UK Centre for
Ecology & Hydrology

Hydrological Status and Outlook System (HydroSOS) Demonstrator

Version 1 Development Report

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https://eip.ceh.ac.uk/hydrology/HydroSOS/

Issue Number 1

Date 01/07/2020

NCAR

WORLD
METEOROLOGICAL
ORGANIZATION

Title Hydrological Status and Outlook System (HydroSOS) Demonstrator

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Date 01/07/2020

Thanks Our thanks go to those who assisted us in the development of this Demonstrator. Particular thanks to those at organisations who provided data, and helped us interpret them, including: Berit Arheimer, Ilias Pechlivanidis, and Louise Crochemore at SMHI; Dave Wolock and Xiaodong Jian at USGS, Juan Bianchi at INA; and Tayba Tamang and Chhimi Dorji at NCHM.

Contents

1 Introduction

Consistent hydrological status and outlook information across large-domain basins or regions of shared hydrological interest are not often available. Furthermore, whilst large-scale modelling capabilities are continually improving, there is an information and confidence gap between locally informed hydrological status information products and those developed globally.

HydroSOS is a World Meteorological Organization (WMO) initiative that aims to increase global resilience to hydro-climatic risks and the management of water resources through the production of hydrological status and outlooks assessments at different scales around the world. Currently in a pilot phase, HydroSOS is being developed through a collaboration between National Hydrometeorological Services (NHMS's), basin organisations, global modelling centres and the research community. The system will provide an appraisal of where the current hydrological status is different from "normal", as well as sub-seasonal to seasonal outlooks indicating whether this is likely to get better or worse over the coming weeks and months (Figure 1).

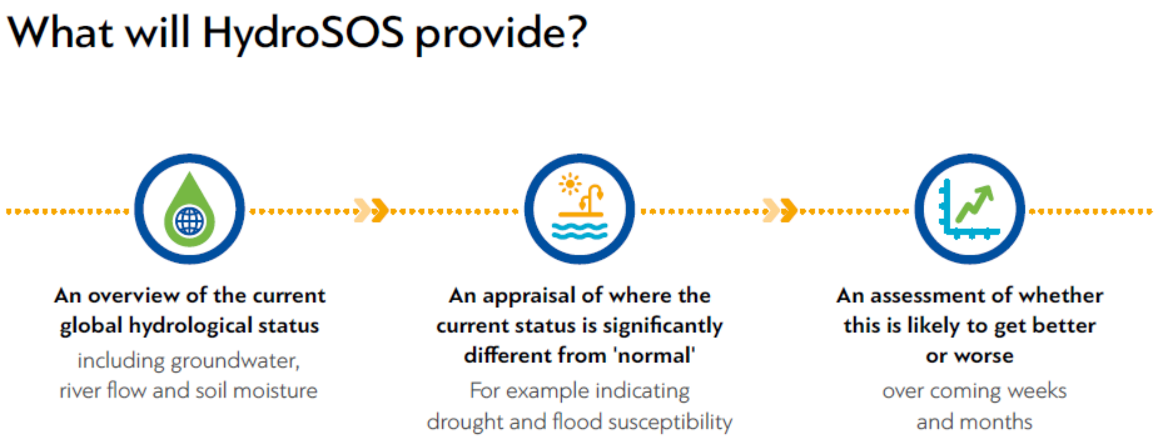

Figure 1 Infographic: What will HydroSOS provide?

The HydroSOS programme consists of five main activity streams:

1. Increasing the interoperability of hydrological status and outlook products through **Common Technical Specifications.**
2. Increasing national capabilities to generate hydrological status and sub-seasonal to seasonal outlook products through **Guidance on Methods and Tools.**
3. Increasing the utility of large-scale hydrological status and outlook modelling through **Co-design of Global Products**, with international partners working from local to global scale.
4. Increasing shared production of transboundary hydrological status and outlook products through **Regional Pilots**, initially in South Asia and the Lake Victoria Basin.
5. Prototyping the integration of hydrological status and outlook products for national, regional and global users through a **Demonstration Portal.**

This document describes the progress in the development of Version 1 of the HydroSOS Demonstration Portal, herein referred to as "the Demonstrator", by the UK Centre for Ecology & Hydrology (UKCEH) and National Center for Atmospheric Research (NCAR), herein referred to as the "Project Team". Many decisions about the information content and user interface had to be made in the development of the Demonstrator. In the longer-term these aspects will be based on the outputs of ongoing activities in other HydroSOS Work Packages however for the Version 1 of the Demonstrator it was necessary to base these decisions on the expert judgement of the Project Team. This document details the decisions that have been made, and why these choices were made over other alternatives. Key considerations for the future of an operational service are also highlighted.

1.1 Aims of the Demonstrator

The HydroSOS Demonstrator is being developed to illustrate the concept of a potential HydroSOS platform to WMO Members, and in particular to National Hydrological and Meteorological Services (NHMSs) who would be central to building any official, operational HydroSOS platform in future. The Demonstrator aims to visualise the novelty of the HydroSOS concept: combining products from various services over different scales (see Figure 2). Whilst the scope of the Demonstrator effort is limited, the outcome should nonetheless provide a starting point that enables this target audience to envision the potential system and services, as well as the linkages of data sources to potential products. The effort to construct the prototype will also provide an opportunity to identify and consider key design and scope decisions, yielding pragmatic insights as to the effort that will be needed to move from a prototype demonstrator to a fully operational system. The Demonstrator is designed such that further information (for example from other NMHSs or at different scales) and other functionality can be trialled in future as the HydroSOS initiative develops.

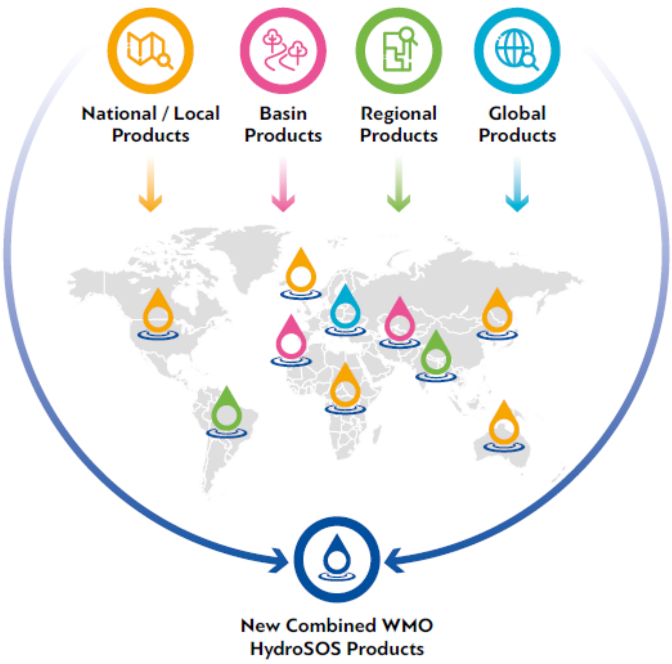

Figure 2 HydroSOS: Integrating across scales

1.2 Target Audience / Key Stakeholders

HydroSOS will help NMHSs build new or enhanced status and outlook information products for their users including the environmental, agricultural, industry, energy and water supply sectors, as well as disaster risk reduction and the general public. By sharing their products through HydroSOS, National Hydrological and Meteorological Services will reach new user communities at the regional and global scale, further enhancing the benefits of their activities. It is anticipated that HydroSOS will benefit six key stakeholder groups, as shown in Figure 3. While the Demonstrator is primarily aimed at representatives of WMO Members, NHMS staff and others who might help develop an operational HydroSOS in future, it is anticipated that it could also be used in consultations with these target user communities to help understand their needs. The demonstrator is also intended to aid discussions with Development Partners, including International Financing Institutions who may play a role in supporting the HydroSOS initiative.

Figure 3 Key stakeholders and target audience for the Hydrological Status and Outlook System

1.3 Scope and Key Requirements

The overall scope of the HydroSOS initiative has been in discussion since the project kick off meeting in Entebbe, Uganda in 2017. Questions over whether and how different types of information regarding hydrology, water resources, extremes such as drought and flooding, climate change, other sectoral outcomes (e.g. agriculture) would be included, as well as the configuration of the governance of the initiative, have arisen and been revisited at multiple HydroSOS interactions. Likewise, the scope and scale of a Demonstrator system has also been discussed and debated over the course of the effort. Given the available timelines and levels of complexity of various potential elements, and recognising the existence of complementary initiatives led by WMO, the HydroSOS Demonstrator Version 1 has been designed with the following objectives and scope:

- It focuses primarily on hydrologic status variables and indices at an intermediate timescale: status and outlook products are primarily bi-weekly to monthly to seasonal, but some higher-frequency status products (such as daily streamflow) are also shown.
- It updates no more frequently than weekly (the prototype is monthly), which allows for a small range of lags in the included datasets.
- It shows a multi-variate and multi-faceted perspective on hydrologic status and outlooks, including multiple hydrologic variables on distributed spatial scales (catchment, basin, political boundary) as well as at point locations.
- It merges global model and observational datasets with national and regional-level datasets, providing a unique blend of global products that contain official national inputs.

The scope outlined above means that HydroSOS is not a flood forecasting system, which is a distinct endeavour that involves substantially more difficult and extensive requirements - i.e., greater real-time coordination, update frequency, data systems engineering and interoperability, data and model validation and assimilation, product reliability - and also carries greater institutional and social risk due to directly informing tactical emergency management. The coarser granularity of the HydroSOS system means that while it can inform decision-making, e.g., for water resources and other sectors, the immediacy of the decisions is lower, affording greater opportunity for correction, as they are more in the realm of management than of operations.

A number of requirements for the HydroSOS demonstrator were further described during the HydroSOS First Technical Meeting in Nanjing, China in 2019. These are summarised in Figure 4.

The Demonstrator must be as intuitive to use as possible, which is a significant challenge given the scope of the information presented. Therefore, it must also provide information buttons for more detailed descriptions. It needs to be able to present categorised data, that illustrates at a minimum whether the hydrological status is “normal”, “above normal” or “below normal”. It needs to be able to present data across multiple scales simultaneously: for example, point or in situ measurement data provided for a certain country together with gridded or polygon (watershed, catchment) data provided nationally to globally. The service needs to be flexible to be able to merge and present data from different input sources, such as APIs and WMSs (see

Section 2.2), as well as data provided manually. The Demonstrator needs to display a map overview of the past, present and future situation, as well as being able to present timeseries graphs and details for a given location. Finally, the Demonstrator must be responsive, and must load quickly – this will be particularly challenging given the volumes of information included, and the need for it to be accessible to users with poor bandwidth/internet connection.

