

# Copernicus Land Monitoring Services – Validation of Products

Validation Services for the geospatial products of the  
Copernicus land Continental and local components  
including in-situ data (lot 1)

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## COMPARATIVE VALIDATION OF DIFFERENT SURFACE WATER PRODUCTS



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## Executive Summary

This report presents the comparative validation of 3 different surface water products: the High Resolution Layer Water and Wetness product for the reference year 2015 (HRL WaW 2015), the EU-Hydro dataset and the occurrence layer from the JRC Global Surface Water product (JRC GSW).

The aim of this study is to compare the characteristics of these products and assess and quantify the strengths and weaknesses of each over the EEA39 area. A comprehensive analysis of the product characteristics is carried out to evaluate which categories and classes are comparable. The study is focused on the classes No Water, Permanent Water and Temporary Water as represented in the HRL WaW 2015. As a basis for comparison 6 polygon feature classes from the EU-Hydro were selected. To derive No Water, Permanent Water and Temporary Water from the continuous JRC GSW occurrence layer a threshold analysis was conducted.

As the basis for an absolute comparison of the three products the study relied on validation samples established during the previous validation of the HRL PWB 2012 [1] and validation samples interpreted for the current validation of the HRL WaW 2015 [2]. Care was taken to adapt the class coding and the cut-off values to account for differences in the product specifications and characteristics. For reporting units with particularly large deviations between map and validation values a selective plausibility analysis of the validation values was conducted.

The results of the absolute comparison show that all three products meet the minimum Producer's and User's accuracies defined for the HRL 2015 layers (85%) for the No Water and the Permanent Water class at the pan-European level. However, no single product dominating in all categories. The EU-Hydro provides the most complete coverage of surface waters but also tends towards higher commission errors in the permanent water class. The occurrence layer produced by JRC in turn yields a more conservative map with few commission errors but higher omission errors. Overall higher User's accuracies for the permanent and temporary water classes are achieved by the HRL WaW 2015 layer. The temporary water class is generally delineated with unsatisfactory accuracies, whereas a fully conclusive comparison is partially hindered by the different reference periods for the HRL and the JRC product (2009-2015 vs. 1984-2015). The geographic distribution of the errors is heterogeneous among the different products. A concentration of errors in the Mediterranean (higher temporal dynamics) and Northern Europe (fewer observations due to more cloud cover) was observed as a general pattern.

A relative comparison of the three products shows a close correspondence between the HRL Water and Wetness Probability Index (WWPI) 2015 and the JRC GSW occurrence with the exceptions of areas in northern Europe (e.g. Iceland) where presumably the reduced number of cloud free optical images degrades the quality of both products. The highest estimates for the total water surface area are provided by the EU-Hydro, followed by either the HRL WaW 2015 layer or the JRC GSW occurrence layer (depending on the threshold used for the JRC product). While the total areas are quite comparable the EU-Hydro polygons tend to include large fractions of temporary surface waters.

The study concludes with some recommendations towards a standard definition of Permanent and Temporary Water which would facilitate the comparison of different products and extracted statistics. This might also include the revision and setup of more firm and comparable definitions for the two Copernicus products.

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## List of Abbreviations

BRME	Biogeographical Regions Map of Europe
CLC	CORINE Land Cover
CORINE	Coordination of Information on the Environment
CRS	Coordinate reference system
DWH	Data warehouse
EEA	European Environment Agency
EPSG	European Petroleum Survey Group
EO	Earth Observation
ESA	European Space Agency
ETC ULS	European Topic Centre on Urban, Land and Soil systems
ETRS	European Terrestrial Reference System
EUREF	Regional Reference Frame Sub-Commission for Europe
FP7	7 <sup>th</sup> Framework Programme
FTS LM	Fast Track Service Land Monitoring
GDAL	Geospatial Data Abstraction Library
GHSL	Global Human Settlement Layer
GIO	GMES Initial Operations
GMES	Global Monitoring for Environment and Security
GRS	Geodetic Reference System
HRL	High Resolution Layer
INSPIRE	Infrastructure for Spatial Information in the European Community
JRC	Joint Research Centre
JRC GSW	Joint Research Centre - Global Surface Water
LAEA	Lambert Azimuthal Equal-Area
LCLU	Land Cover Land Use
LUCAS	Land Use/Cover Area frame Survey
MMU	Minimum Mapping Unit
MMW	Minimum Mapping Width
NDVI	Normalised Difference Vegetation Index
NDWI	Normalised Difference Water Index
mNDWI	Modified Normalised Difference Water Index
PSU	Primary Sample Unit
SSU	Secondary Sample Unit
TIFF	Tagged Image File Format
TWI	Topographic Wetness Index

USGS	United States Geological Survey
WaW	Water and Wetness
WWPI	Water Wetness Probability Index

## 1. Products to be validated

This report's main topic, the comparative validation study (as presented in chapter 2) is preceded by a comprehensive analysis of the product specifications to determine the criteria to be used for the validation exercise. The water surface products which are compared here are two raster datasets being the HRL WaW 2015 and the JRC GSW occurrence layer and a vector-based dataset being the EU-Hydro (public beta). While sharing thematic similarities the datasets differ considerably in terms of reference periods, scale and class specifications which are summarized in Table 1 and discussed in greater detail in the subsequent sections.

*Table 1: Main characteristics of the three water surface products to be compared.*

Product	High Resolution Layer: Water and Wetness 2015	EU-Hydro	Joint Research Centre- Global Surface Water
Acronym	HRL WaW 2015	EU-Hydro	JRC GSW
Data provider	EEA	EEA	JRC
Relevant layers	Status Map 2015	Polygon features	Occurrence
Version	22 Mar 2018	20 Apr 2016, Public Beta	2016
Reference years (s)	2009-2015	2006-2012	1984-2015
Spatial resolution or scale	20 m (national), 100 m (pan-European)	1:50 000	30 m
CRS	ETRS-LAEA (EPSG:3035)	ETRS-LAEA (EPSG:3035)	WGS1984 (EPSG:4326)
Minimum Mapping Unit	400 m <sup>2</sup>	1 ha	900 m <sup>2</sup>
Class coding	0 no water/no wet areas 1 Permanent water 2 Temporary water 3 Permanently wet area 4 Temporary wet areas 254 unclassifiable (no satellite image available, or clouds, shadows, or snow), 255 Sea water and area outside the production unit	<ul style="list-style-type: none"> <li>• point feature classes: Culverts and Nodes;</li> <li>• line feature classes: Canals_l, Ditches_l and River_Net_l;</li> <li>• polygon feature classes: Canals_p, Ditches_p, River_Net_p, InlandWater, Transit_p, Coastal_p and RiverBasins</li> </ul>	0 Not water  1-100% water occurrence  255 No data

<b>Relevant classes for this study</b>	0 no water/no wet areas 1 Permanent water 2 Temporary water 255 Sea water and area outside the production unit	Canals_p Ditches_p River_Net_p InlandWater Transit_p Coastal_p	0 Not water 1-100% water occurrence
<b>Available at</b>	<a href="https://land.copernicus.eu">https://land.copernicus.eu</a>	<a href="https://land.copernicus.eu">https://land.copernicus.eu</a>	<a href="https://global-surface-water.appspot.com/download">https://global-surface-water.appspot.com/download</a>

## 1.1. High Resolution Layer: Water and Wetness 2015 product

The combined Water and Wetness product is a thematic raster layer showing the occurrence of water and wet surfaces over the period from 2009 to 2015. This layer is based on multi-temporal and multi-seasonal optical high-resolution satellite imagery. In addition, this layer is also based on radar information (Sentinel-1 data) with a geometric resolution of 10m and pan-European coverage. A multitude of optical and SAR imagery is used, covering a prolonged time series of 7 years to capture the intra-annual dynamics as much as possible within a given area and generating one image composite per season (each season covered by 3 months) and year during the observation period. The time-series forms the basis for the following products:

- The main Water and Wetness (WAW) product with defined classes of (1) permanent water, (2) temporary water, (3) permanent wetness and (4) temporary wetness.
- The additional expert product: Water & Wetness Probability Index (WWPI)

The products show the occurrence of water and indicate the degree of wetness in a physical sense, assessed independently of the actual vegetation cover and are thus not limited to a specific land cover class and their relative frequencies.

A number of multi temporal and multi sensor high resolution (HR) optical and SAR **imagery was used for the production** of the HRL Water and Wetness and the WWPI secondary (expert) product.

Primary EO data sources used in production were Sentinel-1 data (2014-2016) provided under the Copernicus program, optical imagery from the USGS Landsat programme as well as ENVISAT-ASAR and HR\_IMAGE\_2012 from the ESA DWH:

- Landsat seasonal composites LS-5, -6, -7 and -8 (main indices: mNDWI, NDWI, NDVI)
- Sentinel-1A (10m spatial resolution)
- ENVISAT-ASAR Wide Swath (75m spatial resolution)

Additional ancillary datasets:

- CORINE Land Cover 2012
- Riparian Zones (LCLU)
- EU-DEM (30m spatial resolution)

- Topographic Wetness Index (TWI, derived from the EU-DEM)

The main Water and Wetness product provides a combined thematic information on water and wetness for the 2009-2015 period on the following classes:

- Class 1: permanent water (e.g. rivers, lakes)
- Class 2: temporary water (e.g. temporarily inundated areas)
- Class 3: permanent wet areas (e.g. areas of permanently high soil moisture)
- Class 4: temporary wet areas (e.g. areas of changing soil moisture)
- Class 0: dry areas.

The detailed definitions for these classes can be found in the Annex 1.

The product is available in full spatial resolution of 20m x 20m as well as aggregated to 100m x 100m spatial resolution in European projection ETRS LAEA, and in national projections. Only the 100m layer will be analysed in this study.

**Elements to be included and excluded** from the production of the main HRL Water and Wetness product are listed in the table below:

*Table 2: Elements included or excluded from the production of the main HRL Water and Wetness 2015 [3]*

Elements to be included in the water & wetness product	Elements to be excluded from water & wetness product
<ul style="list-style-type: none"> <li>• Open water bodies (floating or emergent vegetation, only as far as possible) <ul style="list-style-type: none"> <li>◦ permanent lakes, reservoirs, ponds</li> <li>◦ rivers</li> </ul> </li> <li>• Temporary open water bodies (intermittent rivers, changing lake/reservoir levels)</li> <li>• Areas with a permanently high degree of soil moisture (no open water) as far as the vegetation cover permits. <ul style="list-style-type: none"> <li>◦ inland wetlands (mires, bogs, fens, reed beds)</li> <li>◦ coastal wetlands</li> </ul> </li> <li>• Areas with temporary high degree of soil moisture</li> <li>• Temporarily inundated areas (due to snow melt, floods or rain)</li> <li>• Wet agricultural fields, including rice fields and water-logged areas</li> <li>• Wet grasslands and pastures</li> <li>• Transitional coastal water bodies (lagoons, estuaries)</li> </ul>	<ul style="list-style-type: none"> <li>• Sea and ocean (border between sea water and fresh water in river estuaries and coastal lagoons is determined by "EEA Coastline for analysis V.2" dataset)</li> <li>• Permanent snow and glaciers</li> <li>• Small river channels and streams with widths less than approx. 30 to 40m (mixed pixel phenomenon)</li> <li>• Elements below the 20x20m MMU</li> </ul>

The **methodology** applied for the production of the HRL Water and Wetness allows to derive water and wetness out of both high resolution optical and SAR satellite images (Landsat-5, -7, -8 & Sentinel-1). The classification is performed for a time period of seven years from 2009 to 2015, applying 100 x 100 km tiles based on the EEA reference grid as production units. The production is based on an unsupervised classification with subsequent visual improvement of classification results and derivation of water frequencies based on seasonal spectral composites and different biophysical indices such as e.g. NDVI, NDWI and NMDI.

The **accuracy** of the WaW 2015 100m product has been evaluated during this validation contract and the results can be found in the "HRL WAW Validation Report" [2].

The **assessment** of the HRL WaW 100m layer is the base of this comparative study in terms of thematic accuracies, whereas the HRL WaW 20m layer has been used for relative comparison in terms of area. In order to easily compare the different datasets, the class 1 "permanent water" is considered as the common denominator and the most relevant class. This HRL WaW 2015 is compared with the EU-Hydro layer and the JRC GSW layer. The class 2 "temporary water" can also be considered relevant and will be contrasted against the appropriately thresholded JRC GSW occurrence layer and the water surfaces depicted in the EU-Hydro. Furthermore, the HRL WWPI 2015 depicts the frequency with which water is observed and lends itself for a correlation analyses against the JRC GSW occurrence layer.

## 1.2. EU-Hydro

The EU-Hydro is a Pan-European vector-based hydrographic dataset which was initially established in 2009-2012 in the frame of the Preparatory Action for Copernicus Reference Data Access (RDA) based on satellite imagery of the year 2006. The dataset provides a photo-interpreted river network at a scale of 1:30,000 for linear objects and a minimum scale of 1:50,000 for polygons (lakes, wide rivers, coastal and transitional water bodies) for all EEA39 countries. The dataset underwent a major upgrade from 2012-2015 based on VHR satellite imagery acquired in 2009 and 2012 to enrich the dataset and improve its topological consistency. This resulted in a public beta release in 2016 which is the version used within the scope of this comparative study.

The current public beta release comprises 35 geodatabases corresponding to subsets of EU-Hydro which are divided according to major river basins. The dataset includes 12 feature classes which are:

- Culverts: an enclosed channel for carrying a watercourse (for example: a stream, a sewer, or a drain) under another watercourse (for example: a stream, a canal, or a ditch).
- Nodes: a point joining two segments. They are placed on headwaters and mouths of each watercourse, on confluences of watercourses, on inlets and outlets of watercourses into water polygons and in dams derived from ECRINS.
- Canals\_l: an artificial waterway with no flow, or a controlled flow, usable or built for navigation.
- Ditches\_l: an artificial waterway with no flow, or a controlled flow, usually unlined, used for draining or irrigating land.
- River\_Net\_l: a naturally flowing watercourse.
- Canals\_p: an artificial waterway with no flow, or a controlled flow, usable or built for navigation.
- Ditches\_p: an artificial waterway with no flow, or a controlled flow, usually unlined, used for draining or irrigating land.
- River\_Net\_p: a naturally flowing watercourse.
- InlandWater: a large body of water entirely surrounded by land.

- Transit\_p: any water the level of which changes periodically due to tidal action.
- Coastal\_p: coastlines and shorelines of these feature class are used as additional feature for orientation to attach inland hydrologic features.
- RiverBasins: is the area that a river drains including its tributaries.

The topological model for the relationships among those features is presented in Figure 1. The polygon features which delineate permanent water bodies, and therefore are subject of this study, are: InlandWater, River\_Net\_p, Canals\_p, Ditches\_p, Transit\_p and Coastal\_p. The nominal MMU for polygons is 1 ha and they typically tend to delineate the highest water level of the respective water body. More detailed specifications for those feature classes are not available.

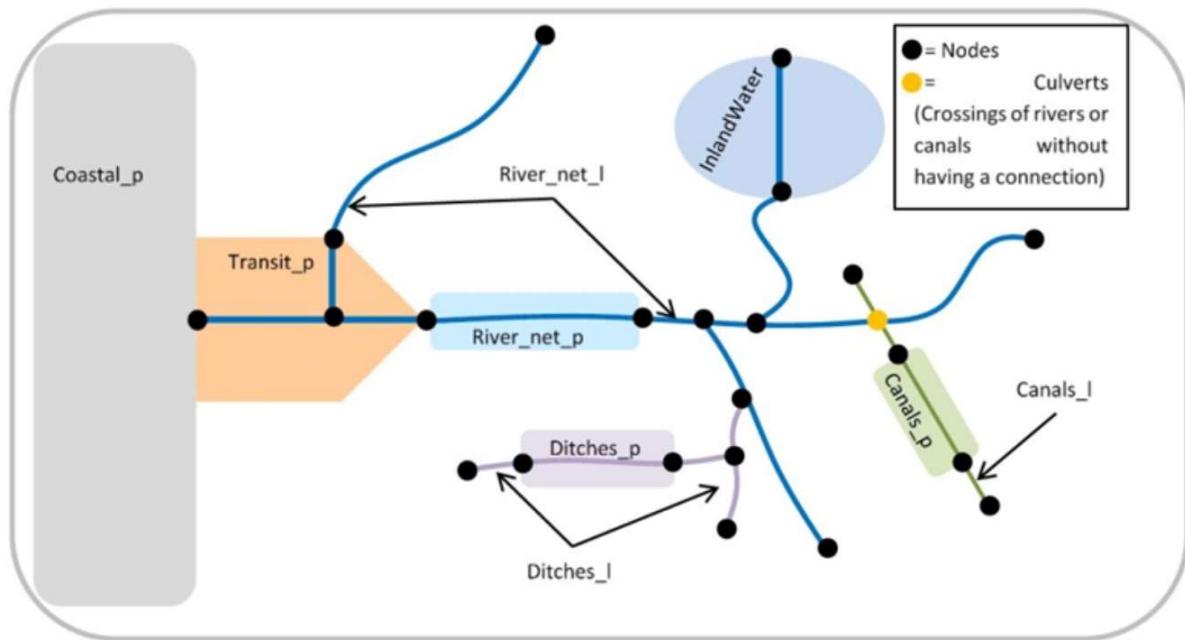


Figure 1: Topological model of the EU-Hydro dataset [4].

The production of the EU-Hydro was based on a number of HR and VHR optical image datasets and existing databases of hydrological and topographic datasets. This includes:

- IMAGE 2006 (DWH\_MG2\_CORE\_02) for the initial delineation of water surfaces and digitizing of the river network.
- VHR IMAGE 2012 (DWH\_MG2b\_CORE\_03) for the corrections and enrichments during the 2012-2015 update.
- IMAGE 2009 (DWH\_MG2\_CORE\_02) during the 2012-2015 update for gap filling of the VHR IMAGE 2012.
- Water Framework Directive (WFD): a database which is the source for the national water body codes.
- Hydrological datasets provided by the EEA Member Countries under the Water Framework Directive (WFD). No data was available for Turkey, Albania, Bosnia-Herzegovina, FYROM, Montenegro, Kosovo and Serbia.
- European Catchments and Rivers Network System (ECRINS): a geographical information system of the European hydrographical systems with full topological information.

