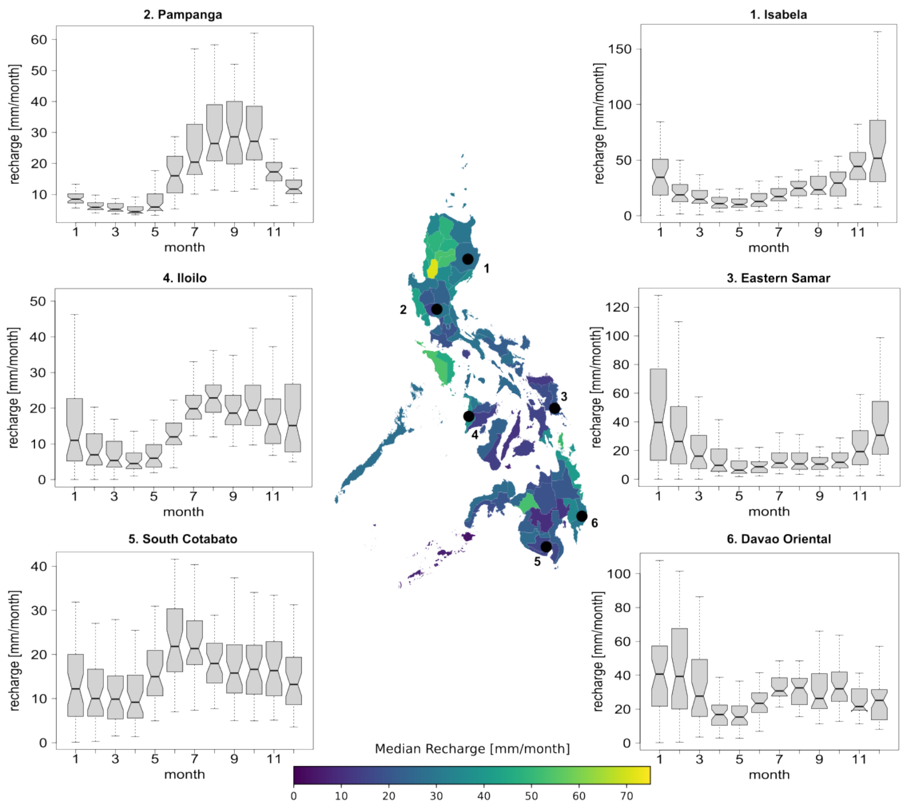

BGS DIGITAL

User Guide: BGS Philippine National Hydrological Model Dataset

Open report OR/24/023

BRITISH GEOLOGICAL SURVEY

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OPEN REPORT OR/24/023

User Guide: BGS Philippine National Hydrological Model Dataset

Johanna Scheidegger

Keywords
Hydrology, climate change, groundwater recharge, evapotranspiration, surface runoff, soil moisture .

Front cover
Groundwater recharge aggregated to Provincial levels BGS © UKRI.

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BRITISH GEOLOGICAL SURVEY

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- be resilient to environmental hazards

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Our products are supported by stakeholder focus groups, identification of gaps in current knowledge and policy assessments. They help to improve understanding and communication of the impact of geo-environmental properties and hazards in Great Britain, thereby improving society's resilience and enabling people, businesses, and the government to make better-informed decisions.

Acknowledgments

This user guide was written by Johanna Scheidegger with editorial input from Andrew Barkwith. A large number of individuals within BGS have contributed to the dataset. This assistance has been received at all stages of the study.

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Summary

The Philippine National Hydrological Model is the first national-scale hydrological model of the country. Its primary purpose is to quantify components of the hydrological cycle at the national level, with model outputs of spatio-temporal patterns of precipitation, evapotranspiration, surface runoff, river flow, groundwater recharge, and groundwater flow. The model has been developed using a version of the macro-scale hydrological modelling software Variable Infiltration Capacity (VIC), into which a gridded groundwater model has been added so that it simulates the integrated surface water and groundwater system. The model has been constructed using openly available global datasets and calibrated against local observations, principally of river flows. The resulting modelling framework provides a means to develop understanding of the water resources across the Philippines and aims to support future national water resources planning.

This report describes the model output available as monthly NetCDF raster at 2 km grid cell resolution and aggregated to district levels as csv spreadsheets. The data set is available from https://doi.org/10.5285/9a8dffe7-5bf7-496c-9d0a-99dea86c631c, (British Geological Survey, 2024).

An example of comparing the provinces of Isabela and Pampanga is given in the report and the user will be able to do similar analysis to any districts using the tools in Appendix 2. A script in the programming language R is provided to analyse regional or district wise water resource components at a monthly time step and the ability to 1) compare time-series of a component of the water cycle for a specified region, 2) create mean monthly distributions of a component of the water cycle, or 3) mean annual balance of the water balance.

This user guide provides the information required to enable the reader to understand and use this BGS data product.

1 Introduction

The Philippine National Hydrological Model Dataset provides model output from the VIC-AMBHAS hydrological model in the Philippines from 1979-2018. The model simulates evapotranspiration, runoff, infiltration, soil moisture, river baseflow and groundwater levels. Aggregated variables at a monthly time interval are provided in this dataset in NetCDF format (**Figure 1**) or aggregated to provincial level in csv format. The provincial levels are based on the first level subdivisions from GADM (https://gadm.org/maps/PHL_1.html). The dataset is available from (British Geological Survey, 2024).

This dataset can be used to assess the current state and historical changes to the water availability across the Philippines. In the future, climate change scenarios will be made available in addition to the historic dataset presented here. For a more extensive description, the user is referred to Scheidegger et al. (2023).

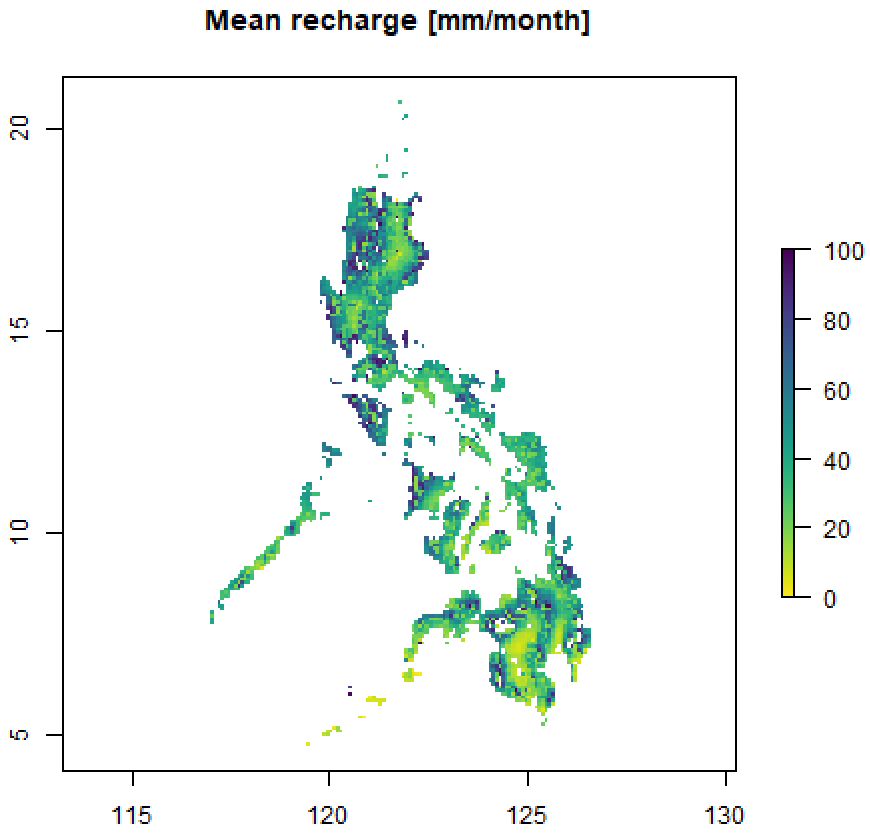


Figure 1 Mean groundwater recharge 1979-2018 at 10 km resolution BGS © UKRI

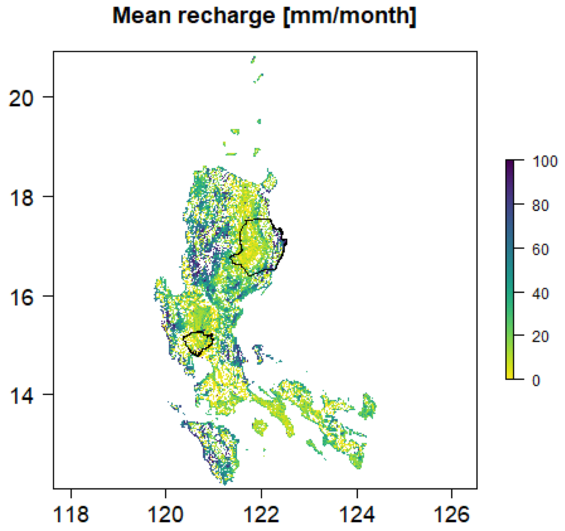
2 Case study: Data processing of an example region

Water security is of particular concern for Philippine cities, which have been designated amongst the worst in Asia for urban water security (Asian Development Bank, 2016). Climate change impacts on water resources are analysed using outputs from the VIC hydrological model. Output from the model can be used as national comparison in components of the hydrological cycle as outlined in (Scheidegger et al., 2023), or regional comparison of two case studies (Scheidegger et al., 2022). For a full case study of hydrological modelling for Panay and Pampanga, Philippines 1979-2089, the reader is referred to Scheidegger et al. (2022).

