Spatial Data for Freshwater Conservation Planning

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This document is written for spatial analysts and conservation planners and intended to provide a quick overview of spatial data and tools available to support freshwater-focused spatial planning in countries and regions where rivers, wetlands, and watersheds have not been mapped at a fine scale or in a format that supports watershed-level analysis for conservation planning. This document is not meant to provide guidance for conservation planning. Many resources exist to guide conservation planning for freshwater ecosystems and biodiversity, including the recently published IUCN Technical Report 'Designing and managing protected and conserved areas to support inland water ecosystems and biodiversity' by Moberg et al. (2024). Several case studies are available in an issue of Freshwater Biology devoted to freshwater conservation planning edited by Turak and Linke (2011). Also note that this guidance describes options for developing a hydrographic analysis framework, specifically river hydrography and watersheds, and does not cover remote sensing applications and platforms for mapping and analysis of wetlands.

Spatial conservation planning seeks to answer fundamental questions of where to direct resources to achieve greatest enduring benefit for biodiversity conservation and local community values, and balance tradeoffs with economic development. These questions include: *What biodiversity, species, and habitats are conservation priorities and/or best represent the area of interest? How much to conserve, or which 30% of the planning geography, to meet 30x30 Global Biodiversity Framework (GBF) targets? Where are species and habitats still intact, or in sufficient condition to withstand future threats? Where are the intersections with socio-cultural values and potential ecosystem service benefits? What configuration of areas will maintain connectivity and ecological processes? What configuration of areas will minimize conflict with economic development?*

Spatial data development to support conservation planning

Effective conservation of freshwater biodiversity and ecosystems must be based on the key ecological attributes of freshwater ecosystems. Therefore, spatial conservation planning ideally includes the following steps.

a. Define and map freshwater ecosystem types – often a biophysical classification or typology of rivers, lakes, and wetlands, based on stream characteristics such as discharge/flow regimes (usually with proxies such as drainage area and climate factors), network position (headwaters streams to large rivers), and stream physical habitat (with proxies such as stream gradient), and watershed characteristics such as hydrogeology, climate, and dominant vegetation. Higgins et al. (2005) developed an approach to classify and map aquatic ecosystems based on zoogeography and abiotic factors that has been applied widely in regional conservation plans. Several case studies describing applications of aquatic ecosystem classifications and environmental surrogates in conservation planning are included in Turak and Linke (2011).
b. Identify focal species, typically native fish, herpetofauna, aquatic megafauna, and/or other endemic and migratory species, and map their distributions. This is always constrained by existing survey data (and sampling bias) and species distribution models. Therefore, conservation planning often employs a coarse-filter (ecosystems and habitat types) / fine-filter (native species distributions) strategy in defining focal biodiversity elements to make best use of existing data to represent multiple levels of organization across species, ecosystems, and ecological processes.
c. Assess ecological connectivity as well as impacts and threats to connectivity. For freshwater ecosystems, ecological connectivity includes longitudinal connectivity across river networks from headwater streams to large rivers, lateral connectivity of the river to its floodplain, and hydrologic connectivity to groundwater. Longitudinal connectivity is essential for migrations, natural flows, other fundamental ecological processes such as sediment and nutrient transport. Lateral connectivity of the river to its floodplain and adjacent riparian ecosystems is critical for exchange of water, sediment, nutrients,

organisms and biotic interactions.

d. Assess freshwater ecological condition based on instream and terrestrial disturbances/threats, considering metrics of upstream land use, population, infrastructure, industrial development, and their cumulative impacts, ideally organized around impacts to individual Key Ecological Attributes (KEAs). For examples, see Thornbrugh et al. (2018), Flotemersch et al. (2016), Khoury et al. (2011), and Heiner et al. (2011).
e. Assess current protections and management status – representation or coverage of freshwater ecosystems and their watersheds in protected areas and other management categories, i.e. local coverage of rivers and wetlands as well as watershed-level protection and management upstream.
f. Assess ongoing and future threats, primarily from economic development, based on development trends and resource potential for mining, energy (petroleum, hydropower, other renewables), forestry, agriculture (including livestock grazing) and agro-forestry, fisheries and aquaculture, as well as urban expansion.
g. Use or develop a spatial data framework to house and analyze the information described above to support conservation planning. Ideally, the framework delineates rivers and their watersheds, supports watershed analysis, and represents longitudinal network connectivity (topology) from headwaters to estuaries.

