

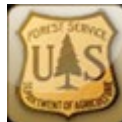
WaSSI Ecosystem Services Model

Version 2.1

User Guide

v1.2

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Introduction

Forests are increasingly being valued for their ability to sequester carbon from the atmosphere, stabilize river flows and climate, provide sources of bioenergy, and buffer the harmful impacts of climate change on society through their ecosystem services. However, these ecosystem functions are threatened by global change. For example, increasing water use in the United States has led to widespread hydrologic manipulation and consumptive off-stream water use, practices that alter river flows (Vörösmarty et al. 2004), threaten the sustainability of the resource (Alcamo et al. 2003), and degrade ecosystem functions (Carlisle et al. 2010). Future changes in climate will place additional pressure on freshwater supplies (Bates et al. 2008). The effect of these stressors will be highly variable over both time and space, making it difficult to assess effects on water resources into the future.

Like water supply, ecosystem productivity (i.e., carbon sequestration dynamics) is a valuable ecosystem service that is vulnerable to the effects of climate change and human activities (Nemani et al. 2003, Beer et al. 2010). Ecosystem water use, or evapotranspiration (ET), is tightly coupled with carbon and nutrient cycles (Law et al. 2002, Sun et al. 2011). As a result, ecosystem productivity is highly controlled by ET and the factors that affect the water cycle (e.g., climate change, land use change). Managing an ecosystem to enhance carbon sequestration will likely have a negative impact on available water supply for human use through the complex interactions of water and carbon cycles at multiple scales.

Management tools are needed that can assess the responses of these ecosystem services to global change at multiple spatial and temporal scales. In the late 1990s, USDA Forest Service Southern Research Station scientists participating in several national-scale assessments of climate change science and climate-related impacts discovered a lack of landscape-scale, integrated ecosystem models from which to draw projections of future hydrologic conditions. Individually, hydrologic models, GCM predictions of climate change, and demographic models of population change had been developed. However, these individual models are designed to work at different spatial scales and were not meant to interact in a manner necessary for assessing cumulative impacts. As a result, the Forest Service scientists developed the Water Supply Stress Index (WaSSI) model to examine how long-term climatic changes interacting with human factors could influence water availability. WaSSI is an integrated model that can be used to project the regional effects of forest land cover change, climate change, and water withdrawals on river flows, water supply stress, and ecosystem productivity (i.e., carbon sequestration). In addition, WaSSI can be used to evaluate trade-offs among management strategies that influence multiple ecosystem services.

Early versions of the model evaluated water supply stress at the annual time step across 13 southern states (Sun et al. 2008). The model was further developed by integrating global eddy flux measurements, soil water balances, watershed flow routing, and county-level water demand databases. In its current form, the model operates at the monthly time step, simulating terrestrial carbon dynamics in addition to water supply stress across the conterminous US (Sun et al., 2011; Caldwell et al. 2011; 2012) and in Mexico. Version 1.0 of a web application for WaSSI, **WaSSIweb**, was released in May 2011, enabling users to define and evaluate the impacts of custom climate and land use scenarios. Version 2.0

of **WaSSIweb** was released in July 2012, updating several of the water balance and flow routing algorithms, increasing the number of future climate scenarios for impact assessment, and adding the **WaSSI Map Viewer** to enable spatial model output viewing. Version 2.1 of **WaSSIweb** was released in September 2013; this version added the Rwanda region for model simulations and an option to download the user guide in Spanish. The Rwanda region spatially covers the countries of Rwanda and Burundi. Users of **WaSSIweb** may include land and water resource managers for making informed management decisions in light of changing environmental conditions; and educators, researchers, NGOs, and the general public for gaining insight on the effects of global change on water and carbon at both local and continental scales. Version 2.1 of WaSSIweb was updated in 2018; those updates included adding 20 general circulation models from the Intergovernmental Panel on Climate Change (IPCC) 5th assessment report, updating the land cover dataset to 2011 and the wateruse dataset to 2010.

This user guide is intended to provide background information regarding the calculations performed by WaSSI, input and output files, instruction on how to navigate and operate the web application, and how to interpret WaSSI results.

Model Overview

WaSSI simulates monthly water and carbon dynamics in the US, Mexico, Rwanda, and Burundi (Figure 1). For the US, the model operates on a watershed basis for 2,099 Watershed Boundary Dataset (WBD; Watershed Boundary Dataset 2010) 8-digit Hydrologic Unit Code (HUC) watersheds. For Mexico, WaSSI operates on a grid cell basis for a total of 701 0.5° grid cells (UNAM; the Universidad Nacional Autónoma de México monthly gridded climate, 2007). For Rwanda and Burundi, WaSSI operates on a watershed basis for 231 watersheds delineated from a 30 x 30 m² ASTER DEM2 (add citation, similar to Mexico grid).

Three modules are integrated within the WaSSI model framework. The water balance module computes ecosystem water use, evapotranspiration (ET); and the water yield from each watershed or grid cell. Water yield is sometimes referred to as runoff and can be thought of as the amount of streamflow at the outlet of each watershed due to hydrologic processes in each watershed in isolation without any flow contribution from upstream watersheds. The ecosystem productivity module simulates carbon gains and losses in each watershed or grid cell as functions of evapotranspiration. The water supply and demand module (US only) routes and accumulates the water yield through the river network according to topological relationships between adjacent watersheds, subtracts consumptive water use by humans from river flows, and compares water supply to water demand to compute the water supply stress index, or WaSSI.

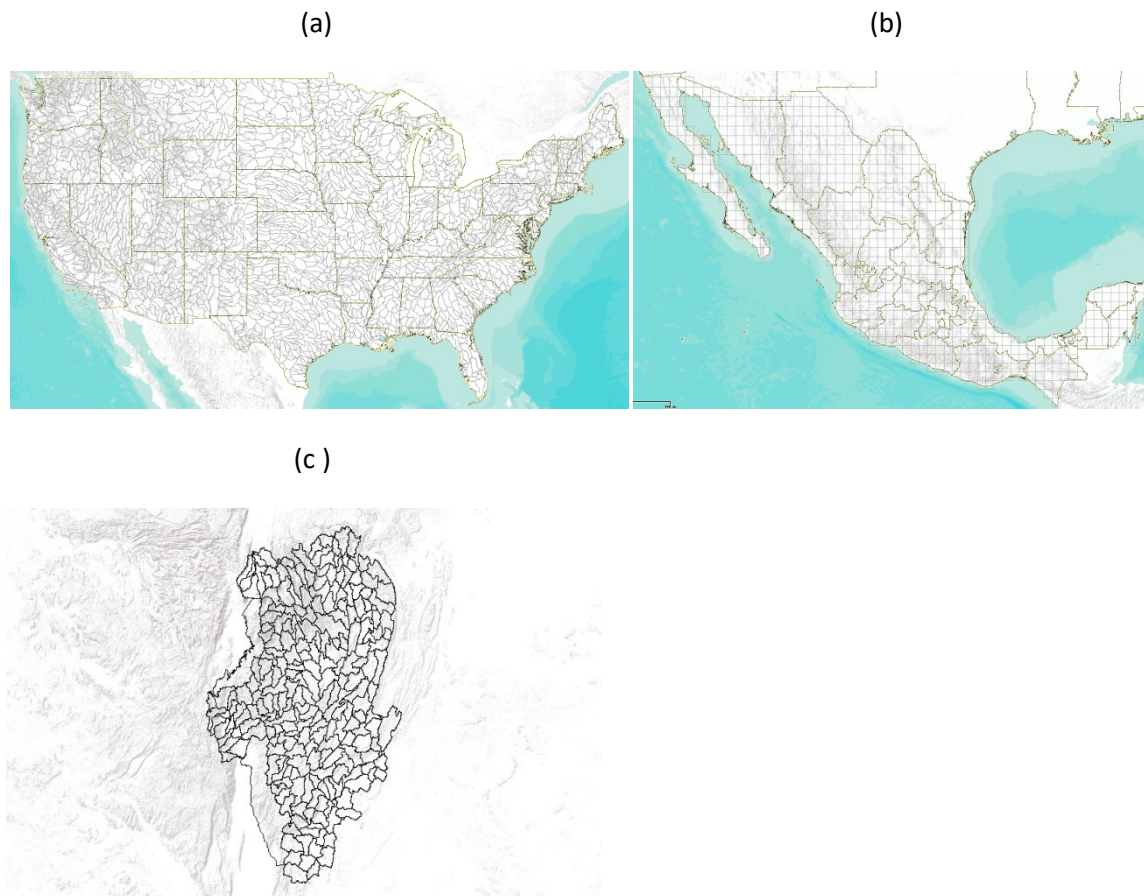


Figure 1. 8-digit HUC watersheds of the US (a), grid cells of Mexico (b), and watersheds of Rwanda and Burundi (c).

Users are encouraged to review Appendix A detailing the WaSSI modules and the peer-reviewed literature cited to gain a thorough understanding of all abilities and limitations. Appendix B provides detailed descriptions of all model inputs and outputs.

Accessing WaSSI

WaSSIweb is a user-friendly interface that allows the development of a simulation scenario of climate, land cover, and water use change so that the impact of those changes on river flows, water supply stress, and ecosystem productivity across the US and Mexico may be assessed. **WaSSIweb** may be accessed on the USDA Forest Service Eastern Forest Environmental Threat Assessment Center website at: <https://www.forestthreats.org/research/tools/WaSSI/>. From this site, select the link “Begin exploring WaSSI”. This link connects to the *About WaSSI* page, which provides a brief description of WaSSI, available resources, and contact information.



WaSSI Ecosystem Services Model

Version 2.1

[English](#) [Spanish](#)

[About](#) [Options](#) [Input Viewer](#) [Simulation Tool](#)

About WaSSI

The Water Supply Stress Index Model (WaSSI) is a web-based tool that can be used to project the effects of land use change, climate change, and water withdrawals on river flows, water supply stress, and ecosystem productivity (i.e. carbon sequestration dynamics) across the conterminous United States and Mexico. As water yield and carbon sequestration are tightly coupled, WaSSI is useful for evaluating trade-offs among management strategies for these ecosystem services.

How does WaSSI Work - The core of WaSSI is a water balance model that is sensitive to land cover and climate, and operates on a monthly time step at the 8-digit Hydrologic Unit Code (HUC) watershed scale across the conterminous U.S., at the 0.5 degree grid resolution in Mexico, and at the watershed scale in Rwanda and Burundi. Gross ecosystem productivity, ecosystem respiration, and net ecosystem carbon exchange are estimated using actual evapotranspiration. For the U.S., annual US Geological Survey (USGS) water demand estimates are adjusted for population, disaggregated to the monthly scale, and compared to groundwater and surface water supply to assess water supply stress. Consumptive water use is subtracted from stream flow throughout the river network.

Who should Use WaSSI - Resource managers for making informed management decisions in light of changing environmental conditions; educators, researchers, NGOs, and the general public for gaining insight on the effects of global change on water and carbon at both local and continental scales.

Who is behind WaSSI - USDA Forest Service scientists from the Eastern Forest Environmental Threat Assessment Center developed the model algorithms. This web application was developed with programming support from [Praecipio Consulting](#) and [Photo Science Inc.](#) through a partnership between the Eastern Forest Environmental Threat Assessment Center and the USDA Forest Service International Programs to facilitate transfer of the science to all users. The application of the WaSSI model in Rwanda was possible through collaboration with the Wildlife Conservation Society and the Rwanda Agricultural Board.

Getting Started with WaSSI - After reading the background information, select the Options tab to define a region for simulation (U.S. or Mexico). Once a region is selected, explore the model inputs by clicking on the Input Viewer tab. A simulation scenario can be created and executed from the Simulation Tool tab. Please be patient!!! The model is simulating the water balance, water supply and demand, ecosystem productivity, and biodiversity for the entire region (U.S. or Mexico) over as many as 100 years and may take several minutes to complete. After a simulation, explore model outputs for your watershed in the Output Viewer or view outputs spatially in the Map Viewer. Try making changes to the simulation scenario to assess the impact of climate, land use, and population change on water resources and ecosystem productivity. Click to download a PDF version of the WaSSI user guide v1.0 in [English](#) or [Spanish](#), which provides an overview and illustrates, step-by-step, how to access, navigate, and run the WaSSI model.

Appropriate Use - WaSSI water and carbon predictions are subject to similar uncertainties associated with all ecosystem models, including uncertainty in input data, uncertainty in the representation of the physical processes that govern the watershed water balance and ecosystem productivity, and uncertainty in how people use and manipulate water resources at the continental scale. WaSSI is designed to provide large-scale global change impact assessments using readily available data collected using consistent methodologies across broad regions (e.g. water use and return flow). As a result, model results at the local scale (e.g. HUC8 watershed) may vary from actual conditions and users are cautioned to consider this uncertainty in interpreting results for their watershed of interest. WaSSI users have the capability of evaluating an unlimited number of climate, land use, and water use scenarios, and are ultimately responsible for determining whether the scenarios they define are realistic or not. For evaluating impacts of future climate scenarios, users are encouraged to consider several general circulation model and emission scenario combinations to cover a range in possible impacts. Users may refer to peer-reviewed WaSSI documentation for further information regarding model assumptions and limitations.

Supported Web Browsers - The recommended web browsers to run WaSSI web in are Internet Explorer 8 or higher and FireFox.

The links provided under the *Resources* section connect to journal articles about WaSSI. Follow these links to learn more about the specifics of the model and its uses.

Resources:

[Caldwell, P. V., Sun, G., McNulty, S. G., Cohen, E. C., and Moore Myers, J. A., 2012, Impacts of impervious cover, water withdrawals, and climate change on river flows in the Conterminous US, Hydrol. Earth Syst. Sci. Discuss. 9:4263-4304, doi:10.5194/hessd-9-4263-2012.](#)

[Caldwell, P.V., Sun, G., McNulty, S.G., Cohen, E.C., and Moore Myers, J.A. 2011. Modeling Impacts of Environmental Change on Ecosystem Services across the Conterminous United States. in Medley, C.N., Patterson, Glenn, and Parker, M.J. \(eds\) Observing, studying, and managing for change: Proceedings of the Fourth Interagency Conference on Research in the Watersheds: U.S. Geological Survey Scientific Investigations Report 2011:5169, 202 p.](#)

[Sun, G., Caldwell, P., Noormets, A., Cohen, E., McNulty, S., Treasure, E., Domec, J. C., Mu, Q., Xiao, J., John, R., and Chen, J., 2011, Upscaling key ecosystem functions across the conterminous United States by a water-centric ecosystem model, Journal of Geophysical Research, 116, G00J05.](#)

[Sun G., K. Alstad, J. Chen, S. Chen, C. R. Ford, G. Lin, N. Lu, S. G. McNulty, A. Noormets, J. M. Vose, B. Wilske, M. Zeppel, Y. Zhang, and Z. Zhang. 2011. A general predictive model for estimating monthly ecosystem evapotranspiration. Ecohydrology 4 \(2\):245-255.](#)

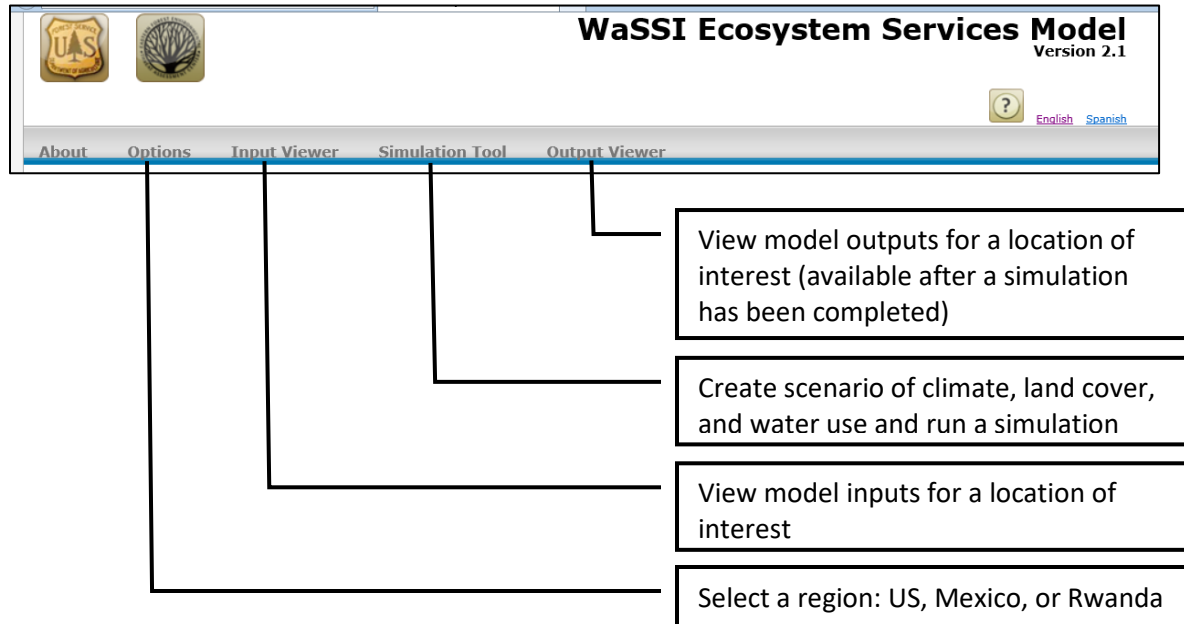
[Sun, G., S.G. McNulty, J.A. Moore Myers, and E.C. Cohen. 2008. Impacts of Multiple Stresses on Water Demand and Supply across the Southeastern United States. Journal of American Water Resources Association 44\(6\):1441-1457.](#)

Contact information for the WaSSI model developers as well as links to methods of accessibility, the watershed boundary dataset, our privacy policy, and notices of importance can be found in the *Contact Us* section.

Contact Us			
Model Development and Applications		Model Functionality and Use	Technical Issues
Steve McNulty	919-515-9489	Peter Caldwell	Erika Cohen
Ge Sun	919-515-9498		919-513-3189
Download Hydrologic Units (HUC) Dataset			
Accessibility	Privacy Policy	Important Notices	Give Us Feedback

General Navigation

The WaSSI web application consists of the **WaSSIweb** tool and the **WaSSI Map viewer**. **WaSSIweb** includes four main components: Options, Input Viewer, Simulation Tool, and Output Viewer. All of these components are accessible using the tool bar located near the top of the page.



The **WaSSI Map Viewer** performs two major functions. First, the viewer allows selection of a location of interest to view model inputs and outputs in **WaSSIweb** by panning, zooming, and selecting a location on a map. The **WaSSI Map Viewer** may be accessed for this purpose by selecting the *Find Watershed* icon on the *Input Viewer* and *Output Viewer* components of **WaSSIweb**:

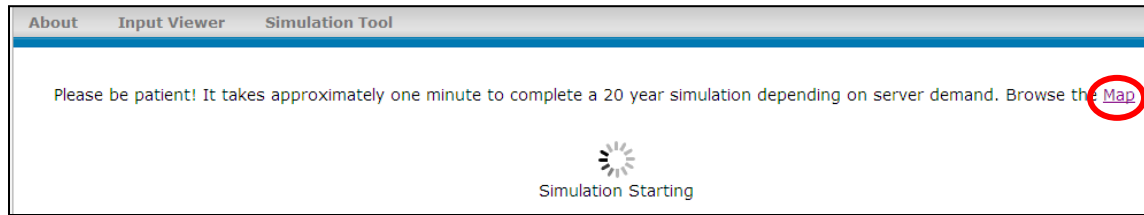


Second, the **WaSSI Map Viewer** displays model outputs for a user-defined simulation as colored maps that can be viewed with ancillary map layers and exported for use in reports. The **WaSSI Map Viewer** may be accessed for this purpose by selecting the icon on the *Output Viewer* components of **WaSSIweb**:



Selecting this icon from the *Input Viewer* accesses the **WaSSI Map Viewer** to allow exploration of viewer functionality and the selection of a watershed or grid cell of interest, but model outputs will not be displayed. Model Outputs can be viewed in the **WaSSI Map Viewer** by selecting this icon from the *Output Viewer* only after a simulation has been performed.

The **WaSSI Map Viewer** may also be accessed while a simulation is being generated. The following window appears when the *Run Simulation* button is clicked on the **WaSSIweb Simulation Tool**. To access the map, click on the *Map* link provided.



From the **WaSSI Map Viewer**, it is possible to navigate back to **WaSSIweb** while model output data are being loaded after a simulation by selecting the *Browse WaSSI* button in the status window.



To navigate back to **WaSSIweb** from **WaSSI Map Viewer** hit the back arrow button in your browser window.

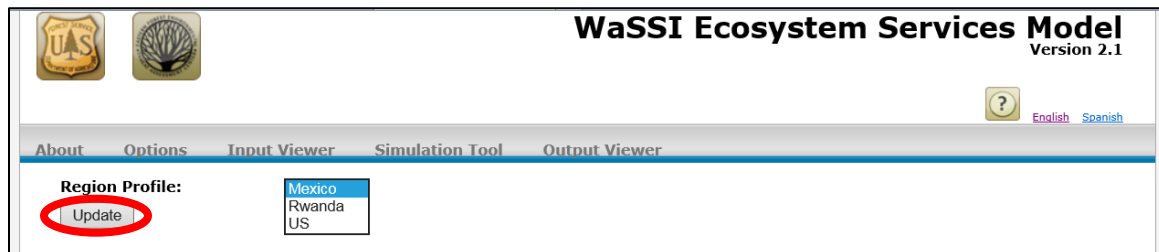
The general sequence of operation for a WaSSI simulation is to first select the region of interest on the *Options* page in **WaSSIweb**, view model inputs for a location within the region of interest in the *Input Viewer* (if desired), develop a simulation scenario using the *Simulation Tool*, and view model outputs for a location within the region of interest in the *Output Viewer* and/or view model outputs for the entire region using the **WaSSI Map Viewer**. These steps are described in detail in the following sections of the WaSSI User Guide.

