GEOSS Water Services for Data and Maps
Engineering Report

GEOSS Architecture Implementation Pilot
Phase 6

Version 0.6
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Abstract

This Engineering Report is one key result of the AIP-6 activities conducted from March to December 2013, specifically dealing with the Water Societal Benefit Area. Key objectives of the AIP-6 Water SBA initiative were to: (1) improve the tools and processes for federating the regional and national picture to a global system (GEOSS); (2) improve discovery and access to water resources data around the world; and (3) improve integration of gridded and time series data. Significant advancement toward these objectives has been achieved, and as a result of work in AIP-6, the GEOSS Water Services demonstrations show greatly simplified, interactive discovery and access to tens of thousands of stream discharge time series descriptors and datasets worldwide, discoverable through a standards-based GEOSS “catalog of catalogs”.

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1. Introduction

1.1 Scope of this document
This AIP-6 GEOSS Water Services Engineering Report (ER) provides a description of the contributed components and services to the GEOSS Architecture Implementation Pilot 6 (AIP-6), in support of the GEO Work Plan 2012-2015\(^1\) and Water Societal Benefit Area (SBA) communities. Community-wide objectives of GEOSS are listed in Section 2 below.

The AIP, as a process, provides a phased delivery of components and services to GEOSS operations, with each phase consisting of:

- Architecture refinement based on user interactions;
- Component deployment and interoperability testing;
- SBA-focused demonstrations.

This Engineering Report is one key result of the AIP-6 activities conducted from March to December 2013. As a result of work in AIP-6, the GEOSS Water Services demonstrations show greatly simplified, interactive discovery and access to tens of thousands of stream discharge time series descriptors and datasets worldwide, discoverable through a standards-based GEOSS “catalog of catalogs”. This addresses a significant subset of water data and web services. The AIP-6 Water Services demonstrations are posted at [http://www.ogcnetwork.net/pub/ogcnetwork/GEOSS/AIP6/index.html](http://www.ogcnetwork.net/pub/ogcnetwork/GEOSS/AIP6/index.html). A separate Summary Engineering Report describes the overall process and results of AIP-6, and thereby provides a context for this Water SBA report.

1.2 Activity key drivers
The GEOSS AIP\(^2\) (Task IN-05 of the GEO Work Plan) matures the process and infrastructure components for the GEOSS Common Infrastructure (GCI) and the broader GEOSS architecture, as a mean of coordinating cross-disciplinary interoperability deployments.

In terms of the Water SBA strategic target\(^3\), GEO intends by 2015 to produce comprehensive sets of data and information products to support decision-making for efficient management of the world's water resources, based on coordinated, sustained observations of the water cycle on multiple scales.

More specific objectives for AIP-6 GEOSS Water Services include:

- Developing and promoting consistent formats and practices supporting regional and national federation of water data in many countries;
- Simplifying registration of water data in GEOSS;
- Enabling distributed search, discovery and access across multiple community data portals using the GEOSS Portal (geoportal.org);
- Enabling & engaging more Latin American countries;
- Facilitating easier workflows for finding data & models to study flooding and drought scenarios.

We have made significant progress in all these objectives. We did not reach demonstration capability in terms of flooding and drought scenarios, due to the need for more development work than could be completed in the time available, but this work should be ready for completion and demonstration in the AIP-7 Water SBA activity.

Regarding the Latin American countries mentioned in this report, the water agencies in these countries were excited by the potential to publish water data with little additional technology and training, but data sharing policy remains a political hurdle to be managed.

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\(^2\) GEOSS Architecture Implementation Pilot (AIP) [http://www.ogcnetwork.net/AIpilot](http://www.ogcnetwork.net/AIpilot)

\(^3\) GEO Water SBA Strategic Target [http://www.earthobservations.org/geoss_wa_tar.shtml](http://www.earthobservations.org/geoss_wa_tar.shtml)
1.3 Summary of AIP-6 water services development

Development for the water information scenario described in this report was a collaborative activity, with contributions from the many participants listed in Section 7, representing these organizations and achievements:

**Academic:**
- University of Texas at Austin, Center for Research in Water Resources (CRWR) and Center for Integrated Earth System Science (CIESS) – science lead and project management;
- Brigham Young University (BYU), Department of Civil and Environmental Engineering – liaison and outreach to Latin American countries; software development for improvements to the Consortium of Universities for Advancement of Hydrologic Science (CUAHSI) HydroServer and HydroDesktop;
- University of Saskatchewan, Global Institute for Water Security (GIWS) – development and hosting of catalog and data services for Environment Canada’s network of precipitation monitors.

