science for a changing world

Prepared in cooperation with the U.S. Department of the Interior South Central Climate Science Center and the U.S. Environmental Protection Agency

The U.S. Geological Survey Monthly Water Balance Model Futures Portal

Introduction

Simulations of future climate suggest profiles of temperature and precipitation may differ significantly from those in the past. These changes in climate will likely lead to changes in the hydrologic cycle, such as the timing of peak snowmelt. As such, natural resource managers are in need of tools that can provide estimates of key components of the hydrologic cycle, uncertainty associated with the estimates, and limitations associated with the climate forcing data used to estimate these components. To help address this need, the U.S. Geological Survey (USGS) Monthly Water Balance Model Futures Portal (https://my.usgs.gov/mows/) was developed. The portal is a user-friendly interface that summarizes monthly historical and simulated future conditions for seven hydrologic and meteorologic variables—actual evapotranspiration (AET), atmospheric temperature (TAVE), potential evapotranspiration (PET), precipitation (PPT), runoff (RO), snow water equivalent (SWE), and streamflow (STRM)—at locations across the conterminous United States (CONUS). The estimates of these variables were derived using a Monthly Water Balance Model (MWBM; McCabe and Markstrom, 2007) (fig. 1) with 222 climate datasets (table 1) for historical conditions (1952 through 2005) and simulated future conditions (2020 through 2099). The MWBM is a modular system that simulates monthly estimates of components of the hydrologic cycle using monthly precipitation and temperature inputs.

There are three primary components of the Monthly Water Balance Model Futures Portal:

- Hydrologic and meteorologic variables indexed to features in the dataset "GIS Features of the Geospatial Fabric for National Hydrologic Modeling" (Viger and Bock, 2014) (fig. 2)—The Geospatial Fabric is a set of hydrographic features derived at a scale appropriate for regional and national hydrologic modeling and analysis. There are three main components of the Geospatial Fabric: (1) hydrologic response units (HRUs) that define areas of similar features, such as slope or soils type or topography, which influence hydrology and route runoff to the stream network; (2) stream segments that route flow through the stream network; and (3) summary nodes or points of interest that represent the outlet of a stream segment where upstream conditions can be summarized. Streamgages are included as a special type of summary node.

- A Web Feature Service for querying and identifying Geospatial Fabric features across the CONUS.

- The capability to dynamically generate graphs and summary reports of the seven MWBM variables for a specific Geospatial Fabric HRU or summary node across the CONUS from a number of user-specified inputs.

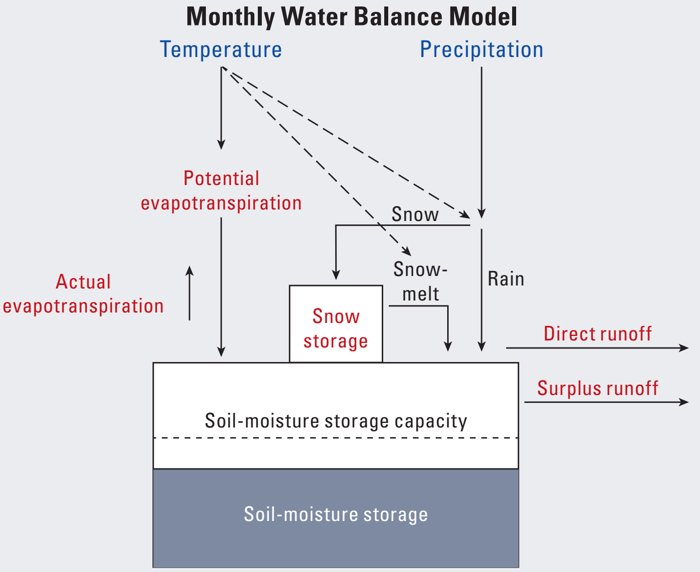

Figure 1. The Monthly Water Balance Model (MWBM). The Monthly Water Balance Model Futures Portal provides data for model input (blue) and output (red) variables. Figure modified from McCabe and Markstrom (2007).