Selecting a Region

The region of interest (US or Mexico) may be selected using the *Options* component of **WaSSIweb**.



Click on the drop down list to access the regions available for simulation, and click on the *Update* button to select the region of interest. The Rwanda region includes the countries of Rwanda and Burundi.



Once the *Update* button has been clicked, **WaSSIweb** will indicate that the options have been saved and it is ready to continue.

Selecting a Location of Interest

In the *Input Viewer* and *Output Viewer* components of **WaSSIweb**, a location of interest to view model inputs and outputs may be selected in one of three ways. In the first way, an 8-digit HUC watershed or grid cell may be selected from the drop down list.

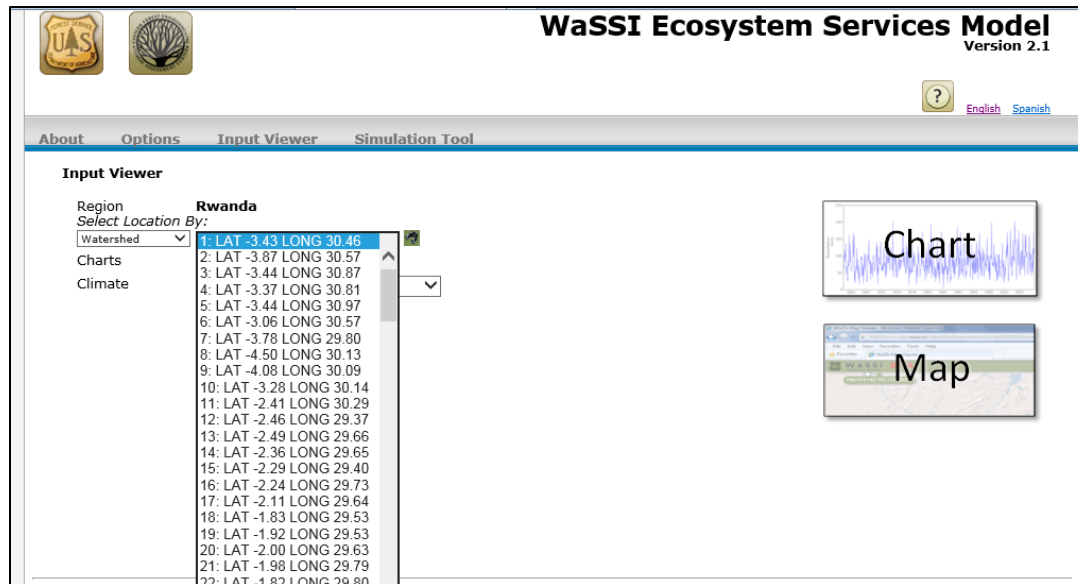
For the US, 8-digit HUC watershed numbers may be selected:

The screenshot shows the WaSSI Ecosystem Services Model Version 2.1 interface. The 'Input Viewer' tab is active. Under the 'Region' dropdown, 'US' is selected. Below it, 'Select Location By:' is set to 'HUC'. A list of 8-digit HUC watersheds is displayed, with '01010001: Upper St. John' selected. To the right, there are two preview windows: 'Chart' and 'Map'.

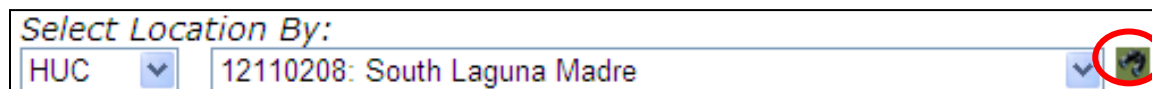
For Mexico, the *Mexico IRI Grid system* is used. The area of interest may be selected using grid cell IDs and/or latitude and longitude coordinates:

The screenshot shows the WaSSI Ecosystem Services Model Version 2.1 interface. The 'Input Viewer' tab is active. Under the 'Region' dropdown, 'Mexico' is selected. Below it, 'Cell' is selected. A list of grid cells is displayed, with '1: Lat 32.25 Long -116.75' selected. To the right, there are two preview windows: 'Chart' and 'Map'.

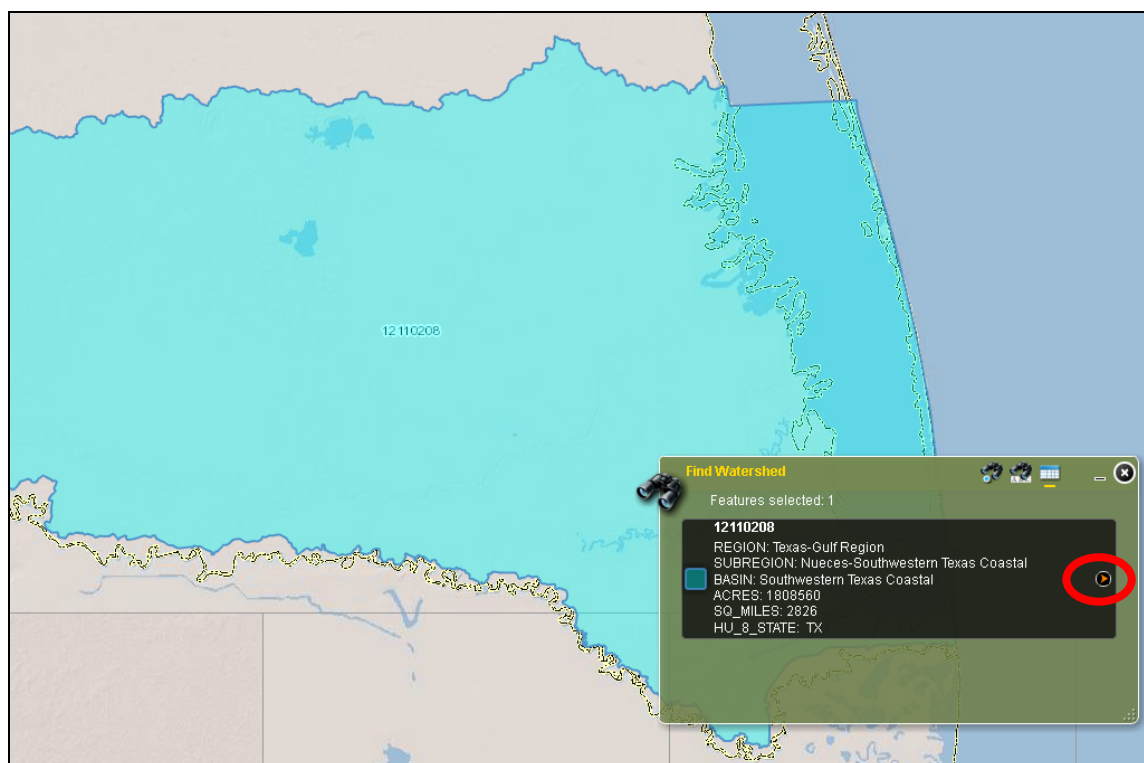
For Rwanda, the area of interest may be selected using watershed IDs and/or latitude and longitude coordinates:



Once a watershed or grid cell is selected, the location may be verified on a map. This may be accomplished by selecting the *Find Watershed* icon next to the drop down list:



When the *Find Watershed* icon is selected, the selected watershed or grid cell will be identified in the **WaSSI Map Viewer**:

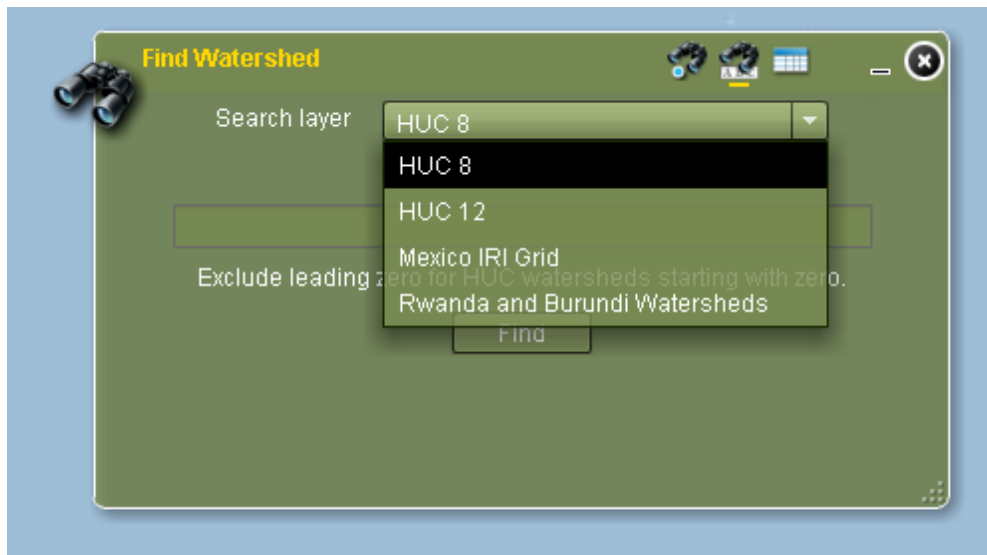


Selecting the red arrow icon in the *Find Watershed* tool will return to the **WaSSIweb Input Viewer** or *Output Viewer*.

The second way to select a location of interest in the **WaSSIweb Input Viewer** or *Output Viewer* is to select a location on a map. First select the map icon:



The *Find Watershed* tool will be open in the **WaSSI Map Viewer**, allowing selection of a watershed or grid cell. For the US, select “HUC 8” as the *Search Layer*. For Mexico, select the “Mexico IRI Grid” as the *Search Layer*.



Once the search layer is selected, the HUC watershed or grid number may be entered in the search field:



Alternatively, if the point selection method is highlighted, the user may pan and zoom to their location of interest, and click on the watershed or grid cell to select it:



Once a watershed or grid cell is found, select the red arrow icon in the *Find Watershed* tool to return to **WaSSIweb**.

The third way to select a location of interest in the **WaSSIweb** *Input Viewer* or *Output Viewer* (US only) is to select *Zipcode* in the *Select Location By* drop down list:

WaSSI Ecosystem Services Model
Version 2.1

English Spanish

About Options **Input Viewer** Simulation Tool

Input Viewer

Region **US**

Select Location By: 01010001: Upper St. John

Climate Historic (1961 - 2010)

Chart

Map

Then enter the US five-digit zip code for the location of interest.

In Rwanda, select District-Sector in the *Select Location By* drop down list, then select by the District-Sector name:

WaSSI Ecosystem Services Model
Version 2.1

English Spanish

About Options **Input Viewer** Simulation Tool

Input Viewer

Region **Rwanda**

Select Location By: CLICK DROPDOWN TO SELECT -

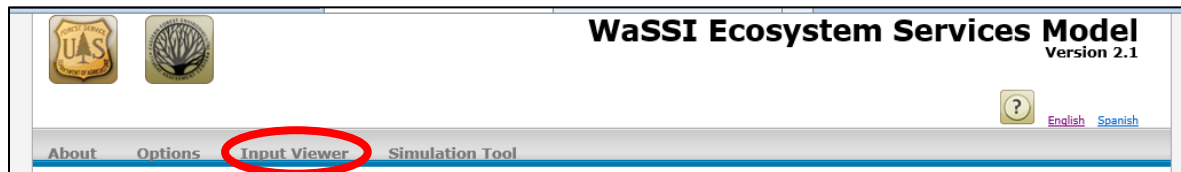
Climate Historic (1961-2009)

Chart

Map

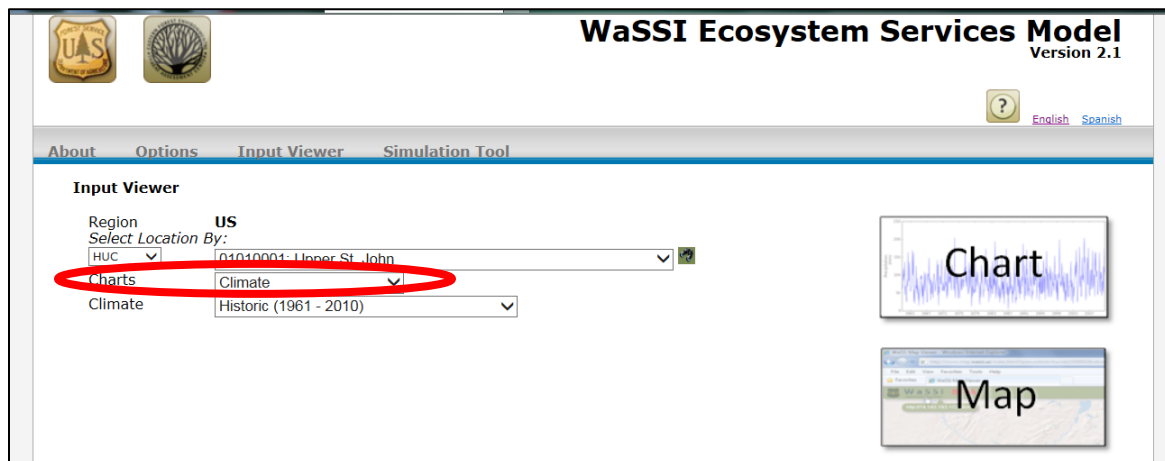
Viewing Model Inputs

Once a region has been selected using the *Options* component, the model inputs may be explored in the **WaSSIweb Input Viewer**.

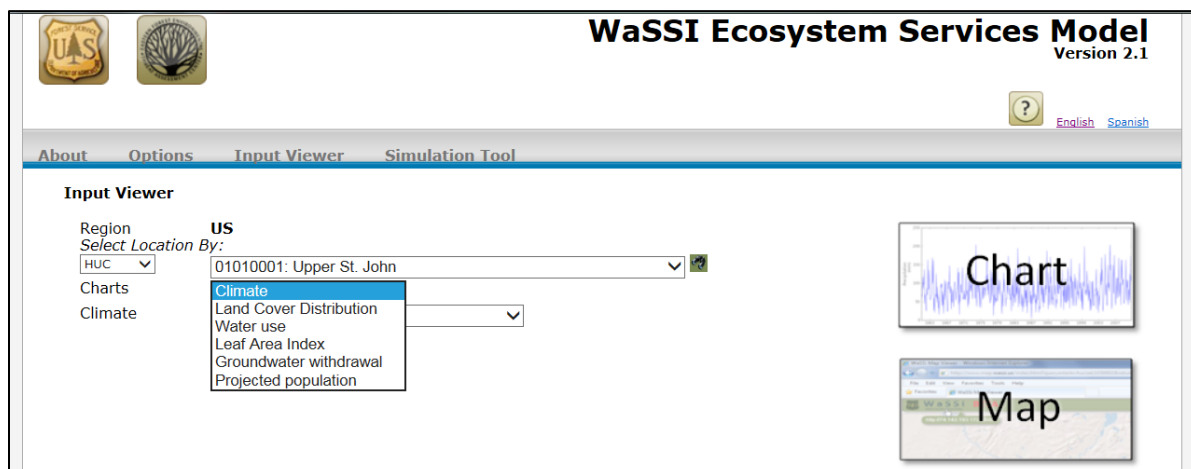


The *Input Viewer* allows selection of a watershed or grid cell location for viewing of model inputs as charts or the data may be downloaded in CSV format.

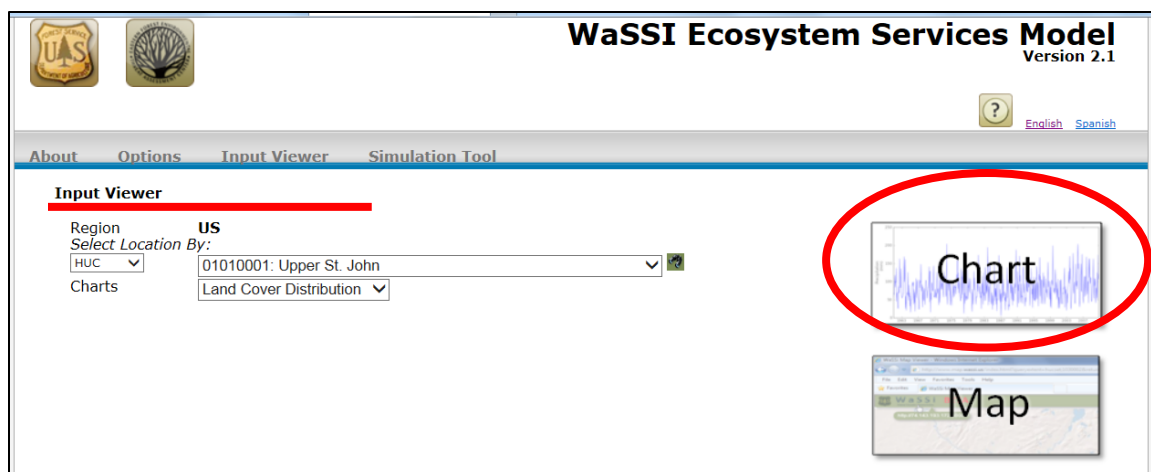
After selecting a location, use the *Charts* drop down list to select the desired input for that area.



Click on the drop down list to access the options and select the desired model input.

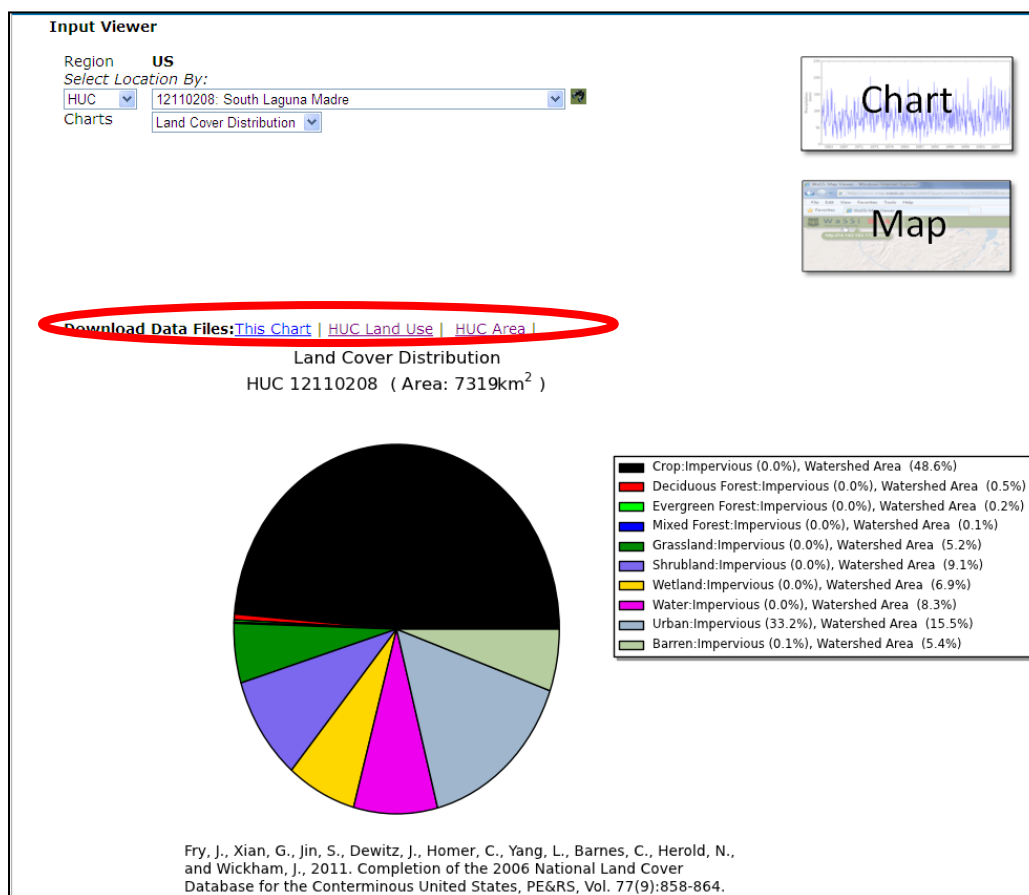


Once all the fields have been selected, click on the *Chart* icon located on the right side of the screen. **WaSSIweb** will then generate a chart of the requested model input at the bottom of the *Input Viewer* page.



Below all the input charts is the reference to the original dataset used to create the model input. *Note: Some Chart options generate several graphs, **SCROLL DOWN** to view the rest of the graphs.*

In addition to viewing model inputs in the **WaSSIweb Input Viewer**, the chart image and the data files used to generate the input charts may be downloaded by clicking on the links in the *Download Data Files* section. See Appendix B for a detailed description of the fields included in the model input data files.



Selecting *Climate* under *Charts* will give access to the *Climate* drop down list. Click on the drop down list to access a list of climate change scenarios that are available for custom WaSSI model runs.

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English Spanish

About Options Input Viewer Simulation Tool

Input Viewer

Region **US**
Select Location By:
HUC

Charts
Climate

- Historic (1961 - 2010)
- CSIRO-Mk3.5 SRES A1B (2002 - 2100)
- MIROC3.2 SRES A1B (2002 - 2100)
- CSIRO-Mk2 SRES B2 (2002 - 2100)
- UKMO-HADCM3 SRES B2 (2002 - 2100)
- CGCM3-A1B (1961-2099)
- CGCM3-A2 (1961-2099)
- CGCM3-B1 (1961-2099)
- CM2-A1B (1961-2099)
- CM2-A2 (1961-2099)
- CM2-B1 (1961-2099)
- HADCM3-A1B (1961-2099)
- HADCM3-A2 (1961-2099)
- HADCM3-B1 (1961-2099)

Chart

Map

Once all *Input Viewer* options have been selected, click on the *Chart* icon located on the right side of the screen to generate the climate change charts. This may take a few seconds, so please be patient.

Running a Simulation

The **WaSSIweb Simulation Tool** can be used to define a climate, land cover, and water use scenario to evaluate using the WaSSI model.