- European Lakes and Reservoirs database (Eldred2): a database organising information on dams and lakes (natural and artificial) in Europe.
- Soviet topographic maps: Declassified military topographic maps established during the Cold War at typical spatial scales between 1:25,000 and 1:100,000.

The applied **methodology** for the initial production comprised the automatic generation of a water mask based on an NDVI index computed from the IMAGE 2006. During the initial production and the subsequent update phase the resulting polygons were visually checked, combined, completed and corrected based on IMAGE 2006, the VHR IMAGE 2012 and HRL PWB 2012. The polygon layers were integrated with the linear river network which similarly was digitized manually based on IMAGE 2006, IMAGE 2009 and VHR IMAGE 2012 during the two production phases.

The **accuracy** of the EU-Hydro has been documented quantitatively and qualitatively considering criteria such as topological consistency and the correctness of attributes, commission / omission errors, documentation and format in [5]. Based on a limited sample of 1,950 sample units the latter report noted a generally low commission error of 2.1% (all feature classes) and very low omission errors (<0.5%) for most feature classes. An exception are features in the class River\_Net\_I and Ditches\_I for which at least one missing feature was found in respectively 26.4% and 9.4% of the checked reference plots [5].

To allow a comparison with the permanent and temporary water bodies depicted in the HRL WAW 2015 and JRC GSW the **assessment** of the EU-Hydro in this comparative study will be focused on the surface water bodies delineated in InlandWater, River\_Net\_p, Canals\_p, Ditches\_p, Transit\_p and Coastal\_p.

### 1.3. JRC Global Surface Water

The Global Surface Water Dataset of the Joint Research Centre (JRC GSW) is a raster dataset which depicts the different aspects of the spatio-temporal distribution of surface water over a period of 32 years from 1984 to 2015 and with global coverage [6]. The dataset comprises multiple layers whose production has been based on **imagery** from the entire archive of the Landsat 5, the Landsat 7 and Landsat 8 imagery.

Additional ancillary datasets used in the production are:

- Randolph Glacier Inventory 5.0
- Global Human Settlement Data Layer
- Digital Elevation Models (GTOPO30, GMTED2010, SRTM90, SRTM30)

The **methodology** for the delineation of water surface was implemented in an expert system. 64,254 training samples were derived through the visual interpretation of 9,149 Landsat scenes. Their spectral properties (NDVI, SWIR, NIR) were visualized as scatterplots to manually delineate decision boundaries (cluster hulls) separating water surfaces from land. This decision was complemented with evidential reasoning taking into account the temporal trajectory of each pixel and auxiliary dataset such as the geographic location, the presence of glaciers, lava flows, settlements, cloud shadows and the position in the terrain. The expert system was built, tuned and tested iteratively during almost 2 years and finally applied on the entire Landsat archive [7].

Based on the individual classified Landsat scenes 6 thematic layers being Occurrence, Occurrence Change Intensity, Seasonality, Recurrence, Transitions, Maximum water extent have been derived. Further yearly and monthly historical summaries can be accessed online as well. For this comparative study the focus is on the

Occurrence layer which shows the water occurrences and overall water dynamics between 1984 and 2015. More specifically it shows the average of water surface occurrences ( $\overline{SWO}$ ) over all months ( $k$ ) computed from the ratio of all water detections ( $WD$ ) and all valid observations ( $VO$ ) for the  $i^{\text{th}}$  month.

$$\overline{SWO} = \frac{1}{k} \sum_{i=1}^k \frac{\sum WD_i}{\sum VO_i}$$

The month-by-month calculation was chosen to normalize for seasonal variation in the number of valid observations across the year. More cloud free observations are typically available for the dry seasons which would give more weight to the dry season if the index would be computed over the full period. The occurrence layer is an integer valued layer ranging from 0 (not water) to 100% occurrence.

The validation protocol established by the authors of the GSW product focused on assessing the **accuracy** of the detection of water surfaces in individual scenes. To this end a total of 40,124 control points were distributed spatially and temporally and visually checked based on available HR and VHR satellite imagery. The assessment suggests an overall omission error of 5% and a commission error of less than 1%. Omission errors are above average for seasonal water bodies and below average for permanent water bodies [7].

As already mentioned above the **assessment** in this study will focus on the occurrence layer (Figure 2) which is the most relevant for the delineation of permanent and temporary water bodies.

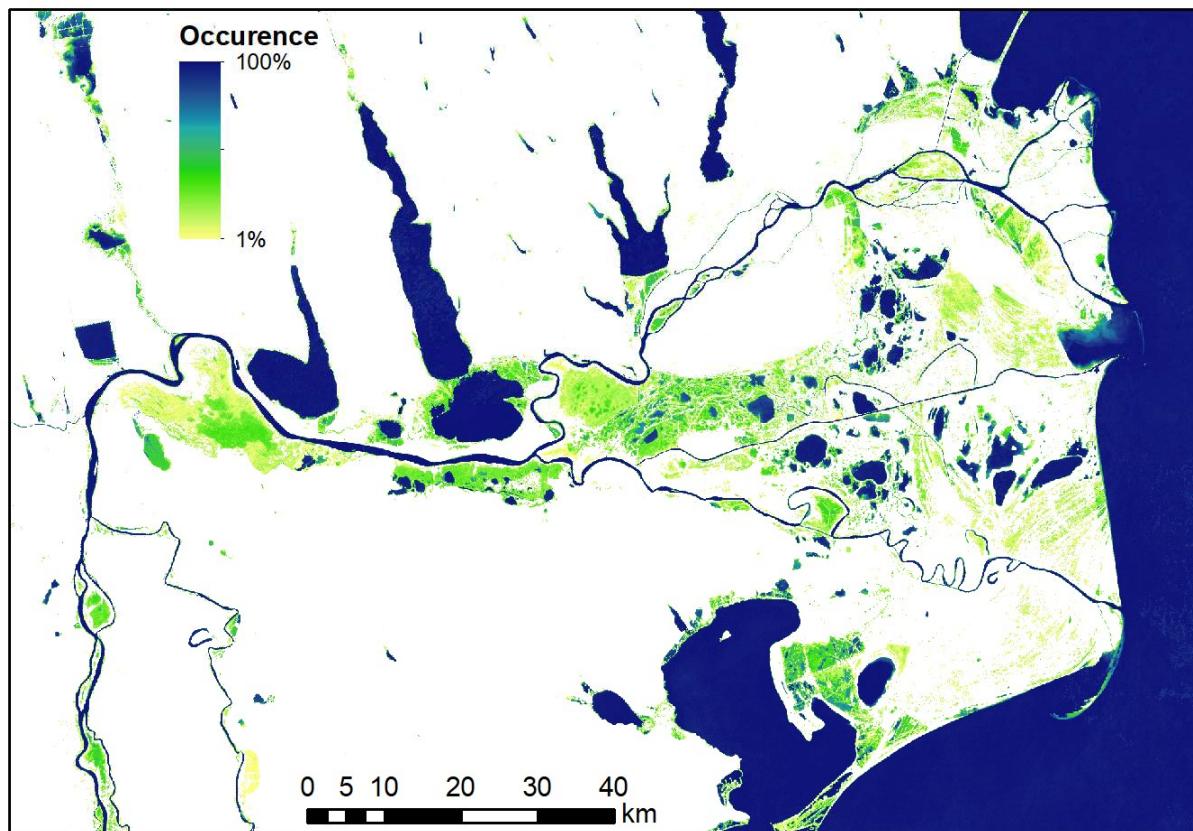


Figure 2: JRC GSW occurrence at the Danube delta.

A central access point to obtain the dataset and documentation is the application hosted at <https://global-surface-water.appspot.com/download>. The website provides comprehensive documentation including licensing terms, scientific references, a user guide [6], colour schemes for ArcGIS and QGIS, and ISO 19139 metadata in XML format. The data itself can be accessed in several ways such as a graphic user interface to download individual tiles, web mapping services and scripts for bulk downloads. The latter (<https://storage.googleapis.com/global-surface-water/downloadsAncillary/downloadWaterDatasets.7z>) was used in this study to gather all JRC GSW occurrence tiles for all EEA39 countries. The tiles were downloaded mosaicked and projected LAEA ETRS89 (EPSG 3035) for further analysis. The 6 standard layers (Water Occurrence, Occurrence Change Intensity, Seasonality, Recurrence, Transitions, Maximum water extent), in addition three history datasets (Monthly Recurrence, Yearly History, Monthly Water History), and the respective metadata are also available on the Google Earth Engine through a Python or JavaScript API.

## 2. Comparative validation framework

The comparison of the three water surface products is based on two pillars being an absolute comparison against reference validation samples for the reference years 2012 and 2015 and a relative comparison among the products in terms of the distribution of values and surface areas. The former will focus in particular on the thematic accuracy and the impact of different thresholds (e.g. threshold to define permanent water from the JRC GSW occurrence layer), while the latter will concentrate on the relative similarities and differences of the three products across Europe.

Results of detailed completeness and logical consistency checks have already been performed as part of the semantic checks undertaken by ETC ULS for the HRL products and a summary of the findings was provided as part of the validation reports for the HRL WaW layer [2] and the EU-Hydro public beta [5] and are not reproduced here. Some considerations regarding the usability, documentation and metadata of the JRC GSW occurrence dataset are included in section 1.3.

### 2.1. Level of reporting

The level of reporting for the comparison includes not only the pan-European level but also different levels of aggregation (as indicated in the Request for Services [8]). The analysis at disaggregated levels allows to detect and evaluate regional differences. The level of aggregation is constrained by the necessity for a compromise between the number of sample units and representativeness of the results at sub-European level. Therefore, the levels of reporting are:

1. Pan-European
2. Biogeographical regions 2016 (Figure 3)

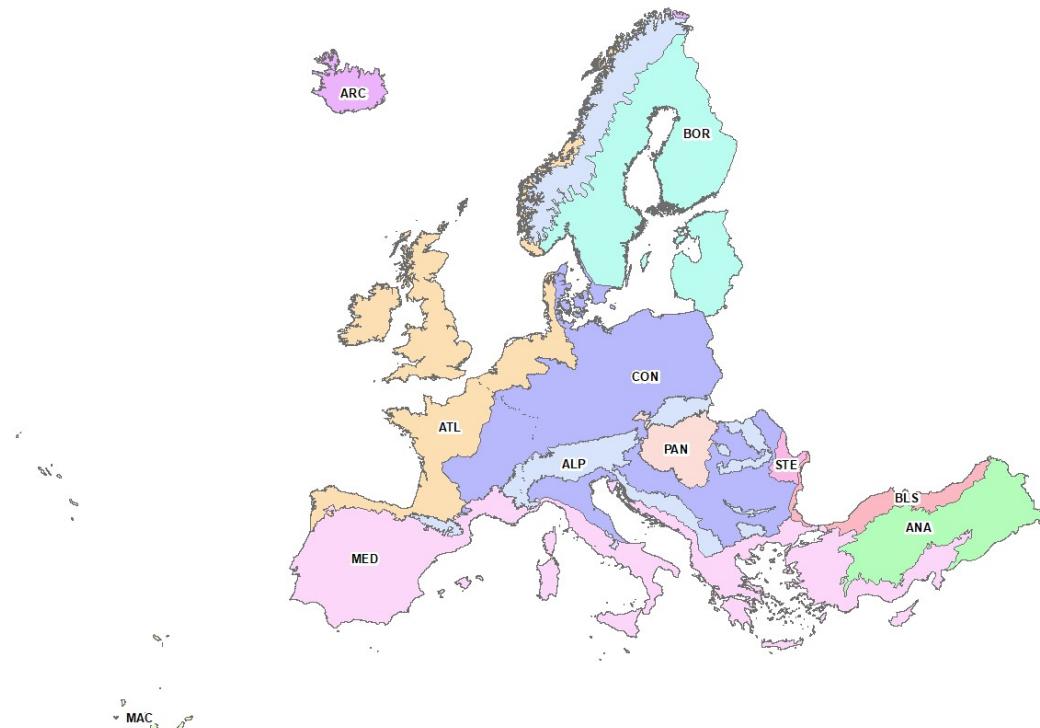


Figure 3: Level of reporting according to the biogeographical regions

3. 23 main countries or groups of countries (including French DOMs). Countries < 90,000 km<sup>2</sup> were grouped into contiguous groups of countries > 90,000km<sup>2</sup> as much as possible (Figure 4).

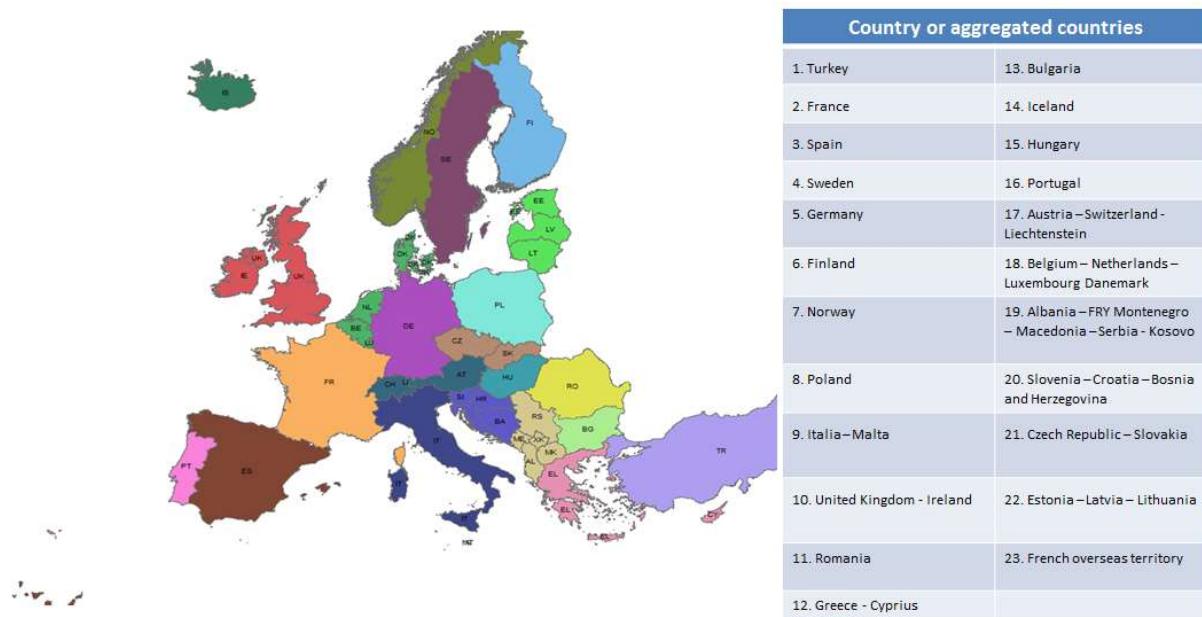


Figure 4: Level of reporting according to the country or aggregated countries level

## 2.2. Absolute comparison against reference validation samples

The thematic accuracy assessment is largely based on two sets of validation samples which were established for the validation of the HRL water products for the reference years 2012 [1] and 2015 [2]. This section details the general approach regarding the sampling design, the sample distribution, the response design and the analyses of the samples. Differences between the 2012 and 2015 datasets are highlighted where relevant.

### 2.2.1. Stratification and sample design

A stratified systematic sampling approach based on LUCAS is used for all thematic layers adapting the number of replicates to each stratum. The LUCAS sampling is densified for small strata. Using LUCAS sampling ensures coherence between the different layers and traceability.

The stratification is generally applied at two levels:

1. Stratification according to countries or groups of countries with an area greater than 90,000 km<sup>2</sup>.
2. Stratification based on a series of omission / commission strata.

The number of primary sample units (PSUs) per stratum should be such to ensure a sufficient level of precision at reporting level. The minimum number of PSUs per stratum should be set at 20 if possible. Priority is given to strata which are known to be difficult to map: i.e. temporary classes.

For the **HRL PWB 2012** reference sample the second level of stratification was defined as follows:

- Commission Low Probability: permanent water density 50-100% & CLC permanent water classes (minimum of 50 PSUs per country / group of countries)
- Commission High Probability: permanent water bodies density 50-100% & CLC non-permanent water classes (minimum of 50 PSUs per country / group of countries)
- Omission High Probability: permanent water bodies 0-49% & CLC permanent water classes (minimum of 150 sample units per country / group of countries)
- Omission Low Probability: Rest of the area (minimum of 50 PSUs per country / group of countries)
- CLC permanent water bodies classes (i.e. where permanent water bodies are potentially present) were defined as follows based on CLC2006:
  - 5.1.1 = Water courses
  - 5.1.2 = Water bodies
  - 5.2.1 = Coastal lagoons
  - 5.2.2 = Estuaries

For the **HRL WaW 2015** reference sample the second level stratification was defined as follows:

- Commission Permanent Water: Permanent Water class
- Commission Temporary Water: Temporary Water class
- Commission Permanent Wet Area: Permanent Wet Area class
- Commission Temporary Water: Temporary Wet Area class
- Omission High Probability/Commission Dry Areas: no water/no wet areas and CLC water and wet areas
- Omission Low Probability Commission Dry Areas: Rest of the area
- CLC Wetness & Water classes (i.e. where permanent water bodies are potentially present) were defined as follows based on CLC2012:

- 411 = Inland marshes
- 412 = Peat bogs
- 421 = Salt marshes
- 422 = Salines
- 423 = Intertidal flats
- 511 = Water courses
- 512 = Water bodies
- 521 = Coastal lagoons
- 522 = Estuaries

Different sampling intensities are applied to distribute more samples on strata for which there is a higher probability that errors will be found. Weighting factors are calculated based on the final sample selected to ensure that the different sampling intensities are accounted for when constructing confusion matrices to avoid the introduction of a bias towards these strata.

Each PSU corresponds to one HRL aggregated product pixel (100 x 100m). Each PSU is then associated to secondary sampling units (SSUs) corresponding to a 5x5 grid with 20m between each SSU (Figure 5). The idea is that each SSU can then be associated with the corresponding HRL 20m layer pixel.



