DATA NOTE

Catchments of German surface water bodies

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Abstract

The European Water Framework Directive demands to assess and report the chemical and ecological status of water bodies (WB). Linking their status to drivers and pressures and deriving suitable mitigation measures require knowledge of the shape and area of WB catchments. We derived a network of 26 570 WB catchments in Germany using the hydrologically-defined drainage basins of the German federal states. We established a network of 338 149 drainage basins. This network underwent plausibility checks and a validation with the catchment areas of 348 monitoring stations across Germany. To this network, we assigned the longest intersecting or the next downstream WB code. To account for geometric inaccuracies we revised spurious intersections resulting in splittings and cycles in the WB network. As WB may be ecologically but not hydrologically well defined, we split them at confluences and intersections. The network of drainage basins matched the monitoring stations with a Nash-Sutcliffe efficiency of 1.00. The final WB network contained 11 005 out of the 11 586 original WBs longer than 1 m. The corresponding local catchment areas range from <<0.0001 to 446 km², with a median of 10 km². The dataset combines the requirements of hydrological and ecological modelling applications at basin or national scales with the needs of the EU reporting which can foster their acceptance by state authorities and river-basin management.

1 | INTRODUCTION

The EU Water Framework Directive (WFD) requires the member states to report the current ecological and chemical status of water bodies (WB) and to assess the compliance with environmental objectives (European Commission, 2000). Despite all efforts, most surface WB in Germany as well as in the EU do not achieve the envisaged ‘good ecological status’, with diffuse emissions of nutrients and pesticides being among the main pressures (BMUB & UBA, 2016; European Environmental Agency, 2018; Lemm et al., 2021).

The stressors originating from these pressures can act at different scales which may require a combination of small- and catchment-scale approaches to improve the ecological status (Lemm et al., 2021). In addition to local WB properties, catchment properties are therefore needed to identify critical source areas and to assess the effectiveness of management options. However, Germany misses a harmonized dataset which connects the requirements for hydrological and other modelling tasks with the requirements for the EU reporting. Accordingly, various catchments were used for German-wide and regional model applications (e.g. Hirt, Kreins, et al., 2012; Hirt, Mahnkopf, et al., 2014). Although digital elevation models (DEM) are often used to derive drainage networks and drainage basins, their accuracy is related to DEM resolution, source and production (Wechsler, 2007), and also depend on site conditions (Yan et al., 2020). To avoid deviations to the complex drainage network consisting of canals, culverts and streams crossing borders, we relied on the drainage basins of the German federal states to derive the WB catchments for regional to national applications.
2 | METHODS

The WB catchments were derived from a network of hydrological drainage basins to which the WB were assigned (WasserBLicK/BfG & Zuständige Behörden der Länder, 2017a, 2017b, 2017c). The drainage polygons had a hierarchical key which the WB polygons (lakes) and polylines (streams) lacked. Maintained by various state authorities, the input data was inconsistent across state borders and revealed different issues with the geometry, the topology and the coding of drainage basins. Thus, establishing the networks required an iterative, semi-manual revision to create an acyclic network of WB without cycles and splittings, that is, nodes with more than one successor. All network analyses were conducted with the Python library NetworkX (Hagberg et al., 2008).

2.1 | Deriving the network of drainage basins

The directed network was obtained from the attributes ‘gewKZ’ (Gewässerkennzahl, ‘water-body code’ which is unrelated to the WB dataset) or, if more detailed, ‘gebKZ’ (Gebietskennzahl, ‘basin code’). These hierarchical numerical codes describe the flow direction within river basins (Länderarbeitsgemeinschaft Wasser, 2005), for example, the river Spree (code 582) is a tributary of r. Havel (code 58), a tributary of r. Elbe (code 5) which eventually discharges into the North Sea.

Implausible and wrong codes hampered the automatic identification of downstream neighbours. The links were manually corrected if the spatial distance was above 500 m and if splittings occurred within the first 1–6 digits (e.g. all drainage basins starting with 5821). The distance threshold accounted for subsurface connection for example, in urban areas or crossing canals. We restricted the revision of splittings to the length of six digits because the number of sub-catchments at this level (46 000) already exceeded the number of WB and splittings became less frequent with seven digits.

During the revision, 118 codes were extended with the pattern '_<letter>' to distinguish disjoint parts of multi-part polygons, albeit not systematically to avoid numerous silver polygons especially along state borders. The final network of 338 149 drainage basins was validated with the reported catchment area \( A \) of 348 stations (Figure 1, Data S1) using the Nash-Sutcliffe efficiency (NSE, Equation (1)). We compared the difference to additional stations near the national border for catchments, which include foreign tributaries. The validation dataset covered areas from 5.6 km\(^2\) to 80 715 km\(^2\) (Interquartile range 265–2246 km\(^2\)).