Spatial data available to support spatial conservation planning

In much of the world, rivers and wetlands have not been mapped accurately or consistently or in a format that allows analysis of watersheds and river networks to support spatial conservation planning. This is true particularly in developing countries that face the dual, compounding challenge of rapid natural resource development and limited biological and biophysical data to support proactive conservation planning and mitigation. Several data sources exist for mapping rivers, wetlands, and watersheds, and these generally fall into three categories: global spatial datasets and databases, hydrographic features delineated with a spatial model, and cartographic features in national and regional maps. Each has advantages and disadvantages as described below, and data development for conservation planning may draw from all three categories. Whether to use existing global datasets or develop finer-scale hydrographic data is largely a project management decision that depends on the project timeline, analysis objectives, and technical capacity of the planning team.

1. **Global datasets** are available in a consistent format across the world and contain a large range of useful attributes including biophysical factors, climate, and land use, and therefore can support global assessments and rapid national and regional assessments. However, river and wetland features in global datasets are typically delineated at a coarse spatial scale and the attributes are derived from globally-available sources, also at a coarse spatial scale, and so have limits in terms of spatial scale and thematic attributes. Notably, estimates of discharge based on global hydro-climatic models are accurate at a coarse, regional scale and have limited use for distinguishing perennial, intermittent, and ephemeral flows of individual rivers, particularly in arid and semi-arid regions. Ideally, a freshwater spatial conservation plan will use or develop spatial data for rivers and wetlands at a scale fine enough to direct wetland protections, and also assess condition and threats with land use data such as mining and energy leases, forest concessions, livestock census units, and water infrastructure. That land use information is typically dynamic, requiring regular updates, and is managed nationally by government agencies and generally not available in global databases. **Table 1** below lists and briefly describes several globally-available datasets for rivers, wetlands, and watersheds.

2. **Hydrographic features** can be delineated with a spatial model at a relatively fine spatial scale. A variety of data sources and tools exist for delineating rivers, wetlands, and watersheds with a spatial flow model similar to that used to produce the global databases, also derived from a hydrologically-conditioned digital elevation model (DEM) but at a finer resolution, typically at 3 arc-seconds resolution (approximately 90m). The

hydrographic features and flow model provide a framework for building a database of biophysical and land use attributes to support conservation planning. However, that data development requires time and capacity. The TNC Global Durable Freshwater Protection team may be able to provide technical advice and assistance with mapping and data development to build a freshwater spatial planning database. **Table 2** below lists several data sources and tools for DEM-derived hydrography. Note that though any DEM can be modified with sink filling functions to delineate hydrographic features, robust hydrologic conditioning (e.g. HydroSHEDS 3 arc-seconds flow surfaces and MERIT Hydro, described below) more accurately preserves the topographic detail of river channels and floodplain wetlands.

3. **Cartographic features** in national and regional maps. These maps exist for most countries, often developed as paper maps through field surveys and aerial photo interpretation, and later digitized and the hydrographic features (rivers, water bodies, and wetland complexes) delineated. Mapping methods and map scale vary, map extents often end at national borders, and the digitized features may contain few or no attributes and do not readily support watershed analysis. However, these cartographic features may be useful references to develop hydrographic spatial models (item #2. above), and may include names of rivers and water bodies that are essential attributes for participatory planning and database development.

Table 1: Global Datasets and Databases

Rivers and watersheds
Whether to use existing global datasets or develop finer-scale hydrographic datasets (Table 2) is largely a project management decision that depends on the project timeline, analysis objectives, and technical capacity of the planning team.

The HydroSHEDS family of data products includes several river databases built on one consistent global river network, watersheds delineated at a range of scales and organized as an interrelated hierarchy of sub-basins, lakes, wetlands, and several other features. These are listed and described below.

HydroSHEDS is a set of gridded flow surfaces (including elevation, hydrologically conditioned elevation, flow directions, and flow accumulation) that support spatial modeling at several resolutions or spatial scales. The intermediate resolution product, at 15 arc-seconds (approx. 450m), is the basis for the global RiverATLAS, GloRiC, and Free-flowing Rivers datasets described below. The finest resolution product, at 3 arc-seconds (approx. 90m), is a useful source for deriving regional and national hydrography as discussed below.