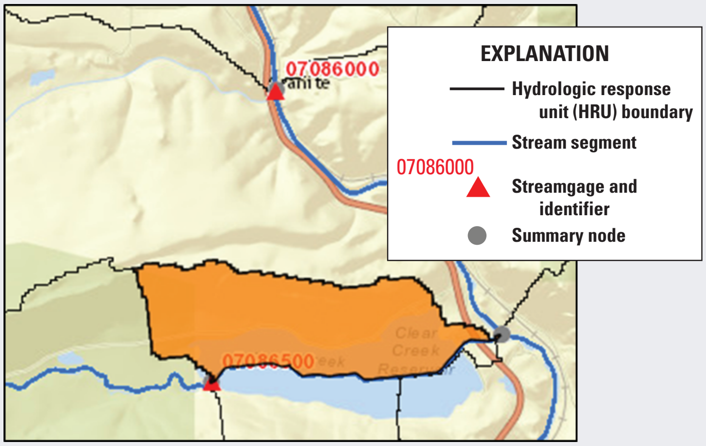

Figure 2. The Geospatial Fabric features used in the Monthly Water Balance Model Futures Portal. A user-selected hydrologic response unit is highlighted in orange.

The Monthly Water Balance Model Futures Database and Portal

The MWBM was calibrated across the CONUS (Bock and others, 2016b), and used to simulate the climate datasets. There are a total of 222 climate datasets available for users to summarize on the portal (table 1). These include 1 station-based dataset available for historical conditions (1952 through 2005; Maurer and others, 2002), and 221 climate datasets derived from the Coupled Model Intercomparison Projects 3 and 5 (CMIP3, CMIP5) for historical conditions (1952 to 2005) and simulated future conditions (2020 to 2099) (Bureau of Reclamation, 2011, 2013).

The climate outputs within each CMIP group are composed of a number of different scenarios, which represent different assumptions about future greenhouse gas emissions and climatic and human-caused conditions. Climate datasets representing emission scenarios (SRES) B1, A1B, and A2 for CMIP3 and representative concentration pathways (RCP) 4.5, 6, and 8.5 for CMIP5 are available on the portal. See Bureau of Reclamation (2011, 2013) for details on the emissions scenarios. Climate data from CMIP3 and CMIP5 were not included for the years 2006 through 2019 to emphasize the use of the datasets for long-term evaluation.

The climate outputs from the CMIP3 and CMIP5 were statistically downscaled to finer resolutions (1/8° or approximately 12 square kilometers [km^2]) from coarser-scale general circulation models (GCMs) by the Bureau of Reclamation using the bias-corrected spatial disaggregation method (Bureau of Reclamation, 2011, 2013). A GCM is a type of climate model that is a representation of the Earth's atmosphere and is used for understanding long-term climate dynamics at continental or global scales. Statistical downscaling of GCMs from their base resolution (approximately 150 km^2) allows for their use in finer-scale applications (Wood and others, 2004). Monthly historical and simulated future conditions for the seven hydrologic and meteorologic variables from the MWBM were organized into the Monthly Water Balance Model Futures database (Bock and others, 2016a), which was configured to allow open and machine-independent access.

The Monthly Water Balance Model Futures Portal connects the Geospatial Fabric features in the Web Feature Service to the Monthly Water Balance Model Futures database. The portal uses a number of custom arguments (fig. 3) to generate one of five different graphical summaries (figs. 4–7). The user can then customize and dynamically generate graphics and summary reports from the portal based on plot type, geographic location, specific climate datasets, period of record, MWBM variable, and options to subset the climate datasets. The portal retrieves the selected output from the MWBM database based on the user's queries, writes the output to a comma-separated variable (csv) file, and transforms the output into the necessary time-step summation to apply to the selected plot. Both the plot (in portable network graphics [png] format) and the csv file are made available to the user for download.