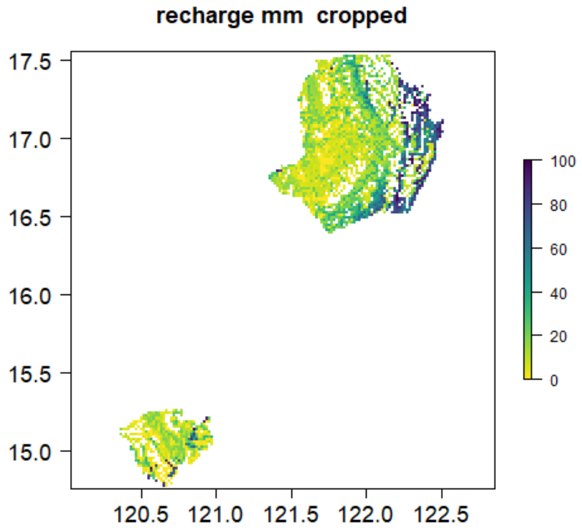
In **Figure 2**, the simulated groundwater recharge is presented for the 'North' model (a). The output from the 'North' model is then cropped to two polygons, Isabela and Pampanga (b). Time-series of groundwater recharge (c), 12 month moving average of groundwater recharge (d) and a boxplot of monthly recharge values (e). A script to extract these examples and extract values for a province is found in Appendix 2.

The province of Isabela receives high values of recharge close to the coastal regions (**Figure 2 a**) and this results in higher mean annual values (28 mm/month) compared to Pampanga (16.9 mm/month). Over a seasonal cycle, this difference is especially pronounced from November-February, when the mean recharge in Isabella is on average 26.5 mm/month higher than in Pampanga (**Figure 2 e**). The water balance for the two districts is shown in **Figure 2 f.** Whereas the absolute components of the water balance differ between the two districts, the relative components are within 1%. ET, Runoff and Baseflow are close to the amount of precipitation, however the discrepancy is because of a change in soil moisture and groundwater store.

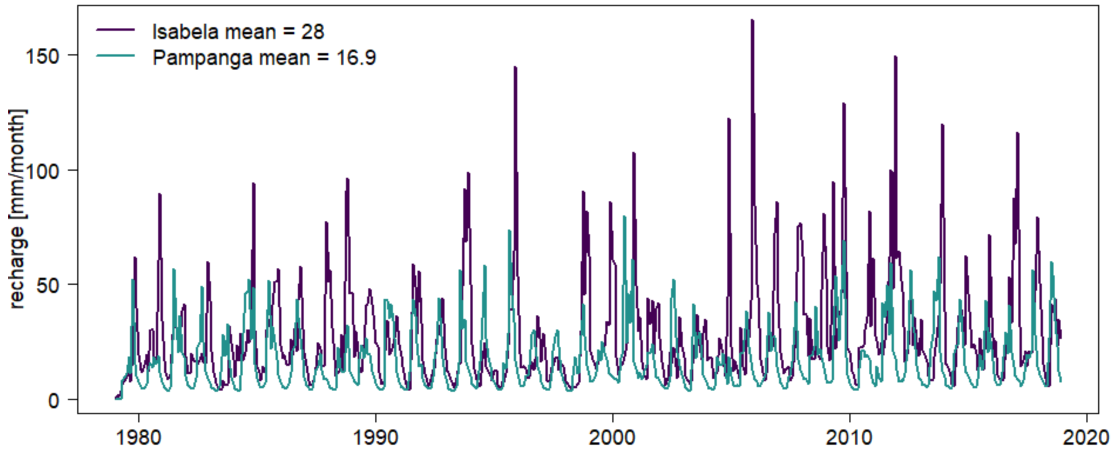
a)


Mean recharge [mm/month]
20
18
16
14
118
120
122
124
126
100
80
60
40
20
0

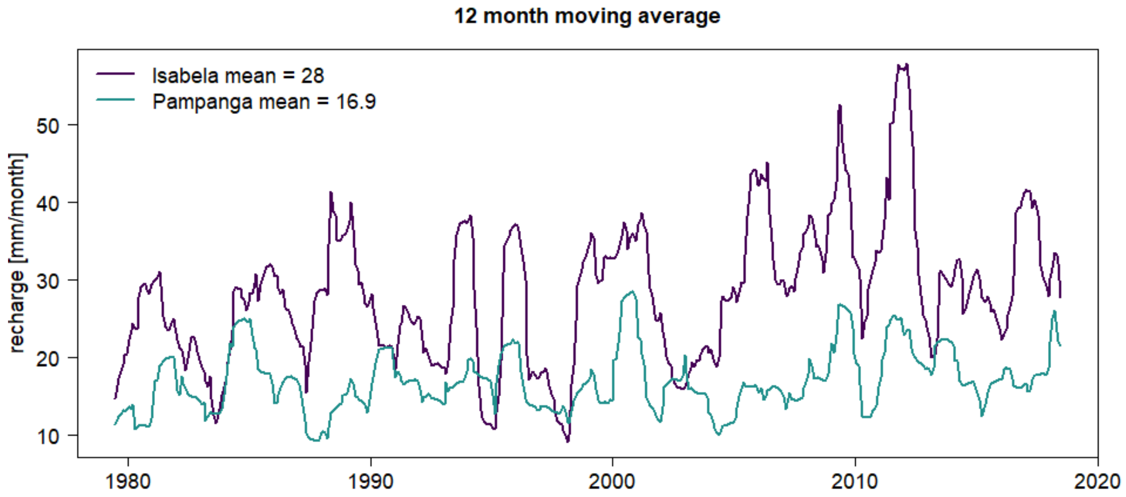
b)


recharge mm cropped
17.5
17.0
16.5
16.0
15.5
15.0
120.5
121.0
121.5
122.0
122.5
100
80
60
40
20
0

c)


Isabela mean = 28
Pampanga mean = 16.9
recharge [mm/month]
150
100
50
0
1980
1990
2000
2010
2020

d)


12 month moving average
Isabela mean = 28
Pampanga mean = 16.9
recharge [mm/month]
50
40
30
20
10
1980
1990
2000
2010
2020

