International Water Management Institute

186

Research Report

Towards the Harmonization of Global Environmental Flow Estimates: Comparing the Global Environmental Flow Information System (GEFIS) with Country Data

Nishadi Eriyagama, Mathis Loïc Messager, Chris Dickens, Rebecca Tharme and Retha Stassen

Research Reports

The publications in this series cover a wide range of subjects—from computer modeling to experience with water user associations—and vary in content from directly applicable research to more basic studies, on which applied work ultimately depends. Some research reports are narrowly focused, analytical and detailed empirical studies; others are wide-ranging and synthetic overviews of generic problems.

Although most of the reports are published by IWMI staff and their collaborators, we welcome contributions from others. Each report is reviewed internally by IWMI staff, and by external reviewers. The reports are published and distributed both in hard copy and electronically (www.iwmi.org) and where possible all data and analyses will be available as separate downloadable files. Reports may be copied freely and cited with due acknowledgment.

About IWMI

The International Water Management Institute (IWMI) is an international, research-for-development organization that works with governments, civil society and the private sector to solve water problems in developing countries and scale up solutions. Through partnership, IWMI combines research on the sustainable use of water and land resources, knowledge services and products with capacity strengthening, dialogue and policy analysis to support implementation of water management solutions for agriculture, ecosystems, climate change and inclusive economic growth. Headquartered in Colombo, Sri Lanka, IWMI is a CGIAR Research Center with offices in 15 countries and a global network of scientists operating in more than 55 countries. www.iwmi.org

IWMI Research Report 186

Towards the Harmonization of Global Environmental Flow Estimates: Comparing the Global Environmental Flow Information System (GEFIS) with Country Data

Nishadi Eriyagama, Mathis Loïc Messager, Chris Dickens, Rebecca Tharme and Retha Stassen

International Water Management Institute (IWMI)
P. O. Box 2075, Colombo, Sri Lanka

The authors:

Nishadi Eriyagama, Regional Researcher, International Water Management Institute (IWMI), Colombo, Sri Lanka.
Mathis Loïc Messager, PhD student in ecohydrology, Department of Geography, McGill University, Montréal, Quebec, Canada, and RiverLY Research Unit, National Research Institute for Agriculture, Food and Environment (Institut national de recherche pour l'agriculture, l'alimentation et l'environnement) (INRAE), Centre Lyon-Grenoble Auvergne-Rhône-Alpes, Villeurbanne, France.
Chris Dickens, Principal Researcher, IWMI, Colombo, Sri Lanka.
Rebecca Tharme, Director, Riverfutures, UK, and Adjunct Principal Research Fellow, Australian Rivers Institute, Griffith University, Queensland, Australia.
Retha Stassen, consultant, South Africa.

Eriyagama, N.; Messager, M. L.; Dickens, C.; Tharme, R.; Stassen, R. 2024. *Towards the harmonization of global environmental flow estimates: comparing the Global Environmental Flow Information System (GEFIS) with country data*. Colombo, Sri Lanka: International Water Management Institute (IWMI). 53p. (IWMI Research Report 186). doi: https://doi.org/10.5337/2024.204

/ environmental flows / estimation / information systems / hydrological data / databases / comparisons / assessment / Sustainable Development Goals / Goal 6 Clean water and sanitation / freshwater / water resources / water stress / rivers / stream flow / runoff / aquatic ecosystems / habitats / ecological factors / catchment areas / land cover / drainage area / hydrological modelling / tools / time series analysis / heterogeneity / indicators / indexes /

ISSN 1026-0862
ISBN 978-92-9090-959-0

Please send inquiries and comments to IWMI-Publications@cgiar.org

A free copy of this publication can be downloaded at www.iwmi.org/publications/iwmi-research-reports/

Acknowledgements

The authors would like to acknowledge the contribution of Chandima Subasinghe (formerly GIS/RS Analyst, International Water Management Institute [IWMI], Colombo, Sri Lanka) in the initial processing of spatial data. Colleagues from the Food and Agriculture Organization of the United Nations (FAO), especially Riccardo Biancalani (Project Coordinator, Integrated Monitoring Initiative for SDG 6) and Michela Marinelli (Environmental Analyst, Integrated Monitoring Initiative for SDG 6), are thanked for their support in sending out requests for e-flow data to several countries. The authors are thankful for the e-flow data received from some of these countries, and gratefully acknowledge the willingness of individual practitioners and institutions to share this knowledge. These data were invaluable for the comparative analyses generated. The authors would also like to thank the two anonymous referees for their constructive comments which helped to enhance the quality of this report.

Project

This study was undertaken as part of the *SDG Support for Food Security and Water Resources* project implemented by IWMI. IWMI has been involved in many aspects of the development of the United Nations Sustainable Development Goal (SDG) indicators. The aim of this project was to contribute to the development of SDG Indicator 6.4.2 (level of water stress: freshwater withdrawal as a proportion of available freshwater resources), which includes a component on environmental flows (e-flows).

Collaborators

IWMI International Water Management Institute

International Water Management Institute (IWMI)

McGill

Department of Geography, McGill University, Montréal, Quebec, Canada

INRAE

RiverLY Research Unit, National Research Institute for Agriculture, Food and Environment (Institut national de recherche pour l'agriculture, l'alimentation et l'environnement) (INRAE), Paris, France

Riverfutures

Riverfutures, UK

Griffith University Australian Rivers Institute

Australian Rivers Institute (ARI), Griffith University, Queensland, Australia

Donors

RESEARCH PROGRAM ON Water, Land and Ecosystems

INITIATIVE ON NEXUS Gains

This study was carried out under the CGIAR Research Program on Water, Land and Ecosystems (WLE) and finalized under the CGIAR Initiative on NEXUS Gains, which is grateful for the support of CGIAR Trust Fund contributors (https://www.cgiar.org/funders).

H2O'Lyon Graduate School, Université de Lyon, Villeurbanne, France

In addition to financial support from the CGIAR Initiative on NEXUS Gains, co-author Mathis Loïc Messager's contribution to this study was supported through funding from the H2O'Lyon Graduate School, Université de Lyon (UdL), Villeurbanne, France (Grant Number: ANR-17-EURE-0018).

Contents

Acronyms and Abbreviations

BBM	Building Block Method
CBD	Convention on Biological Diversity
DRIFT	Downstream Response to Imposed Flow Transformation
DWAF	Department of Water Affairs and Forestry, South Africa
EFA	Environmental Flow Assessment
ELOHA	Ecological Limits of Hydrologic Alteration
EMC	Ecological Management Class
FAO	Food and Agriculture Organization of the United Nations
FDC	Flow Duration Curve
GEFC	Global Environmental Flow Calculator
GEFIS	Global Environmental Flow Information System
GRDC	Global Runoff Data Centre
HFR	High Flow Requirement
IBT	Incident Biodiversity Threat
IWMI	International Water Management Institute
LFR	Low Flow Requirement
MAR	Mean Annual Runoff
PHABSIM	Physical Habitat Simulation Model
SDG	Sustainable Development Goal
VNR	Voluntary National Review
WBM	Water Balance Model

Summary

Environmental flows (e-flows) are defined as the quantity, timing and quality of freshwater flows and levels necessary to sustain aquatic ecosystems which, in turn, support human cultures, economies, sustainable livelihoods, and well-being. E-flows have entered the global stage as an important part of sustainable water resources management. They are now recognized as a key component in the estimation of water stress in the United Nations Sustainable Development Goals (SDGs). The source of data used to estimate the e-flow requirement in SDG Indicator 6.4.2 (level of water stress: freshwater withdrawal as a proportion of available freshwater resources) is the Global Environmental Flow Information System (GEFIS), an online tool produced and managed by the International Water Management Institute (IWMI). In addition to the GEFIS estimate, the Food and Agriculture Organization of the United Nations (FAO), as the custodians of the SDG indicator, encourages countries to put forward their locally determined e-flow estimates, especially if it differs from the GEFIS estimate. To date, however, only a few countries have taken up this opportunity.

The aim of this report is to compare e-flows estimated by GEFIS with independent e-flow assessments performed at the local level to gauge the level of agreement between the two sets of estimates. We compared e-flow estimates from GEFIS with local e-flow estimates at 533 river sites. Local e-flow estimates were sourced through formal requests for data, published literature, public governmental reports and research networks. To compare global pixel-based and local estimates, we first aggregated pixel-based GEFIS e-flow estimates upstream of each local assessment site. As expected, the local e-flow assessments—carried out by governmental authorities or academic scientists—were heterogenous in nature due to the variety of methods used, often based on different conceptual approaches. Some methods worked solely with hydrological data, while others incorporated information on ecosystem responses to flow alteration. GEFIS itself relies on methods dominated by hydrology but does include proxies of instream ecosystem condition.

This study reveals that, overall, there is limited agreement between GEFIS estimates and local-level estimates of e-flows (as a percentage of the Mean Annual Runoff [MAR]) determined using other heterogenous methods. This observed divergence for a given site stems from three combined sources of bias and uncertainty: differences between the streamflow estimated from the global hydrological model and the actual natural flow regime of the watercourse estimated for the local assessment, differences between the present-day ecological conditions inferred by GEFIS and the ecological conditions determined by local assessors, and differences between the method used by GEFIS for estimating e-flow requirements and the e-flow determination method used by the local assessment. In addition to these sources of uncertainty at individual sites, the overall divergence between the two sets of estimates is further amplified by the diversity of methods used in local assessments along with the fundamental differences in scale between global and local estimates. Among these sources of uncertainty, we observed a relatively low degree of disagreement between the hydrological data utilized for GEFIS and local assessments. The observed disagreement results from the use of globally modelled flows in GEFIS as opposed to local assessments which are usually reliant on measured flow or flow estimates from hydrological models that are developed more locally. In comparison, the degree of disagreement is much higher between e-flow estimates (as a percentage of MAR) from GEFIS and local assessments. This heightened disagreement may in part stem from the coarseness of the data used in determining the current ecological status of rivers in GEFIS compared to local assessments, and the purely hydrological character of the method used to estimate e-flows in GEFIS.

This report recommends further investigation using a larger global coverage of data to ascertain whether there is greater/lesser agreement between GEFIS estimates and local-level estimates in different world regions, certain sized catchments and under specific land use conditions. Such an approach may enable the ‘calibration’ of GEFIS against, for example, more holistic methods which encompass a wider range of ecological data. The paper also illustrates the need for considering an ensemble of global hydrological models and more comprehensive ecological input in global e-flow models. With such improvements, GEFIS has the potential to evolve into a robust e-flow tool better suited to represent on-ground realities and thus enhance the service that it currently provides in global sustainable development.

Towards the Harmonization of Global Environmental Flow Estimates: Comparing the Global Environmental Flow Information System (GEFIS) with Country Data

Nishadi Eriyagama, Mathis Loïc Messager, Chris Dickens, Rebecca Tharme and Retha Stassen

Introduction

Environmental flows (e-flows) are defined as the quantity, timing and quality of freshwater flows and levels necessary to sustain aquatic ecosystems which, in turn, support human cultures, economies, sustainable livelihoods and well-being (Arthington et al. 2018). The field of e-flows evolved in response to the widespread deterioration of aquatic ecosystems and the accompanying loss of freshwater biodiversity because of anthropogenic changes in hydrological regimes, such as the establishment of water infrastructure (e.g., dams and diversions), water abstractions and land use change (Horne et al. 2017). E-flow science aims to ensure that changes in flow regimes are restricted to 'acceptable' levels to protect and restore aquatic biodiversity, ecological integrity and important ecosystem services that support societal development. This necessitates the assessment of e-flows, i.e., the quantification of the flow regime, as described in the definition above, for a river site, reach or basin.

The Need for Globally Available and Harmonized E-flow Data

With the widespread uptake of e-flow assessment and implementation, it is now understood to be an important part of water resources management; describing the proportion of river flow that needs to be safeguarded. It also provides a quantitative measure against which restoration activities can be assessed. E-flows have already been adopted by the United Nations (UN) 2030 Agenda for Sustainable Development. Indicator 6.4.2 (level of water stress: freshwater withdrawal as a proportion of available freshwater resources) of the Sustainable Development Goals (SDGs) includes a component on e-flows and is recognized as being important for measuring the amount of stress being exerted on water resources, where it defines the amount of water that is not available for allocation to other users. It is also included within the Planetary Boundary approach (Gerten et al. 2013; Steffen et al. 2015) where e-flows provide the boundary for exploitation of water resources from rivers. More recently, it has been recommended as a component indicator of river protection for the Convention on Biological Diversity (CBD) Post-2020 Global Biodiversity Framework (CBD 2021). Since its role as an indicator of the state of river protection is being increasingly recognized, e-flows are likely to be used in many global reports on the state of ecosystems. However, this global adoption of e-flows is predicated on the existence and availability of harmonized data from around the globe. While this is possible with existing global e-flow models based only on hydrology, the consensus is that these data may not be adequate to globally represent the e-flows of river ecosystems where, ideally, some measure of the ecological response to hydrological alteration should be included. At the local level, there are many detailed methods which work with *in situ* biological data (Poff et al. 2017), but generally it is not possible to upscale these to the global level.

Existing approaches to determine e-flows (Tharme 2003; Poff et al. 2017) are commonly grouped into four basic categories which reflect differences in perspective, models and required data: hydrological, hydraulic rating, habitat simulation and holistic methods. As a result, while one e-flow assessment may be based only on hydrological considerations, another may include a holistic representation of the ecosystem that accounts for ecological and social factors. Furthermore, each approach can be carried out with different levels of intensity and data input which will influence the accuracy of the outputs. The result of this heterogeneity in approaches is that the resulting e-flow estimates are variable; they may represent entirely different aspects of the environmental requirement of the ecosystem. Making comparisons between e-flow estimates originating from different approaches and from different countries is, therefore, fraught with difficulty. The harmonization of e-flow estimates across the world has not yet been conceptualized, but its absence can render the merits of using country derived estimates for calculating a global indicator such as SDG Indicator 6.4.2 to be questionable.

There are many advantages of making use of a global model to represent e-flows for each country, because at least the e-flow determination approach is harmonized across the world. Using a single approach increases the comparability of e-flow estimates across countries, and therefore enables a coherent global assessment of SDG Indicator 6.4.2. The deficiencies associated with this revolve around the data used. Most global modelling efforts are based purely on global hydrological data (e.g., Smakhtin and Eriyagama 2008; Pastor et al. 2014; de

Graaf et al. 2019; Liu et al. 2021) but do not incorporate ecological data to assess the existing condition of a river, which is important for setting a target ecological condition and estimating the corresponding e-flow requirement. In contrast, the Global Environmental Flow Information System (GEFIS),[1] an online tool produced and managed by the International Water Management Institute (IWMI), has introduced a desktop-level assessment of the condition of the river ecosystem for the first time, making use of a subset of the Incident Biodiversity Threat (IBT) index of Vörösmarty et al. (2010); this is in addition to global hydrology. Despite this substantial improvement in assessing the ecological condition of rivers, GEFIS remains a hydrological e-flow assessment method, as opposed to approaches that incorporate ecological information on the specific flow requirements of freshwater ecosystems.

Objectives

The purpose of this report is to compare e-flow estimates made using GEFIS with independent site-specific e-flow estimates that have been determined using multiple heterogenous methods at the same locations. It is not possible to evaluate whether a GEFIS-made estimate or a site-specific estimate is a more accurate representation of the real e-flow requirement at a site. However, this study intends to reveal the extent to which GEFIS can be used to represent the global perspective on e-flows. A single national e-flow estimate for the SDG Indicator 6.4.2 is calculated from multiple grid cells in GEFIS. However, site-specific e-flow estimates in this assessment were derived using the underlying data in GEFIS as elaborated in the section *Methods*.

GEFIS and its Role as a Global Approach

GEFIS has its origins in the first global assessment of e-flows by Smakhtin et al. (2004), which presented global maps of annual e-flow requirement for major river basins of the world. The study (Smakhtin et al. 2014) used times series of monthly river discharge (from 1961 to 1990) generated by the WaterGAP2 global hydrology model (Alcamo et al. 2003; Döll et al. 2003) and derived the mean annual e-flow requirement for a 'fair' ecosystem condition for each 0.5° by 0.5° grid cell of the world. The mean annual e-flow requirement was estimated as the sum of a Low Flow Requirement (LFR) and a High Flow Requirement (HFR) (Smakhtin et al. 2004, 309-310). The LFR for a 'fair' condition was the mean monthly discharge with 90% exceedance probability (Q_{90}). The HFR was a flow component varying in magnitude from grid cell to grid cell depending on the ratio between the LFR and the long-term mean annual river discharge of the grid cell. This initial model estimated the total e-flow requirement for a river basin by averaging the requirement for individual grid cells within a basin and was expressed as a percentage of the mean annual river discharge of the basin.

IWMI's Global Environmental Flow Calculator (GEFC)[2] (Smakhtin and Eriyagama 2008) accelerated the 'operationalizing' of global e-flow assessments by introducing a standalone software tool to determine e-flows for major rivers of the world (Figure 1). While the Smakhtin et al. (2004) assessment estimated e-flows to maintain rivers in only a 'fair' ecosystem condition (but without any ecological basis or data), the GEFC estimated e-flows (at a 0.5° spatial resolution) for six ecosystem conditions, named as Ecological Management Classes (EMCs) A to F (Table 1) following the method put forward by Smakhtin and Anputhas (2006). The set of EMCs were based on those described in the South African classification system for water resources (DWAF 1997). Class A denotes a nearly natural condition while Class E is assumed to be a highly degraded condition. The 'fair' ecosystem condition in the Smakhtin et al. (2004) assessment corresponds to 'Class C' in GEFC. The underlying hydrological data in GEFC are monthly time series of river discharge at 0.5° by 0.5° grid resolution, generated by the University of New Hampshire by combining observed river discharge with those generated by their Water Balance Model (WBM) (Fekete et al. 2002).

[1] http://eflows.iwmi.org/ (accessed on December 14, 2021).
[2] https://www.iwmi.cgiar.org/resources/data-and-tools/models-and-software/environmental-flow-calculators/ (accessed on December 14, 2021).

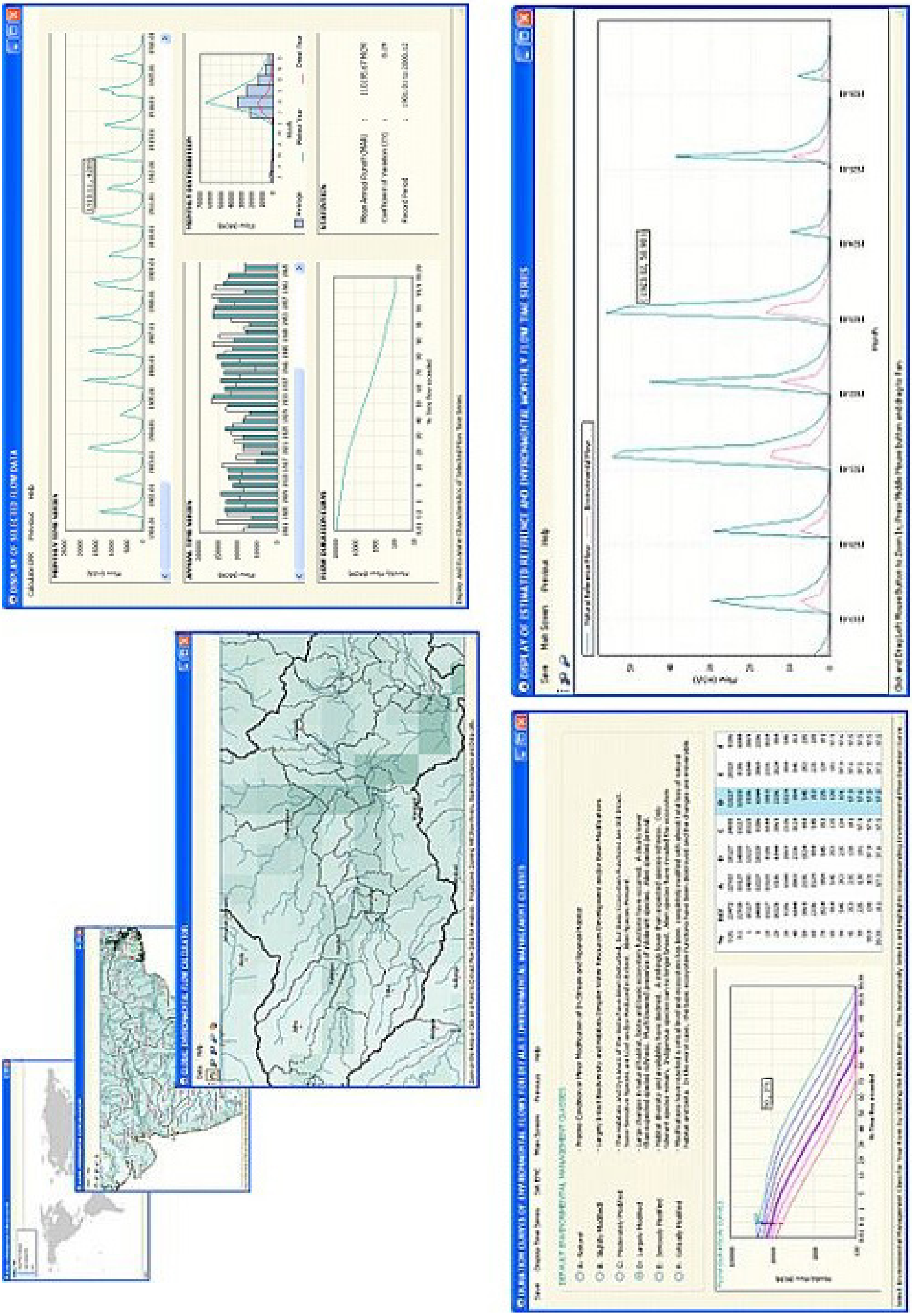


Figure 1. Screenshots showing the user interface of the Global Environmental Flow Calculator (GEFC).

Table 1. Description of Ecological Management Classes (EMCs).