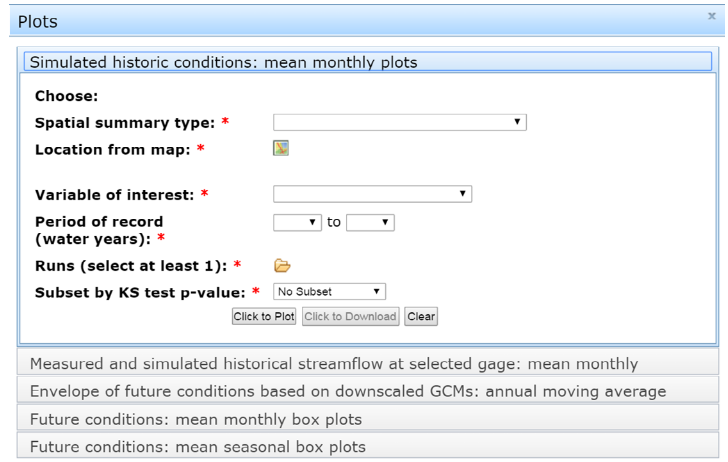

Figure 3. Screenshot of the interactive window on the Monthly Water Balance Model Futures Portal for entering queries, downloading data, and generating plots. The map service, map image, and basemaps of all images shown in this document are the intellectual property of ESRI and are used herein under license (Copyright © 2014 ESRI and its licensors. All rights reserved).

Three types of summary plots based on Talbert and others (2014) can be generated by the portal and vary based on the choices made by the user:

- Mean monthly plots of historical conditions, which depict the mean monthly values of the selected variable for each selected climate dataset (fig. 4). A second version of this plotting option lays out measured and simulated streamflow at a number of USGS streamgages (U. S. Geological Survey, 2014) (fig. 5). Data are ordered by water year (beginning October 1 and continuing through September 30 of the following year).

- Envelope plots that depict the annual variability of change for simulated future conditions from a historical baseline period for a specified MWBM variable (fig. 6).

- Two types of box plots: mean monthly or mean seasonal box plots of simulated future conditions of a MWBM variable (fig. 7). Data in the mean monthly plots and box plots are ordered by water year (October through September).

Mean Monthly—Historical Conditions

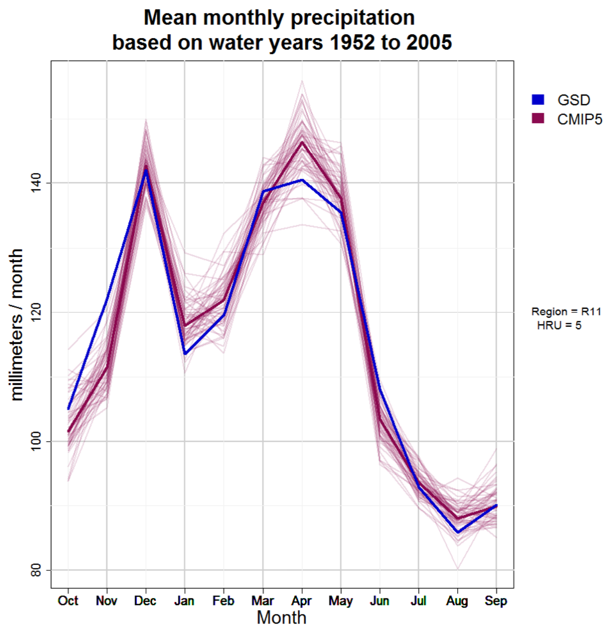

Figure 4. An example of a mean monthly plot of precipitation for historical conditions generated for a user-selected hydrologic response unit (HRU) by the Monthly Water Balance Model Futures Portal, based on data from the gridded station data (GSD) (Maurer and others, 2002) and the Coupled Model Intercomparison Project 5 (CMIP5) (Bureau of Reclamation, 2013).

