U.S. Stream Flow Metric Dataset

Modeled Flow Metrics for Stream Segments in the United States Under Historical Conditions and Projected Climate Change Scenarios

Data Guide

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https://www.fs.usda.gov/research/rmrs/projects/us-stream-flow-metrics

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Overview

The flow regime is of fundamental importance in determining the physical and ecological characteristics of a river or stream, but actual flow measurements are only available for a small minority of stream segments, mostly on large rivers. Flows for all other streams must be extrapolated or modeled. Modeling is also necessary to estimate flow regimes under future climate conditions.

We modeled streamflow across the contiguous United States for the historical period (1977–2006), and two projected future time periods mid-century (2030–2059) and end-of-century (2070–2099). These modeled streamflows are based on gridded simulations of total daily runoff. These use RCP 8.5 temperature and precipitation projections, downscaled to a 1/8 degree (~12 km) cell size, which are used as inputs to the Variable Infiltration Capacity (VIC) macroscale hydrologic model (Reclamation, 2014).

This dataset updates the previous Western U.S. Stream Flow Metric Dataset (Wenger et al., 2010) (a link to the old datasets is available on the project website). It expands the spatial extent of this analysis to the conterminous U.S., uses updated climate scenarios (CMIP 5), and includes additional climate metrics. For each stream segment in the National Hydrography Dataset Plus Version 2 (NHDPlusV2) in the contiguous U.S., we calculated hydrographs for the three time periods. From these, we calculated summary flow metrics, or signatures, to describe flow regimes for each stream segment and each time period, as well as the absolute and percent change between the historical and future time periods. We then joined these to the NHD stream segments for visualization and analysis.

These results allow scientists and managers to easily compare historical and projected flow patterns, including monthly, seasonal, and annual flow, flood and drought events, and timing of the peak and low flows.

Data Coverage

The flow metric files cover all U.S. NHD regions/production units (Figure 1). Canadian and Mexican land areas are not included in this dataset.

Figure 1. NHD production units

Methods

To calculate flow metrics for each stream segment, we started with gridded estimates of total runoff for the conterminous United States for three time periods: the historical period (1977–2006), mid-century (2030–2059), and end-of-century (2070–2099). We downloaded all of these from the Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections archive (*Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections*, 2014; Reclamation, 2014). These calculate total runoff using the Variable Infiltration Capacity (VIC) hydrologic model, which uses climate and other inputs to simulate land-atmosphere fluxes, water balance, and hydrological processes (Liang et al., 1994). These use downscaled climate inputs using the Bias Correction and Spatial Disaggregation method (Wood et al., 2004), producing runoff data with output grid cells of 1/8 degree (~12 km) on a side.

The projected future climate data use RCP 8.5, a high emissions scenario. Offering this single choice is not intended to suggest that this is a likely outcome nor does it reflect, per se, that some literature suggests it is a likely outcome (e.g., Schwalm et al. (2020) for discussion). Rather, it is a choice to reduce the complexity of offered information and not require users to make a choice of scenario to illustrate relative spatial changes. It seems apparent that RCP 8.5 is a scenario with some potential to occur while at the same time representing a general maximum emission scenario under broad contemplation by the research and adaptation communities. Other scenarios generally show a lesser impact and a somewhat different trajectory over the course of the century. If a different scenario is expected, users can just consider that the impact would generally be less than depicted in this set of maps, and that changes would scale roughly with the amount of added greenhouse gas forcing as compared to RCP 8.5.

We used five CMIP5 global climate models (GCMs) (Lawrence Livermore National Laboratory, 2021), following the five used by the Forest Service 2020 RPA Assessment (Joyce & Coulson, 2020):

- Least warm: MRI-CGCM3 (Meteorological Research Institute)
- Hot: HadGEM2-ES (Met Office Hadley Centre / Instituto Nacional de Pesquisas Espaciais)
- Dry: IPSL-CM5A-MR (Institut Pierre-Simon Laplace)
- Wet: CNRM-CM5 (Centre National de Recherches Meteorologiques / Centre Europeen de Recherche et Formation Avancees en Calcul Scientifique)
- Middle: NorESM1-M (Norwegian Climate Centre)

To create stream hydrographs, we applied the approach of Wenger et al. (2010) by taking the runoff for each grid cell and calculating the proportional contribution from each one to calculate the total flow in each of the NHDPlusV2 catchments (U.S. Geological Survey et al., 2012) intersecting that cell. We then applied these values to the stream segments associated with each catchment, applying a unit hydrograph to simulate the distribution of lag times required for runoff to work its way into the stream, and then accumulated these flows downstream (Wenger et al., 2010); see Figure 2 for a visualization of these steps.