**Regional and National Water Agencies:**
- Italian National Institute for Environmental Protection and Research (ISPRA) – coordinates and reports from Italy’s 21 regional water management agencies;
- Regional Agency for Environmental Protection in Emilia-Romagna (ARPA ER) – regional water management agency in northern Italy; ported CUAHSI HydroServer to open-source software platforms, which are now deployed to each regional water management agency in Italy, as well as in Canada and New Zealand;
- New Zealand National Institute for Water and Atmospheric Research (NIWA) – coordinates and reports from New Zealand’s 16 regional water management agencies;
- Horizons Regional Council (HRC) of New Zealand – regional water management agency in northern New Zealand, which implemented the data services conventions developed in this project;
- Central American agencies – the national water management agencies of Nicaragua, Honduras, and Guatemala have begun to learn about and prepare for supporting WaterML 2 and relevant OGC web services, but depend on policy changes that block data sharing for national security purposes.

**International Research Community**
- U.S. National Aeronautics and Space Administration (NASA) Hydrological Sciences Laboratory, Goddard Space Flight Center – provides soil moisture model outputs from Global Land Data Assimilation System (GLDAS);
- Community on Earth Observation Satellites (CEOS) Water Portal (http://waterportal.ceos.org/), based at the University of Tokyo and funded by the Japanese Aerospace Exploration Agency (JAXA);
- European Centre for Midrange Weather Forecasting (ECMWF) in UK – coordinated with JRC to produce WaterML data services for GloFAS flood forecast products.

**Commercial Software Companies:**
- Esri – major international GIS software company, developed interfaces for ArcGIS Online (AGOL) web catalog and client mapping application to support federated search with GEOSS Portal; also developed insightful and compelling mapping applications integrating water data time series at specific sites, with global maps of continuous soil moisture;
- Kisters – major international hydrologic engineering firm, coordinated with Esri on AGOL support for Kisters’ time series data analysis tools; provided observational time series data from WMO Global Runoff Data Centre (GRDC) in Koblenz, Germany;
- The PYXIS Innovation – independent company that has developed a GIS web map viewer and analysis tool, supporting GEOSS integration and OGC data exchange standards.
We are also grateful for the extensive technical support on GEOSS architecture and resource registration provided by the GEO Secretariat in Geneva, the Italian Research Council Institute of Atmospheric Pollution Research (CNR-IIA) and George Mason University in the U.S.

As a result of work in AIP-6, the GEOSS Water Services demonstrations show greatly simplified, interactive discovery and access to tens of thousands of stream discharge time series descriptors and datasets worldwide, discoverable through a standards-based GEOSS “catalog of catalogs” (http://geoportal.org). This addresses a significant subset of water information (time series for stream flow and precipitation encoded as WaterML4) and web services (CSW5, WMS6, WFS7, SOS8). Further work is needed, as outlined below.

1.4 Future work
Future developments for water resources data access in GEOSS should address the following points:

End-user focus
- Develop more application-oriented scenarios around flood, drought, and water quality monitoring and prediction.

Technological focus
- Support discovery and access through GEOSS to additional water resource variables, such as stream depth, precipitation, water quality, soil moisture, evapotranspiration, and total water storage.
- Improve ease of publishing, discovery, and usability of time series water resource information, both historical and real-time. For example:
  - Enable group selection of data points matching a WFS query filter;
  - Enable color shading of monitor station dots based on value range of relevant variable
- Promote migration of water data servers and client applications from legacy CUAHSI WaterML 1.x and WaterOneFlow services to more modular, internationally adopted OGC WaterML 2 encodings and CSW & WFS web services.
- Work needed to develop, promote and adopt international conventions for the specific data exchange requests (i.e., allowed parameters and values) between client applications and water data servers.
- Draft conventions under consideration by the OGCG-WMO Hydrology Domain Working Group should be tested and promoted in future AIP initiatives (OGC login required for access at this time):
  - WaterML-WQ: O&M and WaterML 2.0 profile for water quality data (OGC 14-0039)
  - OGC Sensor Observation Service 2.0 Hydrology Profile (OGC 14-00410) resulting from European FP7 GEOWOW11 program
- Provide cloud-based data services to reduce equipment, software, and training needs for developing countries.

Institutional focus
- Coordinate with IGWCO12 and WMO13 so this development work will become institutionalized by the appropriate international authoritative agencies.

Attention should be given to usage within developing countries having difficulties with communication bandwidth limitations.