EMC	Most likely ecological condition	Management perspective
A (natural)	Natural rivers with minor modification of in-stream and riparian habitat.	Protected rivers and basins. Reserves and national parks. No new water projects (dams, diversions) allowed.
B (largely natural)	Slightly modified and/or ecologically important rivers with largely intact biodiversity and habitats despite water resources development and/or basin modifications.	Water supply schemes or irrigation development present and/or allowed.
C (moderately modified or 'fair' condition)	The habitats and dynamics of the biota have been disturbed, but basic ecosystem functions are still intact. Some sensitive species are lost and/or reduced in extent. Alien species present.	Multiple disturbances associated with the need for socioeconomic development, e.g., dams, diversions, habitat modification and reduced water quality.
D (largely modified)	Large changes in natural habitat, biota and basic ecosystem functions have occurred. Species richness is lower than expected. Much lowered presence of intolerant species. Alien species prevail.	Significant and clearly visible disturbances associated with basin and water resources development, including dams, diversions, transfers, habitat modification and water quality degradation.
E (seriously modified)	Habitat diversity and availability have declined. A strikingly lower-than-expected species richness. Only tolerant species remain. Alien species have invaded the ecosystem.	High human population density and extensive water resources exploitation. Generally, this status cannot be acceptable as a management goal. Management interventions are necessary to restore flow pattern and to 'move' a river to a higher management category.
F (critically modified)	Modifications have reached a critical level and the ecosystem has been completely modified with almost total loss of natural habitat and biota. In the worst case, the basic ecosystem functions have been destroyed and the changes are irreversible.	This status is not acceptable from the management perspective. Management interventions are necessary to restore flow pattern and river habitats (if still possible/ feasible) to 'move' the river to a higher management category.

Source: From FAO (2019) based on Smakhtin and Eriyagama (2008).

The method developed by Smakhtin and Anputhas (2006) uses natural (i.e., no human interventions such as abstractions, reservoirs and irrigation) monthly flow time series at a particular location as input to generate six other monthly flow time series. These series differ in magnitude but are similar in pattern to the natural flows. The method first estimates a flow duration curve (FDC) from the natural monthly discharge across the period of record. This FDC is then shifted to the left along the horizontal axis, using a simple rule of thumb, to estimate six synthetic flow duration curves that correspond to the recommended environmental flows for EMCs A to F (Figure 2). The 17 percentage categories on the (horizontal) probability axis are 0.01%, 0.1%, 1%, 5%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, 95%, 99%, 99.9% and 99.99%. These categories are used as steps in this shifting procedure and illustrate the entirety of the flow duration curve. A lateral shift of the FDC by one step (a distance between two adjacent percentage categories on the horizontal axis) generates the flow duration curve for the next lower EMC. For example, the flow duration curve for EMC A is determined by shifting the 'natural' flow duration curve to the left along the probability axis from its original position; for EMC B, the flow duration curve is derived by shifting the 'natural' flow duration curve two steps to the left. The unit of shift of the FDC (by one percentage category) to reach the next lower EMC has been inferred partially from literature sources and partially through limited 'calibration' against e-flow estimates obtained by more advanced desktop techniques as described in Smakhtin and Eriyagama (2008). Following this lateral shift, the flow duration curves are subsequently converted to time series of environmental flows using a transformation technique developed by Hughes and Smakhtin (1996) and described in detail in Smakhtin and Eriyagama (2008). The underlying principle in this technique is that flows occurring simultaneously in the 'natural' and 'environmental' flow time series correspond to similar percentage categories on their respective FDCs. This procedure ensures that, while the annual and monthly flow requirements decrease in magnitude when moving from Class A to Class F, the overall shape of the natural yearly hydrograph—significant in aquatic ecosystem maintenance—is still preserved in each e-flow time series. Although the estimation of e-flow requirements corresponding to all six classes is possible, classes E and F are generally considered unacceptable. The method has been illustrated in detail in Smakhtin and Anputhas (2006) and Smakhtin and Eriyagama (2008). The software facilitates the assessment of e-flow requirements corresponding to the six EMCs for any location (grid cell) on a river by considering the total river discharge draining through that location (grid cell), including the discharge from upstream. The GEFC is available for download and has been used for research, capacity building and water resources planning studies, as per software download statistics and journal papers (e.g., Salik et al. 2016).

The most recent iteration in global e-flow assessment tools is the online Global Environmental Flow Information System (GEFIS) (Figure 3), which is described in Sood et al. (2017). GEFIS uses the same assessment method as the GEFC (Smakhtin and Anputhas 2006), but incorporates some significant differences:

i. The hydrological data underlying GEFIS are monthly time series of natural runoff at a spatial resolution of 0.1° (approximately 10 km at the equator, instead of 0.5°) generated by the PCRaster Global Water Balance (PCR-GLOBWB) model Version 2.0 (Wada et al. 2016).

ii. GEFIS incorporates an estimate of the most likely present-day EMC of rivers within each grid cell—a feature not available in GEFC (refer to the section Methods for an explanation of this estimation).

iii. It provides estimates of e-flow requirements for different spatial units including countries, administrative units and river basins by aggregating e-flow requirements for individual grid cells.

iv. GEFIS presents e-flow requirements only for classes A to D since classes E and F are considered as unacceptable ecosystem conditions from a management perspective.

v. In addition to e-flows for classes A to D, GEFIS estimates present-day e-flow requirements, based on the most likely present-day EMC in each cell.

GEFIS has been adopted to provide the global estimation of e-flows that is required for computing SDG Indicator 6.4.2 on water stress (FAO 2019). This water stress indicator offers an estimation of the pressure applied by all economic sectors of a country on its renewable freshwater resources. It is defined as the total freshwater withdrawn (TFWW) by all economic sectors divided by the difference between the total renewable freshwater resources (TRWR) and the environmental flow requirements (EFR), multiplied by 100 (Equation 1). It thus describes how much water is left and available for direct human use in the environment. Both TFWW and TRWR are derived from government statistics or estimates by the Food and Agriculture Organization of the United Nations (FAO).

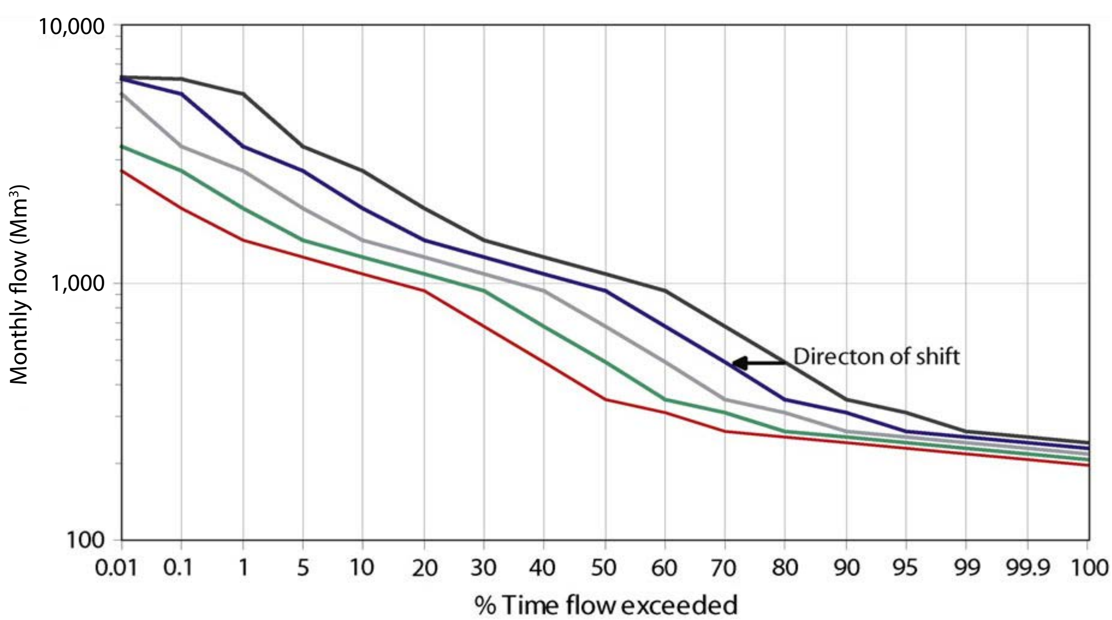


Figure 2. Shifting of the natural flow duration curve to generate environmental flow duration curves. Only classes A to D are shown in the figure while classes E and F considered unacceptable are excluded.

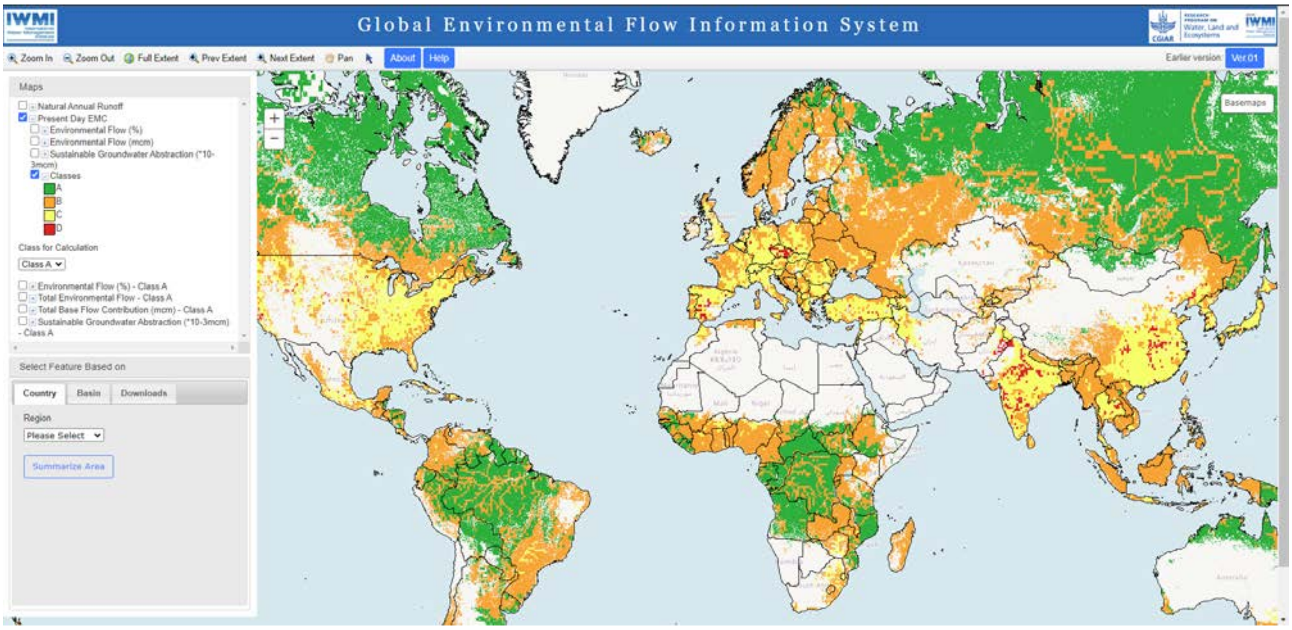


Figure 3. Screenshot of the user interface of the Global Environmental Flow Information System (GEFIS).
Source: http://eflows.iwmi.org
Notes: The grid layer displayed shows the estimated present-day EMC.

$$\textit{Water Stress (\%)} = \textit{TFWW} / (\textit{TRWR} - \textit{EFR}) * 100 \qquad (1)$$

where: the e-flow data are provided by GEFIS for the present-day EMC within each pixel. EFR in Equation (1) is the aggregate e-flow requirement for all pixels within a given country. Water Stress (%) is calculated as a single national figure.

During the periodic data drive by FAO to publish the SDG Indicator 6.4.2 results, country representatives contribute to the global SDG report by being invited to endorse the global data generated by GEFIS for that country. Each country receives the e-flow data from FAO and can lodge comments about its accuracy using the template provided by FAO. Optionally, countries that have conducted e-flow assessments independently may report their own values for country-aggregated e-flows in greater detail and in their preferred data format through Voluntary National Reviews (VNRs). This study sets out to compare the e-flow assessments made by GEFIS against local e-flow assessments carried out within countries.

Cross section survey in progress, Limpopo River, Southern Africa (*photo:* James MacKenzie).

Cross section survey in progress, Limpopo River, Southern Africa (*photo:* James MacKenzie).

A river in Burkina Faso (*photo:* Chris Dickens).

Methods

General Approach

The GEFIS online interface provides global pixel-based estimates of environmental flow requirements at a resolution of 0.1° based on two main data inputs: monthly time series of runoff for natural conditions and the EMC representing the current condition (present-day EMC) of the rivers at that location. The monthly time series of runoff (Wada et al. 2016)—spanning from 1960 to 2010—provides the basis for generating estimates of long-term mean annual runoff (MAR); in million cubic meters per year, 10^6 m^3 yr^{-1}) and mean annual e-flow requirements (as a percentage of MAR, or in 10^6 m^3 yr^{-1}). The present-day EMC is inferred based on a subset of the indicators making up the IBT index (Vörösmarty et al. 2010). The original IBT index integrated 23 individual stressors to human water security and biodiversity organized under four themes (catchment disturbance, pollution, water resource development and biotic factors). A custom IBT index is computed in GEFIS using only the stressors affected by e-flows (included within the 'water resource development' and 'biotic' themes). EMCs are then determined by reclassifying this custom IBT index from a continuous scale (0 to 1) to the ordinal scale from A to E-F where classes E and F are considered to fall into a single category (Table 1) (Sood et al. [2017] describes this reclassification in detail). E-flows for each 0.1° pixel are computed for classes A-D using these two data sources—monthly time series of runoff and the present-day EMC class—based on the method of Smakhtin and Anputhas (2006) as described above. The pixel-based estimates are aggregated to present results for different spatial units. In case the present-day EMC is found to be E or F for a particular pixel, the e-flow requirement for that pixel is calculated as for Class D, since countries are expected to maintain at least the Class D e-flow requirement.

Three combined sources of bias and uncertainty account for the observed divergence when comparing the e-flow estimate from GEFIS to a local e-flow assessment: (i) differences between the streamflow estimated from the global hydrological model and the actual natural flow regime of the watercourse estimated for the local assessment, (ii) differences between the present-day EMC inferred by GEFIS and the EMC determined by local assessors, and (iii) differences between the e-flow estimation method used by GEFIS and the e-flow determination method used by the local assessment.

In this comparison, the role of each of these sources of bias and uncertainty w analyzed in the following manner:

i. We compared the MAR estimates from GEFIS to two other sources of MAR estimates—the local e-flow assessments and WaterGAP v2.2, a widely used global hydrological model (Müller Schmied et al. 2014).

ii. We compared the present-day EMC predicted by GEFIS against the present-day ecological condition category from the local e-flow assessments. We also analyzed the relationship between the EMC assessment undertaken by local assessors and measures of human impact in the catchment of each local e-flow assessment site (based on data from the RiverATLAS database; Linke et al. 2019).

iii. We compared the e-flow estimate from GEFIS with local e-flow assessments in two ways. First, we compared e-flow estimates as a percentage of MAR (i.e., partly removing bias and uncertainty from errors in the global hydrological model), but based on the present-day EMC estimated by GEFIS. Second, we compared e-flow estimates as a percentage of MAR but based on the EMC that best matches the EMC determined by the local e-flow assessment.

This second comparison intends to remove bias and uncertainty, as much as possible, which can arise both from the hydrological model estimates (by comparing percentages rather than absolute water volumes) as well as from the EMC prediction (by using the locally determined EMC). This approach enabled the assessment of divergence in e-flow estimates between GEFIS and local assessments that mostly stem from differences in the e-flow assessment method (Smakhtin and Anputhas [2006], in the case of GEFIS versus, for instance, a holistic method in the case of the local assessment). This study is a *comparison* between GEFIS estimates of e-flow and the local assessments rather than an evaluation of the accuracy of GEFIS. Considering the diversity of methods across the local e-flow assessments in the database, the local e-flow assessments are not deemed to be 'correct' or necessarily any more accurate than GEFIS estimates.

Data Collection and Database Structure

A wide range of countries were contacted at the end of July 2021 with a request to provide a summary of in-country e-flow assessment data. The official request for data was sent out by the Land and Water Division of FAO to contacts in each country to supply data within one month of receipt of the request on a template provided (Annex 1). We also asked other known sources with access to data on in-country e-flow assessments. Countries that were contacted by both channels include Armenia, Brazil, Botswana, Austria, China, Costa Rica, France, Germany, Greece, India, Italy, Kenya, Laos, Mexico, Namibia, Peru, Poland, Russia, South Korea, Senegal, Slovenia, South Africa, Switzerland, Tanzania, USA, Uzbekistan and Vietnam. A general request was also sent to the European Union.

In addition, we incorporated e-flow data previously compiled by the International Water Management Institute (IWMI) into a publicly available database (IWMI's Eco-Hydrological Databases-flow database[3]). This database included data from Australia, Canada, China, France, Hungary, India, Lesotho, Mexico, Slovenia, South Africa, Colombia, Spain, Tanzania, Tunisia and Zambia. The data collection effort aimed to ensure the widest possible distribution across ecoregions as well as climatic zones (e.g., tropical, temperate, wet and dry). All data collected in this manner were harmonized by simplifying or lumping e-flow assessment types and ecological classes into generic categories and were compiled into a master database (Annex 2).

The master database contained information for each data point, i.e., the country, river basin, geographic coordinates, type and name of e-flow assessment method, system to determine ecological condition (such as the EMC system), ecological condition in present day (such as the present-day EMC), natural mean annual runoff (natural MAR), e-flow requirement as a volume, e-flow requirement as a percentage of the natural MAR, and further sources of information on the data. The e-flow assessment methods used in producing the data were classified into five categories (Table 2) adapted from those of Tharme (2003) and Poff et al. (2017).

Table 2. Normalization of the environmental flow assessment method used into five categories.

E-flow method category	Description	Examples
Hydrological: single indices	Hydrological index/indices used as e-flow	Q95, 7-day minimum flow
Hydrological: time series analysis	Hydrological time series analysis using ecologically relevant flow metrics	Indicators of Hydrologic Alteration, South African Desktop Reserve Model
Hydraulic rating	Simple relationship(s) between hydraulic variables and discharge as surrogate for habitat factors	Wetted perimeter, maximum depth
Habitat simulation	Model-based analysis of relationships between quantity and suitability of habitat available for target biota under different discharges	Physical Habitat Simulation Model (PHABSIM)
Holistic/Ecosystem function	Assessment for a site or region considering multiple ecosystem components/processes, involving multidisciplinary experts and field data collection and analysis, culminating in a synthesis workshop where an appropriate e-flow regime(s) is negotiated	Building Block Method (BBM), Downstream Response to Imposed Flow Transformation (DRIFT), PROBFLO, Ecological Limits of Hydrologic Alteration (ELOHA)

Source: Adapted from Tharme 2003 and Poff et al. 2017.

Spatial Pre-processing

The local e-flow assessment records were spatially pre-processed with two objectives: to ascertain the location of the e-flow assessment site (i.e., its geographic coordinates) and to associate each e-flow assessment site with information from GEFIS and ancillary sources of data. To do so, we first verified whether the coordinates provided for each site corresponded to the correct country and river basin. We subsequently co-registered each site to the global baseline hydrographic dataset HydroRIVERS (Linke et al. 2019), a widely used representation of the global river network built on the HydroSHEDS hydrographic database (Lehner et al. 2008; Lehner and Grill 2013). Individual river reaches are delineated on the basis of drainage direction and flow accumulation maps derived from elevation data at a pixel resolution of 3 arc-seconds (~90 m at the equator) and subsequently upscaled to 15 arc-seconds (~500 m at the equator). This co-registration of each site with HydroRIVERS enabled us to ensure that the river network position, upstream drainage area and mean annual runoff (MAR) of the location of the site were consistent with

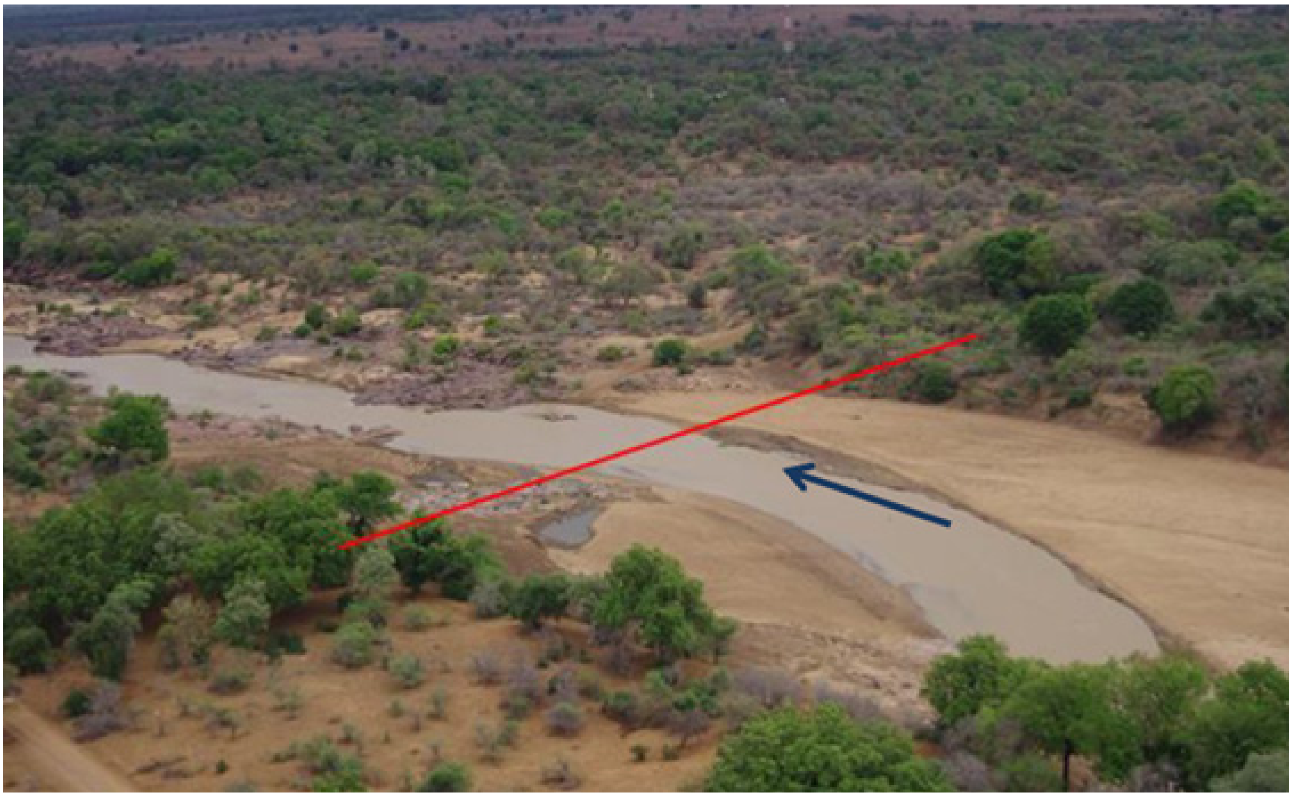
[3] http://waterdata.iwmi.org/applications/efm/efr_home.php (accessed on December 6, 2021).

the attribute information obtained from the local e-flow assessment associated with that site.