The following selections are available in the *Simulation Tool*:

Parameter	Value	Unit	Range
Region:	US		
Climate:	Historic (1961 - 2010)		
Start Year:	1961		
End Year:	2010		
Precipitation Change (-100% to 100%):	0	%	▼ ▲
Temperature (-10C to 10C):	0	C	▼ ▲
Forest Land Cover Change (-100% to 0%):	0	%	▼ ▲
Forest Leaf Area Index Change (-100% to 100%):	0	%	▼ ▲
Total Ground Water Withdrawal Change (-100% to 100%):	0	%	▼ ▲
Domestic Water Use scenario:	Use 2005 USGS Domestic Water Use Data		
Domestic Water Use Change (-100% to 100%):	0	%	▼ ▲
Industrial Water Use Change (-100% to 100%):	0	%	▼ ▲
Irrigation Water Use Change (-100% to 100%):	0	%	▼ ▲
Livestock Water Use Change (-100% to 100%):	0	%	▼ ▲
Mining Water Use Change (-100% to 100%):	0	%	▼ ▲
Thermo Water Use Change (-100% to 100%):	0	%	▼ ▲
Public Supply Water Use Change (-100% to 100%):	0	%	▼ ▲
Aquaculture Water Use Change (-100% to 100%):	0	%	▼ ▲

Run Simulation

US only

Place the cursor over the question marks for more information about each section of the *Simulation Tool*.

For some selections, changes can be made by either manually entering the values in the space provided next to each section or using the red arrows on the right to increase or decrease the values. *Note: Each selection has a different range, so please keep in mind the maximum and minimum values allowed when making adjustments.*

Past Simulations

Selecting a scenario in the *Past Simulations* drop down list populates the *Simulation Tool* with selections from any previous simulations. Select these by clicking on the drop down list to access and select available simulations.

About	Options	Input Viewer	Simulation Tool
Past Simulations:			--Past Scenarios--
Region:	?	--Past Scenarios--	
Climate:	?	Tue Jun 12 08:44:56 2012	
Start Year:	?	Tue Jun 12 08:22:59 2012	
End Year:	?	Tue Jun 12 15:08:31 2012	
		2010	

Region

This section reflects the region that was chosen in the *Options* page. Return to the *Options* page to change the selected region.

Region:	?	US
----------------	---	----

Climate

This option allows selection of a climate scenario that is either historical climate data based on observations or future climate projections from various general circulation models (GCMs) and emission scenario combinations that are available for the simulation. Refer to Appendix B for a description of the climate model/scenario combinations available.

Climate:	?	Historic (1961 - 2010)
Start Year:	?	Historic (1961 - 2010)
End Year:	?	CSIRO-Mk3.5 SRES A1B (2002 - 2100)
		MIROC3.2 SRES A1B (2002 - 2100)
		CSIRO-Mk2 SRES B2 (2002 - 2100)
Precipitation Change (-100% to 100%):	?	UKMO-HADCM3 SRES B2 (2002 - 2100)
Temperature (-10C to 10C):	?	CGCM3-A1B (1961-2099)
		CGCM3-A2 (1961-2099)
		CGCM3-B1 (1961-2099)
Forest Land Cover Change (-100% to 0%):	?	CM2-A1B (1961-2099)
Forest Leaf Area Index Change (-100% to 100%):	?	CM2-A2 (1961-2099)
		CM2-B1 (1961-2099)
		HADCM3-A1B (1961-2099)
Total Ground Water Withdrawal Change (-100% to 100%):	?	HADCM3-A2 (1961-2099)
		HADCM3-B1 (1961-2099)

Start Year

This option allows a start year for the simulation to be selected. Click on the drop down list to access the list of years.

Start Year:	?	1961
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End Year

This option allows an end year for the simulation to be selected. Click on the drop down list to access the list of years. *Note: A shorter time frame will take less time to simulate.*

End Year:	?	2010
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Precipitation Change

This option increases or decreases, by percentage, the monthly precipitation of the climate scenario selected in the *Climate* section. When precipitation is changed, the percentage change entered is applied individually to each month's precipitation value in all watersheds or grid cells for the climate scenario selected.

Precipitation Change (-100% to 100%):	?	<input type="text" value="0"/>	%	▼ ▲
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Temperature Change

This option increases or decreases, in degrees Celsius, the monthly temperature of the climate scenario selected in the *Climate* section. When temperature is changed, the amount of change entered is applied individually to each month's temperature value for the climate scenario selected.

Temperature (-10C to 10C):	?	<input type="text" value="0"/>	C	▼ ▲
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Forest Land Cover Change

This option reduces the proportion of forest land cover in all watersheds by a fixed percentage. When the forest land cover is reduced, Deciduous, Evergreen, and Mixed forest land cover classes that may be present in each watershed or grid cell are reduced by the same fixed percentage.

Forest Land Cover Change (-100% to 0%):	?	<input type="text" value="0"/>	%	▼ ▲
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When the *Forest Land Cover Change* value is adjusted, a new selection will appear: *Forest Land Cover Changed to*, where the land cover class that will replace the forest cover in all watersheds or grid cells may be selected. For example, if it is desired to decrease 10% of the forest land cover by converting to Urban land cover, and a given watershed included 20% Deciduous, 5% Evergreen, 30% Mixed, and 15% Urban land cover, the new land cover distribution would include 18% Deciduous, 4.5% Evergreen, 27% Mixed, and 20.5% Urban. All other land cover classes (e.g. Crop, Grassland, etc.) would remain constant.

Forest Land Cover Changed to	?	<div>Crop ▼</div>		
Forest Leaf Area Index Change (-100% to 100%):	?	<div>Crop Grassland Shrubland Wetland Water Urban Barren</div>		▼ ▲
Total Ground Water Withdrawal Change (-100% to 100%):	?			▼ ▲
Domestic Water Use scenario:	?		GS Domestic Water U	

Forest Leaf Area Index Change

Forest leaf area index (LAI) is the total surface of leaf per unit land area in units of $\text{m}^2 \text{m}^{-2}$ (m^2 of leaf area per m^2 of ground surface). Increasing the LAI of forest land cover will generally increase water loss by evapotranspiration in watersheds or grid cells where forest land cover is present, which will then decrease the water yield and increase the water supply stress. By changing forest LAI, the impacts of forest management practices such as thinning or the effects of increased stand age on the water balance, water supply stress, and carbon sequestration may be investigated. When forest LAI is

changed, the change entered is applied to all Deciduous, Evergreen, and Mixed Forest land cover classes in all watersheds or grid cells.

Forest Leaf Area Index Change (-100% to 100%):	?	<input type="text" value="0"/>	%	▼ ▲
---	---	--------------------------------	---	-----

Total Groundwater Withdrawal Change

This option, available for the US only, changes the amount of groundwater used by all sectors in all watersheds. Decreasing the groundwater withdrawal will increase water supply stress, and conversely, decrease stress if it is increased. A change is entered as a percent, for example a 10% increase in groundwater withdrawal would be entered as a 10 on the space provided. A decrease in water withdrawal would be entered as a negative number (e.g. -10).

Total Ground Water Withdrawal Change (-100% to 100%):	?	<input type="text" value="0"/>	%	▼ ▲
--	---	--------------------------------	---	-----

Domestic Water Use Scenario

This option, available for the US only, selects the method used to compute monthly domestic water use in the scenario. Domestic water use includes indoor and outdoor residential use and is directly impacted by population growth. Domestic water use includes both self-supplied withdrawals (usually from groundwater sources) and the portion of withdrawals from the Public Supply sector that serve the domestic sector. Two options for modifying domestic water use are available. The first option, *Use 2010 USGS Domestic Water Use*, utilizes the 2010 USGS domestic water use data as published for a baseline level of domestic water use, and allows this level of water domestic water use to be changed by a fixed percentage. The second option, *Calculate Domestic Water Use Based on Population* adjusts domestic water use as a function of projected population estimates.

Domestic Water Use scenario:	?	Use 2010 USGS Domestic Water Use Data
Domestic Water Use Change (-100% to 100%):	?	Calculate Domestic Water Use Based on Population

If *Use 2010 USGS Domestic Water Use Data* is chosen, the *Domestic Water Use Change* option will appear. This option allows the domestic water use from the 2010 USGS levels to be changed by a fixed percentage in all watersheds.

Domestic Water Use scenario:	?	Use 2010 USGS Domestic Water Use Data ▼
Domestic Water Use Change (-100% to 100%):	?	<input type="text" value="0"/> % ▼ ▲

If *Calculate Domestic Water Use Based on Population* is selected, per capita water use rates are computed by dividing the sum of 2010 USGS withdrawals for the Domestic sector and the portion of the Public Supply sector serving domestic water use by the 2010 population in each watershed. This per capita water use rate is then multiplied by the population for the year or years specified to compute the population-adjusted domestic water use. Any change in domestic water use as a result of population

change is applied only to surface water withdrawals. Groundwater withdrawals are always held constant at 2010 levels unless the *Total Groundwater Withdrawals* are adjusted as described above.

If *Calculate Domestic Water Use Based on Population* is chosen, then two more options will become available: *Base Population Year for Domestic Water Use Calculations* and *Population Change from Base Year*. *Base Population Year for Domestic Water Use Calculations* allows selection of a particular year between 2010 and 2060 to calculate domestic water use. For example, if it is desired to assess the impact of population change on water supply stress in 2050, the year 2050 would be selected and population for all years of the simulation would be held constant at 2050 levels. Selecting *Time Variable Population* option for *Base Population Year for Domestic Water Use Calculations* will allow domestic water use to vary in time based on the annual projected estimates for each year between 2010 and 2060 instead of remaining constant for a single selected year. Population projection estimates used in WaSSI span the 2010 – 2060 time period, while simulation scenarios may start before or end after this period. If a simulation includes years before 2010 or after 2060, years before 2010 are assigned population estimates from year 2010 and years after 2060 are assigned population estimates from year 2060. The *Population Change from Base Year* changes the population from the base population year by a fixed percentage for all watersheds.

Domestic Water Use scenario:	?	Calculate Domestic Water Use Based on Population
Base Population Year for Domestic Water Use Calculations:	?	Time Variable Population
Population Change from Base Year (-100% to 100%):	?	0 % ▼ ▲

Water Use Change by Sector

The remaining sections of the *Simulation Tool* for the US changes water use for individual water use sectors (other than domestic and the portion of public supply service domestic water use) by a fixed percentage. Any change in water use by sector is applied only to surface water withdrawals. Groundwater withdrawals are always held constant at 2010 levels unless the *Total Groundwater Withdrawals* are adjusted as described above. Refer to Appendix B for a description of the water use sectors.

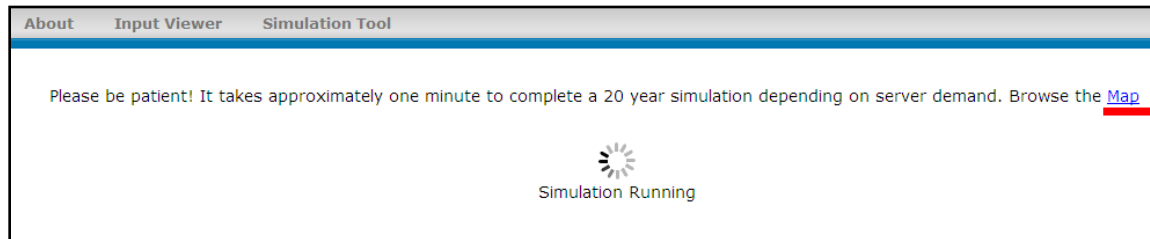
Industrial Water Use Change (-100% to 100%):	?	0 %	▼ ▲
Irrigation Water Use Change (-100% to 100%):	?	0 %	▼ ▲
Livestock Water Use Change (-100% to 100%):	?	0 %	▼ ▲
Mining Water Use Change (-100% to 100%):	?	0 %	▼ ▲
Thermo Water Use Change (-100% to 100%):	?	0 %	▼ ▲
Public Supply Water Use Change (-100% to 100%):	?	0 %	▼ ▲
Aquaculture Water Use Change (-100% to 100%):	?	0 %	▼ ▲

Run Simulation

When finished developing a scenario, click on the *Run Simulation* button to execute the model and view the results.

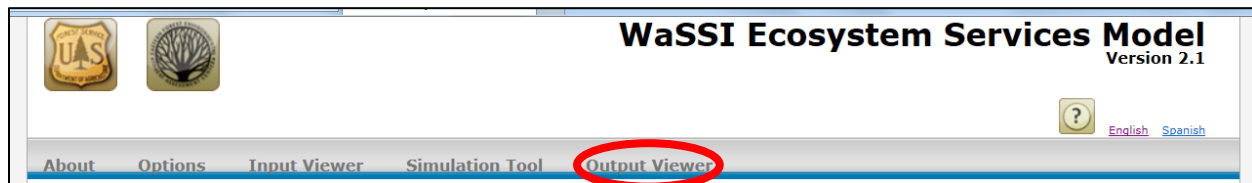
Run Simulation

Once the simulation has been initiated, the following screen will appear. Please be patient while the simulation is running. To browse the **WaSSI Map Viewer** while waiting; simply click on the *Map* link provided.



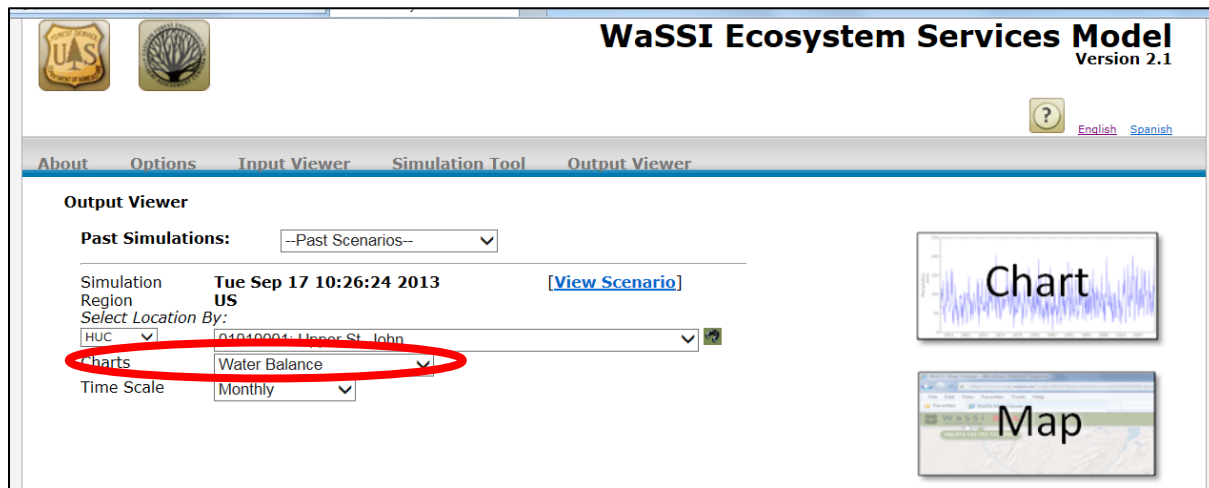
Viewing Model Outputs

Once the simulation is complete, the model outputs may be explored in the **WaSSIweb Output Viewer**.

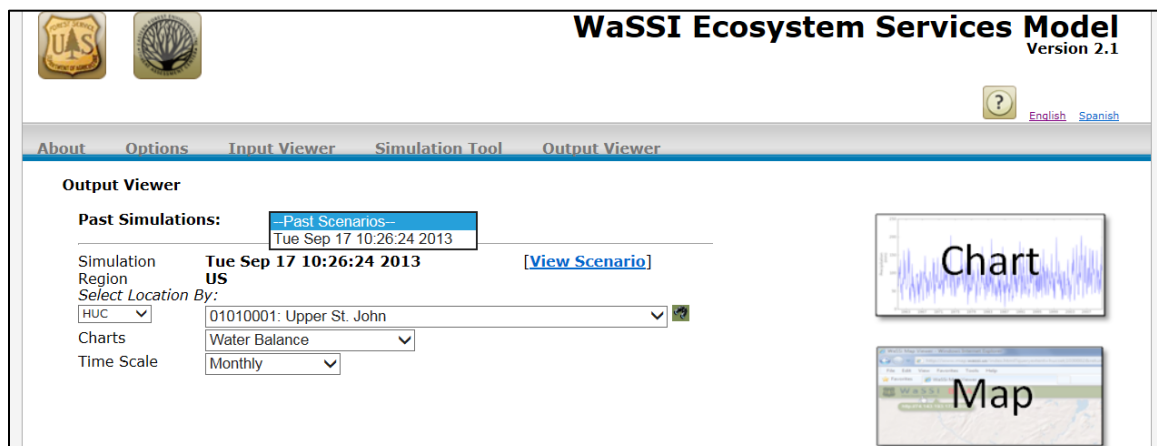


The *Output Viewer* allows the selection of a watershed or grid cell location for viewing of model outputs as charts or the data may be downloaded in CSV format.

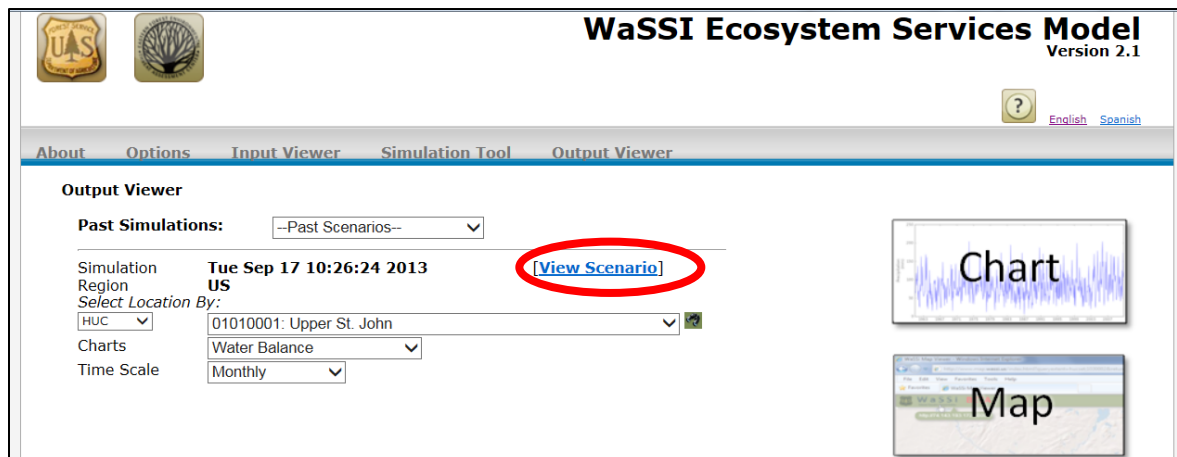
After a location has been selected, use the *Charts* drop down list to select the desired output for that area.



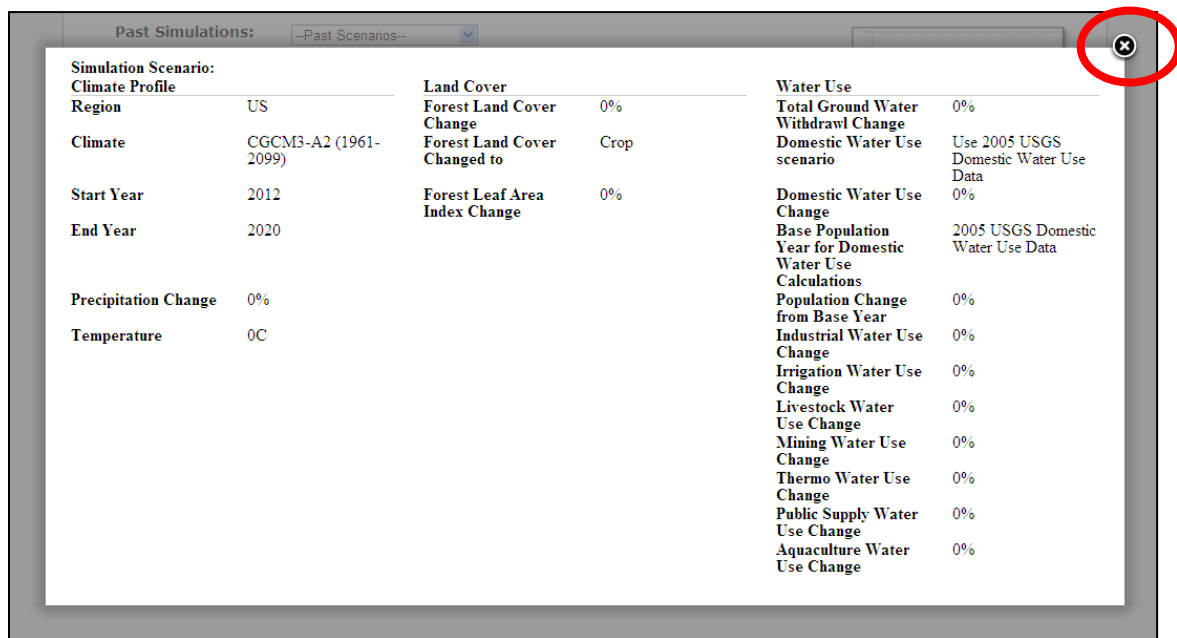
The *Past Simulations* drop down list allows viewing and selection of any previous simulation that has been run in the current session of **WaSSIweb**. To access a previous simulation, click on the drop down list and select the desired simulation. Once a past simulation is selected, outputs for that scenario will be shown in the **WaSSIweb Output Viewer** and the **WaSSI Map Viewer**.