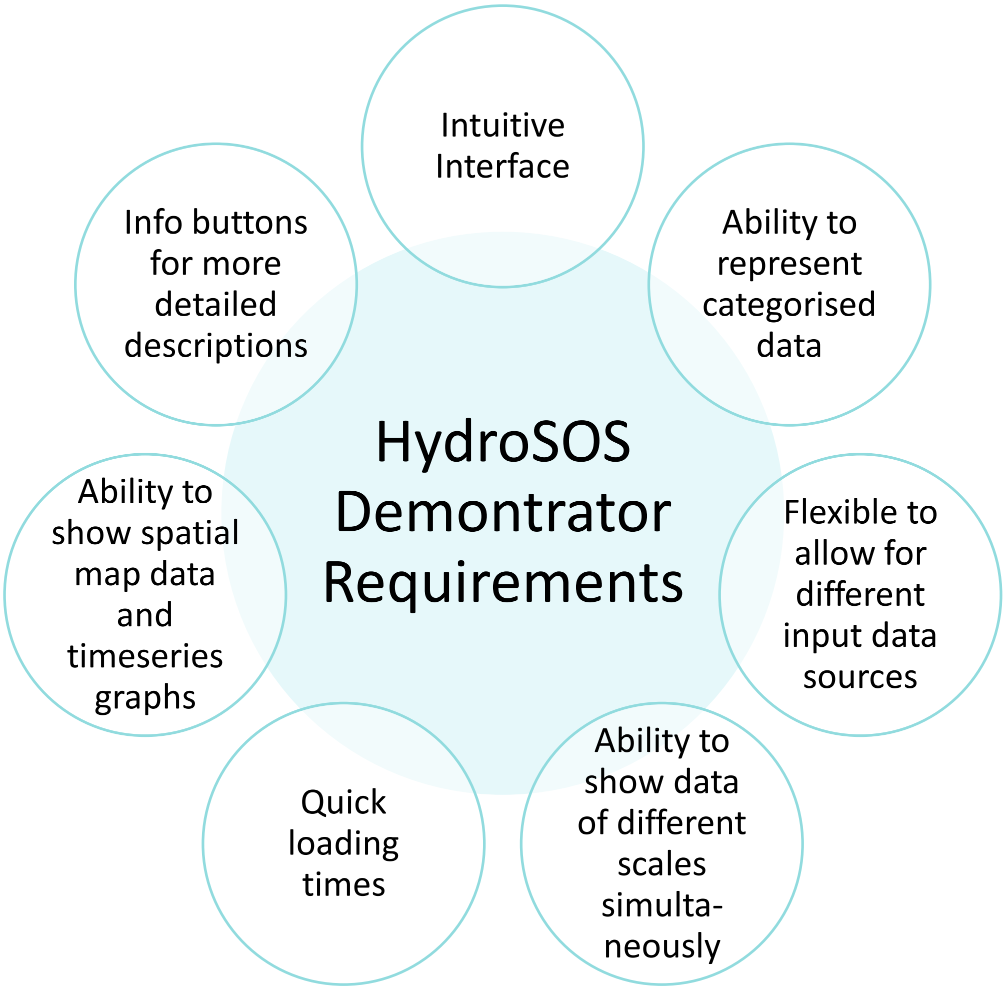

Figure 4 Key requirements for the HydroSOS Demonstrator

2 Development Overview

The scope of the Demonstrator effort dictated that an expedient effort be pursued for data acquisition and processing, thus the workflows involved were built under the assumption that if an operational HydroSOS system is ultimately adopted, such components would be partially or fully replaced with more comprehensively engineered solutions. In order to achieve the key requirements set out in section 1.3, staff at UKCEH set up a technology stack using their experience from the development of the UK Water Resources Portal (eip.ceh.ac.uk/hydrology/water-resources/). Staff at NCAR assisted in the development of the Demonstrator by processing global scale datasets for ingestion, as well as contributing to the design of the Demonstrator. This section describes the products that are included in Version 1 of the Demonstrator, how data were pre-processed and stored for access by the Demonstrator, and the technology stack used to build and present the Demonstrator.

2.1 Exemplar Products

In order to demonstrate a variety of information that could potential be delivered through HydroSOS and a number of aspects of potential functionality, a range of exemplar hydrological status and outlook products were required for the Demonstrator. Decisions about how many and which products to include were driven by the aim of demonstrating what is possible in future, rather than trying to include as many products as possible in Version 1. The design of the Demonstrator is such that other products can easily be added as the initiative develops.

Suitable products for the first iteration of the Demonstrator were sought by the Project Team from NMHSs around the world via teleconference and email contact with other HydroSOS partners, and their colleagues. Global status and forecast product datasets were obtained by NCAR, reprocessed into the forms and/or products required by the UKCEH platform, and transferred to UKCEH for ingestion into the Demonstrator. National product datasets were obtained directly by UKCEH from national sources and staged in the UKCEH platform.

2.1.1 Product requirements

Several sources of global and national level products were considered for the Demonstrator, based on prior experience in developing real-time hydrologic and climate monitoring and prediction systems. It was recognised that each source would require a certain degree of tailored effort but that the development and specification of product and dataset standards would also allow for more general workflows to be developed to process disparate data streams into a consistently presentation. Early protocols for product provision were outlined and will need to be further refined as the operational vision HydroSOS evolves to streamline initialising new services into the website. It is expected that a toolbox of methods and examples will ultimately be provided/produced to assist partners in any source-based reprocessing of data (versus centralised processing at the HydroSOS host-site).

The product requirements for Version 1 of the demonstrator however were deliberately kept tentative because the members of Project Team had resources to work with the data providers to reprocess the data into a consistent format. However, the minimum requirements included factors such as the following:

- Monthly or daily data
- Potentially available in near-real time, which in the context of the development scope meant through June 2020
- Status (current observations or up-to-date modelled variables) and/or outlooks (model-based forecast) data
- At a minimum, runoff and/or streamflow data, a focus in Version 1, and preferably other fields including snow variables, soil moisture, groundwater, and climate fields for use as explanatory variables (precipitation, temperature)
- Historic timeseries of modelled or observed data for use in calculating products showing statistically consistent anomaly products (e.g., the category bandings for thresholds of "below normal", "normal" and "above normal"). Ideally a multi-decadal record is expected.
- Responsive members of staff for required email exchanges to clarify queries and provide additional information.
- Evidence of stable dataset/centre support: e.g., data sources at long-term centres or groups are preferable to data from term-limited research projects.
- Existence of analysis supporting the estimation of product skill, for outlooks in particular, which could be in the form of hindcast datasets or other forms of validation.

Recognising that significant variations in the conformity to such requirements are likely to exist across the range of products of potential interest to HydroSOS, the team chose to adopt a flexible stance on requirements that would allow for greater inclusivity of datasets from centres that might not otherwise meet standards for participation. Such policies would need to be further formalised.

Five products have been integrated into Version 1 of the HydroSOS Demonstrator, as detailed in Table 1 below.

Table 1 Datasets included in Version 1 of the HydroSOS Demonstrator

NMHS Provider	**Swedish Meteorological and Hydrological Institute (SMHI)**	**United Kingdom Centre for Ecology & Hydrology (UKCEH)**	**United States Geological Survey (USGS)**	**National Water Institute Argentina (INA)**	**National Center for Hydrology and Meteorology Bhutan (NCHM)**
Geographic Area	Global	UK	USA	Argentina	Bhutan
Observed / Modelled	Modelled	Observed & Modelled	Observed	Observed	Observed
Areal / Point	Areal	Point	Point	Point	Point
Status / Outlook	Both	Both	Status	Status	Status
Variables	Runoff / Precipitation / Temperature	Streamflow	Streamflow	Streamflow / Stage	Streamflow
Temporal Resolution	Daily (Aggregated to Monthly)	Monthly	Daily	Daily	Monthly
Provision	Manual Transfer	Manual Transfer	API	API	Manual Transfer
Latency	Monthly	Monthly	Daily	Daily	Upon request (< Monthly)

The Australian Hydrologic Reference Stations data from BoM were provided to the Project Team, but were not included in Version 1 of the Demonstrator as the data was purely historical, ending in February 2019, and thus does not reflect current hydrological status. Furthermore, historic bandings of “normal”, “above normal” and “below normal” would need to be provided to categorise the data. The HydroSOS does not aim to be an archive of historic data, and so for these reasons, the completion of the integration of the Argentinian and Bhutanese data were prioritised. Further discussions with BoM will be held to consider if any of the other information products they generate could be incorporated into the next Version of the Demonstrator (see Section 4.1.1).

2.1.2 Geographical coverage

Each of the products chosen for Version 1 include different sites, stations, and geographical areas in their products. For example, the USGS supplies data for the majority of streamflow sites available, UKCEH focus on a core set of ‘indicator catchments’ and SMHI provide areal data for the whole globe. Development of an operational HydroSOS will necessitate consideration of whether and how to standardise the number of data points incorporated and shown. For the demonstrator a range of potential options are shown, including display of a sub-set of sites selected by the NMHS (e.g. UKCEH) and display of different densities of sites at different zoom levels (e.g. USGS – see Section 3.5).

2.1.3 Data transfer

A mixture of data transfer methods were used for Version 1 of the Demonstrator and this is another area where standardisation should be considered in any future operational HydroSOS. As mentioned above, there is significant potential to capitalise on the capabilities the WMO Hydrological Observing System (WHOS) could provide to NMHSs in this regard.

The majority of data transfer for Version 1 was done manually via email and FTPs, although some data are read directly through APIs and WMS where these are already made available by the NMHS. The transfer of reprocessed SMHI global scale data from NCAR to UKCEH through FTP was found to be slow, and the unpacking of data takes a significant amount of time. This is an example of the sort of issue which will need to be addressed for an operational service.

2.1.4 Pre-processing, formatting and storage

A key consideration in future operationalisation of HydroSOS will be the degree to which data providers will be required to process their own information products into a standardised form for ingestion into HydroSOS versus data being provided in a variety of existing forms and then pre-processed centrally. For the Demonstrator however it was decided that it was not possible to ask data providers to undertake significant reprocessing of their products and instead some form of pre- or re-processing was required for all five data sources.

Though provided through an API, USGS data also required historic data to be downloaded, and pre-processed to product the category bandings. The data imported through the API is then cross referenced with these files, so that maps can be displayed efficiently.

Staff at INA provided extensive input in to the Demonstrator, actively producing new API endpoints and amending their existing service to produce their data in a way that could be easily presented in the Demonstrator.

Data from NCHM was provided raw, and was processed to match the format of other status data.