Figure 5: Example of SSUs organised in a 5x5 20m grid

## 2.2.2. Sample distribution

The sampling for the reference year 2012 resulted in 16,900 sample units with a spatial distribution detailed in Table 3. For the 2015 validation samples a total of 17,991 sample units were selected with a strata distribution as detailed in Table 4.

*Table 3: Distribution of reference sample designed for the validation of HRL PWB 2012 per strata and level of stratification.*

LABEL	Commission		Omission		Total
	High	Low	High	Low	
AL+ME+MK+RS+XK	81	80	257	111	529
AT + CH + LI	71	74	227	99	471
BA + HR + SI	73	67	233	100	473
BE + LU+ NL + DK	167	72	218	94	551
BG	41	66	210	93	410
CZ + SK	75	70	229	100	474
DE	143	71	415	191	820
EE + LT + LV	86	82	272	118	558
EL + CY	52	73	239	105	469
ES	185	91	502	249	1,027
FI	409	246	409	183	1,247
FR	196	103	534	266	1,099
HU	66	64	195	86	411
IE + UK	126	95	352	173	746
IS	68	66	210	90	434
IT + MT	119	88	328	168	703
NO	493	92	390	177	1,152
PL	122	102	375	172	771
PT	64	67	196	86	413
RO	109	87	525	143	864
SE	371	324	862	227	1,784
TR	271	158	708	357	1,494
<b>TOTAL</b>	<b>3,388</b>	<b>2,238</b>	<b>7,886</b>	<b>3,388</b>	<b>16,900</b>

*Table 4: Distribution of reference sample designed for the validation of HRL WaW 2015 per strata and level of stratification.*

LABEL	Com. Permanent Water	Com. Temporary Water	Com. Permanent Wet	Com. Temporary Wet	Omission High Probability	Omission Low Probability	Total
AL+ME+MK+RS+XK	31	30	20	20	20	302	423
AT + CH + LI	23	20	20	20	20	227	330
BA + HR + SI	20	20	20	20	20	253	353
BE + LU+ NL + DK	35	20	20	34	20	205	334
BG	20	21	20	20	20	214	315
CZ + SK	20	20	20	20	20	250	350
DE	55	33	20	63	20	668	859
EE + LT + LV	53	23	34	53	42	314	519

<b>EL + CY</b>	20	23	20	20	20	251	<b>354</b>
<b>ES</b>	20	118	20	42	20	997	<b>1,217</b>
<b>FI</b>	345	42	122	132	185	540	<b>1,366</b>
<b>FR</b>	42	59	43	47	24	1,063	<b>1,278</b>
<b>HU</b>	20	20	20	29	21	173	<b>283</b>
<b>IE + UK</b>	35	33	62	211	345	523	<b>1,209</b>
<b>IS</b>	26	114	472	161	43	110	<b>926</b>
<b>IT + MT</b>	27	31	20	20	20	586	<b>704</b>
<b>NO</b>	150	135	32	682	165	440	<b>1,604</b>
<b>PL</b>	36	25	28	58	21	589	<b>757</b>
<b>PT</b>	20	24	20	20	20	173	<b>277</b>
<b>RO</b>	25	29	29	39	37	440	<b>599</b>
<b>SE</b>	421	113	83	344	279	689	<b>1,929</b>
<b>TR</b>	123	204	103	37	45	1,493	<b>2,005</b>
<b>TOTAL</b>	<b>1,567</b>	<b>1,157</b>	<b>1,248</b>	<b>2,092</b>	<b>1,427</b>	<b>10,500</b>	<b>17,991</b>

To ensure that unequal inclusion probabilities are accounted for in the construction of the error matrices, weights are computed according to the size of the strata applied to each stratum as shown in Table 5 and Table 6, respectively:

*Table 5: Weighting factors calculated as described in section 2.2.4 for the reference sample of HRL PWB 2012 to be applied to each stratum and level of stratification for constructing confusion matrices*

<b>LABEL</b>	<b>Commission</b>		<b>Omission</b>	
	<b>High</b>	<b>Low</b>	<b>High</b>	<b>Low</b>
<b>AL+ME+MK+RS+XK</b>	0.008087713	0.070136573	0.003179968	4.013268798
<b>AT + CH + LI</b>	0.004268892	0.077407012	0.001689931	3.603172931
<b>BA + HR + SI</b>	0.002451325	0.026038804	0.004243954	3.677371262
<b>BE + LU+ NL + DK</b>	0.004703801	0.137262219	0.004923677	3.376372486
<b>BG</b>	0.007446869	0.031798906	0.003248510	3.423283794
<b>CZ + SK</b>	0.009003913	0.029058251	0.002231834	3.672304678
<b>DE</b>	0.014777695	0.142209089	0.005060177	5.350600908
<b>EE + LT + LV</b>	0.013266038	0.142094542	0.005295937	4.171432839
<b>EL + CY</b>	0.008271778	0.038391916	0.003483211	3.855889708
<b>ES</b>	0.017105095	0.079139471	0.003640665	5.835875027
<b>FI</b>	0.021645535	0.355879359	0.009129192	4.799843294
<b>FR</b>	0.012253145	0.080547579	0.006651299	5.924996607
<b>HU</b>	0.005082506	0.059131446	0.006721103	3.069557392
<b>IE + UK</b>	0.018119080	0.092151249	0.003846605	5.189743637
<b>IS</b>	0.023808926	0.074489146	0.007158392	3.214753680
<b>IT + MT</b>	0.013677879	0.074615211	0.003561212	5.133138150
<b>NO</b>	0.017131446	0.399422790	0.008050826	5.018681359
<b>PL</b>	0.014551426	0.107916193	0.006139839	5.164984329
<b>PT</b>	0.007126784	0.029623566	0.002901539	3.061930801

RO	0.012408776	0.079740056	0.011312187	4.729208304
SE	0.022694623	0.303312757	0.011816269	5.223187027
TR	0.015276390	0.207262322	0.005576855	6.212312941

Table 6: Weighting factors calculated as described in section 2.2.4 for the reference sample of HRL WaW 2015 to be applied to each stratum and level of stratification for constructing confusion matrices. Empty fields at country level indicate that the same weights as on the Pan-European level apply.

LABEL	Com. Permanent Water	Com. Temporary Water	Com. Permanent Wet	Com. Temporary Wet	Omission High Probability	Omission Low Probability
Pan-European level	0,26304204	0,02710602	0,05058723	0,28842560	0,21769303	1,58042362
Country level						
AL+ME+MK+RS+XK			0,00798887	0,35646594	0,09171215	
AT + CH + LI		0,01146804	0,00709659	0,07996368	0,04701692	
BA + HR + SI	0,22529461	0,25904893	0,00398166	0,31723244	0,07218590	
BE + LU+ NL + DK		0,01506869	0,14624948		1,09765172	
BG	0,16906466		0,00635444	0,04351122	0,05616531	
CZ + SK	0,18408188	0,01492342	0,00329416	0,33898556	0,04380910	
DE			0,09226985			
EL	0,22988224		0,03800002	0,18049930	0,09675803	
ES			0,49082631		1,39638051	
HU	0,79555894	0,04130793	0,02326776			
IT			0,03727305	0,38607136	0,13940287	
PT	0,11760767			0,32803825	0,04110763	

### 2.2.3. Response Design

The original response design for both sets of reference samples (2012 and 2015) was based on the interpretation of thematic classes or surface characteristics (e.g. water presence) at the SSU point level taking into account the details of the product specifications (MMU, MMW, class definitions, etc. ....). The interpretation was based on a combination of available in situ data, for example, the validation could use the VHR mosaic alongside the imagery used in production and virtual globes datasets. LUCAS points were re-interpreted based on available in situ and reference data, but the LUCAS thematic information was not used directly during the process.

A **blind approach** was adopted as the initial process to guarantee the complete independence of the validation data from the map products. This may have underestimated their accuracy where SSU points are uncertain. This was resolved by the subsequent **plausibility approach** for which the interpreter checked the map value to assess whether it can be considered correct or not, within the frame of accepted product specifications. Also, density values were adjusted based on experience of known uncertainties to allow a more realistic comparison.

The original interpretation of the reference samples was conducted respecting specifically the product specifications of the HRL PWB 2012 and the HRL WaW 2015.

### 2.2.3.1. HRL PWB 2012 validation

For the initial interpretation of the **permanent water bodies in the 2012 reference sample**, the specifications from the European Environment Agency (EEA) of the HRL PWB 2012 as documented in [9] and "EEA\_Lot\_6\_Product\_Definition\_and\_Specification\_final\_25\_11\_2014.docx" were strictly observed: Permanent water bodies identify areas with a constant presence of water from 2006 to 2012. A pixel is classified as permanent water body if open water covers >90% of a pixel (including shallow open water and submerged vegetation). According to those definitions water includes the following landscape objects:

- Permanent lakes, ponds (artificial and man-made) including fish ponds;
- Rivers, channels permanently with water, and
- Coastal water surfaces: lagoons, estuaries.

Land cover not to be considered as water:

- Open sea and ocean, and
- Liquid dump sites.

The visual interpretation of the samples relied on VHR-Image 2012 in FCIR mode, HR-Image 2006, 2009, 2012 in FCIR 20m spatial resolution (mostly IRS/SPOT), HR-Image 2012 coverage 2 in RGB 5m spatial resolution (RapidEye), and supporting data such as ArcGIS-World Imagery, EU-Hydro Layer, GoogleEarth, Bing Maps, and national WMS services. As a result each PSU was assigned with a water density value ranging from 0 to 100% representing the relative fraction of SSUs assigned as water. For further details on the response design for the original 2012 validation sample the reader is referred to [1].

### 2.2.3.2. HRL WaW 2015 validation

For **identification of water classes in the HRL WaW 2015 validation sample**, the specifications from the European Environment Agency (EEA) in the document "Wetness\_Water\_Technical\_Specs\_Public\_v1\_GV\_v3.pdf" were strictly observed. The relevant thematic information on water classes for the 2009-2015 period is defined as follows:

1. Dry area (dry in at least 75% of all observations)
2. Permanent Water (water in at least 80% of all observations) includes the following landscape types
  - Permanent inland lakes (natural)
  - Artificial ponds (permanent fish ponds, reservoir)
  - Natural ponds (permanent open water surfaces of inland or coastal wetlands)
  - Rivers
  - Channels (permanently with water)
  - Coastal water surfaces: lagoons, estuaries
  - Liquid dump sites (permanent)
  - Water surfaces with floating vegetation

3. Temporary Water (water in >25% to 80% of all observations) includes the following landscape types
  - Temporary water surfaces associated to permanent water bodies (e.g. oscillating shoreline areas of reservoirs)
  - Temporary natural (e.g. steppe) lakes and temporary artificial lakes (e.g. cassettes of fishponds)
  - Intermittent rivers and temporarily flooded river banks
  - Flood areas
  - Water-logged areas
  - Temporary flooded agricultural fields e.g. rice fields
  - Intertidal areas
  - Temporarily inundated areas (due to snow melt, floods or rain)
4. Permanent Wet (wet in at least in 60% of all observations) includes the following landscape types
  - Reeds
  - Peat land
  - Inland and coastal wetlands (incl. salt marshes)
5. Temporary Wet (water in >25% to 60% of all observations) includes the following landscape types
  - Inland saline marshes
  - Intermittent wetlands
  - Temporary wet agricultural fields
  - Temporary wet meadows

The following elements were excluded:

- Sea and ocean (border between sea water and fresh water in river estuaries and coastal lagoons is determined by “EEA Coastline for analysis V.2” dataset)
- Permanent snow and glaciers
- Small river channels and streams with widths less than approx. 30 to 40m (mixed pixel phenomenon)
- Elements below the 20x20m MMU

The interpretation of the samples was based on VHR-IMAGE 2015 in CIR/RGB (spring or different season compared to the reference), and included also VHR-Image 2012, HR-Image 2009, 2012, ArcGIS-World Imagery, hillshade, DEM, EU-Hydro Layer, GoogleEarth, Bing Maps. For further details on the interpretation procedure the reader is referred to [2].

#### **2.2.3.3. Adjusting for product differences**

While the three analysed water products are considered sufficiently similar to allow a direct comparison and a reuse of the existing sample database, special care had to be taken to compensate differences in the product specifications or implementation to allow a fair comparison. This concerns in particular the threshold on water occurrence frequencies and densities, above or below which surface waters are to be considered permanent, temporary or absent.

When **comparing the HRL WaW 2015 to the JRC GSW occurrence layer** it must be considered that the JRC product does not depict information on wetness. HRL WaW 2015 reference samples classified as permanent and

temporary wet are thus considered as dry for the assessment of JRC GSW occurrence layer. Furthermore, the JRC product does not specify any thresholds for permanent nor temporary water bodies and indeed the layer provides a continuous measurement of the occurrence frequency. Lacking a clear alternative definition of permanent or temporary water a reinterpretation of the reference samples was not considered useful. However, a preliminary analysis between the JRC GSW occurrence layer and the HRL WaW 2015 (section 3.2.1) suggested a close correspondence of the two products. This in turn allows to account for product differences by adjusting the response threshold according to the accuracies achieved on the reference samples (section 2.2.4).

For the **comparison of the EU-Hydro dataset with the HRL PWB 2012 reference sample** a similar approach was taken. However, the response threshold was not applied on the product (EU-Hydro polygons readily provide a binary response) but on the density values in the HRL PWB 2012 reference sample in order to match the inherent product definition of the permanent water bodies represented by polygon feature classes. Based on the observation that the EU-Hydro polygons tend to delineate the maximum extent of surface water bodies a further selective plausibility analysis was conducted. This concerned specifically samples in reporting units with major contradictions between the map value and the reference value resulting from the original plausibility approach. In particular 11 reporting units predominantly located in Southern Europe and a total of 1591 PSU's were reassessed. This additional plausibility analysis followed the general validation approach established for the HRL PWB 2012 but additionally considered the plausibility according to the EU-Hydro product specifications.

## 2.2.4. Estimation and analyses procedures

In general, the thematic accuracy should be presented in the form of an error matrix. Unequal sampling intensity resulting from the stratified systematic sampling approach should be accounted for by applying a weight factor ( $p$ ) to each sample unit based on the ratio between the number of samples and the size of the stratum considered:

$$\hat{p}_{ij} = \left(\frac{1}{N}\right) \sum_{x \in (i,j)} \frac{1}{\pi_{uh}^*}$$

Where  $i$  and  $j$  are the columns and rows in the matrix,  $N$  is the total number of possible units (population) and  $\pi$  is the sampling intensity for a given stratum.

User's and Producer's accuracies are computed from those error matrices for all thematic classes and 95% confidence intervals are calculated for each accuracy. To summarize the accuracies and facilitate the comparison the Kappa coefficient is computed as well.

The standard error of the error rate can be calculated as follows:  $\sigma_h = \sqrt{\frac{p_h(1-p_h)}{n_h}}$  where  $n_h$  is the sample size for stratum  $h$  and  $p_h$  is the expected error rate. The standard error is calculated for each stratum and an overall standard error is calculated based on the following formula:

$$\sigma = \sqrt{\sum w_h^2 \cdot \sigma_h^2}$$

In which  $w_h$  is the proportion of the total area covered by each stratum. The 95% confidence interval is +/- 1.96  $\sigma$ .

To account for deviations of the product characteristics from the response design established for the validation exercises, the thresholds for permanent, temporary and absent surface water are analysed. To explain the underlying rationale, one can consider the following two examples:

1. The threshold for permanent water in the HRL WaW 2015 layer is defined as “at least 80% of all observations”. Given that the JRC GSW occurrence values are computed differently (i.e. on a monthly basis) and are based on different imagery from a different reference period, there is no guarantee that applying the same 80% threshold will lead to permanent water bodies that correspond to the desired extent (i.e. as represented in the validation sample). It is thus necessary to first establish the optimal threshold before assessing the accuracy of the product.
2. Vice versa the polygons in the EU-Hydro dataset readily provide a binary response (water / no water) but the product definition is ambiguous regarding the threshold of spatial density or temporal frequency beyond which a water body should be included. It is thus necessary to determine the inherent (i.e. not explicitly defined) threshold to obtain a binary response from the validation sample which is indeed comparable.

To this end, binary responses are created testing all possible thresholds and computing the respective User’s and Producer’s accuracies. This allows to draw curves (i.e. precision-recall curves) which display how the accuracies of a particular class evolve as a function of the respective thresholds (Figure 6). The threshold which achieves the highest F1-score can be considered as optimal and is used to compute the final accuracy metrics.

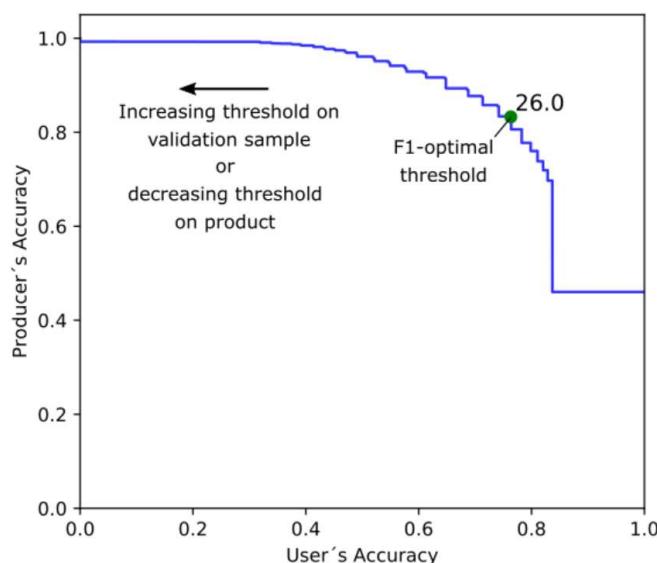


Figure 6: Exemplary precision-recall curve to determine an optimal threshold to generate a binary response from the continuous values in the validation sample or the product. The point on the curve which is the closest to the upper right corner maximizes the F1-score (i.e. the harmonic mean of User’s and Producer’s accuracies).

## 2.3. Relative comparison of water surface products

In addition to the absolute comparison against validation samples (method described in section 2.2) a relative comparison of the three different products is conducted including regression analysis comparisons of the overall surface areas as well as visual qualitative comparisons of the three products.