Image 1 Location and catchment area (in km\(^2\)) of stations used to validate the network of drainage basins (circles). For stations with foreign sub-catchments, the difference to reference stations (squares) was considered

\[
\text{NSE} = 1 - \frac{\sum (A_{\text{reported}} - A_{\text{calculated}})^2}{\sum (A_{\text{reported}} - \bar{A}_{\text{reported}})^2} \quad (1)
\]

2.2 | Assigning the water bodies to the drainage basins

From the 12 001 original river and lake WB, 415 were excluded as being outside the drainage basins or shorter than 1 m (Table 1). River WB within lakes larger than 50 ha, which are relevant for the WFD, were also removed. To distinguish disjoint and intersecting line segments, we created WB segments using the ‘break’ tool of the GRASS GIS command v.clean and extending the WB codes with a unique pattern (Table 2). We assigned the code of the longest segment of the longest WB within a drainage basin to this drainage basin. Drainage basins without intersecting WB were assigned the next downstream WB code. Network splittings due to ditches, crossing canals, inaccurate geometries and deviations between the WB geometry and the flow direction of the drainage basins were resolved by merging or subdividing the extended WB segments (cf. Table 2). In narrow drainage basins at confluences, the tributary WB can be longer than the main river WB. To minimize misleading assignments, we checked for simple cycles of the type A ->B ->A in the network of the original, that is, not extended WB codes.

3 | RESULTS

In total 26 573 WB catchments were derived with local catchment areas (i.e. the assigned drainage basins) ranging from <<0.0001 to 446 km\(^2\), with a median of 10 km\(^2\) (Figure 2). These segments are related to 11 005 WBs, that is, 581 short WBs were neglected due to longer WB. The NSE of 1.00 revealed that the established network of drainage basins is consistent with the monitoring stations. Individual deviations of up to 4.8% (Data S1) can be explained by stations, which are not located at outlets of the assigned drainage basins, small catchment areas, the unknown uncertainty in the official catchment areas and local errors in the network.
Due to the WB segmentation, we avoided the 132 cycles and 277 splittings in the network of the original WB codes. Although three WB segments of the Dortmund Ems canal are missing in the network due to unresolved cycles in the network of drainage basins, the network contains their original WB codes.

4 | OUTLINE OF THE RANGE OF APPLICATIONS IN HYDROLOGY

The network of WB catchments bridges hydrological needs and ecological requirements of the WFD. It can be used to link catchment and in-stream processes to the environmental status of German surface waters. Hydrological and water-quality models can be applied to address impacts of climate change and mitigation measures at scales, which are relevant for water managers and state authorities.

The dataset is compatible to the WB scheme used by the German Federal states as well as the river basin communities. It primarily targets at basin-wide and national model applications. At smaller scales, we advise users to critically verify the catchment areas of WB with additional monitoring stations and to revise the geometry of the underlying drainage basins and the WB assignment, in particular along state and national borders, canals and at confluences. It is noteworthy that 1942 drainage basins along the national border and the coast could not be assigned to any WB. Their area of 7844 km² corresponds to 2.2% of the total drainage area. In addition, drainage basins belonging to canals do not necessarily follow the canal direction, and even flow in opposite directions. This may locally affect the WB network. The WB dataset also inherited the geometric inaccuracies of the drainage basins.

The basic workflow – establishing the network of hydrologically defined units, spatially intersecting these units and WB, deriving the WB network, distributing the WB codes to units without intersections – is generally applicable. It can easily be adapted to other input data and other software tools but may require adjustments to the available datasets and the intended use case. The current network could be improved (a) by integrating more WB which requires subdividing large drainage basins or considering foreign drainage basins, and (b) by considering network splittings at river bifurcations and canals. At the same time, we recommend to eliminate the many extremely short WB.

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| WB type | Code column | Type code | # original | # selected | Criteria |
|---------|-------------|-----------|------------|------------|----------|
| Rivers  | EU_CD_RW    | RW, LW, TW| 10 951     | 10 887     | Outside lakes |
|         | EU_SEG_CD   | RS, LS    | 633        | 573        | Outside lakes, no EU_CD_RW |
| Lakes   | EU_CD_LW    | LW        | 760        | 541        | Lines in areas >50 ha |

TABLE 1 Frequency of water-body (WB) types

| Pattern | Explanation |
|---------|-------------|
| DE_<type>_DE<state>_<sequence> | Original, state-specific WB code, cf. Table 1 |
| <WB code>!!<letters> | WB segments split at intersections |
| <WB code>!!<letters> + <letters> | Aggregated WBs assigned to drainage basins |
| <WB code>!!<letters> + <number> | Split segments, deviating from drainage basins |

TABLE 2 Coding styles for water bodies (WB)

FIGURE 2 Local catchments of the extended water bodies within the river basins as derived from the drainage basins. Each catchment consists of at least one drainage basin. Drainage basins without assigned water-body code are not shown. The total water-body catchments include the upstream local catchments and have to be derived from the network. Extended water bodies may share the same original water-body code.
DATA AVAILABILITY STATEMENT
The dataset can be downloaded from the IGB GeoNode at https://geo.igb-berlin.de/layers/igb_geonode_data:geonode:catchments_of_german_surface_water_bodies. It includes the local WB catchments (cf. Figure 2) and two text files containing the WB network and the WB not assigned to any drainage basin. Please contact the senior author for access to the drainage basins and possible data updates, and to report errors (m.venohr@igb-berlin.de).

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SUPPORTING INFORMATION
Additional supporting information may be found online in the Supporting Information section at the end of this article.

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