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4 OGC Water Markup Language (WaterML) version 2.0.1, see http://www.opengeospatial.org/standards/waterml
5 OGC Catalogue Service for the Web (CSW) version 2.0.2, see http://www.opengeospatial.org/standards/specifications/catalog
6 OGC Web Map Service (WMS) version 1.3, see http://www.opengeospatial.org/standards/wms
7 OGC Web Feature Service (WFS) version 2.0, see http://www.opengeospatial.org/standards/wfs
8 OGC Sensor Observation Service (SOS) version 2.0, see http://www.opengeospatial.org/standards/sos
9 OGC 14-003: https://portal.opengeospatial.org/files/?artifact_id=57014&version=1 (login required)
10 OGC 14-004: https://portal.opengeospatial.org/files/?artifact_id=57327&version=1 (login required)
11 GEOWOW: http://www.geowow.eu/
12 Integrated Global Water Cycle Observations (IGWCO) Theme, see http://www.earthobservations.org/wa_igwco.shtml
13 World Meteorological Organization (WMO), see http://www.wmo.int
2. Community Objectives

2.1 Improving access to global water information via GEOSS

The AIP-6 Water SBA has the following objectives to make global water resources information available through GEOSS:

- Stimulate development of regional/national approaches and conventions for federation of water information that would be practical for developed and developing nations.
- Develop approaches for search, discovery and access to water information that make most use of mapping interfaces and other visualization aids.
- Improve integration of web map clients, both open source and commercial, with the GEOSS infrastructure, including the Discovery and Access Broker (DAB), to provide more ways for users to interact with GEOSS. This will promote wider use and support among hydrology and other domain communities.
- Provide recommendations on improving the GEOSS architecture’s ability to provide water information in an operational context.
- Contribute to the development of standard catalogue services for water information sharing.
- Provide support to the joint WMO/OGC Hydrology Domain Working Group (HDWG) in championing the adoption of standards that facilitate global information sharing such as WaterML 2.
- Provide outreach to the broaden awareness of the importance water sharing in a global context.

We simplified the above list to the following tasks and scenarios:

(1) improve the tools and processes for federating the regional and national picture to a global system (GEOSS), while demonstrating the benefits of an already operational federated regional water data within a country;
(2) improve discovery and access to water resources data around the world; and
(3) improve integration of gridded and time series data.

These objectives are interdependent: the first greatly depends on the other two. How these have been addressed is discussed in context of the participants’ respective case studies.

2.2 Promoting international standards

Underlying the above objectives is the need and importance of agreement among all participants on authoritative, international and institutionalized community standards for water data encodings and web services for data exchange. The core standards we focused on in AIP-6 were:

- CUAHSI WaterML 1 and WaterOneFlow (WOF) Services
- OGC WaterML 2, OGC Web Feature Service (WFS), and OGC Catalog Service for the Web (CSW)

The initial CUAHSI standards are the result of a U.S. research project funded by the National Science Foundation (NSF). They are mature and in wide use within the hydrology research community, the U.S. Geological Survey and other agencies. But they have become superseded by OGC WaterML 2 and OGC web services, which are international standards widely supported by data providers and commercial software vendors worldwide. We are now encouraging all users of legacy WaterML 1.x and WOF to migrate to the more modular and robust OGC standards, for improved industry and institutional support globally.

Still more work is needed to develop, promote and adopt international conventions for the specific data exchange requests (i.e., allowed parameters and values) between client applications and water data servers. The international standards do not define community domain-level application schemas, so this is work to be done within the OGC-WMO Hydrology Domain Working Group. Draft conventions have already been proposed and are under consideration, at the time of this writing (see Section 1.4 Future Work for more details).

2.3 Introduction to participant case studies

Each participant’s experience is summarized in this section (below), and expanded with discussion in Section 3.
2.3.1 Improved tools and processes for federating the regional and national picture to a global system

We started this project hoping to stimulate federation of national sources into a global picture, and we have an enthusiastic start on that with the countries represented. We found that many countries have several regional Hydrological Services, such as in Italy (21 regions) and New Zealand (16 regions). The national water agencies in these countries depend on all their regions to submit accurate, timely, and consistent reports of water resources information, in order to develop a national picture of their overall situation. In practice, this has been quite difficult and time consuming, with the result that such a national picture is never available “on demand” but only at predetermined reporting intervals.

As a result of this project, and thanks to the motivated efforts of participating regional water managers in Italy and New Zealand, these countries are now much closer to being able to generate on-demand national water status reports.