The hydrological and e-flow information provided with each record in the local e-flow master database corresponds to the mean annual water volume flowing through a reach or river cross-section from the e-flow site's entire upstream drainage area. By contrast, information in GEFIS is local and pixel-based such that the MAR and e-flow values associated with each pixel correspond to the water volume that is strictly generated from (and flowing out of) that pixel, excluding upstream water inputs. Consequently, to compare information in the master database of local assessments with GEFIS, it was necessary to spatially delineate the upstream drainage area (i.e., catchment) of each site and then aggregate the information from all GEFIS pixels within that area.

We delineated the catchment of individual e-flow sites based on established global flow direction maps at 15 arc-second resolution from HydroSHEDS (Lehner et al. 2008; Lehner and Grill 2013). We then resampled GEFIS data grids for MAR, the custom Incident Biodiversity Threat (IBT) index (on the continuous 0 to 1 scale), the predicted present-day e-flow volume, and the predicted e-flow volume for each EMC (A, B, C and D) from a resolution of 0.1° (~10 km at the equator) to 15 arc-seconds (~500 m at the equator). This resampling enabled us to weigh the relative contribution of coarse pixels to catchments even if a pixel only partially overlapped with a catchment. For instance, if only 10% of the surface area of a 100 km² pixel fell within a catchment, then it would contribute only a tenth of the MAR estimated by GEFIS for that pixel to the site at the outlet point of that catchment. Similarly, the IBT for that pixel would be weighed by a tenth in computing the weighted average index for the catchment.

Finally, we aggregated GEFIS data for each catchment by (i) summing the MAR and predicted e-flow volume for each EMC, and (ii) averaging the IBT of all resampled pixels within the catchment. The resulting aggregated statistics were used in subsequent comparisons between GEFIS, the local e-flow assessments and other ancillary data. It is worth noting that the sum of MAR across all pixels within the upstream drainage area of a site does not exactly equate to estimating the discharge at the site, since it does not account for in-channel transmission losses through evapotranspiration and infiltration during routing through the river network between the upstream pixels and the site. Figure 4 summarizes the project workflow described above.



Cross section for determination of e-flows of the Limpopo River, Southern Africa (*photo:* Bennie van der Waal).

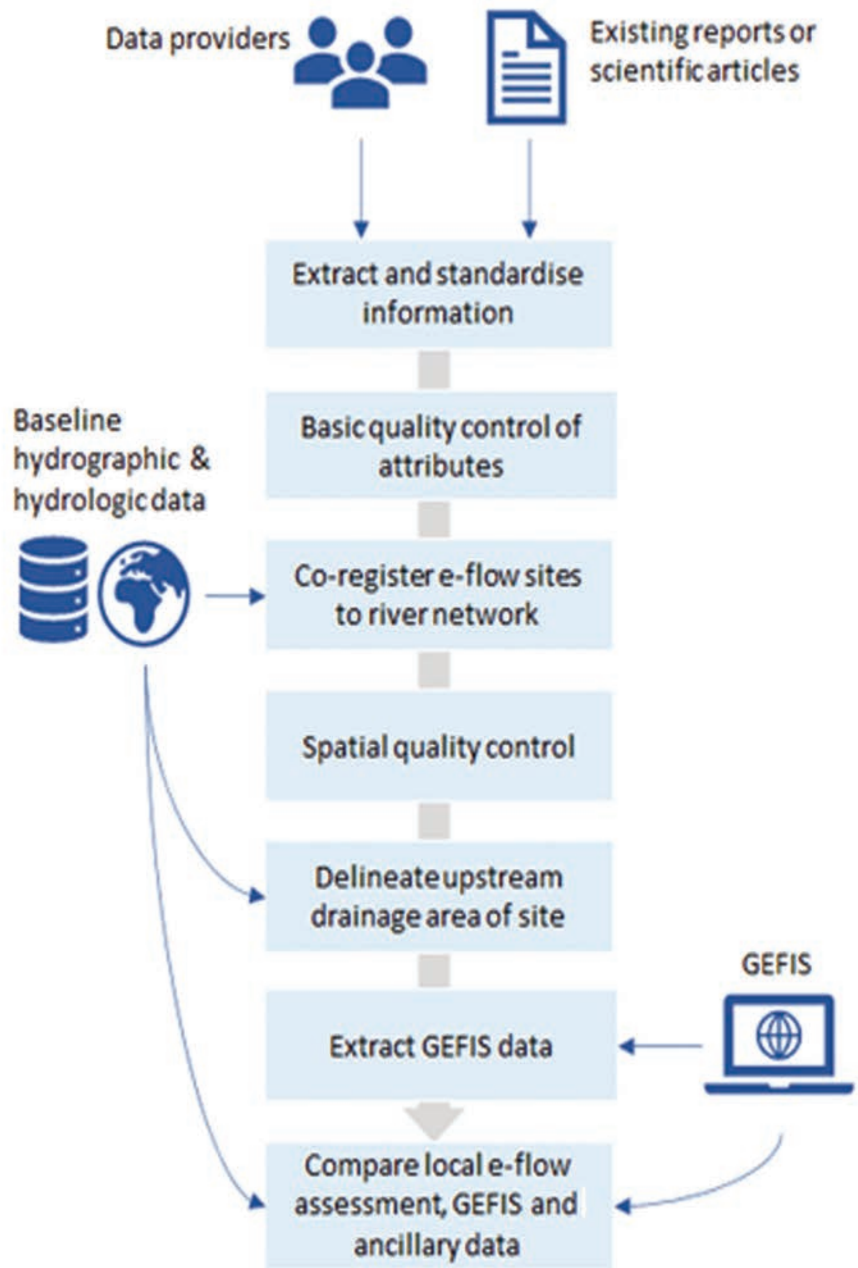


Figure 4. The project workflow.

Hydrological Comparison

We compared the MAR estimate from GEFIS to two other sources of MAR estimates: (i) local e-flow assessment attribute information, and (ii) estimates from another global hydrological model.

For the estimates from the other global hydrological model, we used modelled long-term (1971–2000) mean natural annual discharge estimates associated with each river reach in HydroRIVERS. These estimates are derived through a geospatial downscaling procedure (Lehner and Grill 2013) based on the 0.5° resolution runoff and discharge layers provided by the global WaterGAP model version 2.2 as of 2014 (Alcamo et al. 2003; Müller Schmied et al. 2014). A validation of the downscaled discharge estimates was performed against observations at 2,131 Global Runoff Data Centre (GRDC) gauging stations with ≥20 years of streamflow data (1971–2000) by Messager et al. (2021). Including rivers with mean annual discharge ranging from 0.006 to 180,000 $m^3 s^{-1}$, this assessment showed a strong overall correlation (log-log least-square regression, $R^2 = 0.96$) and a Symmetric Mean Absolute Percentage Error (sMAPE) (see definition below) of 30% between modelled and observed discharge.

To compare MAR estimates across data sources, we computed a set of standard performance statistics, including the Mean Absolute Error (MAE), the Percent BIAS (%BIAS), and the Symmetric Mean Absolute Percentage Error (sMAPE) as shown in the following equations:

$$MAE = \frac{\sum_{i=1}^{N} |\hat{y}_i - y_i|}{N} \quad (2)$$

$$\%BIAS = \frac{100}{N} \sum_{i=1}^{N} \frac{\hat{y}_i - y_i}{y_i} \quad (3)$$

$$sMAPE = \frac{100}{N} \sum_{i=1}^{N} \frac{|\hat{y}_i - y_i|}{(|\hat{y}_i| + |y_i|)/2} \quad (4)$$

where: y_i is the reference value (e.g., MAR reported by the local assessment) and $\hat{y}_i$ is the comparison value (e.g., MAR estimated by GEFIS).

We also computed the coefficient of determination (R^2) of linear least-square regressions between the sources of MAR estimates, with and without outliers (excluded based on studentized residuals larger than three standard deviations).

Management Class Comparison

The EMC of a site relates to the current or desired condition of a river and is perceived as a scenario of the ecological state of a river (Sood et al. 2017). In GEFIS, the lower the Incident Biodiversity Threat Index, the less modified the river, the higher the EMC (e.g., A versus B), and higher the e-flow prescription for that river. To understand how the EMC inferred by GEFIS relates to the EMC determined by local e-flow assessments, we investigated whether there are significant differences in IBT (corresponding to the present-day EMC in GEFIS) between sites with different locally-determined EMC. We first conducted an ANalysis Of VAriance (ANOVA) test followed by Tukey's Honestly Significant Difference (HSD; Tukey 1949) test to assess, for each pair of EMCs (e.g., A vs. B), whether EMCs determined by local assessments differed in terms of the mean IBT within their catchment. In this analysis, we assumed the EMC provided with local e-flow assessments to correspond to present-day conditions, unless otherwise specified.

To examine the factors determining the EMCs identified by local assessments, we also related the locally determined EMCs to various continuous indicators of anthropogenic stressors on ecosystems associated with each river reach in HydroRIVERS. We obtained these indicators from the RiverATLAS database, version 1.0 (Linke et al. 2019). The database provides hydro-environmental information for all rivers of the world, both within their contributing local reach catchment and across the entire upstream drainage area of every reach. We assessed the differences among sites in different EMCs on the basis of the characteristics of their catchment in terms of area used for crops and pasture (Ramankutty and Foley 1999), urban land covers (Pesaresi et al. 2016), area equipped for irrigation (Siebert et al. 2015) and population density (CIESIN 2016). We also compared the degree of regulation (the percent ratio between the total reservoir storage volume of all dams on or upstream of the site and the total annual discharge volume available at the site; Lehner et al. 2011) among sites from different EMCs. Although the GEFIS presents results only for classes A to D, the management class comparison nevertheless included Class E rivers to obtain better knowledge of differences between classes.

Assessing the Impact of Masking

Regions with 'negligible streamflow' (Vörösmarty et al. 2010; Sood et al. 2017) were omitted in the production of GEFIS by deploying two separate masks (Figure 5). The first mask, applied by Sood et al. (2017) to the MAR grid and the grids of estimated e-flow for each EMC, excludes all open water bodies and areas with land covers associated with arid and semi-arid climates. It was applied by first aggregating the GlobCover 2009 land cover dataset (Arino et al. 2012) from a resolution of ~300 m to ~10 km and excluding the following land cover categories: 'bare areas', 'water bodies', 'permanent snow and ice', 'closed to open grassland', 'closed to open shrubland' (for North America and South America) and 'sparse vegetation' (for Africa and Australia). This mask results in the exclusion of 34% of global land area (exclusive of Greenland and Antarctica).

In conjunction with the first mask, a second mask which affects the grids of present-day EMC and the estimated present-day e-flow in GEFIS was also applied. This exclusion mask encompasses areas originally excluded in the IBT—all 0.5° pixels (~50 km at the equator) for which the average annual runoff of upstream cells is <10 mm in Vörösmarty et al. (2010). Finally, a large portion of 0.5° pixels along coastal areas have also been excluded. Altogether, 42% of global land area (exclusive of Greenland and Antarctica) is excluded from the grids of present-day EMC and the estimated present-day e-flow.

We evaluated the impact of these exclusion masks on the GEFIS predictions for MAR, present-day EMC, and the corresponding estimate of present-day e-flow by relating the percentage of the catchment that is masked out to the percentage difference in the variable of interest between GEFIS predictions and local e-flow assessments. Greater differences were expected to be observed for sites for which a higher proportion of the catchment is masked out.

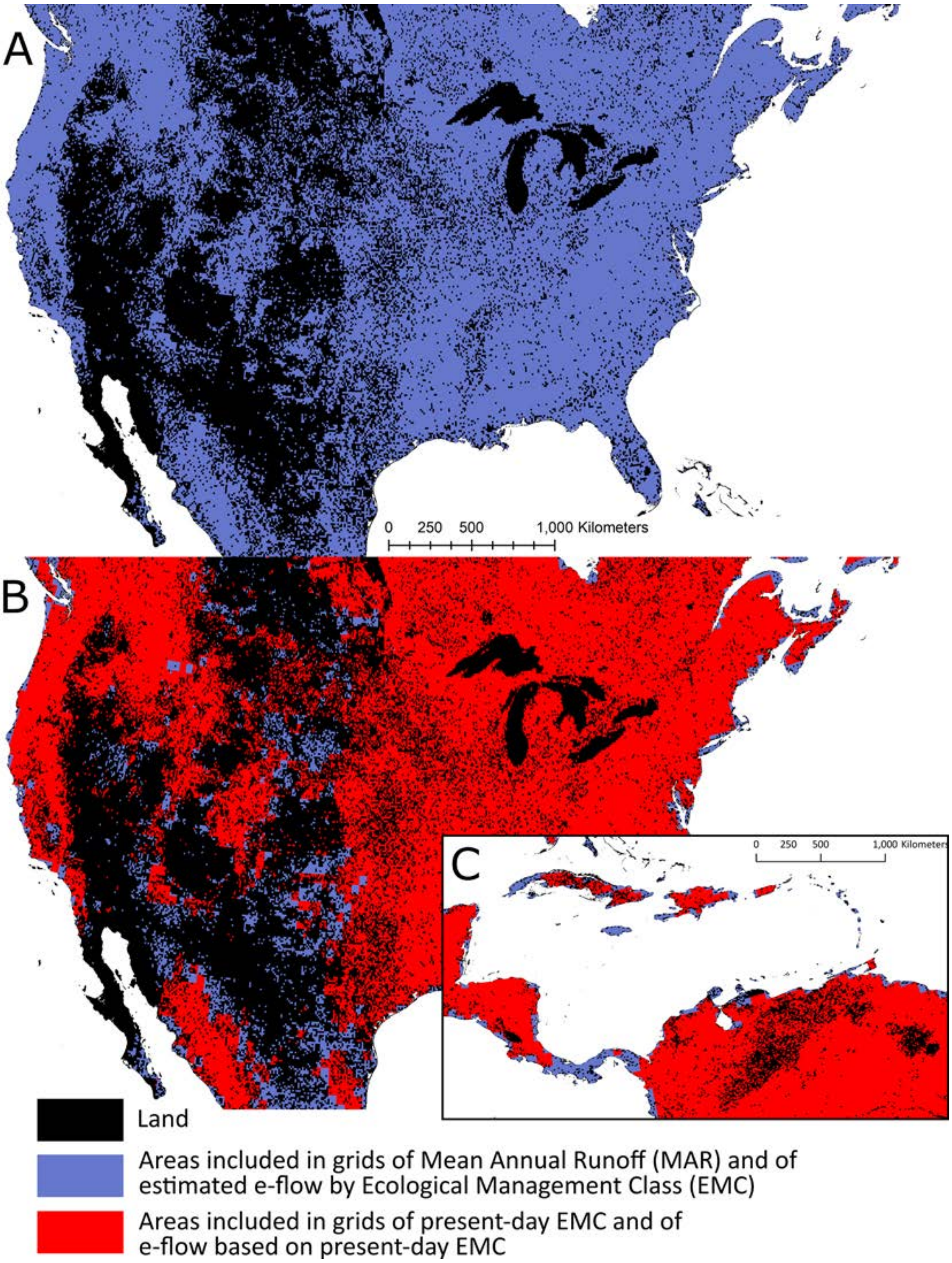


Figure 5. Example maps showing exclusion masks implemented in GEFIS.

Notes: Panel A shows the first mask, which affects grids of Mean Annual Runoff (MAR) and of estimated e-flow by Ecological Management Class (EMC); Panel B shows the second mask, which affects grids of present-day EMC and e-flow based on present-day EMC, overlaid on the first mask; Panel C illustrates the exclusion of many coastal areas such as Panama, by the second mask.

Environmental Flow Comparison

We compared e-flow estimates between GEFIS and local assessments (i) as a percentage of MAR based on the present-day EMC inferred by GEFIS, and (ii) as a percentage of MAR based on the EMC determined by the local e-flow assessment. Comparisons were performed separately by the method of local e-flow assessment (e.g., hydrological time series analysis versus holistic). For each comparison, the same set of standard performance statistics were computed as in the comparison between MARs. For sites where e-flow estimates exist for multiple ecological classes but no class is explicitly designated as the present-day conditions, a range of performance statistics were computed. For this analysis, we included only those sites for which less than 70% of the catchment is masked out.

Kazinga Channel linking Lakes George and Edward, Uganda (*photo:* Chris Dickens).

Danube River in Hungary (*photo:* Chris Dickens).

Results

Overview of the Database of E-flow Assessments

A total of 651 local environmental flow assessments (EFAs) were compiled and formatted into the master database by November 2021. Of these, 611 assessments were associated with 533 unique assessment sites distributed across 27 countries (Figure 6). Some sites were associated with multiple assessments because e-flow requirements are commonly determined for several water use scenarios and/or have been adapted or reassessed over time.

Most local e-flow assessment sites (86%) included in this analysis are either located in South Africa (302 sites) or in the province of Quebec in Canada (154 sites). Consequently, while the sites represent a wide range of environmental conditions, they are only partially representative of the global river network (Figure 7). Most sites are located on medium-sized rivers (median catchment area = 1,820 km^2; median MAR = 10 m^3 s^{-1}) with a few located on small rivers and streams draining less than 100 km^2. On average, the sites drain moderately populated catchments (average population density = 68 people km^{-2}) with a range of forest conditions (average and standard deviation of forest extent: 52±34% of catchment area) but limited agricultural activity (average cropland land cover: 13% of catchment area) and urban influence (average urban extent: 3% of catchment area). Sites for which more than half of the catchment lies within protected areas only account for 9% of the dataset, with most sites (65%) draining unprotected catchments (<10% of the protected area). Lastly, over a third of the sites are regulated by upstream reservoirs with total volume being at least 10% of the mean annual runoff.

Figure 6. Distribution of the local environmental flow assessment sites included in the analysis (n=533).

Notes: The size of the circles is proportional to the number of e-flow assessment (EFA) sites within 1,000 km of the geographic center of the circle.

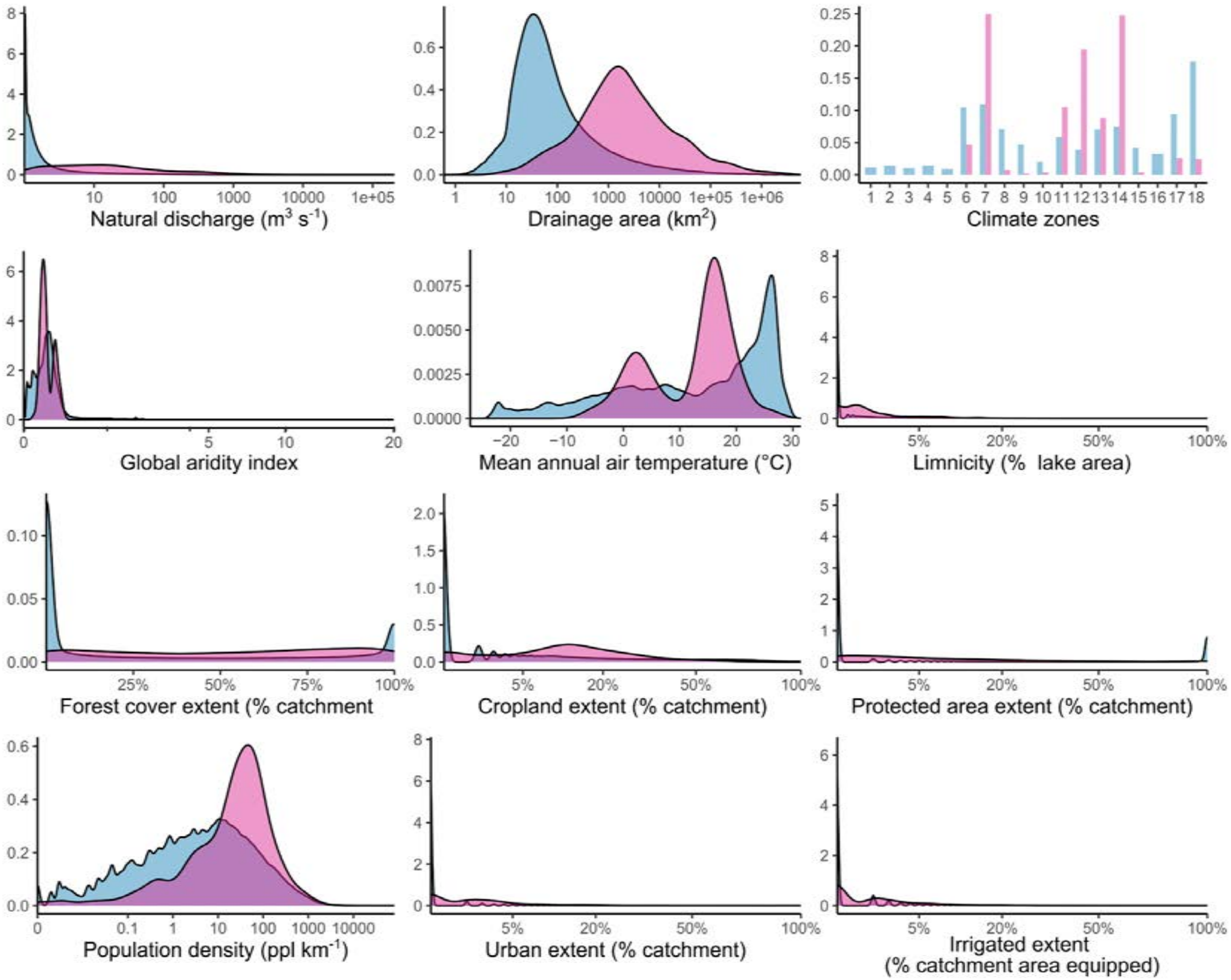


Figure 7. Distribution of 12 hydro-environmental variables across the 533 e-flow assessments sites included in the analysis (purple; n=533) and across all reaches of the global river network (blue).

Notes: All variables (from RiverATLAS) were averaged across the total drainage area upstream of the reach associated with each local e-flow assessment site. The aridity index is the mean annual precipitation over mean annual potential evapotranspiration. Refer to Figure A3 in Annex 3 for a description of the climate zones (1. Arctic 1, 2. Arctic 2, 3. Extremely cold and wet 1, 4. Extremely cold and wet 2, 5. Cold and wet, 6. Extremely cold and mesic, 7. Cold and mesic, 8. Cool temperate and dry, 9. Cool temperate and xeric, 10. Cool temperate and moist, 11. Warm temperate and mesic, 12. Warm temperate and xeric, 13. Hot and mesic, 14. Hot and dry, 15. Hot and arid, 16. Extremely hot and arid, 17. Extremely hot and xeric, and 18. Extremely hot and moist). No sites were located in climate zones 1-5 and 16.

