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SWMM-CAT User's Guide (Version 1.1)

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by

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Although a reasonable effort has been made to assure that the results obtained are correct, the computer programs described in this manual are experimental. Therefore, the authors and the U.S. Environmental Protection Agency are not responsible and assume no liability whatsoever for any results or any use made of the results obtained from these programs, nor for any damages or litigation that result from the use of these programs for any purpose.

ABSTRACT

The Storm Water Management Model Climate Adjustment Tool (SWMM-CAT) is a simple to use software utility that allows future climate change projections to be incorporated into the Storm Water Management Model (SWMM). SWMM can accept a set of monthly adjustment factors for each input meteorological time series to represent future changes in climatic conditions. SWMM-CAT provides a set of location-specific adjustments that were derived from global climate change models run as part of the World Climate Research Programme (WCRP) Coupled Model Intercomparison Project Phase 5 (CMIP5) archive. In SWMM-CAT Version 1.1 climate change projections are obtained from EPA's Climate Resilience Evaluation and Awareness Tool Version 3.1; historical data for 24-Hour design storms are based on CREAT 3.1; evaporation values are determined by the Hargreaves method, using historical temperature data from PRISM observations and GLDAS if PRISM data are unavailable.

FORWARD

The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a scientific knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The Center for Environmental Solutions and Emergency Response (CESER) within the Office of Research and Development (ORD) is the Agency's center for investigation of technological and management approaches for preventing and reducing risks from pollution that threaten human health and the environment. The focus of the Center's research program is on methods and their cost-effectiveness for prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites, sediments, and ground water; prevention and control of indoor air pollution; and restoration of ecosystems. CESER collaborates with both public and private sector partners to foster technologies that reduce the cost of compliance and to anticipate emerging problems. CESER's research provides solutions to environmental problems by: developing and promoting technologies that protect and improve the environment; advancing scientific and engineering information to support regulatory and policy decisions; and providing the technical support and information transfer to ensure implementation of environmental regulations and strategies at the national, state, and community levels.

SWMM-CAT Version 1.1 is an update from Version 1.0. It is a utility that adds location-specific climate change adjustments to a Storm Water Management Model (SWMM) project file. Adjustments can be applied on a monthly basis to air temperature, evaporation rates, and precipitation, as well as to the 24-hour design storm at different recurrence intervals.

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The 2014 version of this report was written by Lewis A. Rossman, Environmental Scientist Emeritus, U.S. Environmental Protection Agency, Cincinnati, OH (USEPA).

Michelle Simon (USEPA) and Colleen Barr (ORISE) updated the original SWMM-CAT Manual to Version 1.1. SWMM-CAT. Version 1.1 contains historical data covering 1990-2019, climate change data from CREAT 3.1, updated NOAA Atlas-14 24-Hour Storm Disaggregation methodologies, and the Hargreaves method for calculating evaporation.

Colleen Barr acquired the updated historical meteorological, climate change, and 24-Hour Storm disaggregation methodologies for SWMM-CAT Version 1.1. Ms. Barr was supported in part by an appointment to the Postgraduate Research Program at the U.S. Environmental Protection Agency, Office of Research and Development, Center for Environmental Solutions and Emergency Response, administered by the Oak Ridge Institute for Science and Education through Interagency Agreement No. (DW-8992433001) between the U.S. Department of Energy and the U.S. Environmental Protection Agency.

Michelle Simon and Matthew Hopton (USEPA) were the work assignment managers for Contract EP-C-17-041 Work Assignments 4-52 with Eastern Research Group. RESPEC was a subcontractor to this work assignment and programmed the updated historical and climate change data into Version 1.1 of SWMM-CAT.

The authors would like to acknowledge the assistance provided by EPA's CREAT project team for the assistance they rendered for us to acquire updated Climate Change Data.

