Hydroviewer: A Web Application to Localize Global Hydrologic Forecasts

Research Article

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Abstract

Earth observation data are increasingly ubiquitous, easily accessible, often freely available, and more usable due to improvements in software, data standards, network infrastructure, and national policies. As a result, greater opportunities arise for using these data in emerging fields such as decision support for local and regional environmental and water resources management. In parts of the world where in situ data are less readily available, global Earth observation data, used in decision support tools, can be a boon to government and other water management agencies. The Group on Earth Observations Global Water Sustainability Initiative (GEOGloWS) works to bring global water management capabilities to local decision-makers. Recently, the European Centre for Medium-Range Weather Forecasts (ECMWF) developed and deployed a global hydrologic modeling system that generates historical simulations and daily ensemble forecasts. This data set is highly informative and potentially transformative for users at local scales as it provides access to local forecast data without requiring the expertise or infrastructure to develop and run predictive models. The ECMWF forecast uses Earth observations, hydrologic modeling, and streamflow routing to forecast flows for every river of the world. However, for these data to be most valuable at local levels, the model data and visualization services ideally should be subsetted to a regional or local scale and presented in a local geographic context. Subsetting this dataset allows for customized data access to support local water management challenges. This paper presents the design, development, and testing of the GEOGloWS Hydroviewer, which is an open source, web-based software that accesses and localizes the global ECMWF forecast services. It can localize these data by subsetting the mapping and modeling services. The resulting data and Hydroviewer app are designed to be a “light-weight” and portable software which supports...
further customizations. This allows individual water management agencies to automatically generate customized views and uses for specific needs and capabilities without reliance on external software. This web-based distribution and data storage removes many of the typical interdependent relationships that often hinder technology transfer to developing countries.

Keywords: ECMWF, GEOGloWS, Streamflow Forecasts, Hydrologic-Modelling-as-a-Service, Hydroviewer

1. Introduction

Management of water resources is essential to provide sustainable water resources for a growing global population. It is predicted that global water demand will increase for the foreseeable future, which generates uncertainty as to whether natural supplies can meet this need (Piesse, 2020; Vörösmarty et al., 2000). To compound this issue, many people that are facing water insecurity or instability live in countries with limited water monitoring infrastructure such as discharge and river gauging stations that measure and archive streamflow records. To meet the need to access and acquire flow data, traditionally, donor organizations and programs have funded the construction of streamflow monitoring stations and model development in countries and regions where they are needed. While these programs provide significant benefit during and shortly after program completion, they are not always sustainable in the long term (de Waal et al., 2017; Kingdom et al., 2018; Rodriguaz et al., 2012; UNICEF, 2021). Because these countries do not always have the financial capacity or trained personnel to operate and maintain the observation networks or models on their own, the programs frequently cannot continue when the intervention program’s funding is gone (Molle, 2008). However, in these regions the need for good hydrologic information persists.

Global hydrologic modeling is a promising solution that addresses some of the issues that arise from the lack of local financial and technical support for local data and infrastructure (Fatichi et al., 2016; Wu et al., 2012). However, there are challenges and limitations to using global models, with a main issue being that they lack the detail or resolution needed for local use (Qiao, Nelson, et al., 2019; Snow et al., 2016; Yu et al., 2006).

Hydrologic Modeling as a Service (HMaaS) is an approach suggested by Souffront Alcantara, et al. (2019) that addresses these barriers. HMaaS provides hydrologic model components, model results, and derived information to local users via web services. These data are created and stored on web servers and are accessed using appropriate data and mapping services. Using this approach, a global hydrologic model can be built, optimized, monitored, and maintained by hydrologic experts with access to the supporting infrastructure while local users can access the data with minimal cyberinfrastructure or modeling capabilities, typically only requiring a computer with a web browser. HMaaS has the additional benefit in that updates to model components, code, and datasets are applied when available. HMaaS removes many barriers to obtaining water data from local users by pushing the funding and expertise required to agencies capable of performing these tasks. HMaaS makes the output data (i.e., historical simulations, forecasts, etc.) from a remote model available using a standard web browser. This provides local end-users with the ability to incorporate simulation data and flood forecasts into their decision-making.