In most countries with legislation mandating the conservation and/or restoration of e-flows, there is a prevalence of stipulated uses of specific e-flow assessment methods or at least common practices. This explains the overall homogeneity of e-flow assessment methods within countries observed in the database (Figure 8). In total, 305 local e-flow assessments in the database used a holistic method, 156 used single hydrological indices, 98 used hydrological time series analysis and 28 used habitat simulation, while 15 did not specify a method. Most habitat simulations (24 out of 28) correspond to assessments in Poland and nearly all single hydrological index assessments are observed for Quebec, Canada.

Hydrological Comparison

Comparing the MAR estimates from GEFIS to those from HydroRIVERS and from local e-flow assessments reveals only moderate predictive performance on the part of GEFIS (Figure 9, panels A and B; Table 3). In both comparisons, GEFIS tends to overestimate MAR for medium to large rivers (MAR > 109 m^3 y^{-1}, equivalent to 32 m^3 s^{-1}) and underestimate MAR for small rivers and streams (MAR < 108 m^3 y^{-1}), indicating a systematic bias. Estimates of MAR by GEFIS account for 82–84% (with and without outliers) of the variance in MAR observed at the local e-flow assessments sites (on a log-log scale, see Table 3). The average percentage error (sMAPE) in the MAR estimates from GEFIS are 20 percentage points higher than the error from HydroRIVERS. We examined the impact of masking on MAR estimates but observed no significant correlation between the proportion of the catchment that was masked out in GEFIS and the percentage error in MAR estimates from GEFIS (using MAR reported by local EFAs as reference; Figure 9, panel D).

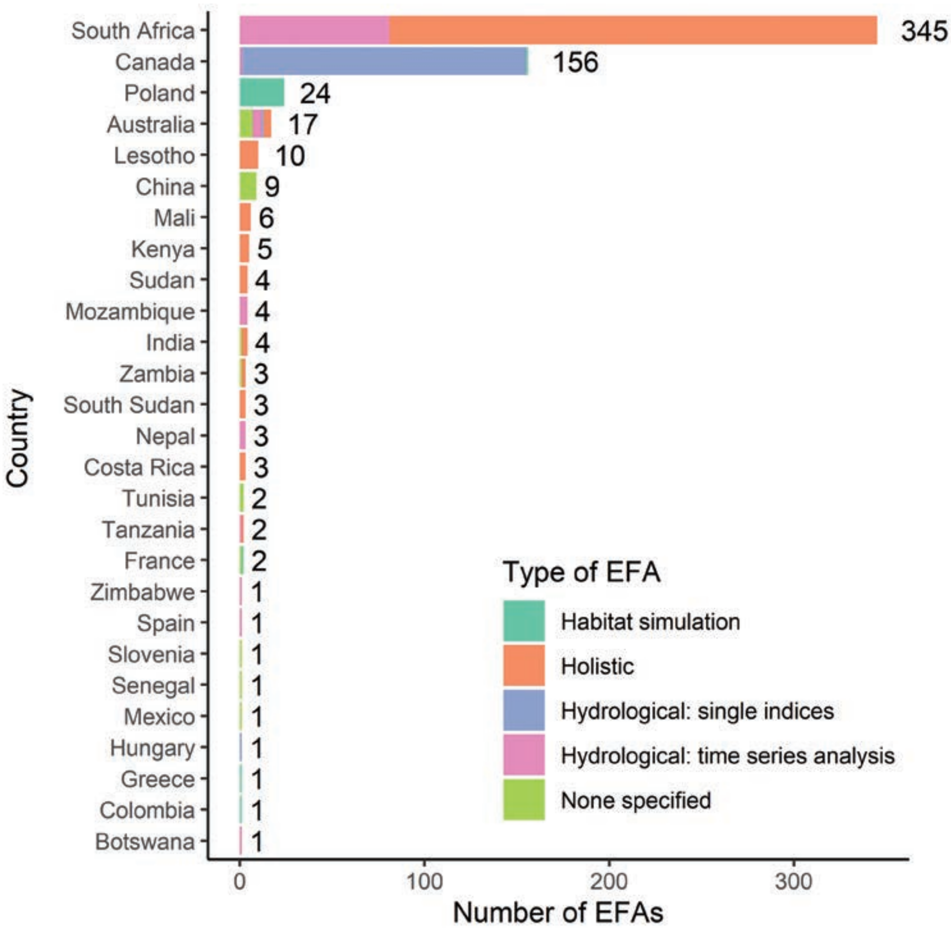


Figure 8. Distribution of environmental flow assessment (EFA) types across countries.

Notes: Multiple EFAs may be associated with a single site.

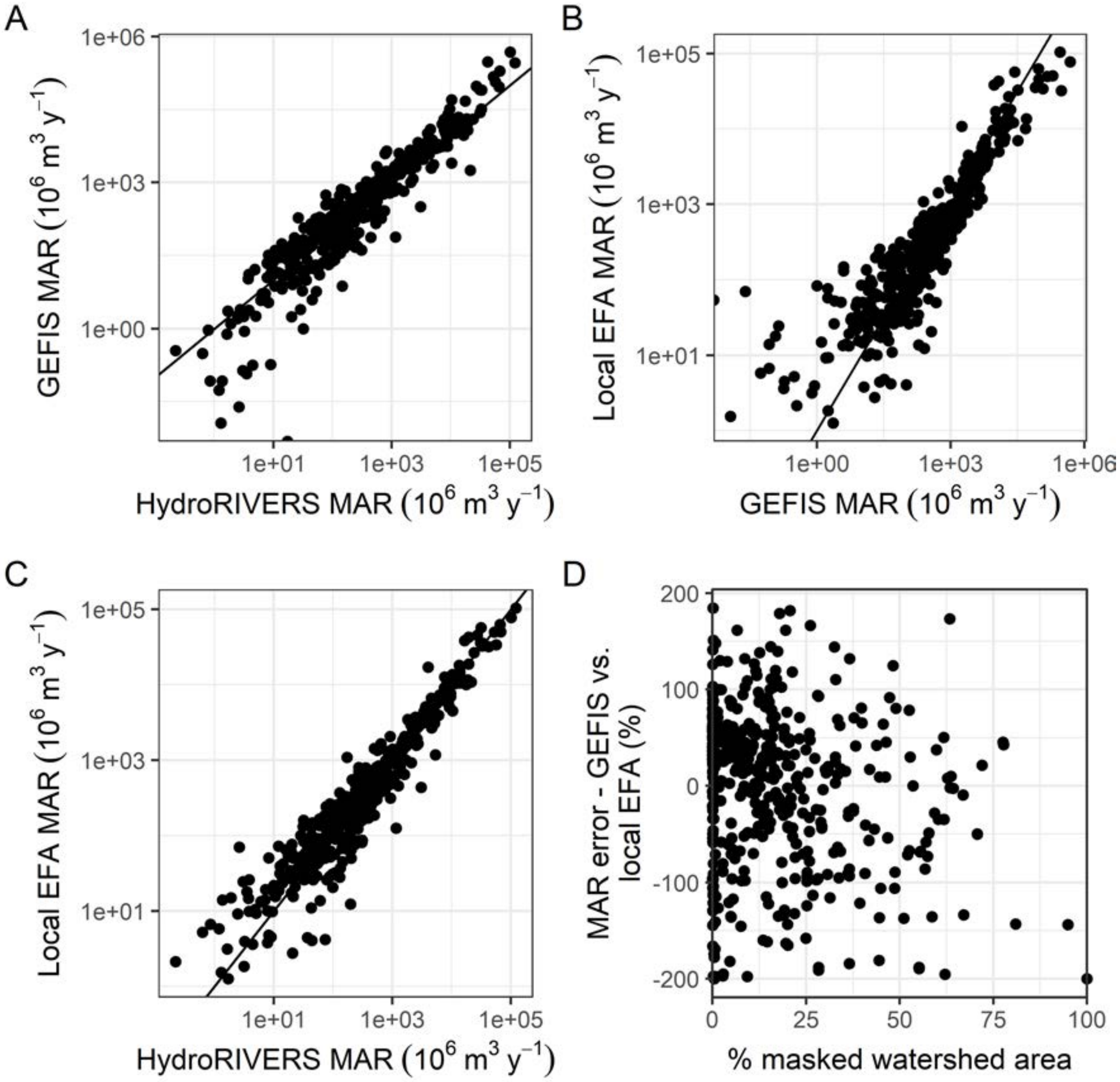


Figure 9. Comparisons of Mean Annual Runoff (MAR) estimates from GEFIS, HydroRIVERS and local e-flow assessments (EFA).

Notes: The percent error between the MAR estimate from GEFIS and that of the local EFAs (panel D) is computed as 100 * (MAR_{GEFIS} – MAR_{EFA})/MAR_{EFA}). MAR estimates from HydroRIVERS are derived through a geospatial downscaling procedure based on the global WaterGAP model version 2.2 (Müller Schmied et al. 2014). Black diagonal lines are identity (1:1) lines.

Table 3. Summary statistics for the comparisons of Mean Annual Runoff (MAR) estimates from GEFIS, the global hydrological model HydroRIVERS and local EFAs.

Comparison	sMAPE (%)	MAE	%Bias	R^2	R^2 (without outliers)	Coefficient p-value	n	# Outliers
GEFIS - HydroRIVERS	55	3,230	-37	0.90	0.90	< 0.001	532	3
GEFIS – local EFA	65	3,691	-51	0.82	0.84	< 0.001	497	4
HydroRIVERS – local EFA	45	759	-18	0.90	0.91	< 0.001	497	1

Notes: Refer to the section *Methods* for equations of the performance statistics and the criterion used to exclude outliers. Regression statistics are based on log-log linear least square regression analyses.

Management Class Comparison

The IBT index, used to determine present-day EMCs in GEFIS, marginally captured the ecological classes determined by local e-flow assessments (Figure 10). In only considering sites with a standard EMC determined in the local e-flow assessment, we noted a statistically significant difference in the mean IBT among standard EMCs (ANOVA, $p = 0.005$, $df = 8$). However, post-hoc tests showed only classes A/B and B to be significantly different from each other in terms of mean IBT ($p < 0.05$). While the lack of differences in IBT associated with sites across EMCs is in part due to the small sample sizes for several ecological classes (e.g., Class A, D/E and E only had two, one and four sites, respectively), the small range in IBT found across all sites is also a significant factor. Almost all sites in the database had an average IBT in their catchment corresponding to either classes B or C on the scale implemented for GEFIS. For other ecological classes which did not correspond to the standard EMC scale (from A to E; 'Other' panel in Figure 10), the small number of sites precluded us from conducting formal tests, but a similarly narrow range of IBT was also observed. Analyzing the IBT value for the specific site locations rather than computing the average IBT across the sites' catchment yielded similar results (*not shown here*).

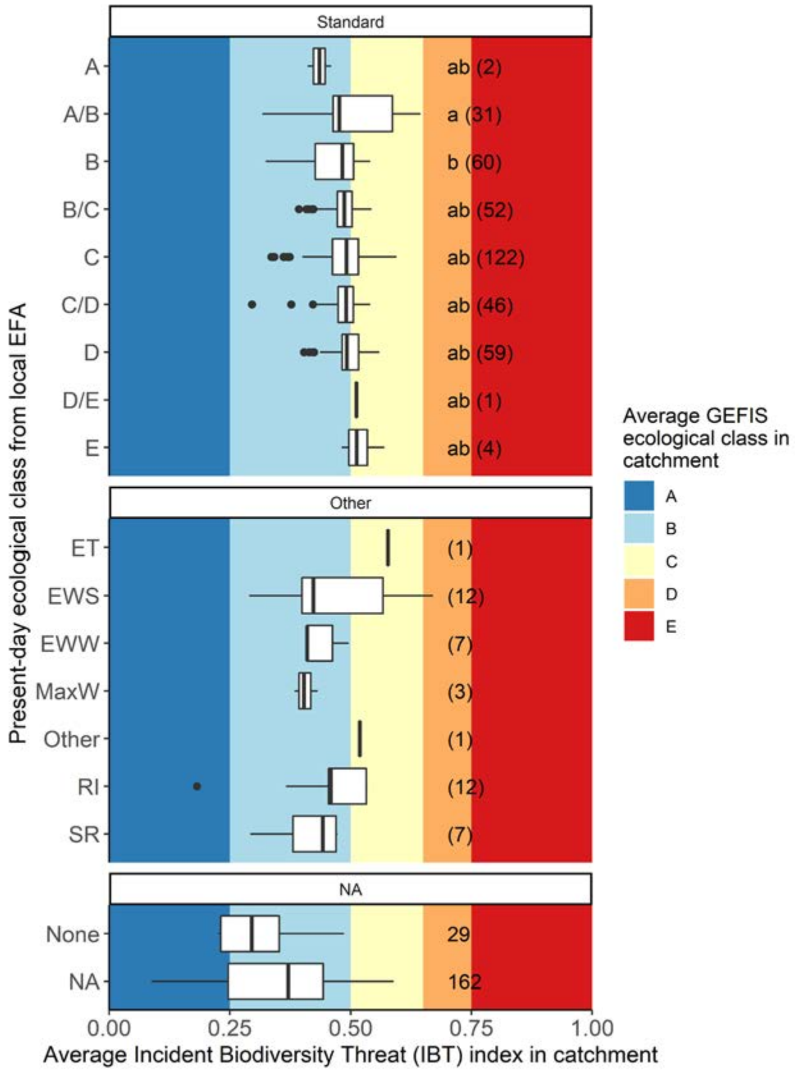


Figure 10. Distribution of Incident Biodiversity Threat (IBT) index for local environmental flow assessment (EFA) sites in different ecological classes.

Notes: IBT values (x-axis) were computed through spatial averaging across the catchment of each site. Present-day ecological classes (y-axis) are from local EFAs. Background colors reflect the present-day Ecological Management Classes (EMC) that correspond to intervals of IBT in GEFIS. Significant differences in IBT between EMCs are indicated by different letters (ANOVA followed by Tukey's HSD, p-value < 0.05). The number of individual sites for each ecological class is in parenthesis to the right of the letters. In the box plots, the main line corresponds to the median, the lower and upper hinges correspond to the first and third quartiles (the 25th and 75th percentiles), whiskers extend from the hinge to the largest value no further than 1.5 times the interquartile range. For descriptions of ecological classes A through E, see Table 1. Classes marked with a dash (/) are transitional. ET: Existing Treaty(ies); EWS: Existing Water Structure(s); EWW: Existing Water Withdrawal(s); MinW: Minimum Water Withdrawal; MinD: Minimum Degradation; SimS: Simulation Scenario; MaxW: Maximum Water Withdrawal; RI: Reduced Impacts; SR: Stressed River; None: local EFA system does not include the concept of ecological classes; NA: no ecological information was provided.

For local e-flow assessment sites where a standard EMC is available, GEFIS inferred the same EMC for 38% of the sites. Notably, since no sites determined to be in Class A or D by local assessors were classified as such by GEFIS, the classification accuracy is driven by the predominance of Class B and C sites in the sample, rather than by performance. GEFIS also assigned more sites to Class C (100) than B (77) for sites determined to be in Class B by local assessors.

We assessed how indicators of anthropogenic stress varied among locally determined EMCs (Figure 11).

Indicators related to agricultural stressors, namely the relative extent of cropland, pasture and irrigation across the sites' catchment, do not substantially and consistently vary from less impacted to more impacted classes. However, there is a clear increase from sites deemed as natural (Class A) to seriously modified sites (Class E) in the degree of regulation by upstream reservoirs, population density and extent of urban land cover. For instance, the 31 sites in EMC Class A/B had 4% of their MAR regulated by upstream reservoirs on average, compared to 72% for sites in EMC Class D.

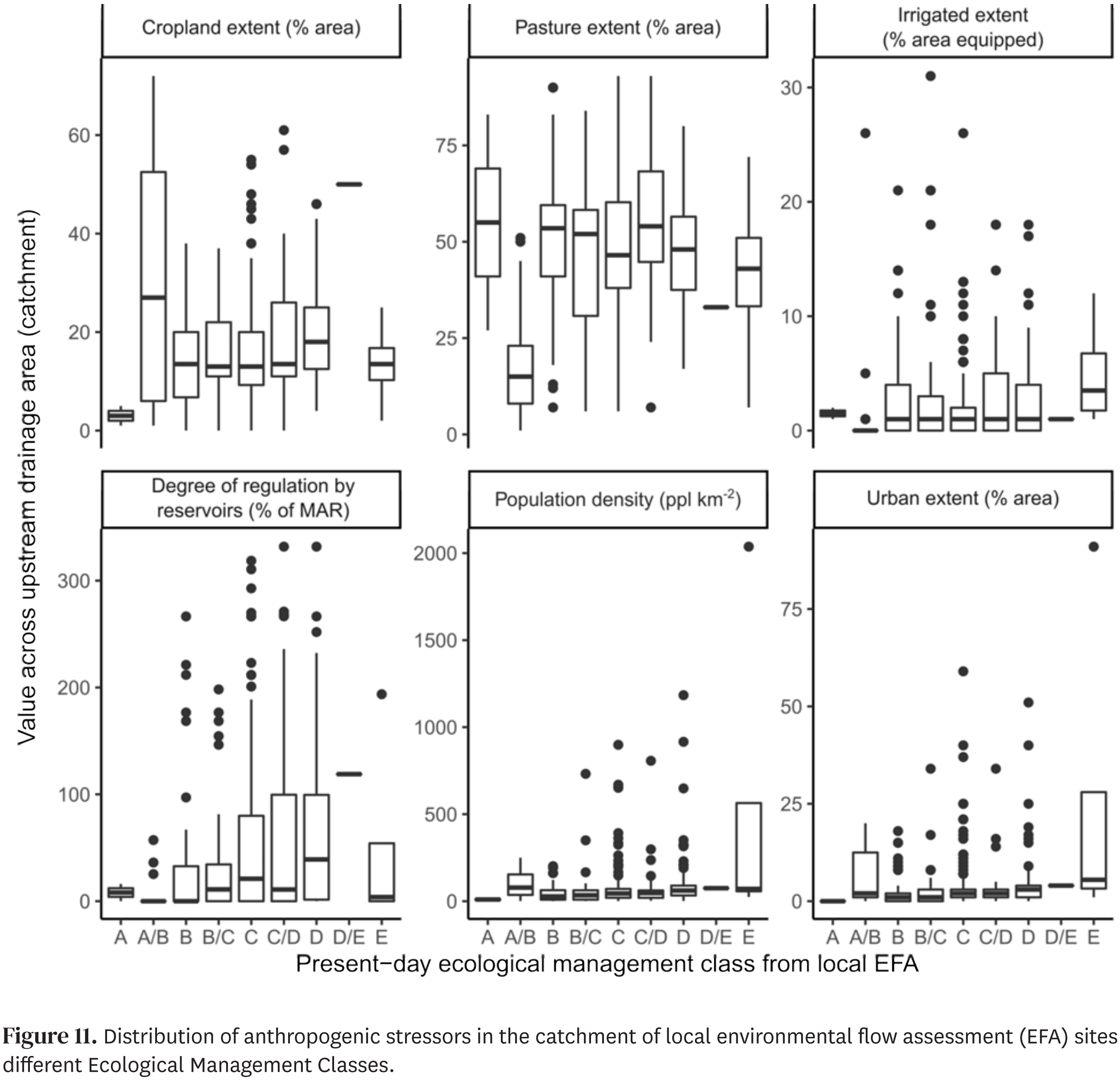


Figure 11. Distribution of anthropogenic stressors in the catchment of local environmental flow assessment (EFA) sites in different Ecological Management Classes.

Notes: nEFA with standard EMC = 370 (of which 337 are in South Africa). In the box plots, the main line corresponds to the median, the lower and upper hinges correspond to the first and third quartiles (the 25th and 75th percentiles), whiskers extend from the hinge to the largest value no further than 1.5 times the interquartile range.

Assessing the Impact of Masking

The masks implemented in GEFIS excluded land covers associated with areas of low flow as well as coastal areas. These exclusion masks resulted in a scarcity of GEFIS data in the catchments of semi-arid and arid sites (Figure 12). It was observed that 62 sites (12%) lacked GEFIS data across more than half of their catchment. The median MAR at these sites (3.15×108 m³ y^{-1}; estimated as part of the local e-flow assessments) was only slightly lower than the median MAR at those sites with GEFIS data available across most of their catchment (4.05×108 m³ y^{-1}). Only 9 sites lacked GEFIS data across their entire catchment.

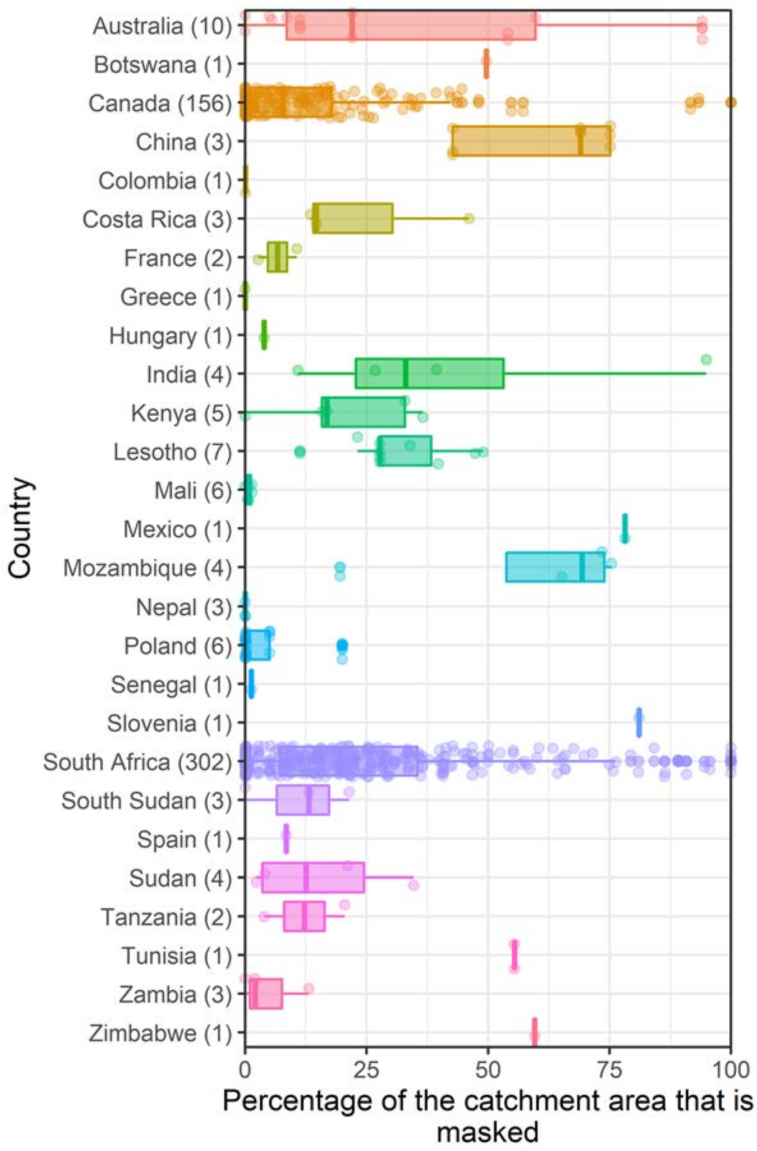


Figure 12. Total extent of masking in the catchment of e-flow assessment sites by country.

