number of overflows or the volume of combined sewage that needs to be captured, treated, or eliminated as per the LTCP. The CSO Model can also help to determine whether the CSO permittee is meeting criteria (i) or (ii).

The presumption approach sets forth criteria that, when met, are presumed to provide an adequate level of control to meet the water quality-based requirements:

> *A program that meets any of the criteria listed below would be presumed to provide an adequate level of control to meet water quality-based requirements of the Clean Water Act, provided the permitting authority determines that such presumption is reasonable in light of data and analysis conducted in the characterization, monitoring, and modeling of the system and the consideration of sensitive areas described above (in Section II.C.4.a). These criteria are provided because data and modeling of wet weather events often do not give a clear picture of the level of CSO controls necessary to protect water quality standards.*
>
> *i. No more than an average of four overflow events per year, provided that the permitting authority may allow up to two additional overflow events per year. For the purpose of this criterion, an overflow event is one or more overflows from a CSS as the result of a precipitation event that does not receive the minimum treatment specified below; or*
>
> *ii. The elimination or the capture for treatment of no less than 85% by volume of the combined sewage collected in the CSS during precipitation events on a system-wide annual average basis.*

As required by the CSO Policy, "The permittee should develop a comprehensive, representative monitoring program that measures the frequency, duration, flow rate, volume, and pollutant concentration of CSO discharges and assesses the impact of the CSOs on the receiving waters." EPA expects that users have such monitoring programs, producing data they can input into the CSO Model. The CSO Model does not address the impacts of pollutant loadings from CSO discharges on receiving waters; however, the CSO Model can help the user understand the impacts of rainfall and increased wet-weather flow on their CSS.

Permittees may also use the CSO Model for the "demonstration approach" if they have a better understanding of their system characterization, precipitation data, land use, and CSO controls that are in place, but may need more precise engineering expertise. To keep the CSO Model simple, EPA is assuming the permittee is using the presumption approach criteria (i) or (ii), which are most widely used for developing LTCPs.

[1] https://www.epa.gov/sites/production/files/2015-10/documents/owm0111.pdf

Runoff Calculations

The runoff component is based on a modified version of the Rational Method. The Rational Method is an approach used to calculate stormwater runoff volumes in small, urban watersheds based on probabilistic rainfall intensities and distributions (also called “design” storms). Although it is still widely used and preferred in many types of engineering design scenarios (Thompson 2006), its dependence on the design storm approach means it is generally a poor predictor of the runoff response from actual rainfall distributions (O’Loughlin et al. 1996), which tend to be short-lived, uneven, and unique. The modification of the Rational Method is therefore based on an approach developed by a group of researchers to maintain relative ease of use while incorporating the time variability of actual rainfall (Bennis and Crobeddu 2007; Crobeddu et al. 2007) for a more accurate depiction of sewershed hydrology. The main modification is to the runoff response function. Instead of using a single triangular hydrograph like the standard Rational Method, the modified version adds together multiple rectangular impulse response functions (Figure 1) to generate a single hydrograph. The width of each impulse response function is determined by the time of concentration (t_c), while the height is determined by the amount of rainfall over that time interval, as illustrated below. The modified response function implies that, for a given rainfall intensity and a doubling of t_c, the runoff response will be half as intense (height), twice as long (width), and of identical volume (area).

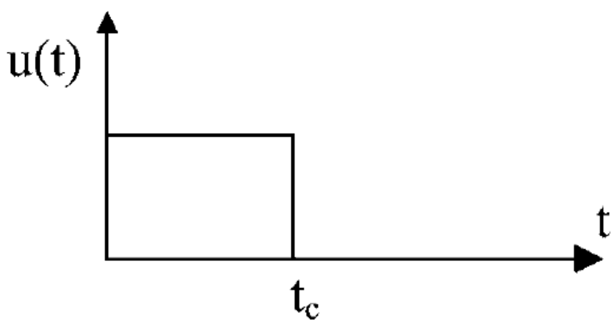


Figure 1. Rectangular impulse response function used by the modified rational method.

Its generic formulation is as follows:

$$u = cIA\left(\frac{1}{t_c}\right)$$

where:

- u = impulse response function (L^2/T)
- I = percent impervious surface
- A = watershed area (L^2)
- t_c = time of concentration (T)
- c = conversion coefficient

To calculate the runoff response over time (i.e., the hydrograph), the model computes the convolution product of the response function and an actual rainfall time series (i.e., the adding together of individual response functions over time) for the storm duration as follows:

$$Q(t) = \int_0^t cI(\tau)u(t-\tau)d\tau$$

where:

- Q = runoff (L^3/T)

I = rainfall intensity (L/T)
c = conversion coefficient

Through the above approach, the model produces a reasonable approximation of a runoff hydrograph using any rainfall time series along with the area, percent imperviousness, and t_c of the watershed.

EPA set the calculation interval of the CSO Model to 15 minutes—the smallest frequency at which easily obtainable and publicly available rainfall data are generally recorded. Using a smaller interval would have added complexity while providing little improvement in accuracy. In the instructions for Tab 3 (t_c and Rainfall), the user is guided through the process of estimating or downloading the rainfall time series that resulted in the CSO event of interest.

The CSO Model calculates t_c using the Kirpich Method (Kirpich 1940), which is used for small drainage areas dominated by channel flow. Of the many options for calculating t_c found in standard hydrology textbooks, the Kirpich Method is both commonly cited and simple in terms of required input parameters. The main inputs—flow path length and slope—can be either obtained from common and free web-based applications or estimated by CSO operators. Moreover, the degree of accuracy conferred by more advanced methods is generally on the order of minutes, whereas the rainfall data and simulation timestep used in the CSO Model is on a 15-minute basis. EPA therefore deemed the Kirpich Method suitable for this application when used to estimate t_c to the nearest 15 minutes. The method is defined as:

$$t_c = 0.00013\left(\frac{L^3}{h}\right)^{.385}$$

where:

t_c = time of concentration (hour)
L = length of main channel or conveyance (feet)
h = relief along main channel (feet)

An initial abstraction term is also included in the CSO Model. Initial abstraction refers to the amount of rainfall at the start of a storm event that is abstracted or absorbed by surfaces (e.g., vegetation, pavement) and micro-depressions (e.g., puddles) and does not contribute to surface runoff. In the CSO Model, this term modifies the rainfall time series so that rainfall does not occur until initial abstraction has been satisfied. Once initial abstraction is satisfied, it does not have any further effect in the model (i.e., it does not renew within the 24-hour simulation period).

CSO Model Schematic

This section presents an overview schematic of the CSO Model. In general, the model is divided into major compartments based on the flow of wastewater through a combined sewershed. In the first compartment, a rainfall event is defined (see previous section for discussion of the calculation approach). Next, runoff is routed through individual CSO sub-sewersheds based on their runoff-generating characteristics and flow is reduced by any flow control measures that may be present. Flow control measures may include stormwater controls and/or combined sewage controls. Flow is either routed to a CSO outfall or to the WWTP, if present, based on the CSO hydraulic control capacity. Last, routing is done for major flows entering the WWTP, including a summation of all individual CSO outfalls that were included in the model.

Figure 2 shows major model compartments and flows, along with a key. Flow identifiers correspond directly to line items within the CSO Model. For the sake of clarity, the graphic and key only include those flow, storage, and routing steps necessary to understand the model function.

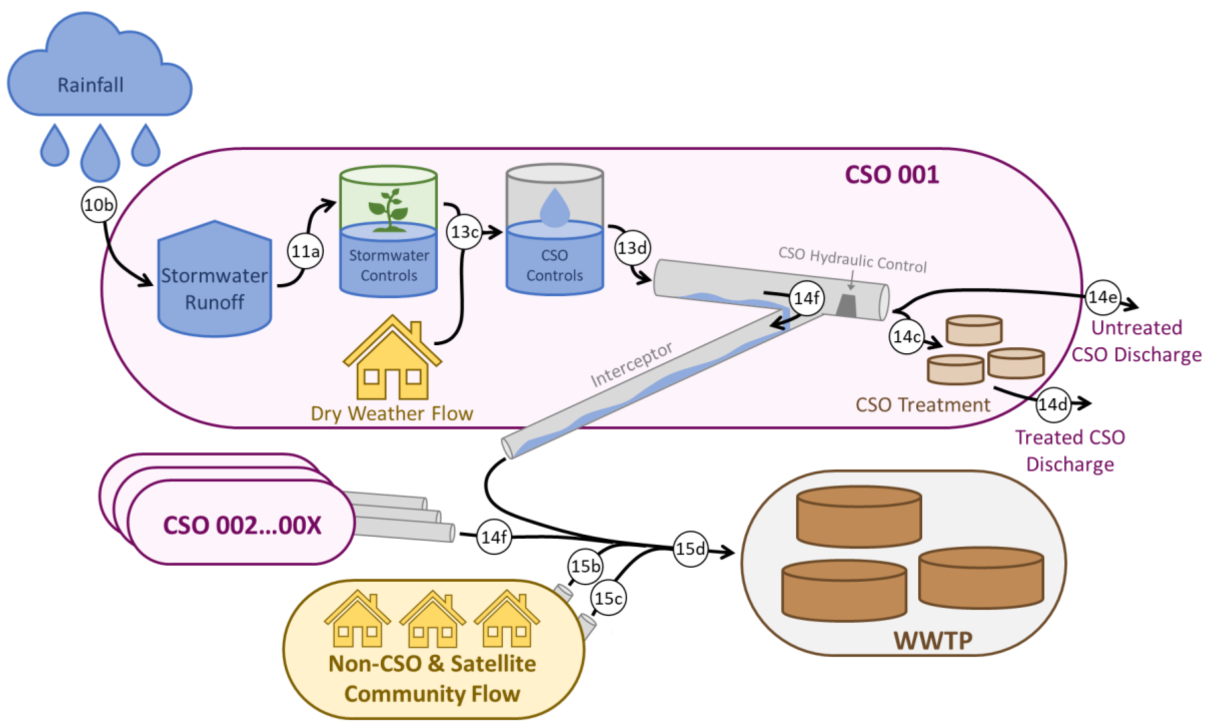


Figure 2. CSO Model schematic.

Model Schematic Key

The Model Schematic above illustrates stepwise calculations performed by the CSO Model. For illustration purposes, steps for a single CSO (CSO 001) are shown. Steps for other CSOs (CSO 002…00X) are identical.

10b. Hourly or 15-minute rainfall input.
11a. Stormwater runoff.
13c. Stormwater runoff after stormwater controls plus dry weather flow.
13d. Combined sewage after stormwater controls and combined sewage controls.
14c. CSO treatment capacity.
14d. Treated CSO discharge.
14e. Untreated CSO discharge.
14f. Combined sewage diverted to WWTP.
15b. Peak flow rate of sewage from non-CSO areas.
15c. Peak flow rate of sewage from satellite communities.
15d. Total sewage conveyed to WWTP.