The web app paradigm is ideal for implementing the HMaaS concept. Web apps can be accessed by anyone with an internet connection. A web app can be easily updated by its maintainers to the most current information and software. All users who access the web app benefit from the same updated data and software. These qualities complement the sustainability approach of HMaaS by removing the need for powerful computing resources and software licenses that would otherwise make intervention programs fail in the long term. Web apps are highly customizable which allows local governments or agencies to adapt an app to a particular watershed, organization, or hydrologic issue.
The Group on Earth Observations Global Water Sustainability Initiative (GEOGloWS) works to bring global water management capabilities to local decision-makers. Recently, the European Centre for Medium-Range Weather Forecasts (ECMWF) developed and deployed an HMaaS global hydrologic modeling system that generates historical simulations and daily ensemble forecasts (Sanchez Lozano et al., 2021). This dataset is highly informative and potentially transformative for users at local scales as it provides access to local forecast data without requiring the expertise or infrastructure to develop and run predictive models. The ECMWF forecast uses Earth observations, hydrologic modeling, and streamflow routing to forecast flows for every river of the world (Sanchez Lozano et al., 2021).

Souffront Alcantara, et al. (2019) demonstrated the HMaaS method by creating an implementation of a global hydrologic model the used the ECMWF forecasts. To implement the HMaaS, Souffront Alcantara, et al (2019) designed and created a global vector data network of streams and watersheds called a GeoFabric. The GeoFabric delineates watersheds over the entire globe using a digital elevation model (DEM). Within each watershed, it uses the global DEM to define stream segments in the watershed. They used the ECMWF data, and the GeoFabric to generate flow forecasts for each stream segment in the global GeoFabric. The GeoFabric is both the basis of the model and a way to display and organize model results. We identified the following issues in the GeoFabric:

1. The average area of watersheds delineated was large, and did not adapt to smaller regions (e.g., Japan or the isthmus of Central America),
2. It did not have unique identifiers for streams, and
3. It did not use a rational numbering scheme for different global areas.

These issues made the data difficult to apply or integrate with other applications. For instance, the model data didn’t have sufficient resolution to be used for building hydrodynamic models or predicting flood inundation extents. In addition, the numbering and naming scheme made the data difficult to localize in graphical interfaces that target regional, national, or watershed level viewers that are useful to decision-makers and planning groups.

As part of the original modeling system, Souffront et al. (2019) created a Representational State Transfer (REST) Application Programming Interface (API) data service to extract the global model results for selected stream reaches. This data service was tightly integrated with the associated web application and could not be easily extended to support new capabilities. Separation of the API from the web application allows any user to make API calls to retrieve, subset, and process data from the global data set.

In this paper, we present our work to improve and extend the original GeoFabric and we present the design and development of a new open-source web application called the “GEOGloWS ECMWF Streamflow Hydroviewer” to use the improved and extended GeoFabric to access and visualize the GEOGloWS ECMWF Streamflow Services on local scales. We designed the Hydroviewer with a creator tool so that Hydroviewers customized for local uses are more easily generated. The global Hydroviewer visualizes and queries modeled flow forecasts on every stream segment in the global GeoFabric and demonstrates how the API can be used to create new applications. We designed our global Hydroviewer so that a localized or regional viewer can be automatically created as a customized html web page that focuses on a specific geographic region or area. A customized Hydroviewer can accept local data, such as observed streamflow or the results from a local model, which are then added to the display of the global ECMWF dataset accessed by the Hydroviewer. We describe the development of the global Hydroviewer and how it can be used to create localized Hydroviewers for a specific area. The remainder of this paper is organized as follows. Section 2 presents the creation of a new and improved global GeoFabric of stream segments and watershed boundaries. Section 3 presents the design of our Hydroviewer web application. Section 4 provides case studies of the different possible Hydroviewer customizations.
2. A New Global GeoFabric

We extended the GeoFabric of Souffront Alcantra et al. (2019) to increase the resolution in parts of the world with smaller watersheds. We created the global Hydroviewer to access and analyze the resulting data for both the streamflow historical simulation and forecast data derived from the ECMWF model based on the new GeoFabric. The global Hydroviewer uses the new GeoFabric and demonstrates the utility of an API in creating applications. Hydroviewer is a web mapping tool used to visualize and access modeling results for each stream segment in the GeoFabric river and present them to local users (Figure 1).