Notes: In the box plots, the main line corresponds to the median, the lower and upper hinges correspond to the first and third quartiles (the 25th and 75th percentiles), whiskers extend from the hinge to the largest value no further than 1.5 times the interquartile range. The number of unique sites is written next to each country's name.

Environmental Flow Comparison

The comparison of e-flow estimates displayed broad agreement but little to no correlation between estimates from GEFIS for present-day EMCs and e-flows determined by local assessors (Figure 13; Table 4). On the one hand, GEFIS estimates are within the same range as local estimates for most sites across local e-flow assessment methods—the mean absolute error (MAE) ranges between 26 and 15 percentage points of MAR (for local assessments using single hydrological indices and holistic assessments, respectively; Table 4). On the other hand, the correlations between GEFIS estimates and local assessments are either weak or non-significant. Indeed, the absolute error translates to a substantial percentage error—GEFIS estimates are on average 50–60% off across e-flow assessment methods. For local assessments in Quebec (Canada) based on single hydrological indices, GEFIS estimates account for 30% of the variance in estimated e-flows, but are substantially higher and thus more conservative than the local estimates (average percentage bias %Bias = 141%).

To control for the uncertainty in e-flow estimates from GEFIS due to the use of different EMCs, another comparison was made between the local e-flow assessments and GEFIS estimates of e-flows for the locally determined EMC. This assessment was constrained to a reduced set of sites where a standard EMC presented by the local assessment was available. As anticipated, matching EMC increased the correspondence between GEFIS estimates and local assessments (Figure 14; Table 5). Although GEFIS still explains only 5-6% of the variance in local e-flow estimates (R^2 for hydrological time series analysis and holistic assessments, respectively), all other performance metrics improved by matching EMCs.

Based on the present-day EMC predicted by GEFIS, e-flow estimates from GEFIS are, on average, more conservative in terms of total annual e-flow than local assessments (positive percentage bias in Table 4). This conservatism may be explained by the fact that GEFIS classifies most sites as being in Class EMC B (Figure 10). Indeed, when using GEFIS e-flows estimated for the locally determined Ecological Management Class in the comparison, GEFIS e-flow estimates are lower than those from local assessments (negative percentage bias in Table 5).

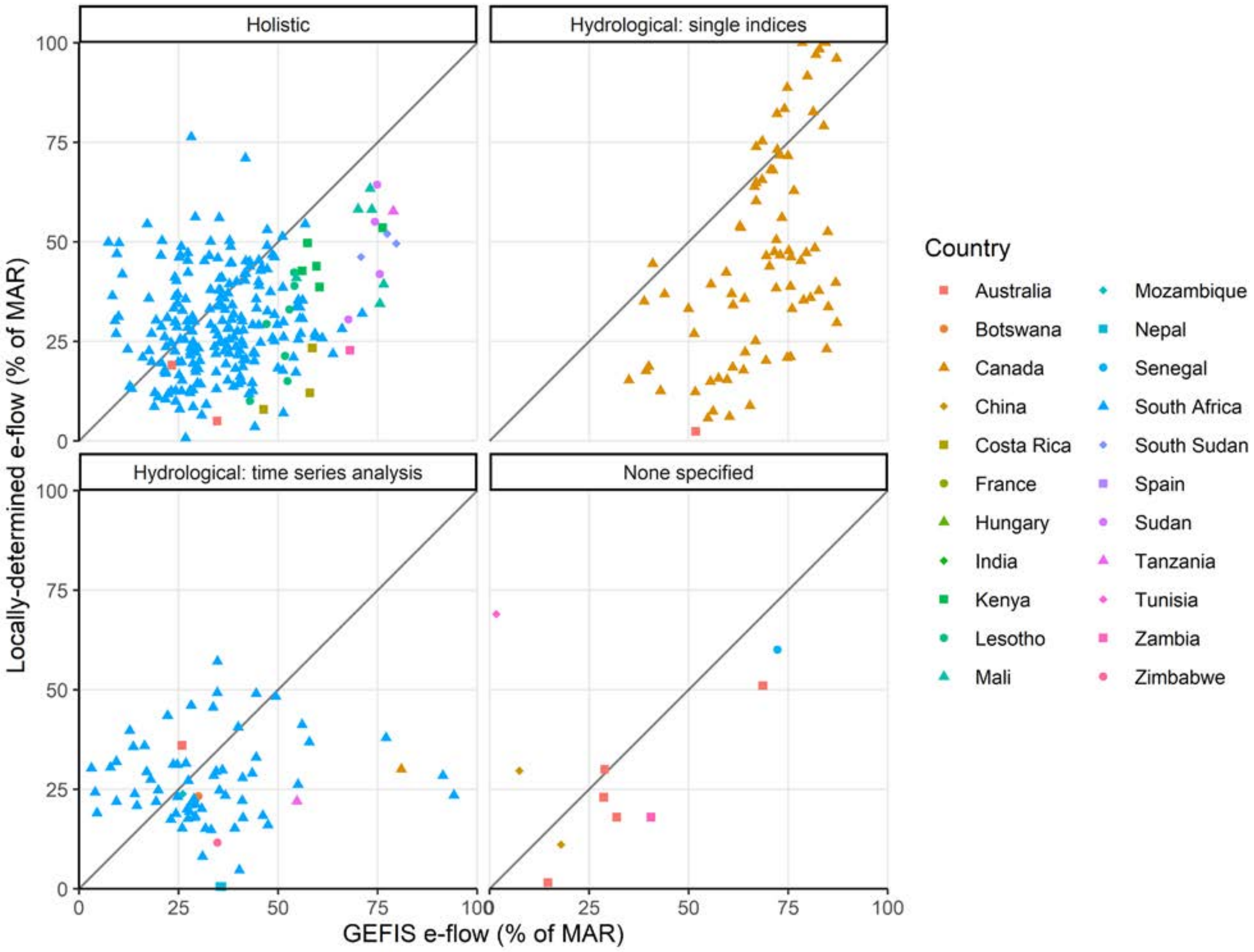


Figure 13. Comparisons between e-flows estimated by GEFIS for the present-day Ecological Management Class (EMC) and e-flows estimated by local assessments.

Notes: The panels are divided based on the type of local e-flow assessment method (see Table 2). Black diagonal lines are identity (1:1) lines. Only sites with present-day GEFIS e-flow estimates for at least 30% of their catchment were included.

Table 4. Summary statistics for the comparisons between e-flows estimated by GEFIS for the present-day Ecological Management Class (EMC) and e-flows estimated by local assessments (EFAs).

Type of local EFA	sMAPE (%)	MAE	%Bias	R^2	Coefficient p-value	n
None specified	73	18	102	-	-	10
Hydrological: single indices	56	26	141	0.30	< 0.001	78
Hydrological: time series analysis	61	17	304	0.01	0.4	72
Habitat simulation	26	12	-19	-	-	2
Holistic	48–50	15-16	70–76	0.07-0.08	< 0.001	246

Notes: Refer to the section *Methods* for equations of the performance statistics and Table 2 for a description of the types of local EFAs. Regression statistics are based on least square regression analyses. Only sites with present-day GEFIS e-flow estimates for at least 30% of their catchment were included. The range of performance statistics for holistic EFAs stems from sites where e-flows are estimated for multiple ecological classes without explicit mention of the present-day class.

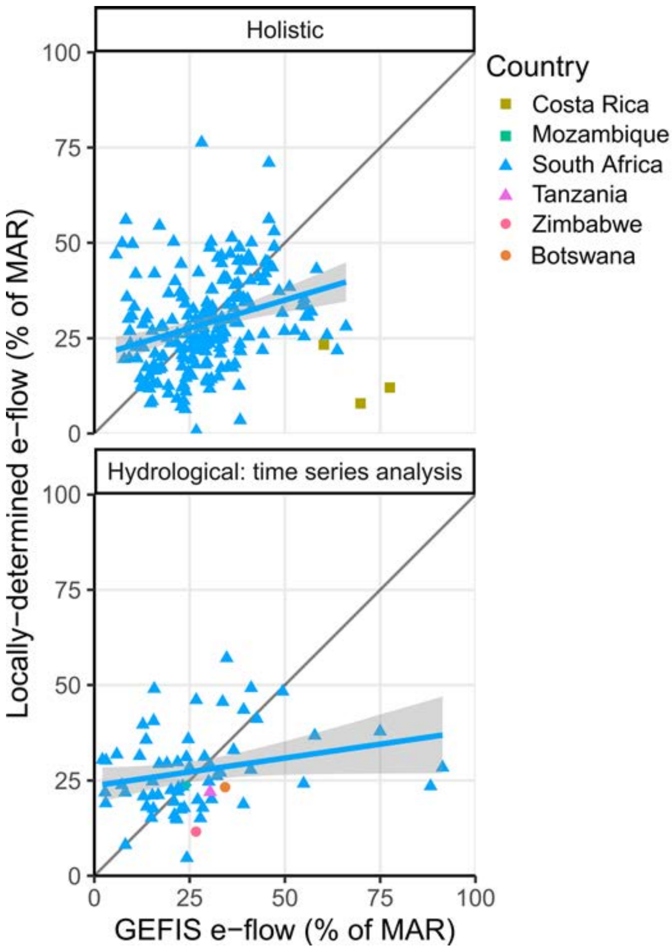


Figure 14. Comparisons between e-flows estimated by GEFIS for the locally determined Ecological Management Class (EMC) and e-flows estimated by local assessments (EFAs).

Notes: The panels are divided based on the type of local e-flow assessment method (see Table 2). The black diagonal lines are identity (1:1) lines. The blue lines (and grey shading) show linear regression fits for South Africa. These comparisons only include local EFAs for which a standard EMC was provided (i.e., A through E). Only sites with present-day GEFIS e-flow estimates for at least 30% of their catchment were included in the comparisons.

Table 5. Summary statistics for the comparisons between e-flows estimated by GEFIS for the locally determined Ecological Management Class (EMC) and e-flows estimated by local assessments (EFAs).

Type of local EFA	sMAPE (%)	MAE	%Bias	R^2	Coefficient p-value	N
Holistic	40	11	-38	0.06	< 0.001	241
Hydrological: time series analysis	51	13	-21	0.05	0.05	73

Notes: Refer to the section *Methods* for equations of the performance statistics and Table 2 for a description of the types of local EFAs. Regression statistics are based on least square regression analyses. Only sites with present-day GEFIS e-flow estimates for at least 30% of their catchment were included in the comparisons.

A river in Ghent, Belgium (*photo:* Chris Dickens).

Discussion

GEFIS is a publicly accessible online platform that provides countries with estimates of their e-flow requirements (as a percentage of the MAR) needed to compute SDG Indicator 6.4.2, along with total water withdrawals. Until this analysis, however, no comparison had been undertaken between GEFIS estimates and the e-flow assessments conducted by countries. This was compounded by the paucity of available data on local e-flow assessments to facilitate such a comparison. This study thus worked with the dual objectives of first assembling a database of local e-flow assessments and to then use this database for comparison with GEFIS estimates of mean annual runoff and e-flow requirements. The database assembly and evaluation were thus focused on comparing e-flow estimates in the format required for the computation of SDG Indicator 6.4.2—the long-term mean annual water requirement (as a percentage of the MAR) deemed necessary to sustain aquatic ecosystems. It should be noted, however, that not merely mean annual water requirement, but multiple aspects of the flow regime should be evaluated and protected to sustain ecosystems, including the frequency, timing, duration and rate of change of flow events.

The data compilation effort initiated as part of this project yielded a rich database that illustrates the global diversity of e-flow assessments in terms of both geographies and methods. Of the 651 e-flow assessments across 27 countries compiled and formatted for this analysis, 207 records were originally part of the erstwhile IWMI-compiled database, 12 were provided by country representatives as part of the official data request by the Land and Water Division of FAO, and the remainder were contributed by direct contacts of the authors. The database includes at least 23 different e-flow assessment methods (the assessment method was not specified for 29% of the records) and 18 different types of ecological classes (and/or water use scenarios) for water discharges ranging in size from 0.04 $m^3 s^{-1}$ to 3,303 $m^3 s^{-1}$. To harmonize the database for analysis, we undertook the simplification or lumping of e-flow assessment types and ecological classes into generic categories, necessitating some degree of subjectivity in the absence of additional information. This heterogeneity reflects not only the varied legislative contexts and environmental conditions across e-flow assessments but also the challenges associated with establishing a standard of evaluation at the global scale for SDG Indicator 6.4.2. The data compilation effort initiated as part of this project is still ongoing. Therefore, the database will become an evolving resource for the continued development and evaluation of global e-flow assessment tools.

The comparison between estimates of MAR, ecological classes and e-flow requirements from GEFIS and data from local e-flow assessments highlighted the inherent limitations involved in the use of global models. Although GEFIS predictions of MAR were concordant with local observations, there was limited agreement between ecological classes and e-flows inferred by GEFIS and local assessments.

A bias in GEFIS estimates of MAR was found both in the comparison with local e-flow assessments and with another global hydrological model. The MAR of small rivers is underestimated while the MAR of large rivers tends to be overestimated. This bias is likely to propagate into GEFIS estimates of e-flow volumes (in 106 $m^3 yr^{-1}$), although it may not be reflected in e-flows which are presented as percentages of the MAR. Further investigation is needed to determine the reason for this bias. To avoid this type of model-specific bias in future developments, we recommend implementation of an ensemble approach whereby the mean (or median) of MAR predictions from multiple global hydrological models is used in conjunction with estimates of prediction uncertainties due to inter-model differences (Sood and Smakhtin 2015; Döll et al. 2016). This approach has already been implemented for assessing global e-flows by Hogeboom et al. (2020) and Virkki et al. (2021). Alternatively, spatially explicit assessments of model errors may identify which hydrological model performs best for each region and river type. This may enable e-flow estimates to be calculated with the most accurate hydrological predictions for every region and river type. Nonetheless, hydrological models not only differ in their regional performance but also in their representation of individual hydrological processes and the associated aspects of the flow regime (Beck et al. 2017; Zaherpour et al. 2018).

One major limitation in this hydrological comparison stems from the format of MAR estimates in GEFIS. For local e-flow assessments (and HydroRIVERS), values of MAR are provided as the total volume of water that flows past a river cross-section in a given year, i.e., the discharge at the site summed for a year. By contrast, GEFIS estimates MAR as the sum of the simulated contribution of surface runoff and groundwater to river flow within each cell. Therefore, it excludes certain processes—evaporation in river channels, transmission losses, and interactions between river channels and delta—which may affect river discharge as water flows (i.e., is routed) downstream (Sood et al. 2017). Although the runoff estimates from GEFIS within the catchment of each site were aggregated for this comparison to approximate the discharge, this lack of routing may nevertheless account for the overestimation of MAR by GEFIS for large rivers compared to the observations from local e-flow assessments and predictions from HydroRIVERS. This bias is likely to be most pronounced in semi-arid and arid areas with high rates of evapotranspiration and river leakage to groundwater (e.g., in Nigeria; Nijssen et al. 2001; Mujere et al. 2021). This lack of routing also contrasts with the IBT index used for determining present-day EMCs in GEFIS, which accounted for the downstream impacts of anthropogenic stressors through routing (Vörösmarty et al. 2010). For carrying out improved comparisons with local e-flow assessment, we therefore recommend that future global e-flow assessment tools incorporate routing processes in their hydrological module.

The e-flow assessment sites included in the database spanned a range of ecological classes, yet it was observed that GEFIS assigned an EMC of B or C to all sites. Even for those local e-flow assessment sites assigned to classes B and C by local assessors, GEFIS demonstrated only a limited predictive performance. This low classification performance stems from the IBT index used to infer EMC classes in GEFIS, which does not capture the variability in anthropogenic stressors found at the local sites. A likely reason for this lack of congruence is the coarse resolution of the IBT index grid. Each pixel in the IBT index grid, which spans ~2,500 km², is likely to encompass a wide range of environmental conditions and ecological integrity. In addition, the IBT index grid accounts for the accumulation and dilution of anthropogenic stressors by water flow downstream. At this coarse resolution, however, the routing of stressors mostly reflects the condition of the largest river within each pixel, likely overestimating the anthropogenic impact on small and medium watercourses in headwater regions within the same pixel.

The exclusion masks implemented in GEFIS preclude e-flow assessment for more than a third of the global land surface. Several countries dominated by semi-arid and arid climates (Namibia and Algeria, among others) are nearly void of hydrological and e-flow information. This mask was originally implemented by Vörösmarty et al. (2010) to remove areas with negligible active flow. Nonetheless, freshwater flow in those areas supports unique ecosystems with increasingly valued biodiversity and ecosystem services which are threatened by rapid degradation (Acuña et al. 2017; Messager et al. 2021). Moreover, climate change and population growth will continue to only exacerbate the stress from natural water scarcity in such regions. It is, therefore, recommended that future versions of GEFIS include estimates of e-flows for all climates and land covers through the inclusion of the full outputs from global hydrological models (without masking) and by updating the data source used to assess the present-day EMC with one which includes areas with low streamflow.

It is observed that the divergence between MAR estimates of GEFIS and the two other sources of hydrological data (local e-flow assessments and HydroRIVERS) is less than the divergence between e-flow estimates of GEFIS and local e-flow assessments (as a percentage of the MAR). Therefore, the differences in methods used to determine the present-day EMC and the e-flow requirement corresponding to this EMC (in GEFIS as well as in local e-flow assessments) may account for the enhanced divergence observed between the two independent e-flow assessments. To ascertain the validity of this hypothesis, a future study may benefit from considering a diversity of methods to estimate the present-day EMC and e-flows at diverse locations (including at the local e-flow assessment sites considered in this exercise) and comparing the results with those obtained from GEFIS at the same locations. Such a process may enable the 'calibration' of GEFIS against, for example, more holistic methods which encompass a wider range of ecological data. A possible future direction that may be pursued is to revise the FDC shifts between EMCs (which is currently fixed at one percentage category on the horizontal [probability] axis) based on results of the above comparison and other attributes of selected sites such as the eco-region of the site's location. In fact, the original publications of the method—Smakhtin and Anputhas (2006) and Smakhtin and Eriyagama (2008)—recommend such a revision of the FDC shifts.

Total station measurement of cross-sectional dimensions to estimate river flow and stream morphology—the Limpopo River, Southern Africa (*photo:* Bennie van der Waal).

Conclusions and Future Directions

This study aimed to compare e-flow estimates made using GEFIS with independent e-flow estimates made at the same locations using a range of different methods. The larger goal of this exercise was to chart potential future directions for the advancement of global e-flow assessments in general and GEFIS in particular. The study shows that, at first glance, there is limited agreement between GEFIS estimates and other independent estimates of e-flows (as a percentage of the MAR). However, it is to be noted that this divergence in estimates does not imply that e-flow estimates made by GEFIS are always less reliable than those made at the same locations using other heterogeneous methods. Part of the observed scatter in the comparison of GEFIS e-flows estimates to local assessments results from the diversity of methods implemented in the latter.

While the study found divergence in e-flow estimates presented as a percentage of the MAR, it did not investigate whether there is higher agreement in certain world regions than in others, in certain sized catchments than in others and in certain types of land uses than in others. This was in part due to geographical biases in the dataset of local assessments—most data points were from South Africa and Canada. Therefore, assessments delving into finer attributes of the data and involving a larger global coverage may reveal trends not evident in the current analysis.

The study illustrates the need for considering an ensemble of global hydrological models and more comprehensive ecological input in global e-flow assessments, which can also advance GEFIS itself. GEFIS is the first attempt at providing global e-flow data to countries to monitor and assess their sustainable development targets. Nevertheless, it has the potential to evolve into an e-flow tool which is more robust and better calibrated to represent realities on the ground, thus enhancing the service that it currently provides in global sustainable development.

Collecting benthic invertebrates from Irrawaddy River, Myanmar (*photo:* Chris Dickens).

References

Acuña, V.; Hunter, M.; Ruhí, A. 2017. Managing temporary streams and rivers as unique rather than second-class ecosystems. *Biological Conservation* 211(Part B): 12–19. https://doi.org/10.1016/J.BIOCON.2016.12.025

Alcamo, J.; Döll, P.; Henrichs, T.; Kaspar, F.; Lehner, B.; Rosch, T.; Siebert, S. 2003. Development and testing of the WaterGAP 2 global model of water use and availability. *Hydrological Sciences Journal* 48(3): 317–337. https://doi.org/10.1623/hysj.48.3.317.45290

Arino, O.; Ramos Perez, J.J.; Kalogirou, V.; Bontemps, S.; Defourny, P.; van Bogaert, E. 2012. Global land cover map for 2009 (GlobCover 2009). European Space Agency (ESA) and Université Catholique de Louvain (UCL), PANGAEA. https://doi.org/10.1594/PANGAEA.787668

Arthington, A.H.; Bhaduri, A.; Bunn, S.E.; Jackson, S.E.; Tharme, R.E.; Tickner, D.; Young, B.; Acreman, M.; Baker, N.; Capon, S.; Horne, A.C.; Kendy, E.; McClain, M.E.; Poff, N.L.; Richter, B.D.; Ward, S. 2018. The Brisbane declaration and global action agenda on environmental flows. *Frontiers in Environmental Science* 6: 45. https://doi.org/10.3389/fenvs.2018.00045

Beck, H.E.; Vergopolan, N.; Pan, M.; Levizzani, V.; van Dijk, A.I.J.M.; Weedon, G.P.; Brocca, L.; Pappenberger, F.; Huffman, G.J.; Wood, E.F. 2017. Global-scale evaluation of 22 precipitation datasets using gauge observations and hydrological modelling. *Hydrology and Earth System Sciences* 21(12): 6201–6217. https://doi.org/10.5194/hess-21-6201-2017

CIESIN (Center for International Earth Science Information Network at Columbia University). 2016. Gridded population of the world, version 4 (GPWv4): Population count. Palisades, New York, USA: NASA Socioeconomic Data and Applications Center (SEDAC). http://doi.org/10.7927/H4X63JVC

CBD (Convention on Biological Diversity). 2021. First draft of the post-2020 global biodiversity framework. UN Environment Programme. Available at https://www.cbd.int/doc/c/abb5/591f/2e46096d3f0330b08ce87a45/wg2020-03-03-en.pdf (accessed on July 14, 2023).

de Graaf, I.E.M.; Gleeson, T.; van Beek, L.P.H.R.; Sutanudjaja, E.H.; Bierkens, M.F.P. 2019. Environmental flow limits to global groundwater pumping. *Nature* 574(7776): 90–94. https://doi.org/10.1038/s41586-019-1594-4

DWAF (Department of Water Affairs and Forestry). 1997. *White paper on a National Water Policy for South Africa*. Pretoria, South Africa: Department of Water Affairs and Forestry. Available at https://www.gov.za/sites/default/files/gcis_document/201409/nwpwp.pdf (accessed on October 19, 2023).