ACRONYMS AND ABBREVIATIONS

CAT	Climate Adjustment Tool
CMIP5	Coupled Model Intercomparison Project Phase 5
CREAT	Climate Resilience Evaluation and Analysis Tool
EPA	United States Environmental Protection Agency
GLDAS	Global Land Data Assimilation System
IPCC	Intergovernmental Panel on Climate Change
NCDC	National Climatic Data Center
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
PRISM	Parameter-elevation Regressions on Independent Slopes Model
SWMM	Storm Water Management Model
WCRP	World Climate Research Programme

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1.0 Introduction

The Storm Water Management Model Climate Adjustment Tool (SWMM-CAT) is a simple to use software utility that allows future climate change projections to be incorporated into the Storm Water Management Model (SWMM). SWMM is a dynamic rainfall-runoff-routing simulation model used for single event or long-term (continuous) simulation of stormwater runoff quantity and quality from primarily urban areas. Various versions of SWMM have been in existence since 1971 and it has been used in thousands of hydrology and drainage system design projects.

SWMM uses externally supplied time series of the following climate-related variables in its hydrologic calculations:

- precipitation is the primary driving force in a SWMM simulation
- evaporation determines how quickly surfaces and soils dry out between storm events
- air temperature is used to model snow melt routines and can also be used to estimate evaporation rates.

SWMM can accept a set of monthly adjustment factors for each of these input time series that represent potential future changes in climatic conditions. Each monthly factor is used to modify all of the user-supplied climate data for a given month. As an example, if the June adjustment factor for precipitation was 1.3, then all June rainfall values supplied to SWMM would be multiplied by 1.3.

Although SWMM users are free to use any set of adjustment factors they want, SWMM-CAT provides a set of location-specific adjustments that were derived from global climate change models run as part of the World Climate Research Programme (WCRP) Coupled Model Intercomparison Project Phase 5 (CMIP5) archive. These are the same climate change simulations that helped inform the United Nations Intergovernmental Panel on Climate Change in preparing its Fifth Assessment report (IPCC 2014). Downscaled results from this archive were generated and converted into changes relative to historical values by another EPA project called CREAT 3.1 (Climate Resilience Evaluation and Analysis Tool) (EPA 2021). It contains a database of climate change effects across the US localized to a grid of 0.5 degrees in latitude and longitude (about 30 by 30 miles). These effects include changes in monthly average precipitation, monthly average temperature, and extreme event 24-hour rainfall amounts for each of three different climate change scenarios in two different future time periods. SWMM-CAT provides the linkage between CREAT 3.1's downscaled climate change estimates and the monthly adjustment factors used by SWMM.

You don't have to run or have knowledge of SWMM to run SWMM-CAT if all you want to see are the projected future changes in monthly air temperature and rainfall at any specific location. However, if you do want to run the two together then you must use SWMM version 5.1.007 or higher for it to recognize the climate adjustments that SWMM-CAT passes on to it.

2.0 Installing SWMM-CAT

SWMM-CAT runs as a desktop application on the Windows 7 or higher operating system. It is distributed as a zipped file named **swmm-cat1_1d** (the label will be updated as newer releases are made). It can be downloaded from the following web site:
https://www.epa.gov/water-research/storm-water-management-model-swmm

The zip file contains three files, **swmm-cat.exe, ZedGraph.dll**, and this document that should be extracted into any folder of your choosing. You can launch SWMM-CAT independently of SWMM by double-clicking **swmm-cat.exe** in Windows Explorer or by creating a shortcut to it for your Start Menu.

If you wish to run SWMM-CAT from within SWMM itself, you have to register it as an add-in tool with SWMM. This can be done using the following steps:

1. Launch SWMM and select **Tools | Configure Tools** from the main menu bar.
2. Click the **Add** button in the Tool Options dialog that appears.
3. Fill in the Tool Properties dialog as shown in **Figure 1** below. Note that this example has the

SWMM-CAT program located in the folder C:\SWMM-CAT. You can click the  button to bring up a file dialog to find its location on your machine.