The SMHI data were provided raw, and were re-processed into new spatial map polygons (see Section 3.4). Historic simulated observations from 1981-2015 were used to define the category bandings ("below normal", "normal", "above normal"). Timeseries data needed to produce three different types of plots were calculated from the ensemble forecasts.

UKCEH data were again provided raw and re-processed. Many of the elements used by the HydroSOS Demonstrator are already calculated as part of the UK Hydrological Outlook, however, as discussed in Section 3.6, the categories used were based upon different flow percentiles, so re-processing was required.

2.1.4.1 Category bandings (thresholds) data

For each dataset, a historic timeseries must be used to calculate the category bandings. For Version 1 five categories are used: 0-10%, 10-33%, 33-67%, 67-90%, 90-100%, see Section 3.6. These need to be calculated for each time step (366 for daily and 12 for monthly time steps). This table is then used to "look up" which category a status or outlook value falls into. An example of this data for SMHI is shown in Figure 5.

	A	B	C	D	E	F	G	H	I	J
1	MonthValid	ClimMean	ClimStdev	ClimMin	ClimThresh10%	ClimThresh33%	ClimThresh50%	ClimThresh67%	ClimThresh90%	ClimMax
2	jan	61.625	23.5866	12.6342	26.9779	48.8031	65.0135	73.5458	92.7786	100.2866
3	feb	39.9701	19.26	10.6146	18.2712	27.9796	34.4096	47.0519	66.5112	94.6231
4	mar	34.7756	17.3239	5.6438	15.3543	24.3592	31.8583	41.463	55.2094	88.8871
5	apr	21.6067	13.7367	4.8889	5.8322	12.5123	20.0348	23.4579	46.1597	52.379
6	may	10.939	6.8689	2.3862	4.6022	7.8818	10.058	11.4706	17.3909	35.7355
7	jun	9.0873	6.0199	2.1985	3.9186	5.6309	6.756	10.0879	15.019	33.3876
8	jul	6.4927	5.1778	1.5525	2.5169	4.3869	5.3544	6.424	10.5978	26.2306
9	aug	7.9019	4.4084	0.5152	2.9248	6.0941	6.8999	9.2226	12.8786	21.5957
10	sep	10.2163	6.0189	2.4047	3.125	6.8735	9.4379	11.7083	17.4643	28.5148
11	oct	19.8947	13.0783	4.1171	6.8447	9.2625	18.8366	20.9333	43.0278	57.7512
12	nov	37.9149	24.5139	7.6444	11.7811	21.7553	35.0875	43.8034	74.3267	121.1539
13	dec	54.0149	23.3295	19.1263	25.0001	42.5	49.7359	65.0659	84.2577	120.0575

Figure 5 Format of SMHI category banding data

For the spatial points data, the bandings are stored as a json file. For the USGS data, the value retrieved from the API is queried against this file to determine the colour of the dot. Figure 6 shows an example of the first 20 rows of the json file for one day.

{"01014000":{"95%": "11000", "90%": "8220", "80%": "6000", "75%": "4960", "50%": "3700",
"25%": "2430", "20%": "2250", "10%": "1670", "5%": "1390"},"01021000":{"95%": "5760",
"90%": "4690", "80%": "3320", "75%": "3050", "50%": "2190", "25%": "1510", "20%": "1250",
"10%": "1010", "5%": "886"},"01034500":{"95%": "19200", "90%": "15500", "80%": "12800",
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Figure 6 Format of USGS json category banding data

2.1.4.2 Timeseries forecast data

Three graph options are plotted in the Demonstrator, as shown in Section 3.8. The count data defines how many ensemble members fall within each of the five categories. An example of the count data is shown in Figure 7. The raw ensemble data, as in Figure 8, (in units, e.g. mm/month for runoff) is given to produce a box plot. Finally, percentile data summarises the ensembles (e.g. what is the 10th percentile, in mm/month, of the 51 ensemble members), see Figure 9.

	A	B	C	D	E	F	G
1	MonthValid	NumValidMembers	Counts0to10	Counts10to33	Counts33to67	Counts67to90	Counts90to100
2	202006	51	7	9	27	7	1
3	202007	51	6	16	17	10	2
4	202008	51	9	19	14	6	3
5	202009	51	8	19	11	8	5
6	202010	51	5	9	15	18	4
7	202011	51	4	4	17	22	4

Figure 7 Format of count data

	A	B	C	D	E	F	G	H	I	J	K
1	MonthValid	Ens1	Ens2	Ens3	Ens4	Ens5	Ens6	Ens7	Ens8	Ens9	Ens10
2	202006	1.7312	2.4204	2.4986	2.7027	2.8465	2.8742	3.4627	4.0737	4.4503	4.4845
3	202007	1.0258	1.262	1.4789	1.7101	2.0651	2.2463	2.8006	2.9803	3.0628	3.3617
4	202008	0.5545	1.2252	1.4589	1.4702	1.5513	1.5629	2.2517	2.514	2.6148	3.1312
5	202009	0.3502	1.22	1.5435	1.6698	2.3699	2.4099	2.5903	2.8375	3.1493	3.5319
6	202010	0.894	3.0971	3.7825	4.8662	5.9886	7.489	7.5058	7.8107	8.7076	8.8375
7	202011	6.1616	8.0269	9.2701	11.2743	12.4279	13.7509	16.7348	19.1494	22.7539	22.9303
8	202012	20.3263	23.1173	28.0859	31.7574	31.9576	34.3492	36.416	36.6556	36.8428	38.0272

Figure 8 Format of ensemble data

	A	B	C	D	E	F	G	H	I	J
1	MonthValid	EnsMean	EnsStdev	EnsMin	Ens10th	Ens33th	Ens50th	Ens67th	Ens90th	EnsMax
2	202006	7.3337	3.1815	1.7312	2.852	5.7287	7.2466	8.3895	11.5994	15.6047
3	202007	5.3329	2.8477	1.0258	2.1013	3.9605	4.7463	5.7869	9.7816	16.5305
4	202008	6.3697	4.009	0.5545	1.5537	4.6752	5.2991	7.2942	11.0276	18.7993
5	202009	8.9453	7.3251	0.3502	2.3779	4.8581	6.7392	9.3979	20.4738	33.8951
6	202010	21.4517	14.1144	0.894	6.2887	13.605	18.464	26.2742	39.4756	59.4043
7	202011	44.6045	22.3059	6.1616	12.6925	32.2883	44.3346	53.4226	73.2815	96.6186

Figure 9 Format of percentile data

2.1.4.3 Global WMS data

Since there will be a lot of SMHI map layers, it was decided to split up the map services as per the table below.

Currently available on the portal are the GADM level 1 administrative areas and HydroSHEDS Basins level 5 catchments (see Section 3.4). These are selected via the Administrative areas and Catchment buttons on the map.

The Demonstrator currently includes three SMHI datasets: precipitation, runoff and temperature. All three will have status data and outlook data.

In future versions of the Demonstrator, there will be three levels of detail for each dataset and each of those three levels will also be available for both administrative or catchment areas.

Table 2 File structure convention for SMHI Global data (map layers).

Spatial Unit Type	CRPC (precip)	CRUN (runoff)	CTMP (temp)	Comments
Administrative Area (AA)	Level 1 ID: CRPC_AA_01	Level 1 ID: CRUN_AA_01	Level 1 ID: CTMP_AA_1	Available in v1
Administrative Area (AA)	Level 2 ID: CRPC_AA_02	Level 2 ID: CRUN_AA_02	Level 1 ID: CTMP_AA_1	
Administrative Area (AA)	Level 3 ID: CRPC_AA_03	Level 3 ID: CRUN_AA_03	Level 3 ID: CTMP_AA_3	
Catchment (CM)	Level 1 ID: CRPC_CM_01	Level 1 ID: CRUN_CM_01	Level 1 ID: CTMP_CM_01	
Catchment (CM)	Level 3 ID: CRPC_CM_03	Level 3 ID: CRUN_CM_03	Level 3 ID: CTMP_CM_03	
Catchment (CM)	Level 5 ID: CRPC_CM_05	Level 5 ID: CRUN_CM_05	Level 5 ID: CTMP_CM_05	Available in v1

It was decided that each dataset would be a separate service and the layers would always be in the same order. The layers are numbered 0-12, where: 0-5 are the six months of status data and 6-12 is the seven months of outlook data provided by SMHI (only six of which are presented in the Demonstrator).

Then, the URLs are as the IDs in the table above: …/HydroSOS/[datasetID]_[administrative area AA or catchment CM]_[detail level] i.e. /HydroSOS/CRPC_AA_01/, /HydroSOS/CRUN_AA_01/, /HydroSOS/CTMP_AA_01/.
HydroSOS/202006_AA_lvl01_CPRC (MapServer)
HydroSOS/202006_AA_lvl01_CRUN (MapServer)
HydroSOS/202006_AA_lvl01_CTMP (MapServer)
HydroSOS/202006_CM_lvl05_CPRC (MapServer)
HydroSOS/202006_CM_lvl05_CRUN (MapServer)
HydroSOS/202006_CM_lvl05_CTMP (MapServer)

2.2 Technology Stack

2.2.1 Hosting and User Interfacing

The portal is hosted on the UKCEH EIP (Environmental Information Platform) server under the domain https://eip.ceh.ac.uk/hydrology/HydroSOS/. The site is coded in a combination of HTML, CSS and JavaScript; the core of modern web development. The files stored locally are hosted on the UKCEH Lancaster Storage Area Network (SAN) and are accessed via HTTP. The service so far needs about 320MB of hosting space per forecast, but much more on disk. UKCEH servers currently have about 30GB of data on disk so far from the five service providers detailed in Section 2.1.

The code that drives the site is stored in UKCEH's Gitlab repository and deployed via a Docker Pipeline. A login screen was enforced on the live site during development to restrict access only to those involved in HydroSOS Work Package 5.

Several packages are employed to aid the smooth interactive running of the Demonstrator. Via a main app controller, jQuery is used to simplify accessing the data and provides interactivity. Leaflet.js is used to create the map and several plugins are used to enhance the experience. Plotly.js is used to create the graphs.

The Bootstrap HTML framework defines the structure of the Demonstrator website. Bootstrap determines the dimensions and layout of the user's display screen, resizing and relocating components of the site to enable it to work optimally on all devices.

Since each product is considerably different, each product has its own JavaScript file which defines how it displays to the map and how each graph is displayed based on the data available.

For point scale data, the display of maps using all individual files is not possible due to loading times. Therefore, the data for each service must be duplicated and reformatted, to provide data files: one for all locations at each time step; and one for each location for all time steps. More information on the file formats required is given in Section 2.1.4. For the operational service, when a large number of national and international services are included, loading all data at the same time will not be a feasible option. For this reason, ways of blending data appropriately over different scales will need to be explored. This is discussed in Section 4.1.