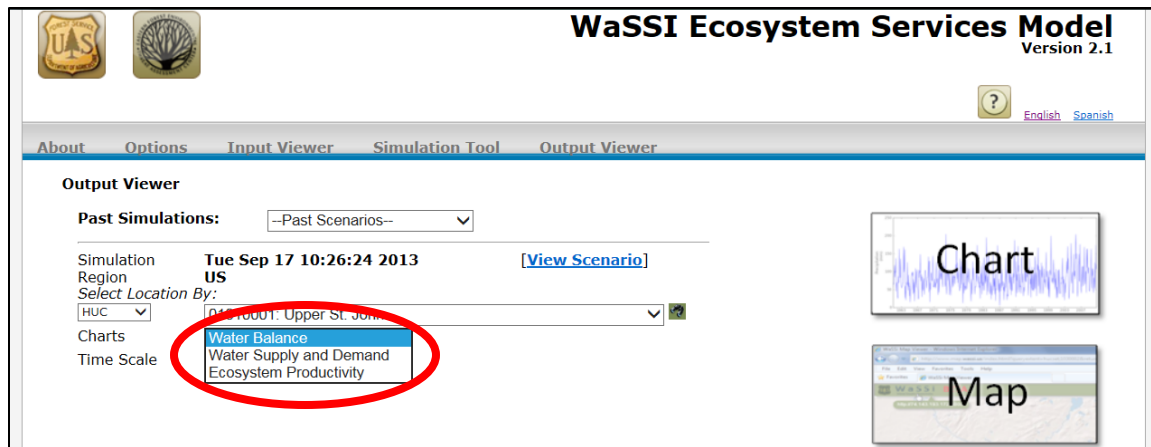
At any time, the scenario settings of the selected simulation defined in the *Simulation Tool* may be reviewed by clicking on the *View Scenario* link.



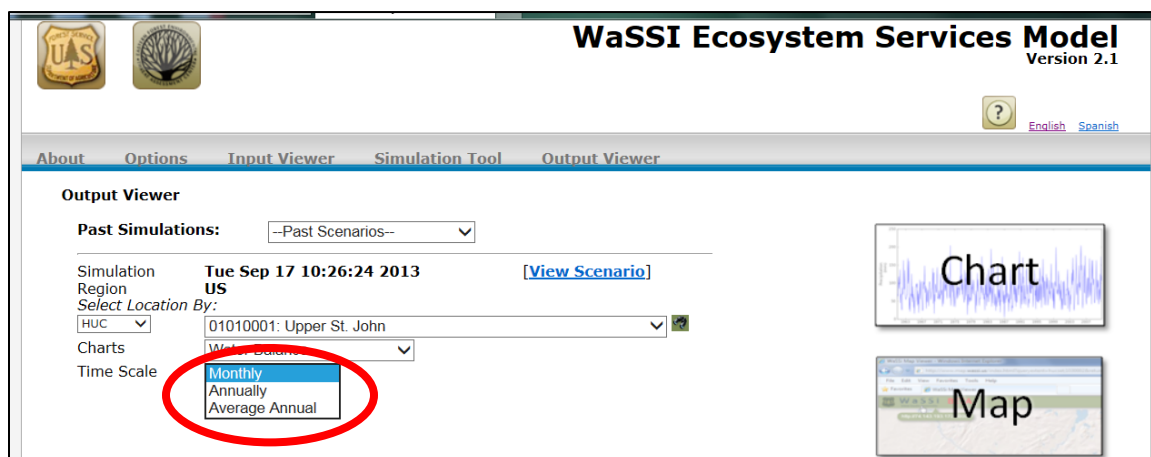
Clicking on the link will open a new window where the details of the chosen simulation scenario may be viewed. Click on the X on the upper right hand corner to exit this screen.



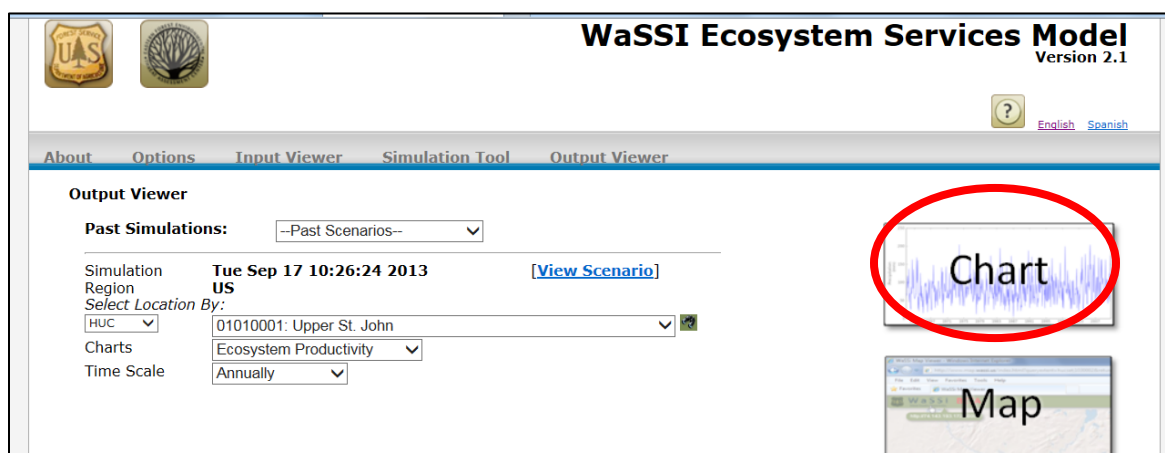
Click on the drop down list to access the available model outputs and select the desired output related to the water balance, water supply and demand, or ecosystem productivity.



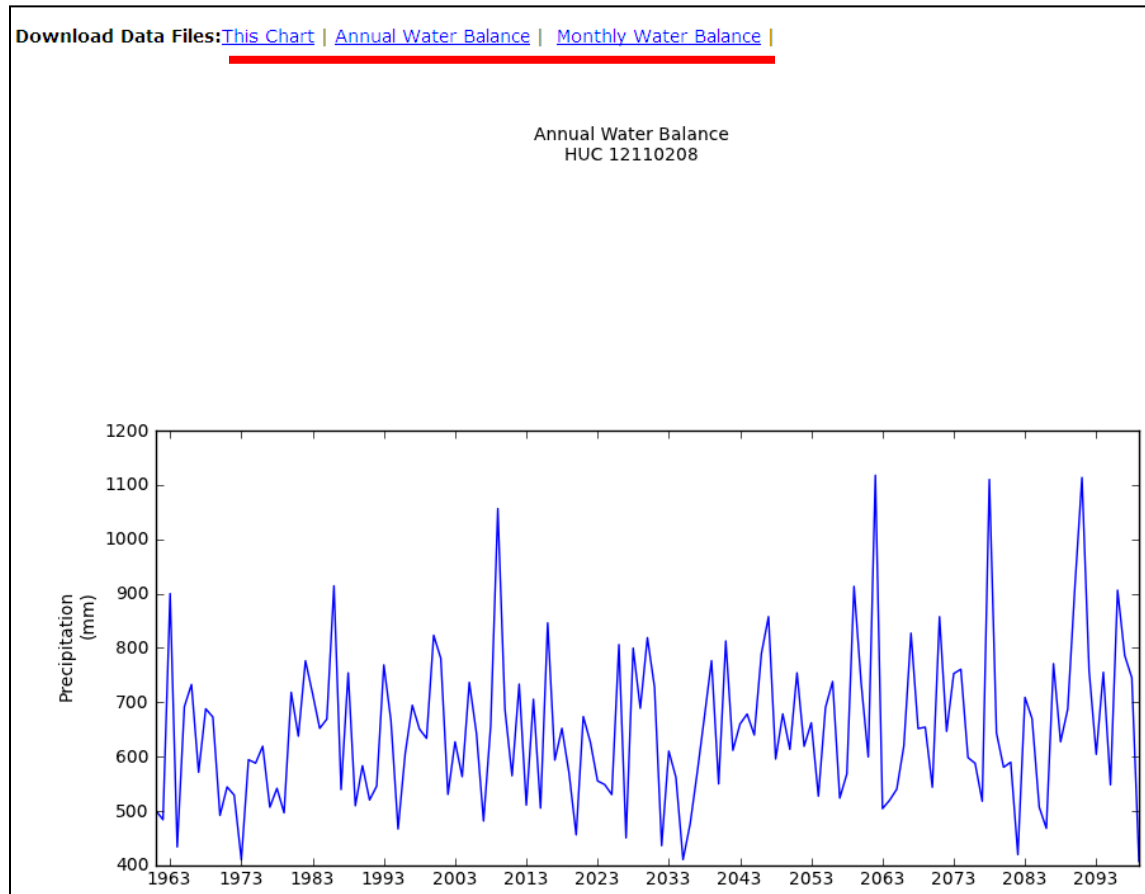
Once an output option has been selected, select the desired time scale using the *Time Scale* drop down list. Click on the drop down list to access the available options.



When all the options have been set, click on the *Chart* icon on the right to view the selected model output as charts. If the *Average Annual* time scale is selected, no chart will be generated, however links to the average annual output data files used to generate the charts will be provided. Chart outputs can be changed by returning to the *Charts* drop down list and selecting a different chart option.



The chart data will appear at the bottom of the *Output Viewer* page. The chart may be downloaded as an image file, or the output data files used to generate the charts may be downloaded by clicking on the provided links. *Note: Some Chart options will have several graphs included, **SCROLL DOWN** to view the rest of the charts.* See Appendix B for a complete description of the fields in the output data files.

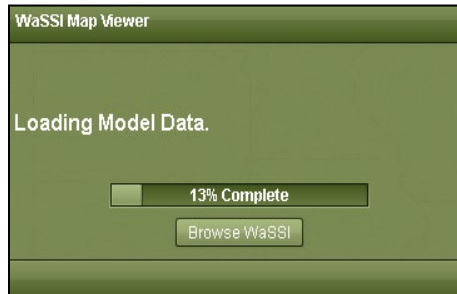


A summary of the simulation scenario selections defined in the *Simulation Tool* is located below all charts.

Climate Profile Region: US CGCM3-A2 (1961-2099) Start Year: 2012 End Year: 2020 Precipitation Change: 0% Temperature : 0C	Land Cover Forest Land Cover Change: 0% Forest Converted: Crop Forest Leaf Area Index Change: 0%	Water Use Total Ground Water Withdrawal Change: 0% Use 2005 USGS Domestic Water Use Data Domestic Water Use Change: 0% Domestic Water Calc Yr: 2005 USGS Domestic Water Use Data Population Change from Base Year: 0% Industrial Water Use Change: 0% Irrigation Water Use Change: 0% Livestock Water Use Change: 0% Mining Water Use Change: 0% Thermo Water Use Change: 0% Public Supply Water Use Change: 0% Aquaculture Water Use Change: 0%
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Using the WaSSI Map Viewer

When the *Map* icon is selected from the **WaSSIweb Output Viewer**, a status window will appear indicating that the model data is loading. This may take several minutes to complete. *Note: The Loading Model Data window will only appear after you have run a simulation.*

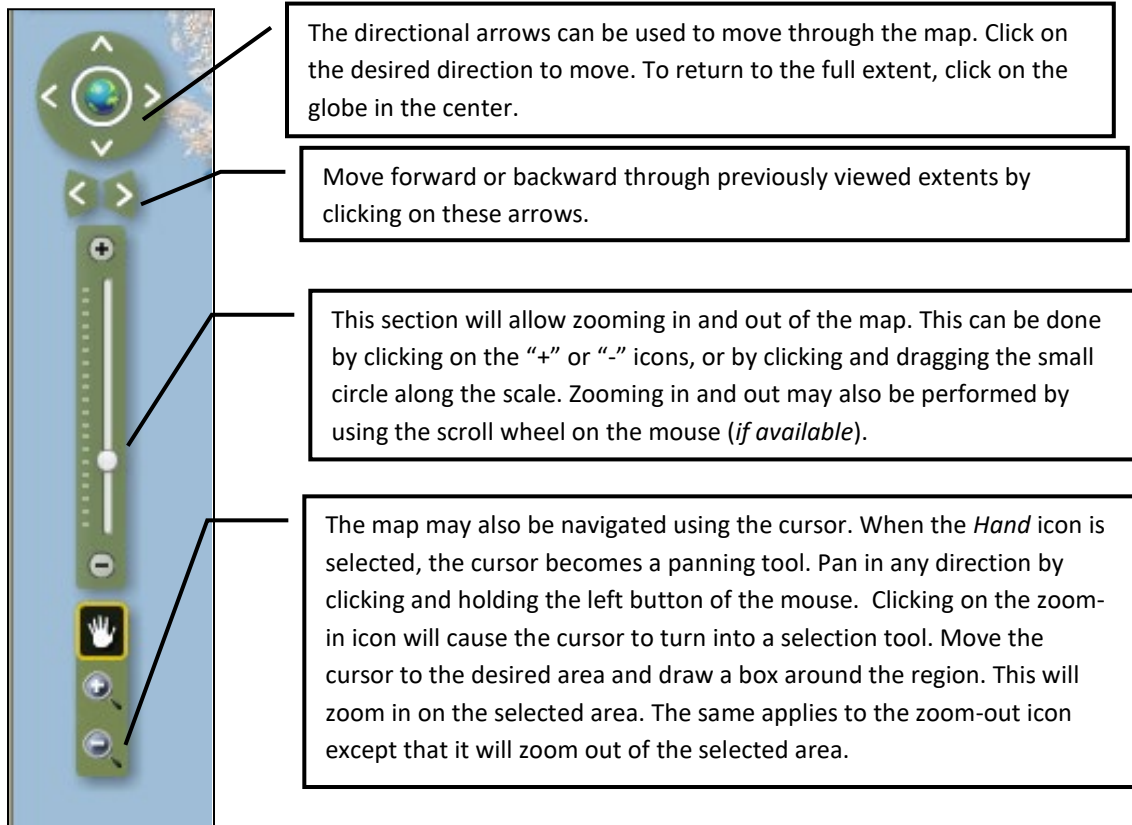


Elements of the **WaSSI Map Viewer** are shown below.



Zoom and Pan Tool

To navigate through the map use the *Zoom and Pan* tool located on the left.



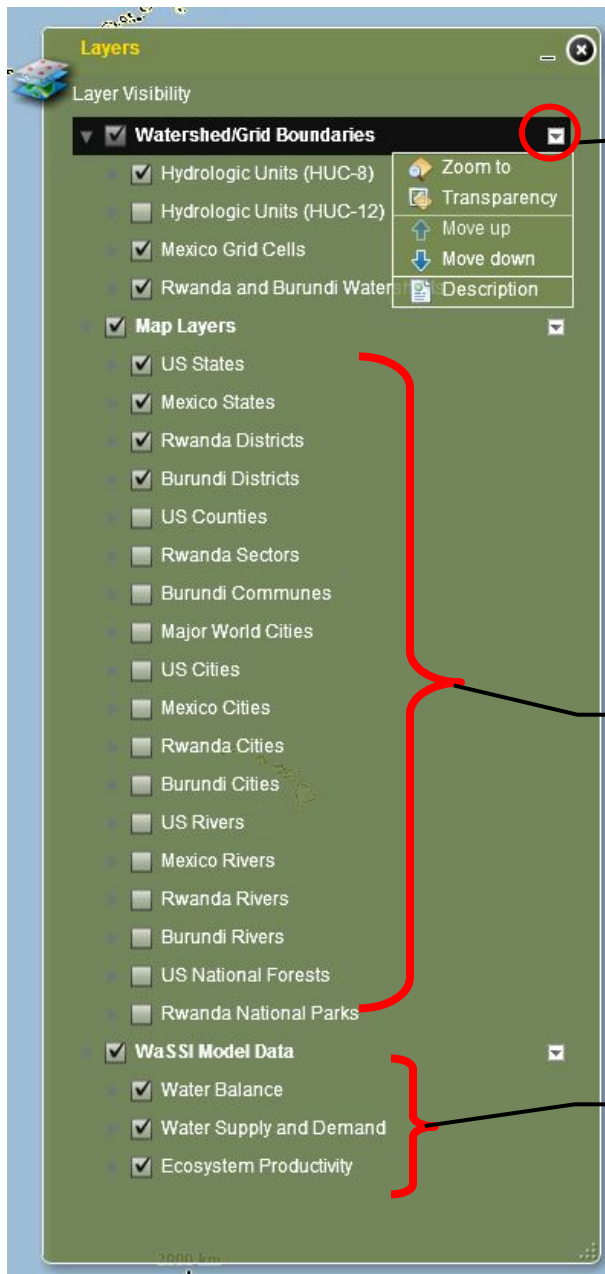
Layer Tool

The *Layer* tool is used to display, hide, and set the transparency of map layers in the **WaSSI Map Viewer**.

The *Layer* tool is open by default, but may be reopened by selecting the *Layer* tool icon in the **WaSSI Map Viewer Tool Bar**:



Layer Visibility is adjusted by checking and unchecking the layers provided. This will turn on and off layers in the **WaSSI Map Viewer**. The top layer of a group (i.e. Watershed/Grid Boundaries, Map Layers, or WaSSI Model Data) must be checked for any lower layers in that group to display.



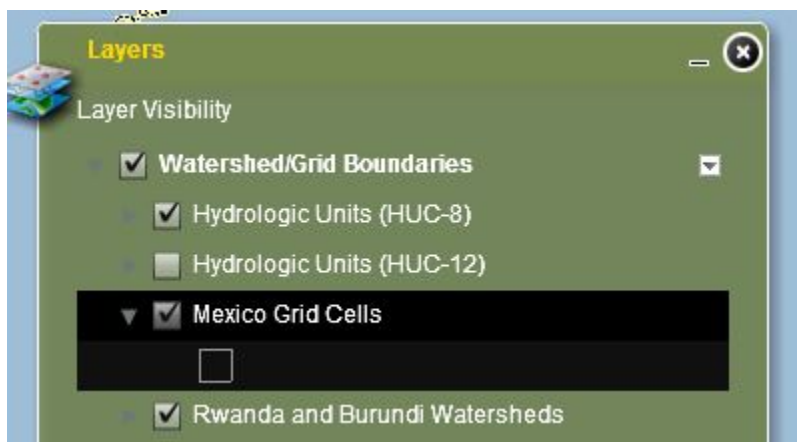
The *Watershed/Grid Boundaries* group displays watershed and grid outlines and may be turned on or off by checking the box next to them. Click on the arrow to control transparency of these layers, zoom to the layers, or see description of the layer. *Note: Transparency, Zoom to, and description are available for Map Layers and WaSSI Model Data layers.*

The *Map Layers* group displays other map features that may be useful in conjunction with WaSSI model data. Checking off a gray box will select a layer to become visible.

The *WaSSI Model Data* group displays layers for a simulation scenario. *Note: WaSSI Model Data is only available after a simulation scenario has been completed.*

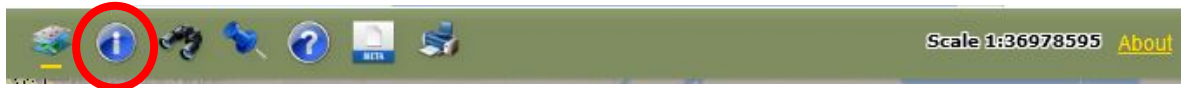


To see the symbology of a dataset. Click on the dataset name and select the grey arrow to the left of the check box. Upon clicking the symbology for that dataset will display below the dataset name.

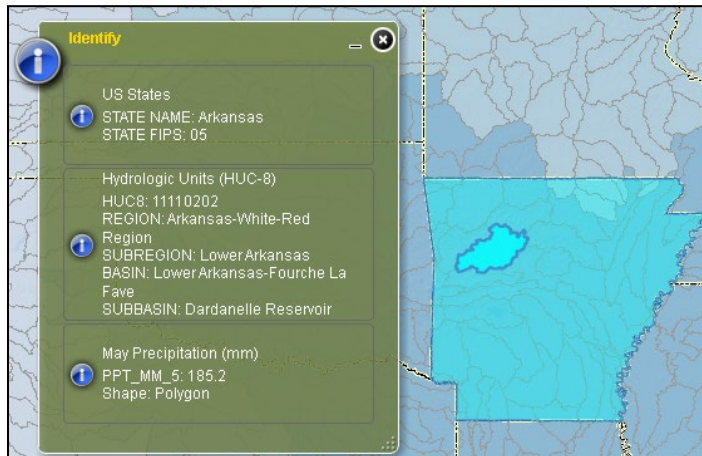


Identify Tool

Click the *Identify* icon on the Tool Bar to open the *Identify* tool.

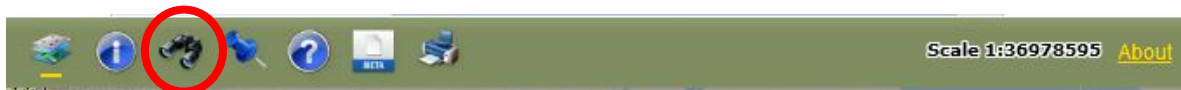


The *identify* tool is used by clicking on a desired location on the map with the mouse (left button). The *Identify* tool displays the attributes from the map layers that are turned on in the *Layer* tool. To close the window, click on the X button on the top right hand corner.



Find Watershed Tool

The *Find Watershed* tool is open by default, but may be reopened by selecting the *Find Watershed* tool icon in the **WaSSI Map Viewer** Tool Bar:



The *Find Watershed* tool is used to locate a watershed or grid cell to view model inputs and outputs for a desired location in the **WaSSIweb Input Viewer** and *Output Viewer*. Please refer to the General Navigation section of the User Guide for more information regarding use of the *Find Watershed* tool.