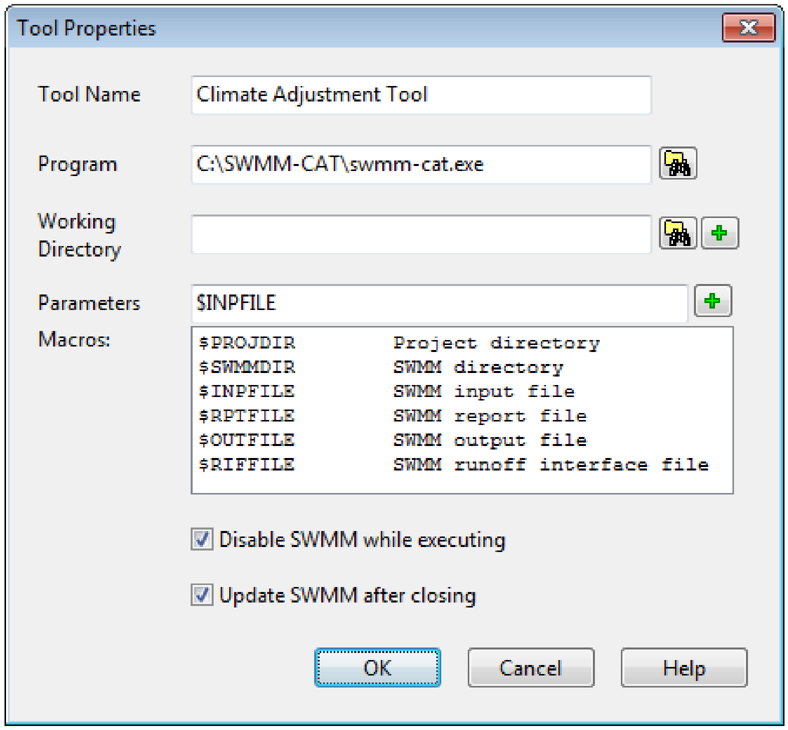

Figure 1 Dialog for Registering SWMM-CAT Add-in Tool

4. Click **OK** to close the Tool Properties dialog and then click **Close** on the Tool Options dialog to close it as well.
5. SWMM-CAT is now registered with SWMM. It appears as a separate option named "Climate Adjustment Tool" on the **Tools** menu which you would select to launch it from within SWMM.

3.0 Running SWMM-CAT

After SWMM-CAT is launched you are presented with the program's main window shown in **Figure 2**. You can find concise instructions on how to proceed on the Help tab, but we will cover these in more detail here.