2.2.2 Web Map Services

Global scale maps are displayed via the Leaflet WMS (Web Map Service) tile layer. A WMS serves georeferenced maps over the internet, using a GIS database. The WMS produced for use by the Demonstrator is hosted on the UKCEH server at: https://wlwater.ceh.ac.uk/arcgis/rest/services/HydroSOS/. The maps use ESRI Geometry Polygons, and support JSON, AMF and geoJSON querying. Since Leaflet does not support the required 'getFeatureInfo' natively, the WMS functionality was extended to use the 'BetterWMS' library, which enables users to query the map by clicking on a polygon, thus prompting the Demonstrator to provide timeseries graphs for that location. Despite the increased speed in serving the maps as raster images through WMS, loading the maps still takes a long time even on fibre-optic broadband. The speed of the Demonstrator will need to be widely tested, and this issue will need to be considered for the operational service.

Detail of the WMS file structure used to serve the SMHI data for the Demonstrator is provided in section 2.1.4.

2.2.3 Application Programming Interfaces

The use of an Application Programming Interface (API) reduces the burden on the hosting service/data storage.

Two services have been integrated into Version 1 of the Demonstrator using APIs: American USGS WaterWatch data and Argentinian INA data. It was discovered that every API the team found served their data differently, whether by using a different language, or a different type of call. For example:

USGS WaterWatch data is queried as:

> "https://waterservices.usgs.gov/nwis/dv/?format=json&sites=02428400&startDT=2019-01-01&endDT=2020-07-22&siteStatus=all&parameterCd=00060"

INA data is queried as:

> "https://alerta.ina.gob.ar/pub/datos/datos&timeStart=2019-01-01&timeEnd=2020-07-22&siteCode=88&varId=2&format=json"

and both services return the data in different formats.

For this reason, the use of APIs requires a fair investment of staff time both from the Demonstrator developers, and staff at the organisation providing data in order to determine how to query the data correctly, and how to interpret the results appropriately. This investment is required for each new data source added to the Demonstrator. Any future development of an operational portal needs to consider carefully how to balance the benefits of standardising the APIs used in HydroSOS with the need to maintain flexibility for information providers. It is hoped that further implementation of the WMO Hydrological Observing System (WHOS) will help in this regard and the potential use of WHOS approaches and technologies to support HydroSOS is something which should be considered in the near future.

The API from INA takes a while to load, which may be a restriction on their server capacity.

3 Functionality and Presentation

3.1 User Interface

The portal's styling is closely based on the WMO template using their logo, fonts and banner. When entering the site for the first time, the "about" window is automatically displayed for information. Once the "about" window is closed, the user sees the map of the world with all data in Version 1 displayed: one global scale service, and four national services. If the user clicks on a location, the map is moved to fill the left half of the screen, and a graph is displayed on the right side. The Bootstrap HTML framework defines the structure of the page according to the size of the screen, so for small screens and mobile devices, the graphs are instead opened up underneath the map.

3.2 Feedback Mechanisms

The Demonstrator has several feedback buttons, marked with speech bubble icons, throughout the site. These icons each have a unique three digit identifier code. They explain the functionality of various elements, and suggest that users can provide feedback, using the identifier codes to allow the team to more easily interpret the user's response. A shared inbox UKCEH email address has been set up to receive feedback on the Demonstrator (wmohydrosos@ceh.ac.uk).

It should be noted that there is another WMO hosted inbox (hydrosos@wmo.int) that is expected to be used for more general queries about the project.

3.3 Temporal Resolution

Both monthly and daily data products have been included in the Demonstrator. The map displays only monthly data (note - the daily data for the last day of the month is shown for USGS and INA data), and the user can skip through the time steps using the date toggle at the top of the map. Monthly data was chosen in order to provide a general overview of current and future water resources. The USGS and INA data are provided on a daily time step though, and it was decided not to aggregate this data and "lose information", instead, the timeseries are displayed as daily data on the timeseries graphs. Some decisions will need to be made in this regard for the future operational HydroSOS, and is discussed further in Section 5.

3.4 Spatial Resolution of Global Scale Data

Hydrologic and climate information available for inclusion in HydroSOS come in myriad resolutions and formats, thus there is a need to standardize spatial products toward a common and computationally feasible spatial configuration. The demonstration platform has limits on the density or size (granularity) of the dataset that can be ingested, stored and displayed in a timely fashion, and some of the raw datasets available exceed this limit. For instance, the input hydrologic global forecasts from SMHI contain approximately 131,000 watersheds, which would be cumbersome to display while being finer than required for the demonstration purposes of the present effort.

To convey a global perspective, the Demonstrator adopts two types of spatial information units: political/administrative boundaries and watershed boundaries. Accurate and complete political boundary delineations for the globe are less widely available than are watershed boundaries, thus we are showing one level of political boundary information and several levels of watershed boundaries. The datasets are described below:

3.4.1 Database of Global Administrative Areas (GADM)

The GADM (www.gadm.org) is a geospatial database of country administrative areas that offers shapefiles and other export formats for non-profit applications. For the purposes of HydroSOS, the best resolution of the dataset was the version 36.0 level 1 boundary set, with a nominal 3610 polygons (available from https://gadm.org/download_world.html). This level provides sub-national boundaries (e.g., states in the US, provinces in Canada), but the resolution of these administrative boundaries is not uniform across the globe. The level 0 of GADM includes only national boundaries. Alternative options for this dataset may exist in other WMO products.

3.4.2 HydroBasins version 1.0

For watershed boundaries, we adopted the HydroBasins dataset of Lehner and Grill (2013; data are available at www.hydrosheds.org). Also publicly available for non-commercial uses, HydroBasins contains watershed boundaries and sub-basin delineations for the entire globe. A particular advantage of the dataset is that it offers a seamless global coverage of consistently sized and hierarchically nested sub-basins at different scales, which can allow for different levels of resolution depending on the view field of a HydroSOS user (e.g. country level out to global). These levels were created using a coding scheme that allows for abstract analysis of watershed topology such as up- and downstream connectivity, independence and nesting. It offers 12 levels, of which levels 2-6 may be used within HydroSOS.

3.5 Scalable Spatial Points

As noted in Section 2.1.2, the issue of which data points to ingest/show in any future operational HydroSOS will require further consideration. One option would be to ask data providers to sub-set their sites so that key indicator stations are shown at a global scale and then additional sites become visible when the user is zoomed in to a small area of the globe. This was implemented for USGS data in Version 1 in order to demonstrate this potential solution.

To prevent spatial points overlapping and becoming indistinguishable when at viewed on a global scale, the USGS data have been integrated on three zoom scales, using US water resources zones, identified with unique hydrologic unit codes (HUCs). HUC Level 2 has 18 sites so is used for the maximum zoom extent. However, when users zoom in on the United States, at a certain point, HUC 4 sites (of which there are 16) and at a closer resolution, HUC 6 sites (of which there are 301) appear. See Figure 10 for example.

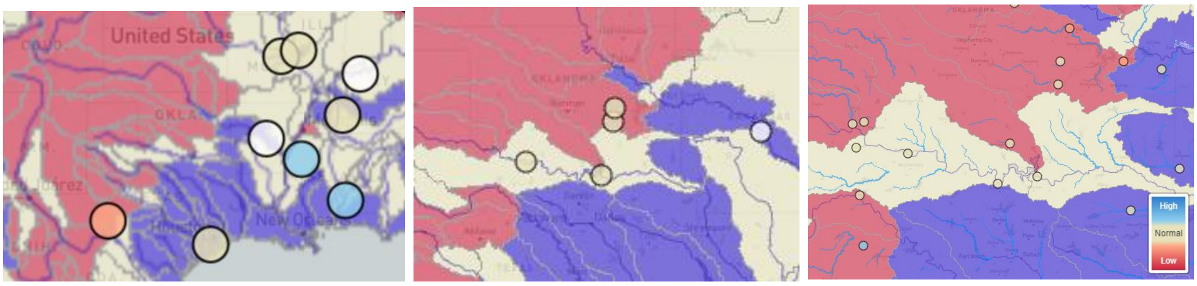

Figure 10 HUC 2 (left), HUC4 (middle), and HUC 6 (right) sites along the Red River Texas/Oklahoma, USA, data displayed for June 2020

3.6 Normalisation Categories

The categories used to define “normal”, “above normal”, and “below normal” vary between nations and products. Examples of categorisations were collected and reviewed, including:

USGS WaterWatch:

- High
- Much Above Normal: >90%
- Above Normal: 76-90%
- Normal: 25-75%
- Below Normal: 10-24%
- Much Below Normal: <10%
- Low

UK Hydrological Outlook/EA Water Situation Reporting:

- Exceptionally High: >95%
- Notably High: 87-95%
- Above Normal: 72-87%
- Normal: 28-75%
- Below Normal: 13-28%
- Notably Low: 5-13%
- Exceptionally Low: <5%

For the Demonstrator it was decided that a categorisation conceptually similar to this would be used. Feedback from stakeholders at the Nanjing Technical Workshop determined that five categories was optimal. A system of five categories has been adopted for the time-series graphs, however, for Version 1 it has been decided that three categories would be more reliable for presenting the dominant forecast category on the map. The Project Team interacted with lead scientists from the International Research Institute (IRI) at Columbia University (https://iri.columbia.edu/our-expertise/climate/forecasts/seasonal-climate-forecasts/), which presents a similar map-based information product, before deciding to adopt a categorisation of five levels, that can be distilled to three equal terciles. This allows an assessment as to whether there is a “dominant“ tercile in the ensemble, and also enables an estimate of the ensemble certainty (how many of the ensemble members that are in the dominant tercile). The five levels allow a more in depth look at the likelihood of more extreme hydrological conditions. The categories are defined as:

- Notably High: 90-100%
- Above Normal: 67-90%
- Normal: 33-67%
- Below Normal: 10-33%
- Notably low: 0-10%

For the map, the below normal and notably low categories are grouped together, and the above normal and notably high categories are grouped together, to give:

- Above Normal: 67-100%
- Normal: 33-67%
- Below Normal: 0-33%

For forecasts, whichever category has the highest number of ensemble members within it, determines the colour of the point or polygon. It is worth noting that this convention narrows the "normal" range in comparison to existing products from some services, but aligns with tercile-based presentations that are common in many countries.

3.7 Colour Scales

Most existing services, such as the UK Water Resources Portal use a rainbow type colour scheme, with reds and yellows indicating below normal, green as normal and blues and grey as above normal (see Figure 11). Whilst this is intuitive, it is not colour-blind friendly. Feedback from the Nanjing Technical Workshop indicated that the blue-white-orange GloFAS colour scheme (see Figure 12) was well received.

