

Web-based decision support system tools: The Soil and Water Assessment Tool Online visualization and analyses (SWATOnline) and NASA earth observation data downloading and reformatting tool (NASAaccess)

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Highlights

- SWATonline & NASAaccess Tethys web apps developed for hydroclimatic applications.
- The web apps are modular and can be hosted anywhere (public or private servers).
- Web apps provide easy access and retrieval capabilities to climate data.
- Web apps address needs for SWAT easy access and visualization functionalities.

Abstract

The current influx of climate related information required scientists to communicate their findings to decision makers in governments, disaster preparedness organizations, and the general public. The Soil and Water Assessment Tool (SWAT) is a powerful modelling tool that allows scientists to simulate many of the physical processes involved in the water cycle. This article presents the design, methods and development efforts to overcome some of the limitations of the previously developed SWAT visualization software programs by creating a set of modular web applications that can be duplicated, customized, and run. Moreover, this article features a web application development tool for climate data retrieval. The NASAaccess fetches, extracts and reformats climate data from the National Aeronautics and Space Administration servers and outputs data compatible with hydrological models. This work has the potential to increase the SWAT's model impact on non-technically trained stakeholders and decision makers charged with water and climate management.

Keywords: Tethys; SWAT; Remote Sensing; Climate; Water Management; NASA

Software availability

All SWATonline and NASAaccess related source code and documentation is available online at <https://github.com/BYU-Hydroinformatics/SWATOnline.git>.

1. Introduction

Over the last several years the issue of climate change has come to the forefront of many political and economic issues. Multiple initiatives of the United Nations such as the 2015 United Nations Climate Change Conference COP 21 Paris Agreement (<https://unfccc.int/>), the Sustainable Development Goals (United Nations, 2016), and the Sendai Framework (United Nations Office for Disaster Risk Reduction, 2015) are strongly linked to the sustainability of the environment and resilience and risk reduction from climatological disasters. In addition to the overly politicized climate change crisis, there are also natural disasters occurring on a very frequent basis. These crises and disasters are generally unavoidable and have led many to question how these global changes (e.g., deforestation, global warming, population growth, and natural disasters) will affect the livelihoods of humans around the world (Foley, 2011). These climate issues have simultaneously emerged into global awareness with the growth of Big Data or, more specifically, the increase in the amount of climate data that is now available (Faghmous and Kumar, 2014). The emergence of better technologies to access, analyze, and share climate information can greatly improve the efforts of governments around the world and also people in disaster-prone areas to prepare for, and respond to changes in climate and the increasing frequencies of disasters.

Earth observations, both from space and ground, when supplemented with climate models and statistical data assimilation methods have already proven to be powerful tools in forecasting future events, analyzing past events, and performing various scenario analyses to assist in disaster preparedness and future infrastructure planning. Efforts are being made within the fields of data science, climatology, hydrology, and hydroinformatics to use these data to better understand water management and to ensure its fair use (e.g., Group on Earth Observations, GEO, <https://www.earthobservations.org>). One commonly used tool for understanding climate and hydrologic information by decision-makers is the Soil and Water Assessment Tool, SWAT, (Arnold et al., 1998). The SWAT model has been used globally to model physical processes involved in the hydrologic cycle, and has proven to be a valuable resource for supporting the decision making responsibilities of water managers (Muleta and Nicklow, 2005). Through using the SWAT, decision-makers and stakeholders can better understand the impacts of both natural and human driven changes on the environment and then make more informed decisions (Arias et al., 2011).

One of the objectives of the relatively new field of hydroinformatics is to use information and communication technologies to store, manage, and analyze water data so that more people can understand the water cycle and its impact on the environment (Chen and Han, 2016). However, even with new advances in data management techniques and the continuous generation of climate data and model simulations, a very small amount these data are actually being used for decision support (Lehmann et al., 2014). In a study done by Overpeck et al. (2011), the amount of climate data is projected to reach 350 petabytes (1 PB = 1,000 TB) by the year 2030, however, according to Selding (2012) only 3-5% of the currently available data is

actually being used. The findings of Dahlhaus et al. (2015) suggest that an even smaller amount of that climate data is reaching those that can use it to make decisions.

Within the petabytes of data from earth observations and climate models, there are patterns that can help us understand the past and predict future changes in the earth's climate (Assunção et al., 2015). Unfortunately, the people responsible for making decisions based on the information from these climate data and models generally do not have the infrastructure, the time, or the technical expertise to sift through and analyze the raw data to make the informed decisions for which the data was produced in the first place (Dahlhaus et al., 2015). For this reason, the full potential of the SWAT model and other climate data sources has yet to be realized. The complexity in obtaining and preparing the necessary data, running the models, and then interpreting the data has been a barrier for those lacking the technical training, software licenses, and computing resources (Jayakrishnan et al., 2005; Lehmann et al., 2017).

The work presented in this article represents an effort to lower technical barriers for the SWAT model through using open source web development, web services, and cloud storage technologies. Using the Tethys platform (Swain, 2015; Swain et al., 2016) as the web framework and the data and model outputs from the upgraded regional SWAT model for the Lower Mekong River Basin in southeast Asia (Mohammed et al., 2018), an online SWAT data portal was developed in the form of two separate modular web applications, the NASAaccess app (Mohammed, 2019) and the SWATonline data viewer. While the SWAT model used here as a case study for the Lower Mekong River Basin, the developed application is completely open source and modular. This means that the apps provided and presented in this work can be replicated, customized, and implemented anywhere (Ames et al., 2016; Croney et al., 2007) for any watershed with the SWAT model output data.

2. Background

2.1. The Soil and Water Assessment Tool (SWAT)

The Soil and Water Assessment Tool (SWAT) is a powerful modelling tool that allows scientists to simulate many of the physical processes involved in the water cycle (Arnold and Fohrer, 2005; Arnold et al., 2012; Douglas-Mankin et al., 2010; Gassman et al., 2007). Each SWAT model simulation produces a large number of output files with a large amounts of information. Each file represents the model outputs for one of the watershed subdivision units outlined above (i.e., full watershed, subbasins, HRUs, and stream reaches). These files are all written in ASCII text format and contain either daily, monthly, or yearly time steps for a wide range of variables for each modeling unit (subbasin, HRU, or stream segment) (Arnold et al., 2012). Among the many output files produced by SWAT, the primary ones are:

- output.sub - time series data for each subbasin,
- output.hru - timeseries data for each HRU,
- output.rch - timeseries data for each stream reach.