Instructions: Tab 1—CSS Input

The first tab in the CSO Model allows users to input general information describing the total CSS. Items 1 and 2 yield mostly descriptive information, but input for Items 3 and 4 is linked to subsequent forms and informs model calculations. Line 3b also allows for expansion of the base model. For CSSs with more than four CSO outfalls, additional forms become visible in subsequent tabs to allow for modeling of up to 28 CSO outfalls. Throughout the CSO Model, green cells require user input while blue cells are automatically populated or calculated.

Using the CSO Model

Data input fields are highlighted green. Any line item marked with an asterisk (*) requires input for the model to function. Line items not marked with asterisks are for description and can be left blank.

Fields that are automatically calculated or populated are highlighted blue and cannot be updated by the user.

General Information

Item 1: Community Information. Enter the community's name, NPDES permit number, owner/operator, facility name, mailing address, telephone number, fax number, email address, and date.

Item 2: System Type. Identify the type of system for which this CSO Model is being developed, which may include a CSS with or without a WWTP

Item 3: CSS Information.

- **Line 3a: Area of CSS (acres).** Enter the total area served by the CSS in acres. Area can be measured directly with a geographic information systems (GIS) or computer-aided design system, or it can be measured by hand by overlaying graph paper and counting squares of known dimension in the CSS or CSO outfall boundaries. This input is intended to be used as a check, as the total area of all CSOs should be about equal to the area of the CSS.
- **Line 3b: Number of CSO outfalls.*** Enter the number of permitted CSO outfalls, which can range from one to 28. The CSO Model is designed to model up to 28 individual CSO outfalls, though will only display enough forms to model the number of CSOs entered here.

Item 4: WWTP. Enter the following information for WWTP capacity in million gallons per day (MGD). If there is no WWTP within the CSS, or users do not wish to calculate total flows directed to the WWTP, Item 4 can be left blank.

- **Line 4a: Primary treatment capacity (MGD).** If applicable, enter the primary treatment capacity of the WWTP.
- **Line 4b: Secondary treatment capacity (MGD).** If applicable, enter the secondary treatment capacity of the WWTP.

Instructions: Tab 2—CSO Input

The first step in modeling CSO events is to describe the runoff-generating potential and the conveyance capacity of individual CSO contributing areas. For the CSO Model, *sub-sewershed* is used to describe the contributing area for each CSO outfall. Tab 2 allows the user to describe some characteristics of the CSO sub-sewersheds and the capacity of their sewer infrastructure. First, users input general descriptions in Item 5. Next, in Item 6, users input data for calculating runoff volume, including size of the contributing area and percent impervious surface. Lastly, the capacity of existing CSO infrastructure to convey and treat that runoff is described in Item 7.

System Characterization

Item 5: CSO Outfall Information. Use one column in Line 5 for each CSO outfall in the CSS (e.g., CSO 001, CSO 002).

- **Line 5a: Permitted CSO outfall number.** Enter an identifying number for each CSO outfall.
- **Line 5b: Description of location.** Enter a narrative description of the location for each CSO outfall.
- **Line 5c: Latitude/longitude.** Enter the latitude and longitude for each CSO outfall, where available.
- **Line 5d: Receiving water.** Enter the name of the receiving water for each CSO outfall.

Item 6: CSS Attributes. Use one column in Line 6 to describe the total area and percent imperviousness of each CSO sub-sewershed.

- **Line 6a: Sub-sewershed area (acres).*** Enter the area for the CSO contributing area. (The sum of sub-sewershed areas input in each column of Line 6a should be consistent with the total CSS area input in Line 3a.)
- **Line 6b: Average impervious surface (%).*** If known, enter the percent of impervious surface present in each sub-sewershed. If unknown, follow the instructions in one of the boxes below to estimate percent impervious surface using a web-based tool. Options are given for GIS- and non-GIS-based approaches. EPA recommends percent impervious surface be used as a calibration parameter and for sub-sewersheds larger than 100 acres, potentially reduced to be more reflective of DCIA (see text box to the right).

Impervious Surface and DCIA

The results of extensive model testing suggest that using total impervious area as a model input for larger (generally >100 acres) sub-sewersheds with percent impervious >20 percent may overestimate flows. This is likely due to the tendency for impervious areas in urban or developed areas to become increasingly disconnected as watershed size increases. EPA therefore recommends that for larger sub-sewersheds, users use percent impervious surface as a calibration parameter and reduce the value until reasonable results are obtained. Based on testing, a reduction of up to 50 percent was found to better predict runoff rates and volumes for larger sub-sewersheds. This reduction makes this model input closer to DCIA than total impervious area. DCIA is impervious area that hydraulically connects stormwater runoff to a sewer system without first flowing over a pervious area. DCIA is discussed further in EPA's factsheet on DCIA[2].

[2] https://www3.epa.gov/region1/npdes/stormwater/ma/MADCIA.pdf

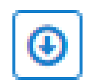
Line 6b: Non-GIS Approach

1. Website: https://www.mrlc.gov/viewer/.
2. Using the scroll function, zoom to an appropriate scale in which you can see the entire sub-sewershed for the CSO of interest. To pan, hold down your left mouse button and drag the map to the desired view extent.
3. Select the “Contents” tab on the upper-left side of the screen. The data of interest are in the “Dataset” layer group, while helpful boundaries and base layers are in the “Boundaries” and “Base Layers” layer groups. If the contents of the “Dataset” layer group are not already visible, toggle the expansion box (the “-” or “+” icon to the left of the layer title).
4. By default, the 2019 CONUS Land Cover and 2016 ALASKA Land Cover layers are toggled on. To better view only the impervious surface layer, first clear these layers from the map window by selecting the boxes to the left of the layer titles and removing the check mark.
5. To view impervious surface, expand the “NLCD Impervious Surface” layer group and select the box to the left of the “2019 CONUS Impervious Surface” layer or select “2016 AK Impervious Surface” layer. Select the “Legend” tab on the upper-left side of the screen to see the corresponding values of percent impervious. As needed, toggle layers on and off to see coverage relative to applicable boundaries.
6. Estimate (to the nearest 10 percent) the average percent impervious surface within the sub-sewershed boundary.
7. Enter this value in Line 6b for each CSO outfall.

Line 6b: GIS Approach

(Assumes user has a basic knowledge of the ArcGIS environment and has digital CSO drainage areas)

1. Website: https://www.mrlc.gov/viewer/.
2. Using the scroll function, zoom to an appropriate scale in which you can see the entire sub-sewershed for the CSO of interest. To pan, hold down your left mouse button and drag the map to the desired view extent.
3. Select the right-most button (see adjacent image) in the list of six tools at the top of the map window. This button will open a “Data Download” menu to the right of the screen. Use the left mouse button to draw a data download box over your area of interest.



4. Select the “Impervious” and “2019 Impervious ONLY” options and enter your email address. Click “Download.”
5. Once you receive the download link via email, download and unzip to a suitable location. Add the .tiff file to a GIS map document.
6. There are several ways to calculate the average impervious surface of the CSO sub-sewershed based on the downloaded data—use the method you are most familiar with. Steps 7 and 8 below outline an example method.
7. Use the “Zonal Statistics as Table” tool (under “Spatial Analyst” → “Zonal” in the “Arc” toolbox) to calculate average impervious surface of each CSO sub-sewershed. Use the feature or shapefile representing the CSO sub-sewershed(s) as the “Input raster or feature zone data,” and the downloaded raster (.tiff file) as the “Input value raster.” Make sure to add the .dbf file extension to the end of the file name chosen in the “Output Table” field.
8. Open the created table. For each CSO outfall, enter the value given under “Mean” as input to Line 6b.

Item 7: CSO Attributes. The routing and fate of combined sewage within a CSS depends on numerous interacting factors, including the type of CSO hydraulic control or regulator, its design capacity, any proactive efforts in the collection system to increase that capacity, and any treatment capacity at each individual CSO outfall. In any system, one or more of these factors may be limiting, resulting in varying amounts of combined sewage that can bypass the main interceptor and be discharged, treated or untreated, at each CSO outfall.

The CSO Model uses *CSO hydraulic control capacity* as a generic term referring to the cumulative effect of the CSO regulator capacity as well as any proactive measures that have been implemented to increase this capacity (see the adjacent box describing possible collection system controls). The term defines the amount of combined sewage that can be diverted to the interceptor, which is a large sewer pipe that conveys dry-weather flow and a portion of the wet-weather flow from individual sub-sewersheds to the WWTP. Any flow exceeding the CSO hydraulic control capacity stays in the individual CSO sub-sewershed and is conveyed to the CSO outfall. If the community has not previously carried out an analysis of the peak hydraulic control capacity of each CSO sub-sewershed, EPA suggests that the determination be carried out by someone experienced in such hydraulic analyses. EPA also cautions communities against evaluating CSO hydraulic control capacity without considering interceptor capacity as well, because the nominal capacity of a regulator could exceed that of its receiving interceptor under the same peak wet-weather conditions.

Collection System Controls

- Maximizing flow to treatment plant
- Monitoring and real-time control
- Inflow reduction
- Sewer separation
- Sewer rehabilitation
- Service lateral rehabilitation
- Manhole rehabilitation

Users can calculate or estimate the hydraulic control capacity of passive regulator structures such as weirs and orifices as long as drawings are available and the dimensions of the structures are known. EPA recommends using standard weir or orifice equations, as appropriate, for the specific structures. In general, the diversion rate of original regulators (i.e., prior to implementing any additional collection system controls) is often three to five times greater than dry-weather flow. For additional collection system controls, use design documentation to revise the total control capacity. If any of these capacities are unknown or resources to determine them are not available, consult a standard hydraulics handbook or a professional engineer familiar with the design and operation of the specific controls.

Hydraulic Control Capacity and Model Calibration

Hydraulic control capacity can be difficult to estimate or measure but is a critical model input for the accurate simulation of overflow volume. Even if its design value is known, overflow behavior is complex and permittees are encouraged to use this model input as a calibration parameter during the model calibration process. For additional information on model calibration, see EPA's Guidance for Modeling and Monitoring and EPA's Post Construction Compliance Monitoring Guidance.

CSO treatment capacity refers to the treatment of overflows implemented in individual sub-sewersheds or CSO outfalls, as opposed to treatment at the WWTP serving the entire sewershed or CSS.

Use one column for each CSO outfall or sub-sewershed in Item 7 to describe the following information:

- **Line 7a: Type of CSO hydraulic control.** Enter the type of hydraulic control used for each CSO outfall (e.g., weir, orifice, pump station).
- **Line 7b: CSO hydraulic control capacity (MGD).*** Enter the capacity of the CSO hydraulic control. In addition to the design capacity of passive control structures like weirs and orifices, CSO hydraulic control capacity should reflect, where applicable, the effects of any of the collection system controls.
- **Line 7c: CSO treatment capacity (MGD).*** Enter the treatment capacity of the CSO treatment system. If no CSO treatment is present, enter 0 here.
- **Line 7d: Name of interceptor or downstream pipe.** Enter the name of the interceptor that receives the diverted flow.