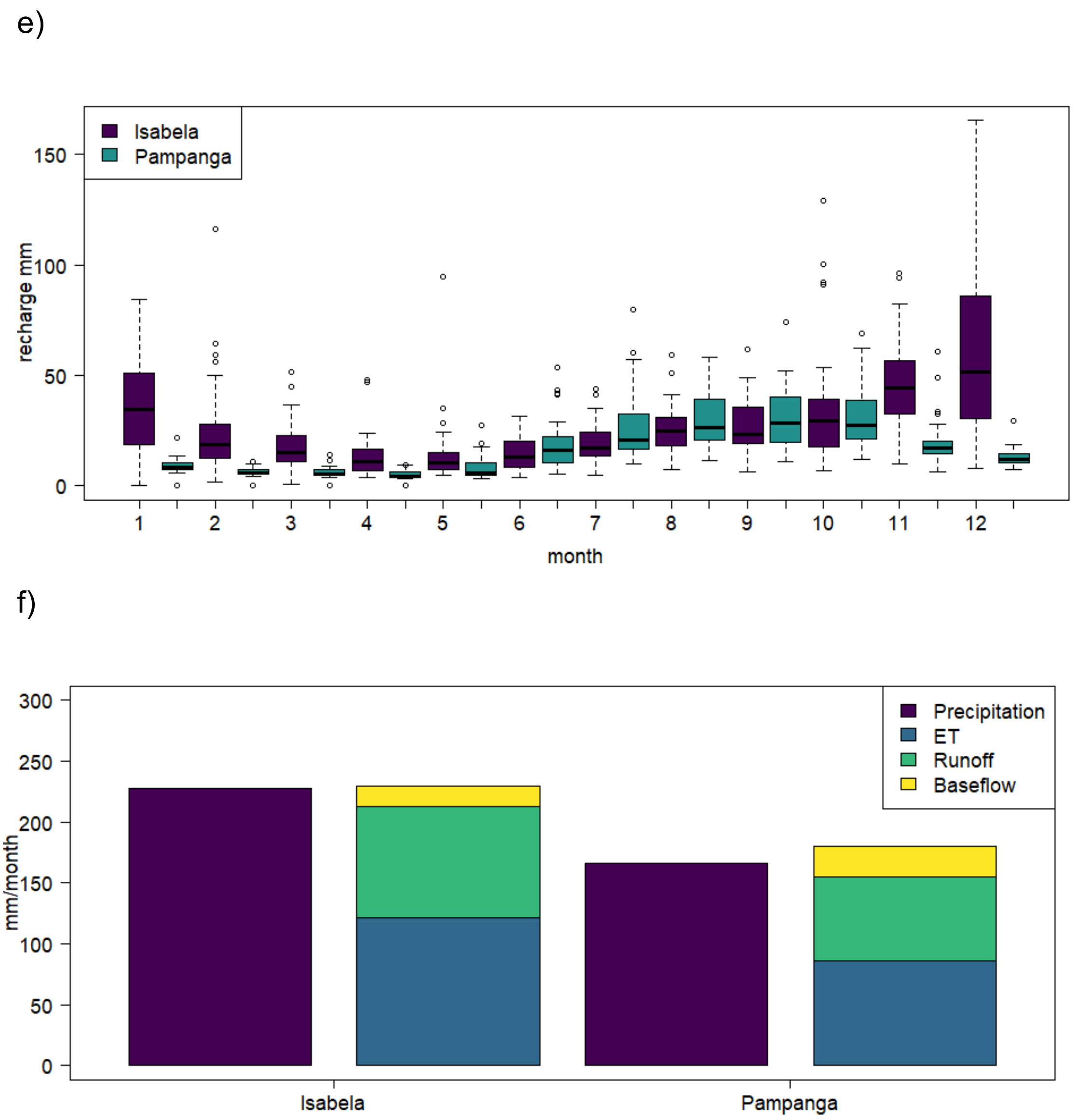


Figure 2 (a) Distributed mean recharge, (b) cropped mean recharge for two regions of Isabela and Pampanga, (c) recharge timeseries of the two regions, (d) 12 month moving average of recharge for both regions, (e) box plots mean monthly recharge and (f) precipitation partitioned into evapotranspiration, runoff and baseflow. Contains modified Copernicus Climate Change Service information (Hersbach et al., 2018). BGS © UKRI.

3 Methodology

For a more detailed description of the methodology, the reader is referred to (Scheidegger et al., 2023; Scheidegger et al., 2022; Scheidegger et al., 2021).

3.1 OVERVIEW

To simulate groundwater recharge in the Philippines, we use the integrated VIC-AMBHAS hydrological model coupled to a lateral groundwater flow model (**Figure 3**), as developed by Scheidegger et al. (2021). VIC is a macro-scale hydrological model, which has been applied widely for water and energy balance studies (Hamman et al., 2018). The model describes full water and energy transport over a grid cell. When precipitation reaches the land surface, it is partitioned into runoff and infiltration. To accumulate flows at river gauging stations, routing of runoff and baseflow is performed by post-processing model output (Lohmann et al., 1996).

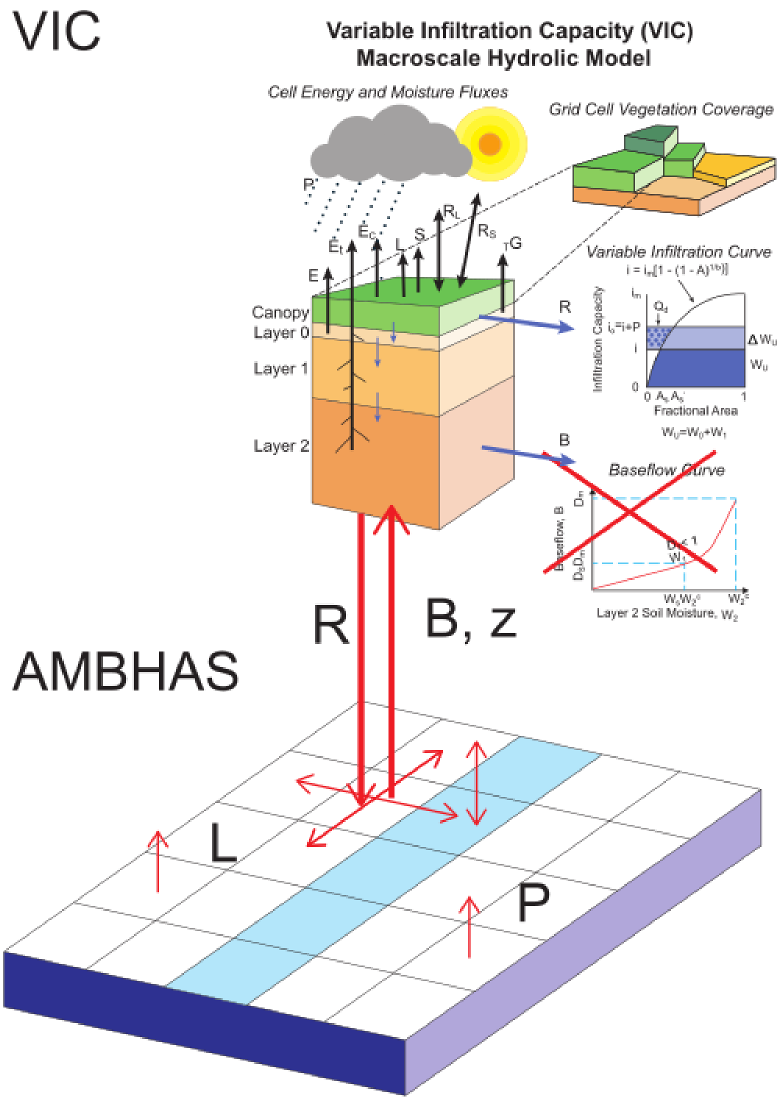


Figure 3 VIC-AMBHAS model framework. The soil column in VIC is coupled using bi-directional exchange of water between the soil and the aquifer. The aquifer allows for river baseflow, abstraction and leakage BGS © UKRI.

The lateral groundwater model coupled to VIC is a distributed, one-layer, two-dimensional groundwater model driven by groundwater recharge and groundwater pumping. Groundwater recharge is derived from interaction of the groundwater model with the VIC soil by allowing bi-directional exchange of water between the aquifer and the soil. A full description of the lateral groundwater model and coupling to VIC is given by Scheidegger et al. (2021).

3.2 SOURCE DATASETS

The model is run on a 1/60° (~2 km) grid across the country and is driven with openly available global datasets. The model is parameterised with spatially distributed parameters from a range of sources that describe the land surface, including soil properties and vegetation properties. The soil properties such as field capacity, plant available water, wilting point, saturated hydraulic conductivity, and residual saturation for the VIC model are taken from a global high-resolution map of soil hydraulic properties (Zhang and Marcel, 2018). Quartz fraction and bulk density values are from SoilGrid1km (Hengl et al., 2014). Landcover vegetation parameters are taken from Modis (Friedl and Sulla-Menashe, 2015), leaf area index and albedo from Copernicus (Smets et al., 2019), and vegetation height from LiDAR-derived Global Estimates of Forest Canopy Height (Healey et al., 2015). The groundwater part of the model requires values for hydraulic conductivity and specific yield, which are classified based on the groundwater availability map of the Philippines (Bureau of Mines and Geo-Sciences and Ministry of Natural Resources, 1986). A full description of the model input is given in Appendix 1.

The VIC model is driven by meteorological forcing data using a gridded, sub-daily time-series of meteorological variables as input. Average air temperature, total precipitation, atmospheric pressure, incoming shortwave radiation, incoming longwave radiation, vapor pressure, and wind speed are required. For the historical simulation (1979 – 2018), ERA5 hourly data from 1979 to present are used (Hersbach et al., 2018). The meteorological forcing data is at 0.25°, and hence a much coarser resolution than the soil and vegetation parameters. Therefore, the meteorological forcing data were downscaled to match the model grid using the delta method (Moreno and Hasenauer, 2016).

4 Technical Information

Two datasets are provided for the Philippine National Hydrological model output. 1) Output aggregated to province levels using the first level subdivision from GADM and the 2) the raw data in 2km grid cell resolution.

4.1 DATA FORMAT

Two data formats are available: a raster dataset in NetCDF format and processed data at provincial level in csv. NetCDF (network Common Data Form) is a self-describing, portable, scalable, appendable, shareable, and archivable data format.

4.1.1 VIC model output in NetCDF

The BGS Philippine National Hydrological Model Dataset is available as a NetCDF raster dataset with output provided in monthly intervals starting from January 1979 to December 2018.

4.1.2 Provincial aggregated data as csv

The provincial aggregated datasets are provided as csv files. The provincial levels are based on the first level subdivisions from GADM (https://gadm.org/maps/PHL_1.html).

4.2 SCALE

The Philippine National Hydrological model has been developed at 1/60° (~2 km) grid resolution and is not suitable for use at larger (i.e. more detailed) scales. The datasets used are predominantly datasets at global spatial extent, and therefore the output should be used as a regional comparison, rather than a point scale evaluation.

4.3 COVERAGE

The extent of the datasets covers the Philippines, as shown in **Figure 1**. The geographic projection is WGS84.

The VIC model output for the raster output is divided into four files:

- North_2km_RUN68.1979-01.nc

  xmin: 119.6417

  xmax: 124.5083
  ymin: 12.10833
  ymax: 20.925

- Center_2km_RUN68.1979-01.nc

  xmin: 120.9083

  xmax: 126.0583

  ymin: 8.941667

  ymax: 12.775

- South_2km_RUN68.1979-01.nc

  xmin: 121.3583

  xmax: 126.6917

  ymin: 5.258333

  ymax: 10.55833

- West_2km_RUN68.1979-01.nc

xmin: 116.825

xmax: 122.025

ymin: 4.541667

ymax: 12.40833

4.4 OUTPUT VARIABLES

4.4.1 VIC model output in NetCDF

Table 1 shows the VIC model output variables of the BGS Philippine National Hydrological Model dataset, in NetCDF format. The output is given in monthly time intervals starting from January 1979 to December 2018.