The original GeoFabric used watersheds created with the same area threshold criterion and does not cover the entire globe. This resulted in large watersheds in terms of total area and geographic extents in addition to large subbasin sizes. This delineation was not compatible with some of the areas that it covered, such as Japan and Central America, where the countries are narrow with relatively small watersheds. The original GeoFabric was created only to map gridded runoff data from the ECMWF model and route the results through the stream network and was not designed to support other applications such as floodplain mapping. We designed the updated GeoFabric to address the shortcomings of the previous version and support additional capabilities. After creating the new GeoFabric, we stored the resulting vector data on an instance of the open-source GeoServer software that is running on HydroShare.org. The streamflow data service shown in Figure 1 is the GEOGloWS Streamflow Forecast Services web service which provides predictions of flow rates on every stream segment within the global GeoFabric.

Figure 1. Hydroviewer architecture overview.
Table 1. List of regions with identifying prefix and average catchment size.

<table>
<thead>
<tr>
<th>Region Name</th>
<th>Number of Reaches</th>
<th>Avg. Catchment Area (km²)</th>
<th>Prefix ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Africa</td>
<td>106,706</td>
<td>308</td>
<td>7</td>
</tr>
<tr>
<td>Australia</td>
<td>62,987</td>
<td>149</td>
<td>2</td>
</tr>
<tr>
<td>Central America</td>
<td>55,358</td>
<td>106</td>
<td>9</td>
</tr>
<tr>
<td>Central Asia</td>
<td>55,621</td>
<td>151</td>
<td>8</td>
</tr>
<tr>
<td>East Asia</td>
<td>79,931</td>
<td>154</td>
<td>4</td>
</tr>
<tr>
<td>Europe</td>
<td>80,769</td>
<td>149</td>
<td>12</td>
</tr>
<tr>
<td>Islands</td>
<td>31,894</td>
<td>100</td>
<td>1</td>
</tr>
<tr>
<td>Japan</td>
<td>5,302</td>
<td>100</td>
<td>3</td>
</tr>
<tr>
<td>Middle East</td>
<td>41,041</td>
<td>155</td>
<td>6</td>
</tr>
<tr>
<td>North America</td>
<td>40,802</td>
<td>250</td>
<td>13</td>
</tr>
<tr>
<td>South America</td>
<td>149,384</td>
<td>136</td>
<td>11</td>
</tr>
<tr>
<td>South Asia</td>
<td>84,095</td>
<td>100</td>
<td>5</td>
</tr>
<tr>
<td>West Asia</td>
<td>84,713</td>
<td>161</td>
<td>10</td>
</tr>
</tbody>
</table>

We divided the globe into the 13 areas shown in Figure 2. A digital resource containing all of the spatial data sets for all of the regions of the world that were created as part of this project was stored on HydroShare.org and is publicly accessible at https://www.hydroshare.org/resource/9241da0b1166492791381b48943c2b4a/ (Kylie Ashby et al., 2021).
Table 1 provides a list of the average catchment size and the number of catchments in each region. To create different size watersheds in different regions, we adjusted the upstream area threshold parameter which affects the DEM processing. It changes the size and number of catchments and the number of streams created. We partitioned the globe into different regions and delineated each region separately using a different upstream area threshold parameter to match the geographic characteristics of that region. The regions were chosen to follow major watersheds boundaries and roughly correlate with geopolitical boundaries.

We chose the spatial resolution to balance several concerns. We selected the threshold parameter which governs the subbasin size to create basins sufficiently small to accurately model the region’s hydrologic processes. The river routing model used by the GEOGloWS ECMWF Streamflow model operates on each delineated subbasin of a watershed and produces one hydrograph result per subbasin. As we increase the spatial resolution by decreasing the average basin size, the computational resources required to process more basins and store their results increases. The higher resolution also increases the density of reporting points on each river segment which aids in comparing model results to in-situ measurement stations or hydraulic control structures. The 13 regions are named for their approximate geographic area and follow the major watershed boundaries. The region extents were not influenced by any political, economic, cultural, or other concerns of the countries within the region.