Instructions: Tab 3—t_c and Rainfall

Once users have defined the runoff-generating potential and conveyance capacity of each CSO, it is necessary to characterize the timing of the runoff response and to input the time series of rainfall that generated the CSO event. Tab 3 allows users to input basic information describing the main flow path within each CSO sub-sewershed, where t_c is approximated using flow path geometry. Space is provided to input a 24-hour time series of 15-minute or 60-minute rainfall, in inches.

Time of Concentration

Item 8: Time of Concentration Input and Calculations. Use one column for each CSO outfall in Lines 8a through 8e (e.g., CSO 001, CSO 002). Detailed instructions for how to determine inputs for Lines 8a, 8b, and 8c are provided in the box below; see Appendix B for an illustrated example.

- **Line 8a: Length of main flow path (feet).*** Enter the length of the main stormwater flow path from the most hydraulically distant (upstream) portion of the CSO sub-sewershed to the CSO outfall. The main flow path may consist of a grass swale, concrete swale, open water channel, pipe, culvert, or any other type of main conveyance feature.
- **Line 8b: Elevation at upstream end of main flow path (feet).*** Enter the elevation of the upstream end of the flow path described in Line 8a. The vertical datum is not important, so long as the same datum is used for Lines 8b and 8c. The elevation should represent the bottom (i.e., invert) of the conveyance feature, to the extent possible.
- **Line 8c: Elevation at downstream end of main flow path (feet).*** Enter the elevation of the downstream end of the flow path described in Line 8a. The vertical datum is not important, so long as the same datum is used for Lines 8b and 8c. The elevation should represent the bottom (i.e., invert) of the conveyance feature, to the extent possible.

Time of Concentration

Time of concentration, or t_c, measures the response of a watershed to a rain event. It is defined as the time it takes stormwater to flow from the most distant point of a watershed to its outlet. A watershed with a small t_c will potentially experience greater peak flows at its outlet compared to one with a larger t_c. As such, model outputs (especially peak flows in small watersheds) can be sensitive to t_c inputs.

Slope is automatically calculated based on user input, with a default minimum of 0.5 percent based on standard conveyance design practice.

Lines 8a, 8b, and 8c

1. Website: https://apps.nationalmap.gov/viewer/.
2. In the search bar at the upper-right side of the screen, type in the name of the city or county of interest to zoom in to a specific CSO sub-sewershed—for example, "Anytown, PA." Using the arrow keys or the mouse, choose the most appropriate option that appears below the search bar. Alternatively, use the zoom functions to zoom to your area of interest.
3. Using the zoom navigation buttons in the upper-left of the screen, zoom to an appropriate scale in which you can see the entire sub-sewershed of the CSO outfall of interest. To pan, use your left mouse button and drag the map to the desired view extent.
4. In the green ribbon at the top of the map, select the icon for "Elevation Profile" (see adjacent image). A dialogue box will appear. 
5. Follow the instructions in the dialogue box by first clicking on the ruler icon that appears and selecting "Feet (US)" as the unit of measure.
6. On the map, place the cursor over the most upstream portion (i.e., most hydraulically distant from the CSO outfall) of the CSO sub-sewershed to start the profile. As best as possible, trace the approximate route of the main stormwater conveyance of the CSO sub-sewershed, following the path all the way to the outfall. At the outfall location, double-click to complete the profile.
7. Enter values for Lines 8a, 8b, and 8c for the CSO outfall, corresponding to the total profile length, the elevation at the upstream end of the main flow path, and the elevation at the downstream end of the main flow path, respectively, as illustrated on the elevation profile. (If the profile that is created looks unreasonable, or if the longest flow path route is uncertain, do this step three times and use the average of each required value as final model input.)

- **Line 8d: Main flow path slope (%).** Line 8d is automatically calculated so long as data are input into Lines 8a, 8b, and 8c. Line 8d, the slope of the main flow path, is calculated as the change in elevation (i.e., difference between Lines 8b and 8c) divided by the total flow path length (Line 8a). If the input values result in a slope that is less than 0.5 percent, the CSO Model will assume a slope of 0.5 percent as this is a typical design minimum.
- **Line 8e: Time of concentration, t_c (hour).** Line 8e is automatically calculated when Lines 8a through 8c have been populated. The model calculates t_c using the Kirpich Method (Kirpich 1940), which requires input for flow path length and change in elevation over the flow path. The equation for the Kirpich Method is as follows:

$$t_c = 0.00013\left(\frac{L^3}{h}\right)^{.385}$$

where:

t_c = time of concentration, rounded to the nearest integer (hour)
L = length of main channel or conveyance (feet; Line 8a)
h = relief along main channel (feet; Line 8b minus Line 8c)

Observed Rainfall

Item 9: Initial Abstraction. Initial abstraction refers to the amount of rainfall at the start of a storm event that is abstracted or absorbed by surfaces (e.g., vegetation, pavement) and micro-depressions (e.g., puddles) and does not contribute to surface runoff. Before entering a rainfall time series, users must enter initial abstraction so the rainfall time series can be modified appropriately.

- **Line 9a: Initial Abstraction (inches).** Enter initial abstraction depth, in inches, for each CSO sub-sewershed. A default value of 0.1 inches is already populated based on CSO Model validation study results but should be modified if more site-specific data are available.

Item 10: Observed or Downloaded Rainfall Input. Space is provided to enter a 24-hour time series of observed rainfall in 15-minute or hourly increments, which will be used to calculate runoff volumes. Using 15-minute rainfall data will greatly improve model accuracy. Initial abstraction (Line 9a) is used to modify the rainfall time series so the initial abstraction depth does not contribute to runoff. Users can estimate rainfall data using site observations, an onsite rain gauge, or historical weather data. If multiple types of data sources are available, use professional judgement and local knowledge to determine which source most closely represents the rain that fell over the sub-sewershed(s) of interest. If multiple rain gauges exist in the same sub-sewershed, an average of the gauges may be used. In these cases, users are encouraged to briefly describe the data sources in the comment box provided in Line 10a. See the box below for instruction on obtaining historical weather data.

Initial Abstraction

Based on extensive model testing, initial abstraction values of 0.1–0.2 are common in urban sewersheds. Although a default value of 0.1 is pre-populated in the model, EPA encourages users to revise this value based on local knowledge of their sewershed.

Permittees can use initial abstraction to calibrate a model to observed conditions, including accounting for the effects of antecedent moisture on runoff generation. For additional information on model calibration, see EPA's CSO Guidance for Modeling and Monitoring and EPA's CSO Post Construction Compliance Monitoring Guidance.

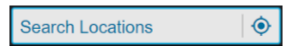
- **Line 10a: Description of rainfall data source**. If desired, provide a brief description or citation of the data source(s) used for rainfall input.
- **Line 10b: Rainfall input (inches).*** In the first of the four columns, enter the time and date of when the rainfall event started. The remaining time cells will update automatically. Next, enter a rainfall time series, in inches, at either an hourly or 15-minute increment in the rows that correspond to the time in the first column. If using hourly rainfall data, enter the data in the third column labeled "Hourly Rain" and leave the fourth column blank. Enter data for the full hourly time series, including "0" for hours where no rainfall occurred. If using 15-minute rainfall data, leave the "Hourly Rain" column blank and enter data in the fourth column labeled "15-Minute Rain." Similarly, enter data for the full 15-minute time series, including "0" for increments where no rainfall occurred.

Line 10b

*The CSO Model requires users to input hourly or better rainfall data. Absent a locally maintained rain gauge, several sources of historical precipitation data are avail*able. The National Oceanic and Atmospheric Administration (NOAA) maintains historical precipitation data (see Appendix A); however, recently available data (i.e., within the last year) are currently only available at timesteps of one hour or more, making them less suitable for use in the CSO Model. NOAA is working to update their recent 15-minute data, which are currently only accessible through 2013. Appendix C provides Instructions for how to ex*plore recent hourly data from NOAA, which can be used to validate precipitation totals from other sources.*

For quick, screening-level analysis of past storm events, users may consult other sources of data at their discretion. For example, the following describes how to obtain data from Weather Underground.

1. Website: www.wunderground.com.
2. Enter your location in the "Search Locations" bar in the top-right of the screen and select the most applicable option that comes up in the drop-down list.



3. In the tab menu that appears for your location of interest, select "History."
4. Make sure "Daily" is selected from the Daily/Weekly/Monthly option, enter the date of the rainfall event you wish to model, and click "View."

5. Scroll down until you see a heading for "Daily Observations," which provides a tabular view of recorded precipitation intervals and depths, among other data.
6. Identify the time that corresponds to the first non-zero precipitation record for the rainfall event you wish to model and enter that time into the first cell of the "Time (hour)" column of Line 10b. Notice that the remaining 15-minute time intervals will automatically calculate.
7. Enter each reported precipitation value from the "Daily Observations" table in the "15-Minute Rain" column of Line 10b, matching the time to the nearest 15 minutes. If the reported time from Weather Underground is slightly different from the automatically calculated 15-minute interval in the CSO Model, enter the reported precipitation value into the closest time interval in the CSO Model. If two precipitation records are close to a single CSO Model time interval, those two values can be summed and input as a single value.

Instructions: Tab 4—CSO Volume

Runoff and overflow volumes in each CSO sub-sewershed are modeled in Tab 4. In the previous tab, users input all the information needed to calculate the runoff response of each CSO sub-sewershed. Runoff response of each CSO sub-sewershed is the first calculation in Tab 4, performed using a version of the Improved Rational Method (Bennis and Crobeddu 2007; Crobeddu et al. 2007).

After calculating stormwater runoff, two types of volume controls can be accounted for in Tab 4: stormwater controls and combined sewage controls. Stormwater controls include green infrastructure practices like green roofs, rain barrels, bioretention systems, and swales, as well as traditional stormwater practices like wet ponds. Combined sewage controls include practices like onsite storage, in-line storage, and off-line storage, and are specifically designed to manage wet-weather flows after stormwater has combined with sanitary sewage. Guidance on how to calculate control volume for both types of practices is included below.

All runoff, attenuation, and routing calculations in Tab 4 are performed on a 15-minute basis. However, in order to show results for up to 28 CSOs, Tab 4 shows only the 24-hour totals. To see plots of runoff or overflow volumes from each CSO sub-sewershed over the full 24-hour simulation period, see Tabs F1 and F2. For plots of the cumulative flow over the entire CSS, see Tab F3.

CSO Volume Calculations

Item 11: Runoff Generated.

- **Line 11a: Stormwater runoff (MG).** Line 11a is automatically calculated for each CSO sub-sewershed following full data input in the preceding tabs.