For more information on the SWAT output files, see the SWAT Input/Output documentation at <https://swat.tamu.edu/documentation/2012-io/>. These SWAT output files can often be very large in size which leads to difficulty in extracting and visualizing data. To handle these complex files, there are a number of robust GIS software systems that have been developed in the SWAT's relatively short history to assist users in preparing input data, running the models, and

then visualizing the model outputs (Abbaspour et al., 2015; Babbar-Sebens et al., 2015; Baird & Associates, 2004; Dile et al., 2016; Fant et al., 2017; Giuliani et al., 2013; Gorgan et al., 2012; Jayakrishnan et al., 2005; Rajib et al., 2016; Winchell et al., 2010; Yen et al., 2016; Yu, 2018; Zhang et al., 2015). Currently, however, many of these software systems are time and knowledge intensive to use, often are not interoperable with other software, and sometimes rely on license restricted software programs like ArcGIS (Giuliani et al., 2013) that must be updated periodically on the user’s desktop computers. Desktop applications, software plugins, and standalone software programs that SWAT users can run from a local computer are currently the most commonly used among SWAT model developers.

Desktop software will likely continue to play a key role in the SWAT model development and visualization for scientists, and developers familiar with the SWAT model. However, there are limitations to how useful these tools can be for stakeholders without technical training in the SWAT model, but for whom data and information from the SWAT models is a vital part of their decision process. Operating system compatibility, licensing costs, and software versioning issues can often inhibit users from having access to the newest or most robust technologies. In addition, the ‘local’ nature of these technologies causes issues when sharing data across disciplines or organizations is required. The technical expertise needed to create a custom SWAT model using these desktop applications requires those interested in the SWAT model to have the computational and storage resources locally to run the model and store all of the outputs. This severely limits the potential for data sharing and collaboration between users unless they are all looking at the same computer screen. In recent years, there have been efforts to bring the SWAT model functionality to the web. These efforts were due, in part, to the need for more collaboration and data sharing between the SWAT model developers and stakeholders. Table 1 is a representation of some of the key features for the most commonly used SWAT model related desktop programs and web services.

Tool	Desktop/Web	Open Source	Modular	Output Visualization	Data Sharing
ArcSWAT (Winchell et al., 2010)	Desktop		X		
QSWAT (Dile et al., 2016)	Desktop	X	X	X	
SWAT-CUP (Abbaspour et al., 2015)	Desktop	X	X	X	
SWAT Output Viewer (Yu, 2018)	Desktop	X	X	X	
VIZSWAT (Baird & Associates, 2004)	Desktop		X	X	
OWS4SWAT (Giuliani et al., 2013)	Web	X	X	X	
WRESTORE	Web	X		X	X

(Babbar-Sebens et al., 2015)

DSS-WMRJ (Zhang et al., 2015)	Web	X	X	
SWATShare (Rajib et al., 2016)	Web	X	X	X
HAWQS (Yen et al., 2016; Fant et al., 2017)	Web	X	X	X
gSWAT (Gorgan et al., 2012)	Web	X	X	X

Table 1. Review of currently available SWAT model software.

From a review of the most relevant software systems for the SWAT model, modularity and data sharing emerge as two key features that, when combined will help make the SWAT model reach to a new level of impact in the SWAT model users' community. The modularity (i.e., think of the independent mobility of the apps on your smartphone) of the desktop applications allows them to meet the unique needs of specific areas, as there is not a one-size-fits-all solution for all situations, especially in hydrology. Since desktop applications fall short in their lack of data sharing capabilities and compatibility across operating systems. On the other hand, the open nature of the web technologies facilitates a much higher level of scientist-stakeholder collaboration and data sharing, than the technically exclusive desktop applications. Adding here that, these web interfaces for the SWAT model are tied to servers hosting them which limit their potential global impact.

The development of new web applications introduced in this work that leverage data sharing capabilities of current web technologies and that can be duplicated, installed, and hosted anywhere, the SWAT model's ability to meet the unique data and modeling needs of stakeholders in any region will improve significantly.

2.2. NASAaccess

One of the main obstacles in running the SWAT model lies in the difficulty of accessing the various input files required. Without access to in-situ observed data from local organizations, a user's options are often limited to having to use a global dataset like the Global Precipitation Measurement, GPM, (Huffman et al., 2018) and the Global Land Data Assimilation System, GLDAS, (Rodell et al., 2004) datasets. While these datasets are available for free, their global nature requires for a substantial amount of pre-processing before the data can be used in a model like SWAT (Rahman et al., 2017). NASAaccess is a software tool built in R software program (R Development Core Team, 2018) that streamlines the retrieval and processing of the global National Aeronautics and Space Administration (NASA) earth observation data products (i.e., GPM and GLDAS) for use in hydrological models such as the SWAT (Mohammed, 2019; Mohammed et al., 2018). The core functionality of the NASAaccess can be summarized as:

- Access the NASA Goddard Space Flight Center (GSFC) servers to download earth observation data,

- Clip needed grids to an input shapefile of a user study watershed,
- Handle temporal and spatial inconsistencies,
- Generate daily climate gridded data files and definition files compatible with the SWAT and other hydrological models.

The NASAaccess software package was built as an R library containing four separate data processing functions which are described in Table 2. It is a very efficient system for accessing earth observation data. However, the number of potential users has been limited in part because of the relatively high learning curve involved in using the R language. Part of the work presented in this article involves an effort to make the NASAaccess software functionality available to a wider audience using a custom web interface developed through the Tethys development framework (Swain, 2015; Swain et al., 2016).

Function	Definition
GLDASwat	Generates SWAT compatible air temperature input files
GPMswat	Generates SWAT compatible precipitation input files
GLDASpolycentroid	Generates air temperature table from GLDAS grids falling within a specified watershed by assigning a pseudo air temperature gauge located at the centroid of the watershed a weighted-average daily minimum and maximum air temperature data record
GPMpolycentroid	Generates precipitation table from TRMM/GPM grids falling within a specified watershed by assigning a pseudo precipitation gauge located at the centroid of the watershed a weighted-average daily precipitation data record

Table 2. List of the NASAaccess software functions.