For the regression analysis between the JRC GSW occurrence layer and the HRL WWPI 2015 layer the map values from both products were extracted at the location of the 16,900 PSUs established during previous validation studies [5]. Points with missing values in any of the two layers were excluded. Samples with a WWPI 2015 code of 255 (i.e. outside the production unit) are exclusively located over the ocean and where hence recoded to value 100%. The results of this analysis are presented in section 3.2.1 at the pan-European and country level.

The established thresholds were used to generate a layer with three classes (dry, temporary water, permanent water) from the JRC GSW occurrence product. The resulting total surface areas were compared to the area estimates based on the EU-Hydro and the HRL WaW. The results of this analysis are presented in section 3.2.2.

## 3. Results

### 3.1. Absolute comparison against reference validation samples

#### 3.1.1. HRL WaW 2015

The thematic accuracies for the HRL WaW 2015 have been assessed in [2] from which User's and Producer's accuracies for the classes no water, permanent water and temporary water have been extracted and are represented in Table 7.

*Table 7: HRL WaW 2015 product plausibility thematic producer's and user's accuracies at the pan-European level covered, per bio-geographical regions and per country groups, for the classes: No water, Permanent water, and Temporary water. For the Permanent water and No Water, the values in green indicate accuracies greater than the 85% threshold, orange greater than 75% and red less than 75% considering a 95% CI. For the class Temporary water, the values in green indicate accuracies greater than the 80% threshold, orange greater than 70% and red less than 70% considering the 95% CI.*

	Prod. Acc. No Water	User Acc. No Water	Prod. Acc. Perm. Water	User. Acc. Perm. Water	Prod. Acc. Temp. Water	User. Acc. Temp. Water
<b>EEA39</b>	98,38%	99,03%	88,57%	99,27%	56,60%	80,53%
<b>Alpine</b>	95,53%	98,45%	82,22%	100,00%	66,46%	63,61%
<b>Anatolian</b>	99,93%	99,43%	98,75%	98,98%	69,60%	96,55%
<b>Arctic</b>	92,41%	92,23%	49,00%	96,15%	78,98%	81,74%
<b>Atlantic</b>	97,51%	98,87%	80,67%	99,21%	54,27%	68,83%
<b>Black Sea</b>	99,94%	99,37%	96,70%	100,00%	71,73%	93,10%
<b>Boreal</b>	97,90%	97,93%	94,19%	99,46%	54,69%	51,08%
<b>Continental</b>	99,16%	99,47%	81,89%	99,42%	37,72%	88,40%
<b>Mediterranean</b>	99,47%	99,81%	92,90%	98,96%	57,98%	96,43%
<b>Pannonic</b>	98,07%	99,16%	93,47%	97,13%	61,11%	98,16%
<b>Steppic</b>	99,12%	99,35%	93,27%	88,89%	100,00%	71,43%
<b>AL+ME+MK+RS +XK</b>	99,60%	99,88%	97,44%	96,77%	73,99%	96,67%
<b>AT + CH + LI</b>	99,51%	99,88%	93,66%	100,00%	87,44%	100,00%
<b>BA + HR + SI</b>	99,16%	99,87%	94,41%	100,00%	100,00%	100,00%
<b>BE + LU+ NL + DK</b>	98,51%	99,01%	86,38%	100,00%	100,00%	86,11%
<b>BG</b>	99,80%	99,52%	68,29%	100,00%	89,66%	95,24%
<b>CZ + SK</b>	98,51%	99,90%	89,82%	100,00%	100,00%	75,90%
<b>DE</b>	98,79%	99,60%	82,66%	98,18%	91,84%	63,64%
<b>EE + LT + LV</b>	98,06%	98,95%	97,74%	100,00%	58,50%	65,22%
<b>EL</b>	99,40%	99,72%	89,70%	100,00%	80,19%	95,65%
<b>ES</b>	99,71%	99,75%	90,37%	100,00%	57,80%	94,07%
<b>FI</b>	98,90%	97,72%	96,65%	99,38%	67,57%	71,79%

	Prod. Acc. No Water	User Acc. No Water	Prod. Acc. Perm. Water	User. Acc. Perm. Water	Prod. Acc. Temp. Water	User. Acc. Temp. Water
FR	99,47%	99,70%	90,51%	100,00%	37,83%	91,53%
HU	98,15%	99,04%	94,27%	100,00%	70,34%	100,00%
IE + UK	96,92%	98,13%	79,97%	100,00%	29,27%	56,67%
IS	92,39%	91,75%	49,09%	96,15%	78,80%	82,30%
IT	99,62%	99,28%	87,09%	100,00%	17,50%	96,77%
NO	88,12%	97,17%	81,41%	100,00%	80,28%	60,32%
PL	99,13%	99,55%	76,55%	97,22%	100,00%	76,00%
PT	98,89%	99,80%	84,91%	100,00%	77,13%	100,00%
RO	99,50%	99,19%	83,86%	96,00%	29,16%	82,76%
SE	95,85%	96,68%	88,71%	99,50%	41,07%	37,61%
TR	99,83%	99,66%	98,83%	98,36%	61,03%	96,53%

### 3.1.2. EU-Hydro

The EU-Hydro dataset comprises six feature classes which represent the extent of water bodies being Ditches\_p, Canals\_p, River\_Net\_p, InlandWater, Transit\_p and Coastal\_p. The definitions of those classes rely predominantly on thematic and geometric aspects, whereas considerations of the temporal persistence of the water body are ambiguous (Annex 2). An exception constitutes the Transit\_p feature class which is defined as “any water the level of which changes periodically due to tidal action”. However, in general the polygons in all feature classes tend to highlight the maximum extent of the water bodies.

In order to better understand the characteristics of the water bodies delineated in the EU-Hydro, the water occurrence values from the 2012 reference samples generated in [5] were initially compared with the different EU-Hydro feature classes. The results presented in Figure 7 show a clear contrast between the ‘no water’ (no EU-Hydro polygon feature) with low values (typically <20-40%) in the validation sample on the one hand, and Coastal\_p (coastal waters) with particularly high water occurrence values in the validation samples (typically >80%) on the other hand. The feature classes River\_Net\_p, Canal\_p, Ditches\_p as well as InlandWaters and Transit\_p typically coincide with occurrence values >20% with significant spread over the full range of possible values.

The occurrence of numerous samples with density values between 20% and 70% in the InlandWaters, River\_Net\_p, Canal\_p, Ditches\_p (Figure 7 b-c) suggests that a large part of the feature classes which delineate permanent water bodies also include temporary water bodies. As outlined above, the cut-off values for temporal frequency and spatial density, beyond which water bodies are to be included in the EU-Hydro dataset, are not clearly defined in the product definitions.

It is thus not immediately clear which threshold is to be applied on the density values in the HRL PWB validation sample to obtain the binary response necessary for the accuracy assessment. To determine the inherent cut-off threshold at which water bodies tend to be included/excluded, a precision-recall [10] threshold analysis was conducted. To this end all possible thresholds [1-100%] are tested to transform the water occurrence value in the HRL PWB 2012 validation sample into a binary response (i.e. water body, no water). Each binary response is then compared with the presence/absence (1, 0) of an EU-Hydro polygon at the location of the sample point,

and for each possible threshold the Producer's accuracy (Recall) and User's accuracy (Precision) are computed. The analysis comprises the use of the weights to adjust the stratified sample for the actual proportion of the different surface types [5]. The result of this analysis is presented in Figure 8 suggesting an optimal cut-off at  $\geq 30\%$ .

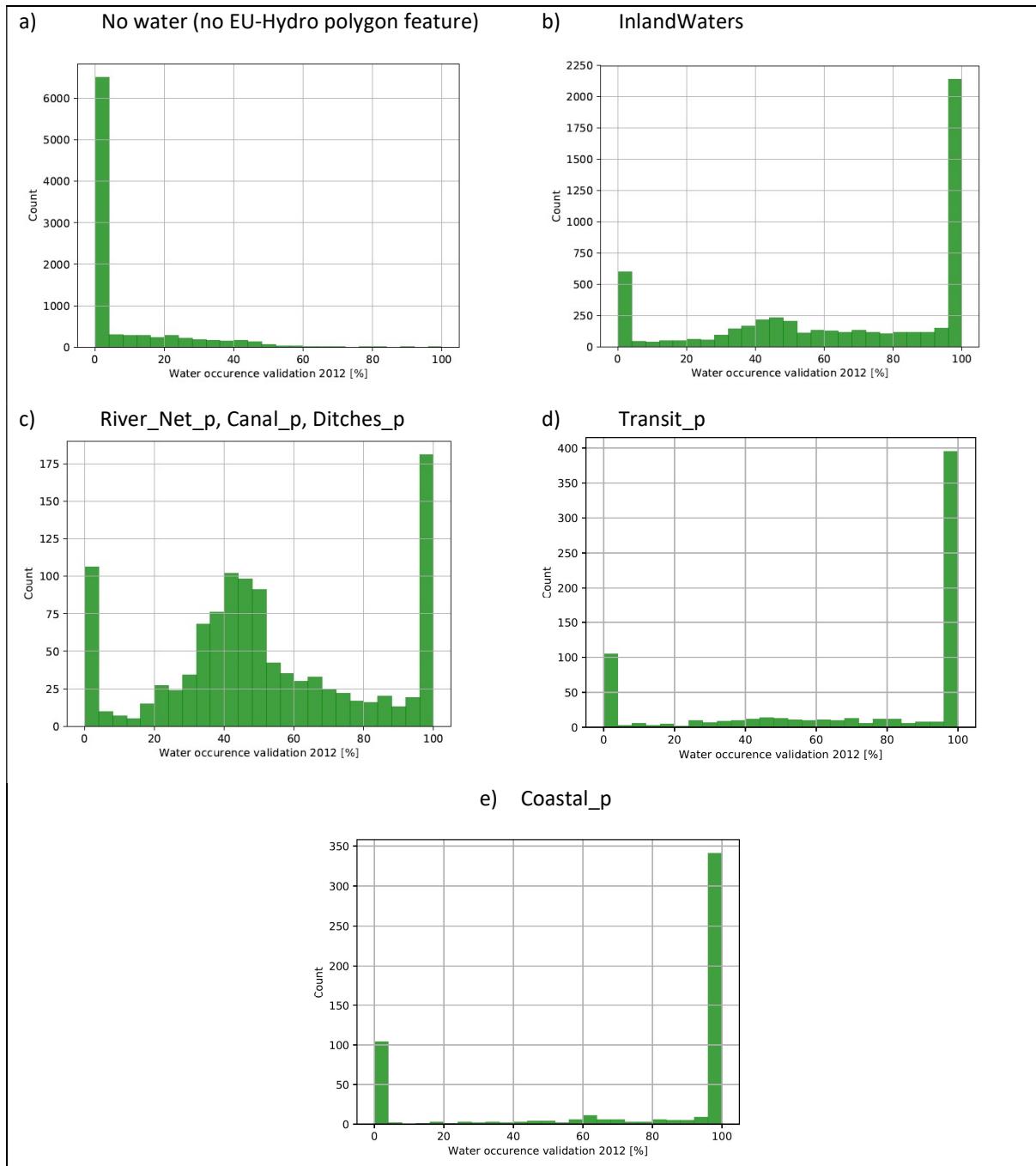


Figure 7: Histograms showing the distribution of the water occurrence values in the HRL 2012 PWB validation samples within different feature classes of the EU-Hydro.

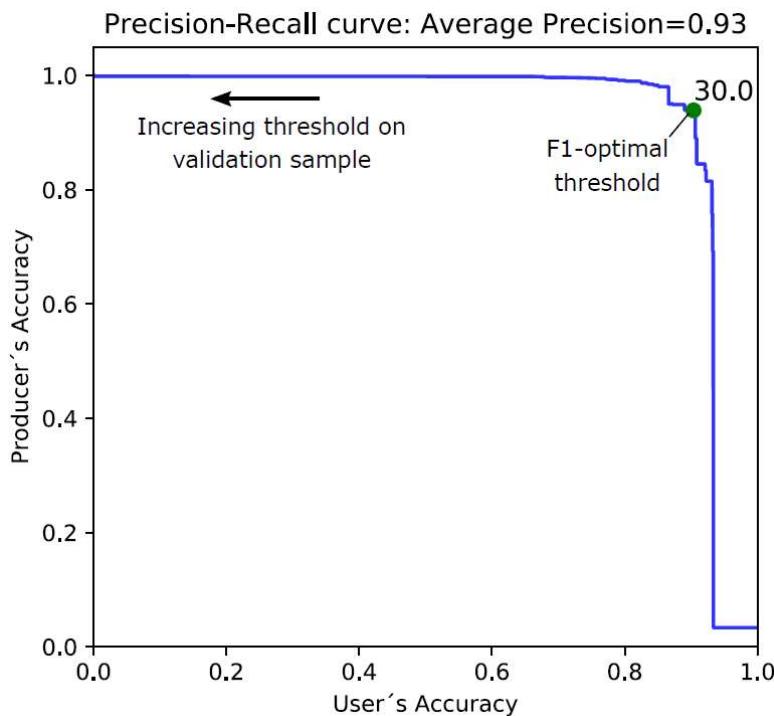


Figure 8: Precision (User's Accuracy)-Recall (Producer's Accuracy) curve for the EU-Hydro polygon feature classes when assessed against an iteratively thresholded HRL 2012 PWB validation sample [5]. The green dot indicates the threshold of  $\geq 30\%$  maximizing the F-measure at 0.91.

The determined cut-off  $\geq 30\%$  can be used to assess the accuracy of the EU-Hydro polygons against a reference sample. This cut-off represents the intrinsic, though not explicitly defined, product specification. The derived confusion matrices and accuracy measures (see Table 8) indicate an excellent accuracy of the delineation of water bodies in the EU-Hydro with a Kappa coefficient of 0.92. The Producer's accuracy for the delineated permanent water bodies is 93% which is slightly higher than the User's Accuracy of 92%. This is in line with the general observation that the delineation tends to mark the maximum extent and is hence slightly more prone to commission errors.

At the level of biogeographic regions and reporting units the accuracies are mostly above the 85% accuracy threshold (as defined for the HRL WaW 2015 product). Exceptions are in particular areas in the Mediterranean regions where various commission and omission errors were detected (Figure 10, Figure 11, Table 9, and Table 10). Typical commission errors, which impact in particular the User's accuracies for Greece and Cyprus, are EU-Hydro polygons which delineate areas that are only occasionally flooded (Figure 9 a). Other typical commission and omission errors (Norway, Italy and Malta, Figure 11, Table 10) occur along the boundaries of rivers and inland water bodies (Figure 9 b). Considering the inherent uncertainties in the delineation of a water body (seasonal and long term changes) and the geometric uncertainties of the reference imagery those errors could be considered less severe than the lower User's and Producer's accuracies for those areas suggest.

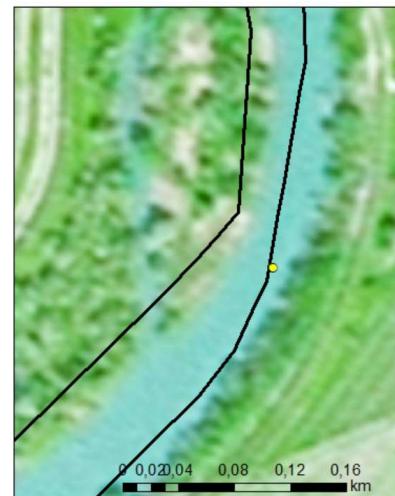
*Table 8: Confusion matrices and accuracies for no water (nowb, no EU-Hydro polygons) and permanent water bodies (pwb, presence of EU-Hydro polygons) when assessed against the HRL 2012 PWB validation sample at a cut-off value of  $\geq 30\%$ .*

Confusion matrix			Confusion matrix, normalized			Prod.'s accuracy [%]	User's accuracy [%]
Reference sample	nowb	pwb	nowb	EU-Hydro	pwb		
nowb	16384.84	40.75	1.00	0.00	0.93	99,75	99,79
pwb	34.98	439.43	0.07	0.93	0.93	92,63	91,51
						<b>Kappa</b>	0,92

a)



b)

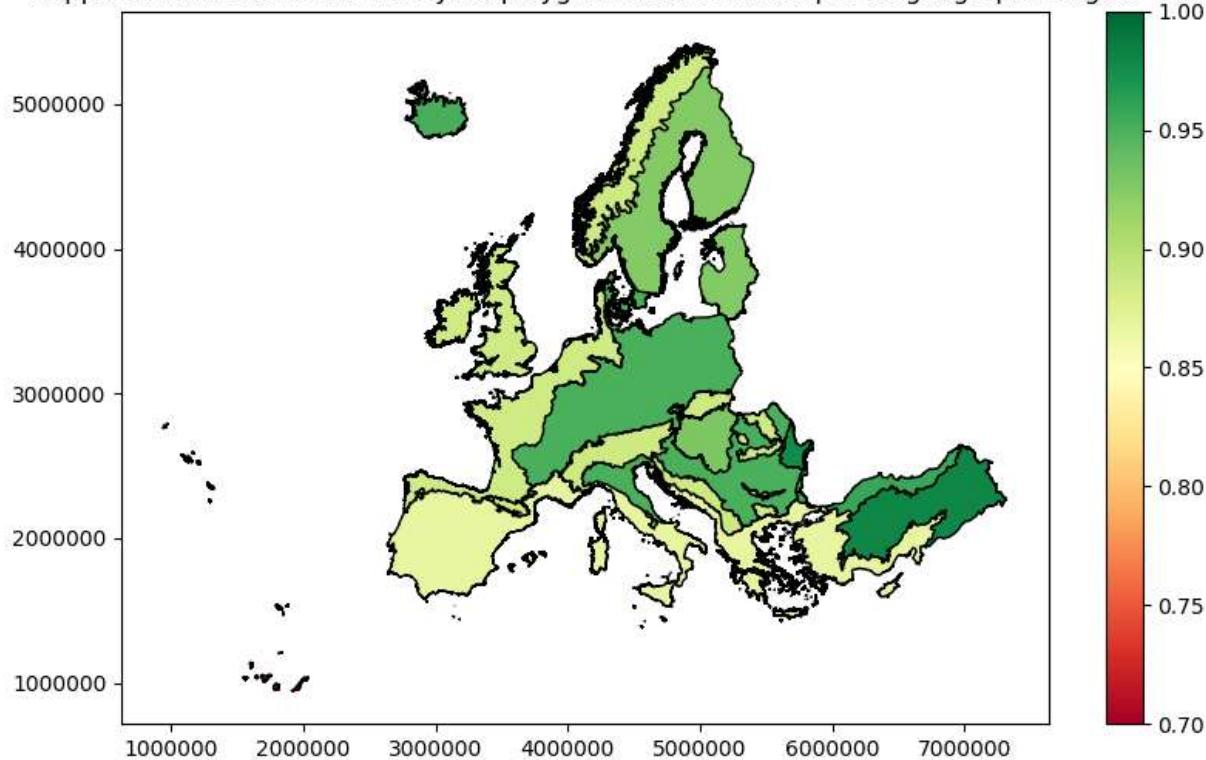


*Figure 9: Examples for commission (a, red, Greece) and omission due to geometric deficiencies (b, yellow, Italy) errors in the EU-Hydro polygon layers (black outline). The background image is the VHR IMAGE 2012.*