Table 1 Output variables of the VIC model output.

Field name	Field description
OUT_PREC	Incoming precipitation [mm/month].
OUT_INFLOW	Moisture that reaches top of soil column [mm/month]
OUT_EVAP	Total net evaporation [mm/month]
OUT_RUNOFF	Surface runoff [mm/month]
OUT_RECHARGE	Groundwater recharge [mm/month]. Bi-directional flux between the soil and the aquifer. Positive values are groundwater recharge and negative values are groundwater discharge.
OUT_SOIL_MOIST	Total soil moisture content for each soil layer [mm]
OUT_DELSOILMOIST	Change in soil water content [mm/month]
OUT_BASEFLOW_AQ	Baseflow from aquifer to river [mm/month]
OUT_Z	Depth to groundwater below DEM [mm]

4.4.2 Provincial aggregated data as csv

The output aggregated to province level is the same as presented in the Philippines National Hydrological model web-tool. It is based on the 2km model output. A csv for the following variables is available:

- Precipitation [mm/month]: Prec_all.csv
- Evapotranspiration [mm/month]: Et_all.csv
- Surface runoff [mm/month]: Runoff_all.csv
- Groundwater recharge [mm/month]: Recharge_all.csv

For each variable, the following model output is given:

- columns A-RM: monthly model output starting in January 1979 to December 2018. The naming convention is VAR YEAR.MONTH.DAY, where VAR is the variable.
- Columns RN-RY: Mean monthly model output from 1979-1998. The naming convention is VAR_mean_1979-1998_MONTH.
- Columns RZ-SB: seasonal outputs for annual, wet-season and dry-season aggregates for 1979-1998. The naming convention is VAR_mean_1979-1998_SEASON.
- Columns SC-SN: Mean monthly model output from 1999-2018. The naming convention is VAR_mean_1999-2018_MONTH.

- Columns SO-SQ: seasonal outputs for annual, wet-season and dry-season aggregates for 1999-2018. The naming convention is VAR_mean_1999-2018_SEASON.
- SR. Name of the Province.

5 Licencing the data

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- British Geological Survey. (2024). Philippine National Hydrological Model Dataset. NERC EDS National Geoscience Data Centre. (Dataset). https://doi.org/10.5285/9a8dffe7-5bf7-496c-9d0a-99dea86c631c

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- Apps
- Map data downloads
- Web services
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- Publications
- Scanned records
- Data collections
- Software

Please refer to OpenGeoscience, see www.bgs.ac.uk/Opengeoscience for more information and a full listing of datasets and services available under this service.

5.3 CONTACT INFORMATION

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NG12 5GG
Direct Tel: +44(0)115 936 3143
Email: digitaldata@bgs.ac.uk

6 Limitations

6.1 DATA CONTENT

The Philippine National Hydrological Model Dataset has been modelled based on openly available global datasets for soil and vegetation properties, land cover, and aquifer properties (Section 3.2). Consequently, the values within this dataset are limited by the components on which they are based. Given the methodology described within this document (Section 3.1) the value provided here are to the best of our knowledge and current data holdings.

6.2 SCALE

The high-resolution model was run at a 2 km grid cell resolution and the data has been aggregated to province levels. However, given the uncertainty of the model inputs and driving data, the output should only be used for regional scale assessment and not for point based analysis.

6.3 ACCURACY AND UNCERTAINTY

The Philippine National Hydrological Model Dataset has only been calibrated to observed streamflow data available from the National Hydrologic Data Collection Program (Department of Public Works and Highways, 2016). All other variables apart from runoff and baseflow are uncalibrated and their uncertainty is unknown.

Comparison of observed and simulated flow (**Figure 4**) shows that 96% of the simulated river flows are within one order of magnitude of the observed river flow, that 81% are within half an order of magnitude of observed stream flow, and 55% within a quarter of order of magnitude. This means that for a hypothetical stream flow of 10^8 m^3/month one order of magnitude would be simulated flows between 10^7 m^3/month to 10^9 m^3/month, a range of half an order of magnitude is between 3.2×10^7 m^3/month to 3.2×10^8 m^3/month and a range of a quarter order of magnitude 5.6×10^7 m^3/month to 1.8×10^8 m^3/month. Only 28% of the simulated river flows are within 26% of observed flow. Reasons for the discrepancy are many, from the model conceptualisation, the change in flow regime after the 1991 eruption of Mount Pinatubo and the change in the flow regime thereafter, the lack of representing water management operations and irrigation practices, or the coarse resolution of the meteorological driving data and model parameterisation.

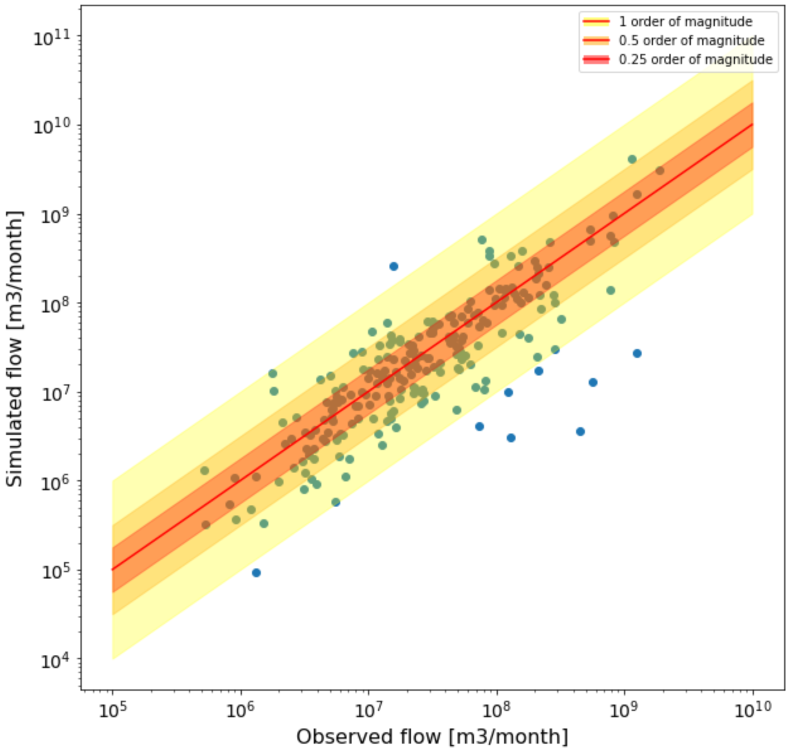

Figure 4 Comparison of simulated mean river flows and observed river flows obtained from the Department of Public Works and Highways (2016).

In the model, the aquifer is represented as a one layer, unconfined aquifer that is connected to the soil column. Confined aquifers, or attenuation of recharge through an unsaturated zone are not represented. This could lead to an overestimation of recharge under mountainous regions where the groundwater table is low.

6.4 ARTEFACTS

In the groundwater model part, groundwater is recharged from the land surface and is discharging into rivers, leaving the aquifer along the coast (set as a specified head boundary) and is allowed to discharge through the soil, where groundwater is shallow. As only the major rivers are implemented, groundwater levels can be too shallow where the river network is absent but required for draining the aquifer (**Figure 5b**). Since the variable OUT_RECHARGE represents the bi-directional flux between the soil and the aquifer, OUT_RECHARGE can become negative where groundwater is discharging to the surface. In **Figure 5c**, only the positive groundwater recharge is shown, leaving negative values as missing values. The user can filter these values out, by setting the values of OUT_RECHARGE that are smaller than 0 to NA and taking a regional average.