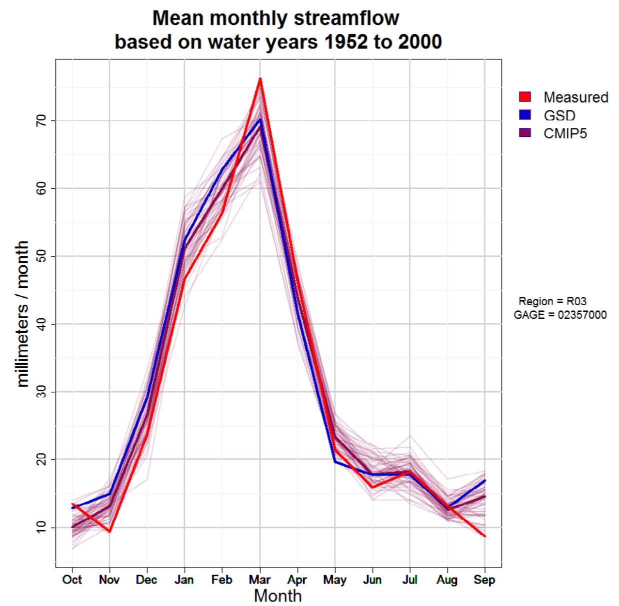

Figure 5. An example of a mean monthly plot of streamflow for historical conditions generated for a user-selected U.S. Geological Survey streamgage (GAGE) by the Monthly Water Balance Model Futures Portal, based on measured streamflow (United States Geological Survey, 2014), the gridded station data (GSD) (Maurer and others, 2002), and the Coupled Model Intercomparison Project 5 (CMIP5) (Bureau of Reclamation, 2013). This plot can be generated for a select number of U.S. Geological Survey streamgages. See Bock and others (2016a, b) for more information.

Annual Variability—Future Conditions

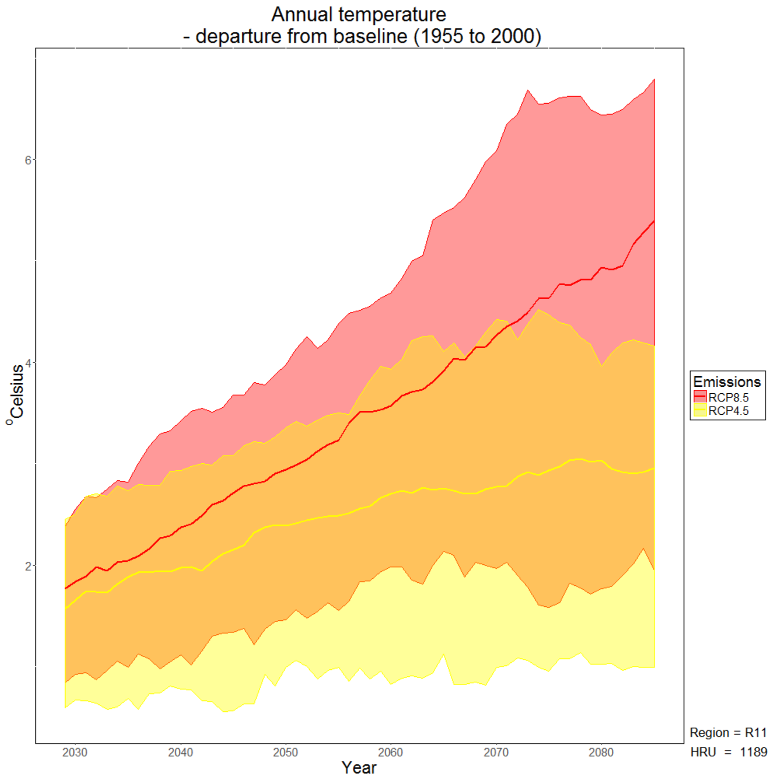

Figure 6. An example of an envelope plot of temperature generated for a user-selected hydrologic response unit (HRU) by the Monthly Water Balance Model Futures Portal that depicts the annual variability of change from historical conditions (1955–2005) to simulated future possible conditions (2020–2099) plotted by Coupled Model Intercomparison Project 5 emission scenarios (representative concentration pathways [RCP] 4.5 and 8.5) (Bureau of Reclamation, 2013).