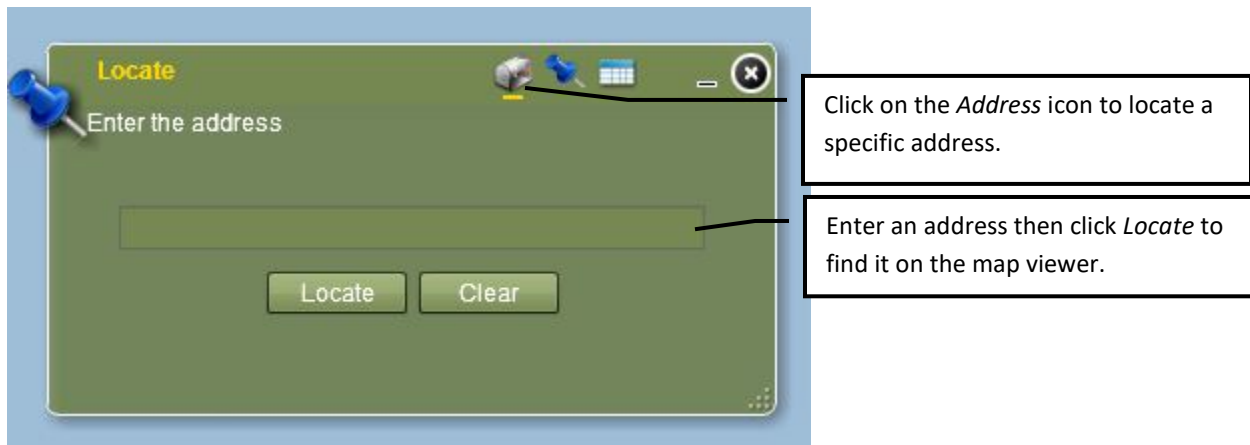
Locate Tool

The *Locate* tool may be opened by selecting the *Locate* tool icon in the **WaSSI Map Viewer** Tool Bar:

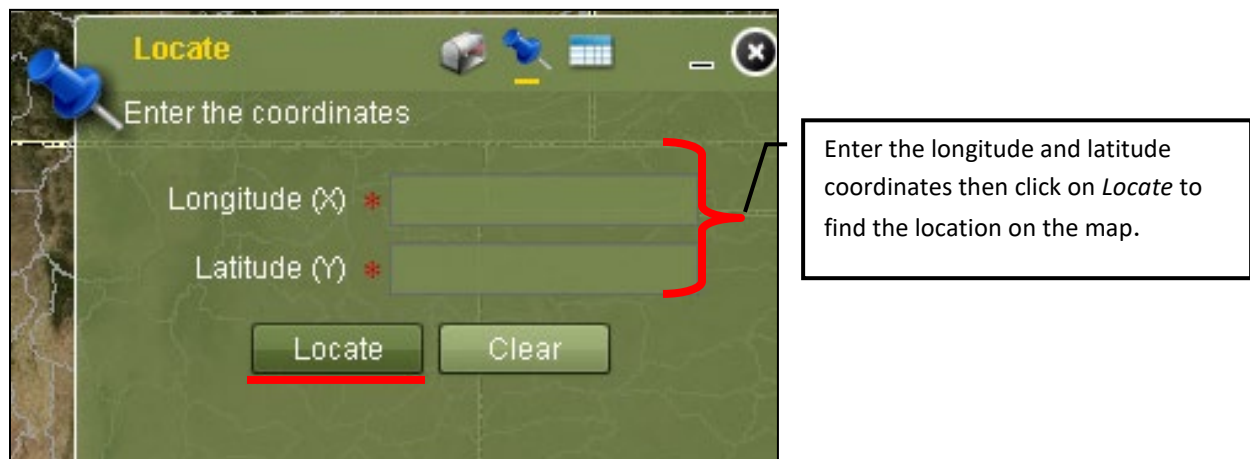


The *Locate* tool may be used to find a location in the **WaSSI Map Viewer**. There are two ways to find a location: entering a street address (US only) or specifying longitude/latitude coordinate values. To use this tool, click on the *Locate* icon on the Tool Bar. *Note: The Base Map may need to be changed to Streets to view a specific location.*

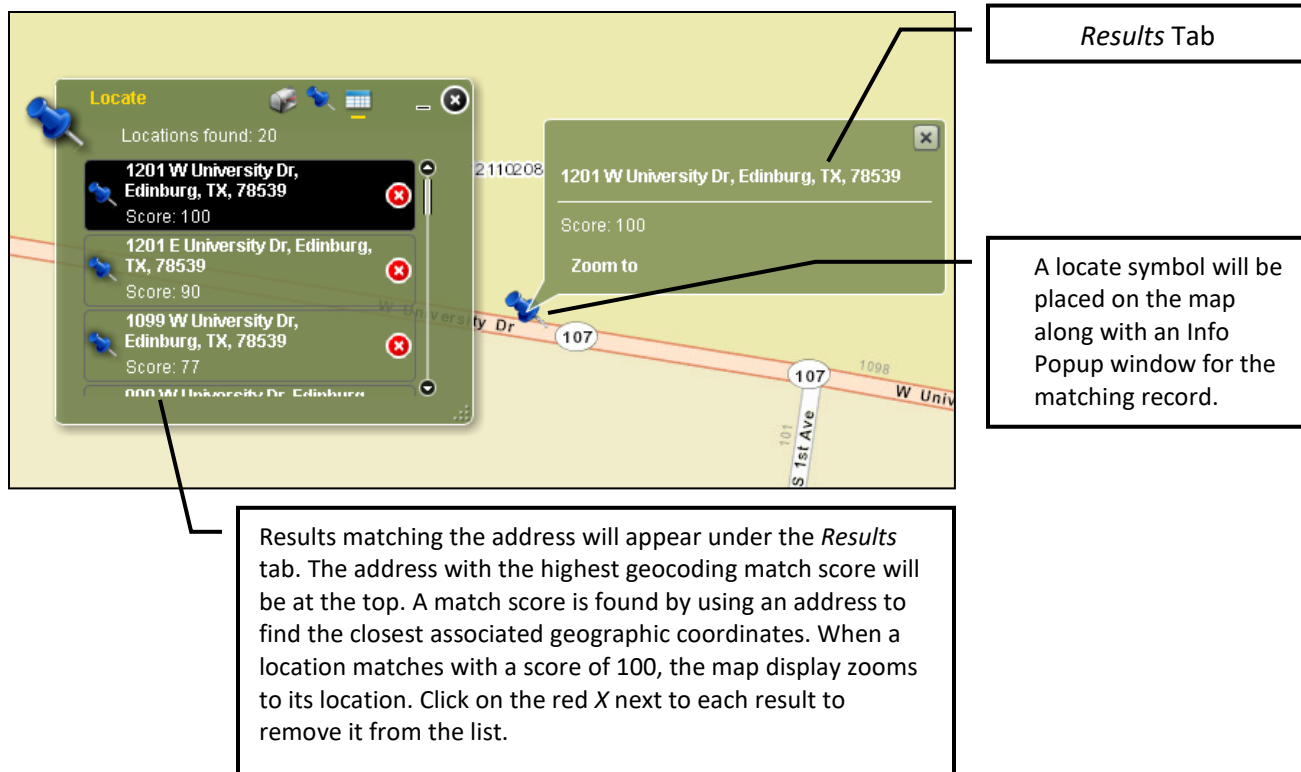
The first option to locate an area is by using its address (US only).



The second option to locate an area is by using its coordinates in decimal degrees (e.g., Longitude (X): - 84.3921, Latitude (Y): 33.7532).



Once the *Locate* button has been selected, the location and information for the selected area will appear on the map.



Print Map Tool

The *Print Map* tool may be opened by selecting the *Print Map* tool icon in the **WaSSI Map Viewer** Tool Bar:



The *Print Map* tool is used to export a map of model output displayed in the **WaSSI Map Viewer**. To export a map, select the desired file format from the drop down list.

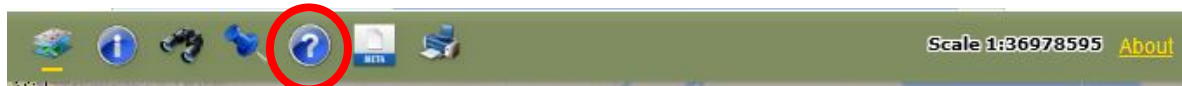


Once the file format has been selected, click on the *Print* button. The map will take a couple of minutes to export, so please be patient.

The exported map will appear in a new window. The map will include a title, legend, and scale bar. The map may be saved and/or printed from this window.

Help Tool

The *Help* tool provides further information on the **WaSSI Map Viewer** tools. Click on the *Help* icon on the **WaSSI Map Viewer** Tool Bar to open the window.

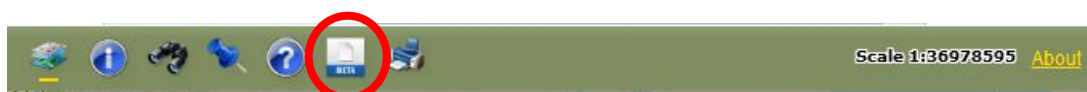


Scroll through the window to find the section of interest or click on the provided links. To close the window, click on the X located on the top right corner of the window.



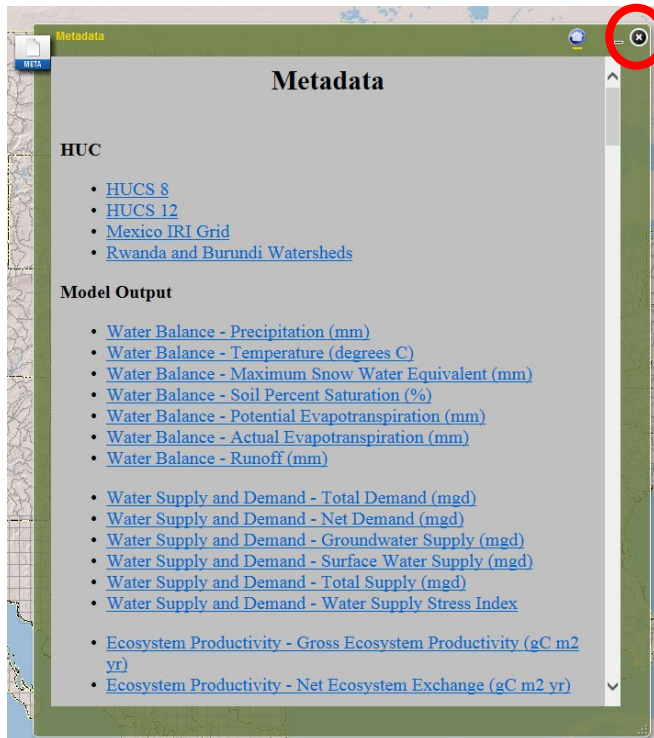
Metadata Tool

The *Metadata* tool may be opened by clicking on the *Metadata* icon located on the **WaSSI Map Viewer** Tool Bar.



The *Metadata* tool lists all of the layers displayed in the map viewer. The ArcGIS-derived metadata file may be accessed, printed and/or saved by clicking on the layer name. Included in each metadata file are

descriptive summaries, keywords, citations, spatial reference information, attribute information, geoprocessing history, and distribution / contact information. Metadata for WaSSI model output layers include only units and descriptive summaries, as the model output is spatially related to watershed or grid boundaries. Refer to Appendix B for more information regarding the model output layers.

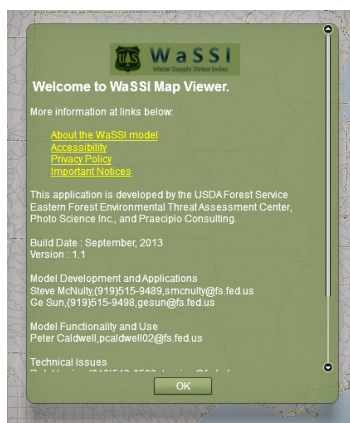


About

Click on the *About* icon on the **WaSSI Map Viewer** Tool Bar to open the about window.

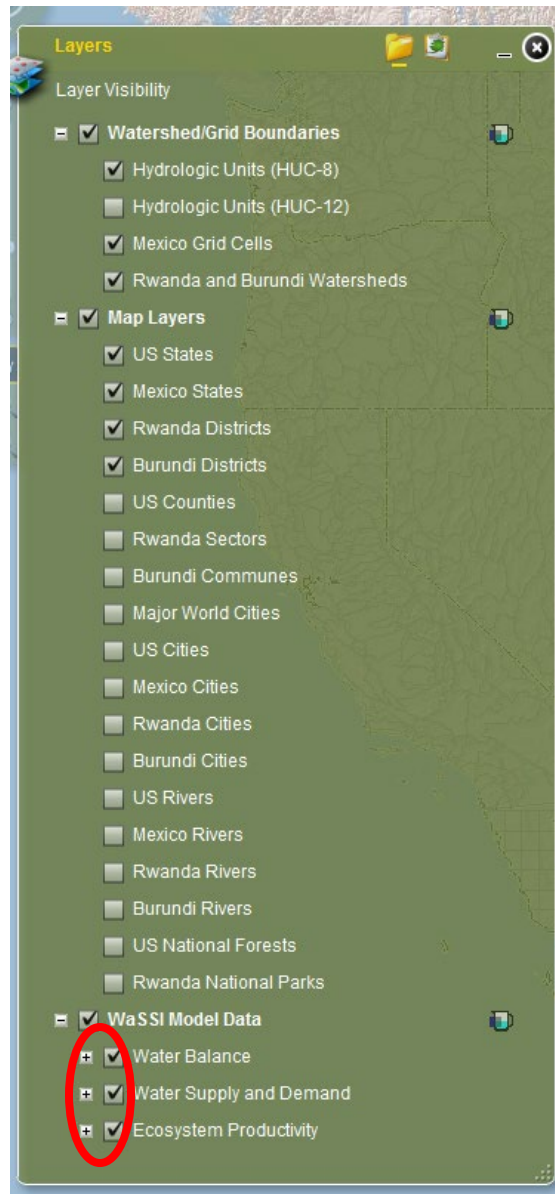


The *About* window will display basic information about **WaSSIweb** and the **WaSSI Map Viewer**, as well as contact information for application developers.



Viewing WaSSI Outputs in the WaSSI Map Viewer

In the **WaSSI Map Viewer** *Layer* tool, there are three output categories under the *WaSSI Model Data*. These model outputs are only available after a model simulation has been performed.



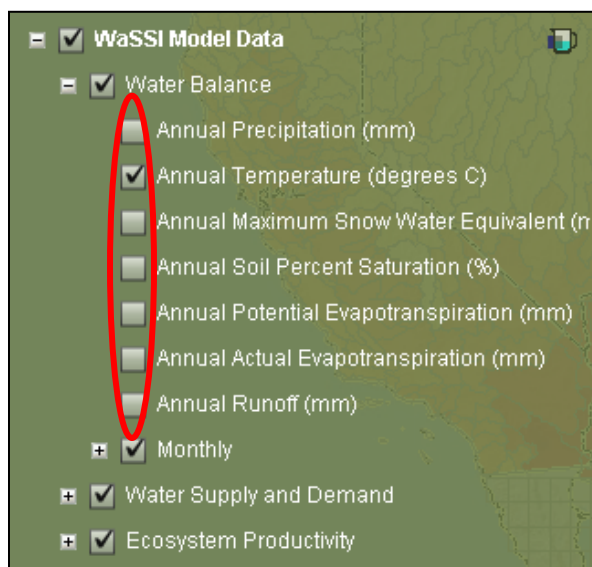
The *Water Balance* category shows results for model inputs or outputs that impact or describe the water balance, including temperature, precipitation, snow water equivalent, soil saturation, potential evapotranspiration, actual evapotranspiration, and runoff.

The *Water Supply and Demand* category (US only) shows results for total water demand, net water demand, groundwater supply, surface water supply, total water supply, and the water stress index.

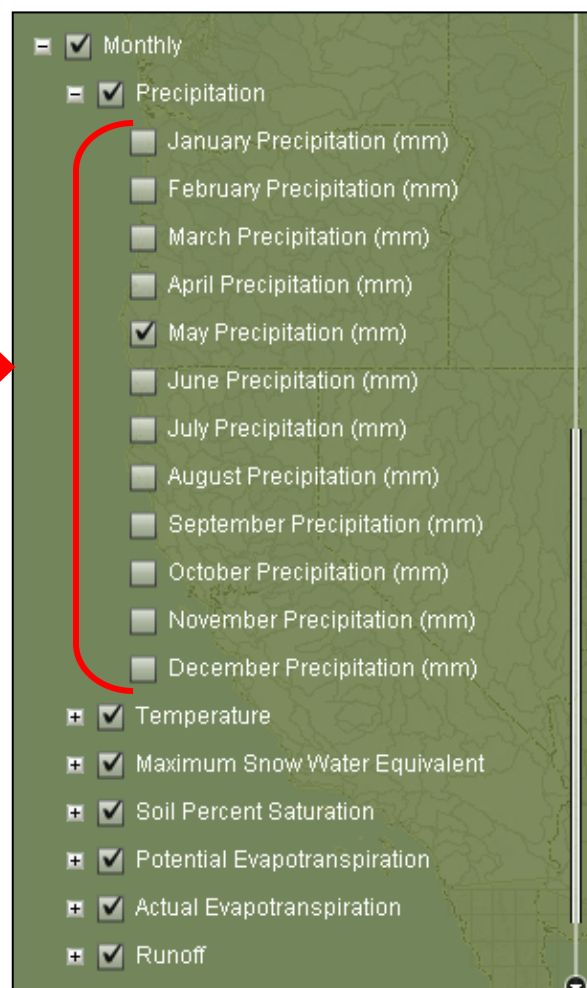
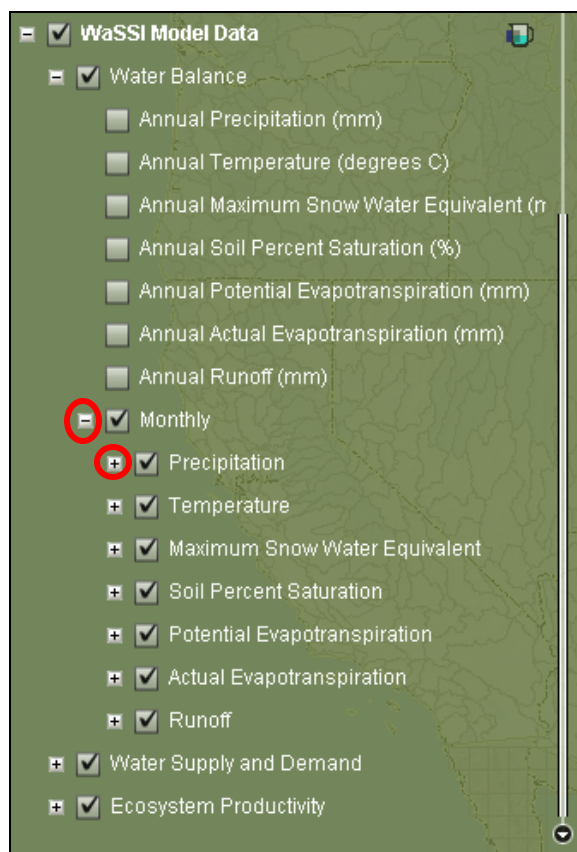
The *Ecosystem Productivity* category shows results for carbon exchange such as gross ecosystem productivity and net ecosystem exchange.

Each model output may be displayed as the mean annual or monthly means of that output, based on model computations for the scenario defined in the **WaSSIweb Simulation Tool** and averaged over the selected time period. To view these data on the map, check off the gray box next to the desired parameter *Note: Several layers may be checked at once, but will only be able to view one at a time. If multiple model outputs are checked, only the uppermost model output in the list will be displayed (e.g., precipitation will be displayed if both precipitation and temperature are checked).*

Mean annual model outputs over the selected time period may be viewed by selecting the desired *Annual* output layer:



Monthly mean model outputs over the selected time period may be viewed by expanding the *Monthly* option to access a new list of the same parameters. Then click on the collapsible icon next to the desired parameter to access the monthly results. To view the results on the map, check off the gray box next to the desired month.



Appropriate Use

WaSSI water and carbon predictions are subject to similar uncertainties associated with all ecosystem models, including uncertainty in input data, uncertainty in the representation of the physical processes that govern the watershed water balance and ecosystem productivity, and uncertainty in how people use and manipulate water resources at the continental scale. WaSSI is designed to provide large-scale global change impact assessments using readily available data collected using consistent methodologies across broad regions (e.g. water use and return flow). As a result, model results at the local scale (e.g. HUC8 watershed) may vary from actual conditions and users are cautioned to consider this uncertainty in interpreting results for their watershed of interest. WaSSI users have the capability of evaluating an unlimited number of climate, land use, and water use scenarios, and are ultimately responsible for determining whether the scenarios they define are realistic or not. For evaluating impacts of future climate scenarios, users are encouraged to consider several general circulation model and emission scenario combinations to cover a range in possible impacts. Users are encouraged to read the peer-reviewed WaSSI documentation for further information regarding model assumptions and limitations.

Acknowledgements

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Appendix A: Detailed description of WaSSI modules

Water Balance Module

The WaSSI water balance module computes the water balance independently for each of several land cover classes in each watershed or grid cell. Sun et al. (2011a, b), and Caldwell et al. (2011, 2012) provide more background information related to the development and application of the WaSSI water balance model.

Evapotranspiration, infiltration, soil storage, snow accumulation and melt, surface runoff, and base flow processes are accounted for within each basin (Figure 1). Required inputs for each watershed or grid cell include monthly precipitation (PPT), temperature (T), mean monthly leaf area index (LAI) for each land cover class, land cover distribution, impervious cover fraction by land cover, and soil properties. Many of these inputs may be adjusted using the **WaSSIweb Simulation Tool**.