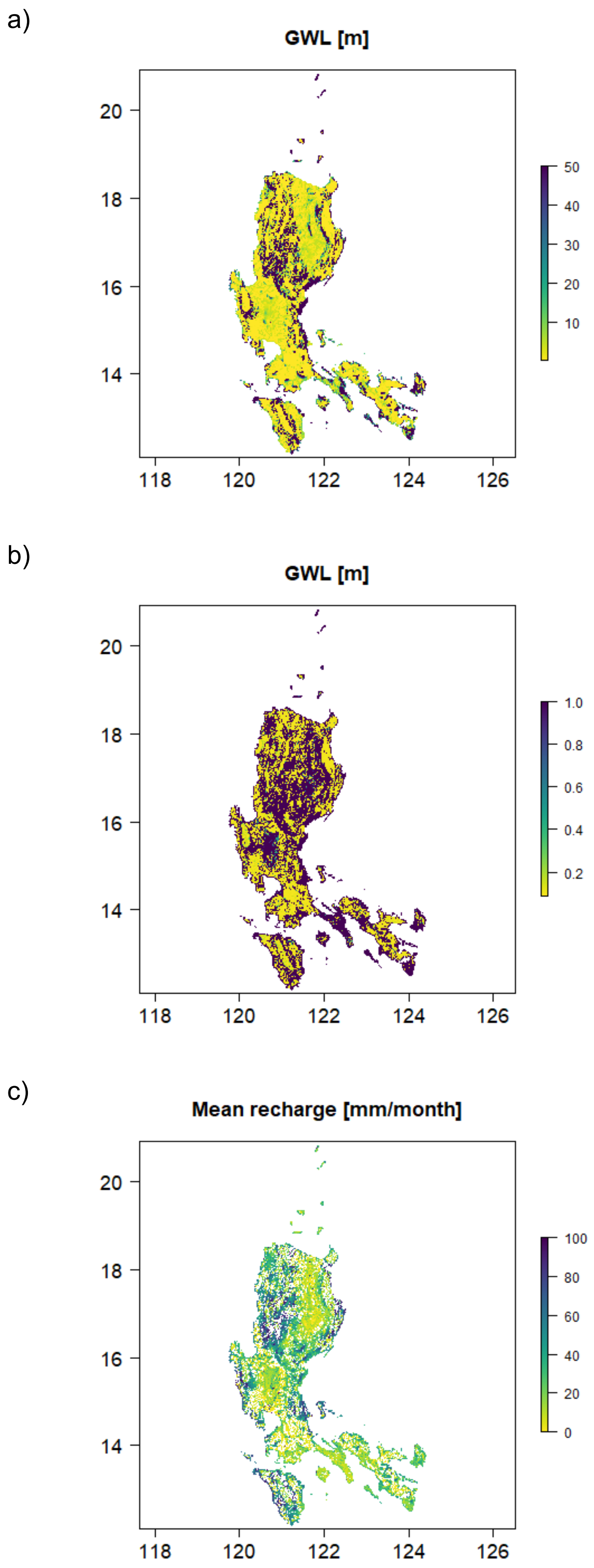

Figure 5 a) Groundwater level, b) groundwater level up to 1 m and c) groundwater recharge. For c) only positive values of groundwater recharge is shown, missing values represent areas of groundwater discharge.

Another artefact of the model is that the groundwater levels have not reached a complete steady state before the simulation started. The model has been spun up using mean climatology, however once running the historic timeseries, the simulated hydraulic heads responded to the changing climate. This is a limitation of the model. However, the mean water balance effect of the changing groundwater levels is 1.8 mm/month or 0.08% of rainfall for the ‘North’ model, which is minimal on a regional level.

6.5 DISCLAIMER

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7 Frequently asked questions

These questions and answers have been provided to address any potential issues relating to how the product can be used or how it can be interpreted. If you have any additional questions, please contact digitaldata@bgs.ac.uk

Q: What does the BGS Philippine National Hydrological Model Dataset show?
A: This dataset shows monthly model outputs of the VIC hydrological model output of the Philippines at 2 km resolution and output aggregated to province levels.

Q: What areas does the BGS Philippine National Hydrological Model Dataset cover?
A: This dataset covers the Philippines.

Q: In what data formats can the BGS Philippine National Hydrological Model Dataset be provided?
A: The dataset is provided as NetCDF format. Aggregated output to province level is provided as csv. More specialised formats may be available but may incur additional processing costs. Please email iprdigital@bgs.ac.uk to request further information.

Q: At what map scale is the BGS Philippine National Hydrological Model Dataset provided?
A: The high-resolution model was run at a 2 km grid cell resolution. Given the uncertainty of the model inputs and driving data, the output should only be used for regional scale assessment and not for point based analysis

Q: How accurate is the BGS Philippine National Hydrological Model Dataset?
A: The Philippine National Hydrological Model is calibrated against streamflow data only at a National level. All other parameters are uncalibrated.

Q: How often will the BGS Philippine National Hydrological Model Dataset be updated?
A: There are no updates planned for this dataset.

Q: Can I use the BGS Philippine National Hydrological Model Dataset as part of a commercial application?
A: This dataset is licenced from BGS, please refer to the terms of your licence or contact iprdigital@bgs.ac.uk for further information.

Appendix 1 VIC model input parameters

Parameters and sources for the VIC parameters are listed in the tables below:

Table 2 Description of variable name, units and dimensions for the VIC global parameter file.

Variable number	Variable name	Units	Precision	Number of dimensions	Dimensions
1	mask	m2	int	2	lon, lat
2	layer	-	int	1	nlayer
3	run_cell	N/A	int	2	lon, lat
4	gridcell	N/A	int	2	lon, lat
5	lats	degrees	double	2	lon, lat
6	lons	degrees	double	2	lon, lat
7	infilt	mm/day	double	2	lon, lat
8	Ds	fraction	double	2	lon, lat
9	Dsmax	mm/day	double	2	lon, lat
10	Ws	fraction	double	2	lon, lat
11	c	N/A	double	2	lon, lat
12	expt	N/A	double	3	lon, lat, nlayer
13	Ksat	mm/day	double	3	lon, lat, nlayer
14	phi_s	mm/mm	double	3	lon, lat, nlayer
15	init_moist	mm	double	3	lon, lat, nlayer
16	elev	m	double	2	lon, lat
17	depth	m	double	3	lon, lat, nlayer
18	avg_T	C	double	2	lon, lat
19	dp	m	double	2	lon, lat
20	bubble	cm	double	3	lon, lat, nlayer
21	quartz	fraction	double	3	lon, lat, nlayer
22	bulk_density	kg/m3	double	3	lon, lat, nlayer
23	soil_density	kg/m3	double	3	lon, lat, nlayer
24	off_gmt	hours	double	2	lon, lat
25	Wcr_FRACT	fraction	double	3	lon, lat, nlayer
26	Wpwp_FRACT	fraction	double	3	lon, lat, nlayer
27	rough	m	double	2	lon, lat
28	snow_rough	m	double	2	lon, lat
29	annual_prec	mm	double	2	lon, lat

30	resid_moist	fraction	double		3	lon, lat, nlayer
31	fs_active	binary	int		2	lon, lat
32	cellnum	N/A	double		2	lon, lat
33	AreaFract	fraction	double		3	lon, lat, snow_band
34	elevation	m	double		3	lon, lat, snow_band
35	Pfactor	fraction	double		3	lon, lat, snow_band
36	veg_descr	string		1	1	veg_class
37	Nveg	N/A	int		2	lon, lat
38	Cv	fraction	double		3	lon, lat, veg_class
39	root_depth	m	double		4	lon, lat, root_zone, veg_class
40	root_fract	fraction	double		4	lon, lat, root_zone, veg_class
41	LAI	m2/m2	double		4	lon, lat, month, veg_class
42	overstory	N/A	int		3	lon, lat, veg_class
43	rarc	s/m	double		3	lon, lat, veg_class
44	rmin	s/m	double		3	lon, lat, veg_class
45	wind_h	m	double		3	lon, lat, veg_class
46	RGL	W/m^2.	double		3	lon, lat, veg_class
47	rad_atten	fraction	double		3	lon, lat, veg_class
48	wind_atten	fraction	double		3	lon, lat, veg_class
49	trunk_ratio	fraction	double		3	lon, lat, veg_class
50	albedo	fraction	double		4	lon, lat, month, veg_class
51	veg_rough	m	double		4	lon, lat, month, veg_class
52	displacement	m	double		4	lon, lat, month, veg_class

Table 3 Description and data source of variables for the VIC global parameter file.

Variable number	Variable name	Source	Description
1	mask	(Global Administrative Areas, 2012)	Country and Island outline
2	layer	-	-
3	run_cell	-	1 = Run Grid cell, 0 = Do not Run
4	gridcell	-	Grid cell number
5	lats	-	Latitude
6	lons	-	Longitude
7	infilt	callibration parameter	Variable Infiltration parameter (binfilt). The binfilt parameter is the parameter used to describe the Variable Infiltration Curve. This is typically a value that is adjusted during the calibration of the VIC model. Parameter values range from 10-5 to 0.4. Higher values The b_infilt parameter is the parameter used to describe the Variable Infiltration Curve. This is typically a value that is adjusted during the calibration of the VIC model. Parameter values range from 10-5 to 0.4. Higher values will produce more runoff. 0.2 is often used as a starting value.
8	Ds	Dummy, not used	The soil parameter Ds represents the fraction of the Dsmax parameter at which non-linear base-flow occurs. This is typically a parameter that is adjusted during the calibration of the VIC model. An initial value of 0.001 may be used. Typically this value is small (less than 1). For the coupled VIC-AMBHAS model, this parameter is not used in the simulation, but needs to be given in the input files.
9	Dsmax	Dummy, not used	The parameter Dsmax is the maximum velocity of baseflow for each grid cell. This can be estimated using

			the saturated hydraulic conductivity, Ksat, for each grid cell multiplied by the slope of the grid cell. The values for Ksat can be averaged for the layers for which baseflow will be included. When working in decimal degrees, the elevation data for the basin should be projected to an equal area map projection, in order to have horizontal dimensions in the same units as the vertical dimensions so that the slopes computed in Arc/Info are meaningful lues. For the coupled VIC-AMBHAS model, this parameter is not used in the simulation, but needs to be given in the input files.
10	Ws	Dummy, not used	The parameter Ws is the fraction of maximum soil moisture where non-linear baseflow occurs. As with the Ds parameter, this is generally adjusted during the calibration phase of applying the VIC model. Values for Ws are typically greater than 0.5. An initial value of 0.9 can be used. For the coupled VIC-AMBHAS model, this parameter is not used in the simulation, but needs to be given in the input files.
11	c	Dummy, not used	c Exponent used in baseflow curve, normally set to 2. For the coupled VIC-AMBHAS model, this parameter is not used in the simulation, but needs to be given in the input files.
12	expt	Calculated from wilting point and field capacity by Zhang and Marcel (2018). https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/UI5LCE The wilting point is given at h = 15000 cm, and the field capacity at h = 330 cm. b = slope of the retention curve in log – log space expt = 3 + 2*b	Exponent n (=3+2/lambda) in Campbells eqn for hydraulic conductivity, HBH 5.6 (where lambda = soil pore size distribution parameter). Values should be > 3.0