- In Italy, the example set by the ARPA-ER regional manager has led to publishing a consistent set of water maps for all 21 regions. For more information see Section 3.1.
- In New Zealand, so far two regions and two national institutes have implemented the data mapping services developed there during the last year. This was a very successful start and provides a model for other New Zealand agencies to follow. To support the wider adoption of water data services in New Zealand, several agencies are currently working on a New Zealand environmental time series exchange standard based on OGC services.

2.3.2 Improved discovery and access to water resources data around the world

- Publication of national precipitation data (Canada): see Section 3.2.
- Outreach to Latin America (Nicaragua, Honduras, Guatemala): see Section 3.3.
- Coordination of CEOS Water Portal with GEOSS (Japan): see Section 3.4.
- Developing support for WaterML within GloFAS (JRC, ECMWF): see Section 3.5.
- Coordination of non-GEOSS catalog with GEOSS catalog for distributed search (Esri): see Section 3.6.

2.3.3 Improved integration of gridded and time series data

- Application development integrating time series data with global maps of soil moisture from NASA Land Data Assimilation System (LDAS) program (Esri, Kisters): see Section 3.7.
3. Participant Experiences

3.1 Federating regional water agencies in Italy

During the last 100 years the Italian hydrological data publication has been the “Hydrological Yearbook”, divided into Parts I and II. Part I comprises observations of temperature, precipitation, snow pack; Part II has observations and measures about river water levels, liquid and solid river discharges, phreatic water levels, and computation of catchment areal precipitations and water balances.

All these data were published after an accurate data validation and became the official hydrologic and hydraulic reference data available in Italy.

There have also been some non-periodic publications about specific events or studies, such as floods, droughts, major storms, storm surges, etc.

For instance, in the case of Po River basin, the major water catchment in Italy, the Parma Hydrographic and Oceanographic Office was in charge of drawing up the Yearbooks, some Event Relations, data collection and validation. Even at the beginning of the work in 1913, there were already some experiences and data exchanges with Italian and foreign Offices, so that the Historical Library at ARPA Parma is rich in precious periodic and non-periodic hydrologic volumes.

In 1998 the “Bassanini Decree”, n. 112, assigned the task in collecting, validating and publishing water data from State to Regions, so from 1998 each Italian Region had to publish their collected hydrologic data. Yearbooks initially were available only in hard copy, and are now made available also via web. But every Italian Region had its own system to provide hydrological data. For instance in Emilia-Romagna Region there is the Dexter system (http://dexter-smr.arpa.emr.it/Dexter/Login), a web access database in which, after a simple registration, enables download of raw or validated data.

The map below shows Italy’s stream gauges, color-coded by regional water districts. Due to the enormous differences among Regions and Administrations, this situation was very heterogeneous and could not lead to a uniform data sharing and collection. By participating in GEOSS AIP-6, ISPRA and ARPA ER learned from and contributed to the experience, conventions and tools for GEOSS Water Services. These conventions and tools will provide additional operational capability, in particular for in situ water observations, to provide “a global registry of water data, map and modeling services catalogued using the standards and procedures of the Open Geospatial Consortium and the World Meteorological Organization”.

ISPRA and ARPA ER built a National water data service, which is the new frontier of water data sharing, using the CUAHSI architecture. The CUAHSI Hydrologic Information System (HIS) is a Web-based system that supports sharing of hydrologic data. The HIS consists of databases connected through Web services, as well as software for data discovery, access, and publication. The HIS is based on an information model for observations at stationary points that support its data services. The CUAHSI Observations Data Model (ODM) provides community-defined semantics needed to allow sharing information from diverse data sources, and is implemented as a relational database model for persistent data storage. The CUAHSI WaterOneFlow (WOF) Web services have been designed to publish hydrologic data using a standard data transmission markup language called WaterML. Data services are registered at a central HIS website, where they become searchable and accessible through its own discovery and data access tools. The CUAHSI HIS catalogue of data services is then registered in GEOSS, for even wider community access.
A significant value of Web services derives from the ability to use them from within a user’s preferred analysis environment, applying community-defined semantics, rather than requiring a user to adopt and learn new software tools for every different data provider’s holdings. This allows a user to work with data from national and academic sources, almost as though it was on their local disk. Users wishing to share or publish their data through CUAHSI HIS may do so by establishing a HydroServer at their institution. This enables to share point and time series observations using standard-based Web feature, map, and coverage services.