Mean Monthly and Seasonal Box Plots—Future Conditions

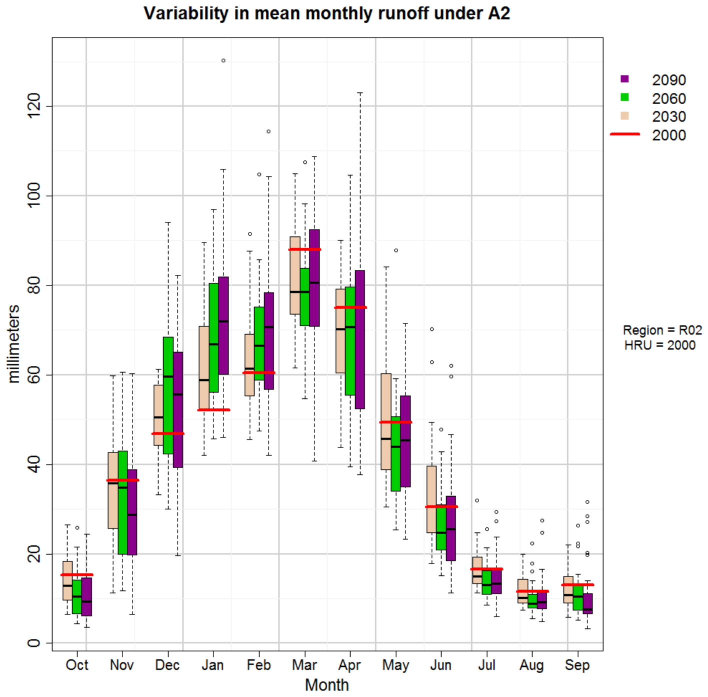

Figure 7. An example of a mean monthly box plot of runoff for simulated future conditions generated for a user-selected hydrologic response unit (HRU) by the Monthly Water Balance Model Futures Portal that depicts the variability in the future of monthly runoff for a single Coupled Model Intercomparison Project 3 emission scenario (A2) (Bureau of Reclamation, 2011) for three periods in the future (2090, 2060, and 2030).

Subsetting Your Selected Climate Data

Previous hydrologic modeling applications using downscaled GCM climate data have suggested that their ability to replicate historical conditions should be the minimum criteria for their use in assessing simulated future conditions (Wood and others, 2004). The portal offers the two-sample Kolmogorov-Smirnov test (KS test) (Conover, 1971) to constrain climate dataset selections to those that best replicate historical conditions at the location chosen for the seven MWBM variables of interest. The KS test is a nonparametric test that determines whether two samples of data are from the same population. The null hypothesis (H_0: Both datasets are from the same population) is rejected if the KS test p-value for a specific pair of samples is below a specified p-value level. Within the portal, the KS test is used to determine if the distribution of a MWBM variable from a climate dataset for historical conditions is similar to that of the same variable from the "observed" climate dataset (GSD in table 1).

Table 1. Climate datasets available on the Monthly Water Balance Model Futures Portal.

Dataset	Period of record	Number of datasets
Gridded station data (GSD)[1]	1952–2005	1
Bias-corrected spatially disaggregated (BCSD) climate data for Coupled Model Intercomparison Project 3 (CMIP3)[2]	1952–2005 2020–2099	94
Bias-corrected spatially disaggregated (BCSD) climate data for Coupled Model Intercomparison Project 5 (CMIP5)[3]	1952–2005 2020–2099	127

[1]Maurer and others, 2002.