13	Ksat	Zhang and Marcel (2018) https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/UI5LCE	Saturated hydraulic conductivity mm/d
14	phi_s	Zhang and Marcel (2018) https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/UI5LCE	Soil moisture diffusion parameter
15	init_moist	Initial soil moisture is set to porosity * layer depth	init_moist in mm Initial moisture content of each layer can be set at any reasonable value. One approach is to use fractional soil moisture content (expressed as a fraction of the maximum soil moisture; max. soil moisture = porosity * layer depth) at the critical point, Wcr, which can be computed for each layer as a depth in i meters by multiplying Wcr by the thickness of the layer in meters, and then multiplying by 1000
16	elev	SRTM dtm 90 m (Jarvis et al., 2008)	Average elevation of grid cell
17	depth		Thickness of each soil moisture layer. This is set to 0.1, 0.5, 2m below ground
18	avg_T	Fick and Hijmans (2017). https://www.worldclim.org/data/worldclim21.html	Average soil temperature. This parameter is the temperature of the soil at the damping depth. This temperature is often assumed to be the same as the average annual air temperature. This temperature is used as the bottom boundary of all thermal flux calculations made for the soil column.
19	dp	4m	This is the soil thermal damping depth. It is defined as the depth in the soil column at which the soil temperature remains nearly constant annually. This is the depth to which soil thermal flux calculations will be made, and is often set to 4m. The constant temperature at this boundary is defined with the parameter avg_T.
20	bubble	bubble =0.32*expt + 4.3	The bubble parameter is the bubbling pressure, h, for the soil texture type (see, e.g., Table 5.3.2 in Rawls, et al (Handbook of Hydrology)). This parameter is necessary for running the VIC model with FULL_ENERGY==TRUE

			or FROZEN_SOIL==TRUE. Values must be > 0.0. If you have a VIC soil parameter file created for water-balance mode runs, in which bubbling pressure has been set to a "nodata" value such as -99, you will not be able to use this soil parameter file for FULL_ENERGY==TRUE or FROZEN_SOIL==TRUE. However, a quick way to estimate bubbling pressure from the existing soil parameters (namely the expt parameter) is: bubble = 0.32*expt + 4.3 This is illustrated in figure 1, generated by taking the data from table 5.3.2 in Rawls, et al (Handbook of Hydrology), computing expt from lambda, and performing a linear regression.
21	quartz	SoilGrid1km variable SNDPPT(Hengl et al., 2014)	Quartz content of soil. Here the sand fraction is used.
22	bulk_density	SoilGrids1km BLDFIE (Hengl et al., 2014)	Bulk density of organic portion of soil.
23	soil_density	Soil particle density, normally 2685 kg/m3	Soil particle density of organic portion of soil.
24	off_gmt	-	Time zone offset from GMT.
25	Wcr_FRACT	Calculated from Zhang using phi_s and the field capacity as follows: phi=phi_s*(0.7*FieldCapacity/psi_s)^(-1/b) Wcr_FRACT=phi/phi_s https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/UI5LCE	The parameter Wcr_FRACT (Wcr) is the fractional soil moisture (expressed as a fraction of the maximum soil moisture; max. soil moisture = porosity * layer depth) at the critical point, which is the water content below which hydraulic conductivity begins to fall below saturated values, as does transpiration. This is set at 70% of the field capacity, in accordance with the different soil textures. Field Capacity is defined as the water content at a tension of -33kPa.
26	Wpwp_FRACT	Wilting point from Zhang and Marcel (2018) divided by phi_s from Zhang and Marcel (2018) https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/UI5LCE	The parameter Wpwp_FRACT (wp) is the fractional soil moisture (expressed as a fraction of the maximum soil moisture; max. soil moisture = porosity * layer depth) at the wilting point. Wilting Point is set at the water content at

			a tension of 1500 kPa, and is approximated for the different soil textures.
27	rough	0.001	Surface roughness of bare soil, expressed in meters, can be set to a value 0.001, and adjusted according to local data.
28	snow_rough	0	The surface roughness of the snowpack, expressed in meters, can be set to an initial value of 0.0005, and can then be adjusted according to local data.
29	annual_prec	Fick and Hijmans (2017) https://www.worldclim.org/data/worldclim21.html	Average annual precipitation
30	resid_moist	Zhang and Marcel (2018). https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/UI5LCE	Soil moisture layer residual moisture content in units of residual moisture content / total layer volume [mm/mm].
31	fs_active	0	If set to 1, then frozen soil algorithm is activated for the grid cell. A 0 indicates that frozen soils are not computed even if soil temperatures fall below 0C
32	cellnum	same as gridcell	Grid cell number
33	AreaFract	1	Fraction of grid cell covered by each elevation band. Sum of the fractions must equal 1.
34	elevation	SRTM dtm (Jarvis et al., 2008)	Mean (or median) elevation of elevation band. This is used to compute the change in air temperature from the grid cell mean elevation
35	Pfactor	1	Fraction of cell precipitation that falls on each elevation band. Total must equal 1. To ignore effects of elevation on precipitation, set these fractions equal to the area fractions
36	veg_descr	MODIS landcover at 0.05 °(Friedl and Sulla-Menashe, 2015). https://lpdaac.usgs.gov/products/mcd12c1v006/	Land cover classification
37	Nveg	1	Number of vegetation tiles in the grid cell

38	Cv	1	Fraction of grid cell covered by vegetation tile
39	root_depth	Fan et al. (2017a) and dataset Fan et al. (2017b) https://wci.earth2observe.eu/thredds/catalog/usc/root-depth/catalog.html	Root zone thickness (sum of depths is total depth of root penetration)
40	root_fract	Calculated from root_depth	Fraction of root in the current root zone
41	LAI	Copernicus LAI at 1km (Smets et al., 2019) https://land.copernicus.eu/global/products/lai	Leaf Area Index, one per month
42	overstory	MODIS landcover at 0.05°(Friedl and Sulla-Menashe, 2015) and VIC vegetation library. https://lpdaac.usgs.gov/products/mcd12c1v006/	Lag to indicate whether or not the current vegetation type has an overstory TRUE for overstory present [e.g. trees], FALSE for overstory not present [e.g. grass])
43	rarc	MODIS landcover at 0.05°(Friedl and Sulla-Menashe, 2015) and VIC vegetation library. https://lpdaac.usgs.gov/products/mcd12c1v006/	Architectural resistance of vegetation type (~2 s/m) Not sure about this!! #use the values from the veglib
44	rmin	MODIS landcover at 0.05°(Friedl and Sulla-Menashe, 2015) and VIC vegetation library. https://lpdaac.usgs.gov/products/mcd12c1v006/	Minimum stomatal resistance of vegetation type (~100 s/m) use the values from the veglib
45	wind_h	MODIS landcover at 0.05°(Friedl and Sulla-Menashe, 2015) and VIC vegetation library. https://lpdaac.usgs.gov/products/mcd12c1v006/	Height at which wind speed is measured
46	RGL	MODIS landcover at 0.05°(Friedl and Sulla-Menashe, 2015) and VIC vegetation library and VIC global parameter file. https://lpdaac.usgs.gov/products/mcd12c1v006/	Minimum incoming shortwave radiation at which there will be transpiration. For trees this is about 30 W/m2, for crops about 100 W/m2.
47	rad_atten	default 0.5	Radiation attenuation factor. Normally set to 0.5, though may need to be adjusted for high latitudes.
48	wind_atten	default 0.5	Wind speed attenuation through the overstory. The default value has been 0.5.

49	trunk_ratio	default 0.2	Ratio of total tree height that is trunk (no branches). The default value has been 0.2.
50	albedo	Copernicus surface albedo at 1km (Smets and Sánchez-Zapero, 2018). https://land.copernicus.eu/global/products/sa	Shortwave albedo for vegetation type
51	veg_rough	Vegetation roughness length is typically 0.123 * vegetation height. Vegetation height is obtained from Healey et al. (2015). https://webmap.ornl.gov/wcsdown/dataset.jsp?ds_id=10023	Vegetation roughness length (typically 0.123 * vegetation height) one value per month
52	displacement	Vegetation displacement height is typically 0.67 * vegetation height. Vegetation height is obtained from Healey et al. (2015). https://webmap.ornl.gov/wcsdown/dataset.jsp?ds_id=10023	Vegetation displacement height (typically 0.67 * vegetation height) one value per month

Table 4 Parameters and sources for the Groundwater model coupled to VIC.