At the office of ISPRA in Rome, an HIS Central server was installed in which all regional services can be registered. Every regional office can upload its water data in its own HydroServer, delivering data by the standard WaterML2. Sample web pages are shown in Figure 1, Figure 2, and Figure 3.
ISPRA Hydrologic Information System Central Web Service Registry

**Figure 2. ISPRA HIS Central Web Registry**

**Figure 3. ARPA ER data services registered in ISPRA HIS Central Registry (partial)**
The Italian HIS Central has now been registered in GEOSS, a worldwide catalog that provides intermediation services among heterogeneous capacities and information systems. This enables any GEOSS user to find this data through the GEOSS Portal at geoportal.org.

### 3.2 Improving discovery and access to precipitation data in Canada

Until recently, near real time Canadian hydrological data at the federal level were mainly available in the Meteorological Point Observation (MPO) XML format through the Environment Canada (EC) national agency. However, this data structure was not convenient for further sharing of the hydrological records. Newest standards established or supported by OGC members suggested the use of WaterML2 encoding for the representation of the hydrological observations data with a specific focus on the time series records.

In order to bridge the gap between the WaterML2 and MPO data standards, the Global Institute for Water Security (GIWS) at the University of Saskatchewan and Kisters data management software company provided the middle tier solution that can be used for sharing the hydrological data between EC and all WaterML2-oriented data consumers. The first phase of this project involved the organization of metadata records, parameters, and time series structures that would accept the daily collected data from over 800 nationwide precipitation stations (Figure 4).

Some of the challenges that we faced during this phase of development were to accurately translate the MPO data format and parse the records containing the information about the station names, codes and locations, as well as the time stamps and precipitation values for each collecting location. Challenges that still remain unsolved are to provide the completeness of the measurement records for locations where daily measurement and collection procedures were disrupted. During the second phase of the project, GIWS and EC will be working together to port the Water Survey of Canada discharge and water level records to the independent database server. After development and testing periods are successfully completed, the porting solution will be fully implemented on the EC data publishing server(s).

![Figure 4. Environment Canada Precipitation Stations](image)
Due to the incompatibility of data formats supported by the EC and other organizations, reports involving near real time hydrological records at the national and international levels required a significant amount of time to create. By publishing the Canadian hydrological records in the WaterML2 notation and making the corresponding data streams available to the public (Figure 5), we are hoping to shorten and automate this process and provide stronger support for sharing the Canadian data through open standards and procedures.

Finally, in order to make the EC precipitation data sets discoverable to the public through the GEOSS Portal website at geoporta.org, GIWS deployed an instance of the GI-cat catalogue broker. This service is used to harvest the precipitation metadata from the local WISKI database at the regular time intervals and expose the OGC CSW interface to the global end users. In such a way, geoportal-based queries can receive responses from various other catalog servers providing the information and links to the relevant WaterML2 endpoints as well as other web services and resources.

3.3 Improving discovery and access to precipitation data in Latin America

In Latin America, outreach from Brigham Young University in Utah has previously brought the water agencies of Dominican Republic to publish selected water data. BYU worked with these three national and regional agencies:

- **Nicaragua – Instituto Nicaragüense de Estudios Territoriales (INETER):** this is the national agency for water resources, meteorology, and cartography/geodesy. They have a well-established database, though the current Oracle database is unwieldy and difficult to use. They operate within an environment where public and free distribution of their data is not allowed, even though most of the people working there believe it should be.

- **Honduras – Comisión Contra Inundaciones Valle de Sula (CCIV):** this Commission Against Flooding in the Valley of San Pedro Sula is a government agency, but operates separately and not under the direction of any specific ministerial agency. This is good, in that they have some autonomy in what they do, but bad in that they have to fight hard for budget and are not really working that closely with other national agencies (meteorology, hydraulics, etc.) that have or do some of the same basic tasks like water data collection. The eastern/Caribbean side of Honduras is the lower valley prone to flooding, but also the major agricultural and economic center of the country, with more than 65% of the country’s productivity. They have developed several dikes and diversion canals and a few dams to help control flooding and manage agricultural and other water resources. The agency was created because of the importance placed on protecting this highly productive region.
- Guatemala – Coordinacion Nacional para la Reduccion de Desastres (CONRED): deals with the response issues after an emergency like flooding, landslides, volcanoes, etc. They search, rescue, and recover while providing needed supplies. Of course there is a unit in the agency trying to do early warning and so they operate a network of telemetry stations that record rainfall and water surface elevation among a few other things in the watersheds of primary vulnerability. However, because they are not charged with hydrology/hydraulics per se, they do not maintain rating curve information where there stations are so they do not have flow rates. Instead they operate their “warning” based on relative changes in water surface elevation. They keep this information in a database, but it is not accessible. There are other agencies in Guatemala (meteorological, hydraulic services) that operate similar equipment but there is little, if any, coordination among them.