*Table 9: Accuracies of permanent water bodies (cut-off value  $a \Rightarrow 30\%$ ) delineated by EU-Hydro polygon feature classes per biogeographic region. The values in green indicate accuracies greater than the 85% threshold, orange greater than 75% and red less than 75% considering a 95% CI.*

Region	Prod. Acc. No Water [%]	User Acc. No Water [%]	Prod. Acc. Perm. Water [%]	User. Acc. Perm. Water [%]	Kappa
Boreal	99,23	99,58	95,10	91,35	0,93
Mediterranean	99,85	99,82	86,02	87,69	0,87
Continental	99,91	99,96	97,12	93,12	0,95
Alpine	99,82	99,40	84,15	94,63	0,89
Black Sea	99,92	99,98	98,11	93,55	0,96
Pannonic	99,86	99,94	95,77	90,46	0,93
Atlantic	99,66	99,76	90,67	87,09	0,89
Steppic	99,90	99,98	99,17	96,51	0,98
Arctic	99,91	99,91	95,13	95,23	0,95
Anatolian	99,93	99,99	99,34	96,84	0,98

*Kappa coefficients for the EU-Hydro polygon feature classes per biogeographic region*



*Figure 10: Distribution of the Kappa coefficients for EU-Hydro polygon feature classes per biogeographic region.*

*Table 10: Accuracies of permanent water bodies (cut-off value at >= 30%) delineated by EU-Hydro polygon feature classes per country/group of countries. The values in green indicate accuracies greater than the 85% threshold, orange greater than 75% and red less than 75% considering a 95% CI.*

Reporting Unit (Country code)	Prod. Acc. No	User Acc. No	Prod. Acc.	User. Acc.	Kappa
	Water [%]	Water [%]	Perm. Water [%]	Perm. Water [%]	
FI	99,19	99,74	97,61	92,78	0,95
ES	99,95	99,98	98,01	95,32	0,97
PL	99,83	99,95	95,93	88,38	0,92
DE	99,84	99,98	97,82	87,52	0,92
SE	99,12	99,36	93,08	90,72	0,91
EE+LT+LV	99,80	99,94	97,50	92,35	0,95
RO	99,94	99,98	98,45	95,26	0,97
RS+AL+MK+ME+XK	99,98	99,98	98,32	98,34	0,98
FR	99,98	99,95	95,81	97,79	0,97
NO	99,06	98,17	79,96	88,64	0,83
CZ+SK	99,98	99,99	98,58	97,79	0,98
AT+CH+LI	99,93	99,98	98,66	95,75	0,97
TR	99,94	99,98	99,01	95,97	0,97
BG	99,92	99,99	98,50	89,81	0,94
UK+IE	99,83	99,97	97,64	86,59	0,92
SI+BA+HR	99,97	99,96	93,44	95,00	0,94
EL+CY	99,03	99,98	98,07	44,66	0,61
IS	99,90	99,91	95,36	95,18	0,95
BE+DK+LU+NL	99,82	99,97	99,41	95,99	0,98
HU	99,79	99,93	95,47	87,45	0,91
IT+MT	99,97	99,37	69,84	98,28	0,81
PT	99,96	99,97	98,74	98,08	0,98

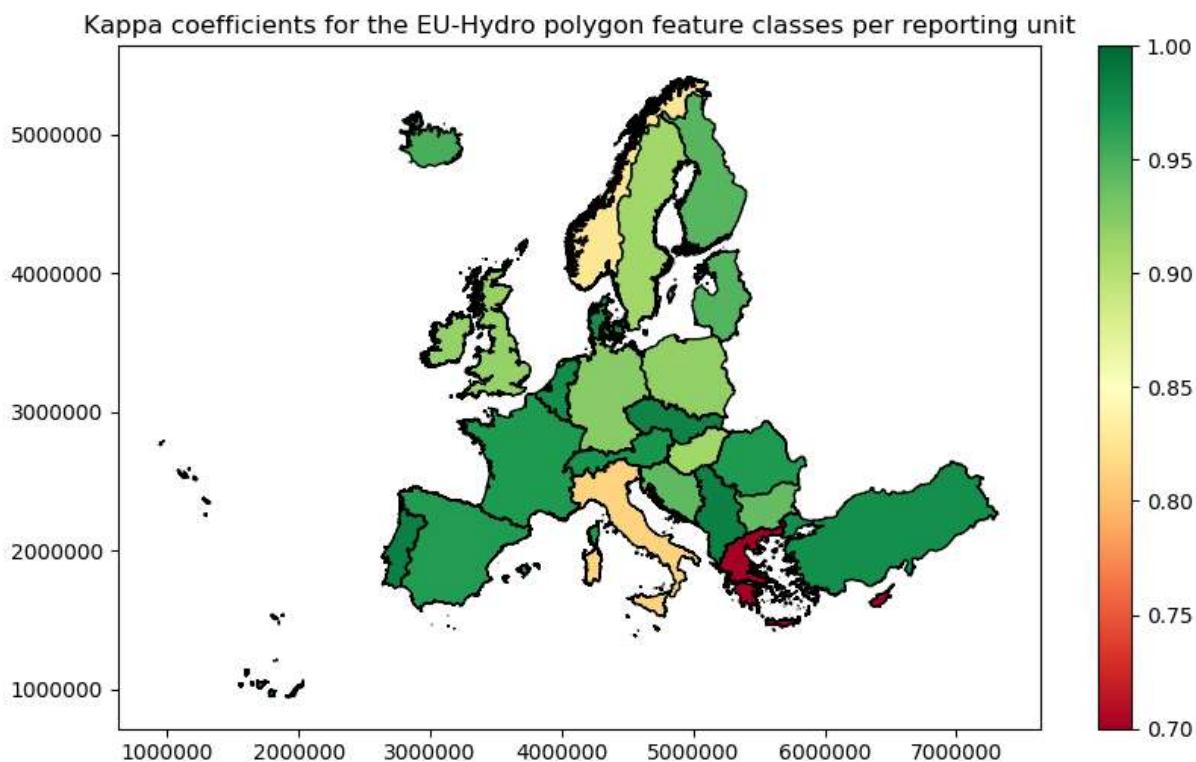
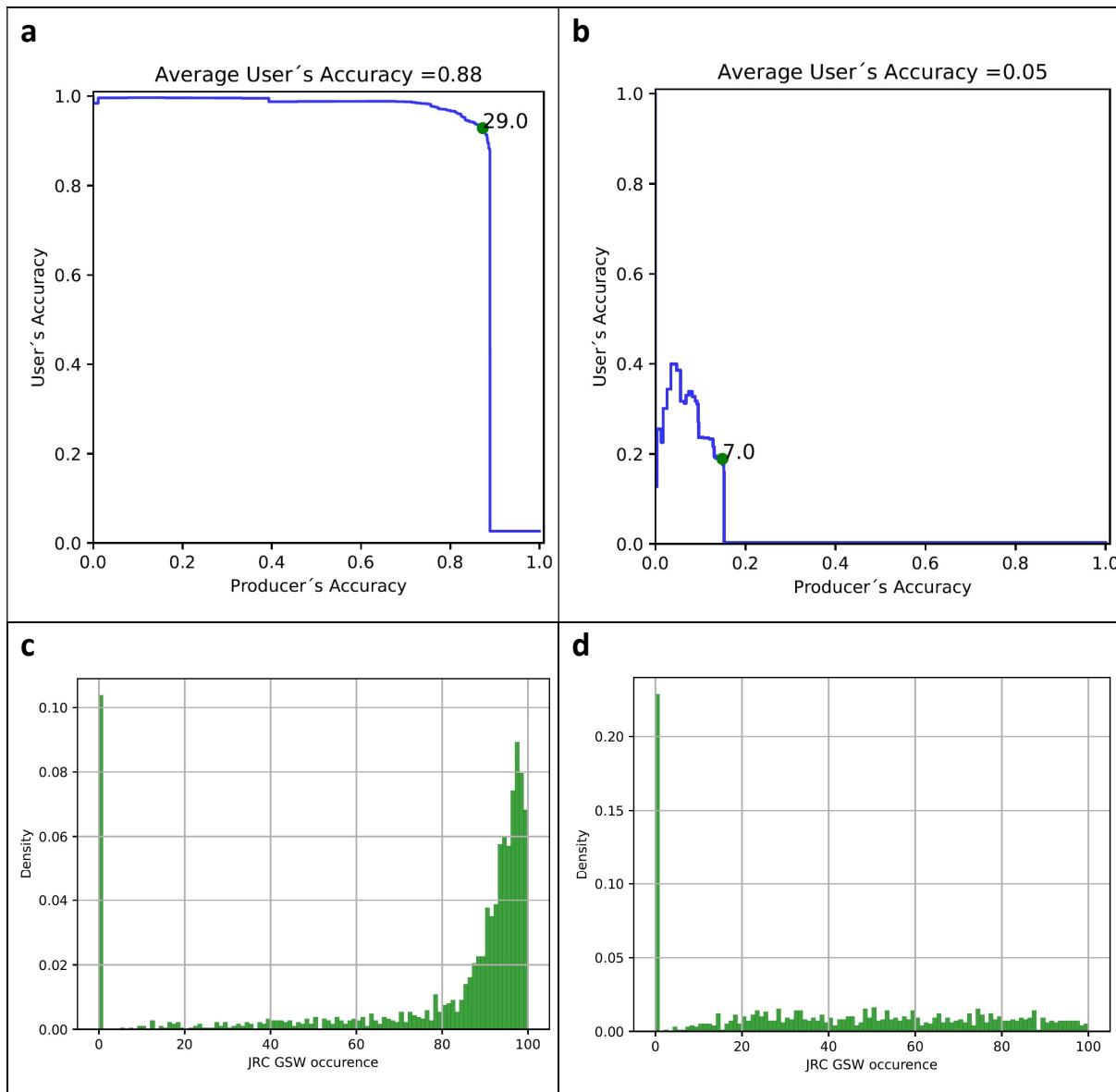


Figure 11: Distribution of the Kappa coefficients for the EU-Hydro polygon feature classes per reporting unit.

### 3.1.3. JRC GSW occurrence

While the thresholds for permanent and temporary water bodies are clearly defined for the HRL WaW 2015 layer (i.e. permanent water: at least 80% of the observations; temporary water: water in >25% to 80% of the observations, water dominates over wet), similar thresholds have not been fixed to classify the continuous layers of the JRC GSW products. The JRC GSW occurrence layer is based on optical data alone so that no observations of wetness (SAR based in HRL WAW) are included in the occurrence frequency. Furthermore, the occurrence is derived from the monthly average of water observations, whereas HRL WAW 2015 layer uses the fraction of all observations as a basis for thresholding into discrete classes.

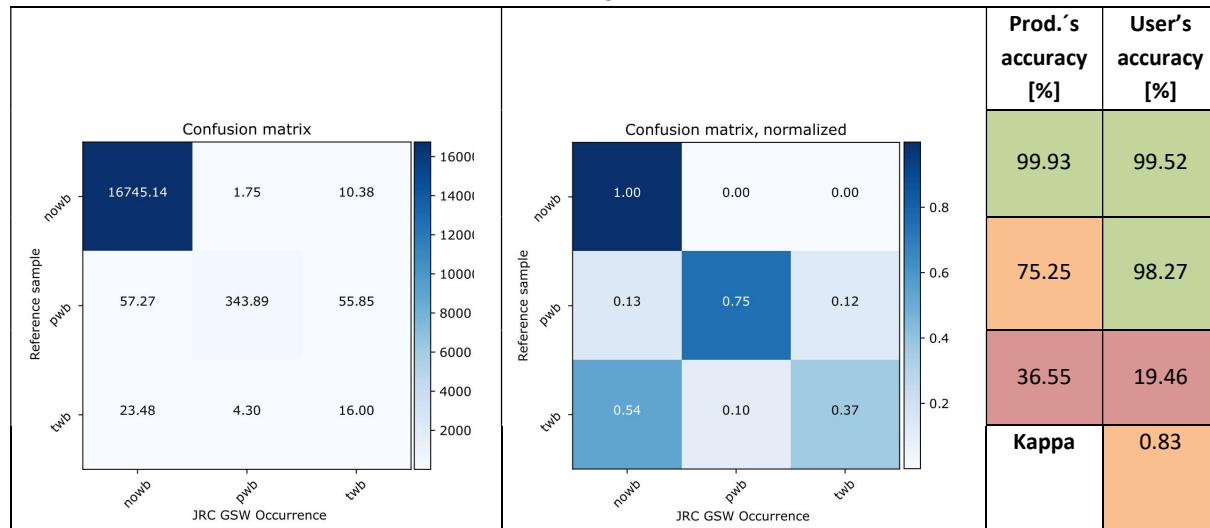
In other words, the JRC GSW occurrence and the occurrence frequencies underlying the HRL WaW classes are not equivalent which is why the thresholds have to be adapted to translate the JRC GSW occurrence into discrete classes that correspond as closely as possible with the class definition in the validation sample (i.e. the class definition of the HRL WAW 2015). To this end Producer's and User's accuracies for both classes (permanent water, temporary water) were evaluated over the full range of plausible thresholds. The outcome of this analysis for the permanent water class is presented in Figure 12 a and shows that the highest accuracy ( $F1=0.90$ ) for this class is achieved when thresholding the JRC GSW at  $\geq 29\%$ . While this suggests a high accuracy for the permanent water class, the lower range of occurrence values appears to be only loosely related to temporary water bodies with a low  $F1$  of 0.20 at an optimal threshold range of  $\geq 7\%$  and  $< 29\%$  (Figure 12 b). This is also corroborated by the histograms in Figure 12 c and d which show a concentration of permanent water samples in higher occurrence value, whereas temporary water samples are almost evenly split across the full range of occurrence values.



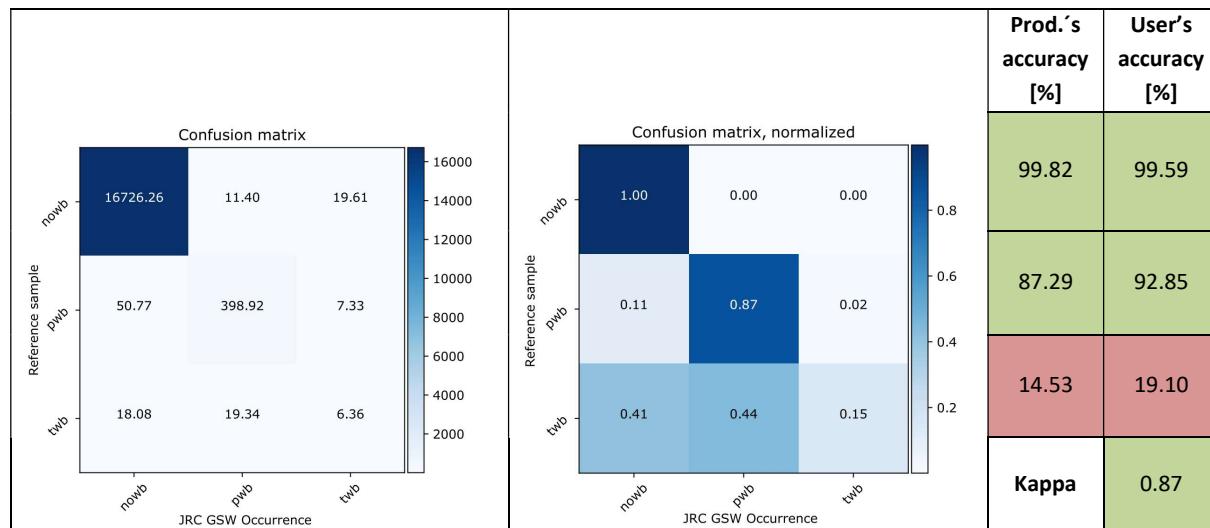
*Figure 12: Threshold analysis of JRC GSW occurrence layer against the HRL 2015 WaW validation sample. Precision-recall curves for (a) the permanent water class showing an optimal cut-off at  $>=29\%$  and (b) the temporary water class showing an optimal cut off at  $>=7\%$  (and  $<29\%$ ). The respective histograms show the occurrence value distribution for (c) all samples validated as permanent water and (d) all samples validated as temporary water.*

The results of the above analysis hence suggest the use of adjusted thresholds to assess the JRC GSW occurrence layer against the reference samples. To further evaluate the impact of adjusted thresholds on the measured accuracies, the assessment at the pan-European scale is carried out testing both the standard thresholds suggested for HRL WaW 2015 and the optimized thresholds for the JRC GSW occurrence layer. The results of both analyses are presented in Table 11 and Table 12 and confirm that the use of optimized thresholds leads to a generally higher accuracy of the discrete map (i.e. Kappa of 0.87 vs. 0.83). In particular the surfaces classified as no water and permanent water are more accurately depicted.

**Table 11:** Confusion matrices and accuracies for no water (nowb), temporary water bodies (twb) and permanent water bodies (pwb) derived from JRC GSW occurrence layer using the same thresholds as defined for the HRL WaW 2015 being <=25% (nowb), >25% and <80% (twb), and >=80% (pwb), respectively. For permanent water and no water, the values in green indicate accuracies greater than the 85% threshold, orange greater than 75% and red less than 75% considering a 95% CI. For temporary water, the values in green indicate accuracies greater than the 80% threshold, orange greater than 70% and red less than 70% considering the 95% CI.