Döll, P.; Kaspar, F.; Lehner, B. 2003. A global hydrological model for deriving water availability indicators: Model tuning and validation. *Journal of Hydrology* 270(1-2): 105–134. https://doi.org/10.1016/S0022-1694(02)00283-4

Döll, P.; Douville, H.; Güntner, A.; Müller Schmied, H.; Wada, Y. 2016. Modelling freshwater resources at the global scale: Challenges and prospects. *Surveys in Geophysics* 37(2): 195–221. https://doi.org/10.1007/s10712-015-9343-1

Fekete, B.M.; Vörösmarty, C.J.; Grabs, W. 2002. High-resolution fields of global runoff combining observed river discharge and simulated water balances. *Global Biogeochemical Cycles* 16(3): 15-1–15-10. https://doi.org/10.1029/1999GB001254

FAO (Food and Agriculture Organization of the United Nations). 2019. *Incorporating environmental flows into "water stress" indicator 6.4.2 - Guidelines for a minimum standard method for global reporting*. 32p. Rome, Italy: Food and Agriculture Organization of the United Nations (FAO). Licence: CC BY-NC-SA 3.0 IGO.

Gerten, D.; Hoff, H.; Rockström, J.; Jägermeyr, J.; Kummu, M.; Pastor, A.V. 2013. Towards a revised planetary boundary for consumptive freshwater use: Role of environmental flow requirements. *Current Opinion in Environmental Sustainability* 5(6): 551–558. https://doi.org/10.1016/j.cosust.2013.11.001

Hogeboom, R.J.; de Bruin, D.; Schyns, J.F.; Krol, M.S.; Hoekstra, A.Y. 2020. Capping human water footprints in the world's river basins. *Earth's Future* 8(2): e2019EF001363. https://doi.org/10.1029/2019EF001363

Horne, A.C.; O'Donnell, E.L.; Webb, J.A.; Stewardson, M.J.; Acreman, M.; Richter, B. 2017. Chapter 1 - The Environmental Water Management Cycle. In: Horne, A.C.; Webb, J.A.; Stewardson, M.J.; Richter, B.; Acreman, M. (eds). *Water for the Environment: From Policy and Science to Implementation and Management*. Academic Press. pp.3–16. https://doi.org/10.1016/B978-0-12-803907-6.00001-2

Hughes, D.A.; Smakhtin, V. 1996. Daily flow time series patching or extension: a spatial interpolation approach based on flow duration curves. *Hydrological Sciences Journal* 41(6): 851–871. https://doi.org/10.1080/02626669609491555

Lehner, B.; Verdin, K.; Jarvis, A. 2008. New global hydrography derived from spaceborne elevation data. *Eos, Transactions, American Geophysical Union* 89(10): 93-94. https://doi.org/doi:10.1029/2008EO100001

Lehner, B.; Reidy Liermann, C.; Revenga, C.; Vörösmarty, C.; Fekete, B.; Crouzet, P.; Döll, P.; Endejan, M.; Frenken, K.; Magome, J.; Nilsson, C.; Robertson, J.C.; Rodel, R.; Sindorf, N.; Wisser, D. 2011. High-resolution mapping of the world's reservoirs and dams for sustainable river-flow management. *Frontiers in Ecology and the Environment* 9: 494–502. https://doi.org/10.1890/100125

Lehner, B.; Grill, G. 2013. Global river hydrography and network routing: baseline data and new approaches to study the world's large river systems. *Hydrological Processes* 27(15): 2171–2186. https://doi.org/10.1002/hyp.9740

Linke, S.; Lehner, B.; Ouellet Dallaire, C.; Ariwi, J.; Grill, G.; Anand, M.; Beames, P.; Burchard-Levine, V.; Maxwell, S.; Moidu, H.; Tan, F.; Thieme, M. 2019. Global hydro-environmental sub-basin and river reach characteristics at high spatial resolution. *Scientific Data* 6(1): 283. https://doi.org/10.1038/s41597-019-0300-6

Liu, X.; Liu, W.; Liu, L.; Tang, Q.; Liu, J.; Yang, H. 2021. Environmental flow requirements largely reshape global surface water scarcity assessment. *Environmental Research Letters* 16(10): 104029. https://doi.org/10.1088/1748-9326/AC27CB

Messager, M.L.; Lehner, B.; Cockburn, C.; Lamouroux, N.; Pella, H.; Snelder, T.; Tockner, K.; Trautmann, T.; Watt, C.; Datry, T. 2021. Global prevalence of non-perennial rivers and streams. *Nature* 594(7863): 391–397. https://doi.org/10.1038/s41586-021-03565-5

Metzger, M. J.; Bunce, R. G. H.; Jongman, R. H. G.; Sayre, R.; Trabucco, A.; Zomer, R. 2013. A high-resolution bioclimate map of the world: A unifying framework for global biodiversity research and monitoring. *Global Ecology and Biogeography* 22(5): 630–638. https://doi.org/10.1111/geb.12022

Mujere, N.; Masocha, M.; Makurira, H.; Mazvimavi, D. 2021. Dynamics and scales of transmission losses in dryland river systems: A meta-analysis. *Australasian Journal of Water Resources* 26(2): 227–241. https://doi.org/10.1080/13241583.2021.1996680

Müller Schmied, H.; Eisner, S.; Franz, D.; Wattenbach, M.; Portmann, F.T.; Flörke, M.; Döll, P. 2014. Sensitivity of simulated global-scale freshwater fluxes and storages to input data, hydrological model structure, human water use and calibration. *Hydrology and Earth System Sciences* 18(9): 3511–3538. https://doi.org/10.5194/hess-18-3511-2014

Nijssen, B.; O'Donnell, G.M.; Lettenmaier, D.P.; Lohmann, D.; Wood, E.F. 2001. Predicting the discharge of global rivers. *Journal of Climate* 14(15): 3307–3323. https://doi.org/10.1175/1520-0442(2001)014%3C3307:PTDOGR%3E2.0.CO;2

Pastor, A.V.; Ludwig, F.; Biemans, H.; Hoff, H.; Kabat, P. 2014. Accounting for environmental flow requirements in global water assessments. *Hydrology and Earth System Sciences* 18(12): 5041–5059. https://doi.org/10.5194/hess-18-5041-2014

Pesaresi, M.; Ehrlich, D.; Ferri, S.; Florczyk, A.J.; Freire, S.; Halkia, M.; Julea, A.; Kemper, T.; Soille, P.; Syrris, V. 2016. Operating procedure for the production of the Global Human Settlement Layer from Landsat data of the epochs 1975, 1990, 2000, and 2014. Luxembourg: Publications Office of the European Union. https://dx.doi.org/10.2788/253582

Poff, N.L.R.; Tharme, R.E.; Arthington, A.H. 2017. Evolution of environmental flows assessment science, principles, and methodologies. Chapter 11 - Evolution of environmental flows assessment Science, Principles, and Methodologies. In: Horne, A.C.; Webb, J.A.; Stewardson, M.J.; Richter, B.; Acreman, M. (eds). *Water for the environment: From policy and science to implementation and management*. Academic Press. pp.203–236. https://doi.org/10.1016/B978-0-12-803907-6.00011-5

Ramankutty, N.; Foley, J.A. 1999. Estimating historical changes in global land cover: Croplands from 1700 to 1992. *Global Biogeochemical Cycles* 13(4): 997–1027. https://doi.org/10.1029/1999GB900046

Salik, K.M.; Hashmi, M.Z.R.; Ishfaq, S.; Zahdi, W. 2016. Environmental flow requirements and impacts of climate change-induced river flow changes on ecology of the Indus Delta, Pakistan. *Regional Studies in Marine Science* 7: 185–195. https://doi.org/10.1016/J.RSMA.2016.06.008

Siebert, S.; Kummu, M.; Porkka, M.; Döll, P.; Ramankutty, N.; Scanlon, B.R. 2015. A global data set of the extent of irrigated land from 1900 to 2005. *Hydrology and Earth System Sciences* 19(3): 1521–1545. https://doi.org/10.5194/hess-19-1521-2015

Smakhtin, V.; Revenga, C.; Döll, P. 2004. A pilot global assessment of environmental water requirements and scarcity. *Water International* 29: 307–317. https://doi.org/10.1080/02508060408691785

Smakhtin, V.U.; Anputhas, M. 2006. *An assessment of environmental flow requirements of Indian river basins*. Colombo, Sri Lanka: International Water Management Institute (IWMI). 36p. (IWMI Research Report 107). http://doi.org/10.3910/2009.106

Smakhtin, V.U.; Eriyagama, N. 2008. Developing a software package for global desktop assessment of environmental flows. *Environmental Modelling and Software* 23(12): 1396–1406. https://doi.org/10.1016/j.envsoft.2008.04.002

Sood, A.; Smakhtin, V. 2015. Global hydrological models: A review. *Hydrological Sciences Journal* 60(4): 549–565. https://doi.org/10.1080/02626667.2014.950580

Sood, A.; Smakhtin, V.; Eriyagama, N.; Villholth, K.G.; Liyanage, N.; Wada, Y.; Ebrahim, G.; Dickens, C. 2017. *Global environmental flow information for the sustainable development goals*. Colombo, Sri Lanka: International Water Management Institute (IWMI). 37p. (IWMI Research Report 168). http://doi.org/10.5337/2017.201

Steffen, W.; Richardson, K.; Rockström, J.; Cornell, S.E.; Fetzer, I.; Bennett, E.M.; Biggs, R.; Carpenter, S.R.; de Vries, W.; de Wit, C.A.; Folke, C.; Gerten, D.; Heinke, J.; Mace, G.M.; Persson, L.M.; Ramanathan, V.; Reyers, B.; Sörlin, S. 2015. Planetary boundaries: Guiding human development on a changing planet. *Science* 347(6223): 1259855. https://doi.org/10.1126/science.1259855

Tharme, R.E. 2003. A global perspective on environmental flow assessment: Emerging trends in the development and application of environmental flow methodologies for rivers. *River Research and Applications* 19(5-6): 397–441. https://doi.org/10.1002/rra.736

Tukey, J.W. 1949. Comparing individual means in the analysis of variance. *Biometrics* 5(2): 99–114. https://doi.org/10.2307/3001913

Virkki, V.; Alanärä, E.; Porkka, M.; Ahopelto, L.; Gleeson, T.; Mohan, C.; Wang-Erlandsson, L.; Flörke, M.; Gerten, D.; Gosling, S.N.; Hanasaki, N.; Müller Schmied, H.; Kummu, M. 2021. Environmental flow envelopes: Quantifying global, ecosystem–threatening streamflow alterations. *Hydrology and Earth System Sciences Discussions*: 1–31. https://doi.org/10.5194/HESS-2021-260

Vörösmarty, C.J.; McIntyre, P.B.; Gessner, M.O.; Dudgeon, D.; Prusevich, A.; Green, P.; Glidden, S.; Bunn, S.E.; Sullivan, C.A.; Liermann, C.R.; Davies, P.M. 2010. Global threats to human water security and river biodiversity. *Nature* 467: 555–561. https://doi.org/10.1038/nature09440

Wada, Y.; de Graaf, I.E.M.; van Beek, L.P.H. 2016. High-resolution modeling of human and climate impacts on global water resources. *Journal of Advances in Modeling Earth Systems* 8(2): 735–763. https://doi.org/10.1002/2015MS000618

Zaherpour, J.; Gosling, S.N.; Mount, N.; Schmied, H.M.; Veldkamp, T.I.E.; Dankers, R.; Eisner, S.; Gerten, D.; Gudmundsson, L.; Haddeland, I.; Hanasaki, N.; Kim, H.; Leng, G.; Liu, J.; Masaki, Y.; Oki, T.; Pokhrel, Y.; Satoh, Y.; Schewe, J.; Wada, Y.; 2018. Worldwide evaluation of mean and extreme runoff from six global-scale hydrological models that account for human impacts. *Environmental Research Letters* 13(6): 065015. https://doi.org/10.1088/1748-9326/aac547

Annex 1. Templates for the Collection of E-flow Data on Local Assessments.

Tables A1 and A2 show the templates shared with countries to collect data on local e-flow assessments indicating two different levels of requirements: minimum level and detailed level. Alternatively, data providers were also given the option to fill out a spreadsheet.

Table A1. Template for minimum data requirement (Level 1).

Country	
Name of e-flow site/area	
Scale of e-flow · *Site* ☐ · *Basin or sub-basin* ☐ · *Reach(es)* ☐ · *Other (e.g., state, protected area)* ☐	
Site coordinates (preferably Decimal Degrees)	
Is there an e-flow assessment report available? Y ☐ N ☐ · Summary data only ☐ · Describes all details ☐	*Please provide a link or attach the report*
Are there raw data? Y ☐ N ☐ Are they available on request? Y ☐ N ☐	
E-flow hydrological statistics for the sites · *Summary table of e-flow recommendations* · *Flow percentile(s) (%flow)* · *Flow volume (Mm³/annum)* · *Discharge per month/season* · *Other (e.g., specific flow events, operating rules, diversion limits)*	*Please provide actual summary data*
Legal framework: Are there national laws regulating e-flows? ☐ Are there supporting regulations? ☐	*Provide name(s) of legislation and regulations*
Additional comments — please provide any relevant comment that will enable interpretation of your data against GEFIS	

TABLE A2. Template for detailed data requirement (Level 2).

(Appended to Table 1)	
Scale of e-flow data (multiple boxes can be checked): • *Site based* ☐ • *Extrapolated to sub-basin* ☐ • *Extrapolated to basin* ☐ • *Extrapolated to country or administrative unit* ☐ • *Extrapolated to biological node* ☐ • *Other* ☐	
E-flow method and/or model used: • *Holistic/ecosystem function* ☐ • *Hydraulic rating* ☐ • *Habitat simulation* ☐ • *Hydrological* ☐ • *Other* ☐	*Name the method (and model) and level of resolution of assessment (e.g., look-up/desktop/intermediate/ comprehensive)*
Name/description of system used to link e-flows to ecological condition (e.g., A-E or A-C Ecological Management Class; 'Good' ecological condition).	
What was the ecological condition (or range of conditions) established for the location?	
Which hydrological regime was considered in setting the e-flow? • *Present day* ☐ • *Natural* ☐ • *Desired* ☐ • *Other* ☐ • *None* ☐	
Level of confidence in the assessment (Include specific confidence rating scale, where this was specified and used) • *Strong holistic evidence* ☐ • *Weak holistic evidence* ☐ • *Evidence for only parts of method/ecosystem* ☐ • *Low confidence with few datasets used* ☐ • *Very low confidence modelled data only* ☐ • *Precautionary (i.e., expected to be high, but desktop level)* ☐	*Confidence rating ___________*
Natural hydrology at appropriate scale *Please provide the raw data and/or hydrological statistics for the site, but only if there is no summary report available* • *Real measured data* • *Modelled data* • *Hydrological summary statistics* • *Flow duration curves (annual/seasonal/monthly)* • *Other (e.g., ecologically relevant flow metrics)*	*Please attach or provide a link to the data*

E-flow hydrology at appropriate scale *Please provide the raw data and/or hydrological statistics for the site, but only if there is no summary report available* · *Summary table of e-flow recommendations* · *Flow percentile(s) (%flow)* · *Flow volume (Mm³/annum)* · *Discharge per month/season* · *Other (e.g., specific flow events, operating rules, diversion limits)*	*Please attach or provide a link to the data*
E-flows geomorphological, ecological and sociocultural data. *Please provide the raw data, but only if there is no summary report available (e.g., ecological reasons for specific recommended flows)* · *No geomorphological, ecological and/or sociocultural reasons documented* ☐ · *Geomorphological, ecological and/or sociocultural reasons documented* ☐	*Please attach or provide a link to the data*
Additional comments. *Please provide any relevant comment that will enable interpretation of the e-flow data provided against GEFIS*	

Annex 2. Database.

No.	Country	River	Latitude	Longitude	E-flow as a percentage of natural/naturalized Mean Annual Runoff (%)
1	Australia	Balonne	-28.78	147.93	43%
2	Australia	Balonne	-28.78	147.93	58%
3	Australia	Balonne	-28.78	147.93	77%
4	Australia	Balonne	-28.78	147.93	53%
5	Australia	Derwent	-42.69	146.91	51%
6	Australia	Glenelg	-37.92	141.27	18%
7	Australia	Glenelg	-37.37	141.21	30%
8	Australia	Glenelg	-37.17	141.59	23%
9	Australia	Lachlan	-34.35	143.95	1.54%
10	Australia	Lachlan	-34.35	143.95	2.31%
11	Australia	Macalister	-30.5	135.6	2.4%
12	Australia	Ord	-15.8	128.68	36%
13	Australia	Shoalhaven	-34.87	150.73	5%
14	Australia	Shoalhaven	-34.87	150.73	9%
15	Australia	Shoalhaven	-34.87	150.73	3%
16	Australia	Wimmera	-36.13	141.95	19%
17	Australia	Wimmera	-36.13	141.95	2%
18	Canada	West Salmon	48.2	-56.25	30%
19	China	Haihe	38.95	117.72	11.11%
20	China	Haihe	38.95	117.72	15.03%
21	China	Haihe	38.95	117.72	8.51%
22	China	Luanhe	27.06	102.21	28.51%
23	China	Luanhe	27.06	102.21	11.44%
24	China	Luanhe	27.06	102.21	16.96%
25	China	Tarim	41.06–39.40	86.62–88.5	47–61%
26	China	Zhangweixin	38.23	117.82	29.62%
27	China	Zhangweixin	38.23	117.82	53.08%
28	China	Zhangweixin	38.23	117.82	41.21%
29	Colombia	Río Palacé (Cauca)			92%
30	France	Durance	43.92	4.73	
31	France	Rhone	45.75	4.85	28%
32	Hungary	Hungary Danube	48	17.2	18–24%
33	India	Satluj	31.16	77.33	64.5%
34	Lesotho	Malibamasto	-28.47	29.33W	33%
35	Lesotho	Malibamasto	-28.47	29.33W	66%
36	Lesotho	Malibamasto	-28.47	29.33W	19%
37	Lesotho	Malibamasto	-28.47	29.33W	4%
38	Lesotho	Matsoku	-28.62	29.38W	15%
39	Lesotho	Senqunyane	-28.62	29.38W	10%
40	Mexico	Colorado	32.5	114.75W	0.71%
41	Senegal	Senegal	13.19	10.43W	60%
42	Slovenia	Rizana	45.55	13.75	4%
43	South Africa	Berg	-33.906	19.057	39%
44	South Africa	Berg	-33.906	19.057	33.6%
45	South Africa	Berg	-33.426	18.971	32.6%
46	South Africa	Bivane	-27.531	31.077	29.1%
47	South Africa	Bivane	-27.461	31.275	37.4%
48	South Africa	Bivane	-27.461	31.275	29.2%
49	South Africa	Bosemans	-33.335	26.078	30.6%
50	South Africa	Breede			33%
51	South Africa	Breede			27%
52	South Africa	Breede			29%
53	South Africa	Breede	-34.39	20.83	39%
54	South Africa	Breede	-34.39	20.83	49%

No.	Country	River	Latitude	Longitude	E-flow as a percentage of natural/naturalized Mean Annual Runoff (%)
55	South Africa	Breede	-33.72	19.158	49%
56	South Africa	Breede	-33.78	19.672	40%
57	South Africa	Breede	-34.179	20.506	35.6%
58	South Africa	Breede	-34.076	19.634	42%
59	South Africa	Breede	-34.002	19.502	71%
60	South Africa	Buffalo	-32.784	27.379	37.1%
61	South Africa	Buffalo	-32.969	27.527	26.1%
62	South Africa	Buffalo	-33.004	27.821	19.3%
63	South Africa	Crocodile	-25.425	30.789	40.8%
64	South Africa	Elands	-25.631	30.325	35.2%
65	South Africa	Elands	-25.631	30.325	48.8%
66	South Africa	Elands	-25.631	30.325	33.1%
67	South Africa	Elands	-25.566	30.668	28.4%
68	South Africa	Elands	-25.566	30.668	43.8%
69	South Africa	Gatberg	-31.294	28.169	39.7%
70	South Africa	Gatberg	-31.285	28.213	35.7%
71	South Africa	Gqunube	-32.798	27.863	18.8%
72	South Africa	Koekedou/Dwars	-33.371	19.29	24.6%
73	South Africa	Koekedou/Dwars	-33.364	19.302	23.6%
74	South Africa	Koekedou/Dwars	-33.38	19.321	22.7%
75	South Africa	Komati	-26.103	31.41	54.5%
76	South Africa	Komati	-25.684	31.778	27%
77	South Africa	Kromme	-33.931	24.261	21.8%
78	South Africa	Kromme	-33.931	24.261	29.5%
79	South Africa	Kromme	-34.013	24.498	8.1%
80	South Africa	Kromme	-34.092	24.743	17.2%
81	South Africa	Kromme	-33.998	24.7	23.5%
82	South Africa	Kromme	-34.008	24.847	3.3%
83	South Africa	Kromme	-34.008	24.847	15.4%
84	South Africa	Kromme	-34.008	24.847	24.2%
85	South Africa	Kubusi	-32.591	27.456	14.6%
86	South Africa	Kubusi	-32.564	27.687	23%
87	South Africa	Kubusi	-32.52	27.736	22.5%
88	South Africa	Letaba	-23.885	30.366	42.3%
89	South Africa	Letaba	-23.639	30.729	25.4%
90	South Africa	Letaba	-23.643	31.069	0.7%
91	South Africa	Luvuvhu	-22.836	30.758	13.1%
92	South Africa	Luvuvhu	-22.429	31.198	13.7%
93	South Africa	Matlabas	-24.121	27.449	27.1%
94	South Africa	Mhlatuze	-28.741	31.612	28.1%
95	South Africa	Mhlatuze	-28.842	31.878	25.8%
96	South Africa	Mkomazi	-29.74	29.913	30.7%
97	South Africa	Mkomazi	-29.923	30.086	25.5%
98	South Africa	Mkomazi	-30.01	30.251	33.6%
99	South Africa	Mkomazi	-30.129	30.673	33.5%
100	South Africa	Mogalakwena	-23.704	28.602	12.1%
101	South Africa	Mogalakwena	-23.502	28.662	8.6%
102	South Africa	Mogalakwena	-23.058	28.686	11%
103	South Africa	Molenaars	-33.73	19.26	42%
104	South Africa	Molenaars	-33.73	19.26	53%
105	South Africa	Molenaars	-33.73	19.26	38%
106	South Africa	Mooi	-29.1	30.175	45.2%
107	South Africa	Mooi	-29.05	30.304	40%
108	South Africa	Mtata	-31.554	29.259	36.8%
109	South Africa	Mtata	-32.001	28.854	48.3%
110	South Africa	Mtata	-31.78	28.896	15.2%