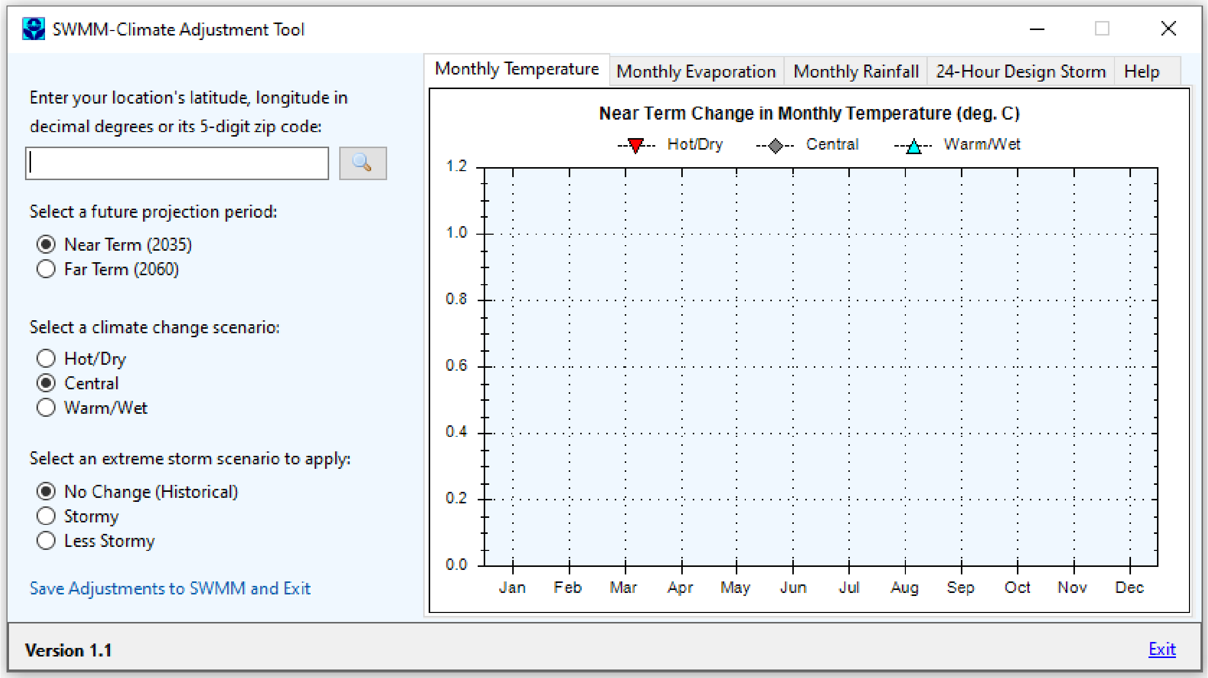

Figure 2 ESWMM-CAT's Main Window

The first step is to identify the location you are interested in viewing adjustments for. You can either enter its latitude and longitude coordinates (in decimal degrees separated by a comma) or its five-digit zip code. You would then hit the Enter key or click the  button to load in the CMIP5-CREAT 3.1 adjustments that are closest to your site. **Figure 3** is a screenshot showing how SWMM-CAT looks after a location has been supplied to it:

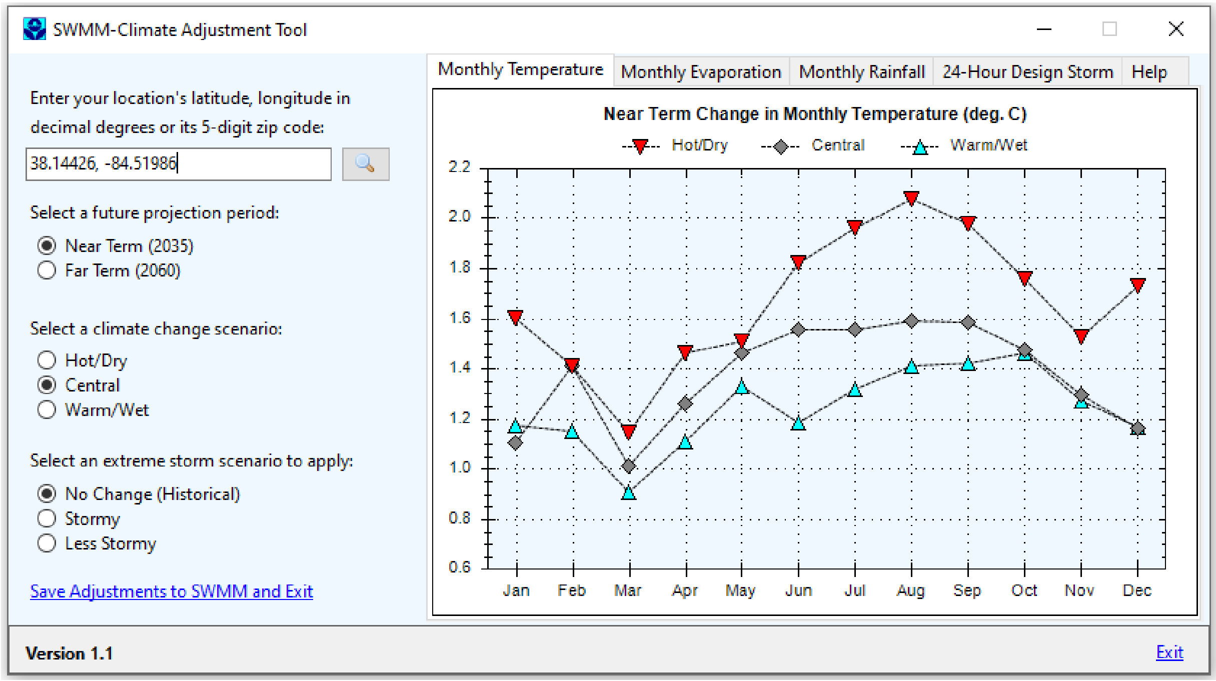

Figure 3 Example of Monthly Temperature Adjustments

The Monthly Temperature tab shows the change in average air temperature by month of the year over a future projection period. These changes are relative to the historical average monthly air temperatures from 1981 – 2010 (EPA 2021). A choice of two future 30-year projection periods is available: a near term projection from 2035 (average projections from 2025 – 2045) and a far term projection from 2060 (averaged projections from 2050 – 2070).

Note that for each month three different values are displayed. These reflect the variability in the outputs of the different global climate models from which the changes were derived. The Hot/Dry values reflect projections from models that were closer to both the highest annual average temperature and lowest annual rainfall, the Warm/Wet values represent model projections closer to the lowest annual temperature and highest annual rainfall, while the Central values come from model projections whose results fell closer to the median annual temperature and rainfall. More information on how the projections were selected from the CMIP5 model runs is presented in section 4 of this manual.

The Monthly Evaporation and Monthly Rainfall tabs display changes in potential monthly evapotranspiration rate and monthly precipitation, respectively. Changes in potential evaporation rates are expressed as differences between the average monthly evapotranspiration rate computed from the Hargreaves Evapotranspiration equation for the selected projection period as compared to the historical period. The rainfall changes are expressed as a percentage change from historical values. E.g., a 20 percent change for August means that the average total rainfall in August over the future projection period is 20 percent higher than over the historical record at the location being considered. A -10 percent change would mean that average rainfall was 10 percent lower than that from the historical record.

The 24-Hour Design Storm tab shows the percent change in the highest annual 24-hour rainfall that occurs at a given return period. “Stormy” and “Less Stormy” scenarios are displayed. A stormy future scenario represents ensemble-averaged models that produce a higher change in precipitation per degree of warming for the 5-year storm event and a less stormy future scenario represents models with lower changes in precipitation per degree of warming. Looking at **Figure 4**, we see that for the near-term projection period under the Warm/Wet scenario, the largest 24-hour rainfall that occurs on average once every 5 years increases by 6 percent relative to the historical value. The once in 50-year rainfall for this scenario increases by only 2 percent.

You can observe the numerical value of a point plotted on any of SWMM-CAT’s graphs by holding the mouse over the point.