**Table 12:** Confusion matrices and accuracies for no water (nowb), temporary water bodies (twb) and permanent water bodies (pwb) derived from JRC GSW occurrence layer using adjusted thresholds of <=7% (nowb), >7% and <29% (twb), and >=29% (pwb), respectively. For permanent water and no water, the values in green indicate accuracies greater than the 85% threshold, orange greater than 75% and red less than 75% considering a 95% CI. For temporary water, the values in green indicate accuracies greater than the 80% threshold, orange greater than 70% and red less than 70% considering the 95% CI.



This overall improvement comes at the price of a further decrease in the producer's accuracy for the temporary water class. In summary, Table 12 provides the final accuracies for no water (nowb), temporary water bodies (twb) and permanent water bodies (pwb) derived from the JRC GSW at the pan-European level. It suggests an excellent accuracy for the classes no water and permanent water bodies, whereas the delineation of temporary water bodies comprises large uncertainties. For the permanent water class it can be noted that omission errors are more important than commission errors, which is in line with the internal validation of the underlying individual time steps as carried out by the JRC [7].

At the level of biogeographic regions and reporting units the accuracies for no water and permanent water are mostly above the 85% accuracy threshold as defined for the HRL WaW 2015 product. Exceptions are in particular areas in the Mediterranean, Atlantic and Arctic regions where numerous commission and omission errors were detected (Table 13, Table 14, Figure 14, Figure 15).

Typical omission errors in Norway, Iceland, Germany and Bulgaria are located at the borders of rivers and inland water bodies which have been classified as permanent in the validation but are depicted with an occurrence value of 0 in the JRC GSW (Figure 13 a and b). While a tendency towards higher omission errors has already been reported by the authors of the product [7], the analysis presented here suggests that those omission errors are particularly prominent in those geographic areas. In general, it should also be noted that many of the detected errors are associated to locations at the borders of water bodies. Due to changes over time, mixed pixels, resolution differences and geometric uncertainties such areas are typically associated with higher uncertainties that affect both the products and the validation. It could thus be considered that errors in such areas are less severe than for example the omission of entire water bodies or land areas.

Commission errors, are particularly concentrated in the Mediterranean and especially for Spain a User's accuracy of only 56% is achieved. As illustrated in Figure 13 c those commission errors are typically located on the edges of inland water bodies with occurrence values below 60%. In the validation sample such areas are correctly classified as temporary water whereas they are classified as permanent (adjusted threshold of  $\geq 29\%$ ) based on the JRC GSW occurrence layer. This suggests that one global threshold is not ideal to extract permanent water bodies with comparable characteristics across all geographic areas from the JRC GSW occurrence layer. This might also be related to the fact that the expert system for the production of the JRC GSW uses regionally adapted thresholds [7] which in turn can lead to differences in the product characteristics from one region to another. While the observed omission errors are an inherent characteristic of the dataset, the detected commission errors could maybe be assessed with slightly lower values, if using regionally adapted thresholds for the User's accuracy.

The temporary water class is generally characterized by very low Producer's and User's Accuracies across all reporting units. This is likely due to a combination of three factors being i) the threshold which has been adjusted to compensate omission errors in the permanent water class (reducing and shifting the range for the temporary water class), ii) the inherently greater changes over time in the temporary water class which inevitably lead to larger deviations between the HRL WaW 2015 reference period (2009-2015) and the JRC GSW reference period (1984-2015) and iii) the fewer (and different sensor) observations underlying the JRC GSW product (longer repeat pass cycle of Landsat, only optical and not SAR observations) which may reduce the likelihood of observing short term changes in the water extent.

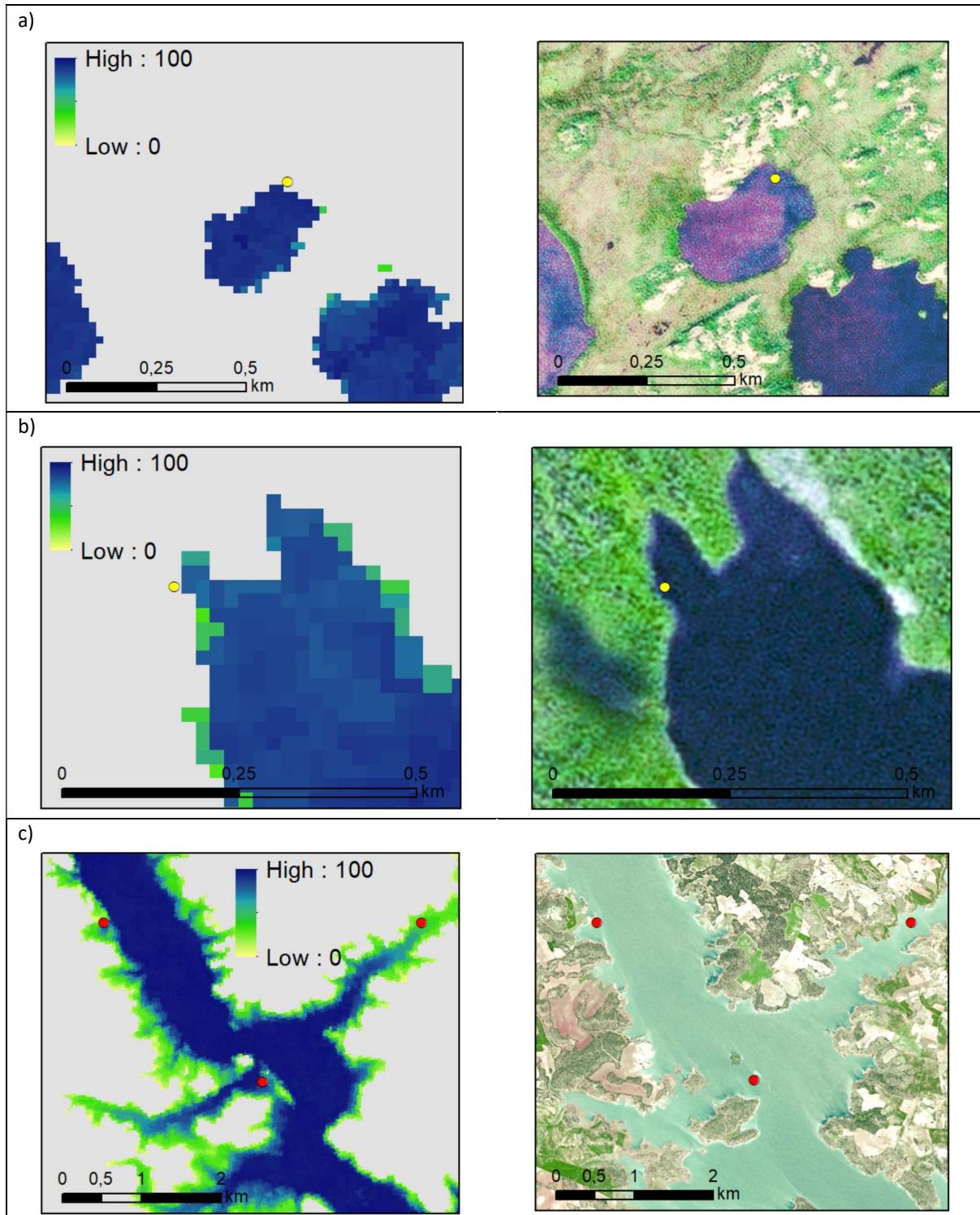
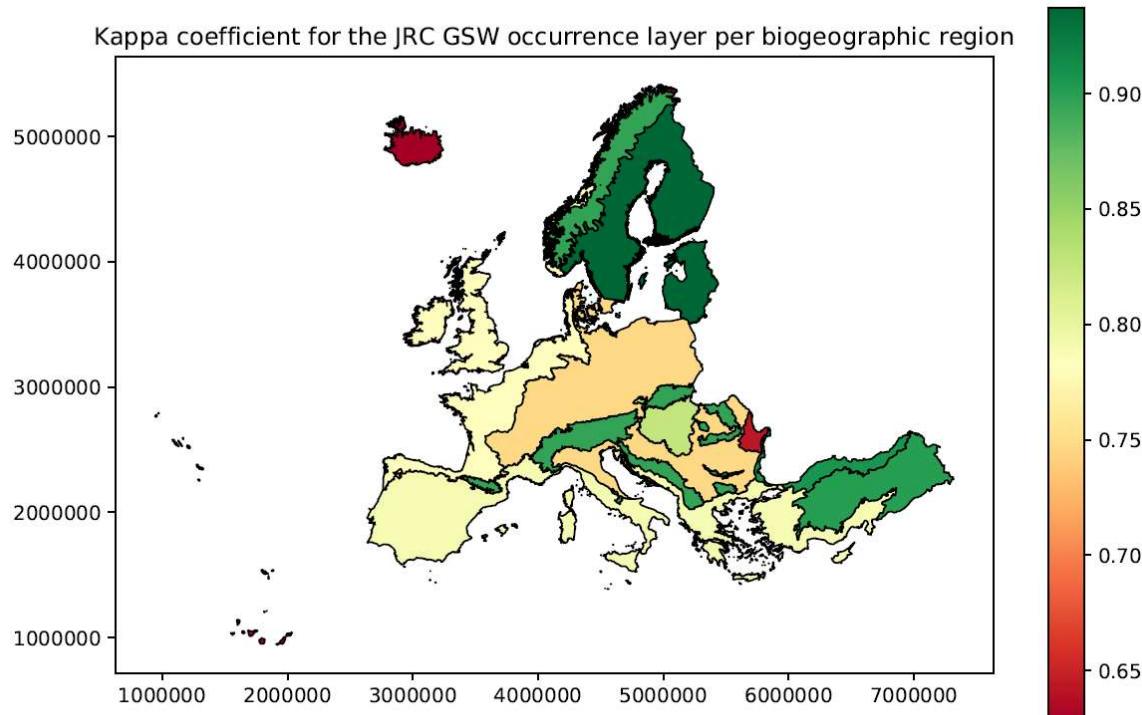


Figure 13: Examples for omission errors (yellow, a: Iceland, b: Norway) and commission errors (c, red, Spain) in the Permanent Water class as derived from the JRC occurrence layer (left column) using adjusted thresholds of  $\leq 7\%$  (No water),  $>7\%$  and  $<29\%$  Temporary water), and  $\geq 29\%$  (Permanent water), respectively. The background image in the right column is the VHR IMAGE 2012.

*Table 13: Producer's, user's accuracies and Kappa coefficients per bio-geographical region for the classes: No water, Permanent water, and Temporary water as derived from the JRC GSW occurrence layer using adjusted thresholds of <=7% (No water), >7% and <29% Temporary water), and >=29% (Permanent water), respectively.*

*For permanent water and no water, the values in green indicate accuracies greater than the 85% threshold, orange greater than 75% and red less than 75% considering a 95% CI. For temporary water, the values in green indicate accuracies greater than the 80% threshold, orange greater than 70% and red less than 70% considering the 95% CI.*

Region	Prod. Acc.	User Acc.	Prod. Acc.	User. Acc.	Prod. Acc.	User. Acc.	Kappa
	No Water	No Water	Perm. Water	Perm. Water	Temp. Water	Temp. Water	
Mediterranean	99,87	99,84	91,40	74,29	20,10	57,34	0,79
Anatolian	99,79	99,98	98,88	88,35	28,40	33,16	0,90
Black Sea	100,00	99,98	100,00	82,13	26,57	100,00	0,91
Atlantic	99,83	99,47	73,09	89,98	10,54	10,24	0,78
Continental	99,76	99,59	79,64	87,62	8,38	10,03	0,75
Steppic	98,22	99,71	88,34	83,03	20,00	3,32	0,64
Alpine	99,98	99,51	86,70	94,89	6,95	37,72	0,89
Pannonian	99,53	99,78	89,15	91,56	35,67	17,72	0,83
Arctic	100,00	95,82	57,00	90,36	1,68	100,00	0,63
Boreal	99,77	99,40	92,52	98,55	11,58	5,49	0,94

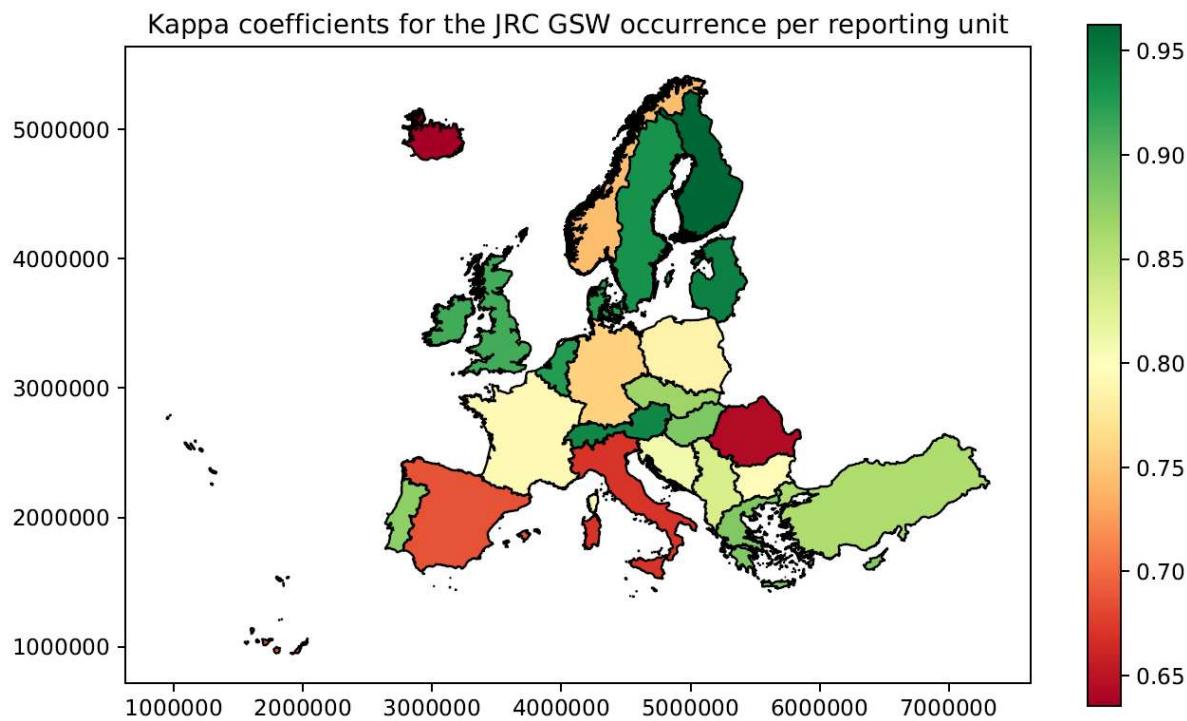


*Figure 14: Distribution of the Kappa coefficients per bio-geographical region for the classes: No water, Permanent water, and Temporary water as derived from the JRC GSW occurrence layer using adjusted thresholds of <=7% (No water), >7% and <29% Temporary water), and >=9% (Permanent water), respectively.*

*Table 14: Producer's, user's accuracies and Kappa coefficients per bio-geographical region for the classes: No water, Permanent water, and Temporary water as derived from the JRC GSW occurrence layer using adjusted thresholds of <=7% (No water), >7% and <29% Temporary water), and >=29% (Permanent water), respectively.*

*For permanent water and no water, the values in green indicate accuracies greater than the 85% threshold, orange greater than 75% and red less than 75% considering a 95% CI. For temporary water, the values in green indicate accuracies greater than the 80% threshold, orange greater than 70% and red less than 70% considering the 95% CI.*

Reporting Unit (Country code)	Prod.	User Acc.	Prod.	User.	Prod.	User.	Kappa
	Acc. No	No Water	Acc.	Acc.	Acc.	Acc.	
	Water	Water	Perm.	Perm.	Temp.	Temp.	Water
TR	99,80	99,91	99,09	82,31	23,65	43,01	0,86
UK+IE	99,96	99,92	94,71	89,90	8,38	26,29	0,91
RO	99,45	99,58	83,40	87,51	4,86	3,11	0,64
EL+CY	99,96	99,85	88,41	91,29	20,30	32,44	0,88
BG	99,94	99,48	73,17	92,47	13,45	27,20	0,79
IS	100,00	95,71	58,34	90,64	1,69	100,00	0,64
HU	99,90	99,68	88,28	92,64	19,78	25,07	0,88
PT	100,00	99,93	85,13	90,66	38,14	37,36	0,88
AT+CH+LI	99,98	99,84	94,39	96,19	9,19	100,00	0,94
BE+DK+LU+NL	100,00	99,70	86,99	99,24	47,31	21,10	0,92
RS+AL+MK+ME+XK	99,60	99,85	92,17	89,50	35,80	18,83	0,83
FR	99,97	99,77	84,61	89,32	3,50	12,35	0,79
SI+BA+HR	99,91	99,81	77,26	84,14	28,44	27,87	0,81
CZ+SK	99,98	99,82	81,07	93,94	14,90	15,57	0,87
EE+LT+LV	99,87	99,89	97,81	96,27	7,80	10,04	0,95
ES	99,86	99,85	86,36	56,30	22,36	66,86	0,69
SE	99,78	99,26	91,73	98,26	21,10	12,34	0,93
DE	99,68	99,60	74,33	86,89	17,49	4,73	0,76
FI	99,92	99,49	95,26	98,67	2,41	4,85	0,96
NO	99,52	97,68	67,42	95,86	2,11	1,35	0,74
PL	99,62	99,85	85,23	83,57	31,58	6,54	0,79
IT+MT	99,78	99,50	87,20	75,38	2,55	15,45	0,67



*Figure 15: Distribution of the Kappa coefficients per reporting unit for the classes: No water, Permanent water, and Temporary water as derived from the JRC GSW occurrence layer using adjusted thresholds of <=7% (No water), >7% and <29% Temporary water), and >=29% (Permanent water), respectively.*

### 3.2. Relative comparison of water surface products

This section presents the results of the relative comparison of the three products including a regression analysis among the HRL WWPI 2015 and the JRC GSW occurrence products as well as the total water surface areas estimated by the different products.