No.	Country	River	Latitude	Longitude	E-flow as a percentage of natural/naturalized Mean Annual Runoff (%)
111	South Africa	Mtata	-31.925	29.136	16%
112	South Africa	Mvoti	-29.151	30.687	23.7%
113	South Africa	Mvoti	-29.239	30.986	16.2%
114	South Africa	Mvoti	-29.245	31.031	25.1%
115	South Africa	Olifants	-32.45	18.98	56%
116	South Africa	Olifants	-25.729	29.285	18.6%
117	South Africa	Olifants	-24.468	30.416	12.1%
118	South Africa	Olifants	-24.329	30.736	8.5%
119	South Africa	Olifants	-24.423	30.825	34.5%
120	South Africa	Olifants	-24.093	31.033	23.5%
121	South Africa	Olifants	-24	30.679	31.2%
122	South Africa	Olifants	-24.022	31.143	24.8%
123	South Africa	Olifants	-24.052	31.231	21.6%
124	South Africa	Olifants	-25.489	29.244	22.5%
125	South Africa	Olifants	-25.489	29.244	19.2%
126	South Africa	Olifants	-25.673	29.342	27%
127	South Africa	Olifants	-25.673	29.342	19.7%
128	South Africa	Olifants	-25.621	29.001	29.9%
129	South Africa	Olifants	-25.311	29.426	19%
130	South Africa	Olifants	-25.311	29.426	24.6%
131	South Africa	Olifants	-25.11	28.949	16.9%
132	South Africa	Olifants	-24.56	29.537	12.6%
133	South Africa	Olifants	-24.235	30.073	15.2%
134	South Africa	Olifants	-24.864	30.044	14.5%
135	South Africa	OlifDor	-32.177	18.887	33.8%
136	South Africa	OlifDor	-31.878	18.643	36.4%
137	South Africa	OlifDor	-31.58	18.356	16%
138	South Africa	Palmiet	-34.097	19.052	56.2%
139	South Africa	Palmiet	-34.291	18.946	41.1%
140	South Africa	Palmiet	-34.332	18.989	46.6%
141	South Africa	Pienaars	-25.652	28.348	49.9%
142	South Africa	Pienaars	-25.129	27.915	26.1%
143	South Africa	Pienaars	-25.642	28.344	54.5%
144	South Africa	Sabie	-24.993	31.115	40.2%
145	South Africa	Sabie	-25.018	31.251	29.2%
146	South Africa	Sabie	-24.981	31.306	50.1%
147	South Africa	Sabie	-24.959	31.559	33.1%
148	South Africa	Sabie	-25.049	31.812	45.2%
149	South Africa	Sabie	-24.72	31.23	47.2%
150	South Africa	Sabie	-24.796	31.539	46.1%
151	South Africa	Sabie	-24.967	31.623	46.7%
152	South Africa	Swartkops	-33.723	25.317	33.6%
153	South Africa	Swartkops	-33.803	25.27	17.3%
154	South Africa	Swartkops	-33.867	25.468	18.8%
155	South Africa	Swartkops	-33.851	25.353	16%
156	South Africa	Swartkops	-33.82	25.57	16%
157	South Africa	Thukela	-28.724	29.369	29.9%
158	South Africa	Thukela	-28.724	29.369	17.3%
159	South Africa	Thukela	-29.2	30.029	18.6%
160	South Africa	Thukela	-29.2	30.029	29.9%
161	South Africa	Thukela	-29.2	30.029	43.6%
162	South Africa	Thukela	-29.117	30.135	23.5%
163	South Africa	Thukela	-29.117	30.135	36.2%
164	South Africa	Thukela	-29.117	30.135	42.1%
165	South Africa	Thukela	-28.902	30.439	23%
166	South Africa	Thukela	-28.902	30.439	35.4%

No.	Country	River	Latitude	Longitude	E-flow as a percentage of natural/naturalized Mean Annual Runoff (%)
167	South Africa	Thukela	-28.902	30.439	41%
168	South Africa	Thukela	-28.154	30.477	22.2%
169	South Africa	Thukela	-28.154	30.477	16%
170	South Africa	Thukela	-28.438	30.595	18.1%
171	South Africa	Thukela	-28.438	30.595	18.1%
172	South Africa	Thukela	-28.785	30.912	18.3%
173	South Africa	Thukela	-28.785	30.912	25.5%
174	South Africa	Thukela	-29.148	31.332	36.1%
175	South Africa	Thukela	-29.148	31.332	28.4%
176	South Africa	Thukela	-28.717	29.621	18.1%
177	South Africa	Thukela	-28.717	29.621	38.5%
178	South Africa	Thukela	-28.717	29.621	27.3%
179	South Africa	Thukela	-28.781	29.616	24.7%
180	South Africa	Thukela	-28.781	29.616	18.6%
181	South Africa	Thukela	-28.781	29.616	42.8%
182	South Africa	Thukela	-28.746	30.145	22%
183	South Africa	Thukela	-28.746	30.145	31.7%
184	South Africa	Thukela	-28.746	30.145	28.4%
185	South Africa	Thukela	-28.897	30.036	45.4%
186	South Africa	Thukela	-28.897	30.036	32.7%
187	South Africa	Thukela	-28.801	30.167	32.1%
188	South Africa	Thukela	-28.801	30.167	44.7%
189	South Africa	Thukela	-28.458	30.054	25.8%
190	South Africa	Thukela	-28.458	30.054	36.8%
191	South Africa	Thukela	-28.637	30.203	28.7%
192	South Africa	Thukela	-28.637	30.203	14.4%
193	South Africa	Thukela	-28.769	30.515	20.3%
194	South Africa	Thukela	-28.769	30.515	27.8%
195	South Africa	Vaal	-29.047	23.836	14.8%
196	South Africa	Vaal	-29.047	23.836	14.8%
197	South Africa	Vaal	-29.047	23.836	14.8%
198	South Africa	Waterval	-26.646	29.019	21.9%
199	South Africa	Waterval	-26.646	29.019	15.8%
200	South Africa	Waterval	-26.885	28.884	20.1%
201	South Africa	Waterval	-26.885	28.884	14.3%
202	Spain	Ebro/Tortosa upstream Ebro delta	31.11–42.81	0.78 to -7	18–23%
203	Tanzania	Great Ruaha/Msembe Ferry	-7.5	35	22%
204	Tunisia	Ichekuel/World Heritage site	9.67	37.17	69%
205	Tunisia	Ichekuel/World Heritage site	9.67	37.17	26%
206	Zambia	Kafue/Itezhi-Tezhi dam	-26	-15.75	18%
207	Zambia	Zambezi/Delta Marromeu Complex			
208	South Africa	Buffalo	-27.6221	29.9617	23.44%
209	South Africa	Horn	-27.888	29.921	33,65%
210	South Africa	Ncandu	-27.8017	29.884	29.36%
211	South Africa	Ngagane	-27.819	29.987	19.44%
212	South Africa	Buffalo	-28.0107	30.3931	18.15%
213	South Africa	Buffalo	-28.153	30.476	17.36%
214	South Africa	Buffalo	-28.437	30.595	23.24%
215	South Africa	Sundays	-28.3479	29.9682	31.48%
216	South Africa	Sundays	-28.458	30.053	19.71%
217	South Africa	Sundays	-28.636	30.204	19.55%
218	South Africa	Nsonge/Hlatikulu	-29.2377	29.7853	28.99%
219	South Africa	Mooi	-29.21	30.002	18.34%
220	South Africa	Mooi	-29.116	30.135	20.57%

No.	Country	River	Latitude	Longitude	E-flow as a percentage of natural/naturalized Mean Annual Runoff (%)
221	South Africa	Mnyamvubu	-29.161	30.2884	19.94%
222	South Africa	Mooi	-28.9193	30.4189	29.82%
223	South Africa	Bushmans	-28.897	30.035	29.04%
224	South Africa	Bushmans	-28.8483	30.1496	40.62%
225	South Africa	Bushmans	-28.801	30.167	30.47%
226	South Africa	Thukela	-28.722	29.376	7.04%
227	South Africa	Thukela	-28.717	29.621	17.67%
228	South Africa	Little Thukela	-28.383	29.616	24.71%
229	South Africa	Klip	-28.3952	29.7197	22.15%
230	South Africa	Thukela	-28.747	30.145	25.09%
231	South Africa	Thukela	-28.769	30.515	20.26%
232	South Africa	Thukela	-28.785	30.911	21.98%
233	South Africa	Thukela	-29.1603	31.3373	37.83%
234	South Africa	Thukela	-29.1677	31.4037	37.79%
235	South Africa	Upper Elands	-25.303074	28.46311	20.87%
236	South Africa	Lower Wilge	-25.619625	28.999047	36.28%
237	South Africa	Wilge River	-25.843984	28.871978	15.11%
238	South Africa	Olifants	-25.759183	29.309564	17.8%
239	South Africa	Klein Olifants	-25.748872	29.458649	27.47%
240	South Africa	Olifants	-25.496324	29.254597	29.83%
241	South Africa	Kranspoortspruit	-25.437714	29.475619	30.26%
242	South Africa	Selons	-25.379969	29.435557	21.86%
243	South Africa	Klein Olifants	-25.6736	29.342	19.8%
244	South Africa	Olifants	-25.304	29.422	12.51%
245	South Africa	Lower Elands	-25.116	28.9565	10.48%
246	South Africa	Spookspruit	-25.8605	29.4029	30.12%
247	South Africa	Olifants	-24.5289	29.5464	9.89%
248	South Africa	Olifants	-24.239917	30.082457	15.19%
249	South Africa	Olifants	-24.307563	30.785695	12.81%
250	South Africa	Lower Spekboom	-24.694155	30.361267	23.16%
251	South Africa	Steelpoort	-24.775	30.165	23.33%
252	South Africa	Dwars	-24.8358	30.08345	31.24%
253	South Africa	Steelpoort	-24.4965	30.399	12.69%
254	South Africa	Ohrigstad	-24.5473	30.73807	17.41%
255	South Africa	Upper Blyde	-24.734412	30.778321	46.08%
256	South Africa	Lower Blyde	-24.407481	30.827404	31.14%
257	South Africa	Lower Ga-Selati	-24.0225	31.146667	19.45%
258	South Africa	Upper Ga-Selati	-24.0012	30.6823	27.53%
259	South Africa	Olifants	-24.12843	31.01457	22.37%
260	South Africa	Olifants	-24.049426	31.731751	21.06%
261	South Africa	Letaba	-23.8268	31.59061	17.34%
262	South Africa	Letsitele	-23.893155	30.357356	17.59%
263	South Africa	Great Letaba	-23.915	30.05228	24.76%
264	South Africa	Broederstroom	-23.80068	29.97741	49.22%
265	South Africa	Shingwedzi	-23.1849	31.52508	22.5%
266	South Africa	Vaal	-26.8728	29.61384	39.41%
267	South Africa	Vaal	-26.9211	29.27929	13.61%
268	South Africa	Waterval	-26.64608	29.01857	3.5%
269	South Africa	Waterval	-26.88543	28.88357	6.4%
270	South Africa	Vaal	-26.99087	28.72971	14.3%
271	South Africa	Vaal	-26.84262	28.1123	21.55%
272	South Africa	Vaal	-26.93243	27.01367	34.1%
273	South Africa	Klip	-27.36166	29.48503	26.54%
274	South Africa	Wilge	-28.20185	29.55827	45.88%
275	South Africa	Wilge	-27.80017	28.76778	11.77%
276	South Africa	Suikerbosrand	-26.6467	28.38197	41.89%

No.	Country	River	Latitude	Longitude	E-flow as a percentage of natural/naturalized Mean Annual Runoff (%)
277	South Africa	Suikerbosrand	-26.68137	28.16798	34.39%
278	South Africa	Blesbokspruit	-26.47892	28.42488	18.14%
279	South Africa	Klein Vaal	-26.91275	30.17497	24.71%
280	South Africa	Mooi River	-26.25867	27.15973	19.05%
281	South Africa	Vaal	-26.93615	26.85025	28.28%
282	South Africa	Vaal	-27.10413	26.52185	35.8%
283	South Africa	Vals	-27.48685	26.8132	17.05%
284	South Africa	Vet	-27.93482	26.12569	18.2%
285	South Africa	Klein Vet	-28.564708	26.943946	19.54%
286	South Africa	Sand	-28.1131994	26.9080556	23.82%
287	South Africa	Sand	-28.1228333	26.5855555	23.49%
288	South Africa	Schoonspruit	-26.31172	26.31172	35.8%
289	South Africa	Schoonspruit	-26.675	26.586108	30.9%
290	South Africa	Schoonspruit	-26.93333	26.66528	31.2%
291	South Africa	Vaal	-27.65541	25.59564	13.02%
292	South Africa	Harts	-28.37694	24.30305	85.95%
293	South Africa	Vaal	-28.70758	24.07578	21.87%
294	South Africa	Crocodile	-25.8004	27.896	24.07%
295	South Africa	Jukskei	-25.9539	27.9621	29.19%
296	South Africa	Crocodile	-25.7168	27.8431	25.02%
297	South Africa	Pienaars	-25.4155	28.312	20.98%
298	South Africa	Pienaars	-25.12657	27.80457	11.82%
299	South Africa	Hex	-25.5214	27.3749	14.96%
300	South Africa	Crocodile	-24.88661	27.51743	9.14%
301	South Africa	Crocodile	-24.64476	27.32569	14.22%
302	South Africa	Magalies	-25.72655	27.56581	45.58%
303	South Africa	Elands	-25.80739	26.72044	30.48%
304	South Africa	Sterkstroom	-28.2224	27.47848	28.41%
305	South Africa	Buffelspruit	-24.8304	28.2224	35.85%
306	South Africa	Elands	-25.48108	26.69039	21.9%
307	South Africa	Waterkloofspruit	-25.48108	26.69039	28.27%
308	South Africa	Magalies	-25.8969	27.5982	21.18%
309	South Africa	Rietvlei	-26.01885	28.30442	27.83%
310	South Africa	Kaaloog-se-Loop	-25.777	26.433	76.32%
311	South Africa	Groot Marico	-25.669	26.435	50.26%
312	South Africa	Groot Marico	-25.461	26.392	23.62%
313	South Africa	Groot Marico	-24.706	26.424	7.96%
314	South Africa	Klein Marico	-25.516	26.159	4.67%
315	South Africa	Polkadraaispruit	-25.64697	26.48928	31.87%
316	South Africa	Mokolo	-24.28937	28.0924	22.6%
317	South Africa	Mokolo	-24.17828	27.97768	17.6%
318	South Africa	Mokolo	-24.06496	27.78716	19.8%
319	South Africa	Sterkstroom	-24.30554	27.89699	28.41%
320	South Africa	Mokolo	-23.968	27.72689	12.5%
321	South Africa	Mokolo	-23.7712	27.75525	16.5%
322	South Africa	MatlabasZynKloof	-24.41203	27.60324	57.07%
323	South Africa	Komati	-23.91769	30.05083	27.5%
324	South Africa	Gladdespruit	-23.25081	30.49572	26.9%
325	South Africa	Komati	-23.88806	30.36125	18.3%
326	South Africa	Teespruit	-23.75264	31.40731	35.3%
327	South Africa	Komati	-23.67753	31.09864	17.2%
328	South Africa	Lomati	-23.64939	30.66064	17.3%
329	South Africa	Crocodile	-25 29.647	30 08.656	30.3%
330	South Africa	Crocodile	-25 24.555	30 18.955	35.63%
331	South Africa	Crocodile	-25 27.127	30 40.865	48.8%
332	South Africa	Elands	-25.631	30.32625	48.82%

No.	Country	River	Latitude	Longitude	E-flow as a percentage of natural/naturalized Mean Annual Runoff (%)
333	South Africa	Elands	-25.567972	30.666694	45.02%
334	South Africa	Crocodile	-25 30.146	31 10.919	31.74%
335	South Africa	Kaap	-25 38.968	31 14.572	21.84%
336	South Africa	Crocodile	-25 28.972	31 30.464	22.2%
337	South Africa	Crocodile	-25 23.430	31 58.467	12.53%
338	South Africa	Sabie	-25 04.424	30 50.924	40.31%
339	South Africa	Mac Mac	-25 00.800	31 00.243	45.31%
340	South Africa	Sabie	-25 01.675	31 03.099	28.2%
341	South Africa	Marite	-25 01.077	31 07.997	28.57%
342	South Africa	Sabie	-24 59.256	31 17.572	37.94%
343	South Africa	Thulandziteka (Sand)	-24 40.829	31 05.188	32.67%
344	South Africa	Mutlumuvi	-24 45.352	31 07.923	28.46%
345	South Africa	Sand	-24 58.045	31 37.641	25.46%
346	South Africa	Heinesspruit	-29.13054	30.640024	27.9%
347	South Africa	Mvoti	-29.26398	31.03513	24.7%
348	South Africa	Mngeni	-29.46184	30.29832	20%
349	South Africa	Mngeni	-29.64521	30.74556	25.8%
350	South Africa	Mkomazi	-29.921	30.08448	35%
351	South Africa	Mkomazi	-29.921	30.08448	35.4%
352	South Africa	Mkomazi	-30.132	30.66245	30.7%
353	South Africa	Mngeni	-29.5125	30.09417	26.2%
354	South Africa	Karkloof	-29.4401	30.30328	43.5%
355	South Africa	Lovu	-30.09997	30.73603	37.9%
356	South Africa	Mtanvuna	-30.85608	30.07268	41.2%
357	South Africa	Tsitsa	-31.148	28.674	31%
358	South Africa	Thina	-31.072	28.913	30.1%
359	South Africa	Kinira	-30.758	28.994	33.3%
360	South Africa	Mzimvubu	-31.39636	29.29671	23.8%
361	South Africa	Groot Brak	-33°58.621'	22°11.510'	30%
362	South Africa	Malgas	-33°56.251'	22°25.278'	32%
363	South Africa	Kaaimans	-33°58.263'	22°32.864'	49.7%
364	South Africa	Goukamma/Homtini	-33°56.845'	22°55.160'	47%
365	South Africa	Diep	-33 ° 54' 48.9"	22 ° 42'29'	26.9%
366	South Africa	Karatara	-33 ° 52' 56.5"	22 ° 50' 18.7"	36.4%
367	South Africa	Knysna	-33 ° 53' 27.8"	23 ° 01' 57.1"	33%
368	South Africa	Gouna	-33 ° 59' 27.3"	23 ° 02' 29.2"	46.5%
369	South Africa	Assegaai	-27 3'44.28"	30 59'19.68"	33.32%
370	South Africa	Pongola	-27 21'50.88"	30 58'10.62"	51.33%
371	South Africa	Mkuze	-27 35'31.56"	32 13'4.80"	44.53%
372	South Africa	Black Mfolozi	-27 56'20.04"	31 12'37.08"	30.1%
373	South Africa	Black Mfolozi	-28 0'50.04"	31 19'27.48"	30.11%
374	South Africa	White Mfolozi	-28 13'53.24"	31 11'17.97"	50.27%
375	South Africa	Nseleni	-28 38'2.76"	31 55'51.24"	46.15%
376	South Africa	Matigulu	-29 1'12.36"	31 28'13.44"	43.18%
377	South Africa	Orange	-29.0055	22.16225	15.2%
378	South Africa	Orange	-28.4287	19.9983	19.2%
379	South Africa	Orange	-28.7553	17.71696	12.2%
380	South Africa	Caledon	-28.6508	28.3875	26%
381	South Africa	Caledon	-30.4523	26.27088	20.1%
382	South Africa	Kraai	-30.8306	26.92056	18.1%
383	South Africa	Touws	-33.72707	21.16507	28.2%
384	South Africa	Gamka	-33.36472	21.63051	25%
385	South Africa	Buffels	-33.38452	20.94169	28%
386	South Africa	Gouritz	-33.90982	21.65233	23.8%
387	South Africa	Keurbooms	-33.88955	23.24392	46.7%
388	South Africa	Duiwenhoks	-34.25167	20.99194	27.1%

No.	Country	River	Latitude	Longitude	E-flow as a percentage of natural/naturalized Mean Annual Runoff (%)
389	South Africa	Goukou	-34.09324	21.293	21%
390	South Africa	Doring	-33.79137	20.92699	22.8%
391	South Africa	Olifants	-33.43813	23.20587	26.1%
392	South Africa	Kammanassie	-33.73286	22.6974	21%
393	Lesotho	Senqu	-29.35442	28.80408	42.29%
394	Lesotho	Senqu	-29.5518	28.7466	38.92%
395	Lesotho	Senqu	-30.0657	28.4091	21.32%
396	Lesotho	Senqu	-30.3653	27.5737	29.33%
397	Mali	Niandan			39.32%
398	Mali	Sankarani			34.43%
399	Mali	Niger			58.12%
400	Mali	Bani			40.93%
401	Mali	Niger			63.35%
402	Mali	Niger			58.16%
403	Zambia	Kalungwishi			22.76%
404	Zambia	Kalungwishi			23.58%
405	Botswana	Limpopo	-23.944697	26.930778	
406	South Africa	Limpopo	-22.18419	29.40524	
407	Zimbabwe	Mwanedzi	-22.0639	31.42312	
408	Mozambique	Limpopo	-22.4596	31.503	
409	Mozambique	Limpopo	-23.47173	32.44381	
410	South Africa	Shingwedzi	-23.144094	31.472816	
411	Mozambique	Limpopo	-24.50018	33.01039	
412	Mozambique	Changane	-24.11416	33.78387	
413	Tanzania	Kagera	-1.24943	31.420205	57.7%
414	Kenya	Victoria Nile	0.515718	33.12336	53.5%
415	South Sudan	Bahr el Jebel	4.885574	31.646235	52%
416	South Sudan	Baro River	8.247126	34.576519	49.6%
417	South Sudan	Sobat	9.335111	31.588712	46.2%
418	Sudan	White Nile	9.538513	31.643643	64.3%
419	Sudan	Blue Nile	11.859816	34.375262	41.9%
420	Sudan	Atbara	14.364169	35.855135	30.5%
421	Sudan	Nile	19.183147	30.489857	55%
422	Kenya	Mara			42.75%
423	Kenya	Mara			43.86%
424	Kenya	Talek			42.7%
425	Kenya	Nyangores			38.64%
426	Kenya	Amala			49.71%
427	Brazil				50%
428	Brazil				50%
429	Brazil				50%
430	Brazil				50%
431	Brazil				50%
432	Brazil				50%
433	Brazil				50%
434	Brazil				50%
435	Brazil				50%
436	Brazil				50%
437	Brazil				50%
438	Brazil				50%
439	India	Reach from Gangotri to Rishikesh	30°04’29.9”	78°30’09.9”	72% in a normal year and 44% in a drought year
440	India	Reach from Narora to Farrukhabad	27°55’59.8”	78°51’42.5”	45% in a normal year and 18% in a drought year
441	India	Reach from Kannauj to Kanpur	26°36'51.9"	80°16'28.6"	47% in a normal year and 14% in a drought year