These calculations resulted in three long-term time series of daily streamflow for each stream segment: one for the historical period, one for the middle of the 21st century, and one for the end of the century. We calculated the 26 streamflow metrics described below for each stream segment and time period. We then averaged the results of the five models above to produce an ensemble projection; individual model results are available upon request. We removed stream segments without values for these flow metrics, as well as coastal line segments.

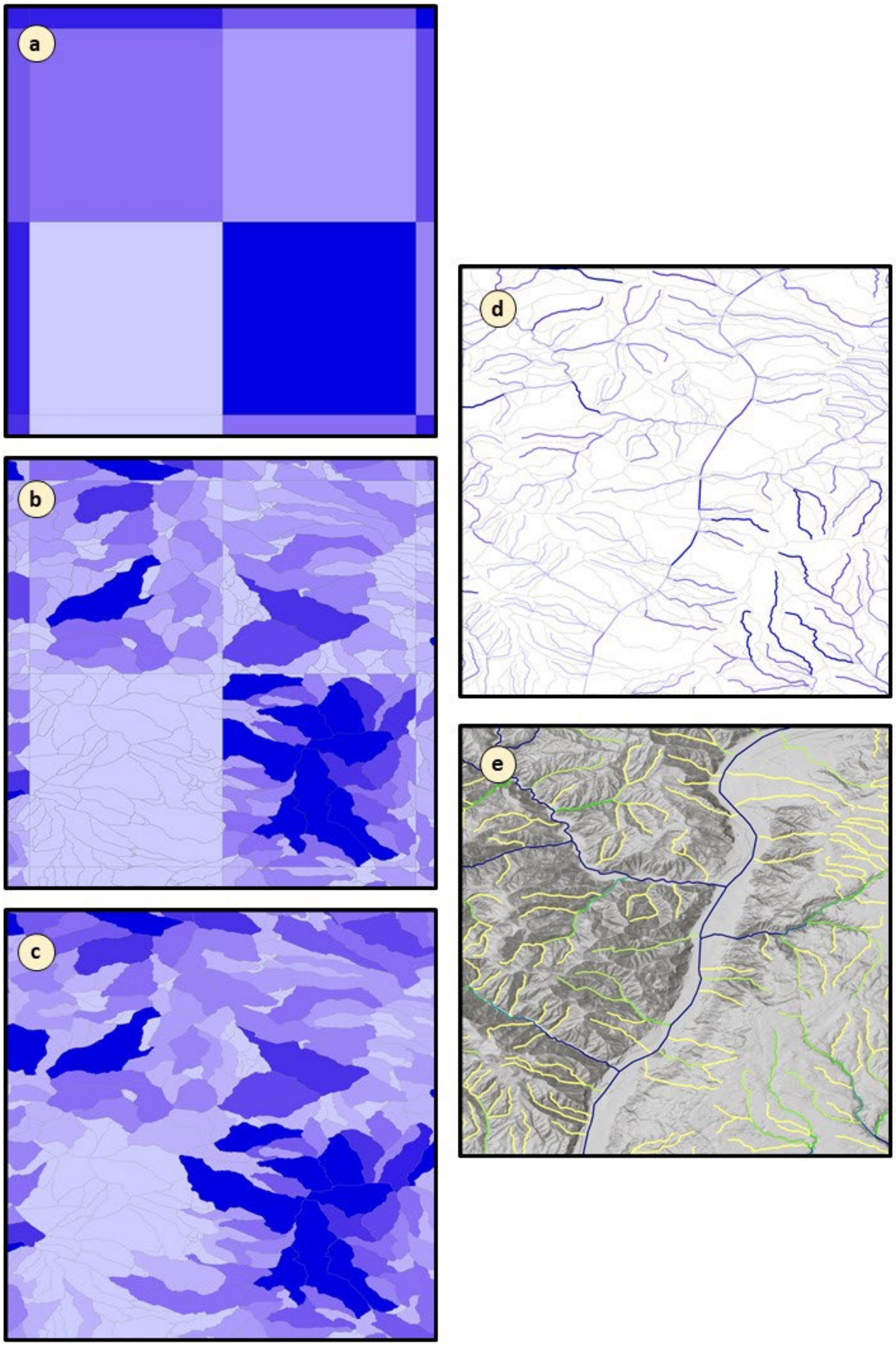

Figure 2. Conceptual visualization of the workflow for converting from daily gridded runoff data to daily streamflow: a) total runoff per grid cell for a particular day, with darker colors representing more runoff, b) runoff allocated to catchments based on the proportional catchment area in the grid cell, c) runoff totaled for catchments crossing grid cells, d) these values are assigned to the stream segment associated with each catchment, with a time lag applied in how long it takes the runoff to reach the streams, e) for each stream, the daily flow is totaled for that segment and all the upstream segments.