[2]Bureau of Reclamation, 2011.

[3]Bureau of Reclamation, 2013.

Three different p-value levels are available to select for the portal KS test: 0.01, 0.05, and 0.10. A p-value of 0.01 is the least stringent level, while the p-value of 0.10 is the most stringent level, in that there is a greater probability that the null hypothesis will be rejected at a higher p-value and that fewer datasets will be included in the plot. If the KS test p-value for a selected GCM simulation is below a specified p-value, it is excluded from the specified plot and attributed as an excluded dataset in the header of the csv files (dataset name in the csv columns preceded with a “0-” instead of a “1-”). A user can also choose not to enable the KS-test filter by selecting the option “No Subset.” A mean monthly plot for historical conditions with no KS test applied is shown in figure 8, and the application of the KS test p-value of 0.01 to a mean monthly plot for historical conditions is shown in figure 9.

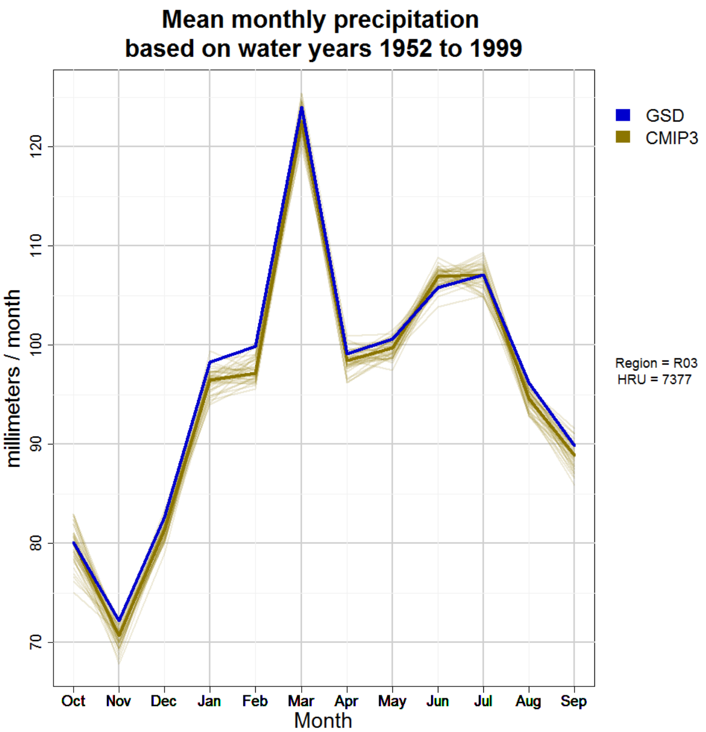

Figure 8. An example of a mean monthly plot of precipitation for historical conditions showing no Kolmogorov-Smirnov (KS) test subset. Generated for a user-selected hydrologic response unit (HRU) by the Monthly Water Balance Model Futures Portal, based on data from the gridded station data (GSD) (Maurer and others, 2002) and the Coupled Model Intercomparison Project 3 (CMIP3) (Bureau of Reclamation, 2011).