No.	Country	River	Latitude	Longitude	E-flow as a percentage of natural/naturalized Mean Annual Runoff (%)
442	Nepal	NA	Latitude and longitude not available		56%
443	Nepal	NA	Latitude and longitude not available		56%
444	Nepal	NA	Latitude and longitude not available		56%
445	Costa Rica	Reventazón	10°05' 10.08"	-83°33' 18.72"	23.33%
446	Costa Rica	Savegre	9°27' 2.76"	-83°57' 59.05"	12.06%
447	Costa Rica	Río General y Térraba	9°5' 27.77"	-83°16' 32.0"	7.9%
448	Canada	Saskatchewan	53.7069°	-103.2986°	
449	Canada	Grande Rivière	48.47777778	-64.52861111	29.45%
450	Canada	Bonaventure	48.18722222	-65.55916667	35.36%
451	Canada	Petite Cascapédia	48.23222222	-65.73305556	38.74%
452	Canada	Cascapédia	48.62916667	-66.16611111	46.20%
453	Canada	Nouvelle	48.15722222	-66.34861111	35.97%
454	Canada	Matapédia	48.49166667	-67.44888889	34.09%
455	Canada	Matapédia	48.10777778	-67.13027778	
456	Canada	Saint-Jean	48.76916667	-64.51583333	
457	Canada	York	48.83416667	-64.62805556	33.17%
458	Canada	York	48.80694444	-64.91666667	38.36%
459	Canada	Au Renard	48.98222222	-64.42694444	
460	Canada	Dartmouth	48.97777778	-64.69972222	21.86%
461	Canada	Madeleine	49.20277778	-65.29472222	44.47%
462	Canada	Sainte-Anne	49.04361111	-66.47583333	39.29%
463	Canada	Cap-Chat	49.05555556	-66.66916667	36.98%
464	Canada	Matane	48.77361111	-67.54027778	
465	Canada	Blanche	48.76694444	-67.66611111	
466	Canada	Neigette	48.51777778	-68.15972222	17.58%
467	Canada	Rimouski	48.41277778	-68.555	
468	Canada	Des Trois Pistoles	48.08916667	-69.19527778	
469	Canada	Du Loup	47.61194444	-69.64472222	18.68%
470	Canada	Ouelle	47.38111111	-69.95388889	15.28%
471	Canada	Boyer Sud	46.7075	-70.96055556	12.54%
472	Canada	Boyer	46.81583333	-70.90055556	
473	Canada	Du Sud	46.82	-70.75611111	
474	Canada	Etchemin	46.69138889	-71.06805556	26.89%
475	Canada	Beaurivage	46.65694444	-71.28888889	18.47%
476	Canada	Chaudière	46.58694444	-71.21361111	
477	Canada	Chaudière	45.69166667	-70.78527778	
478	Canada	Famine	46.16694444	-70.63916667	17.71%
479	Canada	Chaudière	46.20111111	-70.74444444	
480	Canada	Chaudière	46.09638889	-70.65444444	
481	Canada	Bras d'Henri	46.54027778	-71.34	15.69%
482	Canada	Petite du Chêne	46.50055556	-72.10833333	14.90%
483	Canada	Bécancour	46.30611111	-71.45055556	25.09%
484	Canada	Bullard	46.17555556	-71.45722222	
485	Canada	Bécancour	46.04527778	-71.44722222	
486	Canada	Bécancour	46.19472222	-72.28333333	22.27%
487	Canada	Nicolet Sud-Ouest	45.79166667	-71.96805556	
488	Canada	Nicolet	46.06027778	-72.31305556	20.18%
489	Canada	Coaticook	45.28444444	-71.90083333	
490	Canada	Eaton	45.46805556	-71.655	21.14%
491	Canada	Saint-Germain	45.87666667	-72.51027778	
492	Canada	Au Saumon	45.58	-71.385	20.94%
493	Canada	Noire	45.49972222	-72.90583333	
494	Canada	Yamaska Sud-Est	45.20611111	-72.7475	
495	Canada	David	45.95416667	-72.85972222	5.65%
496	Canada	Yamaska Nord	45.38388889	-72.50111111	
497	Canada	Yamaska Nord	45.35027778	-72.5152778	

No.	Country	River	Latitude	Longitude	E-flow as a percentage of natural/naturalized Mean Annual Runoff (%)
498	Canada	Yamaska	45.62888889	-72.93916667	
499	Canada	Noire	45.61861111	-72.60416667	
500	Canada	Des Hurons	45.49055556	-73.18583333	7.41%
501	Canada	Aux Brochets	45.12277778	-72.99638889	12.26%
502	Canada	L'Acadie	45.39027778	-73.37083333	6.10%
503	Canada	Châteauguay	45.33027778	-73.76222222	
504	Canada	Des Anglais	45.15805556	-73.82472222	8.86%
505	Canada	Doncaster	46.09638889	-74.12111111	33.66%
506	Canada	Rouge	46.35388889	-74.77916667	
507	Canada	Rouge	45.73833333	-74.68916667	
508	Canada	Saint-Louis	46.37388889	-74.50472222	23.06%
509	Canada	De la Petite Nation	45.79083333	-75.08944444	
510	Canada	Suffolk	45.88388889	-75.02166667	
511	Canada	Désert	46.47361111	-76.04277778	
512	Canada	Picanoc	46.07638889	-76.07305556	37.70%
513	Canada	Gatineau	47.08333333	-75.75361111	48.39%
514	Canada	Coulonge	45.87361111	-76.68416667	
515	Canada	Dumoine	46.34638889	-77.81555556	52.51%
516	Canada	Dumoine	46.82222222	-77.86805556	68.63%
517	Canada	Maganasipi	46.33138889	-78.34722222	29.66%
518	Canada	Kinojévis	48.36583333	-78.85444444	46.44%
519	Canada	Du Chêne	45.56027778	-73.9775	
520	Canada	Matawin	46.67722222	-73.915	39.77%
521	Canada	Croche	47.76861111	-72.735	47.76%
522	Canada	Vermillon	47.67694444	-73.04083333	
523	Canada	Batiscan	46.58555556	-72.40472222	47.21%
524	Canada	Sainte-Anne	46.8525	-71.87472222	
525	Canada	Bras du Nord	46.97666667	-71.8475	50.49%
526	Canada	Portneuf	46.70916667	-71.87416667	36.86%
527	Canada	Aux Pommes	46.69638889	-71.68777778	35.07%
528	Canada	Décharge du lac Clair	46.96638889	-71.66416667	
529	Canada	Montmorency	46.89583333	-71.15222222	
530	Canada	des Eaux Volées	47.27166667	-71.16222222	73.86%
531	Canada	des Eaux Volées	47.27055556	-71.13722222	64.82%
532	Canada	des Aulnaies	47.29	-71.16194444	60.26%
533	Canada	Noire	47.32666667	-71.10222222	
534	Canada	Du Gouffre	47.4475	-70.51	45.25%
535	Canada	Malbaie	47.69416667	-70.21777778	
536	Canada	Ouareau	46.03083333	-73.705	
537	Canada	L'Assomption	46.01305556	-73.42944444	
538	Canada	Noire	46.34055556	-73.65416667	
539	Canada	Beauport	45.89333333	-73.86555556	
540	Canada	De L'Achigan	45.84611111	-73.4925	15.37%
541	Canada	Maskinongé	46.30111111	-73.09611111	
542	Canada	Mastigouche	46.44166667	-73.46194444	
543	Canada	Du Loup	46.60055556	-73.18611111	
544	Canada	Petit Saguenay	48.18611111	-70.05	33.15%
545	Canada	Petit Saguenay	48.09166667	-70.02972222	
546	Canada	Ha! Ha!	48.27472222	-70.86722222	
547	Canada	Aux Écorces	48.18277778	-71.64472222	67.92%
548	Canada	Pikauba	47.94194444	-71.38222222	63.85%
549	Canada	Cyriac	48.23583333	-71.28861111	47.43%
550	Canada	Belle Rivière	48.41194444	-71.70361111	
551	Canada	Métabetchouane	48.37555556	-71.99666667	56.06%
552	Canada	Petite Péribonca	48.81472222	-72.04638889	53.90%
553	Canada	Ashuapmushuan	48.68555556	-72.48777778	75.31%

No.	Country	River	Latitude	Longitude	E-flow as a percentage of natural/naturalized Mean Annual Runoff (%)
554	Canada	Ashuapmushuan	49.27861111	-73.35555556	82.14%
555	Canada	Ashuapmushuan	49.25666667	-73.70777778	83.38%
556	Canada	Aux Saumons	48.68388889	-72.51277778	35.75%
557	Canada	Mistassini	48.88861111	-72.2725	73.11%
558	Canada	Mistassibi	48.89972222	-72.21083333	88.69%
559	Canada	Valin	48.48805556	-70.97222222	65.62%
560	Canada	Sainte-Marguerite Nord-Est	48.26805556	-69.90833333	53.56%
561	Canada	Des Escoumins	48.37138889	-69.47361111	
562	Canada	Portneuf	48.64833333	-69.18194444	
563	Canada	Godbout	49.33083333	-67.65472222	46.66%
564	Canada	Moisie	50.3525	-66.18666667	91.58%
565	Canada	Aux Pékans	52.18888889	-66.89055556	
566	Canada	Au Tonnerre	50.2825	-64.78194444	42.31%
567	Canada	Magpie	50.68555556	-64.57861111	82.66%
568	Canada	Aguanish	50.2475	-62.11666667	
569	Canada	Natashquan	51.14166667	-61.61027778	
570	Canada	Natashquan	50.4275	-61.71222222	79.10%
571	Canada	Étamaniou	50.38361111	-59.98972222	
572	Canada	Du Petit Mécatina	51.84361111	-60.12361111	
573	Canada	Du Petit Mécatina	50.68083333	-59.60194444	
574	Canada	Saint-Augustin	51.6125	-58.70138889	
575	Canada	Coxipi	51.50222222	-58.395	
576	Canada	Saint-Paul	51.77083333	-57.60111111	62.80%
577	Canada	Harricana	48.59777778	-78.11027778	68.10%
578	Canada	Turgeon	49.98527778	-79.095	43.80%
579	Canada	Nottaway	50.13444444	-77.42083333	100.43%
580	Canada	Waswanipi	49.69666667	-75.98472222	
581	Canada	Bell	49.75472222	-77.61694444	71.58%
582	Canada	Waswanipi	49.8575	-77.18722222	97.00%
583	Canada	Broadback	50.74583333	-76.38722222	96.06%
584	Canada	De Rupert	51.44861111	-76.86611111	113.28%
585	Canada	Témiscamie	51.08333333	-72.87722222	98.33%
586	Canada	Rupert	51.04194444	-73.80972222	129.27%
587	Canada	Pontax	51.53361111	-78.09666667	71.69%
588	Canada	Eastmain	52.17111111	-74.59166667	
589	Canada	De Pontois	53.1675	-74.4725	
590	Canada	Anistuwach	54.41527778	-78.80305556	
591	Canada	Grande rivière de la Baleine	55.23777778	-76.98472222	
592	Canada	Denys	55.00861111	-77.06361111	
593	Canada	Du Nord	56.53472222	-76.21388889	
594	Canada	Nastapoca	56.86138889	-76.20805556	
595	Canada	Aux Mélèzes	57.25861111	-71.07916667	
596	Canada	Aux Mélèzes	57.67972222	-69.61722222	
597	Canada	Swampy Bay	56.64277778	-68.56305556	
598	Canada	FALSE	57.67111111	-68.26916667	
599	Canada	À la Baleine	57.88861111	-67.6	
600	Canada	George	56.78305556	-64.86805556	
601	Canada	Dauphine	46.96666667	-70.85583333	
602	Canada	À l'Huile	49.80138889	-63.57222222	
603	Greece	Acheloos Uper part (mountainous part)	39.479443	21.32651	
604	Poland	fish biological type 1			200%
605	Poland	fish biological type 2			125%
606	Poland	fish biological type 3			155%

No.	Country	River	Latitude	Longitude	E-flow as a percentage of natural/naturalized Mean Annual Runoff (%)
607	Poland	fish biological type 4			103%
608	Poland	fish biological type 5			121%
609	Poland	fish biological type 6			108%
610	Poland	fish biological type 1			129%
611	Poland	fish biological type 2			93%
612	Poland	fish biological type 3			113%
613	Poland	fish biological type 4			74%
614	Poland	fish biological type 5			111%
615	Poland	fish biological type 6			88%
616	Poland	fish biological type 1			165%
617	Poland	fish biological type 2			111%
618	Poland	fish biological type 3			188%
619	Poland	fish biological type 4			157%
620	Poland	fish biological type 5			178%
621	Poland	fish biological type 6			164%
622	Poland	fish biological type 1			126%
623	Poland	fish biological type 2			160%
624	Poland	fish biological type 3			141%
625	Poland	fish biological type 4			153%
626	Poland	fish biological type 5			134%
627	Poland	fish biological type 6			142%
628	Poland	Skawa	49.636497	19.830306	194%
629	Poland	Kamienna	50.822537	15.439504	118%
630	Poland	Mienia	52.145127	21.273621	127%
631	Poland	Sąpólna	53.660012	15.168414	183%
632	Poland	Swider	52.13903	21.330356	136%
633	Poland	Drawa	53.217643	15.7639	144%
634	Poland	Skawa	49.636497	19.830306	93%
635	Poland	Kamienna	50.822537	15.439504	132%
636	Poland	Mienia	52.145127	21.273621	99%
637	Poland	Sąpólna	53.660012	15.168414	126%
638	Poland	Swider	52.13903	21.330356	97%
639	Poland	Drawa	53.217643	15.7639	99%
640	Poland	Skawa	49.636497	19.830306	116%
641	Poland	Kamienna	50.822537	15.439504	132%
642	Poland	Mienia	52.145127	21.273621	280%
643	Poland	Sąpólna	53.660012	15.168414	201%
644	Poland	Swider	52.13903	21.330356	186%
645	Poland	Drawa	53.217643	15.7639	120%
646	Poland	Skawa	49.636497	19.830306	150%
647	Poland	Kamienna	50.822537	15.439504	111%
648	Poland	Mienia	52.145127	21.273621	373%
649	Poland	Sąpólna	53.660012	15.168414	251%
650	Poland	Swider	52.13903	21.330356	186%
651	Poland	Drawa	53.217643	15.7639	158%

Annex 3. Distribution of Global Climate Zones.

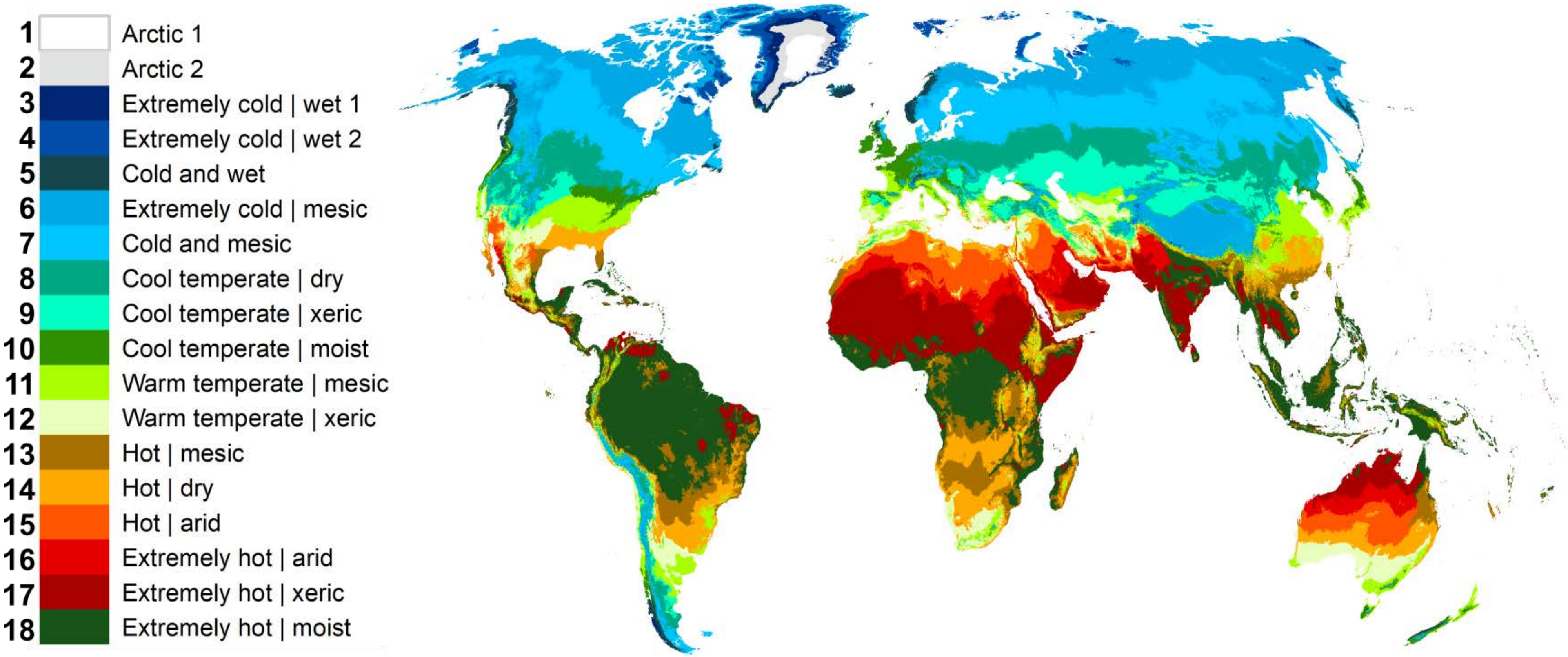
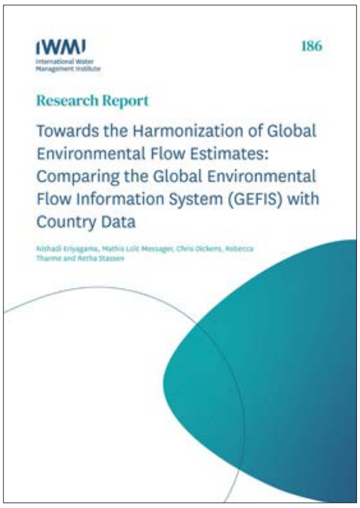


Figure A3. Distribution of global climate zones used in Figure 6.

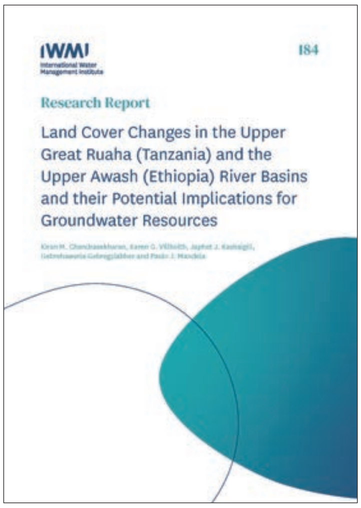
Source: Data provided by Global Environmental Stratification ([GEnS]; Metzger et al. 2013).

IWMI Research Report Series

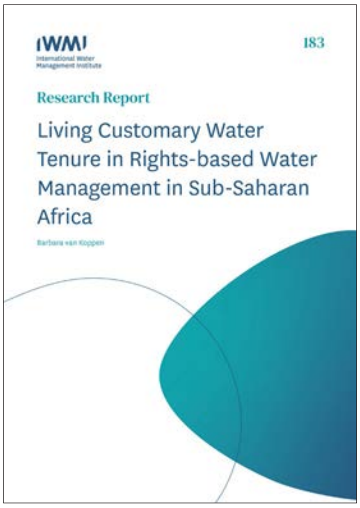


186 Towards the Harmonization of Global Environmental Flow Estimates: Comparing the Global Environmental Flow Information System (GEFIS) with Country Data
https://doi.org/10.5337/2024.204

185 Institutional Gender Mainstreaming in Small-Scale Irrigation: Lessons from Ethiopia
https://doi.org/10.5337/2023.218

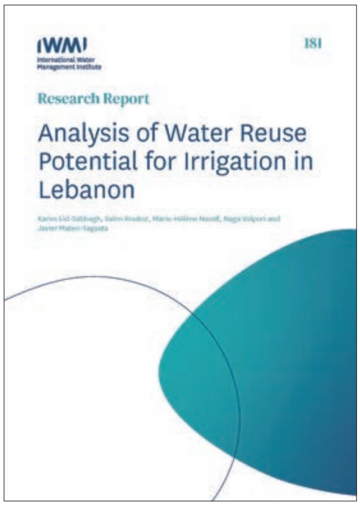


184 Land Cover Changes in the Upper Great Ruaha (Tanzania) and the Upper Awash (Ethiopia) River Basins and their Potential Implications for Groundwater Resources
https://doi.org/10.5337/2023.212



183 Living Customary Water Tenure in Rights-based Water Management in Sub-Saharan Africa
https://doi.org/10.5337/2022.214

182 Legal Recognition of Customary Water Tenure in Sub-Saharan Africa: Unpacking the Land-Water Nexus
https://doi.org/10.5337/2022.215



181 Analysis of Water Reuse Potential for Irrigation in Lebanon
https://doi.org/10.5337/2022.211

For access to all IWMI publications, visit www.iwmi.org/publications/

Headquarters
127 Sunil Mawatha
Pelawatta
Battaramulla
Sri Lanka

Mailing address
P. O. Box 2075
Colombo
Sri Lanka

Telephone
+94 11 2880000

Fax
+94 11 2786854

Email
iwmi@cgiar.org

Website
www.iwmi.org

International Water Management Institute

IWMI is a CGIAR Research Center

ISSN 1026-0862
ISBN 978-92-9090-959-0