Most of BYU’s efforts have been in helping them put their information into the CUAHSI HIS database with the Spanish (soon to have other languages too) version of the HydroServer tool being developed at BYU. They see the larger picture of GEOSS and what the AIP-6 team in water is doing, along with the important examples achieved in Italy and New Zealand, but they know that before they can really benefit they have to stand up their own information. In other words they know that a system of systems doesn’t work unless you have strong constituent of “systems” in the first place from which you can draw from. There is more observation and data hosting capacity in Latin America than might be expected, but while some are more able, they all suffer from each trying to “recreate the wheel” in their own institutions rather than being able to rely on a broader network of support, in most cases among their own different government institutions, but also across the region. This is exactly why the idea of GEOSS and world water online (linking people everywhere to water) resonated so well with them.

From BYU’s experience, the following themes have emerged:

1) They desperately need and want the kind of tools and information we are building within the concept of GEOSS and the world water online.
2) They have pockets of expertise but it is difficult for each institution to individually develop and retain people with good informatics backgrounds.
3) They need to be able to take ownership of whatever level of system they are managing, otherwise in the long run, it leads to largely wasted efforts regardless of the intent. To do this they need to build human capacity in informatics, something that will happen organically as they join this larger network of people involved in the same things in different countries.
4) Being open and sharing of data will bring so many positive impacts, including the ability for their universities to educate students who will later be more capable of contributing in these same agencies.

In summary, these countries are now starting to get up to speed on the technology, mainly held back by political and national security concerns. We hope to see further progress with these and other Latin American countries in future projects.

### 3.4 Coordination of CEOS Water Portal with GEOSS

The Committee on Earth Observation Satellites (CEOS) has developed a portal for water data to serve the geosciences research community, with these partner data providers:
This portal provides faceted, OpenSearch access to numerous data types for hydrology and atmospheric sciences.

![CEOS Water Portal](http://waterportal.ceos.org/)

**Figure 6. CEOS Water Portal**

In AIP-6, the CEOS Water Portal support team developed linkages between its own catalog of data services, and the GEOSS catalog of catalogs. It is now possible to search the GEOSS Portal for any of the holdings in the CEOS Water Portal.

### 3.5 Developing support for WaterML within GloFAS

The Global Flood Awareness System or GloFAS is a flood forecasting system for all the major rivers around the world. It is developed by the Joint Research Center of the European Commission and the European Center for Medium Range Weather Forecasting.

GloFAS uses ensemble weather forecasts in combination with the land-surface scheme of ECMWF and the routing feature of the hydrological model LISFLOOD to produce daily probabilistic discharge forecasts with a lead time of up to 20 days for rivers with a minimum basin size of 10,000 sq.km.

Although still in the early development phase, GloFAS has been producing daily flood forecasts in a pre-operational manner since June 2011. It has shown its potential, for example, during the floods in Pakistan in August 2013 and in Sudan in September 2013.

Using the international standards for hydrologic information such as WaterML2 and its associated data sharing services, JRC/ECMWF are currently testing to provide GloFAS simulation results at points where observed river discharge is available through web services.

This would provide a twofold benefit: First of all model simulations could be verified against measurements all around the world where water data is shared through web services. Secondly, GloFAS discharge forecasts at these specific locations could be better integrated as complementary information into national/regional flood forecasting services. See Figure 7 for an illustration of this, and [http://www.globalfloods.eu/](http://www.globalfloods.eu/) for more details.
3.6 Coordination of non-GEOSS catalog with GEOSS catalog for distributed search

ArcGIS Online (AGOL) is Esri’s Software-as-a-Service (SAAS) platform for geospatial information sharing and collaboration that includes an increasing number of analytical capabilities. For this project, Esri configured an Esri Community Portal for GEOSS in AGOL where various relevant public items available from organizations using AGOL were organized according to the GEO Societal Benefit Areas. The Esri Community Portal is available at http://geoss.maps.arcgis.com.
In addition, Esri configured its open source Geoportal Server technology ([http://esriurl.com/geoportalserver](http://esriurl.com/geoportalserver)) to provide an OGC CSW interface to public content from ArcGIS Online. This CSW is available at: [http://geoss.esri.com/csw/csw?request=GetCapabilities&service=CSW&version=2.0.2](http://geoss.esri.com/csw/csw?request=GetCapabilities&service=CSW&version=2.0.2). This enables GEOSS users to discover and access public content available through AGOL. As of this writing, over 100,000 public items from ArcGIS Online are accessible through this CSW interface. The AGOL CSW interface is registered in the GEOSS Component and Service Registry. Esri also configured an instance of the Geoportal Server to provide distributed searches of registered catalogs including to the GEOSS Discovery and Access Broker (DAB), ArcGIS Online. This federated ‘discovery client’ is accessible at [http://geoss.esri.com/csw](http://geoss.esri.com/csw).