2.3. The Tethys Platform: A modular platform for visualizing and sharing SWAT input and output data

The Tethys platform (Swain, 2015; Swain et al., 2016) was created to lower barriers of web application development for engineers and hydrologists so they could better share models and data. The Tethys combines many of the most commonly used technologies and scripting languages for database management, data processing, and web design into a relatively easy to use framework for developing web-based applications and decision support tools. The architecture used by Tethys can be divided into three main components: Tethys SDK (Software Development Kit), Tethys Portal, and Tethys Software Suite. The combination of these three components in Tethys provide developers with all the tools needed to create robust, modular web-based tools for processing and sharing data.

Tethys web apps are developed using the Python programming language and a Software Development Kit (SDK). The SDK provides Python module links to each software component of the Tethys Platform, making the functionality of each component more accessible to “novice” programmers who have a working knowledge of Python but not all of the underlying web technologies such as html, javascript, css, PostGIS, GeoServer and others used by Tethys and

necessary to create a robust geospatial web application. Developers can use any of the Python packages that they are accustomed to using in their scientific modeling to control the functionality of their web apps.

The second component, Tethys Portal, is where developed apps are published. It acts as an app landing page for the users to access installed apps. Based on the django framework, it includes tools and functionalities to customize features such as user permissions, portal design, security, and content management.

The final component, the Tethys Software Suite, contains tools and packages such as Geoserver, PostgreSQL, OpenLayers, and more that are used commonly when developing geospatial web apps. Each of these tools has been built in to the overall functionality of Tethys and accessible through Python making it a very powerful tool, not only for displaying data, but also for any number of geoprocessing and database services. A visual representation of the Tethys platform software architecture can be reviewed at Swain et al. (2016). The complete documentation for the Tethys platform is available at <http://docs.tethysplatform.org/en/stable/index.html>.

3. Online SWAT data portal software organization

The application structure for both the NASAaccess and the SWATonline data viewer apps follows the Model-View-Controller (MVC) software architecture as shown in Figure 1 and Figure 2. This allows for simple, readable, and reusable code. The web app model is responsible for initializing the database, a PostgreSQL database in this case, and managing the database structure. The controllers are scripts written in Python that handle the logic and functionality of the web application and connect the data in the database and the server to the front end. Within these controller functions, scientists are able to leverage the wealth of already developed Python packages (e.g., pandas, gdal, numpy) along with their own customized scripts to control the data retrieval, processing, and analysis functions of an app. The data is then passed from the controller to the views. The views represent the HTML pages that are rendered for the users to see and include necessary web-based GIS mapping functionalities. The data from the controllers is passed in the form of context variables, meaning variables that are created every time the app is initiated, thus ensuring that the data is dynamic.

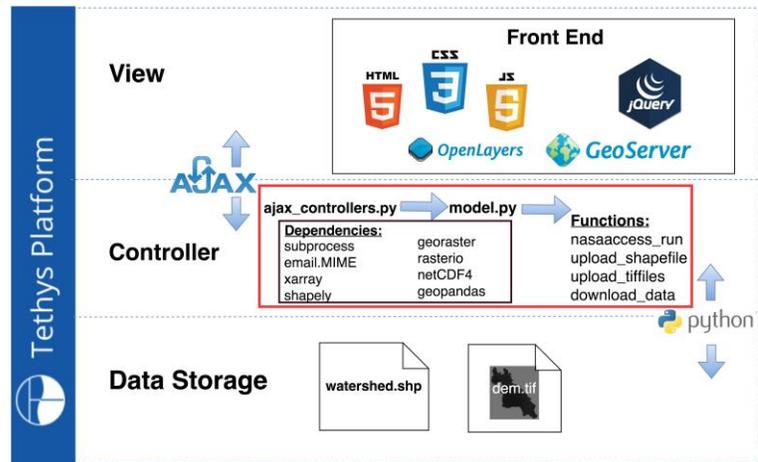


Figure 1. A schematic that illustrates the NASAAccess app model-view-controller architecture. The NASAAccess Tethys web app model contains four developed functions highlighted with a red rectangle to retrieve, extract, and reformat weather and climate data.

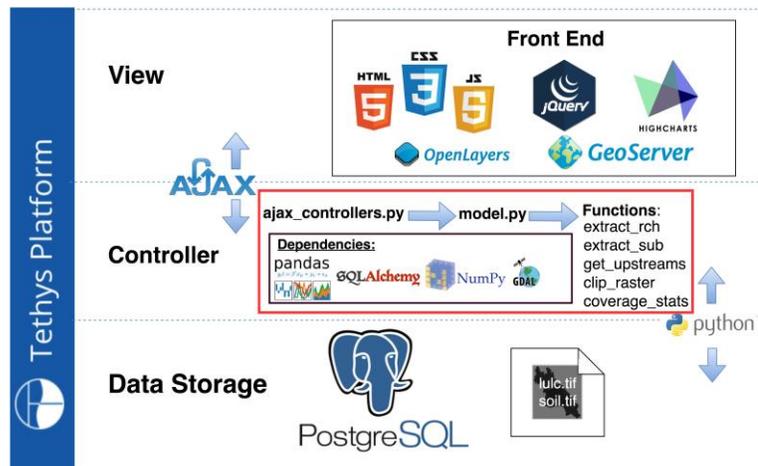


Figure 2. A schematic that describes the SWATonline app model-view-controller architecture. The SWATonline Tethys web app model processes and handles various SWAT model input and outputs files. The SWATonline app model-view-controller architecture allows SWAT input and output data to be viewed as HTML pages and include necessary web-based GIS mapping functionalities.

The Tethys App folder structure was designed for easy duplication and deployment. In the app package each file plays a role in making the app work as illustrated in the file structure diagrams shown in Figure 3 and Figure 4. The 'controllers.py' file contains all of the code directly related to the initial view of the app. It also manages all of the user actions within the app. In other words, it takes user inputs from the app interface, passes them into the various data processing python functions and then renders or updates the app interface based on the output data of the functions called. The templates directory contains the HTML pages that are rendered to the front end. The public directory contains resources that are responsible for rendering the HTML content, such as JavaScript, Cascading Style Sheets (CSS), and Images. The

public directory also contains any external libraries. The original Django app structure has several moving parts within the MVC architecture, and thus is not straightforward for novice developers. The Tethys project app structure has all the MVC components within the app directory, making it easier for first-time web developers to leverage the MVC structure and focus on their own code in Python through the 'controllers.py' file.