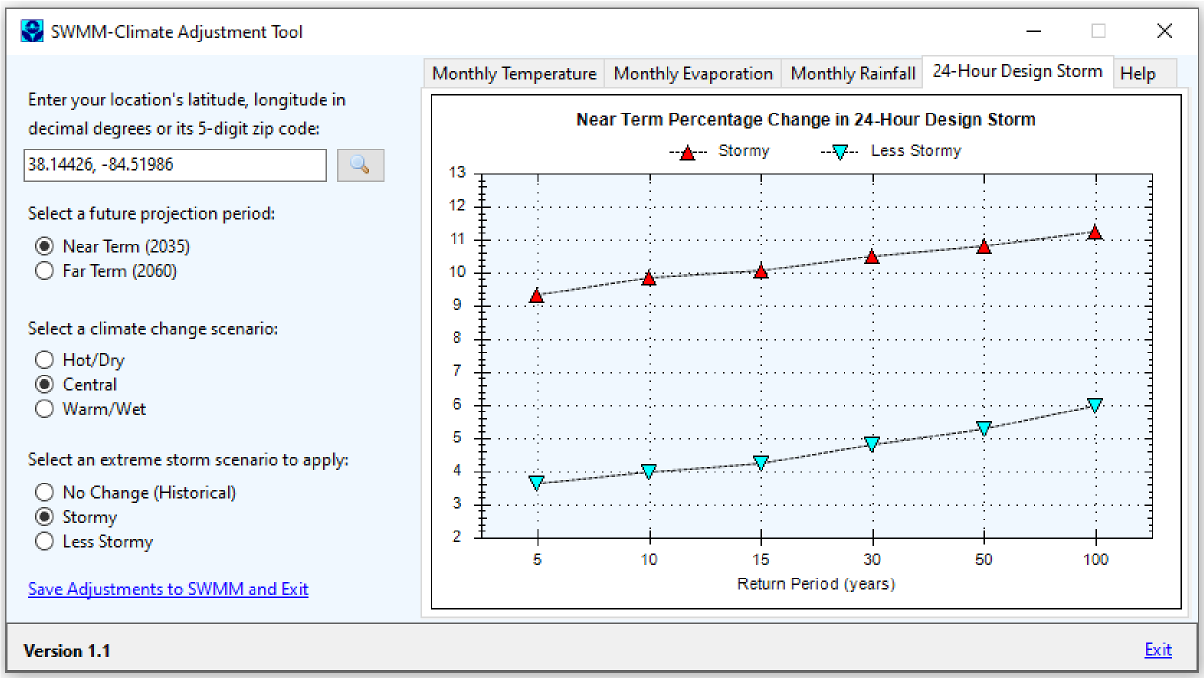

Figure 4 Example of 24-Hour Design Storm Adjustments

Once you have selected a future projection period, a climate change scenario (Hot/Dry, Central, or Warm/Wet), and an extreme storm scenario (Stormy or Less Stormy) to use, you can click the Save Adjustments to SWMM and Exit label to save the adjustments associated with those choices to a SWMM input file. **Figure 5** shows the dialog box that appears asking for the name of an existing SWMM input file and which type of adjustments to save to it. You can click the  button to open a file selection dialog to locate your SWMM input file.

> If you launched SWMM-CAT from within SWMM then the SWMM file name box will be disabled since SWMM has created and passed in to SWMM-CAT a temporary file containing the project data, you were working on in SWMM. After SWMM-CAT closes, control is passed back to SWMM which reads the climate adjustments from the updated input file and makes them available for editing in its Climatology Editor (see below).

Figure 5 Dialog Box Used to Save Adjustments to SWMM

Since only one set of rainfall adjustments can be used in a SWMM project, the Monthly Rainfall and 24- Hour Design Storm options are mutually exclusive. If you select the Design Storm option, then you should also select a return period for the adjusted storm's magnitude from the drop-down list box next to it.

SWMM-CAT always displays temperature changes in degrees Celsius and evaporation changes in inches/day. When saving these adjustments to a SWMM file it will automatically detect the unit system used in the file and convert temperature to degrees Fahrenheit for US units and convert evaporation to mm/day for SI units.

Once you click the Save and Exit button SWMM-CAT will terminate with your selected set of adjustments saved to your SWMM input file. If you launched SWMM-CAT from within SWMM, then the SWMM window will appear once again. At this point you can verify that the adjustments were made (or edit them if you wish) by opening SWMM's Climatology Editor and selecting its Adjustments tab. (To open the editor, select Climatology from the Project Browser list box and click the button below it.) The Climatology Editor is pictured in **Figure 6** below.