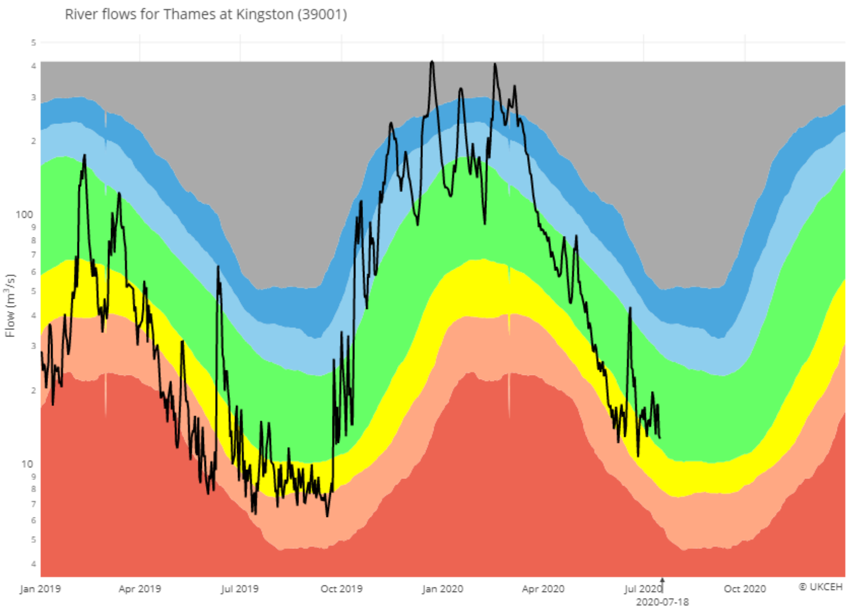

Figure 11 Example of rainbow colour scheme used by the UKCEH Water Resources Portal (eip.ceh.ac.uk/hydrology/water-resources)

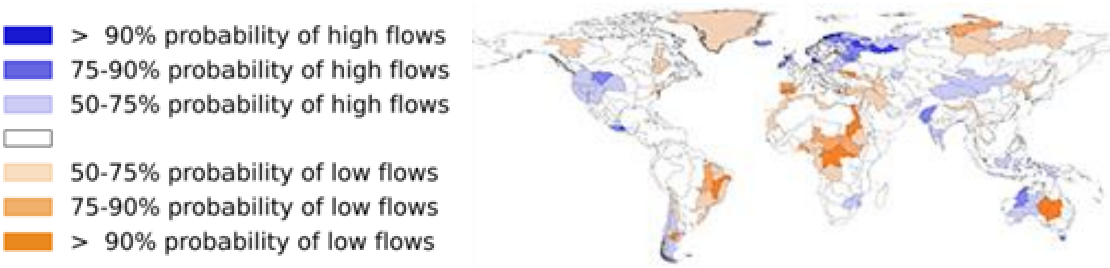

Figure 12 Example of blue-white-orange colour scheme used by Copernicus GloFAS (https://www.globalfloods.eu/glofas-forecasting/)

Therefore, the colour scale used in the HydroSOS Demonstrator is similar to that, with RGB values:

Table 3 Colour specification for the HydroSOS Demonstrator

Category	R	G	B	Colour
Notably High	44	125	205	
Above Normal	142	206	238	
Normal	231	226	188	
Below Normal	255	168	131	
Notably Low	205	35	63	

The decision was made to give the “Normal” category a neutral tan colour, as we wanted to distinguish between “no data” which would be displayed as white, and “normal”, displayed as tan. This format is consistent between data providers, map polygons, map points, and on the graphs, as shown in Figure 13. It is worth noting that for the global (SMHI) and UKCEH map data, the data were distilled to three rather than five categories. Therefore the map displays three colours, all taken from the colours in Table 3: the darker of the two blues, the tan colour and the red.

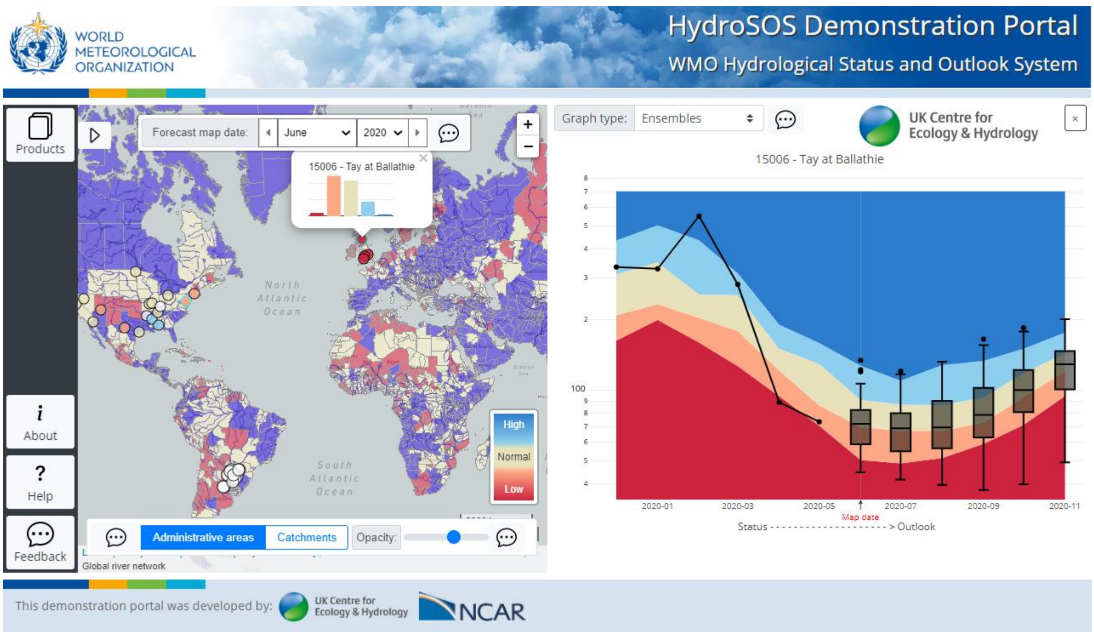

Figure 13 Demonstration of consistent colour scheme across the maps and graphs on the HydroSOS Demonstrator.

3.8 Graph Formats

Several graph formats are displayed in the Demonstrator in order to suggest possible formats for the operational service. The different formats offer different levels of detail, allowing even sensitive data to be presented.

3.8.1 Status "Values" Graphs

Used where only status information is available, these graphs show the absolute values of the variable being shown. The background colours show the historic reference levels for each time step (e.g. above normal, normal and below normal, as shown in the USGS data) or thresholds for alerts (as shown in the Argentinian gauge height data). This enables the viewer to see if the observed flows were "normal" or "above normal" for example.

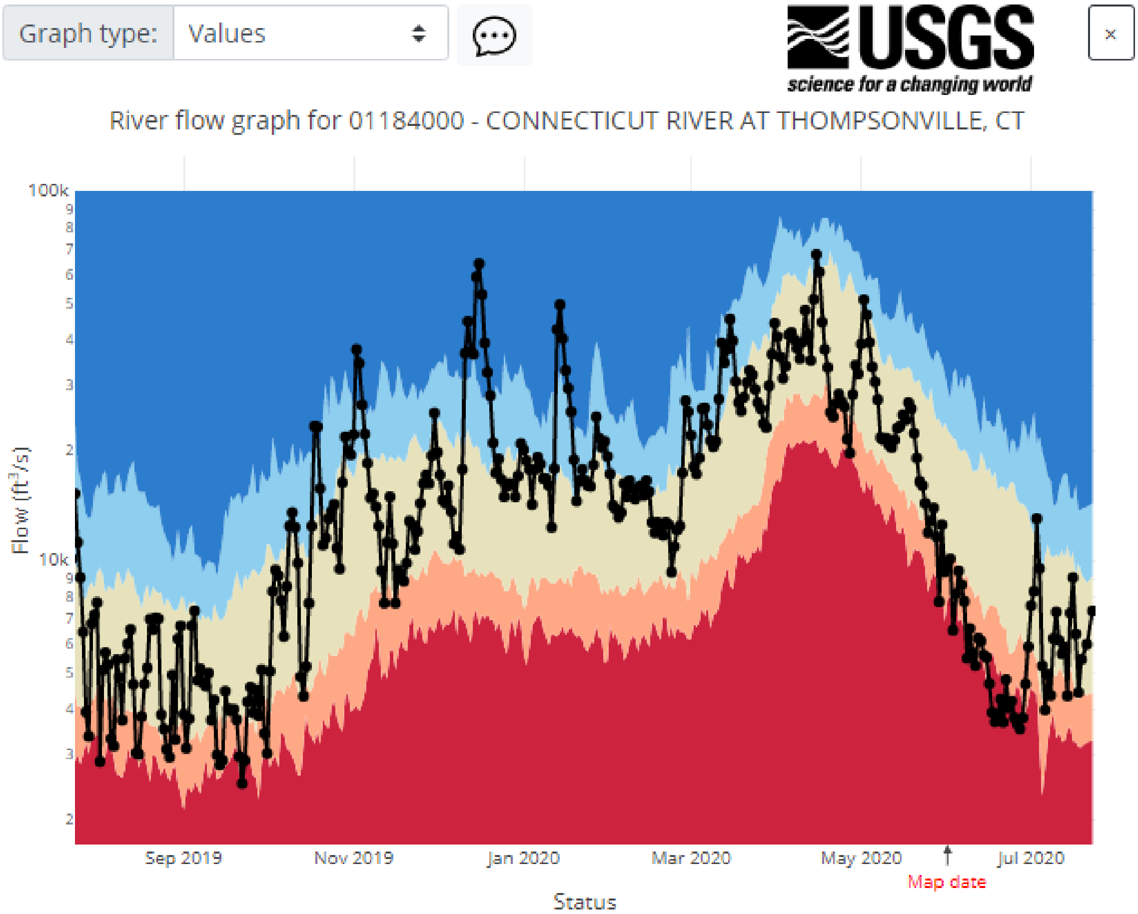

Figure 14 Values Graph showing Status information with historic category thresholds as background from USGS WaterWatch