Item 12: Green Infrastructure and Other Stormwater Controls. Item 12 provides space to account for any existing stormwater volume control practices in each CSO sub-sewershed. Although stormwater practices operate in a variety of ways and provide a diverse range of hydrologic benefits to a watershed, it is mainly their ability to temporarily store stormwater that affects CSO events through the attenuation of peak flows. To that end, the CSO Model treats any stormwater practices present within a sub-sewershed as a temporary storage volume, assumed to be empty at the start of the simulation period and fillable with stormwater only once. When the storage volume is filled, the CSO Model operates as if the stormwater practices do not exist. This approach assumes that the flow rates of the possible loss pathways (e.g., infiltration, evapotranspiration, controlled outflow) are negligible in comparison to the much larger runoff flow rates that generate CSO events. This assumption is not quite realistic (most loss pathways are continuously active during storm events), but the degree to which loss pathways vary across practices, geographical locations, design standards, and even storm events makes modeling them under the current framework impractical. Moreover, the omission of loss pathways adds a degree of conservatism to the final modeled runoff volumes.

For the input of storage volume, or runoff control capacity, associated with any stormwater practice within a sub-sewershed, the CSO Model allows for two approaches: manual entry and/or a simple calculation template. If the total storage volume of all practices in the sub-sewershed is known, simply input the volume directly into the first line of Item 12. If that volume is unknown but general attributes of each stormwater practice area known, the CSO Model also provides a simplified, generic template for estimating a stormwater practice’s runoff control capacity.

- **Line 12a: Estimated stormwater control capacity (MG).** If the total storage volume of all stormwater control practices is known, users can simply enter it into Line 12a. If it is unknown, Lines 12a1 through 12a9 provide space to calculate the cumulative storage capacity of any three stormwater practices that are present. If a sub-sewershed has more than three practices, these rows can be used as a calculation template to add up the cumulative storage capacity and enter it in Line

12a. These lines use a generic volume equation that can be adapted to either a runoff reduction standard or design storm approach depending on local stormwater design requirements. See the instructions for Lines 12a1 through 12a3 for additional description of these two approaches. The equation is as follows:

$$V = kPAR_v$$

where:

V = practice storage capacity (MG)
k = unit conversion (.0272 MG/acre*inches)
P = runoff retention standard or design storm depth (inches)
A = practice drainage area (acre)
R_v = volumetric runoff coefficient (fraction, 0-1)

Lines 12a1 through 12a3 are described below. Repeat these steps for additional stormwater practices in lines 12a4 through 12a6 and 12a7 through 12a9.

- **Line 12a1: Practice 1—Runoff standard or design storm depth (inches).** Some communities have onsite stormwater retention standards (e.g., retain first inch of rainfall). If this is the case, enter the value here. If no design standard was used or if the standard is unknown, use the lookup function in Tab A1 of the CSO Model to find the 85th percentile rainfall depth that corresponds to the community's ZIP Code and enter it here. The 85th percentile rainfall depth is generated from Shrestha et al., 2013, and corresponds to a design approach increasingly used in stormwater design manuals across the United States (Shrestha et al., 2013).

- **Line 12a2: Practice 1—Total drainage area (acres).** Enter the practice drainage area, in acres. Drainage area can generally be found in stormwater practice design plans or documents.

- **Line 12a3: Practice 1—Volumetric runoff coefficient.** If known based on practice design plans or documents, enter the volumetric runoff coefficient. If unknown, use percent impervious surface of the practice drainage area (the fraction of drainage area impervious surface to total drainage area) as a proxy. Impervious surface area can generally be found in stormwater practice design plans or documents.

- **Line 12b: Total stormwater control capacity (MG).** Line 12b is automatically calculated and is equal to the sum of the capacities entered in Line 12a or calculated in Lines 12a1 through 12a9.

- **Line 12c: Stormwater runoff (MG).** Line 12c is automatically populated and is equal to Line 10a.

- **Line 12d: Stormwater runoff after stormwater controls (MG).** Line 12d is automatically calculated as the difference between stormwater runoff volume (Line 12c) and total stormwater control capacity (Line 12b).

Item 13: Combined Sewage Controls. In addition to stormwater controls, CSSs may include combined sewage controls such as onsite storage, in-line storage, or off-line storage (e.g., tanks, basins, tunnels). Similar to stormwater controls, these practices provide temporary storage of peak flows, to be drawn down and treated following a storm event. The CSO Model treats combined sewage controls similarly to stormwater practices: as a temporary storage volume assumed empty at the start of the simulation period and fillable only once. Once a control is filled, the CSO Model operates as if it does not exist.

CSO Volume Controls

Examples of typical CSO volume control measures:

- Off-line storage
- In-line storage
- Onsite storage

- **Line 13a: Total combined sewage control (MG).** Enter the total control volume of all combined sewage (i.e., non-stormwater) control practices within the CSO sub-sewershed.
- **Line 13b: Dry weather flow rate (MGD).** Enter the average dry-weather flow rate for each sub-sewershed in Line 13b. If unknown, develop an estimate by either averaging a series of direct measurements made at different times of day or allocating the dry-weather flow reported on the Discharge Monitoring Report for the WWTP for the entire sewer service area. The second approach should take into consideration sub-sewershed characteristics that influence the rate of dry-weather flow, including population, employment, and inflow and infiltration (I/I), if known. The sum of dry-weather flow from the CSS plus the dry-weather flow from non-CSO areas and satellite communities, if present, should equal the dry-weather flow at the WWTP.
- **Line 13c: Stormwater runoff after stormwater controls plus dry weather flow (MG).** Line 13c is automatically calculated as the sum of Lines 12d and 13b.
- **Line 13d: Combined sewage after stormwater controls and combined sewage controls (MG).** Line 13d is automatically calculated as the difference between the stormwater runoff after stormwater controls plus dry-weather flow (Line 13c) and total combined sewage control (Line 13a).

Item 14: CSO Flows. The final step in modeling CSO events is to calculate CSO flows. Item 14 summarizes these aspects and compares the combined sewage flow after volume controls to the hydraulic control capacity and CSO treatment capacity of each sub-sewershed. The result is, for each CSO outfall, a volume of combined sewage conveyed to the WWTP (if present), a volume of combined sewage that exceeds the sub-sewershed's hydraulic control capacity, and a volume of combined sewage that is discharged treated and/or untreated. As previously stated, individual lines are calculated on a 15-minute basis, while the results presented in Tab 4 represent the cumulative volumes over the 24-hour simulation period.

- **Line 14a: CSO hydraulic control capacity (MGD).** Line 14a is automatically populated based on data entered in Line 7b on Tab 2 and represents the combined capacity of any CSO hydraulic controls, such as regulator, pump station(s), or collection system controls. Any flow below this capacity is conveyed to an interceptor or pipe and ultimately to the WWTP, while any flow in excess of this capacity is conveyed to the CSO outfall.
- **Line 14b: Total CSO volume (MG).** Line 14b is automatically calculated as the difference between combined sewage after stormwater controls and combined sewage controls (Line 13d), and the sub-sewershed hydraulic control capacity (Line 14a).
- **Line 14c: CSO treatment capacity (MGD).** Line 14c is automatically populated based on data entered in Line 7c on Tab 2.
- **Line 14d: Treated CSO discharge (MG).** Line 14d is automatically calculated as the CSO volume (Line 14b) that is equal to or less than the CSO treatment capacity (Line 14c).
- **Line 14e: Untreated CSO discharge (MG).** Line 14e is automatically calculated as the difference between total CSO volume (Line 14b) and treated CSO discharge (Line 14d).
- **Line 14f: Combined sewage diverted to the WWTP (MG).** Line 14f is automatically calculated as the difference between combined sewage after stormwater controls and combined sewage controls (Line 13d), and total CSO volume (Line 14b).

Instructions: Tab 5—CSO Volume Summary

Tab 5 summarizes total volumes throughout the CSS, including total CSO volume and total volume of combined sewage conveyed to a WWTP. In many cases, where a WWTP is present, combined sewage that is directed to the WWTP from CSO sub-sewersheds is combined with sewage flows from non-CSO areas or satellite communities, both of which may increase due to wet-weather effects like I/I. During larger storm events, the wet-weather conditions may result in flow rates that approach the design capacity of the WWTP and should be monitored.

Similar to Tab 4, in order to show results for up to 28 CSOs, Tab 5 shows only the 24-hour totals. To see plots of CSS flows over the 24-hour simulation period, see Tab F3.

CSO and CSS Volumes

Item 15: Flows Conveyed to WWTP. Item 15 adds up the combined sewage flows conveyed to the WWTP from the different CSO sub-sewersheds, as calculated in Tab 4. If applicable to the CSS, it allows users to incorporate peak flows from non-CSO areas and satellite communities.

- **Line 15a: Combined sewage diverted to WWTP (MG).** Line 15a is automatically populated based on the cumulative Line 14f volumes calculated for each CSO sub-sewershed on Tab 4.

- **Line 15b: Peak flow rate of sewage from non-CSO areas (MGD).** Enter the peak flow rate of sewage directed to the WWTP from non-CSO areas, which enter directly into an interceptor or pipe and do not pass through any CSO conveyance. For the purpose of this model, peak flow is distinguished from average or base flow by possible wet-weather effects like I/I, which can substantially increase total flows. Given the variability and site specificity of I/I, direct measurement is the best approach for determining peak rate. If direct measurement is impractical, the rate can be estimated based on local knowledge of the service area and typical peaking factors. For example, newer sewer systems might have peaking factors between 1.0 and 1.5; older, leakier systems might have peaking factors between 1.5 and 3.0 or even higher.

> **Inflow and Infiltration (I/I)**
>
> EPA's Wastewater Collection System Toolbox provides additional information on I/I, including a guide for estimating its effects on a CSS.

- **Line 15c: Peak flow rate of sewage from satellite communities (MGD).** Enter the peak flow rate of sewage directed to the WWTP from satellite communities, which enter directly into sanitary sewers and bypass any CSO conveyance. For the purpose of this model, peak flow is distinguished from average or base flow by possible wet-weather effects like I/I, which can substantially increase total flows. Given the variability and site specificity of I/I, direct measurement is the best approach for determining peak rate. If direct measurement is impractical, the rate can be estimated based on local knowledge of the service area and typical peaking factors. For example, newer, tight sewer systems might have peaking factors between 1.0 and 1.5; older, leakier systems might have peaking factors between 1.5 and 3.0 or even higher.

- **Line 15d: Total sewage conveyed to WWTP (MG).** Line 15d is automatically calculated as the sum of combined sewage diverted to the WWTP (Line 15a), peak flow rate of sewage from non-CSO areas (Line 15b), and peak flow rate of sewage from satellite communities (Line 15c).

Item 16: Total Overflow Volumes. Item 16 summarizes the total overflow volumes modeled across all CSO outfalls over the 24-hour simulation period.

- **Line 16a: Total CSO volume at all CSO outfalls (MG).** Line 16a is automatically calculated as the total CSO volume across all CSO outfalls (Line 14b of Tab 4).

- **Line 16b: Total treated CSO discharge (MG).** Line 16b is automatically calculated as the total treated CSO discharge across all CSO outfalls (Line 14d of Tab 4).
- **Line 16c: Total untreated CSO discharge (MG).** Line 16c is automatically calculated as the total untreated CSO discharge across all CSO outfalls (Line 14e of Tab 4).

References

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Appendix A:
Additional Data and Modeling Resources

Appendix A
Additional Data and Modeling Resources

This appendix lists some resources for accessing precipitation and land cover data.