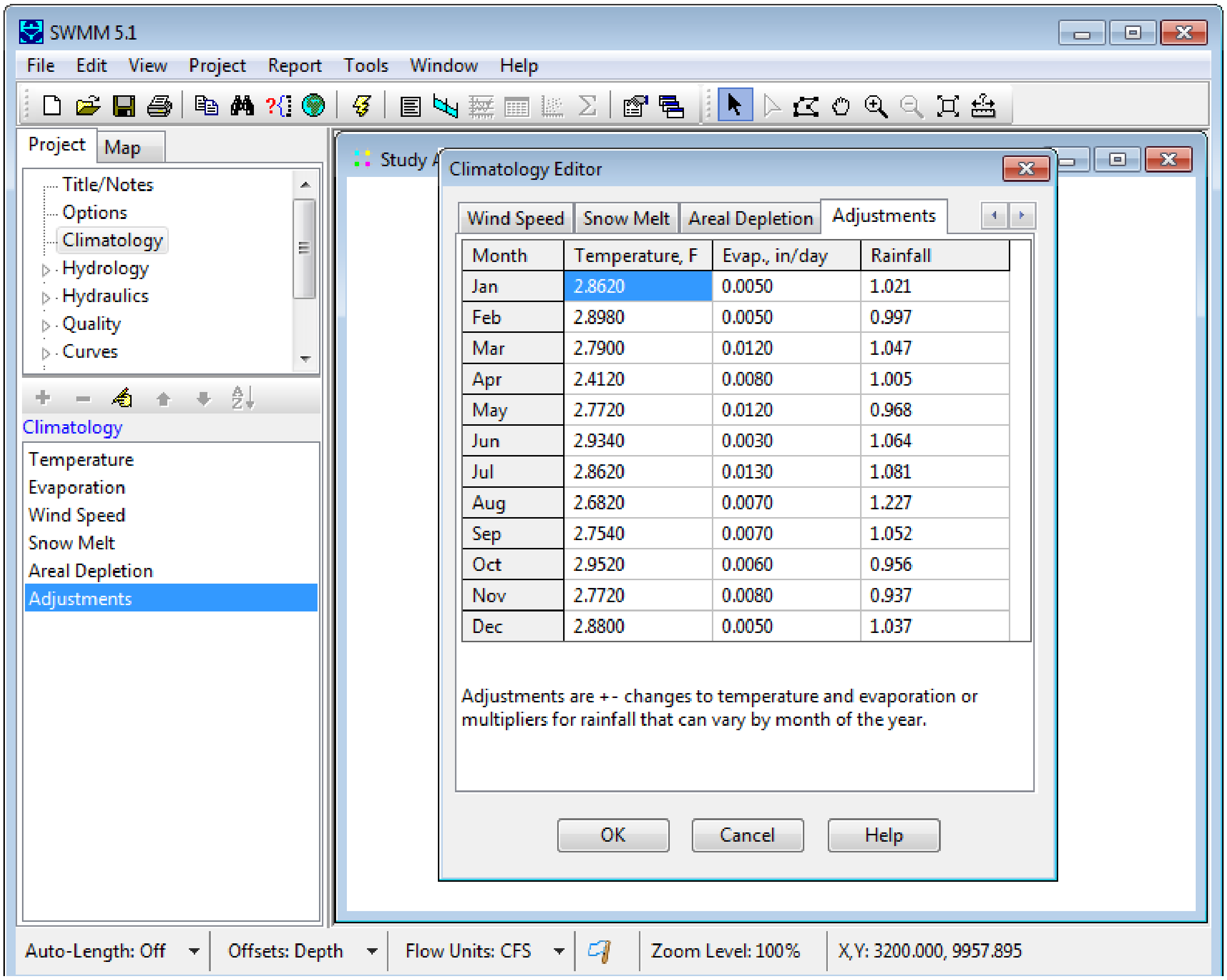

Figure 6 SWMM's Climatology Editor

4.0 Source of Data for Climate Adjustments

As stated earlier, SWMM-CAT obtains its climate change scenarios, e.g., projected changes in precipitation and temperature from another EPA project called CREAT 3.1 (Climate Resilience Evaluation and Analysis Tool) (EPA, 2021). CREAT is a decision support tool to assist drinking water and wastewater utility owners in understanding, evaluating, and addressing climate change risks. It contains a database of climate change effects across the US localized to a grid of 0.5 degrees in latitude and longitude (about 30 by 30 miles). These effects include changes in monthly average precipitation, monthly average temperature, and extreme event 24-hour rainfall amounts for each of three different climate change scenarios in two different future time periods.