Esri worked closely with the ESSI Lab, developers of the GEOSS DAB, to enable discovery of ArcGIS Online through the GEOSS DAB. This can be seen on the GEO Web Portal as in the image below:

![Figure 9. ArcGIS Online searchable through GEOSS Portal](image)

Searching GEOSS resources from the other direction can also be done, as shown in the next figure ([http://geoss.esri.com/csw/catalog/search/search.page](http://geoss.esri.com/csw/catalog/search/search.page)). This illustrates a query for resources having the characters “gws” (as in GEOSS Water Services), which in this case returned two metadata records. These are the same results obtained from the same search initiated from the GEOSS Portal.
3.7 Integration of gridded and time series LDAS model outputs

Esri and Kisters have done significant application development integrating time series data with global maps of soil moisture from NASA Land Data Assimilation System (LDAS) program. The web app shown in Figure 10 displays a global soil moisture map (gridded data) with overlaid time series below for 2 selected locations. The user can change the global map by selecting a different date on the time line at bottom. Another option for the time series display is to overlay multiple years at a single location, for year-to-year comparisons (Figure 11). These prototypes can be exercised here: [http://bit.ly/1gPbUS1](http://bit.ly/1gPbUS1).
Figure 10. World Soil Moisture Explorer: overlaid time series at two locations (Esri, Kisters, NASA)

Figure 11. World Soil Moisture Explorer: overlaid years at one location (Esri, Kisters, NASA)
4. System Model for Water Data Sharing

4.1 System architecture: main components

The system architecture for this project had the following requirements:

- Provide a means of visualizing hundreds of thousands of stream gauges on a geographic map
- Provide search capability to discover specific stream gauges by location, site name, or observed property
- Enable search result to include heterogeneous data providers’ gauges (e.g., USGS, GRDC, etc)
- Upon identifying the specific stream gauges of interest, enable access to the data services for that gauge
- Data services should include a graph of data values over a selected time period; WaterML format for the same data; and tabular/CSV file download for the same data

A study conducted by the OGC for CUAHSI and published in 2011\textsuperscript{15}, identified two alternative architectures for accomplishing these requirements. In both cases, there were three tiers of servers: two for discovery of data sites and one for serving time series data as WaterML. In the report, the first tier was typically a CSW catalog service of data providers for a given domain of data; the second tier could be either a feature data service (WFS) of site-specific data, or a second CSW catalog of the site-specific data; and the third tier was typically an SOS data service returning time series for a selected stream gauge. Following this architecture, we chose the WFS alternative for the middle tier, treating it as a map service of gauge sites for visual selection, see Figure 12. The web portal application mediates user requests and data display among the services.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{Figure12.png}
\caption{Information flows for 3-tier service architecture}
\end{figure}

This figure shows the general order of processing from discovery to data access. The “Community Web Portal” could be a data provider’s own client application, or one with broader scope, such as CUAHSI HIS Central, Esri ArcGIS Online (AGOL, see Figure 8), the CEOS Water Portal (Figure 6), etc. Using the relevant portal tools, the user initiates a search of the portal’s catalog to find features of interest. For illustration purposes, we are assuming the search is for streamflow gauges; that a WFS map layer of such gauges has been registered in the portal catalog; and that SOS data services for charting, WaterML data exchange, and CSV download are online and accessible. For development prototyping purposes, UT CRWR research staff have created a number of feature data layers containing locations of USGS, GRDC, and several other data producers’ stream gauge observations (Figure 13), which can be browsed publicly at the URL in upper right of this figure.


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Figure 13. Global Streamflow Map (by UT CRWR)

At this scale it is hard to tell, but there are hundreds of thousands of stream gauges represented in this figure, at least half of which are in the U.S. This map is composed of separate feature layers for each of the data producers identified in the map legend in left sidebar. These are the WFS map layers mentioned in Figure 12. We expect most users will want to zoom in to a large scale on the map, where individual gauges can be easily distinguished. But even at this scale, it is possible to find a gauge point with recent data. (Many gauge points have only historical data, some quite old.) In Figure 14 and Figure 15, you can see the various forms of data that are being served by this data provider (in this case, Kisters is re-hosting a subset of GRDC data, converted from legacy format to WaterML 2.0). Figure 15 is a subset of the complete WaterML 2.0 output document for this stream gauge; the first column contains the time series description details defined by the OGC Observations and Measurement 2.0 standard, and the second column has a partial set of data values (many more data values were cut out, just above the bottom 5 rows).
Figure 14. Example time series description and data service links

Figure 15. WaterML 2.0 sample time series data
4.2 Role of GEOSS in system architecture

We have now seen all the main components except for GEOSS. Most users just see the main GEOSS Portal browser interface, which has recently changed substantially, see Figure 16.