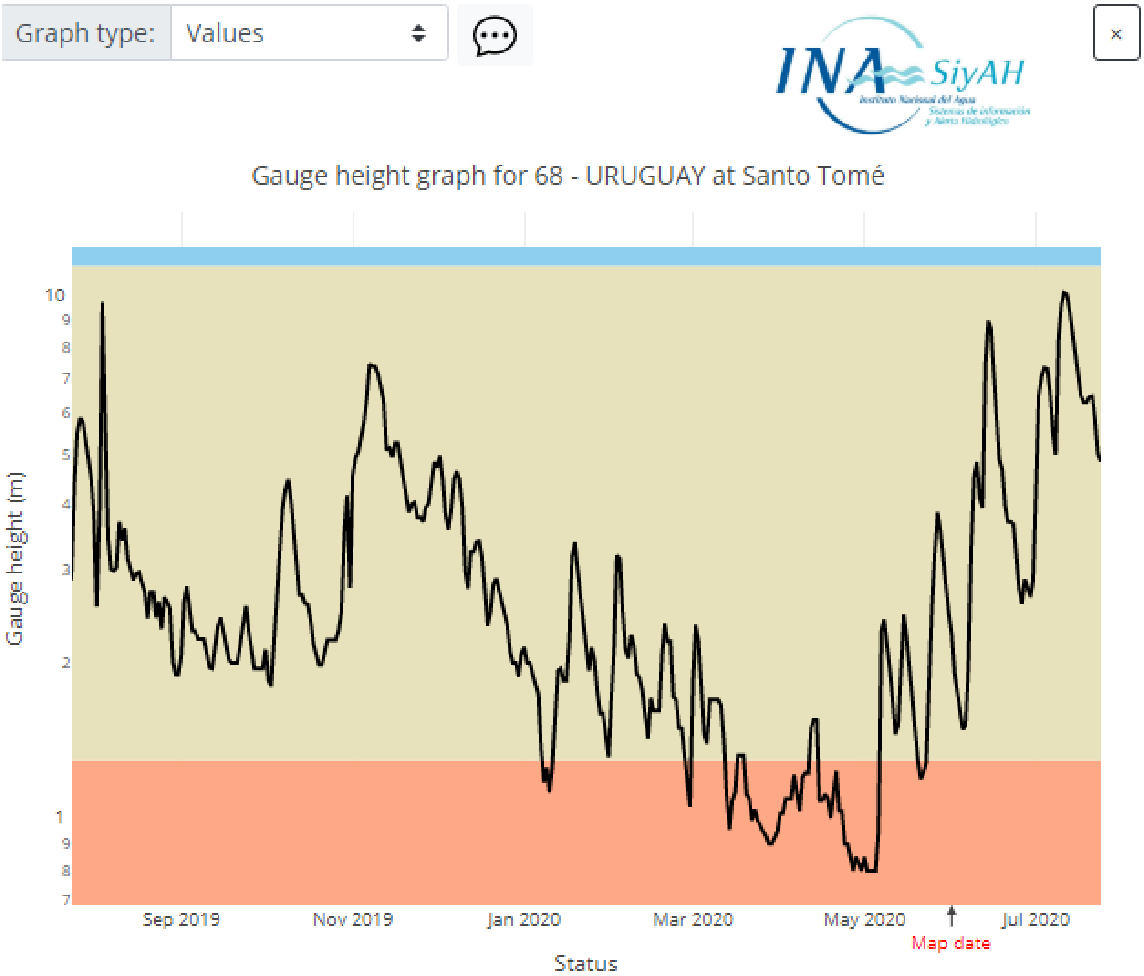

Figure 15 Values Graph showing Status information with "Alert" background levels from INA data

3.8.2 Count Graphs

The count graphs show the data categorically, and may be useful where data is seen as sensitive and they do not wish to present the data's absolute values in any way.

The six bars on the left represent the status of the preceding six months. The colour represents the category (defined by long term records) the observation sits in. In Figure 16 for example, December 2019 was classed as "above normal" (light blue), January through to April 2020 were classed as "notably high" (dark blue), and May was classed as "notably low" (dark red).

The outlook graph on the right shows the distribution of the forecast ensembles for the next 6 months. The height of each colour at each time step shows the percentage of ensemble members that fall into that category. In Figure 16 for example, for June on the left hand side of the plot, 0% of ensemble members fell into the "notably low" (dark red) category, 21% of ensemble members fell into the "below normal" (orange) category, 59% in the "normal" (tan) category, 18% fell into the "above normal" (light blue) category, and 2% fell into the "notably high" (dark blue) category. This shows that the majority of ensemble members forecast June to be "normal". By July, more ensemble members fall into the "above normal" category, and the blue area becomes larger. By the end of the forecast in November, on the right hand side of the graph, more of the ensemble members are in the "below normal" category, and the orange area is larger.

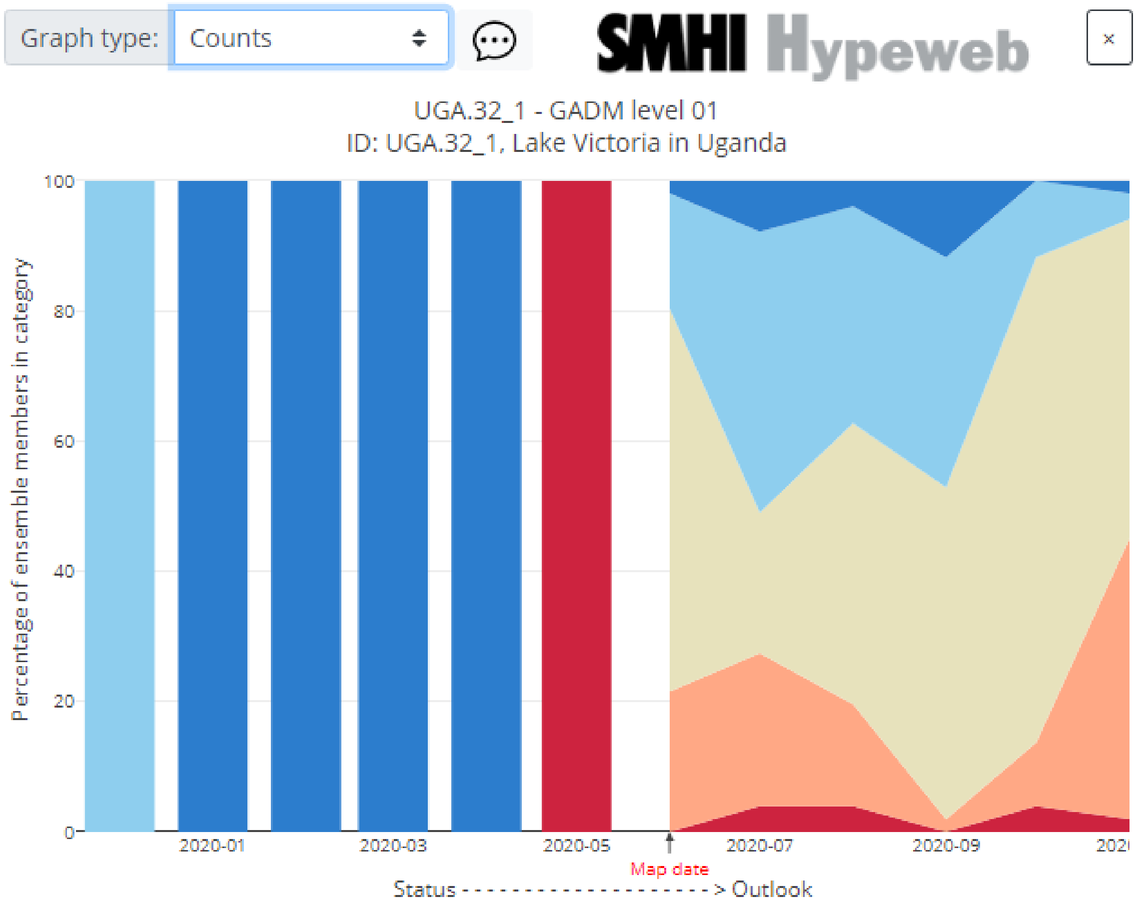

Figure 16 Counts graph showing status (left hand bar plot) and outlook (right hand stacked plot) from SMHI data

3.8.3 Ensembles Graphs

The ensembles graph (as in Figure 17) shows the data in real units of measure, overlaid on the long-term average categories. This enables the viewer to see if the observed and forecast flows were/are "normal" or "above normal" for example.

The status part of this graph provides a line with the simulated observations from the model for six months in the run up to the forecast. The outlook part of the graph shows box plots of the forecast ensemble members.

For the SMHI global outlook, the data is given as monthly forecasts at each lead time. For the UKCEH outlook, the data is given as accumulated forecasts (e.g. the three-month forecast is an average of the one-, two- and three months' model results.

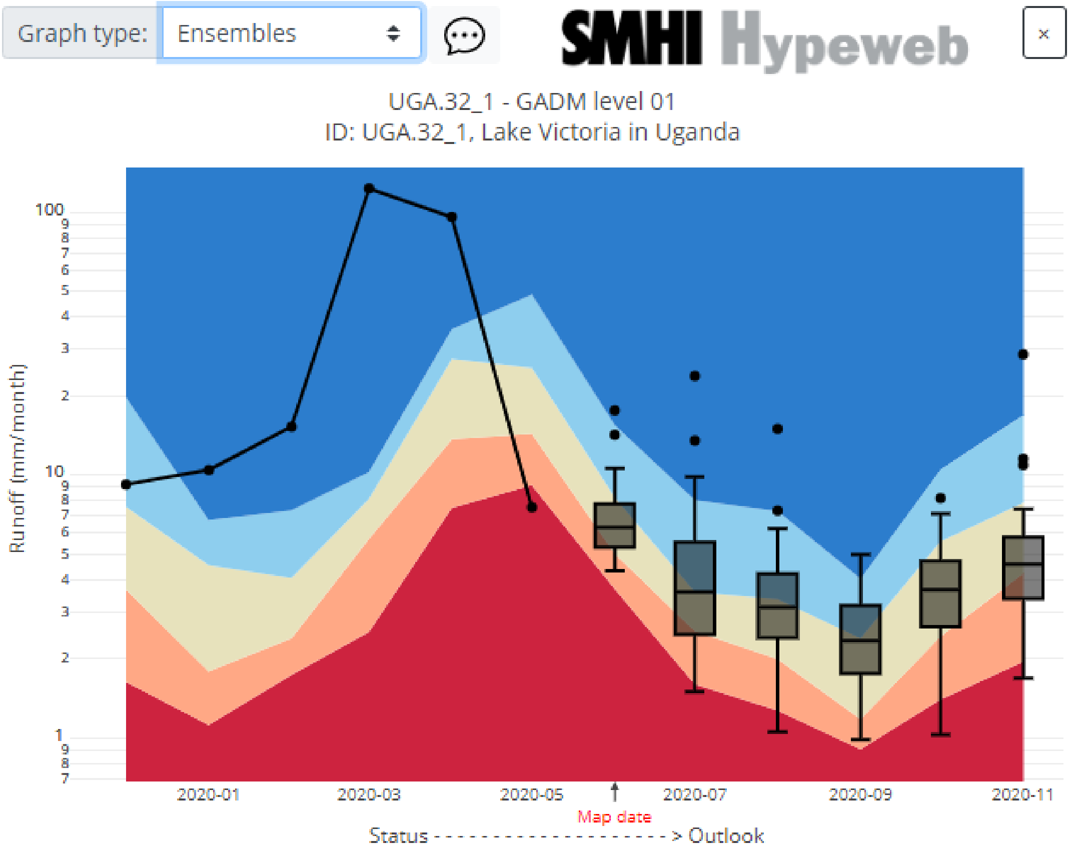

Figure 17 Ensembles status and box plot graph for SMHI data (note log y axis)

3.8.4 Percentiles Graphs

The percentiles graph (as shown in Figure 18) is an alternative display to the ensembles graphs. The status graph shows the observations in real units of measure, overlaid on the long-term average categories (distilled to just three categories), as well as the long-term observed monthly mean. The outlook graph shows the ensemble forecasts displayed as a shaded "fan" plot, giving confidence levels at the 10th–90th percentiles (light grey), and the 33rd–67th percentiles (darker grey), as well as the ensemble mean (black line).