#### 3.2.1. Regression analysis of HRL WWPI 2015 vs JRC GSW occurrence

To quantify and better understand the differences and similarities among the products a statistical analysis was conducted for a relative comparison of the continuous HRL WWPI 2015 and the JRC GSW Occurrence layer. Figure 16 presents the results of regression analyses between the values of the two products. To allow for a comparison with the figures presented in the validation of the HRL PWB 2012 [1] either all HRL PWB 2012 samples (Figure 16, left), or LUCAS replicate 1 points [11] only (Figure 16, right) were used. The Adjusted R<sup>2</sup> of 0.65 and 0.77, respectively, are comparable to the correlation between map values and validation values reported in the initial validation of the HRL PWB 2012 [1]. Considering the different temporal references, spatial resolutions and methodological approaches of the two products this underlines the close similarity of the JRC GSW occurrence and the HRL WWPI 2015. In other words, it indicates that the differences among the two products are within the range of typical uncertainties of large-area satellite-derived water products.

The HRL WWPI 2015 values are generally slightly higher than the values of corresponding pixels in the JRC GSW occurrence layer which is likely due to the different methodologies and input datasets. For example, the

numerous samples for which the JRC GSW occurrence indicates values of 0% and the HRL WWPI 2015 indicates values between 20-60% can be attributed to temporary and permanent wet areas. Such areas are included in the HRL WWPI 2015 based on soil moisture estimates from Sentinel-1 data but are not represented in the JRC GSW relying on optical data alone.

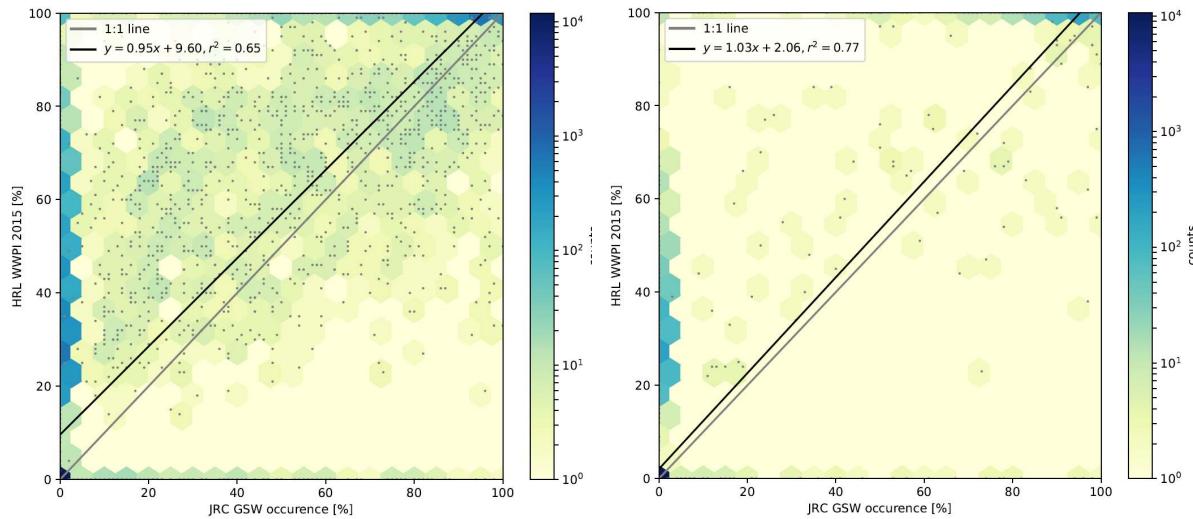


Figure 16: Linear regression analysis between JRC GSW occurrence and HRL WWPI 2015 at all sample locations ( $n=16,900$ , left) and at the European LUCAS replicate 1 only ( $n=3,916$ , right) using sample locations from [1].

An analysis of the spatial variation of the correlation of the two products across Europe (Figure 17) furthermore highlights two main areas with discrepancies being Iceland and, to a lesser extent Great Britain and Ireland. The larger differences in those areas can be explained mainly by more frequent cloud cover which increases the uncertainties in both products. More specifically it increases the relative importance of SAR-based observations in the HRL WWPI which in turn leads to a relative higher frequency of values between 20-60% and the related temporary and permanent wet classes (Figure 18). In the JRC GSW occurrence, on the other hand, the reduced number of optical observations seemingly leads to numerous false positive land areas in the ocean (Figure 18).

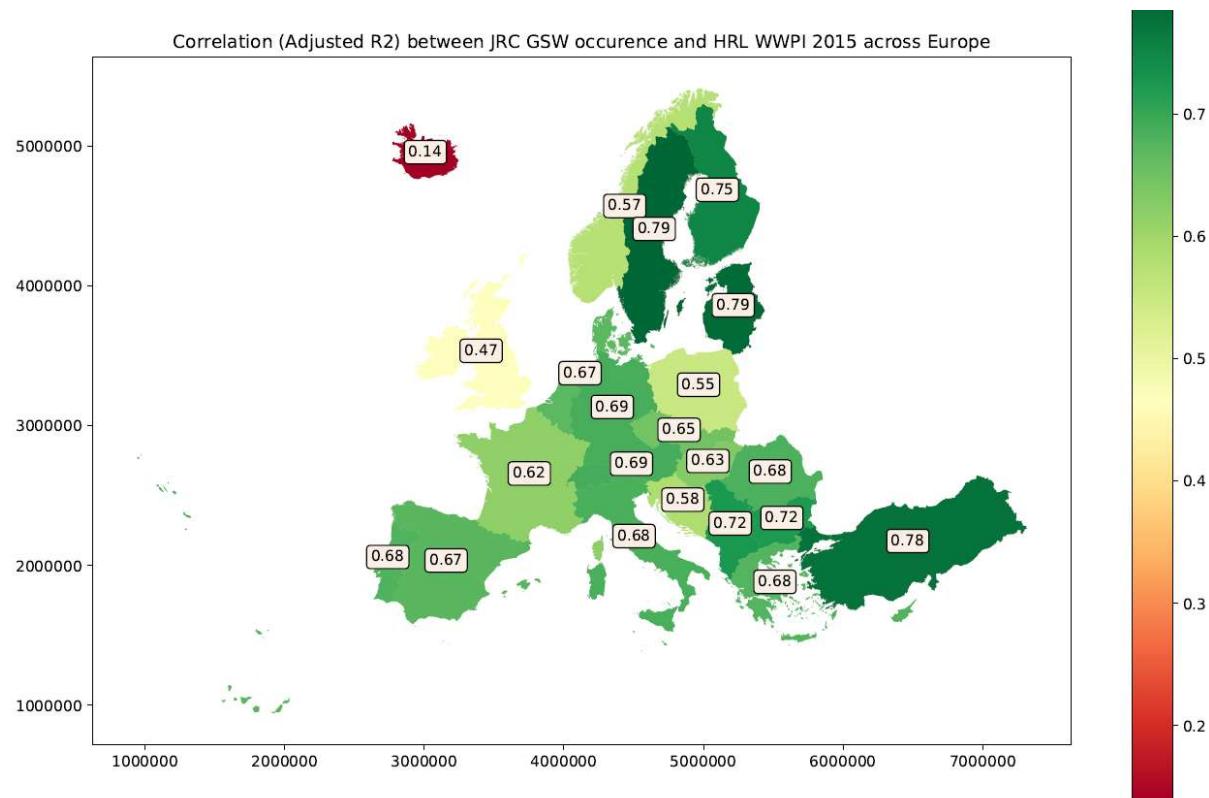


Figure 17: Adjusted  $R^2$  for the linear regression analysis between JRC GSW occurrence and HRL WWPI 2015 at sample locations from [1] grouped per EEA39 member country/group of countries.

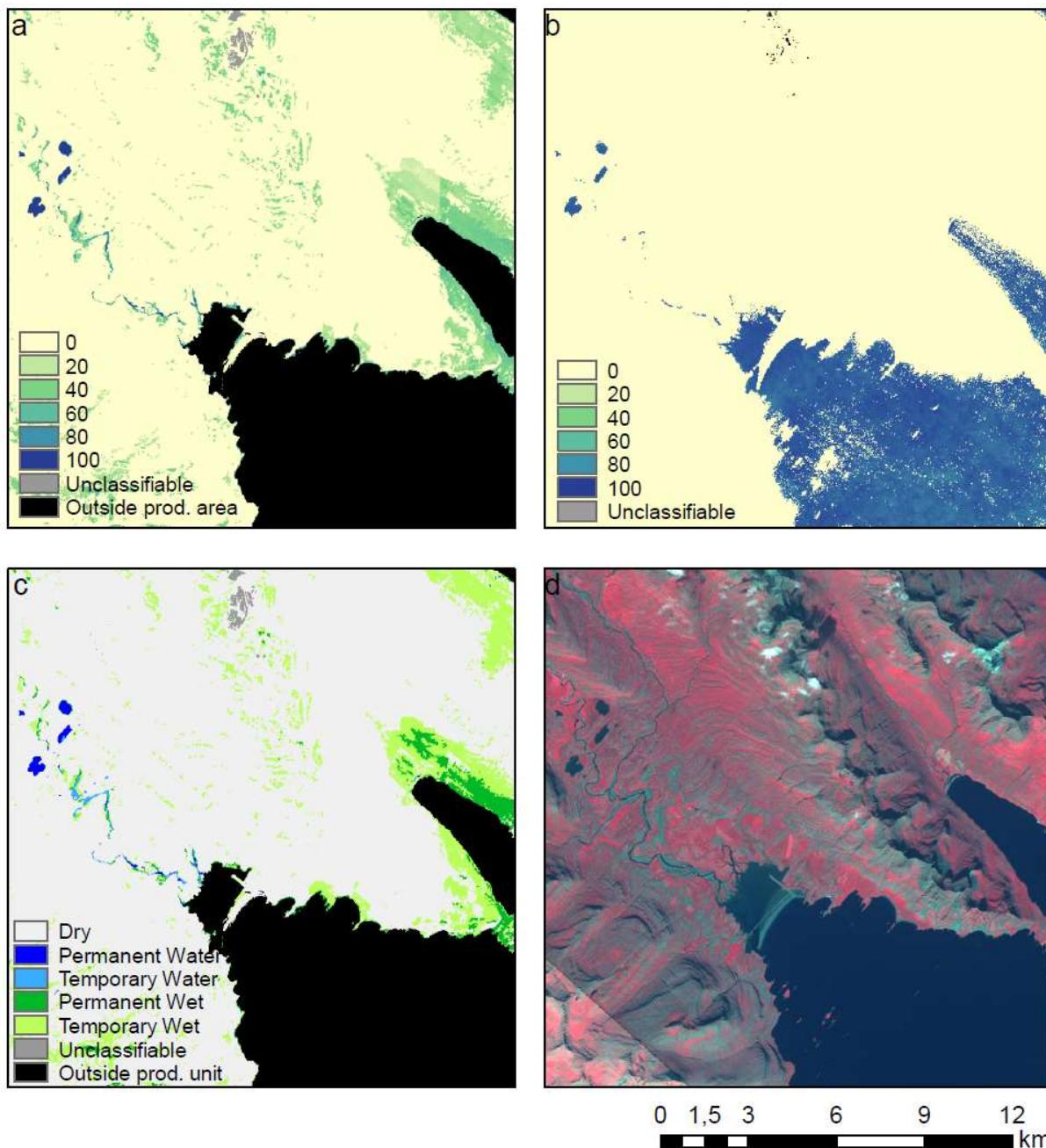


Figure 18: Exemplary comparison of (a) HRL WWPI 2015, (b) JRC GSW occurrence and (c) HRL WAW 2015 for an area with particularly large differences (Eastern Iceland). A false colour composite (VHR IMAGE 2012) of the area is shown in subfigure (d).

### 3.2.2. Water surface areas

This section provides the results of the analysis of the water surface areas according to three different products at the pan-European level (Figure 19, Table 15), per biogeographic region (Figure 20, Table 16) and per reporting unit (Figure 21, Table 17). In general the EU-Hydro data indicate the largest surface water extents. Using the standard HRL WaW 2015 thresholds, the total water surfaces extracted from the JRC GSW occurrence are slightly lower than those from the HRL WaW 2015 (Figure 19 a). The opposite is true when the thresholds for the JRC GSW occurrence are adjusted (as described in section 3.1.3) to best match the reference sample (Figure 19 b). Even when considering the sum of both the permanent and temporary water classes, the total area extracted from HRL WaW 2015 and JRC GSW occurrence generally lack behind the area depicted in the EU-Hydro. The main reason for this discrepancy is probably the more generous inclusion of areas such as broad and mostly dry river beds and partially silted lakes in the EU-Hydro. A noticeable exception is Turkey where the area extracted from the JRC product is larger. This can be traced back to the shrinking of endorheic lakes and is as such an effect of the different reference periods.

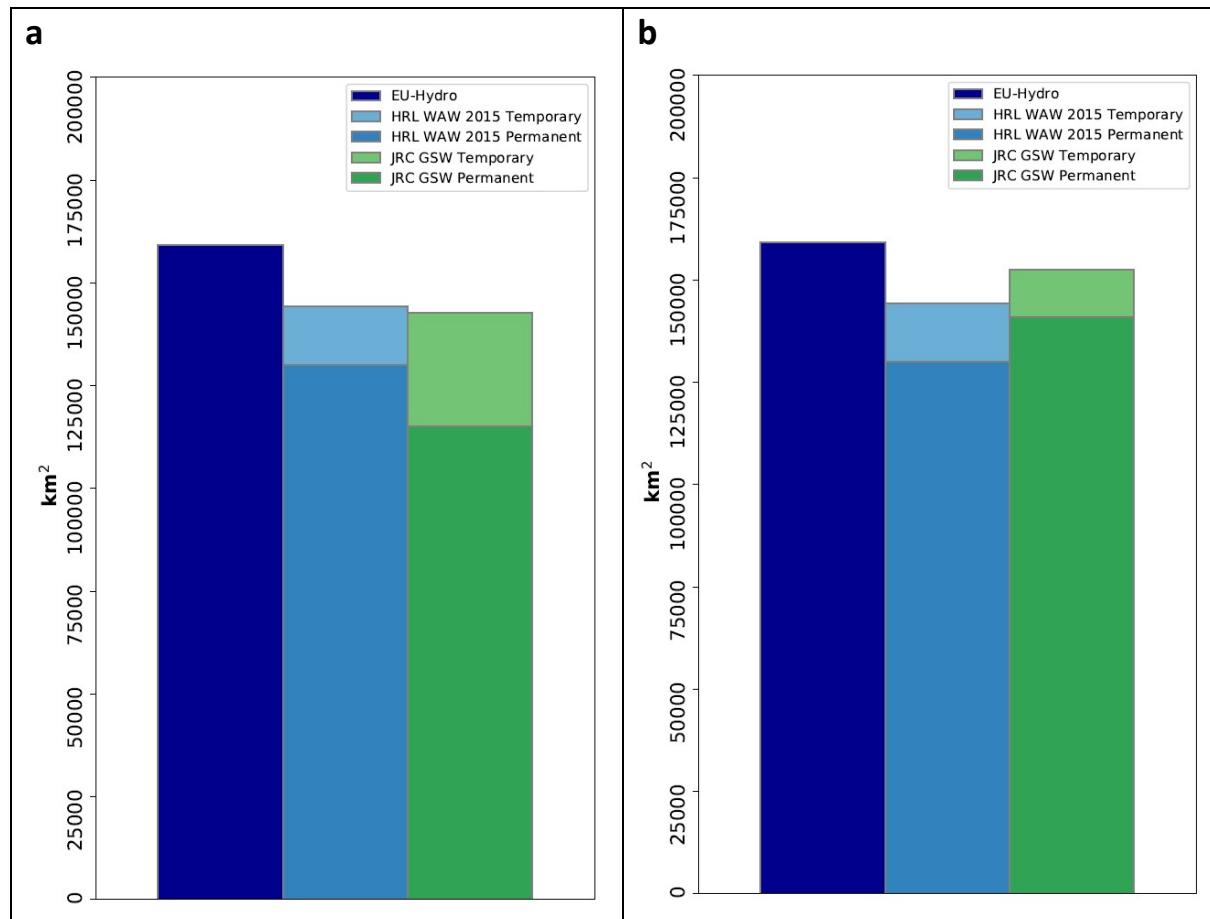
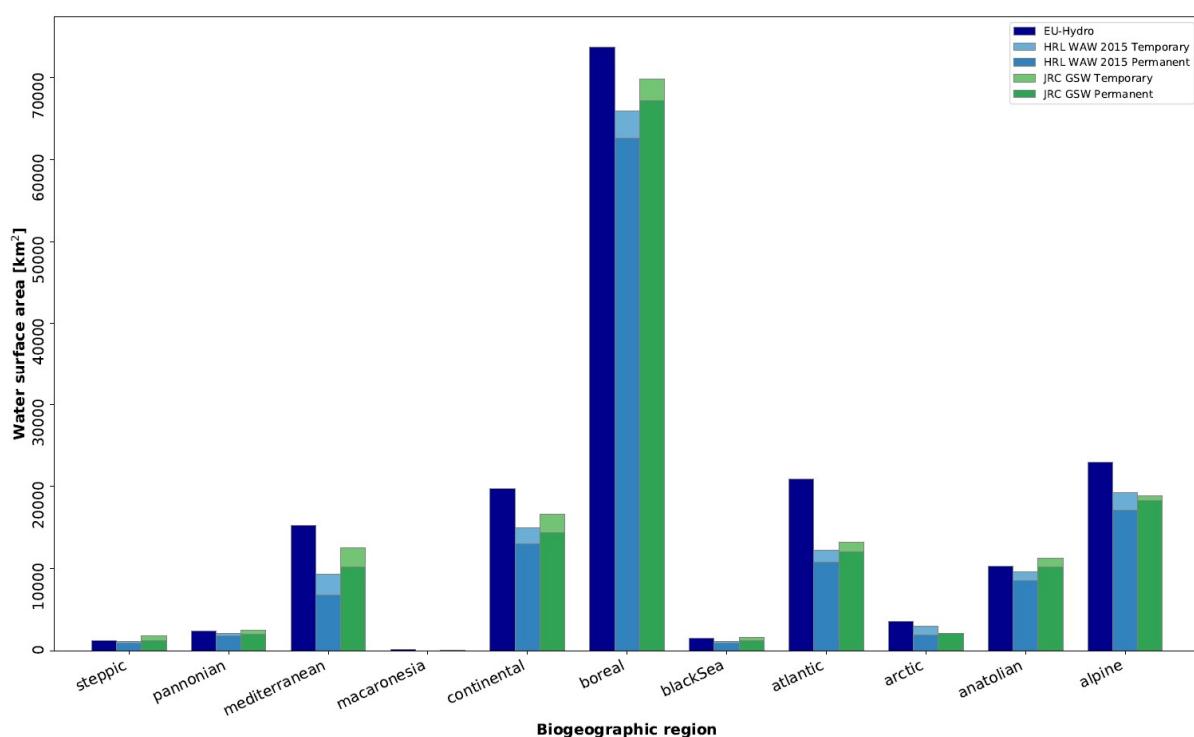


Figure 19: Comparison of water surface area at the pan-European level (EEA39) as estimated by the three different products with (a) using the HRL WaW thresholds on the JRC GSW occurrence and (b) using the adjusted thresholds on the JRC GSW occurrence.