We used Esri ArcMap GIS software and ArcHydro tools and followed the methods described by Li (2014) to create the stream networks and watersheds included in our new GeoFabric. We did not compute flow direction rasters directly from DEMs, but rather used corrected flow direction raster data based on the HydroSHEDS dataset provided by the Esri Living Atlas (Lehner et al., 2008). We then converted the flow direction and accumulation raster data to create vectorized spatial data that represent streams and watershed boundaries.

HydroSHEDS provides vector data of catchments and stream segments and the underlying flow direction and flow accumulation raster datasets from which they are derived. These data were created using a “hydroconditioning” to improve the stream delineation (Lehner et al., 2008). Hydroconditioning adjusts the digital elevations to force delineated rivers to conform to known features that represent rivers. This method results in flow rasters that are often obstructed by artificial or digital dams. One disadvantage to using the HydroSHEDS raster datasets is that the hydroconditioning is “burned” in, meaning the source elevation data were artificially lowered where known streams exist. These modified DEMs make it difficult to use these data for applications such as hydraulic models and floodplain mapping.

Yamazaki et al. (2017) created the MERIT DEM dataset which performs hydroconditioning but without “burning” the rivers into the DEM. We evaluated the MERIT DEM dataset but found that automated delineations using the MERIT DEM data often placed streams erroneously or failed to correctly connect stream networks. We did not evaluate the more recent version of the MERIT DEM, MERIT Hydro (Yamazaki et al., 2019) because at the time it was unavailable. Given the data available at the time, we decided to use the HydroSHEDS raster datasets obtained from Esri to delineate the stream segments and watershed boundaries.
Figure 2. Boundaries of 13 global regions.

We post-processed the data to create the GeoFabric that can be used for hydrologic modeling. Our hydrologic modeling approach requires a 1:1 ratio between the catchments and streams, that is, each catchment should have exactly one stream. We analyzed the data created by the initial effort and removed catchments that did not contain a stream as shown in Figure 3, Panel a. We then modified catchments that contained multiple streams by splitting the catchment based on the underlying topography (Figure 3, Panel c). In some cases, rather than splitting the catchment we removed extraneous stream(s) (Figure 3, Panel b). We choose to remove streams if we deemed them to be inconsequential to the stream network or if their removal would have little impact on the modeling results.
Figure 3. A 1:1 ratio was achieved by either (a) removing empty catchments, (b) removing extra streams, or (c) splitting catchments.

The original GeoFabric identified stream and catchment elements using region names with stream identification numbers that were repeated for the different regions being evaluated. A unique global stream identifier makes it easier to access and use the data programmatically. We generated a unique numeric identifier for each catchment and stream feature pair that contains a prefix that identifies which region the feature is located and a unique number for that segment. An example stream number is 7056896 which represents stream number 056896 in Africa (region 7). This segment numbering scheme provides a unique identifier for every stream segment in the database and is used by Geoviewer to retrieve the data. The previous GeoFabric used names, rather than numbers to identify regions. To make data easier to access programmatically, we address different regions
by a numerical prefix. Table 1 provides assigned prefixes each region in the GeoFabric while Figure 2 shows a map of these regions.

We used new GeoFabric data as the computational network for a hydrologic routing model. A global Hydroviewer accesses the flow estimates from this routing model through a streamflow data service. Our model routes the ECMWF forecasted surface runoff data product generated by the HTESSEL land surface model using the GeoFabric stream network (Balsamo et al., 2009). Routing is performed with the Muskingum method as implemented by the Routing Application for Parallel computation of Discharge (RAPID) model (C. H. David et al., 2008; Cédric H. David et al., 2016). We derive the routing parameters using geospatial analysis methods following Qiao, Nelson, et al., (2019). A software architecture diagram which shows how these services interrelate is presented in Section 3.1.

The streamflow data service is an extension of the original service by Souffront et al., (2019) where the original REST API was separated from the web application. The new API allows other applications or users to access this service and associated data more readily.