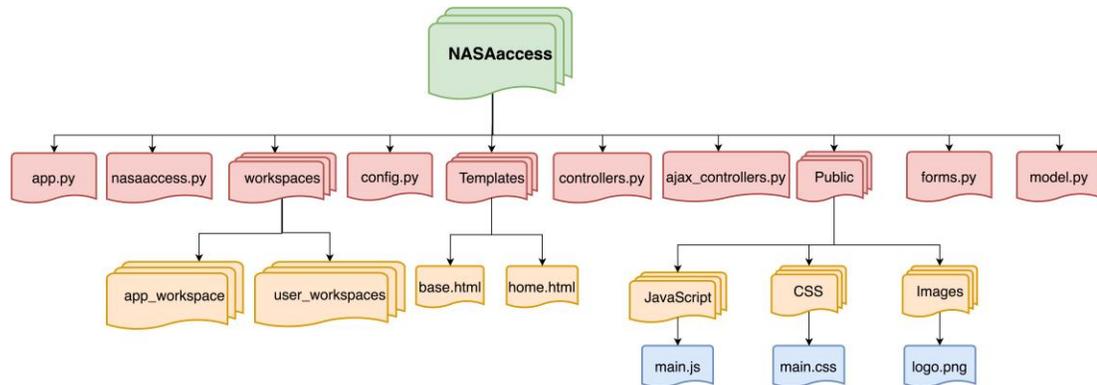


Figure 3. The NASAAccess Tethys web app file folder structure design. The design has been made to include all the model-view-controller components within the web app directory to enhance the software development.

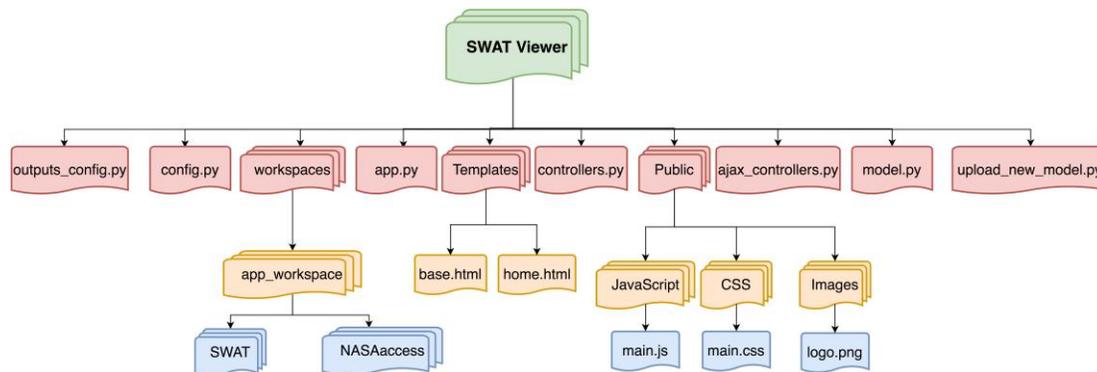


Figure 4. The SWATOnline data Viewer Tethys web app file structure design. The design has been developed to work with the NASAAccess Tethys web app (Figure 3) so that users can visualize weather and climate data concurrently while querying and analyzing SWAT model input and output data.

4. The SWATOnline design and key capabilities

In this section, the key functionalities of the NASAAccess and the SWATOnline data viewer apps will be introduced. Data and model outputs from the upgraded regional SWAT model for the Lower Mekong River Basin (Mohammed et al., 2018) will be used for illustration purposes. The NASAAccess web app is simply a user interface for accessing the NASAAccess software (Mohammed, 2019) which acts as a data portal for those interested in accessing climate data from NASA with limited time or technical background. The SWATOnline data viewer is a fully customizable interface for visualizing, processing, and downloading the SWAT model outputs (Figure 5). Developers are encouraged to visit the related NASAAccess and SWATOnline web apps source code and documentation available at <https://github.com/BYU->

Hydroinformatics/SWATOnline.git. In summary, the NASAaccess and SWATonline web apps can be used to simplify the SWAT input and output data querying, visualization, and sharing processes in addition to providing decision makers and water managers with simple data visualization tools to use while engaging with stakeholders.

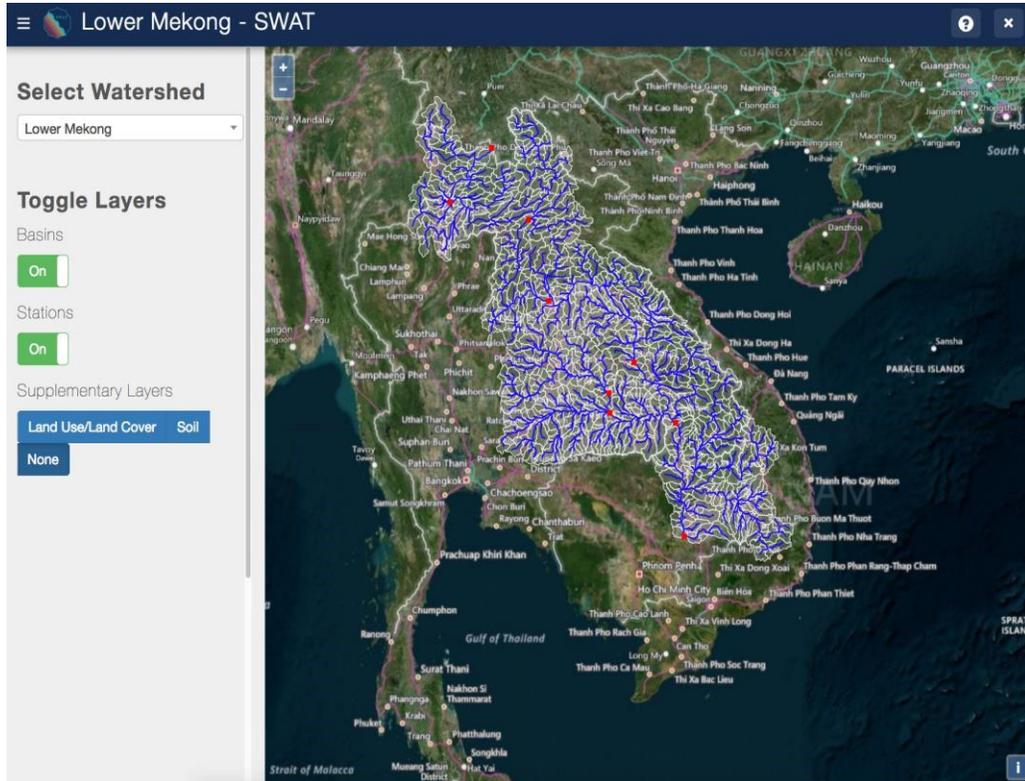


Figure 5. The SWATonline data viewer home view. The SWATonline uses the SWAT model shapefiles (e.g., stream network, sub-basin) along with the Microsoft® Bing™ Maps Platform APIs for enhanced querying and visualizing the SWAT model input and output data products. The lower Mekong River Basin SWAT model data (Mohammed et al., 2018) has been used here as an input to elucidate the SWATonline web app capabilities.