HydroATLAS is a compilation of a wide range of hydro-environmental attributes for rivers, watersheds, and lakes (Linke et al., 2019).

- RiverATLAS, GloRiC, and Free-flowing Rivers are all built on a global river network derived from HydroSHEDS at 15 arc-seconds (approx. 450m). RiverATLAS contains a large database of attributes describing hydrology, physiography, climate, landcover, soils/geology, and anthropogenic factors.
- BasinATLAS is a global watershed hierarchy, also derived from HydroSHEDS at 15 arc-seconds (approx. 450m), and defined by Pfafstetter order.
- LakesATLAS is a global dataset of lakes and attributes describing hydrology, physiography, climate, landcover, soils/geology, and anthropogenic factors.

Free-flowing Rivers is a global river database of connectivity metrics and connectivity status (Grill et al., 2019).

GloRiC is a biophysical rivers classification based on hydrologic, physio-climatic, and geomorphic factors (Ouellet Dallaire et al., 2019).

Hydrologic Derivatives for Modeling and Analysis (HDMA; Verdin, 2017; data download) includes rivers, catchments, flow directions, flow accumulation, slope, and compound topographic index derived at 3 arc-seconds (approximately 90m resolution) from a hybrid of HydroSHEDS (Lehner et al., 2008), GMTED2010 (Danielson and Gesch, 2011), and SRTM (Farr and Kobrick, 2000). The vector river lines only include large rivers with catchments larger than 250 sq.km. The structure of the database is modeled on the Hydro1k database (Verdin and Jenson, 1996). This was developed to support continental scale modeling and analysis.

Rivers and Water Resource Zones (Yan et al., 2019; data download) is derived from SRTM and ASTER GDEM V2 DEM data at 3 arc-seconds (approximately 90m resolution) and manually-delineated large river lines to improve accuracy, but includes only large rivers with drainage basins larger than 100 sq.km., and a simple four-level hierarchy of watershed size classes, and does not include flow directions. This was developed to support global, broad-scale hydrological modeling.

Wetlands and waterbodies *(not comprehensive)*

Multiple global wetlands datasets exist, derived from different sources with different methods, and with varying typology and attributes. Several are listed below. Planning teams should review and assess each dataset to choose which datasets and which features are most accurate and relevant for their work.

Global Wetlands with Fine Classification System at 30m resolution (GWL_FCS30; data download) by Zhang et al. (2024) maps eight wetland types (permanent water, swamp, marsh, flooded flat, saline, mangrove forest, salt marsh and tidal flat) at 30m resolution by combining multiple global wetland products and a remote sensing time-series (Landsat and Sentinel-1 SAR).

Global Lakes and Wetlands Database (GLWD v2) is a global map of inland surface waters classified as 33 waterbody and wetland types (distinguishing riverine, lacustrine, palustrine types) at a raster resolution of 450m, created by harmonizing the best available ground- and satellite-based data sources. This was first developed in 2004 and recently updated as version 2 (Lehner et al., *in prep;* data download). This is part of the HydroSHEDS family of hydro-environmental data products described above. Like all global datasets, the map scale is coarse (resolution is 450m) and so generally over-estimates wetland area extent, particularly in arid regions.

Several other global wetlands datasets include CIFOR-SWAMP Global Wetlands V3 (Gumbricht et al., 2017a; 2017b; data download; web app), Multi-source global wetland maps combining surface water imagery and groundwater constraints (Tootchi et al., 2019; data download), and Global non-floodplain wetlands (Lane et al., 2023; data download). Note that these were developed for global analysis and generally over-represent the area extent of wetlands.

Surface water extent and flooding dynamics may also be useful to map or model the location, extent, and type of water bodies and wetlands at a relatively high resolution. Several global compilations of surface water data are available, including the following.