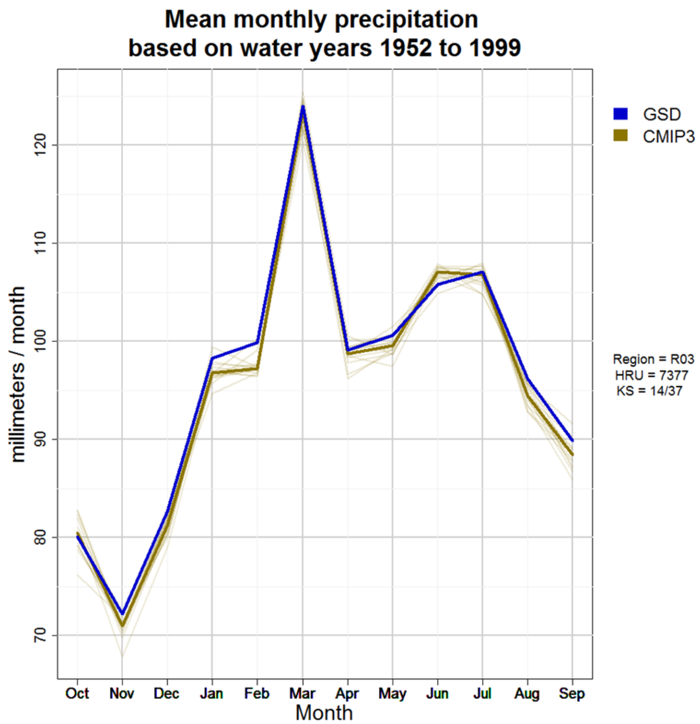

Figure 9. An example of a mean monthly plot of precipitation for historical conditions showing a subset using the Kolmogorov-Smirnov (KS) test for climate datasets with a p-value > 0.01. Generated for a user-selected hydrologic response unit (HRU) by the Monthly Water Balance Model Futures Portal, based on data from the gridded station data (GSD) (Maurer and others, 2002) and the Coupled Model Intercomparison Project 3 (CMIP3) (Bureau of Reclamation, 2011).

Acknowledgments

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References

Bock, A.R., Hay, L.E., Markstrom, S.L., and Atkinson, R.D., 2016a, Monthly Water Balance Model Futures: U.S. Geological Survey data release, accessed June 15, 2016, at http://dx.doi.org/10.5066/F7VD6WJQ.

Bock, A.R., Hay, L.E., McCabe, G.J., Markstrom, S.L., and Atkinson, R.D., 2016b, Parameter regionalization of a monthly water balance model for the conterminous United States: Hydrology and Earth System Sciences, v. 20, p. 2861–2876.

Bureau of Reclamation, 2011, West-wide climate risk assessments—Bias-corrected and spatially downscaled surface water projections: Bureau of Reclamation Technical Memorandum No. 86-68210-2011-01, 138 p.

Bureau of Reclamation, 2013, Downscaled CMIP3 and CMIP5 climate and hydrology projections—Release of hydrology projections, comparison with preceding Information, and summary of user needs: Bureau of Reclamation, 110 p.

Conover, W.J., 1971, Practical nonparameteric statistics: New York, John Wiley and Sons, 462 p.

Maurer, E.P., Wood, A.W., Adam, J.C., Lettenmaier, D.P., and Nijssen, B., 2002, A long-term hydrologically based dataset of land surface fluxes and states for the conterminous United States: Journal of Climatology, v. 15, p. 3237–3251.

McCabe, G.J., and Markstrom, S.L., 2007, A monthly water-balance model driven by a graphical user interface: U.S. Geological Survey Open-File Report 2007–1088, 6 p.

Talbert, Marian; Gross, John; and Morisette, Jeff, 2014, Graphics catalog for climate primers: U.S. Department of the Interior, North Central Climate Science Center, 19 p., accessed June 3, 2016, at http://revampclimate.colostate.edu/sites/default/files/GraphicsCatalog.pdf.

U. S. Geological Survey, 2014, National Water information System: U.S. Geological Survey database, accessed March 27, 2014 at: http://waterdata.usgs.gov/nwis/.

Viger, R.J., and Bock, Andrew, 2014, GIS features of the Geospatial Fabric for National Hydrologic Modeling: U.S. Geological Survey data release, accessed March 3, 2014, at http://dx.doi.org/10.5066/F7542KMD.

Wood, A.W., Leung, L.R., Sridhar, V., and Lettenmaier, D.P., 2004, Hydrologic implications of dynamical and statistical approaches to downscaling climate model outputs: Climate Change, v. 62, p. 189–216.

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