File Naming and Organization

Flow metrics are organized as a set of file geodatabase feature classes or shapefiles, representing the historical, mid-century, and end-of-century time periods, and the absolute and percent changes between the historical and future time periods.

The feature class contains the following NHD attributes, described in more detail in the NHDPlus Version 2 User Guide (McKay et al., 2012).

Field	Definition
COMID	Common identifier of the NHD feature
GNIS_Name	Feature name from the Geographic Names Information System
LengthKM	Feature length in kilometers
FType	NHD feature type (334: Connector, 336: Canal/Ditch, 428: Pipeline, 460: Stream/River, 558: Artificial Path, e.g., a straight line through the center of a lake)
PU_Code	The NHD region (2-digit hydrologic unit codes) or a subdivision of regions based on NHDPlus ‘production units,’ designated by letters appended to the region code, such as ‘10U’ (the upper Missouri River basin); see Figure 1
TotDASqKM	The total upstream cumulative drainage area in square kilometers; when using this dataset for analysis of high-flow events, we recommend excluding streams with a cumulative upstream drainage area greater than 10,000 sq km, since the time lag estimation will be less accurate over large areas
Tidal	Indicates whether the stream is tidally influenced
WBAreaType	Indicates for artificial paths whether the line represents one of the following: ‘Area of Complex Channels,’ ‘Canal/Ditch,’ ‘Lake/Pond,’ ‘Reservoir,’ ‘Stream/River,’ or ‘Wash’

The remaining fields are the flow metrics. Column names are composed of the metric abbreviation (such as “MA” for mean annual), an underscore, and the time period suffix (e.g., MA_Hist, the historical mean annual flow):

- Hist: historical
- 2040: mid-century time period, centered around the 2040s
- 2080: end-of-century time period, centered around the 2080s
- a2040: absolute change between the historical and mid-century time period
- a2080: absolute change between the historical and end-of-century time period
- p2040: percent change between the historical and mid-century time period
- p2080: percent change between the historical and end-of-century time period

The flow metric attributes are described below:

Metric Abbreviation	Description	Units
MA	Mean annual flow: calculated as the mean of the yearly discharge values	Cubic feet per second
MJan	Mean flow for January	Cubic feet per second
MFeb	Mean flow for February	Cubic feet per second
MMar	Mean flow for March	Cubic feet per second
MApr	Mean flow for April	Cubic feet per second
MMay	Mean flow for May	Cubic feet per second
MJun	Mean flow for June	Cubic feet per second
MJul	Mean flow for July	Cubic feet per second
MAug	Mean flow for August	Cubic feet per second
MSep	Mean flow for September	Cubic feet per second
MOct	Mean flow for October	Cubic feet per second
MNov	Mean flow for November	Cubic feet per second
MDec	Mean flow for December	Cubic feet per second
MMAM	Mean spring flow: calculated as the mean of the March/April/May discharge values, weighted by the number of days per month	Cubic feet per second
MJJA	Mean summer flow: calculated as the mean of the June/July/August discharge values, weighted by the number of days per month	Cubic feet per second
MSON	Mean autumn flow: calculated as the mean of the September/October/November discharge values, weighted by the number of days per month	Cubic feet per second
MDJF	Mean winter flow: calculated as the mean of the December/January/February discharge values, weighted by the number of days per month	Cubic feet per second
HiQ1_5	1.5-year flood: calculated by first finding the greatest daily flow from each year; the 33rd percentile of the annual maximum series defines the flow that occurs every 1.5 years, on average	Cubic feet per second
HiQ10	10-year flood: the flow that occurs every 10 years, on average, calculated as the 90th percentile of the annual maximum series	Cubic feet per second

Metric Abbreviation	Description	Units
H1Q25	25-year flood: the flow that occurs every 25 years, on average, calculated as the 96th percentile of the annual maximum series	Cubic feet per second
Lo7Q1	1-year minimum weekly flow: the average across years of the lowest 7-day flow during each year. 'Year' is defined either as January–December or June–May, whichever has a lower standard deviation in the date of the low-flow week. This was done so that, for example, in areas with winter droughts, a December to January drought would not be split up by the start of a new year.	Cubic feet per second
Lo7Q10	10-year minimum weekly flow: average lowest 7-day flow during a decade (calculated as the 10th percentile of the annual minimum weekly flows)	Cubic feet per second
Lo7Q1Dt	Date of minimum weekly flow: average date of the center of the lowest 7-day flow of the year, with 'year' defined either as January–December or June–May, whichever has a lower standard deviation in the date of the low-flow week. This was done to prevent erroneous results when the drought season crosses the break between years: e.g., if the lowest flow was on December 31 of the first year (day #365) and January 1 of the second year (day #1), this would give an average of day #183, July 2nd; switching the range of months in this case prevents this error.	Day number of calendar year
BFI	Baseflow index: the ratio of the average daily flow during the lowest 7-day flow of the year to the average daily flow during the year overall. This can be used as a rough estimate of the proportion of streamflow originating from groundwater discharge, rather than from recent precipitation.	Ratio
CFM	Center of flow mass/center of timing: calculated using a weighted mean: $CFM = \frac{(flow_1 * 1) + (flow_2 * 2) + [\ldots] + (flow_{365} * 365)}{flow_1 + flow_2 + [\ldots] + flow_{365}}$ where *flow*$_i$ is the flow volume on day *i* of the water year. This can be used to indicate areas where most of the precipitation occurs early in the water year (fall), or later (spring/summer).	Day number of water year (October to September)
W95	Number of winter floods: calculated as the average number of daily flows between December 1 and March 31 that exceed the 95th percentile of daily flows across the entire year	Count