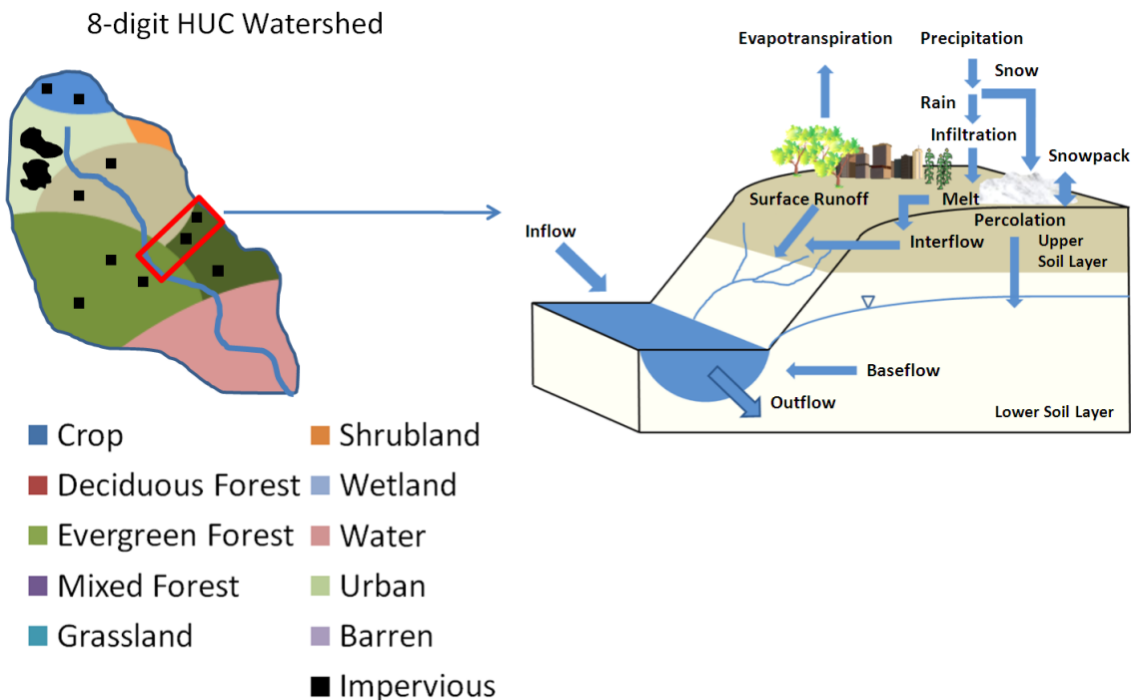


Figure 1. Land cover classes and hydrologic processes simulated by WaSSI.

There are several individual components of the WaSSI water balance module that are individually calculated and that interact to create a complete water balance. Each component will be individually described.

Snow melt and accumulation

Precipitation (PPT) is partitioned into rain and snow according to the simple conceptual snow model of McCabe and Wolock (1999) as described in McCabe and Markstrom (2007). The amount of PPT that falls as snow (PPT_{snow}) is calculated as:

$$PPT_{snow} = PPT \times \left(\frac{T_{rain} - T}{T_{rain} - T_{snow}} \right)$$

Where:

T = average air temperature for the month

T_{rain} = temperature above which all PPT falls as rain

T_{snow} = temperature below which all PPT falls as snow

The PPT_{snow} is accumulated on the land surface as snow water equivalent (SWE). The fraction of SWE that melts in a model time step (SMF) is computed as:

$$SMF = \left(\frac{T - T_{snow}}{T_{rain} - T_{snow}} \right) \times M$$

Where:

M = maximum melt rate

Regional snow water model parameters T_{rain} , T_{snow} , and M were estimated for each USGS Water Resource Region (WRR), or HUC2 by comparing predicted regional monthly mean SWE to remotely-sensed SWE from the Snow Data Assimilation System (SNODAS, National Operational Hydrologic Remote Sensing Center, 2004).

Evapotranspiration

An initial estimate of evapotranspiration (ET_{est}) is computed as a function of potential ET using the Hamon method (PET_{hamon}), PPT, and leaf area index (LAI) based on empirical relationships derived from multisite eddy covariance measurements (Sun et al. 2011 a, b). The ET_{est} is computed explicitly for each land cover class within each watershed or grid cell and is later constrained by soil moisture as described later. Two models are required to capture the spatial distribution of ET_{est} because of differences in the relationship between ET and PET_{hamon} , PPT, and LAI across the diverse ecoregions of the conterminous US (Sun et al. 2011 b). For HUC watersheds located in the Northeast and Upper Midwest US with more than 20% forest cover, ET_{est} for land cover i is calculated as:

$$E_{est_i} = 0.4 \times PET_{hamon} + 7.87 \times LAI_i + 0.00169 \times PPT \times PET_{hamon}$$

For all other HUC watersheds in the US and all grid cells in Mexico, ET_{est} for land cover i is calculated as:

$$ET_{est_i} = 0.174 \times PPT + 0.502 \times PET_{hamon} + 5.31 \times LAI_i + 0.0222 \times PET_{hamon} \times LAI_i$$

Where:

LAI_i = monthly leaf area index for land cover i

Units for ET_{est} , PPT , and PET_{hamon} in the above equations are in mm, LAI is $m^2 m^{-2}$ or unitless. PET_{hamon} is computed using the methods of Hamon (1963) as:

$$PET_{hamon} = 0.1651 \times n \times K \times \rho_w$$

Where:

N = number of days in the month

K = length of daytime (units of 12 hours)

ρ_w = saturated vapor pressure density at the mean air temperature for the month ($g m^{-3}$)

The daytime length (K) is computed as:

$$K = 2 \times \frac{\omega_s}{\pi}$$

Where:

ω_s = sunset hour angle (radians), computed as:

$$\omega_s = \cos^{-1}(-\tan(L) \times \tan(\delta))$$

Where:

L = latitude of the watershed or grid cell centroid (radians)

δ = angle of solar declination for the mid-month Julian day (radians) computed as:

$$\delta = 0.4093 \times \sin\left(\frac{2 \times \pi \times J}{365} - 1.405\right)$$

Where:

J = the Julian date for the mid-month day

The saturated vapor pressure density (ρ_w) is computed as:

$$\rho_w = 216.7 \times \frac{e}{TEMP + 273.3}$$

Where:

$TEMP$ = mean air temperature for the month (°C)

e = saturated vapor pressure at the mean air temperature for the month (mb), computed as:

$$e = 6.108 \times \exp \left(17.2693882 \times \frac{TEMP}{TEMP + 237.3} \right)$$

Infiltration, soil moisture, surface runoff, and baseflow

Infiltration, surface runoff, soil moisture, and baseflow processes for each HUC watershed land cover class are estimated using algorithms of the Sacramento Soil Moisture Accounting Model (SAC-SMA, Burnash et al. 1973, Burnash 1995). A detailed description of the SAC-SMA algorithm may be found in Burnash (1995) and Koren et al. (2003) and is summarized here.

The soil profile is divided into a relatively thin upper layer and usually a much thicker lower layer which supplies moisture to meet the evapotranspiration demands (Figure 2). Each layer consists of tension water storages (i.e., between soil water tensions of field capacity and the plant wilting point) and free water storages (i.e., soil water tension greater than field capacity) that interact to generate surface runoff, lateral water movement from the upper soil layer to the stream (interflow), percolation from the upper soil layer to the lower soil layer, and lateral water movement from the lower soil layer to the stream (baseflow). The free water storage of the lower layer is divided into two sub-storages: the LZFSM which controls supplemental (fast) base flow, and the LZFBM which controls primary (slow) ground water flow.

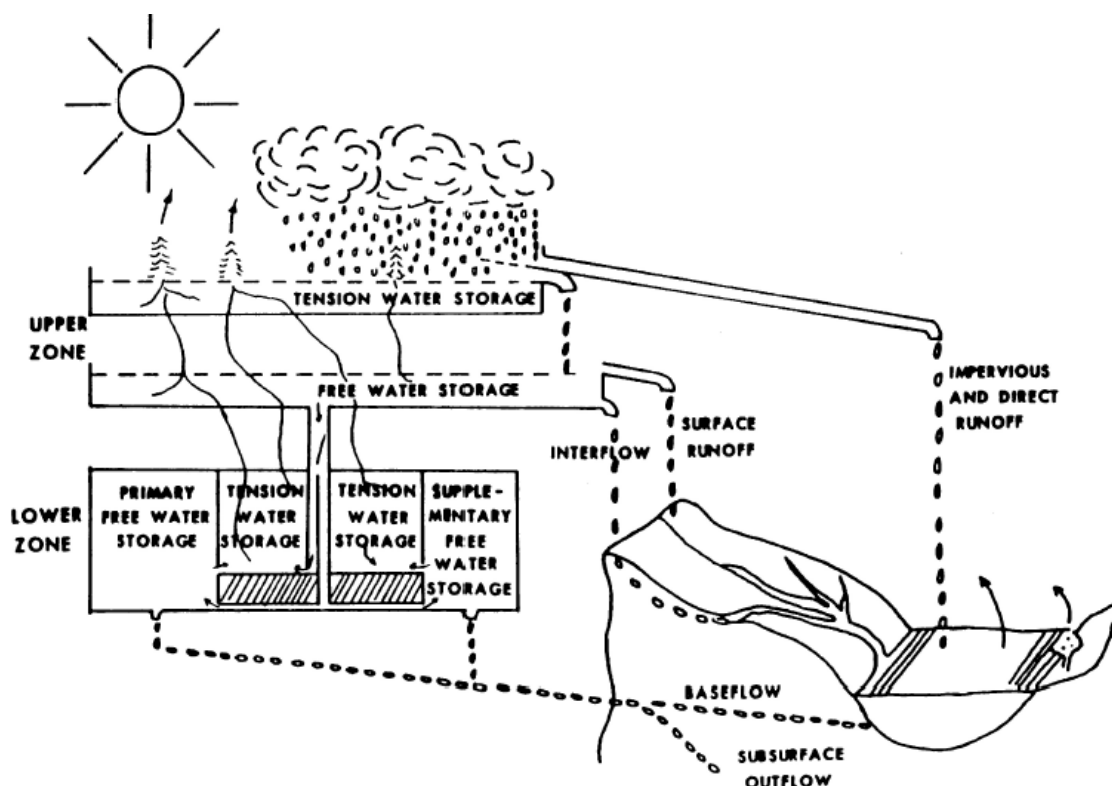


Figure 2. Conceptual schematic of the Sacramento Soil Moisture Accounting Model soil storages and fluxes (from Burnash 1995).

Partitioning of rainfall into surface runoff and infiltration is constrained by the upper layer soil moisture conditions and the percolation potential of the lower layer. No surface runoff occurs before the tension water capacity of the upper layer, UZTWM, is filled. After that, surface runoff generation is controlled by the content of the upper layer free water storage, UZFWM, and the deficiency of lower layer tension water, LZTWM, and free water storages LZFPM and LZFSM. Each free water reservoir can generate runoff depending on a depletion coefficient of the reservoir, namely the UZK coefficient for the upper layer, and LZSK and LZPK for the lower layer supplemental and primary free water storages, respectively. The percolation rate into the lower layer is a nonlinear function of the saturation of lower layer reservoirs and the upper layer free water reservoir, computed using the ZPERC and REXP parameters. Percolated water into the lower layer is divided among three storages of the layer. The PFREE parameter is used to express the fractional split of percolated water between tension and free water storages of the lower layer. Deep groundwater losses are considered negligible and assumed to be zero.

The ET_{est} is compared to available soil water storage to compute actual ET (AET). The ET demand is first supplied by the upper layer tension water as a function of the ratio between the upper layer tension water content and the upper layer tension water capacity (UZTWM). If the ET demand is not met by the upper layer tension water, additional water is supplied by the lower layer tension water as a function of the ratio between the lower layer tension water content and the sum of the upper and lower tension

water capacities (UZTWM and LZTWM) until either the ET demand is met or available soil moisture is depleted.

Note: Monthly total precipitation can artificially exceed the soil storage capacity in months of high precipitation when applied in a single model time step. This can cause over-prediction of surface runoff in months of high precipitation and under-prediction of baseflow in subsequent months. In reality, the monthly total precipitation occurs over several days in the month, allowing more infiltration to occur because soil water is continuously removed by ET and baseflow processes while it is added as infiltration. This issue is addressed by dividing the monthly step into smaller increments as a function of the amount of available infiltration in excess of the available upper soil layer tension water storage.

All water balance components are computed independently for each land cover class within each HUC watershed or grid cell and accumulated as an area-weighted average to estimate the totals for the watershed or grid cell. For the watershed impervious fraction (US only), storage and ET are assumed to be negligible, thus all precipitation falling on the impervious portion of a watershed for a given month is assumed to generate surface runoff in the same month and is routed directly to the watershed outlet.

Ecosystem Productivity Module

The Ecosystem productivity module computes carbon dynamics between terrestrial ecosystems and the atmosphere. Sun et al. (2011b) provides more background information related to the development and application of the WaSSI ecosystem productivity model.

Carbon sequestration, or net ecosystem exchange (NEE), is the difference between ecosystem respiration (Re) from autotrophic and heterotrophic bacteria and gross ecosystem productivity (GEP), or photosynthetic assimilation of carbon by foliage:

$$NEE = GEP - Re$$

When NEE for an ecosystem is negative, the ecosystem is a net carbon sink and carbon is sequestered from the atmosphere. When NEE is positive, the ecosystem is a net source of carbon and carbon dioxide is released to the atmosphere. Ecosystem water use, or evapotranspiration (ET), is tightly coupled with ecosystem productivity (Law et al. 2002, Sun et al. 2011 b) and thus may be used to estimate ecosystem productivity.

Ecosystem GEP, Re, and NEE (in units of g Carbon m⁻² mo⁻¹) are estimated using calculated actual evapotranspiration (AET) from the WaSSI water balance model (see section 2.2). The water use efficiency parameters (Table 2) were derived from measured site-level water and carbon fluxes for a variety of land cover types monitored by the FLUXNET system of eddy-covariance flux towers (Sun et al. 2011 b).

Ecosystem GEP is computed as:

$$GEP = a \times AET$$

Where:

a = ecosystem water use efficiency (g Carbon $\text{m}^{-2} \text{mo}^{-1}$ per mm of water used)

Ecosystem Re is computed as:

$$Re = m + n \times GEP$$

Where m and n are regression coefficients. If the mean monthly TEMP is less than -1.0°C , GEP and Re are assumed to be zero.

Table 2. Model parameters for estimating GEP as a function of AET, and Re as a function of GEP, after Sun et al. (2011 b).

Land cover class	a	m	n
Crop	3.13	40.6	0.43
Deciduous	3.20	30.8	0.45
Evergreen	2.46	9.9	0.69
Mixed forest	2.74	24.4	0.62
Grassland	2.12	18.9	0.64
Shrubland	1.35	9.7	0.56
Wetland (US only)	2.74	24.4	0.62
Open water (US only)	n/a	n/a	n/a
Urban (US only)	1.35	9.7	0.56
Barren (US only)	1.35	9.7	0.56
Savanna (MX only)	1.26	25.2	0.53
Water/Urban/Barren (MX only)	1.53	9.7	0.56

All carbon fluxes are computed independently for each land cover class within each HUC watershed or grid cell and accumulated to estimate the totals for the watershed or grid cell. The impervious fraction of each land cover is assumed to have no carbon flux, thus GEP and Re are assumed to be zero for these areas.

Water Supply and Demand Module

The WaSSI water supply and demand module is currently available only for the US. This module performs three functions: (1) Calculate the total monthly water demand, groundwater withdrawals, and return flows across the domestic, industrial, power generation, irrigation, livestock, mining, public supply, and aquaculture sectors in each watershed based on county-level 2005 annual US Geological Survey (USGS) estimates (Kenny et al. 2009, Solley et al. 1998) and the simulation scenario created in the **WaSSIweb Simulation Tool**; (2) Accumulate and route the water yield generated in each HUC watershed through the river network at a monthly time step, subtracting consumptive use (withdrawals minus return flows) from river flows at the watershed outlets; and (3) Compute the Water Supply Stress Index, or WaSSI, value for each watershed at a monthly time step. Sun et al. (2008), Caldwell et al. (2011), and Caldwell et al. (2012) provide more background information related to the development and application of the WaSSI water supply and demand model.

Monthly Water Demand

The annual total and groundwater withdrawals for each water use sector are disaggregated to the monthly scale so that they may be used to compute monthly consumptive use and water supply stress. The annual withdrawals for the industrial, livestock, mining, and aquaculture sectors are divided evenly across all 12 months. The annual withdrawals for the domestic, irrigation, power generation, and public supply sectors are disaggregated using region specific water use functions of the form:

$$M_{frac} = a \times m^3 + b \times m^2 + c \times m + d$$

Where:

M_{frac} = fraction of the annual withdrawal applied to month m

m = number value of the month 1 – 12 (e.g., January $m=1$, February $m=2$, etc.)

a, b, c, d are regression coefficients derived from water use data collected at the state-level in each USGS Water Resource Region (WRR), or HUC2.

Flow Accumulation and Routing

The connectivity and flow accumulation of the 8-digit HUC watershed river network is estimated by overlaying the National Hydrography Dataset (NHD; National Hydrography Dataset 2010) flow lines on to the Watershed Boundary Dataset (WBD; Watershed Boundary Dataset 2010) 8-digit HUC boundaries (Figure 3). No interbasin transfers (i.e., canals, aqueducts, pipelines, etc.) or water storage reservoirs are included in the flow network because these features are not completely represented in NHD and their flows are intensively managed with very little data available at the conterminous US scale.



Figure 3. River network (blue lines) connecting 8-digit HUC watersheds of the conterminous US.

Headwater watersheds (green) have no upstream watersheds draining into them but flow into a downstream watershed. Flow-through watersheds (brown) have upstream watersheds contributing to flow at the watershed outlet. Isolated watersheds (white) have no outlet or drain directly to the ocean or an international boundary.

For each month of a simulation, flow accumulation and routing calculations are performed in order from the most to the least upstream of the ocean or an international border. In each watershed, consumptive water use that takes place in that watershed is subtracted from the routed flow to the next downstream watershed. Each watershed is assumed to have one outlet but may have no or more than one watershed flowing into it. The flow out of any watershed (Q_{out}) is computed as:

$$Q_{out} = \sum Q_{in} + Y - \sum CU$$

Where:

$\sum Q_{in}$ = sum of the flows from upstream watersheds, if present

Y = water yield generated in the watershed

$\sum CU$ = sum of the consumptive use over all water use sectors in the watershed

The sum of consumptive water use in each watershed ($\sum CU$) across all water use sectors is computed as:

$$\sum CU = \sum ((1 - R_{frac}) \times WD_{SW+GW} - WD_{GW})$$

Where:

R_{frac} = fraction of total water withdrawn from surface and groundwater sources that is not consumed

WD_{SW+GW} = total freshwater withdrawals from surface and groundwater sources

WD_{GW} = freshwater withdrawals from groundwater sources only

It is assumed that all return flows (i.e., water withdrawn but not consumed), regardless of whether they originated from surface or groundwater, are discharged to surface water at the inlet of the next downstream watershed. Groundwater withdrawals are assumed to be completely isolated from surface water flow dynamics, and thus do not impact river flows in any way. In months where consumptive water use exceeded river flow at a watershed outlet, flow is set to zero and the remaining water demand is assumed to be supplied by an infinite water supply reservoir. All water in the flow network is assumed to be routed in the same month it was generated, and in-stream flow transmission losses to deep groundwater are assumed to be negligible.

Water Supply Stress

The Water Supply Stress Index (WaSSI) is computed for each watershed as:

$$WaSSI = \frac{D}{S}$$

Where:

D = total water demand, or withdrawals, in the watershed

S = total water supply in the watershed

The total water demand (D) is computed as:

$$D = \sum WD_{SW+GW}$$

The total water supply (S) in the watershed is computed as:

$$S = Q_s + \sum WD_{GW}$$

Where:

Q_s = the total amount of surface water supply (i.e., river flow) available at the watershed outlet

Surface water supply (Q_s) is computed as:

$$Q_s = \sum Q_{in} + Y$$

The Q_s is similar to Q_{out} but does not include losses due to consumptive water use in the watershed. These losses are accounted for in the next downstream watershed. However, the Q_s does include the consumptive losses from upstream watersheds. All surface water is currently assumed to be available for human use without reserving water for ecological flows or pollution assimilation. No attempt is made to track the amount of groundwater available in subsurface aquifers for withdrawals, and it is assumed that withdrawals may be made perpetually at 2005 levels.

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Watershed Boundary Dataset:

<http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/water/watersheds/dataset>, Accessed: September 1, 2009.

Appendix B: Model Inputs and Outputs

WaSSI model inputs and outputs available for download in the **WaSSIweb** application are described below. In addition, the **WaSSI Map Viewer Metadata** tool provides supplemental information regarding model inputs and outputs.

Model Inputs

Inputs for the WaSSI model are based on readily available remotely-sensed (satellite observations) and other geographically referenced databases. These datasets are available in differing spatial resolutions, with some represented in grid format and others at the county scale. All inputs for WaSSI are overlaid with the Watershed Boundary Dataset (WBD) eight digit Hydrologic Unit Code (HUC8) watershed boundaries, and rescaled to the HUC8 using an area-weighted averaging technique in a Geographical Information System (GIS).

Climate Scenarios

Climate inputs available in the **WaSSIweb Input Viewer** and *Simulation Tool* include both a historical and several future climate scenarios. The future climate datasets are based on downscaled climate projections from several combinations of General Circulation Models (GCMs) and IPCC SRES or RCP emission scenarios. The future scenarios are identified in **WaSSIweb** as (AAA SRES or RCP BBB (CCCC – DDDD), where AAA denotes the GCM used to simulate the climate record, BBB denotes the IPCC SRES or RCP emission scenario, CCCC denotes the first year of climate estimates available, and DDDD denotes the last year of climate estimates available. For example, climate scenario “HADCM3-A1B (1961-2099)” is based on the Hadley Centre for Climate Prediction and Research / Met Office, UK: UKMO-HadCM3 GCM, using the A1B IPCC SRES emission scenario, and includes years 1961 through 2099.

Fields included in the climate input data files available for download in the **WaSSIweb Input Viewer** include:

HUC8 (US), Cell (Mexico), or WSname (Rwanda)-	The WBD HUC8 watershed number (US), grid cell identifier (Mexico), or watershed number (Rwanda) for the data record. HUC8 numbers that start with zero do not include the leading zero.
YEAR-	The calendar year associated with the data record
MONTH-	The month associated with the data record
pptMM-	The total precipitation in mm for the HUC/cell/watershed, year, and month associated with the data record, averaged over the entire HUC8/cell/watershed.

tavgC-

The mean air temperature in degrees Celsius for the HUC/cell/watershed, year, and month associated with the data record, averaged over the entire HUC/cell/watershed.