4.1. Accessing SWAT climate inputs through the NASAaccess app

The main purpose of the NASAaccess web application is to give users access to the NASAaccess data processing functions, the sole purpose of which is to create SWAT model compatible climate input files, within an easy to use interface. Thus, the key functionality of the app resides in the four input elements in the left pane of the app as shown in Figure 6. The user may select the watershed boundary, digital elevation model, and date range to be used as input arguments in the NASAaccess functions. The user is also given the option to select one or multiple NASAaccess functions to run using those arguments. The app uses these input elements to pass user requests as input arguments into the NASAaccess functions as shown in the flowchart in Figure 7.

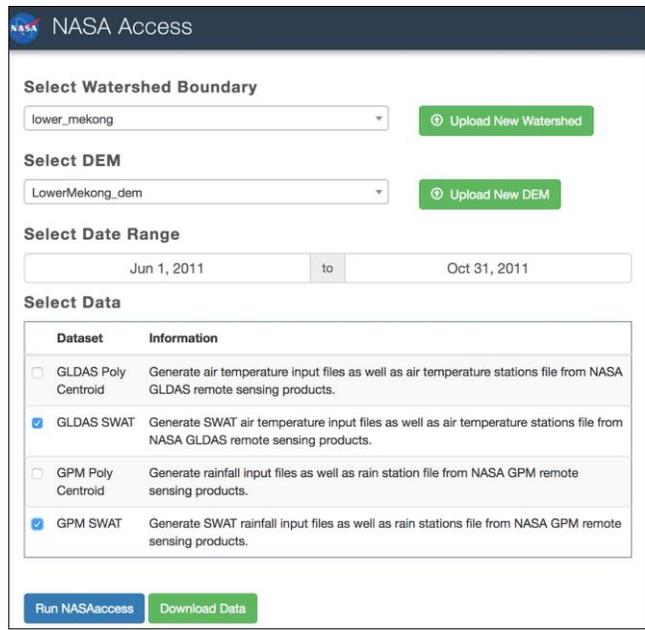


Figure 6. The NASAAccess web app user interface. The NASAAccess web app user requires a digital elevation model raster file in a *tiff* format and a shapefile for a study area along with a date range to retrieve and reformat various climate data from the EarthData portal (i.e., Earth Observing System Data and Information System, <https://earthdata.nasa.gov/>) using the four NASAAccess functions displayed. The NASAAccess web app functionalities can generate gridded ascii tables of weather data (GPM, TRMM, GLDAS) needed to drive various hydrological models.

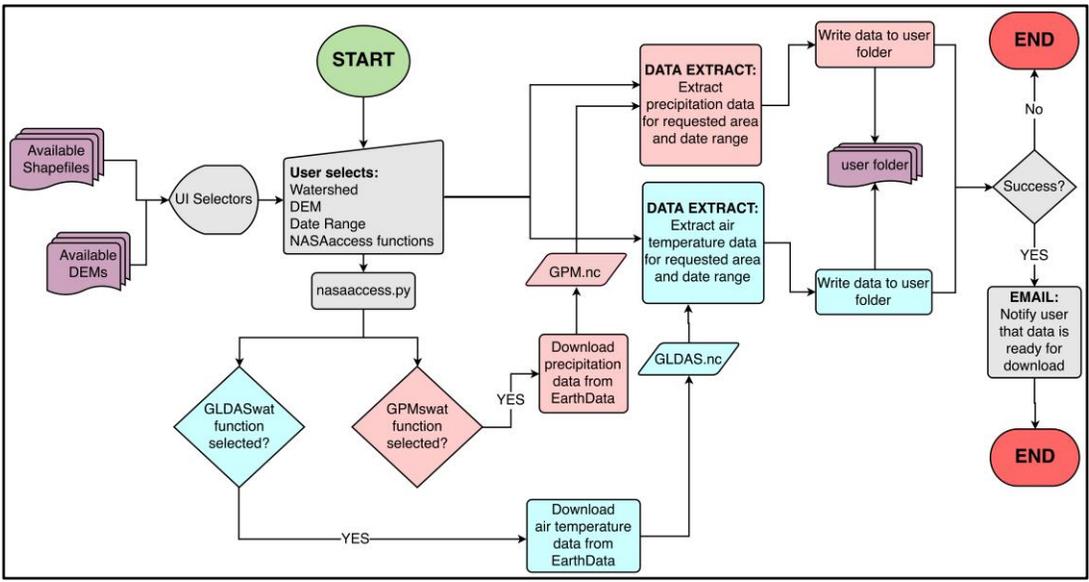


Figure 7. The NASAAccess Tethys web app flowchart for weather and climate data processing. Multiple python libraries (e.g., *netCDF4*, *geopandas*, *xarray*) have been utilized to extract weather and climate data from grids within a specified watershed shapefile and a specific date range. The NASAAccess Tethys web app retrieves weather and climate data from EarthData (<https://earthdata.nasa.gov/>) without the need for

user credentials and notifies the user with email once the data retrieve, extraction, and reformat is completed.

4.2. The SWAT model output querying and time-series visualization

The SWATonline application supports time series visualization of variables from the SWAT model rch and sub output files, it also supports the geospatial visualization of the stream network. The stream network visualization is done through GeoServer map publishing framework and OpenLayers a JavaScript Mapping Library. A watershed of interest is uploaded to GeoServer using the GeoServer REST API. The published layer is then available as a WMS endpoint. The OpenLayers library can access the WMS endpoint and displays it on an interactive map.

Selecting a reach on the map will open a modal window with options to query different SWAT model output files. As seen in Figure 8, once the variable and time range are selected, the resulting data is shown as a time series plot through the Highcharts JavaScript plotting library.