Precipitation data sources are from NOAA and are all on an hourly timestep or greater. As such, they are suitable for use as a check to total rainfall depths obtained from other sources but are less suitable for direct use in the CSO Model. Land cover resources include alternative ways to access the Multi-Resolution Land Characteristics (MRLC) Consortium's National Land Cover Dataset.

Precipitation Data Resources	Website
NOAA: National Weather Data	https://www.weather.gov/
NOAA: Weather	http://www.noaa.gov/weather
NOAA: Hydrologic Prediction Service	https://water.weather.gov/precip/
NOAA: Daily Precipitation Data	https://www.weather.gov/marfc/DailyPrecipitation
NOAA: Recent Temperature and Precipitation Data	https://www.weather.gov/lwx/cliplotall
NOAA: Climate Data Online	https://www.ncdc.noaa.gov/cdo-web/
NOAA: Forecast/Future Precipitation Data	https://www.weather.gov/serfc/wxobsfcst_future_precipitation

Land Cover Resources	Website
MRLC: National Land Cover Database (NLCD) 2016	https://www.mrlc.gov/national-land-cover-database-nlcd-2016
USGS: The National Map	https://www.usgs.gov/core-science-systems/national-geospatial-program/national-map
USGS: Land Cover and Land Use Database	https://catalog.data.gov/dataset/national-land-cover-database-nlcd-land-cover-collection
USGS: Land Cover Data Portal	https://gapanalysis.usgs.gov/gaplandcover/
EPA: EnviroAtlas Dynamic Data Matrix	https://www.epa.gov/enviroatlas/enviroatlas-dynamic-data-matrix
EPA: EnviroAtlas Master Web Service	https://enviroatlas.epa.gov/arcgis/rest/services/National/National2016_master/MapServer

Appendix B:
Illustrated Example of Time of Concentration Data Input

Appendix B
Illustrated Example of Time of Concentration Data Input

To help explain the steps needed to determine t_c inputs, an illustrated example is provided below. For reference, the instructions first given in the main text under Tab 3 (t_c and rainfall) are repeated here:

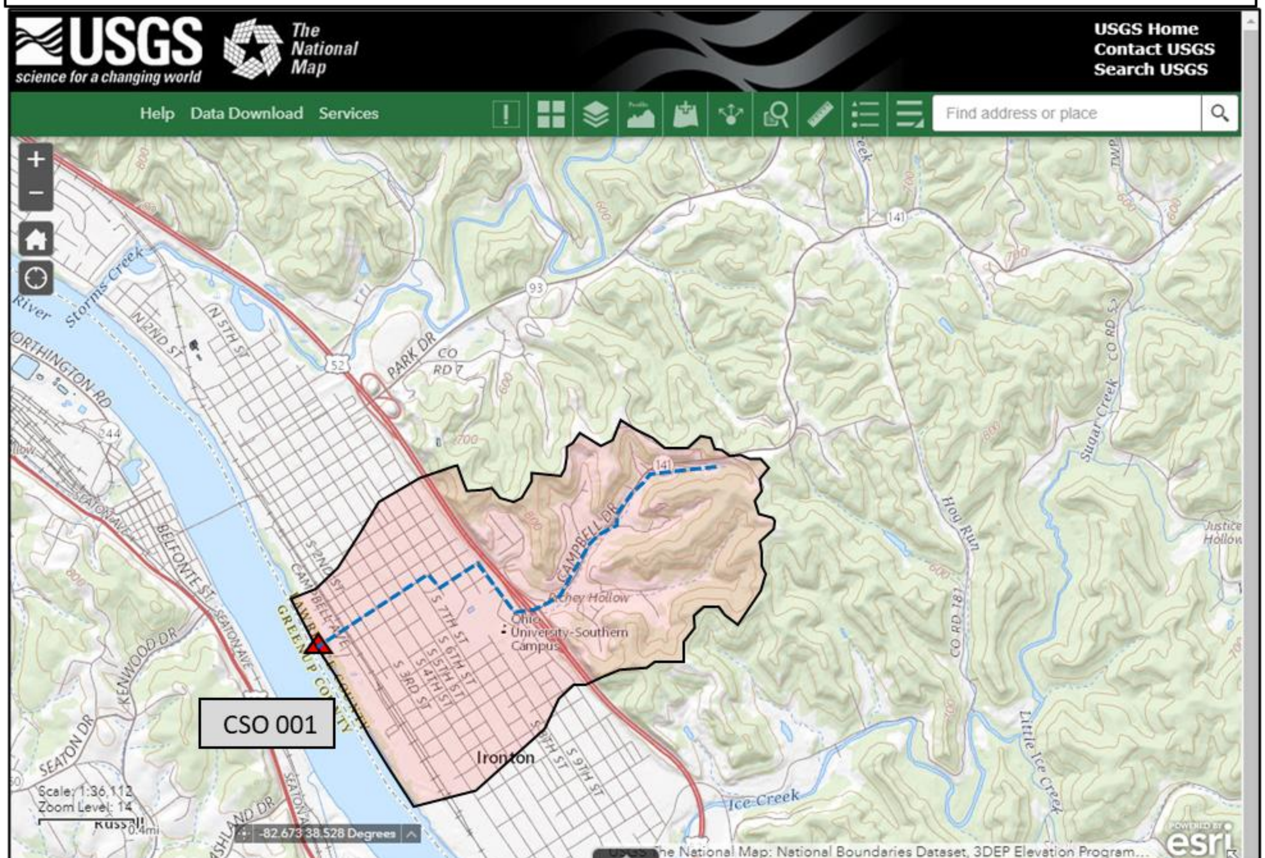
Lines 8a, 8b, 8c, and 8e

1. Website: https://apps.nationalmap.gov/viewer/.
2. In the search bar at the upper-right side of the screen, type in the name of the city or county of interest to zoom in to a specific CSO sub-sewershed—for example, “Anytown, PA.” Using the arrow keys or the mouse, choose the most appropriate option that appears below the search bar. Alternatively, use the zoom functions to zoom to your area of interest.
3. Using the zoom navigation buttons in the upper-left of the screen, zoom to an appropriate scale in which you can see the entire sub-sewershed of the CSO outfall of interest. To pan, use your left mouse button and drag the map to the desired view extent.
4. In the green ribbon at the top of the map, select the icon for “Elevation Profile” (see adjacent image). A dialogue box will appear.

5. Follow the instructions in the dialogue box by first clicking on the ruler icon that appears and selecting “Feet (US)” as the unit of measure.
6. On the map, place the cursor over the most upstream portion (i.e., most hydraulically distant from the CSO outfall) of the CSO sub-sewershed to start the profile. As best as possible, trace the approximate route of the main stormwater conveyance of the CSO sub-sewershed, following the path all the way to the outfall. At the outfall location, double-click to complete the profile.
7. Enter values for Lines 8a, 8b, and 8c for the CSO outfall, corresponding to the total profile length, the elevation at the upstream end of the main flow path, and the elevation at the downstream end of the main flow path, respectively, as illustrated on the elevation profile. (If the profile that is created looks unreasonable, or if the longest flow path route is uncertain, do this step three times and use the average of each required value as final model input.)

Steps:

1. Website: https://apps.nationalmap.gov/viewer/.
2. In the search bar at the upper-right side of the screen, type in the name of the city or county of interest to zoom in to a specific CSO sub-sewershed—for example, "Anytown, PA." Using the arrow keys or the mouse, choose the most appropriate option that appears below the search bar. Alternatively, use the zoom functions to zoom to your area of interest.
3. Using the zoom navigation buttons in the upper-left of the screen, zoom to an appropriate scale in which you can see the entire sub-sewershed of the CSO outfall of interest. To pan, use your left mouse button and drag the map to the desired view extent.

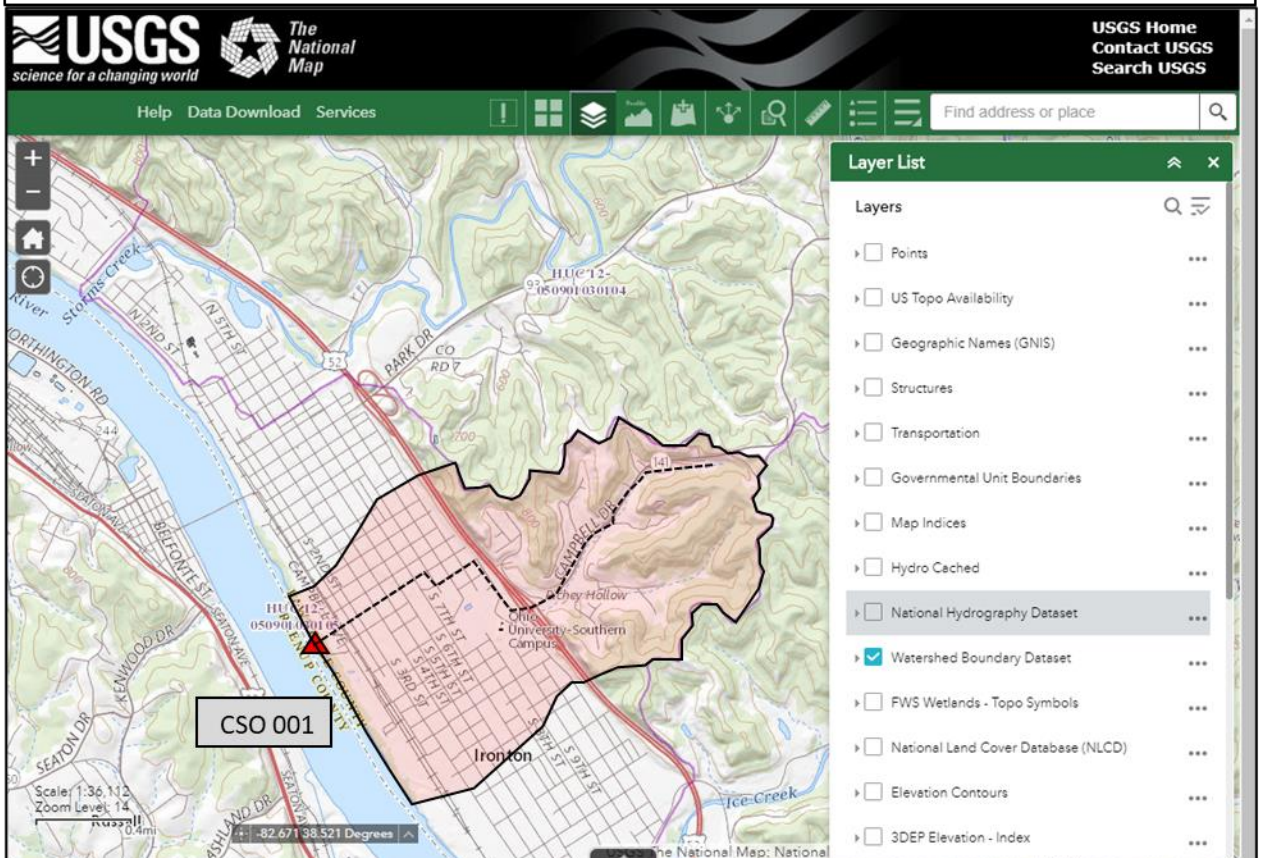


A.	▲ CSO Outfall	Major Flowpath	Sub-sewershed Boundary

Steps 1-3 are illustrated in Figure A. At this point, the user has navigated to their CSO of interest, and has the entire sub-sewershed boundary in view. In practice, the sub-sewershed attributes will not be shown on the user's screen but are included here for illustration purposes. It is assumed that the user is familiar enough with their sub-sewershed boundaries to approximate the route of the major flowpath, which begins at the most upstream extent of the sub-sewershed and ends at the CSO outfall.