US

The historical climate dataset (Historic 1961 – 2015) was developed based on historical observations at weather observation stations that were interpolated to a grid format using the Precipitation Elevation Regression on Independent Slopes Model (PRISM; Daly, 1994). The Intergovernmental Panel on Climate Change (IPCC) develops climate change assessment reports that review global climate models. The model ensembles are called the Climate Model Intercomparison Project (CMIP). WaSSI includes future GCMs from CMIP3 and CMIP5. CMIP3 was released in 2010 with the IPCC 4th Assessment Report, and CMIP5 was released in 2013 with the IPCC 5th Assessment Report. The future climate scenario GCMs available for the US are shown in Table B1. For GCMs from CMIP3 please refer to IPCC (2000) for more information about the IPCC SRES emission scenarios and to Meehl et al. (2007) for more information regarding the GCMs available for WaSSI model input for the US. For GCMs from CMIP5 please refer to IPCC (2014) for more information about the IPCC RCP emission scenarios and to Taylor et al. (2012) for more information regarding the GCMs available for WaSSI Model input for the US.

Table B1. WASSI Future Climate Scenario GCM Descriptions

WaSSIweb Climate Scenario GCM Identifier	Model Agency / GCM Description	Model Ensemble
BCC-CSM1-1	Beijing Climate Center, China Meteorological Administration	CMIP5
BCC-CSM1-1-M	Beijing Climate Center, China Meteorological Administration	CMIP5
BNU-ESM	College of Global Change and Earth System Science, Beijing Normal University, China	CMIP5
CanESM2	Canadian Centre for Climate Modeling and Analysis	CMIP5
CCSM4	National Center of Atmospheric Research, USA	CMIP5
CGCM3	Canadian Centre for Climate Modeling & Analysis: CGCM3.1 (T47)	CMIP3
CM2	US Dept. of Commerce / NOAA / Geophysical Fluid Dynamics Laboratory, USA: GFDL-CM2.0	CMIP3
CNRM-CM5	National Centre of Meteorological Research, France	CMIP5
CSIRO-Mk2	CSIRO Atmospheric Research, Australia: CSIRO-Mk2	CMIP3
CSIRO-Mk3.5	CSIRO Atmospheric Research, Australia: CSIRO-Mk3.5	CMIP3
CSIRO-Mk3-6-0	Commonwealth Scientific and Industrial Research Organization/Queensland Climate Change Centre of Excellence, Australia	CMIP5
GFDL-ESM2G	NOAA Geophysical Fluid Dynamics Laboratory, USA	CMIP5
GFDL-ESM2M	NOAA Geophysical Fluid Dynamics Laboratory, USA;	CMIP5
HADCM3	Hadley Centre for Climate Prediction and Research / Met Office, UK: UKMO-HadCM3	CMIP3
HadGEM2-CC	Met Office Hadley Center, UK	CMIP5
HadGEM2-ES	Met Office Hadley Center, UK	CMIP5
INMCM4	Institute for Numerical Mathematics, Russia	CMIP5

IPSL-CM5A-LR	Institut Pierre Simon Laplace, France	CMIP5
IPSL-CM5A-MR	Institut Pierre Simon Laplace, France	CMIP5
IPSL-CM5B-LR	Institut Pierre Simon Laplace, France	CMIP5
MIRCO5-ESM	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology	CMIP5
MIROC3.2	Center for Climate System Research (The University of Tokyo), National Institute for Environmental Studies, and Frontier Research Center for Global Change (JAMSTEC), Japan: MIROC3.2 (medres)	CMIP3
MIROC5	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology	CMIP5
MIROC5-ESM-CHEM	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology	CMIP5
MRI-CGCM3	Meteorological Research Institute, Japan	CMIP5
NorESM1-1	Norwegian Climate Center, Norway	CMIP5
UKMO-HADCM3	Hadley Centre for Climate Prediction and Research / Met Office, UK: UKMO-HadCM3	CMIP3

Scenario(s): Historic (1961 – 2015)

Data Citation: Daly, C., Neilson, R. P., and Phillips, D. L.: A statistical-topographic model for mapping climatological precipitation over mountainous terrain, J. Appl. Meteorol., 33, 140–158, doi:10.1175/1520-0450(1994)033<0140:ASTMFM>2.0.CO;2, 1994.

Download Site: <http://www.prism.oregonstate.edu>

Date Downloaded: May 2011

Native Spatial Resolution: 4 km X 4 km grid

Time Period: 1961 - 2015

Temporal Resolution:	Monthly
Parameters:	Total monthly precipitation, maximum and minimum monthly air temperature. Monthly mean temperature for use in WaSSI was estimated by computing the mean of the monthly maximum and minimum temperatures.
Scenario(s):	CGCM3-A1B (1961–2099), CGCM3-A2 (1961–2099), CGCM3-B1 (196 1–2099), CM2-A1B (1961–2099), CM2-A2 (1961–2099), CM2-B1 (196 1–2099), HADCM3-A1B (1961–2099), HADCM3-A2 (1961–2099), HADCM3-B1 (196 1–2099)
Data Citation:	Meehl, G. A., Covey, C., Delworth, T., Latif, M., McAvaney, B., Mitchell, J. F. B., Stouffer, R. J., and Taylor, K. E., 2007. The WCRP CMIP3 multi-model dataset: A new era in climate change research, Bulletin of the American Meteorological Society, 88, 1383-1394.
Download Site:	http://www-pcmdi.llnl.gov/ipcc/about_ipcc.php
Date Downloaded:	June, 2009
Native Spatial Resolution:	1/8 X 1/8 ° grid (~12 km X 12 km)
Time Period:	1961 - 2099
Temporal Resolution:	Monthly
Parameters:	Monthly mean daily precipitation, monthly mean air temperature. Monthly total precipitation computed by multiplying the monthly mean daily precipitation by the number of days in each month.
Scenario(s):	CSIRO-Mk3.5 SRES A1B (2002 – 2100), MIROC3.2 SRES A1B (2002 – 2100), CSIRO-Mk2.0 SRES B2 (2002 – 2100), UKMO-HADCM3 SRES B2 (2002 – 2100)
Data Citation:	Coulson, D.P., L.A. Joyce, D.T. Price, and D.W. McKenney, 2010a. Climate scenarios for the conterminous United States at the county spatial scale using SRES scenarios B2 and PRISM climatology. U.S. Forest Service, Rocky Mountain Research Station. Coulson, D.P., L.A. Joyce, D.T. Price, D.W. McKenney, S.R. Martin, P. Papadopol, and K. Lawrence, 2010b. Climate scenarios for the conterminous United States at the county spatial scale using SRES scenarios A1B and A2 and PRISM climatology. U.S. Forest Service, Rocky Mountain Research Station.

Download Site:	http://www.fs.fed.us/rm/data_archive/dataaccess
Date Downloaded:	June, 2010
Native Spatial Resolution:	County
Time Period:	2002 - 2100
Temporal Resolution:	Monthly
Parameters:	Total monthly precipitation, maximum and minimum monthly air temperature. Monthly mean temperature for use in WaSSI was estimated by computing the mean of the monthly maximum and minimum temperatures.
Scenario(s):	BCC-CSM1-1 RCP4.5 (1961-2099), BCC-CSM1-1 RCP8.5 (1961-2099), BCC-CSM1-1-M RCP4.5 (1961-2099), BCC-CSM1-1-M RCP8.5 (1961-2099), BNU-ESM RCP4.5 (1961-2099), BNU-ESM RCP8.5 (1961-2099), CanESM2 RCP4.5 (1961-2099), CanESM2 RCP8.5 (1961-2099), CCSM4 RCP4.5 (1961-2099), CCSM4 RCP8.5 (1961-2099), CNRM-CM5 RCP4.5 (1961-2099), CNRM-CM5 RCP8.5 (1961-2099), CSIRO-Mk3-6-0 RCP4.5 (1961-2099), CSIRO-Mk3-6-0 RCP8.5 (1961-2099), GFDL-ESM2M RCP4.5 (1961-2099), GFDL-ESM2M RCP8.5 (1961-2099), GFDL-ESM2G RCP4.5 (1961-2099), GFDL-ESM2G RCP8.5 (1961-2099), HadGEM2-ES RCP4.5 (1961-2099), HadGEM2-ES RCP8.5 (1961-2099), HadGEM2-CC RCP4.5 (1961-2099), HadGEM2-CC RCP8.5 (1961-2099), INMCM4 RCP4.5 (1961-2099), INMCM4 RCP8.5 (1961-2099), IPSL-CM5A-LR RCP4.5 (1961-2099), IPSL-CM5A-LR RCP8.5 (1961-2099), IPSL-CM5A-MR RCP4.5 (1961-2099), IPSL-CM5A-MR RCP8.5 (1961-2099), IPSL-CM5B-LR RCP4.5 (1961-2099), IPSL-CM5B-LR RCP8.5 (1961-2099), MIRCO5 RCP4.5 (1961-2099), MIROC5 RCP8.5 (1961-2099), MIROC-ESM RCP4.5 (1961-2099), MIROC-ESM RCP8.5(1961-2099), MIROC-ESM-CHEM RCP4.5 (1961-2099), MIROC-ESM-CHEM RCP8.5(1961-2099),MRI-CGCM3 RCP4.5 (1961-2099), MRI-CGCM3 RCP8.5 (1961-2099), NorESM1-M RCP4.5 (1961-2099), NorESM1-M RCP8.5(1961-2099)
Data Citation:	Climate forcings in the MACAv2-LIVNEH were drawn from a statistical downscaling of global climate model (GCM) data from the Coupled Model Intercomparison Project 5 (CMIP5, Taylor et al. 2010) utilizing a modification of the Multivariate Adaptive Constructed Analogs (MACA, Abatzoglou and Brown, 2012) method with the Livneh(Livneh et.al.,2013) observational dataset as training data.

Download Site: <https://climate.northwestknowledge.net/MACA/index.php>

Date Downloaded: April, 2015

Native Spatial Resolution: 1/6 X 1/6 ° grid (~6 km X 6 km)

Time Period: 1961 - 2099

Temporal Resolution: Monthly

Parameters: Monthly mean daily precipitation, monthly mean air temperature.
Monthly total precipitation computed by multiplying the monthly mean daily precipitation by the number of days in each month.

Mexico

The historical climate dataset (CCA UNAM 1902-1984) was developed based on the gridded monthly climate product provided by Universidad Nacional Autónoma de Mexico (UNAM, 2007). The future climate scenario GCMs available for Mexico are shown in Table B2. Please refer to IPCC (2000) for more information about the IPCC SRES emission scenarios and to EOS-Webster (2009) for more information regarding the GCM available for WaSSI model input for Mexico.

Table B2. WASSI Future Climate Scenario GCM Descriptions for Mexico

WaSSIweb Climate Scenario GCM Identifier	GCM Description
NCAR CCSM3	National Center for Atmospheric Research, USA: CCSM3

Scenario(s): CCA UNAM (1902-1984)

Data Citation: UNAM, 2007. Cressman analysis of monthly precipitation, and maximum and minimum temperature for Mexico and surroundings based upon CLICOM daily station data, GHCN Version 2 monthly station data, and University of East Anglia Climate Research Unit (CRU) monthly gridded data as the "first guess" for the Cressman analysis, from the Centro de Ciencias de la Atmósfera. Universidad Nacional Autónoma de México (UNAM).

Download Site: <http://iridl.ldeo.columbia.edu/SOURCES/.UNAM/.gridded/.monthly/.v0705/>

Date Downloaded:	July, 2010
Native Spatial Resolution:	0.5 X 0.5 ° grid
Time Period:	1902 - 1984
Temporal Resolution:	Monthly
Parameters:	Total monthly precipitation, maximum and minimum monthly air temperature. Monthly mean temperature for use in WaSSI was estimated by computing the mean of the monthly maximum and minimum temperatures.
Scenario(s):	NCAR CCSM3 SRES A2 (2001-2099), NCAR CCSM3 SRES A1B (2001-2099), NCAR CCSM3 SRES B1 (2001-2099)
Data Citation:	EOS-WEBSTER, 2009. NCAR Science & Research Data for IPCC AR4.
Download Site:	http://eos-webster.sr.unh.edu/data_guides/ci_science_dg.jsp
Date Downloaded:	September, 2009
Native Spatial Resolution:	1.40625 X 1.40625 ° grid
Time Period:	2001 – 2099
Temporal Resolution:	Monthly
Parameters:	Total monthly precipitation, maximum and minimum monthly air temperature. Monthly mean temperature for use in WaSSI was estimated by computing the mean of the monthly maximum and minimum temperatures.

Rwanda

The historical climate dataset (Historic 1961-2009) was developed from monthly observations at meteorological stations that were interpolated to a grid with a 0.5°x0.5° resolution (Harris et al., 2013). The future climate scenario GCMs available for Rwanda are shown in Table B3. Please refer to IPCC (2000) for more information about the IPCC SRES emission scenarios and to Meehl et al. (2007) for more information regarding the GCMs available for WaSSI model input for Rwanda.

Table B3. WaSSI Future Climate Scenario GCM Descriptions for Rwanda

WaSSIweb Climate Scenario GCM Identifier	GCM Description
CCCMA CGCM3	Canadian Centre for Climate Modeling & Analysis: CGCM3.1 (T47)

GFDL CM2	US Dept. of Commerce / NOAA / Geophysical Fluid Dynamics Laboratory, USA: GFDL-CM2.0
NCAR CCSM3	National Center for Atmospheric Research, USA: CCSM3
UKMO HADCM3	Hadley Centre for Climate Prediction and Research / Met Office, UK: UKMO-HadCM3

Scenario(s): CRUTS 3.1 (1961-2009)

Data Citation: University of East Anglia Climatic Research Unit (CRU). [Phil Jones, Ian Harris]. CRU Time Series (TS)3.10.01 high resolution gridded datasets, [Internet]. NCAS British Atmospheric Data Centre, 2012,

Download Site: http://badc.nerc.ac.uk/view/badc.nerc.ac.uk__ATOM__dataent_1256223773328276

Date Downloaded: May, 2011

Native Spatial Resolution: 0.5 X 0.5 ° grid

Time Period: 1961 – 2009

Temporal Resolution: Monthly

Parameters: Total monthly precipitation, monthly mean air temperature.

Scenario(s): CCCMA CGCM3 A1B (1961-2099), CCCMA CGCM3 A2 (1961-2099), GFDL CM2 A1B (1961-2099), GFDL CM2 A2 (1961-2099), NCAR CCSM3 A1B (1961-2099), NCAR CCSM3 A2 (1961-2099), UKMO HADCM3 A1B (1961-2099), UKMO HADCM3 A2 (1961-2099)

Data Citation: Global climate model output, from the World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model dataset (Meehl et al., 2007), were obtained from www.engr.scu.edu/~emaurer/global_data/. These data werdownscaled as described by Maurer et al. (2009) using the bias-correction/spatial downscaling method (Wood et al., 2004) to a 0.5 degree grid, based on the 1950-1999 gridded observations of Adam and Lettenmaier (2003).

Download Site: http://www.engr.scu.edu/~emaurer/global_data

Date Downloaded: July, 2010

Native Spatial Resolution: 1.40625 X 1.40625 ° grid

Time Period:	1961 – 2099
Temporal Resolution:	Monthly
Parameters:	Total monthly precipitation, maximum and minimum monthly air temperature. Monthly mean temperature for use in WaSSI was estimated by computing the mean of the monthly maximum and minimum temperatures.

Land Cover Distribution

Land cover distribution data used in the WaSSI model and available in the **WaSSIweb Input Viewer** may be accessed by selecting the *HUC Land Use* link made available after a land cover distribution chart has been displayed. Also available are the HUC area and mean elevation data, accessible by selecting the *HUC area* link (US only).

US

Land cover used for the US is based on the 30 X 30 m resolution 2011 National Land Cover Dataset (NLCD; Homer et al., 2015). The land cover classes of the NLCD were aggregated to 10 classes for use in WaSSI as follows.

<u>WaSSI Class</u>	<u>NLCD Class</u>
Crop	81 Pasture/Hay, 82 Cultivated Crops
Deciduous Forest	41 Deciduous Forest
Evergreen Forest	42 Evergreen Forest
Mixed Forest	43 Mixed Forest
Grassland	21 Developed, Open Space, 71 Grassland/Herbaceous
Shrubland	51 Dwarf Scrub, 52 Shrub/Scrub
Wetland	90 Woody Wetlands, 95 Emergent Herbaceous Wetlands
Open Water	11 Open Water
Urban	22 Developed, Low Intensity, 23 Developed, Medium Intensity, 24 Developed High Intensity
Barren	31 Barren Land (Rock/Sand/Clay)

Fields included in the *HUC Land Use* land cover input data files available for download in the **WaSSIweb Input Viewer** include:

ID	A numeric identifier for the HUC8 watershed
HUC_8	The WBD HUC8 watershed number for the data record. HUC8 numbers that start with zero do not include the leading zero.
Lat	Latitude of the HUC8 centroid
Long	Longitude of the HUC8 centroid
Crop	Fraction of HUC8 watershed in crop land cover
Decid	Fraction of HUC8 watershed in deciduous forest land cover
Evergreen	Fraction of HUC8 watershed in evergreen forest land cover
Mixed	Fraction of HUC8 watershed in mixed forest land cover
Grassland	Fraction of HUC8 watershed in grass land cover
Shrubland	Fraction of HUC8 watershed in shrub land cover
Wetland	Fraction of HUC8 watershed in wetland land cover
Water	Fraction of HUC8 watershed in open water land cover
Urban	Fraction of HUC8 watershed in urban land cover
Barren	Fraction of HUC8 watershed in barren land cover
Total	Sum of all land cover fractions (may not equal 1 due to rounding)

The HUC8 watershed area is derived from attributes of the Watershed Boundary Dataset (2010). HUC8 watershed mean elevation is computed based on the 30 x 30 m resolution National Elevation Dataset (Gesch et al., 2009). Fields included in the *HUC Area* input data files available for download in the **WaSSIweb Input Viewer** include:

ID	A numeric identifier for the HUC8 watershed
HUC_8	The WBD HUC8 watershed number for the data record. HUC8 numbers that start with zero do not include the leading zero.
AreaM2	Total area of the HUC8 watershed in m ²
ElevM	Mean elevation of the HUC8 watershed in m above mean sea level

Mexico

Land cover used for Mexico is based on the 2005 Land Cover of North America at 250 m (Center for Environmental Cooperation, 2010).

Fields included in the *HUC Land Use* land cover input data files available for download in the **WaSSIweb Input Viewer** include:

Cell	The grid cell number for the data record
Lat	Latitude of the grid cell center
Long	Longitude of the grid cell center
Crop	Fraction of grid cell in crop land cover
Decid	Fraction of grid cell in deciduous forest land cover
Evergreen	Fraction of grid cell in evergreen forest land cover
Mixed	Fraction of grid cell in mixed forest land cover
Grassland	Fraction of grid cell in grass land cover
Shrubland	Fraction of grid cell in shrub land cover
Savannas	Fraction of grid cell in savanna land cover
Water_urban	Fraction of grid cell in water and urban land cover
Total	Sum of all land cover fractions (may not equal 1 due to rounding)

Rwanda

Land cover used for Rwanda and Burundi is based on the 300 X 300 m resolution 2009 Globcover dataset. The land cover classes of Globcover were aggregated to 10 classes for use in WaSSI as follows.

<u>WaSSI Class</u>	<u>Globcover Class</u>
Crop	14 Rainfed croplands 20 Mosaic cropland (50-70%) / vegetation (grassland/shrubland/forest) (20-50%)
Deciduous Forest	50 Closed (>40%) broadleaved deciduous forest (>5m) 60 Open (15-40%) broadleaved deciduous forest/woodland (>5m)
Evergreen Forest	None present in study area
Mixed Forest	40 Closed to open (>15%) broadleaved evergreen or semi-deciduous forest (>5m)

	90 Open (15-40%) needleleaved deciduous or evergreen forest (>5m)
	100 Closed to open (>15%) mixed broadleaved and needleleaved forest (>5m)
Grassland	30 Mosaic vegetation (grassland/shrubland/forest) (50-70%) / cropland (20-50%)
Shrubland	110 Mosaic forest or shrubland (50-70%) / grassland (20-50%)
	120 Mosaic grassland (50-70%) / forest or shrubland (20-50%)
	130 Closed to open (>15%) (broadleaved or needleleaved, evergreen or deciduous) shrubland (<5m)
	140 Closed to open (>15%) herbaceous vegetation (grassland, savannas or lichens/mosses)
Water_Urban	150 Sparse (<15%) vegetation
	160 Closed to open (>15%) broadleaved forest regularly flooded (semi-permanently or temporarily) - Fresh or brackish water
	170 Closed (>40%) broadleaved forest or shrubland permanently flooded – Saline or brackish water
	180 Closed to open (>15%) grassland or woody vegetation on regularly flooded or waterlogged soil - Fresh, brackish or saline water
	190 Artificial surfaces and associated areas (Urban areas >50%)
	200 Bare areas
	210 Water bodies

Fields included in the *HUC Land Use* land cover input data files available for download in the **WaSSIweb Input Viewer** include:

Wsname	Watershed number for the data record
Lat	Latitude of the wsname centroid
Long	Longitude of the wsname centroid
Crop	Fraction of wsname watershed in crop land cover
Decid	Fraction of wsname watershed in deciduous forest land cover
Evergreen	Fraction of wsname watershed in evergreen forest land cover
Mixed	Fraction of wsname watershed in mixed forest land cover
Grassland	Fraction of wsname watershed in grass land cover
Shrubland	Fraction of wsname watershed in shrub land cover
Savannas	Fraction of wsname watershed in savanna land cover
Water_urban	Fraction of wsname watershed in water, urban, and barren land cover
Total	Sum of all land cover fractions (may not equal 1 due to rounding)

Leaf Area Index by Land Cover

Mean monthly leaf area index (LAI) by land cover was computed by overlaying the land cover data with remotely sensed LAI using 1 x 1 km resolution 2000-2012 Moderate Resolution Imaging Spectroradiometer (MODIS) MOD15 leaf area index product (Zhao et al., 2005). The 8-day time step LAI data were used to compute monthly mean LAI. LAI data in the *WaSSIweb Input Viewer* may be accessed by selecting the *Leaf Area Index* link made available after a leaf area index chart has been displayed.