Figure 8. The SWATonline web app stream reach outflow time-series plot example. The SWATonline provides spatial and temporal data views for a user selected stream reach (spatial location is shown as stream reach colored in red color on the right side). The user can find the highest flow for instance by pointing the mouse to the time series plot as shown above where on September 26, 2011 the streamflow discharge amount was 1,790 m³/sec. Data used in the time-series plot example is obtained from the SWAT model simulated streamflow for a tributary of the Mekong River near Pakse, Laos People's Democratic Republic (Mohammed et al., 2018).

4.3. Land use land cover and soil coverage layers statistics

The land use land cover and soil layers coverage statistics are represented as pie charts within the SWATonline platform. When a reach is selected on the map, the corresponding sub-basin is highlighted. The land use land cover and soil layers coverage maps are clipped to that

subbasin boundary using GDAL and coverage statistics are computed for the selected area. The clipped rasters are published as a WMS layer to the GeoServer. The WMS layer is then displayed through OpenLayers for a visual representation of the Land Use Land Cover, and Soil Coverage classification. A pie chart of the classification is rendered through the Highcharts library. The chart can be queried for a breakdown of more distinct classification as seen in Figure 9 and Figure 10. Data used in the land use land cover and soil layers examples are obtained from the SWAT model described by Mohammed et al., (2018).



Figure 9. The SWATOnline land use land cover layer coverage statistics example. Panel (A) gives the main land cover land use class statistics for the selected sub-basin displayed in the map shown on the panel's right side. The land cover coverage for the selected sub-basin is dominated by forest cover (i.e., 74% of the selected sub-basin area has forest coverage). Panel (B) gives a breakdown of the sub-basin forest land cover depicted in Panel (A) into various forest types (deciduous, evergreen, ... etc.). Panel (C) gives the remaining land cover land use class statistics for the selected sub-basin being examined in Panel (A). Note here that agricultural lands cover about 26% of the sub-basin area being examined. Panel (D) gives a breakdown of the agricultural lands at the selected sub-basin as described in Panel (C). Panel (D) highlights the various types of agricultural lands found at the study sub-basin with rice cultivated twice during the year found at the majority of the agricultural land areas within the examined sub-basin.

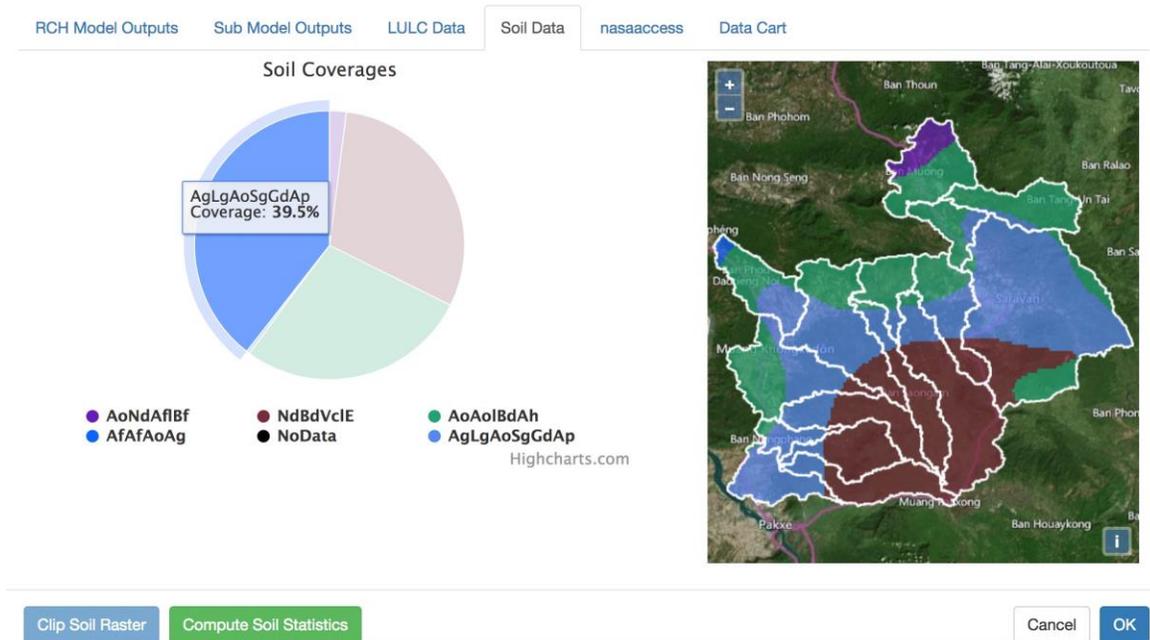


Figure 10. The SWATonline soil layer coverage statistics example. With the pie chart soil coverage statistics users are able to quickly obtain useful information related to the dominant soil texture types at any selected sub-basin within the SWAT model study area.

4.4. Data storage and upload

The applications presented in this work rely on three types of data: 1) The SWAT model watershed shapefiles, 2) The SWAT model output files, and 3) The SWAT model land use land cover and soil input files. These data are stored in a combination of three different storage technologies: 1) a GeoServer for geospatial datasets, 2) a PostgreSQL database, and 3) local storage on the server hosting the apps. Included in the app package is a python script called 'upload_new_model.py' that will take each of the files described earlier and upload or save them to their correct location within the storage architecture of the app. Figure 11 and Figure 12 are comprehensive flow charts of the data upload, storage, and visualization methods used by the applications.

The SWAT watershed files include geospatial files such as stream network, subbasin, and gage station shapefiles. These files are published as WMS layers to the GeoServer. Once published they are accessible as WMS services. The connectivity information (i.e., downstream IDs for the stream and subbasin networks) is uploaded to a table in the PostgreSQL database using the Psycopg2 python package.

The SWAT model output files are also uploaded to the PostgreSQL database. The SWATonline application has its own database to store the output files. Each output file is stored in a database table specifically created for that file. Each record in the table for the output files holds the following information: 1) watershed ID, 2) year-month-day, 3) Reach ID, 4) variable name and, 5) value. The tables are then indexed for improving the efficiency for querying the time series.

The land use land cover and soil files and their metadata are stored in multiple forms for the SWATonline app to process. Initially, the files are published to the GeoServer for display in the app’s map view as WMS services. The lookup tables used to translate the raster pixel values to land use land cover and soil classification names are uploaded to a table in the PostgreSQL database so that the app can quickly identify and display coverage information. The original land use land cover and soil files are also stored locally on the hosting server to be used in the clipping and raster calculations when requested by a user.