Variable number	Variable name	Units	Description	Data source
1	Sy	[-]	Specific_yield	Groundwater availability map of the Philippines parameterised (Bureau of Mines and Geo-Sciences and Ministry of Natural Resources, 1986).
2	Trans	[m2/day]	Transmissivity – a value must be given, even if K is specified	dummy
3	K	[m/day]	hydraulic_conductivity – a value must be given, even if T is spcified	Groundwater availability map of the Philippines parameterised (Bureau of Mines and Geo-Sciences and Ministry of Natural Resources, 1986).
4	mask	[-]	mask: active cells of the model domain are set to 1	-
5	dem	[m]	digital elevation model	SRTM dtm (Jarvis et al., 2008)
6	zbase	[m]	Base of the aquifer in m above datum	100 m
7	zriver	[m]	elevation of the river elevation, e.g DEM or DEM - 5	Dem -5
8	driver	[m]	Thickness of the river bed	1
9	C_eff	[1/day]	Conductance for leakage cells of effluent_river	calibration
10	C_in	[1/day]	Conductance for leakage cells of influent_river	
11	C_leak_eff	[1/day]	Conductance for leakage cells effluent	0
12	C_leak_in	[1/day]	Conductance for leakage cells influent	0

13	headBC	[m]	Head[m] of specific head boundary cells, or -999 for non-specified head boundary nodes	0 at the coast
14	river_area	[m2]	River area or cells where a river is present	Grid cell area
15	aquifer map	[-]	Zones of 1 are unconfined aquifer, and zones of 0 are confined aquifer	1
16	c_n	[m]	distance of the cell centre to the cell centre of the cell to the north [m]	Calculated distance
17	c_e	[m]	distance of the cell centre to the cell centre of the cell to the east [m]	Calculated distance
18	e_n	[m]	length of the northern edge of the cell [m]	Calculated distance
19	e_e	[m]	length of the eatern edge of the cell [m]	Calculated distance
20	cell_area	[m2]	cell area of each cell in [m2]	Calculated distance
21	z_soil	[m]	total soil depth used in the VIC model	2
22	Sy_soil	[m]	specific yield of the soil as used in the VIC model	Phi_s from Zhang and Marcel (2018)

Appendix 2 Script to extract NetCDF data

The **R** script below allows the user to extract the NetCDF data, and create the plots as presented in Section 2. **R** is a language and environment for statistical computing and graphics. **R** and **Rstudio** can be downloaded from https://cran.r-project.org/ and https://posit.co/download/rstudio-desktop/.