![GEOSS Portal](www.geoportal.org)

However, this portal is just the visible part of a substantial architecture called the GEOSS Common Infrastructure (GCI). The GCI has multiple registries, a discovery and access broker framework, semantic tools, and more, see Figure 17. Discussion about the GCI components is beyond the scope of this report; however, it is important for data producers wishing to register their service offerings in GEOSS to know where to direct their attention.

The GCI undergoes steady evolution as it is adapted to meet changing requirements and experience. At the time of this writing, data producers wishing to register catalog services, data services, community portals and other technologies, would normally register these capabilities using the GEOSS Registry Publication Portal ([http://geossregistries.info/geosspub/](http://geossregistries.info/geosspub/)), using the online forms to describe their data holdings. In the case of registrants having very large data holdings or complex system architectures requiring custom harvesting by the GCI, it may be recommended for such data producers to contact the Discovery and Access Broker (DAB) development team directly, at the Italian Research Council office in Florence. The DAB routinely harvests the content of the GEOSS Registry, but in some cases it may be better to bypass this step and harvest specific community catalogs due to their size, dynamic nature, or other complexities.

The DAB was initially developed by a European Commission FP7 project, EuroGEOSS Broker Framework. Further background on DAB and how to use it can be found here: [http://www.eurogeoss.eu/](http://www.eurogeoss.eu/).
Data services, catalogs, portals, even datasets can be registered in GEOSS. However, through working on the AIP-6 Water SBA project, we have come to the decision that data producers wishing to register their stream gauge or rainfall monitoring networks should register the WFS and SOS services in their own managed catalog, or that of a community portal with which they are familiar. This catalog would then be registered in GEOSS, thus enabling distributed search from the GEOSS Portal to all the publicly accessible federated data sources. Figure 18 illustrates this pattern.

5. Recommendations for International Standards and Community Conventions

This project leads us to recommend two levels of standards and practices, regarding mapping and exchange of water data:

- International data exchange standards
- Hydrologic domain community conventions

5.1 Recommendations for international standards usage in water data exchange

- Use OGC WaterML 2 for water-variable time series data (streamflow, precipitation, runoff, etc).
- Use OGC WFS 2 for a feature layer of water data sites; one WFS service per data layer / producer.
- Use OGC SOS 2 as the web data service for WaterML 2, but be prepared for the many sites running CUAHSI WaterOneFlow (WOF) web service for WaterML 1.x data.
- Each data provider could install and manage a catalog registry of relevant time series descriptions (WFS feature layers), or use an established community catalog for that purpose (eg. CUAHSI HIS Central). This catalog should support OGC CSW 2.0.2 interface standard, which itself should be registered in GEOSS.
5.2 Recommendations for hydrologic community conventions for time series data exchange

Implementing standards for data exchange requires more than developing compliant server and client software; it also requires that these components follow consistent conventions for the exchange of requests and results. This level of convention is not appropriate to include in the general standard, but depends on each distinct end-user community’s desired workflows. Based on our experience with several related projects now, we recommend a minimal set of feature attributes to characterize time series, as the essential content schema for each WFS map layer of services hosted by a given data provider:

- **WaterMLURL** for a REST call to a separate data service endpoint, that enables a time series to be queried from this location.
- **GraphURL** and **DownloadURL** for graphing or downloading the data (e.g., comma-separated-values or CSV format), if available.
- **BeginDate** of the data (the time of first information, using ISO 8601 time format).
- **EndDate** of the data (make Null if this is current time).
  - If the **EndDate field is empty (null)**, this means the data service is a near-real-time feed, not just an historical dataset.
- **Descriptor** – text descriptor of this feature (e.g. Site name for gaging station, COMID for NHDPlus, etc)
- **Source** – text field that specifies the source of the data e.g. USGS, etc.

We ask the international hydrologic community to observe these sets of recommendations, in the interests of minimizing the programming effort and training needed to support everyone’s implementations of servers and client software.
6. References

The following are copied from each page’s footnotes, collected here for convenience.

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