- GLAD global surface water dynamics developed by the University of Maryland (Pickens et al., 2020; data download)
- Global river flood hazard maps developed by the developed by the European Commission Joint Research Centre (Baugh et al, in prep; data download)
- Global Surface Water (GSW) developed by the European Commission Joint Research Centre (Pekel et al., 2016; data download)

- Copernicus Global Land Service has produced global land cover products at 100m resolution (collection 3, 2019) that include cover fraction of permanent and seasonal water (Buchhorn et al., 2020; data download)

Table 2: Data sources for mapping fine-scale hydrographic features with a DEM-derived flow model

HydroSHEDS (version 1) DEM-derived flow surfaces (Lehner et al., 2008; data download). This is the finest-resolution set of HydroSHEDS gridded flow products, at 3 arc-seconds (approx. 90m), and includes the hydrologically conditioned DEM and flow directions. This has been widely applied and tested to derive river networks and watersheds. Note that HydroSHEDS version 2, derived from TanDEM-X 12m, is expected later in 2024 with significant improvement in scale and accuracy, and may become the gold standard for DEM-derived hydrography and topographic flow models.

MERIT Hydro (Yamazaki et al., 2019; data download) is also a set of gridded flow surfaces at 3 arc-seconds (approx. 90m) derived from SRTM3 (Farr et al., 2007) and ALOS PRISM DEMs (Tadono et al., 2016) using a new method of hydrological conditioning and flow delineation with improvement in accuracy of derived river lines and other topographic features.

References

Buchhorn, M., Lesiv, M., Tsendbazar, N.E., Herold, M., Bertels, L. and Smets, B., 2020. Copernicus global land cover layers—collection 2. Remote Sensing, 12(6), p.1044.

Danielson, J.J., and Gesch, D.B., 2011, Global Multi-resolution Terrain Elevation Data 2010 (GMTED2010): U.S. Geological Survey Open-File Report 2011–1073, 26 p.

Farr, T.G., and Kobrick, M., 2000, Shuttle radar topography mission produces a wealth of data: Eos, Transactions, American Geophysical Union, v. 81, no. 48, p. 583–585.

Flotemersch, J.E., Leibowitz, S.G., Hill, R.A., Stoddard, J.L., Thoms, M.C. and Tharme, R.E., 2016. A watershed integrity definition and assessment approach to support strategic management of watersheds. River Research and Applications, 32(7), pp.1654-1671. (available online).

Gumbricht T, Roman-Cuesta RM, Verchot L, Herold M, Wittmann F, Householder E, Herold N, Murdiyarso D (2017a) An expert system model for mapping tropical wetlands and peatlands reveals South America as the largest contributor. Global Change Biology 23, 3581–3599. doi:10.1111/gcb.13689

Gumbricht T, Román-Cuesta RM, Verchot LV, Herold M, Wittmann F, Householder E, Herold N, Murdiyarso D (2017b) Tropical and subtropical wetlands distribution version 2. (Center for International Forestry Research, CIFOR)

Grill, G., Lehner, B., Thieme, M., Geenen, B., Tickner, D., Antonelli, F., Babu, S., Borrelli, P., Cheng, L., Crochetiere, H. and Ehalt Macedo, H., 2019. Mapping the world's free-flowing rivers. Nature, 569(7755), pp.215-221 (available online).

Heiner, M., Higgins, J., Li, X. and Baker, B., 2011. Identifying freshwater conservation priorities in the Upper Yangtze River Basin. Freshwater Biology, 56(1), pp.89-105 (available online).

Higgins, J. V., Bryer, M. T., Khoury, M. L., & Fitzhugh, T. W. (2005). A freshwater classification approach for biodiversity conservation planning. Conservation Biology, 19(2), 432-445 (available online).

Khoury, M., Higgins, J. and Weitzell, R.O.Y., 2011. A freshwater conservation assessment of the Upper Mississippi River basin using a coarse-and fine-filter approach. Freshwater Biology, 56(1), pp.162-179 (available online).

Lane, C.R., D'Amico, E., Christensen, J.R., Golden, H.E., Wu, Q. and Rajib, A., 2023. Mapping global non-floodplain wetlands. Earth System Science Data Discussions, 2023, pp.1-61.

Lehner, B., Verdin, K. and Jarvis, A., 2008. New global hydrography derived from spaceborne elevation data. Eos, Transactions American Geophysical Union, 89(10), pp.93-94.