Using the Files

More information about the stream data source, NHDPlusV2, can be found in the NHDPlusV2 User Guide (McKay et al., 2012).

An edited version of the NHDPlusV2 flowlines, called the National Stream Internet (NSI), is also available. These data have been edited to remove braids, diversions, and converging flow, and all stream reaches that do not participate in the NHDPlus Value Added Attribute schema. This dataset is fully dendritic and may be more applicable to basic hydrography applications since much of the superfluous data is removed. The flow metric data can be linked to the NSI flowlines through the COMID field. Please see the NSI User Guide for detailed information about how to use the NSI dataset.

We recommend that line segments with an upstream area greater than 10,000 km^2 be removed from the dataset (using the field 'TotDASqKM') for consideration of high flow metrics since the downstream routing was simply an accumulation function. This is reasonable for metrics with integration time scales of a month or greater but would be inaccurate for estimating floods at daily time scales on larger watersheds. Note also that the 10+ year flood models are not generally appropriate for direct use in engineering and design applications.

Differences from Past Datasets

This differs from previous versions of the flow metrics dataset in that:

a) It covers the entire contiguous United States, rather than just the western states.
b) It uses updated input data with newer climate scenarios and models (CMIP5/RCP 8.5 instead of CMIP3/A1B).
c) There are a variety of new flow metrics included in this version.
d) In the previous version, the gridded runoff data from 10 different GCMs were averaged together, and then this average was used as the input for the flow metrics calculation. In this version, we calculated flow metrics for each GCM, and then averaged these outputs across the GCMs. The reason for this change is that in previous versions of the models, future projections involved perturbing the historical input weather time series. All models used the same historical time series, with flood events on the same days, just differences in their magnitudes, so all could be averaged together. In the new models, the input data were modeled stochastically, with resampled months scaled to projected monthly precipitation and temperatures, in order to represent appropriate spatial and temporal correlations for the projected climate. This yielded flood events falling on different days in different models, so averaging the gridded output from the different models had the effect of smoothing out extremes in the hydrographs, muting the magnitude of flood events (see Reclamation (2014) appendix A.3.1 for details). Calculating the flow metrics for each model separately and then averaging the results at the end resolves this issue.
e) Data are made available as geospatial data, not .dbf files.

Additional Information

Requests for additional data and any questions or comments can be directed to:

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Recommended Citation

Please include this in your in-line citations:

Figures x.x through x.y show expected changes in streamflow (USDA Forest Service OSC, 2022; Authors, in review; Wenger et al., 2010, Reclamation, 2014).

Please include these in your references section:

USDA Forest Service Office of Sustainability and Climate. (2022). Streamflow in a Changing Climate: Flow Metric Map Exporter. Retrieved from https://storymaps.arcgis.com/stories/6a6be7d624db41638a24b659305af522 (last accessed [date]).

Authors. (in review). *U.S. Stream Flow Metric Dataset: Modeled Flow Metrics for Stream Segments in the United States Under Historical Conditions and Projected Climate Change Scenarios: Data Guide*.

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Reclamation, 2014, Downscaled CMIP3 and CMIP5 Hydrology Projections – Release of Hydrology Projections, Comparison with Preceding Information and Summary of User Needs. U.S. Department of the Interior, Bureau of Reclamation, 110 p., available at: https://gdo-dcp.ucllnl.org/downscaled_cmip_projections/techmemo/BCSD5HydrologyMemo.pdf.

Please include this in your acknowledgments section:

We acknowledge the World Climate Research Programme's Working Group on Coupled Modelling, which is responsible for CMIP, and we thank the climate modeling groups (listed in the Data Guide above) for producing and making available their model output. For CMIP, the U.S. Department of Energy's Program for Climate Model Diagnosis and Intercomparison provides coordinating support and led development of software infrastructure in partnership with the Global Organization for Earth System Science Portals.

VIC modeled runoff data downloaded from "Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections" archive at http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/ (last accessed May 7, 2021).

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