Steps:

1. Website: https://apps.nationalmap.gov/viewer/.
2. In the search bar at the upper-right side of the screen, type in the name of the city or county of interest to zoom in to a specific CSO sub-sewershed—for example, "Anytown, PA." Using the arrow keys or the mouse, choose the most appropriate option that appears below the search bar. Alternatively, use the zoom functions to zoom to your area of interest.
3. Using the zoom navigation buttons in the upper-left of the screen, zoom to an appropriate scale in which you can see the entire sub-sewershed of the CSO outfall of interest. To pan, use your left mouse button and drag the map to the desired view extent.

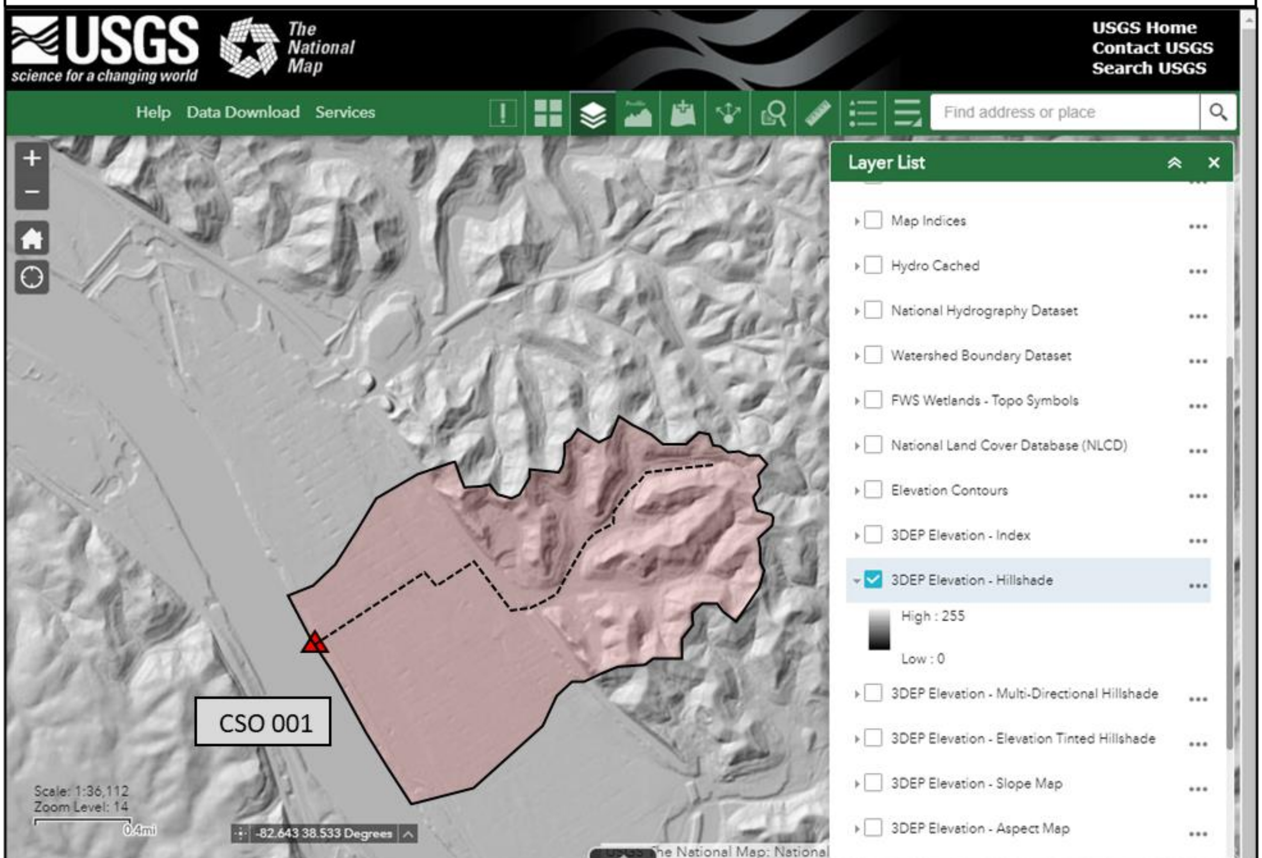


B. CSO Outfall — Major Flowpath — Sub-sewershed Boundary

In addition to elevation data that will eventually be determined, the National Map Viewer allows for viewing of other data layers that may be helpful in this exercise. These other data layers are accessed by toggling the layer list, as shown in Figure B. In this case, the Watershed Boundary Dataset is toggled on, which shows major watershed delineations in purple. While these delineations are generally not detailed enough to show individual CSO sub-sewersheds, some users may find them helpful to delineate various extents. In this hypothetical example, the Watershed Boundary Dataset is used to help delineate the upstream extent of the CSO sub-sewershed.

Steps:

1. Website: https://apps.nationalmap.gov/viewer/.
2. In the search bar at the upper-right side of the screen, type in the name of the city or county of interest to zoom in to a specific CSO sub-sewershed—for example, "Anytown, PA." Using the arrow keys or the mouse, choose the most appropriate option that appears below the search bar. Alternatively, use the zoom functions to zoom to your area of interest.
3. Using the zoom navigation buttons in the upper-left of the screen, zoom to an appropriate scale in which you can see the entire sub-sewershed of the CSO outfall of interest. To pan, use your left mouse button and drag the map to the desired view extent.

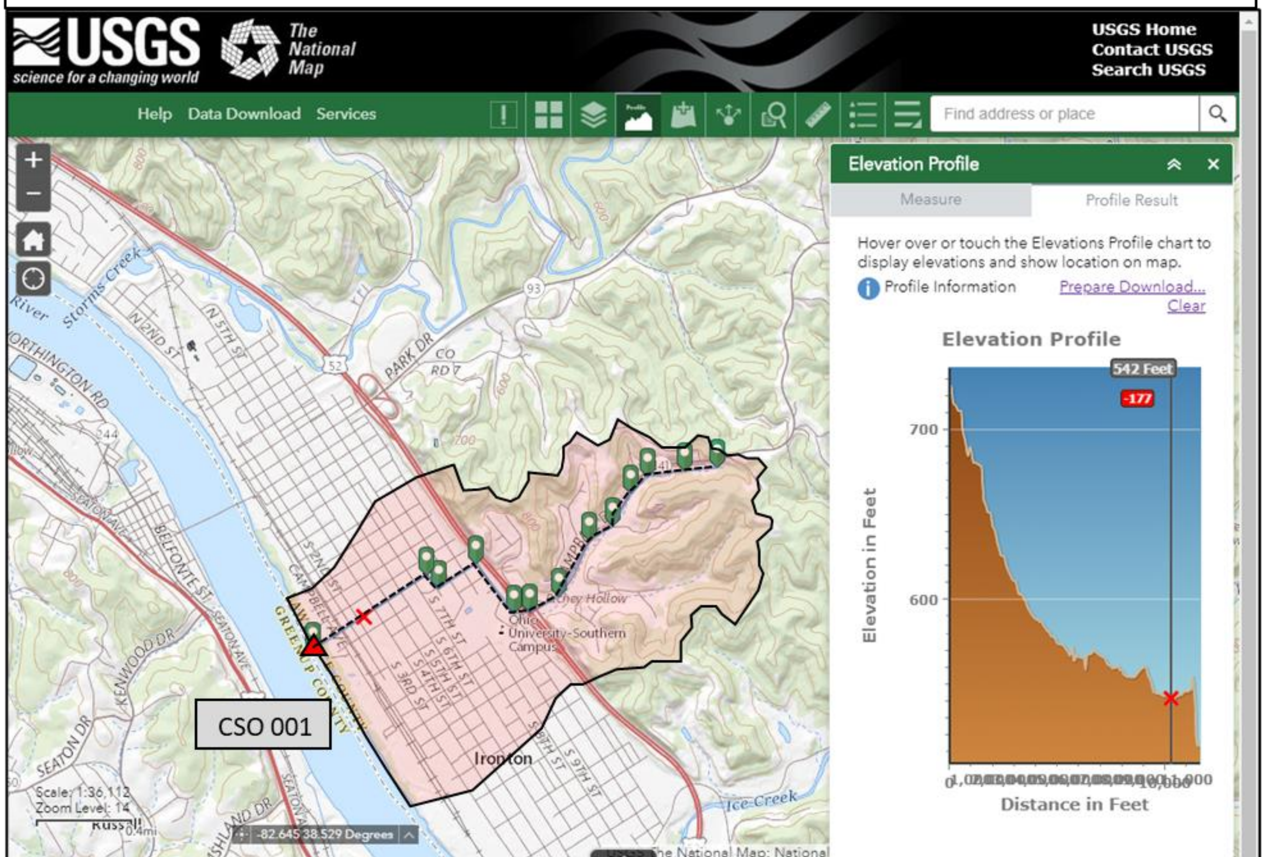


C. CSO Outfall Major Flowpath Sub-sewershed Boundary

Other useful datasets that may be helpful in this exercise are the 3DEP Elevation Datasets. In Figure C, the "Hillshade" version is displayed, which shows a 3-dimensional overview of the sub-sewershed and surrounding area topography. The user is encouraged to explore the various elevation products as they may be helpful in determining major flow directions.

Steps:

4. In the green ribbon at the top of the map, select the icon for "Elevation Profile" (see adjacent image). A dialogue box will appear.
5. Follow the instructions in the dialogue box by first clicking on the ruler icon that appears and selecting "Feet (US)" as the unit of measure.
6. On the map, place the cursor over the most upstream portion (i.e., most hydraulically distant from the CSO outfall) of the CSO sub-sewershed to start the profile. As best as possible, trace the approximate route of the main stormwater conveyance of the CSO sub-sewershed, following the path all the way to the outfall. At the outfall location, double-click to complete the profile.



D. CSO Outfall — Major Flowpath — Sub-sewershed Boundary

Figure D shows the outcome of Steps 4-6. At this point, the user has traced the major flowpath with the Elevation Profile tool. The resulting profile is shown in the window to the right of the Figure. From here, the user can move their cursor over the profile view and see the corresponding location on the plan view to the left, indicated with a red "X". The required inputs for Lines 8a, 8b and 8c can be taken off the profile to the right as the approximate elevations of the upstream and downstream extents and the total length, respectively.