We store the GeoFabric files on HydroShare.org and use the HydroShare instance of GeoServer to generate the web mapping service (WMS) necessary for inclusion in web applications. The global Hydroviewer then uses this WMS to visualize and provide a basis for accessing the hydrological simulation datasets. HydroShare.org is a web platform for storing, discovering, sharing, and collaborating on research using hydrologic data (Tarboton et al., 2012; Horsburgh et al., 2016; Yi et al., 2018; Crawley et al., 2017). We chose HydroShare because public, free mapping services allow easy programmatic access to our data and services. HydroShare organizes data into user-created resources. Each resource can have limitations as to who can edit the resource, and how the resource can be discovered should it be made public. All spatial data that are uploaded to HydroShare are automatically registered in the instance of GeoServer running on HydroShare.org and are made available to others via various web services.

3. Hydroviewer Design

3.1 Architecture

Figure 4 illustrates the Hydroviewer architecture which follows a Model-View-Controller (MVC) framework. We developed the global Hydroviewer using Tethys Platform (Swain et al., 2016; Qiao, Li, et al., 2019; Nelson et al., 2019). The MVC architecture allows us to implement the required geoprocessing on a remote server where a central copy of the GeoFabric Shapefile data is available in addition to sufficient computational power to execute the processing scripts. This provides greater efficiency by removing the need to duplicate data stores and develop new geoprocessing workflows for each use case and each new user.

The model portion of the MVC pattern includes all the data used by the application which are traditionally databases of some format. In this case, the data includes the GeoFabric shapefiles and the subset of the data that are stored on HydroShare where they are easily accessible to a Hydroviewer. The developer can specify the location of these files on the web server using an admin interface for specifying custom settings.

The View portion of the MVC pattern deals with the user interface. We built the user interface as a progressive web app where the steps of the model subsetting process are split across several web pages and are managed from overview pages. We felt this was more suitable than a single page web app because it kept the process more organized and therefore more accessible and intelligible by the targeted users.
We built the web maps for Hydroviewer using the Leaflet library because of its performance, simplicity, and usability (Crickard III, 2014). Leaflet is an open-source library used to build web maps. Leaflet handles how the GeoServer WMS images are retrieved and displayed and provides tools for users to interact with the resulting maps. This includes drawing custom boundaries and displaying specific map layers. If the Hydroviewer data are on an Esri MapServer, Leaflet can access and present Esri layers, providing additional display capabilities.

The Controller portion of the MVC pattern reads, processes, and returns data to the user. We used the Python language and GeoPandas Python package to process spatial data (Jordahl, 2014). GeoPandas can access files inside a zip archive which reduces the amount of local storage required to host Hydroviewer and associated data. GeoPandas relies on other Python packages but does not rely on external spatial databases or other external software to function. This makes hosting or transferring Hydroviewer easier and reduces the effort to maintain the application.

We use hs_restclient package (http://hs-restclient.readthedocs.io/) to access HydroShare resources, and we use the geoserver-restconfig package (https://github.com/GeoNode/geoserver-restconfig) to access GeoServer web mapping services. This allows Hydroviewer to establish connections and transfer subsetted data selected by GeoPandas to HydroShare or GeoServer. Using the HydroShare or GeoServer REST APIs, the subsetted data generated by Hydroviewer are directly uploaded to HydroShare. Uploading the data to HydroShare generates the necessary web map services in GeoServer that display the data on custom, dynamic web maps.

Figure 4. Overview of model-view-controller layout for Hydroviewer.
3.2 Hydroviewer Functions

3.2.1 Hydroviewer Functions Overview

Three different types of Hydroviewers are possible. The first is the global Hydroviewer as web app to access and view the global dataset, the second is a Hydroviewer Project which can be created from the global Hydroviewer that is customized to a specific country, region or other watershed boundary and accessed through a standard web page. The third is using the customized or extracted portions of the GeoFabric to create a custom Hydroviewer. Customized Hydroviewers have all the functions of the global Hydroviewer but have been designed to display and analyze a specific region or subset of the global data and can be extended to include local data that have been integrated into the app.