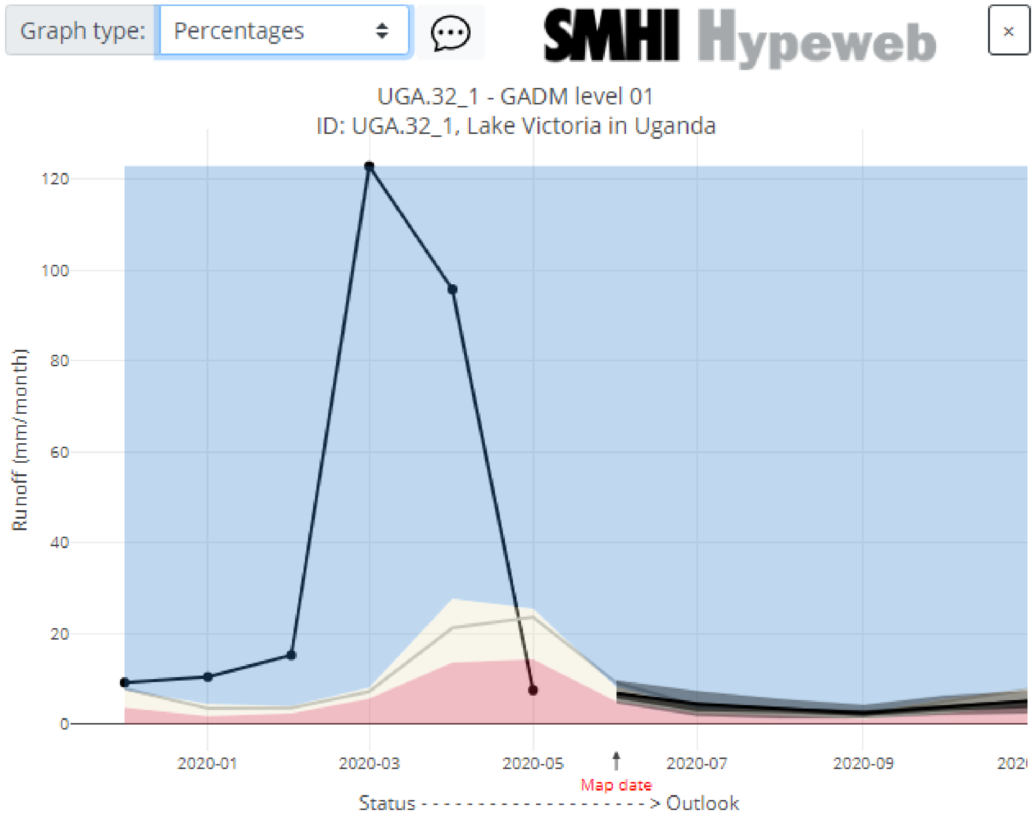

Figure 18 Percentiles fan graph for SMHI data (note NOT a log y axis)

4 Next steps for the Demonstrator

This section highlights some of the next steps for the Demonstrator, which we would hope to be achieved within the next 6-9 months (before April 2021).

4.1 Products

Generally, there is a need for more products to be integrated into the Demonstrator in order to highlight how different products can be integrated in a consistent manner, as well as how some products may pose particular challenges.

The Demonstrator has so far focussed on streamflow data, although SMHI have also provided precipitation and temperature data. Remotely sensed soil moisture products from TU Wien have been highlighted as a valuable demonstration dataset, and will be integrated into the next iteration of the web service. Groundwater products are also being discussed.

Some potential products for integration at different scales are highlighted in the following subsections.

4.1.1 National

Data from the Czech Hydrometeorological Institute has been volunteered for inclusion in the Demonstrator. With an API already set up to deliver daily discharge data for a multitude of sites, it is promising that this may be a “quick win”. CHMI also produce both flood warning and drought monitoring, so categorise their flows in a meaningful way. It would be beneficial (as with the INA data) to demonstrate the difference in displaying the data according to a consistent set of categories versus their own category system.

It was mentioned in Section 2.1 that the Australian Reference Network data were not included in Version 1 of the Demonstrator. However, the Bureau of Meteorology produce their own seasonal forecasts, and will no doubt have all the data needed to mimic the SMHI and UKCEH outputs already in the Demonstrator. Therefore, these data will be sought and Australian data hopefully added in due course.

Other NMHSs will be contacted to try and source different example products for future versions of the Demonstrator.

4.1.2 Regional

The Demonstrator does not currently include any regional, or large basin level datasets. It is hoped that the HydroSOS partners working on Work Packages 3a and 3b will be able to assist in liaising with regional stakeholders (including the Regional Climate Outlook Forums) in the Lake Victoria Basin and South Asian Regions to integrate some datasets on this scale.

4.1.3 Global

The first stage of development in the global products is to include additional levels of spatial resolution. As set out in Sections 2.1.4 and 3.4 it is anticipated we include 3 levels of GADM administrative boundaries and 3 levels of HydroBasins catchment boundaries. We will test these using the SMHI data in the first instance.

Secondly, forecast data from Copernicus' GloFAS system have been offered for inclusion in the Demonstrator. This will make an interesting comparison with the SMHI data in terms of formatting, and results. Furthermore, the inclusion of several global products raises the question of how to blend ensemble data from multiple sources and present it soundly and usefully. This is one of the main considerations for members of HydroSOS Work Package 4 to address. Methods of how to create such a blended product are being explored but will include some kind of choice of weighting based on historic performance of the model in climate-hydrology regions.

As well as GloFAS, the Japanese product *Today's Earth* currently offers global simulations of current status, and will soon be releasing forecasts, so we will continue liaising with our Japanese partners on the inclusion of this data.

4.2 Functionality and Presentation

Along with the integration of additional products, the functionality of the Demonstrator will continue to be developed.

4.2.1 Incorporating recommendations from WP2

The development of the Demonstrator has been progressing in tandem with the efforts of Work Package 2 members. Work Package 2a seeks to consider how data will be sourced, stored and transferred within the HydroSOS. Work Package 2b seeks to address the complexities of status data, and how it is defined from observations or modelled data. Work Package 2c focuses on forecasting protocols. Each of these work packages is tackling a series of issues that need to be resolved for the operational service through expert elicitation and research. Before the conclusion of this research, some of the questions raised have been temporarily addressed for the Demonstrator, but may not have been according to the longer term recommendations that might be realised by the WP2 partners. Section 5 raises some of the issues that were particularly challenging for the Demonstrator, or are expected to be particularly challenging for the much larger operational service. It is hoped that as WP2 progresses, some of the questions will be answered, and the Demonstrator may need to change accordingly.

4.2.2 Incorporating feedback from Version 1

We anticipate that the circulation of Version 1 of the Demonstrator among HydroSOS partners and their colleagues, as well as dissemination to academics and practitioners in the wider water resources community will prompt some feedback. This feedback will be received via the shared UKCEH inbox wmohydrosos@ceh.ac.uk and will be recorded for consideration and action.

4.2.3 Representation of forecast skill/confidence

The forecasts in the HydroSOS Demonstrator are currently coloured simply according to three equal categories (below normal: 0-33%, normal: 33-67%, above normal: 67-100%). The number of ensemble members that fall into each category are counted, and the category with the highest number of ensemble members (the dominant category) determines the colour of the map (see Figure 19). This however does not account for forecast confidence or skill. The confidence of the forecasts can be addressed fairly simply by representing how many ensemble members fall into each category. If the number of ensemble members is close to 1/3, the forecast has low confidence. However if the majority of ensemble members fall into one category, it has high confidence. Confidence has been presented using an opacity slider in the EDgE proof-of-concept project, where the map is transparent where less than *n*% of the ensemble members fall into the dominant category (Figure 20). Alternatively, the confidence has been expressed in a categorical way as a probability of the forecast being above and below normal, though also using depth of colour tone, in the Copernicus GloFAS web service (Figure 21).

Forecast skill is much harder to present. Skill dictates how accurate the forecast is likely to be, and is calculated using "hindcast" experiments to determine whether a forecast made of a past date would have been accurate or not. Skill is calculated in many ways, and not all forecast services use the same method. HydroSOS could just provide the statistic calculated by the data provider, however when the data have been recalculated over different spatial units (e.g. GADM and HydroSHEDs), the skill statistics are then misrepresentations of the skill over the area displayed.