Appendix C:
Accessing Recent Rainfall Data from NOAA

Appendix C
Accessing Recent Rainfall Data from NOAA

To help explain the steps needed to obtain recent rainfall data from NOAA, an illustrated example is provided below. At the time of this writing, only hourly data are available from NOAA for years after 2013. However, NOAA is currently working to make 15-minute data available for recent years. When available, users should be able to use the same steps below to access both recent hourly and 15-minute data.

Line 10b

1. Website: https://www.ncdc.noaa.gov/cdo-web/datatools/lcd.
2. Navigate to the weather station nearest to the CSO outfall(s) of interest using either the “Select a Location Type” menu or the “Map Tool.”
3. If using the “Map Tool,” zoom to the CSO outfall of interest on the map using the scroll function, the zoom buttons within the map, or the search box (to search for a particular city or county). If using the “Select a Location Type” option, follow prompts to select the nearest station with data coverage for your date(s) of interest and skip to Step 7.
4. With the CSO sub-sewershed in the view window, zoom out until a weather station icon appears.
5. Once you identify a station, click the wrench icon in the “Layers” tab within the menu on the left side of the window. This icon will pull up a toolset that will allow you to select a specific station.
6. Using the “Identify” tool, select the nearest weather station that has data coverage for the dates of interest. If the closest station does not have the requisite data, zoom out further until a different station appears. Repeat until you get the necessary data.
7. In the “Results” tab of the menu on the left side of the screen, check the selection box next to the station of interest, then click “Add to Cart” at the bottom of the menu. Note that you only need to provide an email address to check out and there is no requirement to pay for the data from NOAA.
8. Follow instructions on the new tab that opens automatically. You can use any output format, but make sure to select “Hourly Precipitation Output.” (Note: If NOAA has released their 15-minute data for years after 2013 at the time of this reading, select that option here instead.)
9. In the date range box, input the desired date range, making sure to cover the storm event of interest. If unsure of exact timing, input a range of one day on either side of the event.
10. Select “Continue” at the bottom of the screen.
11. Enter a valid email address to which data will be sent.
12. Select “Submit Order.”
13. When the order is complete, download the data.
14. On Line 10b, enter the time and date that correspond to the start of the event that is being modeled.
15. Enter precipitation amounts, in inches, for hours 1–24, with hour 1 corresponding to the first recorded rainfall value of the storm event of interest. For events lasting less than 24 hours, enter 0 for the remaining hours.

Steps:

1. Website: https://www.ncdc.noaa.gov/cdo-web/datatools/lcd.
2. Navigate to the weather station nearest to the CSO outfall(s) of interest using either the "Select a Location Type" menu or the "Map Tool."

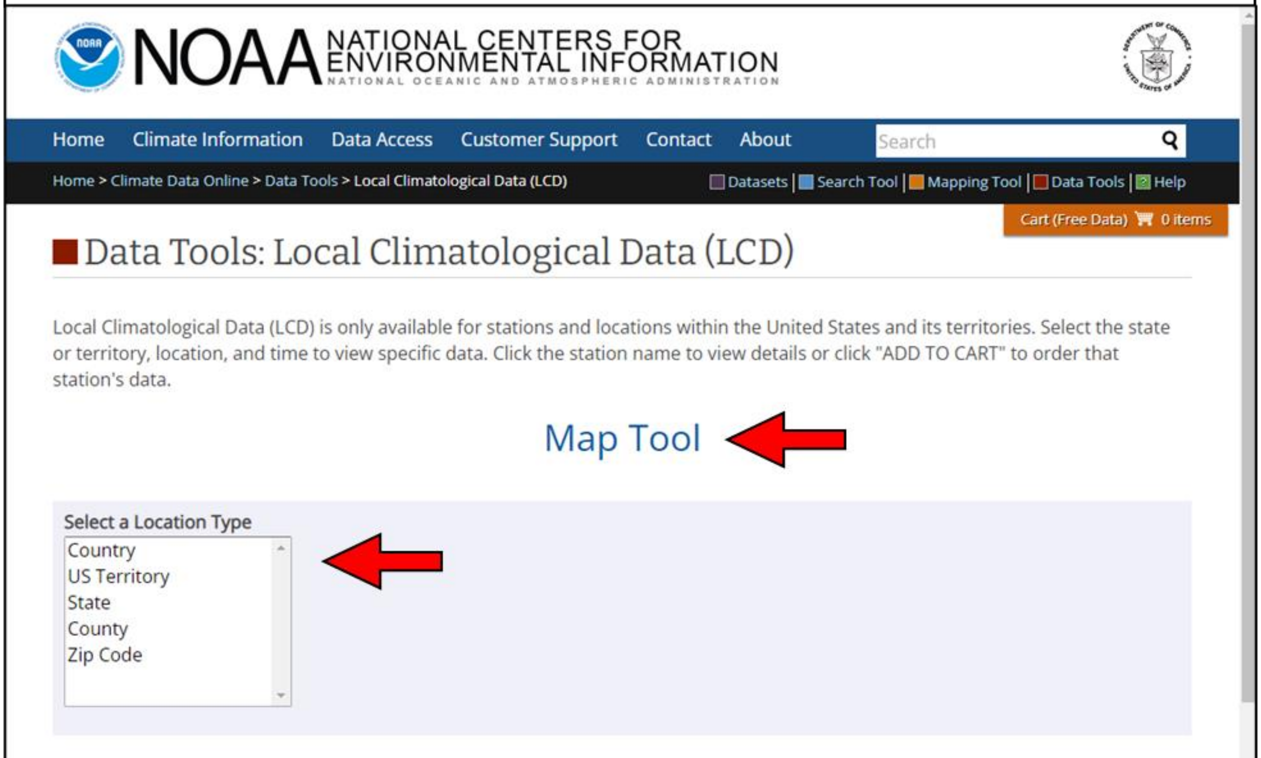


Figure A. Use one of the two navigation options available as illustrated by the red arrows (⬅).

Steps:

3. If using the "Map Tool," zoom to the CSO outfall of interest on the map using the scroll function, the zoom buttons within the map, or the search box (to search for a particular city or county). If using the "Select a Location Type" option, follow prompts to select the nearest station with data coverage for your date(s) of interest and skip to Step 7.
4. With the CSO sub-sewershed in the view window, zoom out until a weather station icon appears.
5. Once you identify a station, click the wrench icon in the "Layers" tab within the menu on the left side of the window. This icon will pull up a toolset that will allow you to select a specific station.

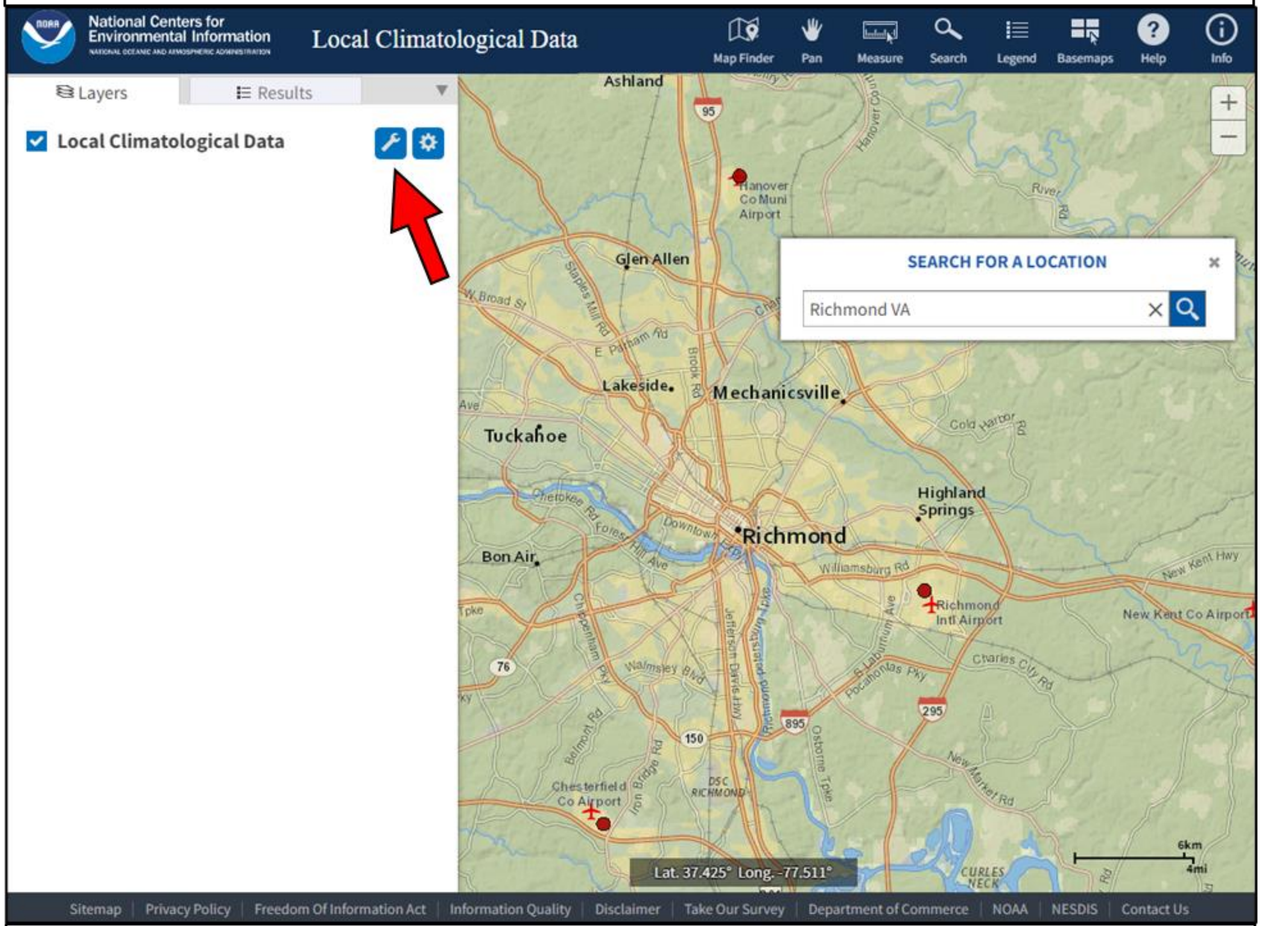


Figure B. Find the station nearest your CSO sub-sewershed(s). As an example, we have zoomed into Richmond, VA using the "Search for a Location" window that opens with the Map Viewer. As can be seen from this view, three weather stations, indicated by red dots (●), are in the Richmond, VA area. The wrench icon required in Step 5 is indicated with a red arrow (⬅).

Steps:

5. Once you identify a station, click the wrench icon in the “Layers” tab within the menu on the left side of the window. This icon will pull up a toolset that will allow you to select a specific station.
6. Using the “Identify” tool, select the nearest weather station that has data coverage for the dates of interest. If the closest station does not have the requisite data, zoom out further until a different station appears. Repeat until you get the necessary data.
7. In the “Results” tab of the menu on the left side of the screen, check the selection box next to the station of interest, then click “Add to Cart” at the bottom of the menu. Note that you only need to provide an email address to check out and there is no requirement to pay for the data from NOAA.