The user will need to install RStudio and install the packages listed at the top of the script.

```
###########################################################################
#R script to read netcdf outputs of the Philippine National Hydrological
#model, save the data into raster bricks, plot maps of different time steps,
#calculate mean state variabes, export to asci grid, crop with a shapefile such
#as the disctricts, extract time-series of a district and plot the variable,
#create mean monthly comparison of water balance terms, and compare mean water
#balance terms for different regions

#prepared by Johanna Scheidegger 14/6/2024
###########################################################################

#load packages
library(ncdf4)
library(raster)
require(rgdal)
require(RColorBrewer)
library(viridis)
library(zoo)


rm(list=ls(all=TRUE))

#specify path to the data folder
path="W:\\Teams\\I_Services\\BusinessSolutions\\Data\\Data_Products_Approval_Worksheet\\2023_24\\PhilippineNationalHydrologicalModel\\Data\\netcdf"


setwd(path)
getwd()
```

```
#delete tempdir as this fills up the computer and it crashes
tmp_dir <- tempdir()
list.files(tempdir())
unlink(paste0(normalizePath(tempdir()), "/", dir(tempdir())), recursive = TRUE)

#select region: North, South, Center, West
region = 'North'

filename<-paste0( paste0(region,'_2km_RUN68.1979-01.nc'))

nc <- nc_open(filename)

#################################################################################
#read in each variable from the netcdf file and store it in a raster brick
#################################################################################

for(i in 1:nc$nvars){
  d<-nc$var[[i]]
  if (d$ndims==3){
    par(cex.main=0.7)

    names <- 'r'
    rhs<-'brick(filename, varname=d$name, stopIfNotEqualSpaced=F)'
    eq<-paste(paste(names,rhs,sep="<-"))
    eval(parse(text=eq))

    teststring=d$name
    teststring=gsub("OUT_", "", teststring)

    names=names(r)
    names=gsub('X', teststring, names)
    names(r)<-names

    names <- paste(d$name, sep="")
    rhs<-'r'
    eq<-paste(paste(names,rhs,sep="<-"))
    eval(parse(text=eq))

  }
```

```
if (d$ndims==2){

  names <- 'r'
  rhs<-'raster(filename, varname=d$name, stopIfNotEqualSpaced=F)'
  eq<-paste(paste(names,rhs,sep="<-"))
  eval(parse(text=eq))

  teststring=d$name
  teststring=gsub("OUT_", "", teststring)

  names=names(r)
  names=gsub('X', teststring, names)
  names(r)<-names

  names <- paste(d$name, sep="")
  rhs<-'r'
  eq<-paste(paste(names,rhs,sep="<-"))
  eval(parse(text=eq))

}

if (d$ndims==4){

  aa=3

  for(m in 1:aa){
    names <- 'r'
    rhs<-paste0('brick(filename, varname=d$name, stopIfNotEqualSpaced=F, level=',m,')')
    eq<-paste(paste(names,rhs,sep="<-"))
    eval(parse(text=eq))

    teststring=d$name
    teststring=gsub("OUT_", "", teststring)

    names=names(r)
    names=gsub('X', teststring, names)

    names <- paste(d$name,'_', m, sep="")
    rhs<-'r'
```

```
   eq<-paste(paste(names,rhs,sep="<-"))
   eval(parse(text=eq))

  }

  names <-d$name
  rhs=paste0('stack(', paste0(d$name,'_',1:aa, collapse=","), ')')
  eq<-paste(paste(names,rhs,sep="<-"))
  eval(parse(text=eq))

 }

}
nc_close(nc)

#get extent of raster
extent(OUT_Z)

#get the time dimension
namesRaster = names(OUT_Z)
namesRaster = substr(namesRaster, nchar(namesRaster)-9, nchar(namesRaster)-0)
rasterDates = as.POSIXct(namesRaster, format =  "%Y.%m.%d", tz="")

ntimes = length(rasterDates)

############################################################################
# look at output for different time steps
############################################################################

plot(OUT_PREC[[1:12]]) # output for first 12 time steps
plot(OUT_PREC[[(ntimes-11):ntimes]]) # output for last year
plot(OUT_EVAP)
plot(OUT_RECHARGE, zlim=c(0,200))
plot(OUT_RUNOFF)
plot(OUT_BASEFLOW_AQ)
plot(OUT_DELSOILMOIST)
plot(OUT_Z[[400]]/1000,  zlim=c(0,20))

#create mean maps for annual, wet season and dry season
```

```
#########################################################################
# calculate mean state variables and plot them
#########################################################################
#
# #OUT_RECHARGE is a bi-directional flux, if we want recharge only in downward direction,
# #then we need to filter this out
#
Down_recharge = OUT_RECHARGE
Down_recharge[Down_recharge<0] = NA

Up_recharge = OUT_RECHARGE
Up_recharge[Up_recharge>0] = NA

plot(mean(OUT_INFLOW), main='mean precipitation [mm/month]')
plot(mean(OUT_EVAP), main='mean evapotranspiration [mm/month]')
plot(mean(OUT_DELSOILMOIST), main='mean soil moisture change [mm/month]')
plot(mean(Down_recharge, na.rm=TRUE), main='mean downward recharge [mm/month]')
plot(mean(OUT_PREC, na.rm=TRUE), main='mean soil aquifer flux [mm/month]')
plot(mean(OUT_BASEFLOW_AQ), main='mean baseflow [mm/month]')

png(paste0('Recharge', region,'.png'))
plot(mean(Down_recharge, na.rm=TRUE), col = rev(viridis(250)), zlim = c(0, 100),
   main = 'Mean recharge [mm/month]',las=1, cex.lab=1.5, cex.main=1.5, cex.axis=1.5,)
dev.off()

meanGWL=(mean(OUT_Z, na.rm=TRUE))/1000

meanGWL50=meanGWL
meanGWL50[meanGWL50>50]=50

png(paste0('WaterTable50', region,'.png'))
plot(meanGWL50, col = rev(viridis(250)),main = 'GWL [m]',
   las=1, cex.lab=1.5, cex.main=1.5, cex.axis=1.5)
dev.off()

png(paste0('WaterTable', region,'.png'))
meanGWL1=meanGWL
meanGWL1[meanGWL1>1]=1
```

```
plot(meanGWL1, col = rev(viridis(250)), main = 'GWL [m]',
    las=1, cex.lab=1.5, cex.main=1.5, cex.axis=1.5)
dev.off()

#############################################################################
#export to ascii grid
#############################################################################
writeRaster(mean(Down_recharge, na.rm=TRUE), paste0('meanRecharge_',region,'.asc'),
format="ascii", overwrite=T)

#############################################################################
#crop data with a shapefile
#############################################################################
#download data
GADM_data = getData("GADM", country="Philippines", level=1)

plot(GADM_data)

#select provinces to compare
province = c('Isabela', 'Pampanga')

#select variable name
myVar = Down_recharge
#select name of the variable for plotting
myVarLabel = 'recharge mm'

polygon = GADM_data[GADM_data@data$NAME_1==province,]
plot(polygon)

plot(myVar[[13]])
plot(polygon, add=TRUE)

png('RechargeSelection.png')
plot(mean(Down_recharge, na.rm=TRUE), col = rev(viridis(250)), zlim = c(0, 100),
    las=1, cex.lab=1.5, cex.main=1.5, cex.axis=1.5,
    main = 'Mean recharge [mm/month]')
plot(polygon, add=TRUE)
dev.off()

#extract data from a raster
```

```
mean_myVar_crop = mask(crop(mean(myVar, na.rm=TRUE), polygon, snap="out"), polygon)


png('RechargeNorth_Cropped.png')
plot(mean_myVar_crop , main=paste(myVarLabel, ' cropped'),col = rev(viridis(250)), zlim = c(0,
100),
    las=1, cex.lab=1.5, cex.main=1.5, cex.axis=1.5,)
dev.off()


#extract data from a raster brick
myVar_crop = mask(crop(myVar, polygon, snap="out"), polygon)
plot(myVar_crop, main=paste0(myVarLabel, " cropped to ", province))


#####################################################################################
#extract time series from the polygons and plot them
#####################################################################################
ts_data =  extract(myVar, fun=mean, na.rm=TRUE, polygon)
mycols = viridis(length(polygon)+1)


png('RechargeTimeSeries.png',width = 960, height = 480, units = "px", pointsize = 12)
plot(rasterDates, ts_data[1,], type='l', xlab="", ylab="recharge [mm/month]",
    col=mycols[1], lwd=2, las=1, cex.lab=1.5, cex.main=1.5, cex.axis=1.5  )
for(p in 2:length(province)){
  lines(rasterDates, ts_data[p,], col=mycols[p], lwd=2)


}
legendText = paste(province, 'mean =', signif(rowMeans(ts_data), digits = 3))
legend('topleft', legendText, col=mycols, lwd=2, bty='n', ncol=1, cex=1.5)
dev.off()


#create moving average



png('RechargeTimeSeriesMovAverage.png',width = 960, height = 480, units = "px", pointsize =
12)
plot(rollmean(rasterDates, 12),rollmean(ts_data[1,],12), type='l', lwd=2, xlab="",
    ylab="recharge [mm/month]",col=mycols[1], main="12 month moving average", las=1,
cex.lab=1.5, cex.main=1.5, cex.axis=1.5 )
for(p in 2:length(province)){
  lines(rollmean(rasterDates, 12),rollmean(ts_data[p,],12),col=mycols[p], lwd=2)
}
```

```
legend('topleft', legendText, col=mycols, lwd=2, bty='n', ncol=1, cex=1.5)
dev.off()

#################################################################################
#create monthly boxplots
#################################################################################
my_df = data.frame(t(ts_data))
my_df$Month = as.numeric(format(as.Date(rasterDates,  format =  "%Y.%m.%d"), "%m"))
myData = c()
for(i in 1:length(province)){
  myData = c(myData, my_df[,i])
}



boxplot_df = data.frame(Month = rep(my_df$Month, length(province)),
                        Region = rep(province, each = length(rasterDates)),
                        Data = myData)

png('RechargeBoxplot.png',width = 960, height = 480, units = "px", pointsize = 12)
box = boxplot(boxplot_df$Data ~ boxplot_df$Region* boxplot_df$Month,
col=mycols[1:length(polygon)],
              ylab=myVarLabel, xlab = 'month',  las=1, cex.lab=1.5, cex.main=1.5, cex.axis=1.5,
              names=  c(rbind(c(1:12), rep(" ", 12*(length(province)-1)))))
legend('topleft', province, fill=mycols, cex=1.5)
dev.off()
test = c(rbind(c(1:12), rep(" ", 12*(length(province)-1))))

#create a variable for each province with median monthly data
for(p in 1:length(province)){
  names <- paste0('median_monthly_var_', province[p])
  rhs<-paste('c(',paste0('box$stats[3,',seq(p, length(box$stats[3,]), length(province)),'
]',collapse=","),')'  )
  eq<-paste(paste(names,rhs,sep="<-"))
  eval(parse(text=eq))
}


#################################################################################
#create mean water balance terms for the polygons
#################################################################################
```

```
mean_WB_df = data.frame(Province = province,
                Precipitation = extract(mean(OUT_PREC), fun=mean, na.rm=TRUE, polygon),
                Evapotranspiration = extract(mean(OUT_EVAP), fun=mean, na.rm=TRUE,
polygon),
                Runoff = extract(mean(OUT_RUNOFF), fun=mean, na.rm=TRUE, polygon),
                Recharge = extract(mean(OUT_RECHARGE), fun=mean, na.rm=TRUE,
polygon),
                Baseflow = extract(mean(OUT_BASEFLOW_AQ), fun=mean, na.rm=TRUE,
polygon),
                Change_GWL = extract((OUT_Z[[1]] - OUT_Z[[ntimes]]), fun=mean,
na.rm=TRUE, polygon)
)

png('WaterBalance.png',width = 960, height = 480, units = "px", pointsize = 12)
prov = length(province)
plot(NULL, xaxt='n', xlab = "", ylab = "mm/month", xlim = c(0, 2*length(province)),
    ylim = c(0, 300),  las=1,cex.lab=1.5, cex.main=1.5, cex.axis=1.5,)
for(prov in 1:length(province)){
  loc = 2*prov

  rect(loc - 1.9, 0, loc -1.1, mean_WB_df$Precipitation[prov], col=viridis(4)[1])
  rect(loc - 0.9, 0, loc - 0.1, mean_WB_df$Evapotranspiration[prov], col=viridis(4)[2])
  rect(loc - 0.9, mean_WB_df$Evapotranspiration[prov], loc - 0.1,
mean_WB_df$Evapotranspiration[prov] +mean_WB_df$Runoff[prov] , col=viridis(4)[3])
  rect(loc - 0.9, mean_WB_df$Evapotranspiration[prov] +mean_WB_df$Runoff[prov], loc - 0.1,
mean_WB_df$Evapotranspiration[prov] +mean_WB_df$Runoff[prov]
+mean_WB_df$Baseflow[prov] , col=viridis(4)[4])

}
axis(1, at = seq(1,(prov*2-1), 2), labels = province, cex.axis=1.5)
legend('topright', fill =  viridis(4), legend=c('Precipitation', 'ET', 'Runoff', 'Baseflow'), cex=1.5)

dev.off()
#as percentage of recharge
mean_WB_Percentage = data.frame(PercEvap = mean_WB_df$Evapotranspiration /
mean_WB_df$Precipitation,
                        PercRunoff = mean_WB_df$Runoff / mean_WB_df$Precipitation,
                        PerBaseflow  = mean_WB_df$Baseflow  / mean_WB_df$Precipitation)

##############################################################################
#create mean water of entire model
```

```
################################################################################

dSoilStore = sum(OUT_DELSOILMOIST)

All_mean_WB_df = data.frame(Province = 'All',
                    Precipitation = mean(mean(OUT_PREC)[], na.rm=TRUE),
                    Evapotranspiration = mean(mean(OUT_EVAP)[], na.rm=TRUE),
                    Runoff = mean(mean(OUT_RUNOFF)[], na.rm=TRUE),
                    Recharge = mean(mean(OUT_RECHARGE)[], na.rm=TRUE),
                    #Discharge = extract(mean(Up_recharge), fun=mean, na.rm=TRUE, polygon),
                    Baseflow = mean(mean(OUT_BASEFLOW_AQ)[], na.rm=TRUE),
                    Change_GWL = mean((OUT_Z[[1]] - OUT_Z[[ntimes]])[],na.rm=TRUE),
                    dSoilStore = mean(dSoilStore[], na.rm=TRUE)/ntimes
)

All_mean_WB_dfLastYear = data.frame(Province = 'All',
                         Precipitation = mean(mean(OUT_PREC[[(ntimes-11):ntimes]])[],
na.rm=TRUE),
                         Evapotranspiration = mean(mean(OUT_EVAP[[(ntimes-11):ntimes]])[],
na.rm=TRUE),
                         Runoff = mean(mean(OUT_RUNOFF[[(ntimes-11):ntimes]])[],
na.rm=TRUE),
                         Recharge = mean(mean(OUT_RECHARGE[[(ntimes-11):ntimes]])[],
na.rm=TRUE),
                         #Discharge = extract(mean(Up_recharge), fun=mean, na.rm=TRUE,
polygon),
                         Baseflow = mean(mean(OUT_BASEFLOW_AQ[[(ntimes-11):ntimes]])[],
na.rm=TRUE),
                         Change_GWL = mean((OUT_Z[[(ntimes-11)]] -
OUT_Z[[ntimes]])[],na.rm=TRUE),
                         dSoilStore = mean(sum(OUT_DELSOILMOIST[[(ntimes-11):ntimes]])[],
na.rm=TRUE)/12
)

#get the water balance as percentage of precip
All_mean_WB_Percentage = data.frame(PercEvap = All_mean_WB_df$Evapotranspiration /
All_mean_WB_df$Precipitation,
                         PercRunoff = All_mean_WB_df$Runoff / All_mean_WB_df$Precipitation,
                         PerBaseflow  = All_mean_WB_df$Baseflow  /
All_mean_WB_df$Precipitation)
```

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The British Geological Survey holds most of the references listed below and copies may be obtained via the library service subject to copyright legislation (contact libuser@bgs.ac.uk for details). The library catalogue is available at https://envirolib.apps.nerc.ac.uk/olibcgi.

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