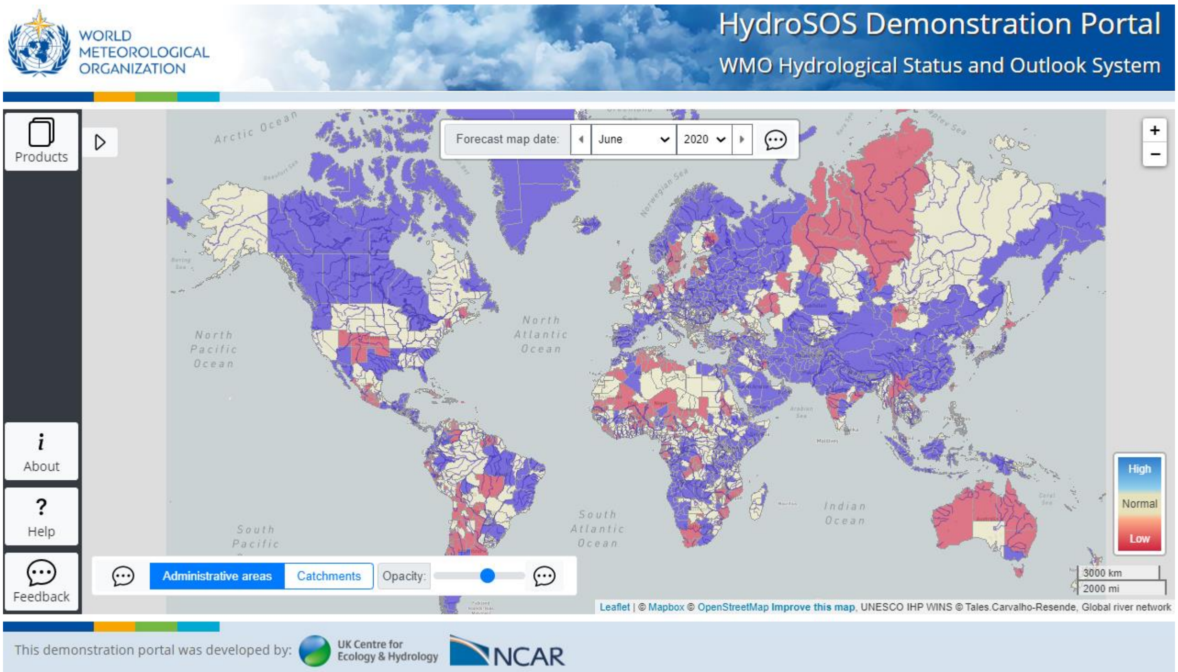

Figure 19 Current three colour map in v1 of the HydroSOS Demonstrator

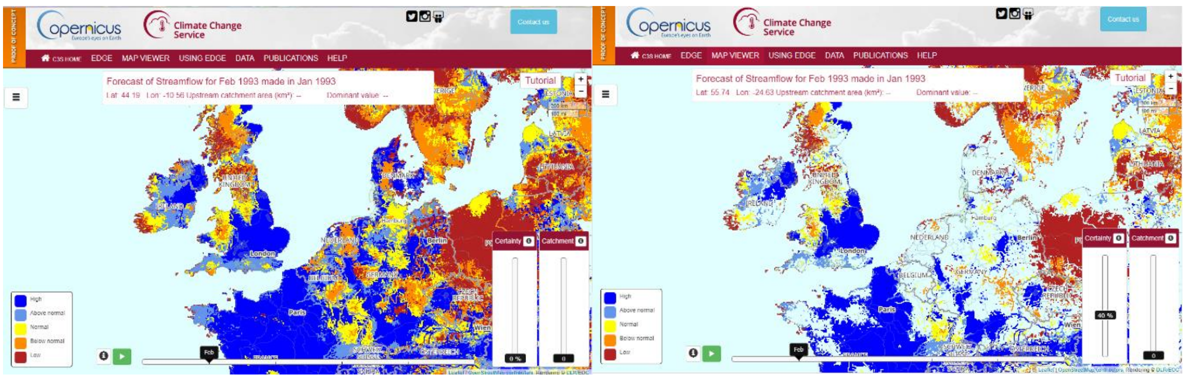

Figure 20 Representation of certainty using a slider in the EDgE proof-of-concept web service (http://edge.climate.copernicus.eu/Apps/#seasonal)

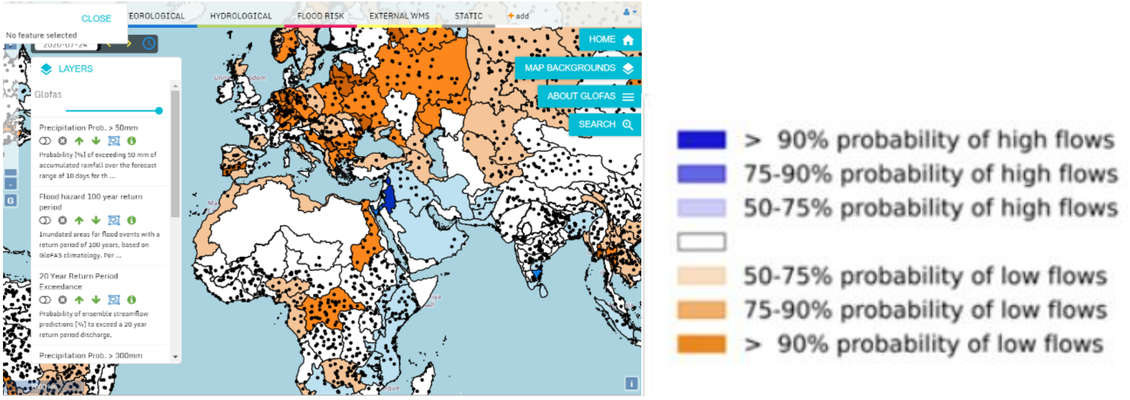

Figure 21 Representation of certainty using depth of tone in the GloFAS web service (https://globalfloods.eu/glofas-forecasting)

4.2.4 "Normalised" percentile graphs

Another method of plotting the graphs that does not reveal the absolute flow values, but is less abstract than the "count" graphs in Section 3.8.2, is by plotting the flow percentiles. However, if the categories were calculated on a monthly basis, the background thresholds would be straight lines (e.g. below normal would be below 33% for all months). Thus, there may be confusion that a forecast that moves from "below normal" in month 1 to "normal" in month 2 might imply rising streamflow, whereas actually the flow might remain steady, or indeed decline, if it is normal for the flow of month 2 to be lower than that of month 1. In order to get around this, the graph could be "normalised" by the annual average flow, thus retaining the seasonality of the flow regime. An example of such a graph is given in Figure 22.

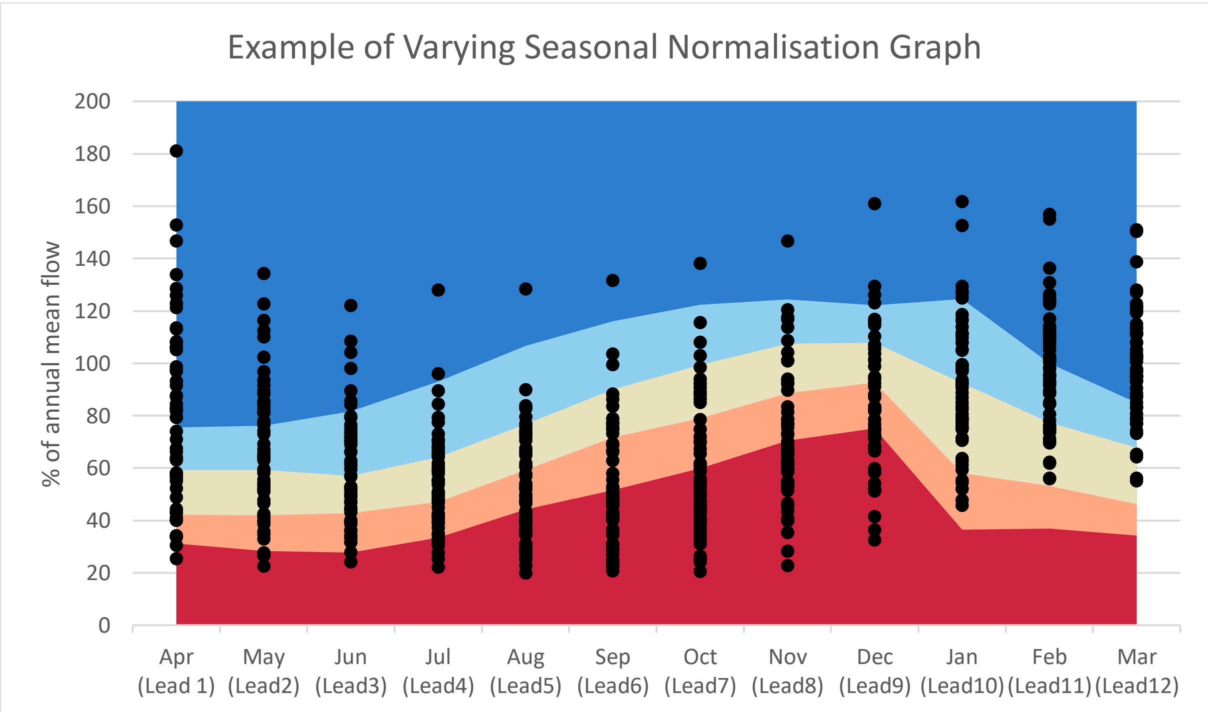

Figure 22 Example of a percentile graph, normalised by annual average flow.

5 Considerations for an Operational HydroSOS

The table below highlights some of the issues that have arisen in the production of the Demonstrator. It is by no means exhaustive. Many of these questions are larger issues that will require expert elicitation as well as consultation with stakeholders and anticipated end users. Some of the decisions made to produce the Demonstrator have been attempts to address these issues pre-empting the outcomes of the other work packages included in the HydroSOS project. As such, the table suggests which work packages should consider the issues raised.

Table 4 Issues identified in the production of the Demonstrator Version 1, and work packages suggested to help seek longer term resolutions.

Issue	Key Questions/Considerations	Suggested Work Package
Data Storage	- Data size with multiple global datasets and national datasets if provided raw. - Data sensitivity, protection	WP1 / 5
Data Transfer	- Transfer of large data is slow - How best can the WHOS initiative be linked with HydroSOS to help support the integration of data via standardised APIs.	WP2a / 5
Speed of Service	- Loading the maps can be slow	WP1 / 5
Displaying all data on start-up	- Loading all the data simultaneously won't be possible when there is much more data in the service - Should national to regional products replace global products where they are available? If so, should point scale data be aggregated up to area data to provide an "overview"?	WP4 / 5
Effort initialising each service	- Loading in each new product or variable takes time on formatting and interpretation - Sets of protocols should be followed by data providers to make sure they are as close to consistent with other products as possible - Tools may need to be developed to assist data providers in reformatting their products	WP2b / 2c
Display of point data at different scales	- Too many points in a small space overlap when zoomed out. How should they be presented at a large scale? - Should only the largest catchments be shown until you zoom in? - Or should it be the more strategically important sites?	WP2b

	- Or should they be combined/averaged somehow?	
Spatial/ Temporal resolution of data	- What is the optimal spatial/temporal resolution? What is too detailed / not detailed enough to be useful? - What are the technical limitations of the online service?	WP2b / 2c / 5
Period of normalisation	- How many years of historic data are needed to determine what's "normal"? - Should datasets with less than this amount of data be excluded, or included with some kind of quality flag? - Does the period need to be consistent between datasets?	WP2b
Categorisation	- What is the "best" categorisation scheme? - Should all products conform to one categorisation, or should "normal" be defined differently for different places?	WP2b

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