In this section we present the core functions of the three different ways a Hydroviewer might be used: the global Hydroviewer application, the Hydroviewer Creator interface that allows users to develop a customized Hydroviewer Project, and a demonstration of a customized Hydroviewer for a specific region where additional functionality for a web app has been programmed. The following is a list of capabilities for each of these different uses:

1. A global Hydroviewer:
   1.1. Displays the global stream network;
   1.2. Displays ECWMF routed flow data, including forecast and historical simulation data in each global stream segment;
   1.3. Has the ability to download the displayed data sets;
   1.4. Searches for specific streams or specific coordinates at which to display data; and
   1.5. Changes or toggles layers displayed by the map (i.e., streams, catchment, basemap, etc.).

2. A Hydroviewer project:
   2.1. Shows a preview of the user-defined project region for creating a custom Hydroviewer project;
   2.2. Allows local data to be uploaded to HydroShare or GeoServer; and
   2.3. Has the ability to download data subsets associated with the selected region for use in other applications.

3. A custom Hydroviewer:
   3.1. Creates a local or custom web page viewer based on a selected region;
   3.2. Displays flow data in the local or custom Hydroviewer similar to the global Hydroviewer, even when presenting local data not available to the global application; and
   3.3. Can be extended to include local datasets such as gauge data or land surface products when they are available.

The remainder of this section presents additional detail and demonstrations of these three different uses for the Hydroviewer application.

3.2.2 Global Hydroviewer

Figure 5 shows the global Hydroviewer display of the global streamflow network. This displays and provides access to the streamflow data, including forecasts and historical data. Time series data plots are created by selecting (i.e., clicking on) segments of the displayed stream network. After clicking, the data associated with the selected segment is displayed in a line graph. The Hydroviewer includes the option to search for a specific stream or location using stream IDs and coordinates, which also display the associated data after selection.
3.2.3 Hydroviewer Project

Within the global Hydroviewer, users with the correct credentials can use the Hydroviewer Creator to create a localized Hydroviewer Project as a subset of the global hydrologic model. The Hydroviewer Creator has three different steps, each with its own view or page: the Project Selection page, the Edit Hydroviewer page, and the Project Overview page. Once created, the Hydroviewer project can be implemented on a web page by including an HTML file generated by the Hydroviewer Creator process. This page includes links to the necessary servers and all the information required to access and display the regional view. This makes it very easy for local organizations to include Hydroviewer functionality in their web site by adding the HTML page created.

To create a new custom project, the developer first names the project. The Hydroviewer Creator then creates a project folder on the server to contain all the data to create the Hydroviewer Project. This includes items such as configuration settings for the map view and the subsetted shapefile data. New projects can be created from scratch or by editing existing projects. Projects can be deleted if no longer required or if errors were made.

Figure 6 shows the Project Overview page. Project Overview includes a preview map that displays the selected area and data from WMS data service. The Project Overview page is where the region for the custom viewer is defined, and Hydroviewer Creator uses those descriptions to subset the global data set and provide a limited set of data to the custom view.

The processes to define a region, subset the data, and create a Hydroviewer project includes:
1. Draw or select boundaries for the project’s area of interest;
2. Run a custom script to subset shapefile data;
3. Export shapefiles to a local zip archive, GeoServer, or HydroShare resource; and
4. Render an HTML file for the Hydroviewer
Each option becomes available when the previous step is completed. For instance, the boundaries for the project need to be created before the shapefiles can be clipped and exported.

Figure 6. Mock layout of the “Project Overview” page

Figure 7 shows the final page of the Hydroviewer Project which is the Render Hydroviewer page. On this page the Hydroviewer Creator downloads an HTML file that will act as the Hydroviewer when included in a web site.

The Hydroviewer Project exports an HTML file that is the Hydroviewer. This simple web page version of a Hydroviewer displays the same data in the global Hydroviewer but for a specific subset. Global data are displayed by linking to the data service that accesses the streamflow data and the WMS service which stores the data. Since the HTML Hydroviewers access this data via web services, the files are lightweight in terms of computer storage space and can be easily shared, uploaded, and hosted on websites. Organizations can add a localized Hydroviewer to their web sites by simply including this HTML page on their web server.