Lehner, B., Anand, M., Fluet-Chouinard, E., Tan, F., Aires, F., Allen, G.H., Bousquet, P., Canadell, J.G., Davidson, N., Finlayson, C.M., Gumbricht, T., Hilarides, L., Hugelius, G., Jackson, R.B., Korver, M.C., McIntyre, P.B., Matthews, E., Nagy, S., Olefeldt, D., Pavelsky, T., Pekel, J.-F., Poulter, B., Prigent, C., Wang, J., Worthington, T.A., Yamazaki, D., Thieme, M. (in preparation). Mapping the world's inland waters: an update to the Global Lakes and Wetlands Database (GLWD v2).

Linke, S., Lehner, B., Ouellet Dallaire, C., Ariwi, J., Grill, G., Anand, M., Beames, P., Burchard-Levine, V., Maxwell, S., Moidu, H. and Tan, F., 2019. Global hydro-environmental sub-basin and river reach characteristics at high spatial resolution. Scientific data, 6(1), p.283.

Moberg, T., Abell, R., Dudley, N., Harrison, I., Kang, S., Rocha Loures, F., Shahbol, N., Thieme, M., & Timmins, H.L. (2024). Designing and managing protected and conserved areas to support inland water ecosystems and biodiversity. IUCN WCPA Technical Report Series No. 8. IUCN (available online).

Ouellet Dallaire, C.O., Lehner, B., Sayre, R. and Thieme, M., 2019. A multidisciplinary framework to derive global river reach classifications at high spatial resolution. Environmental Research Letters, 14(2), p.024003 (available online).

Pekel, J., Cottam, A., Gorelick, N., Belward, A.S. High-resolution mapping of global surface water and its long-term changes. Nature 540, 418-422 (2016). (doi:10.1038/nature20584)

Pickens, A.H., Hansen, M.C., Hancher, M., Stehman, S.V., Tyukavina, A., Potapov, P., Marroquin, B. and Sherani, Z., 2020. Mapping and sampling to characterize global inland water dynamics from 1999 to 2018 with full Landsat time-series. Remote Sensing of Environment, 243, p.111792.

Tadono, T., Nagai, H., Ishida, H., Oda, F., Naito, S., Minakawa, K., & Iwamoto, H. (2016). Generation of the 30 M-MESH global digital surface model by ALOS PRISM. International Archives of the Photogrammetry. Remote Sensing & Spatial Information Sciences, XLI-B4, 157–162. https://doi.org/10.5194/isprsarchives-XLI-B4-157-2016

Thornbrugh, D.J., Leibowitz, S.G., Hill, R.A., Weber, M.H., Johnson, Z.C., Olsen, A.R., Flotemersch, J.E., Stoddard, J.L. and Peck, D.V., 2018. Mapping watershed integrity for the conterminous United States. Ecological indicators, 85, pp.1133-1148. (available online).

Tootchi, A., Jost, A. and Ducharne, A., 2019. Multi-source global wetland maps combining surface water imagery and groundwater constraints. Earth System Science Data, 11(1), pp.189-220 (available online).

Turak, E. and Linke, S. 2011. Freshwater biodiversity and conservation planning: an introduction. Freshwater Biology, 56(1), pp.1-5 (available online).

Verdin, K.L., 2017. Hydrologic Derivatives for Modeling and Analysis—A new global high-resolution database (No. 1053). US Geological Survey.

Verdin, K.L., and Jenson, S.K., 1996, Development of continental scale DEMs and extraction of hydrographic features, in Third International Conference/Workshop on Integrating GIS and Environmental Modeling, Santa Fe, N. Mex., January 21–26, 1996, Proceedings [CD-ROM]: Santa Barbara, Calif., National Center for Geographic Information and Analysis, p. 397–402.

Yamazaki, D., Ikeshima, D., Sosa, J., Bates, P.D., Allen, G.H. and Pavelsky, T.M., 2019. MERIT Hydro: A high-resolution global hydrography map based on latest topography dataset. Water Resources Research, 55(6), pp.5053-5073.

Yan, D., Wang, K., Qin, T., Weng, B., Wang, H., Bi, W., Li, X., Li, M., Lv, Z., Liu, F. and He, S., 2019. A data set of global river networks and corresponding water resources zones divisions. Scientific data, 6(1), p.219.

Zhang, X., Liu, L., Zhao, T., Wang, J., Liu, W. and Chen, X., 2024. Global annual wetland dataset at 30 m with a fine classification system from 2000 to 2022. Scientific Data, 11(1), p.310 (available online).