Climate change scenarios are based on projections from 38 global climate models available in the CMIP5 archive. CREAT uses an ensemble-informed selection method to define three scenarios. Hot/Dry projection is the average of five individual model results that are nearest to the 95th percentile temperature projection and 5th percentile precipitation projection. Central projection is the average of five individual model results nearest to the median (50th percentile) of both temperature and precipitation projections. Warm/Wet future conditions were determined from the average of five models nearest to the 95th percentile precipitation projection and 5th percentile temperature projection. Once the individual models were selected, they were ensemble-averaged to calculate annual and monthly changes for temperature and precipitation. The future time periods represented are 2035 (near term; based on projection data for 2025-2045) and 2060 (far term; based on projection data for 2050-2070). More detail on CREAT methodology can be found in EPA (2021).

24-Hour Design Storms were based on CREAT 3.1 estimates for 5, 10, 15, 30, 50, and 100-year return periods. A storm event with a return period of 100 years is an event that has a 1% chance of being observed or exceeded in any year, based on the historical record. This event is sometimes called the 100-year storm. It is possible for historically rare events to occur more often than the return period (EPA 2021, Section 4.3.2).

Changes in evaporation rate, which were not part of the CREAT database, were developed in a slightly different manner. SWMM-CAT's historical evaporation data were determined from the Hargreaves Method (EPA 2016), which uses the daily minimum and maximum temperatures and the study area's latitude. The equation for calculating the evaporation rate E (mm/day) is:

$$E = 0.0023\left(\frac{R_a}{\lambda}\right)T_r^{\frac{1}{2}}(T_a + 17.8)$$

where:

R_a	=	water equivalent of incoming extraterrestrial radiation, ($MJm^{-2}d^{-1}$),
λ	=	latent heat of vaporization, ($MJkg^{-1}$), $\lambda = 2.50 - 0.0023661T_a$,
T_r	=	average daily temperature range for a period of days, (degree C),
T_a	=	average daily temperature for a period of days, (degree C).

SWMM uses a 7-day running average of the daily temperature range and daily temperature. For more detail on the Hargreaves Method, please see Hargreaves and Samani (1985) and Hargreaves and Allen (2003).

The daily minimum and maximum air temperatures were found at all locations where precipitation data was available. Where possible, PRISM was used as the daily temperature source. When not available, GLDAS data was used. If GLDAS data was not available, the closest grid cell with available GLDAS data was used.

The extraterrestrial radiation R_a is computed as:

$$R_a = 37.6 d_r (w_s \sin\varphi \sin\delta + \cos\varphi \cos\delta \sin w_s)$$

where:

d_r	=	relative earth-sun distance	=	$1 + 0.033 \cos\left(\frac{2\pi J}{365}\right)$
J	=	Julian day (1 to 365)		
w_s	=	sunset hour angle (radians)	=	$\cos^{-1}(-\tan\varphi \tan\delta)$
φ	=	latitude (radians)		
δ	=	solar declination (radians)	=	$0.4093 \sin\left(\frac{2\pi(284+J)}{365}\right)$

After the historical monthly evaporation rates were determined, the temperature adjustments were applied to the historical temperature data for each scenario, and the Hargreaves equation was used to calculate adjusted monthly evaporation rates. The change in monthly evaporation rate was then calculated by comparing the adjusted monthly evaporation rate to the historical monthly evaporation rate for each scenario.

5.0 Summary

SWMM-CAT Version 1.1 provides a set of location-specific adjustments that were derived from global climate model projections run as part of the World Climate Research Programme (WCRP) Coupled Model Intercomparison Project Phase 5 (CMIP5) archive. Monthly change factors representing a range of projected future changes in input meteorological time series are obtained from EPA's Climate Resilience Evaluation and Awareness Tool Version 3.1; historical data for 24-Hour design storms are based on CREAT 3.1; evaporation values are determined by the Hargreaves method, using historical temperature data from PRISM observations and GLDAS if PRISM data are unavailable.

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