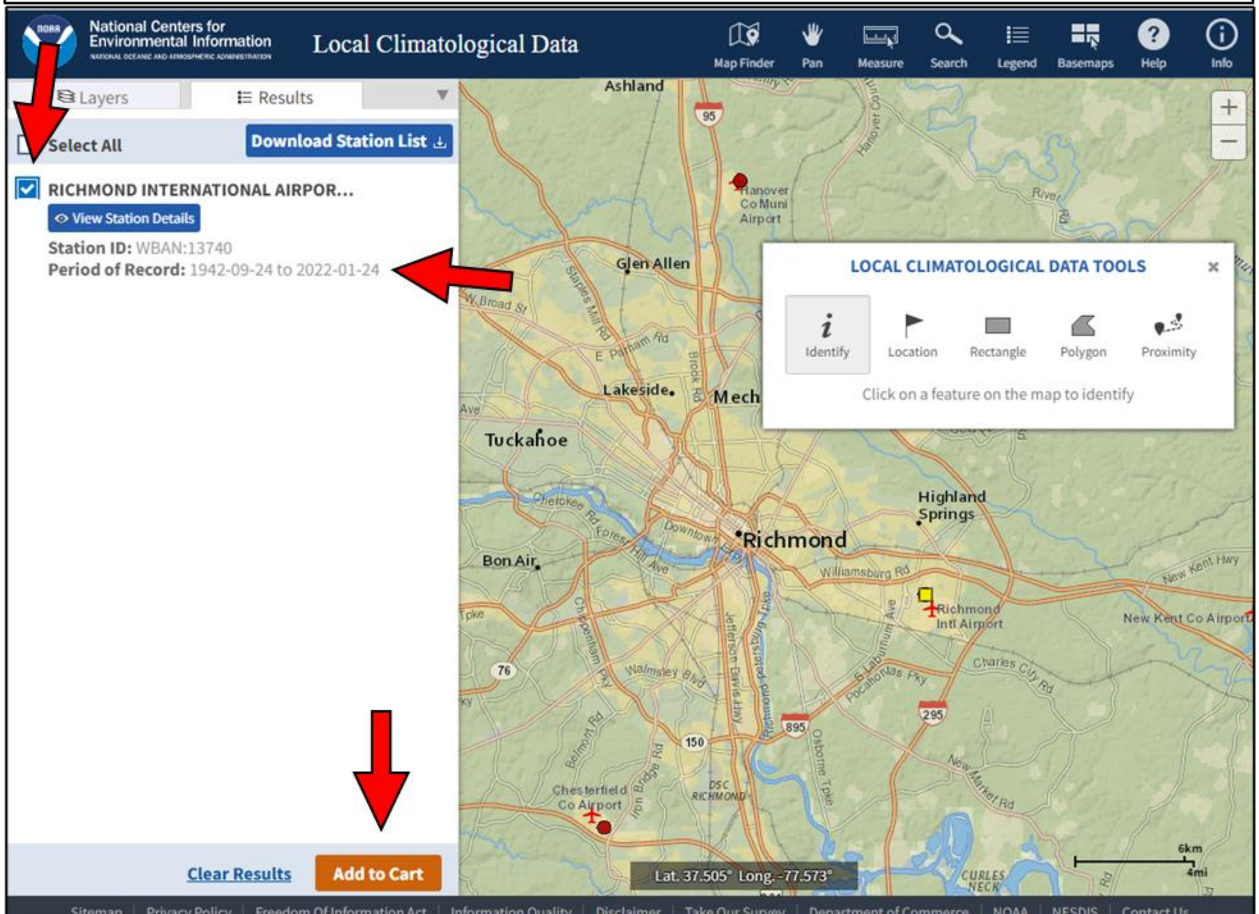


Figure C. After pressing the wrench icon from Step 5 (see Figure B), a toolset window opens. Starting with the weather station closest to your CSO sewershed(s), use the “Identify” tool (selected in Figure C) to click on the station icon. Once selected, the station icon will change to a yellow square (□). Look at the Period of Record for the selected station as illustrated with the red arrow (⬅). Specifically, make sure the period of record covers the storm event you wish to model. If the period of record does not span the day of interest, repeat step 6 for the next closest station. When a station with the necessary data is found, move on to Step 7 by clicking the station’s checkbox and the “Add to Cart” button (also illustrated with red arrows ⬅).

Steps:

8. Follow instructions on the new tab that opens automatically. You can use any output format, but make sure to select “Hourly Precipitation Output.” (Note: If NOAA has released their 15-minute data for years after 2013 at the time of this reading, select that option here instead.)
9. In the date range box, input the desired date range, making sure to cover the storm event of interest. If unsure of exact timing, input a range of one day on either side of the event.
10. Select “Continue” at the bottom of the screen.

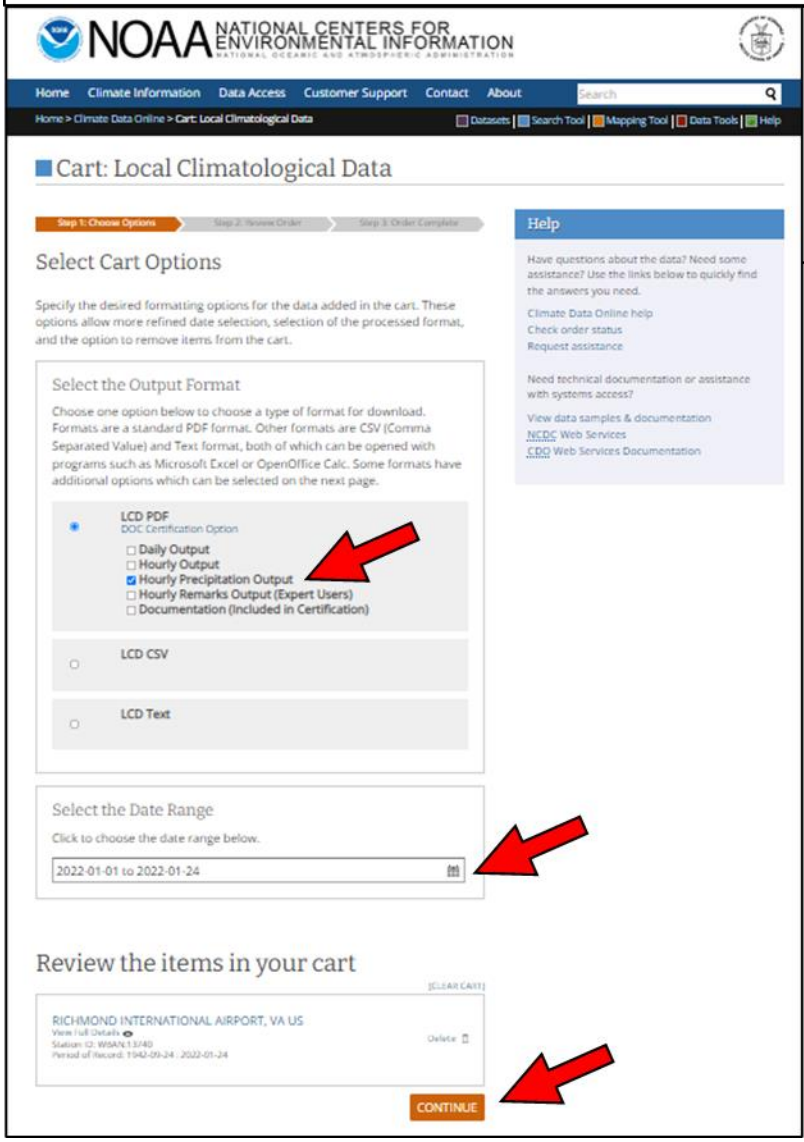


Figure D. Select hourly (or better, if available) precipitation output, make sure the date range of interest is selected, and select “Continue” at the bottom of the screen. Each step is illustrated with a red arrow (⬅).

Steps:

11. Enter a valid email address to which data will be sent.

12. Select “Submit Order.”

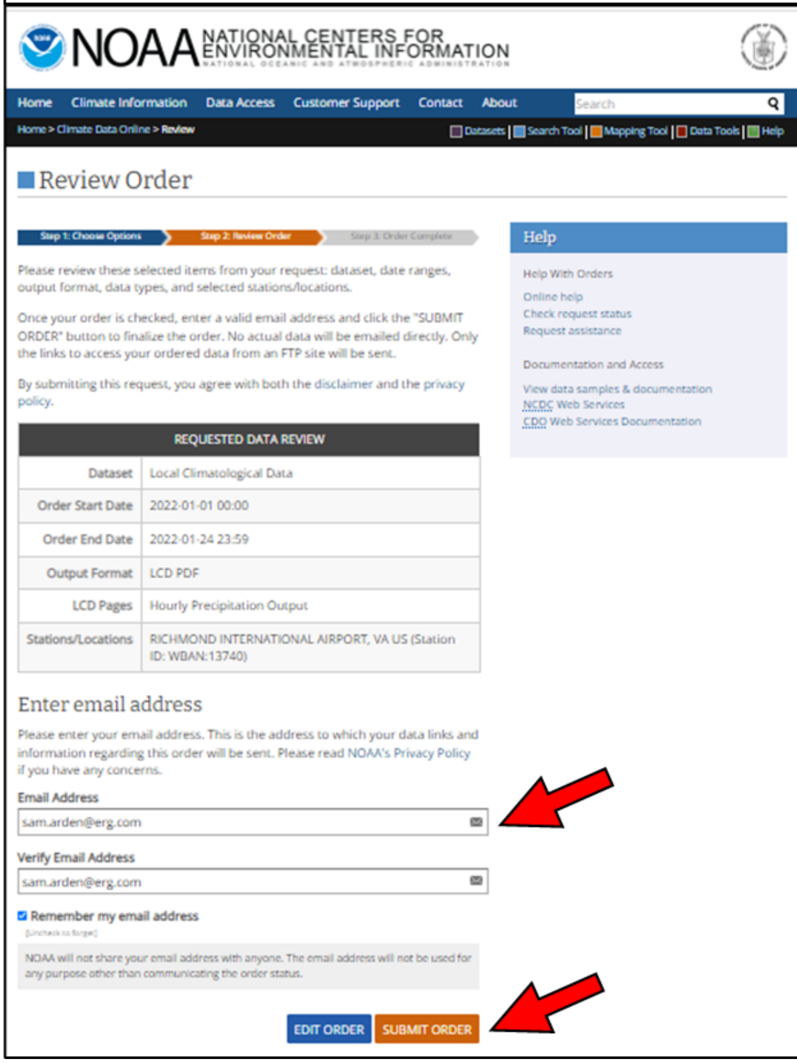


Figure E. Enter an email address where you would like to receive the data and select “Submit Order” (illustrated with red arrows). When the order is complete, you will receive a link to download the data. Find the data that corresponds to your event of interest and enter the precipitation amounts, in inches per hour or inches per 15 minutes, into Line 10b of the CSO Model.