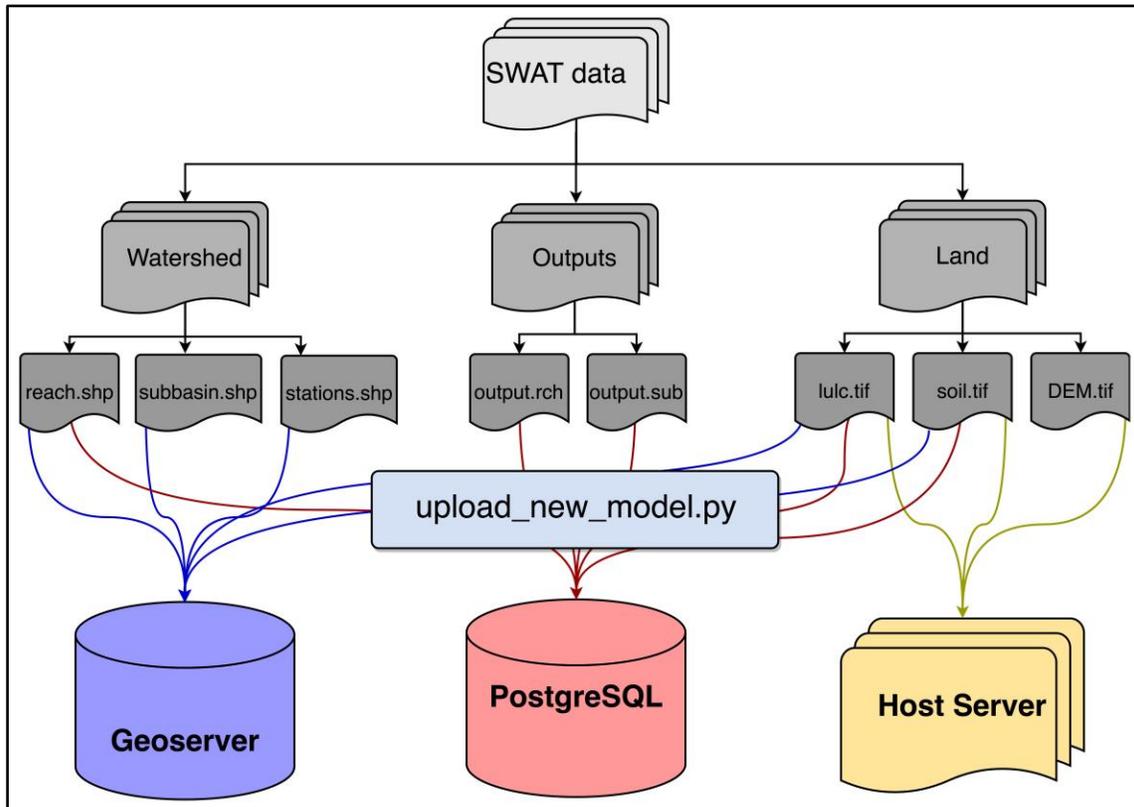


Figure 11. The SWATonline data viewer upload and storage methods. The SWATonline handles three types of files that include shapefiles, SWAT model input files (i.e., *.tiff format*), and SWAT model output files by uploading or saving the various file types to their correct location within the storage architecture of the SWATonline app using the “upload_new_model” tool.

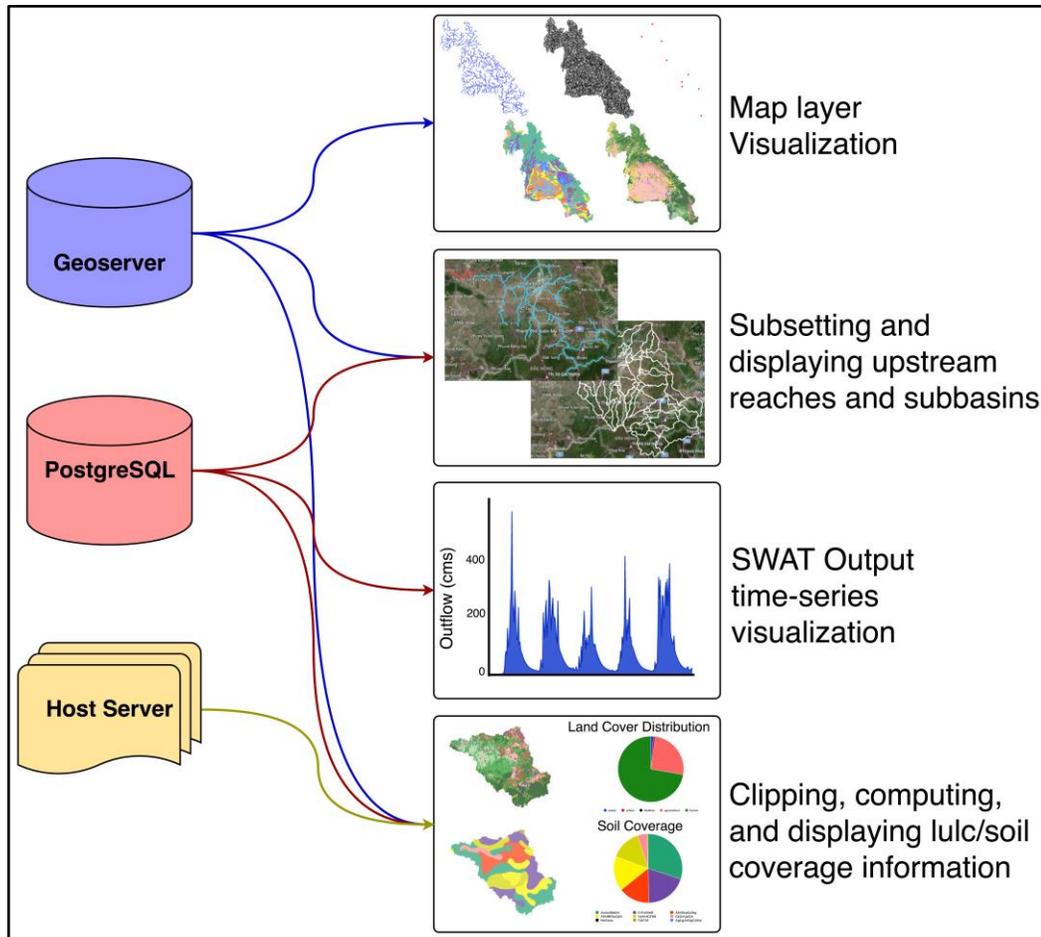


Figure 12. The SWATonline data viewer visualization methods. Various SWAT model input and output files are handled within the SWATonline Tethys web app as presented to enhance data analysis and SWAT model output results interpretation.