Other data services can be added to the HTML Hydroviewer, further extending its applicability as desired. These customizations are based on the same standard web programming approaches used by the customized Hydroviewer and can vary widely by local circumstances and need. Examples of creating such customizations are beyond the scope of this paper.
3.2.4 Custom Hydroviewer

Custom Hydroviewers are a localized subset of the global GEOGloWS ECMWF Streamflow Services created within a web app. It is a standalone web app which connects to web services for the visualization and model data. The Hydroviewer Creator generates subsetted shapefiles for watershed boundaries and stream networks as part of creating a project. These geometries can then be uploaded to a GeoServer or other mapping service software for display on the customized Hydroviewer’s interface.

The HTML page can be enhanced with additional geographic datasets when they are available. The customized Hydroviewer shows an interactive map of the stream network and allows users to retrieve GEOGloWS model streamflow forecast and historical simulation. That streamflow data is plotted in the graphical interface and can be saved to the user’s computer. However, additional datasets are available in some regions which can complement the GEOGloWS data. For example, the user could generate spatial datasets representing gauge locations or include raster datasets of rainfall forecasts. With additional programming work, the base HTML can be enhanced to show those other datasets on the same map. If there are data services for observation data such as river stage measurements, then those can also be integrated to create a more comprehensive watershed interface.
4. Case Study

4.1 Case Study Overview

In this section we present an example of using the global Hydroviewer, creation of a custom Hydroviewer for Columbia, and demonstrate various capabilities of the custom Columbia Hydroviewer.

4.2 Global Hydroviewer

The global Hydroviewer displays the entire global stream network. These data can be presented using two different display options using either HydroShare’s GeoServer or a MapServer operated by Esri as the visualization source.

The Esri-hosted map service can display stream segments based on the flow in the segment. Streams with larger flows are displayed with thicker lines than streams with less flow. The Esri display adjusts the scale used to display the number of river reaches on the map depending on the map zoom level. At the default zoom level, only streams with larger flows are displayed. As the zoom level increases (zooming into the map), additional stream segments are displayed, including the smaller reaches. Figure 8 displays stream network visualizations provided by an Esri server. At this zoom level the display only shows stream segments with larger flows. If a stream segment is this display is selected, if data are stored on an Esri ArcGIS server, the map animates the stream display, showing past, present, and future changes to stream flow by changing the line thickness. Extreme flows are represented by changing the color of the stream segment. This dynamic display presents information in an intuitive manner.

If the data are hosted on a generic GeoServer, the data are displayed using information from the GeoFabric shapefile. This display shows the full stream network, but displayed stream segments are not modified based on flow volume. All the stream segments are shown with the same line weight.

Figure 8. Global Hydroviewer page of the web app.
4.2 Hydroviewer Project

Figure 9 shows the Columbia custom project in the Hydroviewer Creator. For this project, we selected the region based on Columbia’s political boundaries. Alternatively, boundaries could be a watershed or other boundary defined by any polygon. The Hydroviewer Creator then creates a subset of the global geospatial data. A WMS of the geospatial data can be generated by downloading and used on a local GeoServer instance or exported to a HydroShare where its GeoServer can be leveraged. This allows local organizations or agencies to customize views according to their needs and as a reference to access the GEOGloWS ECMWF Streamflow Service for that subset of streams.

Figure 9. Project Overview page for the Colombia Hydroviewer project.

4.3 Hydroviewer Examples

Figure 10 displays two different custom Columbia Hydroviewers. The first is a simple HTML file produced by the Hydroviewer Creator (Figure 10 top panel) that only contains a subset of the global model data. The second is a Tethys Platform web application that shows further customization by including additional stream gage services and other visualizations. Both Hydroviewers display the catchments and streams from the GeoFabric within Colombia and are views of the regionalized GeoFabric generated by the Hydroviewer Creator. The first Hydroviewer accesses the subset of global data on the server defined during creation of the project. The second Hydroviewer accesses these same global data from the same server but also contains local data that have been integrated. The local data indicated by the various icons shown on the map. Red dots represent observed streamflow gauging stations. Colored triangles represent warning levels for various degrees of flood probability as indicated in the map legend included in the figure. The disadvantage of the simple HTML Hydroviewer is the lack of direct integration of external data sources (e.g., the streamflow gauging stations) and additional analytics (e.g., the flood probability indicators).
Figure 10. Simple HTML Hydroviewer for Colombia (top) compared to customized Hydroviewer that includes local data for the same area (bottom).
5. Conclusions