*Table 15: Water surface area estimated according to the three different products at the Pan-European level. For the JRC GSW occurrence layer both the figures with standard thresholds and adjusted thresholds are presented.*

Source	Permanent Water Bodies	Temporary Water Bodies	Total [km <sup>2</sup> ]
	[km <sup>2</sup> ]	[km <sup>2</sup> ]	
EU-Hydro	159.174,1	0,0	159.174,1
HRL WaW 2015	129.983,3	14.392,4	144.375,7
JRC GSW occurrence (adjusted thresholds)	141.033,0	11.602,4	152.635,4
JRC GSW occurrence (standard thresholds)	115.121,3	27.588,7	142.710,1



*Figure 20: Comparison of the water surface areas per biogeographic region in the EU-Hydro (InlandWater, River\_Net\_p, Canals\_p, Ditches\_p, Transit\_p and Coastal\_p), the HRL WaW 2015 (Permanent + Temporary) and the JRC GSW (Permanent + Temporary using the adjusted thresholds).*

Table 16: Water surface area estimated according to the three different products per biogeographic region. For the JRC GSW occurrence layer the figures with adjusted thresholds are presented.

Region	EU-Hydro [km <sup>2</sup> ]	HRL WaW 2015 perm. water [km <sup>2</sup> ]	HRL WaW 2015 temp. water [km <sup>2</sup> ]	HRL WaW 2015 total [km <sup>2</sup> ]	JRC GSW occur. perm. water [km <sup>2</sup> ]	JRC GSW occur. temp. water [km <sup>2</sup> ]	JRC GSW occur. total [km <sup>2</sup> ]
Steppic	1.216,3	917,7	178,2	1.095,8	1.189,9	660,2	1.850,0
Pannonian	2.450,3	1.849,2	253,3	2.102,5	2.000,9	476,9	2.477,8
Mediterranean	15.303,2	6.801,3	2.558,1	9.359,4	10.237,2	2.348,7	12.585,9
Macaronesia	204,6	8,9	3,0	11,9	52,3	10,2	62,5
Continental	19.766,2	13.027,0	1.939,3	14.966,4	14.419,2	2.238,2	16.657,4
Boreal	73.721,9	62.615,1	3.339,9	65.955,0	67.248,8	2.542,3	69.791,0
Black Sea	1.487,1	952,3	234,8	1.187,1	1.243,6	350,0	1.593,6
Atlantic	20.953,1	10.830,9	1.424,2	12.255,1	12.082,3	1.122,5	13.204,8
Arctic	3.575,9	1.918,2	1.075,0	2.993,2	2.125,9	9,8	2.135,7
Anatolian	10.346,2	8.594,1	1.069,9	9.664,0	10.227,8	1.084,4	11.312,2
Alpine	22.970,5	17.091,5	2.201,3	19.292,8	18.266,9	631,2	18.898,1

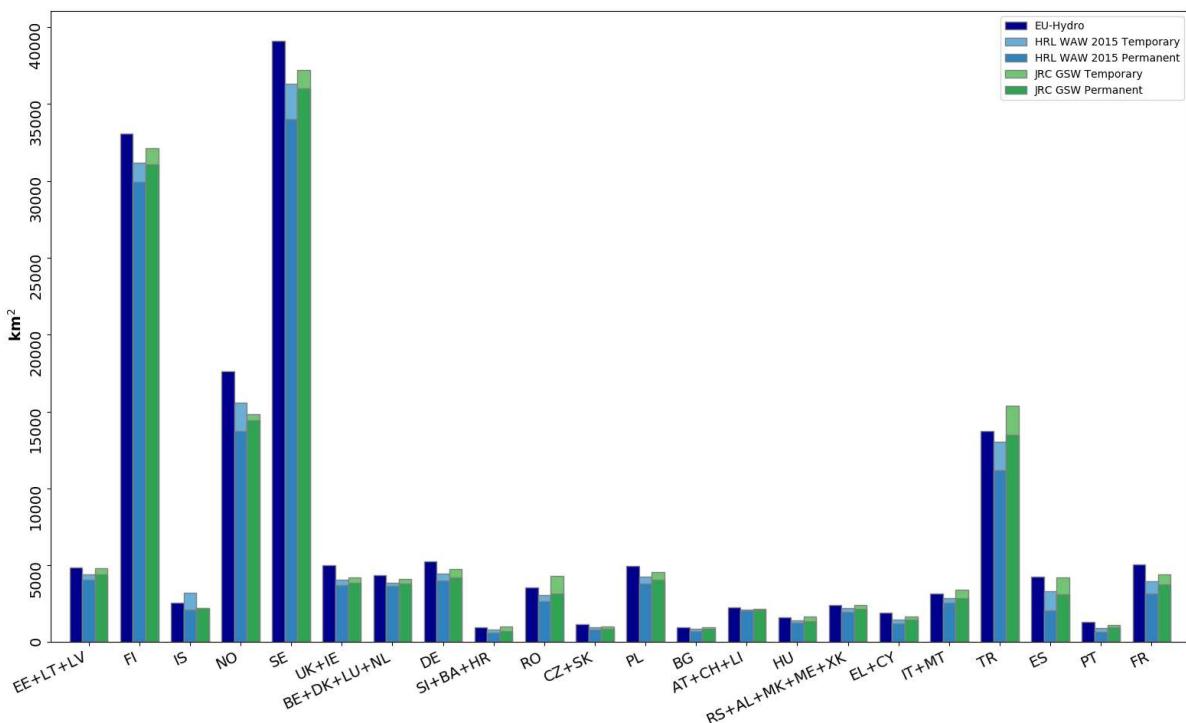


Figure 21: Comparison of the water surface areas per reporting unit in the EU-Hydro (InlandWater, River\_Net\_p, Canals\_p, Ditches\_p, Transit\_p and Coastal\_p), the HRL WaW 2015 (Permanent + Temporary) and the JRC GSW (Permanent + Temporary using the adjusted thresholds).

Table 17: Water surface area estimated according to the three different products per reporting unit. For the JRC GSW occurrence layer the figures with adjusted thresholds are presented.

Region	EU-Hydro [km <sup>2</sup> ]	HRL WaW	HRL WaW	HRL WaW	JRC GSW	JRC GSW	JRC GSW
		2015	2015	2015 total	occur. perm.	occur. temp.	occur. water
		perm. water [km <sup>2</sup> ]	temp. water [km <sup>2</sup> ]	[km <sup>2</sup> ]	[km <sup>2</sup> ]	[km <sup>2</sup> ]	[km <sup>2</sup> ]
EE+LT+LV	4.843,2	4.078,4	328,2	4.406,6	4.424,0	404,3	4.828,3
FI	33.058,0	29.935,0	1.219,0	31.154,1	31.064,7	1.077,8	32.142,5
IS	2.539,6	2.096,2	1.122,0	3.218,2	2.201,0	7,5	2.208,4
NO	17.606,4	13.712,3	1.852,4	15.564,7	14.427,0	421,9	14.848,9
SE	39.081,4	34.042,8	2.280,2	36.323,1	36.000,4	1.225,7	37.226,1
UK+IE	5.018,9	3.691,1	389,5	4.080,6	3.858,7	366,8	4.225,5
BE+DK+LU +NL	4.338,3	3.678,6	167,3	3.845,8	3.834,0	275,8	4.109,8
DE	5.274,5	3.995,5	481,0	4.476,5	4.216,1	549,5	4.765,6
SI+BA+HR	959,7	604,1	198,8	803,0	742,9	269,2	1.012,1
RO	3.584,0	2.663,8	419,8	3.083,7	3.161,7	1.135,0	4.296,7
CZ+SK	1.188,0	830,1	139,9	970,0	887,6	123,3	1.010,8
PL	4.976,0	3.799,5	482,1	4.281,6	4.072,5	499,8	4.572,3
BG	990,4	708,2	174,6	882,8	857,8	113,4	971,2
AT+CH+LI	2.241,4	2.040,1	84,3	2.124,4	2.096,9	69,8	2.166,7
HU	1.609,6	1.246,2	163,9	1.410,2	1.355,7	308,3	1.663,9
RS+AL+MK +ME+XK	2.418,8	1.942,7	277,9	2.220,5	2.173,6	250,8	2.424,4
EL+CY	1.892,3	1.234,3	210,0	1.444,3	1.484,3	174,3	1.658,7
IT+MT	3.179,7	2.569,9	301,2	2.871,0	2.846,4	557,6	3.404,0
TR	13.719,8	11.188,5	1.820,9	13.009,4	13.486,7	1.896,8	15.383,6
ES	4.262,7	2.078,1	1.235,1	3.313,2	3.128,9	1.074,3	4.203,1
PT	1.314,9	676,2	260,3	936,4	962,6	153,1	1.115,8
FR	5.076,5	3.171,7	783,9	3.955,6	3.749,5	647,6	4.397,0

## 4. Conclusions and recommendations

This study conducted a detailed comparative analysis of three different water products being the HRL WaW 2015, the JRC GSW occurrence and the EU-Hydro public beta with a particular focus on the delineation of permanent and temporary water surfaces. The analysis is based on an absolute comparison against reference validation samples (including a selective plausibility analysis) to evaluate appropriate cut-off values and to assess the thematic accuracy. Subsequently a relative comparison of the products is focused on a regression analysis between the HRL WWPI 2015 and the JRC GSW occurrence layer as well as the comparison of the water surface areas extracted from the different products.

The results of the precision-recall analyses presented in section 3.1.1, 3.1.2 and 3.1.3 allow to quantify the heterogeneous thresholds with which water bodies are delineated in the three datasets. Adapting the respective cut-off values allows to normalize for those differences as a necessary step towards a fairer comparison of the thematic accuracies. At the pan-European level all products meet the minimum Producer's and User's accuracies for the No Water and the Permanent Water class as defined for the HRL WaW 2015 product, whereas no single product dominates in all categories (Table 18).

*Table 18: Summary of the pan-European User's and Producer's accuracies for No Water, Permanent Water, and Temporary Water for all three products.*

	Prod. Acc. No Water	User Acc. No Water	Prod. Acc. Perm. Water	User. Acc. Perm. Water	Prod. Acc. Temp. Water	User. Acc. Temp. Water
HRL WaW 2015	98,38%	99,03%	88,57%	<b>99,27%</b>	<b>56,60%</b>	<b>80,53%</b>
EU-Hydro	99,75%	<b>99,79%</b>	<b>92,63%</b>	91,51%	N/A	N/A
JRC GSW 2015	<b>99,82%</b>	99,59%	87,29%	92,85%	14,53%	19,10%

While the EU-Hydro provides the most complete coverage of surface waters, it also tends toward higher commission errors in the permanent water class. Thresholds specifically tailored to the JRC product in turn yield a more conservative map with fewer commission errors. The best User accuracy for the permanent and temporary water classes are achieved with the HRL WaW 2015 layer. Both the mapping and the validation of the temporary water areas is particularly difficult. The low accuracies for the temporary water class obtained from the JRC GSW occurrence product should be interpreted with caution since the adjusted thresholds are not able to fully compensate the different reference periods (2009-2015 vs. 1984-2015). The geographic distribution of the errors is heterogeneous among the different products but a concentration of errors in the Mediterranean (higher temporal dynamics) and Northern Europe and the British Isles (fewer observations due to more cloud cover) emerged as a general pattern.

The relative comparison of the products suggest a close correspondence of the HRL WWPI 2015 and the JRC GSW occurrence even though the observation of wetness is only included in the HRL WWPI 2015. Major deviations generally exist in areas where frequent cloud cover reduces the number of valid observations (e.g. Iceland). The total water surface area is generally highest with the EU-Hydro. Using the standard HRL WaW 2015 thresholds the total surfaces extracted from the JRC GSW occurrence are generally lower than those from the HRL WaW 2015. The opposite is true when the thresholds are adjusted for the JRC GSW occurrence.

The different product specifications (or lack thereof) and target use cases with which the three datasets have been created prohibit a conclusive comparison in terms of high or lower accuracies. While all three products can be used to extract permanent water bodies with excellent accuracies, the exact accuracies ultimately depends on the applied cut-off values. An international standard to define permanent and temporary water bodies (e.g. in terms of water cover percentage of a given time period) would be helpful to simplify not only the comparison of different products but also the comparability of extracted statistics such as surface areas.

In this context it is also noteworthy that none of the three products establishes a physical unit for the mapping of surface water (e.g. percentage of a certain fixed time interval); both the HRL WaW 2015 and the JRC GSW occurrence layer define the percentages only relative to the total of valid observations. Given the repeat pass cycle of the respective satellites and the frequency with which clouds hinder optical observations it should be possible to transform these values to a probability of water being present. The latter could have the advantage of being comparable independently of the particular input satellite imagery and analysis method. Similarly there is currently no explicitly defined cut-off value on the temporal occurrence for the inclusion / exclusion of water surface in the EU-Hydro. The definition of such a cut-off value should be considered for future upgrades of the dataset. This should take into account readily established international standards and other existing water surface products [12]–[14].

Continuous layers as analysed in this study (HRL WWPI 2016, JRC GSW occurrence) are generally useful since they allow to adapt thresholds for specific use cases. This includes specifically lower level analysis layers which provide direct access to the initial observations (e.g. JRC GSW history layers). The HRL WWPI 2015 satisfies this need only partially since it combines the rather distinct phenomena water and wetness, which hinders specific analyses by experts that might be interested in either the one or the other phenomenon.

## Annex 1. Definition of Water and Wetness classes in the HRL WaW Product 2015

Code	Wetness/Water layer	Explanation	Examples
0	No water / no wet area	always <b>dry</b> (dry in at least 75% of all observations)	
1	Permanent water	always <b>water</b> (water in at least 80% of all observations)	<ul style="list-style-type: none"> <li>• Permanent inland lakes (natural)</li> <li>• Artificial ponds (permanent fish ponds, reservoir)</li> <li>• Natural ponds (permanent open water surfaces of inland or coastal wetlands)</li> <li>• Rivers</li> <li>• Channels (permanently with water)</li> <li>• Coastal water surfaces: lagoons, estuaries within the boundaries of the EEA coastline for analysis V2.</li> <li>• Liquid dump sites (permanent)</li> <li>• Water surfaces with floating vegetation where detectable with remote sensing techniques.</li> </ul>
2	Temporary water	alteration of <b>dry</b> and <b>water</b> or alteration of <b>wet</b> and <b>water</b> (water in >25% to 80% of all observations, with varying degrees of wet and dry; water dominates over wet)	<ul style="list-style-type: none"> <li>• Temporary water surfaces associated to permanent water bodies (e.g. oscillating shoreline areas of reservoirs)</li> <li>• Temporary natural (e.g. steppe) lakes and temporary artificial lakes (e.g. cassettes of fishponds)</li> <li>• Intermittent rivers and temporarily flooded river banks</li> <li>• Flood areas</li> <li>• Water-logged areas</li> <li>• Temporary flooded agricultural fields e.g. rice fields</li> <li>• Intertidal areas</li> <li>• Temporarily inundated areas (due to snow melt, floods or rain)</li> </ul>
3	Permanently wet areas (wetness)	always <b>wet</b> (wet in at least ~60% of all observations, region dependent)	<ul style="list-style-type: none"> <li>• Reeds</li> <li>• Peat land</li> <li>• Inland and coastal wetlands (incl. salt marshes)</li> </ul>

4	Temporary wet area (wetness)	alteration of <b>dry</b> and <b>wet</b> (wet in >25% to 60% of all observations, with varying degrees of wet and dry; wet dominates over dry)	<ul style="list-style-type: none"> <li>• Inland saline marshes</li> <li>• Intermittent wetlands</li> <li>• Temporary wet agricultural fields</li> <li>• Temporary wet meadows</li> </ul>
254	unclassifiable	No satellite image available, clouds, shadows, snow and glaciers	
255	Outside production unit	Sea and ocean, land area outside the production unit	

## Annex 2. Relevant class definitions in the EU-Hydro

Feature class	Definition according to [4]
River_Net_p	<ul style="list-style-type: none"> <li>• A naturally flowing watercourse</li> <li>• Rivers wider than 50m</li> </ul>
Canals_p	<ul style="list-style-type: none"> <li>• An artificial waterway with no flow, or a controlled flow, usable or built for navigation.</li> <li>• Canals wider than 50m</li> </ul>
Ditches_p	<ul style="list-style-type: none"> <li>• An artificial waterway with no flow, or a controlled flow, usually smooth, used for draining or irrigating land.</li> <li>• Ditches wider than 50m</li> </ul>
InlandWater	<ul style="list-style-type: none"> <li>• A large body of water entirely surrounded by land.</li> <li>• Width and length must exceed 100m</li> <li>• Minimum size: 1 ha</li> </ul>
Transit_p	<ul style="list-style-type: none"> <li>• Any water the level of which changes periodically due to tidal action</li> </ul>
Coastal_p	<ul style="list-style-type: none"> <li>• Coastlines and shorelines of these feature class are used as additional feature for orientation to attach inland hydrologic features</li> </ul>

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