4.5. Data download

While the SWATonline apps presented allow for basic data visualization and sharing for a wide range of users, they are limited in in-depth data analysis functionality. For this reason, the apps both facilitate data downloading for users who are interested so that further data analysis can be performed. The SWATonline data viewer app features a “Data Cart” capability that functions very similar to an online shopping cart. The user can perform any number of data queries from the watershed, the SWAT model output, and land use land cover or soil data that the app provides, add the data to their “cart”, and then download a zip file containing all of that data to use for advanced data analysis or further modeling processes. The data query and download process is shown in Figure 13.

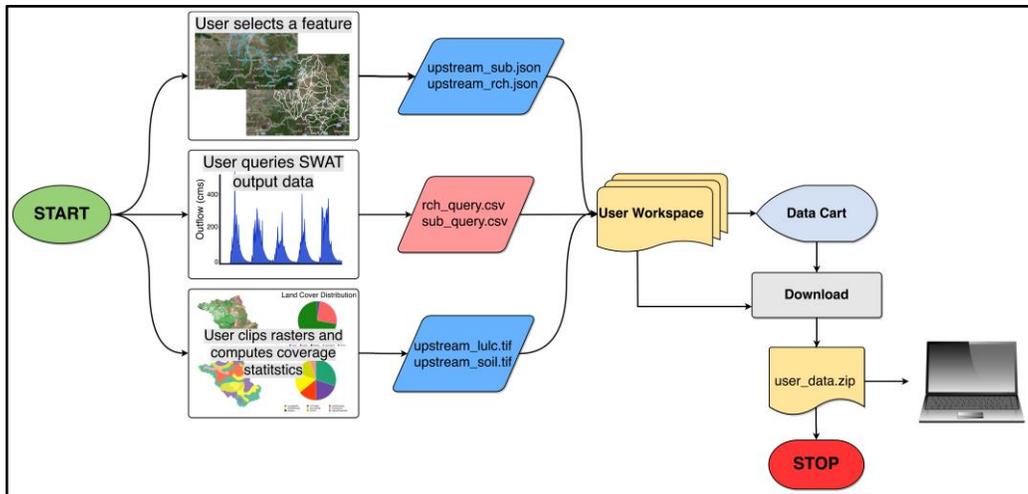


Figure 13. The SWATonline data viewer data download methodology.

4.6. The SWATonline App modularity and customization

The 'upload_new_model.py' script included in the SWATonline app package will work for any new SWAT model and will automatically update the app features based on available data for the given model (i.e., the land use land cover data visualization and data processing features will be disabled if a land use land cover raster file wasn't uploaded with the model). The modularity and customizability of the SWATonline data viewer is helpful and essential when analysis for different regions or different countries is thought by stakeholders or individuals as demonstrated by the Lower Mekong River Basin multi-countries SWAT model example (Mohammed et al., 2018).

5. Discussion and conclusions

The information that the SWAT hydrological model uses and simulates has the potential to have a significant impact on the future decisions of water and climate scientists, policy makers, and communities around the world (Lehmann et al., 2017; Lehmann et al., 2014). However, the SWAT model's impact has been limited because of the complicated nature of the various model outputs. While the technical barrier for creating and running the SWAT hydrological model will likely never be eliminated completely, improving the way the model inputs and outputs are visualized and shared can increase the SWAT model impact substantially.

For scientists and the SWAT model developers, accessing inputs for the SWAT model can pose a challenge. The Global Precipitation Measurement (GPM) mission and Global Land Data Assimilation System (GLDAS) data products, produced regularly by NASA on a global scale, contain valuable information on the current state of the world's climate and can be used as inputs for any SWAT model setup. However, the use of these earth observation datasets, available for free from the NASA earth data website (<https://earthdata.nasa.gov/>), has been limited due to the high technical requirements for accessing, processing, and understanding it. The work done by Mohammed (2019) to develop the NASAaccess workflow was an important step in opening these datasets up to those that could benefit from them. However, similar to the limitations of the datasets themselves, the NASAaccess software package has been limited in use because it is available only within the R software environment.

The NASAaccess web application was developed to lower the technical barrier that was keeping interested parties from accessing the powerful capabilities of the NASAaccess package and, ultimately, the information available in the GPM and GLDAS datasets. The NASAaccess web interface frees users from needing any technical background in R or earth observation data processing, yet still allows them to process large amounts of data into small, more manageable data files. The NASAaccess app produces data that is then ready to be used in a wide range of climatological and hydrological uses, including hydrologic modeling programs like the SWAT, climate modeling, statistical analysis, and data visualization for decision support.

For decision makers and stakeholders in an area where the hydrologic process plays a key part in environmental, and economic sustainability, the SWAT model can provide crucial information to future planning and analysis of past events. However, due to high technical requirements in using the SWAT model, its impact on stakeholders and decision makers has been severely limited. The SWATonline data viewer was designed to overcome the limitations of existing desktop and web technologies for the SWAT model visualization. Instead of being tied down with software licensing and versioning issues inherent in the current desktop applications, the SWATonline data viewer is completely open source and was built to be resilient to changes in SWAT software. It is also completely modular, unlike other SWAT related web interfaces, which means that the app can be duplicated, installed, and run from any machine (private or public, local or shared) with a Tethys Platform installed, making it adaptable to any specific user needs.

While the applications presented in this work are limited to some extent in their functionality when compared to the currently available programs and services for the SWAT model, the customizability, modularity, and easy to use interfaces of these two apps have the potential to simplify the SWAT model data analysis and visualization for those lacking technical training in the SWAT model development.

With all the new technical developments in the fields of hydrology, earth observations, and software and web development, complicated science continues to become more accessible to a wider group of people. The SWATonline data viewer and the NASAaccess applications have the potential to meet the goal of full stakeholder adoption. The apps have significantly simplified the process of accessing the climate inputs and model outputs for the SWAT model. They can be implemented anywhere, by any interested organization or individual, and can be used for any SWAT model for any watershed. This potential for stakeholder adoption can be realized through an increased effort to inform stakeholders of the current developments, train them in using the apps, and then to involve them in future developments.

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