For this work, we improved on the initial HMaaS implementation in three key ways: 1) we created a new GeoFabric by adapting watershed sizes to the various landforms to ensure all areas were properly represented in the modeling process; 2) we added unique identifiers to the GeoFabric features (i.e., streams and catchments) to help manage and access the global data without confusion; and 3) we created the Hydroviewer Creator web application to assist in visualizing and subsetting the model data.

The global Hydroviewer application can access, distribute, and display the streamflow data and the underlying spatial information contained in GeoFabric data in various formats. The Hydroviewer Creator provides users with the tools to create custom regionalized Hydroviewers. These projects display the global data but limited to a local region. These custom Hydroviewers can contain local data, separate from the global model results and forecasts. Hydroviewer Project creates these local Hydroviewers as HTML files, which means that custom Hydroviewers can be readily viewed, shared, or hosted on an organization’s web page. The Hydroviewer projects can be further customized as web apps to provide additional functionality or display other relevant data which can help decision-makers in their process of managing water resources.

This work can be extended in the future by comparing additional approaches to generating the stream network. Other DEM sources, average catchment sizes, and numbers of region divisions can be considered to provide a more accurate stream network and greater computational efficiency as the GEOGloWS model matures and requires updates. The app used to visualize and subset these geographic datasets can similarly grow to match the updates in the data. As the density of the network changes, more sophisticated geoprocessing web services should be utilized to ensure the subsetting can be completed in a web server environment in a timely manner.

Definitions

- **Earth observations** – Remote or local observations of earth processes such as rainfall, discharge from satellite or in situ measuring devices.
- **ECMWF** – The European Centre for Medium-range Weather Forecasts
- **GEOGloWS** – Group on Earth Observations Global Water Sustainability Initiative
- **GEOGloWS ECMWF Streamflow Service** – A global hydrologic model accessible through web visualization and data services which the Hydroviewer apps are based on
- **GeoServer** – An open-source software package for sharing spatial data as web services
- **GeoFabric** – A continuous spatial dataset over a region – specifically for this paper, global-scale polyline stream centerlines and polygon watershed boundaries used by the GEOGloWS ECMWF Streamflow Service.
- **CUAHSI** – The Consortium of Universities for the Advancement of Hydrologic Science
- **HydroShare** – A web site by CUAHSI for storing, sharing, and conducting collaborative research using hydrologic data and models
- **SaaS** – The Software-as-a-Service software distribution model where applications are hosted in the cloud and made available to users via the internet
- **HMaaS** – Hydrologic-Modelling-as-a-Service, the idea that hydrologic models can be shared through web services.
- **GEOGloWS Hydroviewer** – A web app that facilitates access to the GEOGloWS ECMWF Streamflow Model’s global mapping and data services. The Hydroviewer Creator web app was integrated with this existing web app.
Software and Data Availability

- At the time of publication of this article, the live, running version of the GEOGloWS Hydroviewer, including Hydroviewer Project, can be accessed on the Aquaveo Tethys portal (https://geoglows.apps.aquaveo.com/apps/geoglows-hydroviewer/). However, administrator privileges are required to access the Hydroviewer Creator of the application and these features cannot be access on this web portal. Interested users can download the source code from GitHub (https://github.com/BYU-Hydroinformatics/geoglows_hydroviewer) and install it on their own computers. The source code was developed by Riley Hales and is made available under the MIT license without warranty.

- Derived Hydrography of World Regions, Kyler Ashby, E. James Nelson, Daniel P. Ames, Data is in Public Domain, Retrievable at https://www.hydroshare.org/resource/9241da0b1166492791381b48943c2b4a/

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