Fields included in the *Leaf Area Index* input data files available for download in the **WaSSIweb Input Viewer** include:

HUC8 (US), or CELL (Mexico), or Wsname(Rwanda)	The WBD HUC8 watershed number (US) , grid cell identifier (Mexico), or watershed number (Rwanda) for the data record. HUC8 numbers that start with zero do not include the leading zero.
MONTH	The month of the data record, expressed as a number (e.g. 1=January, 2=February...12=December).
XXXX_LAI	The mean LAI for land cover XXXX for the HUC8/CELL and month of the data record.

Soil Parameters

The 11 soil parameters of the Sacramento Soil Moisture Accounting Model used in WaSSI to compute the watershed water balance are based on soil texture estimates of the 1 x 1 km STATSGO-based CONUS Soils data product (Miller and White, 1998) available at:

http://www.soilinfo.psu.edu/index.cgi?soil_data&conus. A combination of local soil texture information from Rwanda and the Harmonized World Soils Database version 1.2 (FAO, 2012) for Burundi were used to derive the Sacramento Soil Moisture Accounting Model parameters for Rwanda and Burundi. Using these soil texture data vs. depth, the soil parameters UZTWM, UZFWM, UZK, PFREE, ZPERC, REXP, LZTWM, LZFSM, LZFP, LZSK, and LZPK were estimated using the methods of Koren et al. (2003, 2005). These soil parameters are not currently available for download on **WaSSIweb**.

Water Use (US only)

Total water use data by sector used in the WaSSI model and available in the **WaSSIweb Input Viewer** may be accessed by selecting the *Gross Water Use* link made available after a water use chart has been displayed. These data are based on the county resolution USGS Estimated use of water in the United States in 2010 data product (Maupin et al., 2014).

Fields included in the *Gross Water Use* input data files available for download in the **WaSSIweb Input Viewer** include:

ID	A numeric identifier for the HUC8 watershed
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HUC_8	The WBD HUC8 watershed number for the data record. HUC8 numbers that start with zero do not include the leading zero.
Domestic	Total freshwater withdrawals (surface and groundwater) for the Domestic sector in million gallons per day
Industrial	Total freshwater withdrawals (surface and groundwater) for the Industrial sector in million gallons per day
Irrigation	Total freshwater withdrawals (surface and groundwater) for the Irrigation sector in million gallons per day
Livestock	Total freshwater withdrawals (surface and groundwater) for the Livestock sector in million gallons per day
Mining	Total freshwater withdrawals (surface and groundwater) for the Mining sector in million gallons per day
Thermo	Total freshwater withdrawals (surface and groundwater) for the Thermoelectric sector in million gallons per day
Public_supply	Total freshwater withdrawals (surface and groundwater) for the Public Supply sector in million gallons per day
Aquaculture	Total freshwater withdrawals (surface and groundwater) for the Aquaculture sector in million gallons per day
Total	Total freshwater withdrawals (surface and groundwater) for all sectors in million gallons per day
Ps_del_dom	Total freshwater withdrawals (surface and groundwater) that are delivered to the Domestic sector in million gallons per day

Return flow fractions by sector used in the WaSSI model and available in the **WaSSIweb Input Viewer** may be accessed by selecting the *Return Flow Percentage* link made available after a water use chart has been displayed. These data are based on the county resolution USGS Estimated use of water in the United States in 1995 data product (Solley et al., 1998). Return flows were not reported in the Estimated use of water in the United States in 2010 report (Maupin et al., 2014).

Fields included in the *Return Flow Percentage* input data files available for download in the **WaSSIweb Input Viewer** include:

ID	A numeric identifier for the HUC8 watershed
HUC_8	The WBD HUC8 watershed number for the data record. HUC8 numbers that start with zero do not include the leading zero.

Domestic_rf	Fraction of total freshwater withdrawals from surface and groundwater returned (not consumed) by the Domestic sector
Industrial_rf	Fraction of total freshwater withdrawals from surface and groundwater returned (not consumed) by the Industrial sector
Irrigation_rf	Fraction of total freshwater withdrawals from surface and groundwater returned (not consumed) by the Irrigation sector
Livestock_rf	Fraction of total freshwater withdrawals from surface and groundwater returned (not consumed) by the Livestock sector
Mining_rf	Fraction of total freshwater withdrawals from surface and groundwater returned (not consumed) by the Mining sector
Thermo_rf	Fraction of total freshwater withdrawals from surface and groundwater returned (not consumed) by the Thermoelectric sector
Public_supply_rf	Fraction of total freshwater withdrawals from surface and groundwater returned (not consumed) by the Public Supply sector
Aquaculture_rf	Fraction of total freshwater withdrawals from surface and groundwater returned (not consumed) by the Aquaculture sector

Groundwater Withdrawal (US only)

Groundwater withdrawal data by sector used in the WaSSI model and available in the **WaSSIweb Input Viewer** may be accessed by selecting the *Ground Water* link made available after a Groundwater Withdrawal chart has been displayed. These data are based on the county resolution USGS Estimated use of water in the United States in 2010 data product (Maupin et al., 2014).

Fields included in the *Ground Water* input data files available for download in the **WaSSIweb Input Viewer** include:

ID	A numeric identifier for the HUC8 watershed
HUC_8	The WBD HUC8 watershed number for the data record. HUC8 numbers that start with zero do not include the leading zero.
Domestic	Total freshwater groundwater withdrawals for the Domestic sector in million gallons per day
Industrial	Total freshwater groundwater withdrawals for the Industrial sector in million gallons per day
Irrigation	Total freshwater groundwater withdrawals for the Irrigation sector in million gallons per day

Livestock	Total freshwater groundwater withdrawals for the Livestock sector in million gallons per day
Mining	Total freshwater groundwater withdrawals for the Mining sector in million gallons per day
Thermo	Total freshwater groundwater withdrawals for the Thermoelectric sector in million gallons per day
Public_supply	Total freshwater groundwater withdrawals for the Public Supply sector in million gallons per day
Aquaculture	Total freshwater groundwater withdrawals for the Aquaculture sector in million gallons per day
Total	Total freshwater groundwater for all sectors in million gallons per day

Projected Population (US only)

2010-2060 projected population estimates used in the WaSSI model and available in the **WaSSIweb Input Viewer** may be accessed by selecting the *Population* link made available after a Projected Population chart has been displayed. These data are based on the county resolution IPCC SRES A1 scenario decadal population projections of Zarnoch et al. (2010). Annual population estimates were computed by linear interpolation between the decadal population data.

Fields included in the *Population* input data files available for download in the **WaSSIweb Input Viewer** include:

HUC_8	The WBD HUC8 watershed number for the data record. HUC8 numbers that start with zero do not include the leading zero.
Year	The year of the data record
Pop	Projected population in thousands

Model Outputs

Outputs of the WaSSI model are computed based on the simulation scenario in the **WaSSIweb Simulation Tool**. Output data files at the monthly, annual, and mean annual time scale are available for download on the **WaSSIweb Output Viewer** when an output chart is displayed. Please review Appendix A for a description of how the model outputs are computed.

Water Balance

Monthly Water Balance

The monthly water balance output computed in the WaSSI model and available in the **WaSSIweb Output Viewer** may be accessed by selecting the *Monthly Water Balance* link made available after a Water Balance chart has been displayed with the Monthly or the Annually time scale selected.

Fields included in the *Monthly Water Balance* output data files available for download in the **WaSSIweb Output Viewer** include:

CELL	The WBD HUC8 watershed number (US), grid cell identifier (Mexico), or watershed number (Rwanda) for the data record. HUC8 numbers that start with zero do not include the leading zero.
YEAR	Year of the data record.
MONTH	Month of the data record, expressed as a number (e.g. 1=January, 2=February...12=December).
RAIN_MM	Total precipitation for the month in mm.
SOLPSAT	Soil moisture expressed as a fraction of saturation for the month (unitless).
SNWPK_MM	Mean snow water equivalent on the land surface for the month in mm.
PET_MM	Total potential evapotranspiration (PET) for the month in mm, computed using the Hamon PET equation (Hamon, 1963).
PAET_MM	Total PET for the month in mm, computed using leaf area index, precipitation, and Hamon PET (Sun, 2011).
AET_MM	Total actual evapotranspiration (AET) for the month in mm, accounting for available soil moisture.
AETPETR	Ratio of AET:PET, with PET computed using the Hamon equation.
RO_MM	Total runoff (water yield) for the month in mm, is the sum of surface runoff, interflow, and baseflow.

Annual Water Balance

The annual water balance output computed in the WaSSI model and available in the **WaSSIweb Output Viewer** may be accessed by selecting the *Annual Water Balance* link made available after a Water Balance chart has been displayed with the Monthly or the Annually time scale selected.

Fields included in the *Annual Water Balance* output data files available for download in the **WaSSIweb Output Viewer** include:

CELL	The WBD HUC8 watershed number (US), grid cell identifier (Mexico), or watershed number (Rwanda) for the data record. HUC8 numbers that start with zero do not include the leading zero.
YEAR	Year of the data record.

RAIN	Total precipitation for the year in mm.
SOLPSAT	Mean soil moisture expressed as a fraction of saturation for the year (unitless).
PET	Total potential evapotranspiration (PET) for the year in mm, computed using the Hamon PET equation (Hamon, 1963).
AET	Total actual evapotranspiration (AET) for the year in mm, accounting for available soil moisture and land cover (Sun et al., 2011).
AETPETR	Ratio of AET:PET, with PET computed using the Hamon equation.
RUNOFF	Total runoff (water yield) for the year in mm, is the sum of surface runoff, interflow, and baseflow.
RUN_P	Fraction of precipitation as runoff for the year.
ET_P	Fraction of precipitation as evapotranspiration for the year.
RUNET_P	Fraction of precipitation as runoff and evapotranspiration for the year.
MAXSWE	Maximum monthly snow water equivalent on the land surface for the year in mm.

Average Annual Water Balance

The mean annual water balance output computed in the WaSSI model and available in the **WaSSIweb Output Viewer** may be accessed by selecting the *Average Annual Water Balance* link made available after a Water Balance chart has been displayed with the Average Annual time scale selected.

Fields included in the *Average Annual Water Balance* output data files available for download in the **WaSSIweb Output Viewer** include:

CELL	The WBD HUC8 watershed number (US), grid cell identifier (Mexico), or watershed number (Rwanda) for the data record. HUC8 numbers that start with zero do not include the leading zero.
RAIN	Mean annual precipitation for the HUC8/cell in mm.
TEMP	Mean annual temperature for the HUC8/cell in degrees Celsius.
MAX_SWE	Mean annual maximum snow water equivalent on the land surface for the HUC8/cell in mm.
SOLPSAT	Mean annual soil moisture expressed as a fraction of saturation for the HUC8/cell (unitless).

PET	Mean annual potential evapotranspiration (PET) for the HUC8/cell in mm, computed using the Hamon PET equation (Hamon, 1963).
AET	Mean annual actual evapotranspiration (AET) for the HUC8/cell in mm, accounting for available soil moisture and land cover (Sun et al., 2011).
AETPETR	Ratio of AET:PET, with PET computed using the Hamon equation.
RUNOFF	Mean annual runoff (water yield) for the HUC8/cell in mm, is the sum of surface runoff, interflow, and baseflow.
RUN_P	Fraction of mean annual precipitation as runoff for the HUC8/cell.
ET_P	Fraction of mean annual precipitation as evapotranspiration for the HUC8/cell.
RUNET_P	Fraction of mean annual precipitation as runoff and evapotranspiration for the HUC8/cell.

Ecosystem Productivity

Monthly Ecosystem Productivity

The monthly ecosystem productivity output computed in the WaSSI model and available in the **WaSSIweb Output Viewer** may be accessed by selecting the *Monthly Carbon* link made available after an Ecosystem Productivity chart has been displayed with the Monthly or the Annually time scale selected.

Fields included in the *Monthly Carbon* output data files available for download in the **WaSSIweb Output Viewer** include:

CELL	The WBD HUC8 watershed number (US), grid cell identifier (Mexico), or watershed number (Rwanda) for the data record. HUC8 numbers that start with zero do not include the leading zero.
YEAR	The year of the data record.
MONTH	The month of the data record, expressed as a number (e.g. 1=January, 2=February...12=December).
GEP(gC_M2_MO)	Gross ecosystem productivity (GEP) for the month in grams of carbon per m ² per month
RES	Ecosystem respiration (RES) for the month in grams of carbon per m ² per month
NEE	Net ecosystem exchange (NEE) for the month in grams of carbon per m ² per month

Annual Ecosystem Productivity

The annual ecosystem productivity output computed in the WaSSI model and available in the **WaSSIweb Output Viewer** may be accessed by selecting the *Annual Carbon* link made available after an Ecosystem Productivity chart has been displayed with the Monthly or the Annually time scale selected.

Fields included in the *Annual Carbon* output data files available for download in the **WaSSIweb Output Viewer** include:

CELL	WBD HUC8 watershed number (US), grid cell identifier (Mexico), or watershed number (Rwanda) for the data record. HUC8 numbers that start with zero do not include the leading zero.
YEAR	Year of the data record.
GEP(gC_M2_YR)	Total gross ecosystem productivity (GEP) for the year in grams of carbon per m ² per year.
RES	Total ecosystem respiration (RES) for the year in grams of carbon per m ² per year.
NEE	Total net ecosystem exchange (NEE) for the year in grams of carbon per m ² per year.

Average Annual Ecosystem Productivity

The average annual ecosystem productivity output computed in the WaSSI model and available in the **WaSSIweb Output Viewer** may be accessed by selecting the *Average Annual Carbon* link made available after an Ecosystem Productivity chart has been displayed with the Average Annual time scale selected.

Fields included in the *Average Annual Carbon* output data files available for download in the **WaSSIweb Output Viewer** include:

CELL	WBD HUC8 watershed number (US), grid cell identifier (Mexico), or watershed number (Rwanda) for the data record. HUC8 numbers that start with zero do not include the leading zero.
YRS	Number of years over which the mean annual ecosystem productivity was computed.
GEP(gC_M2_YR)	Mean annual gross ecosystem productivity (GEP) for the HUC8/CELL in grams of carbon per m ² per year.
RES	Mean annual ecosystem respiration (RES) for the HUC8/CELL in grams of carbon per m ² per year.

NEE Mean annual net ecosystem exchange (NEE) for the HUC8/CELL in grams of carbon per m² per year.

Water Supply and Demand (US only)

Monthly Water Supply and Demand

The monthly water supply and demand output computed in the WaSSI model and available in the **WaSSIweb Output Viewer** may be accessed by selecting the *Monthly WaSSI* link made available after an Water Supply and Demand chart has been displayed with the Monthly or the Annually time scale selected.

Fields included in the *Monthly WaSSI* output data files available for download in the **WaSSIweb Output Viewer** include:

CELL	WBD HUC8 watershed number for the data record. HUC8 numbers that start with zero do not include the leading zero.
YEAR	Year of the data record.
MONTH	Month of the data record, expressed as a number (e.g. 1=January, 2=February...12=December).
SWS_MGD	Total surface water supply available for use at the outlet of the HUC8 for the month in millions of gallons per day.
GWS_MGD	Total groundwater water supply available for use in the HUC8 for the month in millions of gallons per day.
TOTSUP_MGD	Total water supply available for use in the HU8 for the month in millions of gallons per day. This is the sum of SWS_MGD and GWS_MGD.
GROSSDEM_MGD	Total gross water use (surface and groundwater) in the HUC8 for the month in millions of gallons per day, not accounting for return flows.
NETDEM_MGD	Total net water use (surface and groundwater) in the HUC8 for the month in millions of gallons per day, after accounting for return flows.
WASSI	Monthly Water Supply Stress Index (WaSSI) for the HUC8 and month, computed as the gross water use (GROSSDEM_MGD) divided by the total water supply (TOTSUP_MGD).
CONSUSE_Mm3_MO	Total consumptive water use removed from the outflow of the HUC8 to the next downstream HUC8 for the month in millions of m ³ per month.
FLWOUT_Mm3_MO	Total outflow of the HUC8 to the next downstream HUC8 for the month after accounting for consumptive water use in the HUC8 of the data record, in millions of m ³ per month.

DEMSTOR_Mm3_MO	Total excess demand assumed to come from an infinite storage reservoir if the gross water demand (GROSSDEM_MGD) for the HUC8 and month exceeds available water supply (TOTSUP_MGD) for the HUC8 and month in millions of m ³ per month.
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Annual Water Supply and Demand

The annual water supply and demand output computed in the WaSSI model and available in the **WaSSIweb Output Viewer** may be accessed by selecting the *Annual WaSSI* link made available after an Water Supply and Demand chart has been displayed with the Monthly or the Annually time scale selected.

Fields included in the *Annual WaSSI* output data files available for download in the **WaSSIweb Output Viewer** include:

CELL	WBD HUC8 watershed number for the data record. HUC8 numbers that start with zero do not include the leading zero.
YEAR	Year of the data record.
SWS_MGD	Total surface water supply available for use at the outlet of the HUC8 for the year in millions of gallons per day.
GWS_MGD	Total groundwater water supply available for use in the HUC8 for the year in millions of gallons per day. This is the same as the total groundwater withdrawals in the USGS Estimated Use of Water in the United States in 2010 data product (Maupin et al., 2014) unless the groundwater withdrawals were modified in the WaSSIweb Simulation Tool .
TOTSUP_MGD	Total water supply available for use in the HU8 for the year in millions of gallons per day. This is the sum of SWS_MGD and GWS_MGD.
GROSSDEM_MGD	Total gross water use (surface and groundwater) in the HUC8 for the year in millions of gallons per day, not accounting for return flows. This is the same as the total water use in the USGS Estimated Use of Water in the United States in 2010 data product (Maupin et al., 2014) unless water use was modified in the WaSSIweb Simulation Tool .
NETDEM_MGD	Total net water use (surface and groundwater) in the HUC8 for the year in millions of gallons per day, after accounting for return flows.
WASSI	Annual Water Supply Stress Index (WaSSI) for the HUC8 and year, computed as the gross water use (GROSSDEM_MGD) divided by the total water supply (TOTSUP_MGD).

CONSUSE_Mm3_YR	Total consumptive water use removed from the outflow of the HUC8 to the next downstream HUC8 for the year in millions of m ³ per year.
FLWOUT_Mm3_YR	Total outflow of the HUC8 to the next downstream HUC8 for the year after accounting for consumptive water use in the HUC8 of the data record, in millions of m ³ per year.
DEMSTOR_Mm3_YR	Total excess demand for the year assumed to come from an infinite storage reservoir for the HUC8 for months in the year where the gross water demand (GROSSDEM_MGD) exceeds available water supply (TOTSUP_MGD) in millions of m ³ per year.

Average Annual

The average annual water supply and demand output computed in the WaSSI model and available in the **WaSSIweb Output Viewer** may be accessed by selecting the *Average Annual WaSSI* link made available after an Water Supply and Demand chart has been displayed with the Average Annual time scale selected.

Fields included in the *Average Annual WaSSI* output data files available for download in the **WaSSIweb Output Viewer** include:

CELL	WBD HUC8 watershed number for the data record. HUC8 numbers that start with zero do not include the leading zero.
YRS	Number of years over which the mean annual water supply and demand was computed.
SWS_MGD	Mean annual total surface water supply available for use at the outlet of the HUC8 in millions of gallons per day.
GWS_MGD	Mean annual total groundwater water supply available for use in the HUC8 in millions of gallons per day. This is the same as the total groundwater withdrawals in the USGS Estimated Use of Water in the United States in 2010 data product (Maupin et al., 2014) unless the groundwater withdrawals were modified in the WaSSIweb Simulation Tool .
TOTSUP_MGD	Mean annual total water supply available for use in the HU8 in millions of gallons per day. This is the sum of SWS_MGD and GWS_MGD.
GROSSDEM_MGD	Mean annual total gross water use (surface and groundwater) in the HUC8 in millions of gallons per day, not accounting for return flows. This is the same as the total water use in the USGS Estimated Use of

Water in the United States in 2010 data product (Maupin et al., 2014) unless water use was modified in the **WaSSIweb Simulation Tool**.

NETDEM_MGD	Mean annual total net water use (surface and groundwater) in the HUC8 in millions of gallons per day, after accounting for return flows.
WASSI	Mean annual Water Supply Stress Index (WaSSI) for the HUC8, computed as the gross water use (GROSSDEM_MGD) divided by the total water supply (TOTSUP_MGD).
CONSUSE_Mm3_YR	Mean annual total consumptive water use removed from the outflow of the HUC8 to the next downstream HUC8 in millions of m ³ per year.
FLWOUT_Mm3_YR	Mean annual total outflow of the HUC8 to the next downstream HUC8 after accounting for consumptive water use in the HUC8 of the data record, in millions of m ³ per year.
DEMSTOR_Mm3_YR	Mean annual total excess demand assumed to come from an infinite storage reservoir for the HUC8 for months where the gross water demand (GROSSDEM_MGD) exceeds available water supply (TOTSUP_MGD) in millions of m ³ per year.

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Appendix C: WaSSI Publications

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