Supplement of

The Great Lakes Runoff Intercomparison Project Phase 4: the Great Lakes (GRIP-GL)

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Comparison of gridded ERA5-Land SWE estimates and ground-truth SWE observations from CanSWE database

The ERA5-Land SWE estimates (Muñoz Sabater, 2019) were compared with the SWE observations available in the version 2 of the CanSWE dataset (Vionnet et al., 2021). CanSWE combines historical manual (snow surveys) and automatic SWE measurements collected across Canada by different provincial and territorial agencies as well as hydro-power companies. CanSWE is an evolving dataset. Please refer to the following repository to check for version updates of the dataset: https://10.5281/zenodo.4734371.

In this study, only manual SWE measurements were used to make sure that the snow data would be available over the period from 2000 to 2017. In Ontario and Quebec, manual SWE data are collected on a biweekly to monthly basis. The times series of ERA5-Land SWE estimates were extracted at the grid cells corresponding to the snow observation locations available in CanSWE. Only stations with at least 34 observations (i.e., on average at least two observations per year during the study period from 2001 to 2017) were kept in the analysis. A total of 272 stations was considered and the results are shown in Fig. S1.

Figure S1. Comparison of ERA5-Land and CanSWE snow water equivalent estimates. Panel (A) displays the spatial distribution of the Kling-Gupta efficiency (KGE) between the CanSWE observations (obs) and ERA5-Land (sim) estimates at the N = 272 snow observation locations available in the CanSWE dataset with at least 34 observations (i.e., on average at least two observations per year during the study period from 2001 to 2017). Panel (B) summarizes these KGE values by a cumulative distribution function showing that around 83% of the stations have medium performance, 57% are good, and 14% show an excellent performance.

ERA5-Land shows good performances (KGE larger than 0.65) at 57% of the stations (Fig. S1B). These stations are mostly located in the Ottawa River watershed, in the Lake Superior watershed and in the northern part of the Lake Huron watershed (Fig. S1A). These regions are characterized by the largest mean winter SWE in the Great Lakes regions (Fig. 2 in the main manuscript). More contrasted results, including stations with performances less than medium (KGE lower than 0.48), are
found in the Canadian portions of the Lake Ontario and Lake Erie watersheds. There regions are characterized by milder winter conditions than the northern of the Great Lakes region with frequent occurrences of winter precipitation near 0°C (Mekis et al., 2020) associated challenging conditions for snowpack models due to complex precipitation phase and mid-winter melt resulting from rain-on snow events. Nonetheless, ERA5-Land remains a robust gridded SWE product in this region, especially when compared with other existing gridded SWE datasets such as the US SNODAS analyses characterized by a strong underestimation of SWE in Ontario (King et al., 2020).

The scripts to derive the estimates presented here are available in the data repository (see A9_Scripts/compare_ERA5-swe_CanSWE) (Mai et al., 2022b).

S2 Visual depiction of the multi-objective multi-variable model analysis

The concept of non-dominance/dominance in multi-objective analyses is used for the multi-objective multi-variate model analysis (Sec. 2.9 main manuscript). This refers to the classic definition of that concept which is independent of the shape of the pareto front. Fig. S2 is provided as a visual explanation of what it means that a model dominates other models (panel A), a model is dominated by another model (panel B), a model that is not dominated by other models (panel C), the entire set of non-dominated models (panel D) forming the Pareto front (panel E). We visualized this in 2D picking two objective functions (here KGE regarding streamflow and AET) for demonstration purposes. In the study itself only 3D or 4D pareto fronts were evaluated and reported on in Fig. 8 of the main manuscript. The 3D and 4D examples would, however, be harder to visualize intuitively. All these concepts can (mathematically) be applied for n-dimensional problems though.

S3 Additional information about participating models

In this section additional information will be provided about the participating models. Besides additional descriptions about model setup and calibration detail, a table of the parameters used for the model calibration is provided for each model. The section is organized as follows: globally calibrated Machine-Learning based LSTM-lumped model in Sect. S3.1, the locally calibrated models LBRM-CC-lumped in Sect. S3.2, HYMOD2-lumped in Sect. S3.3, GR4J-lumped in Sect. S3.4, HMETS-lumped in Sect. S3.5, Blended-lumped in Sect. S3.6, Blended-Raven in Sect. S3.7, and VIC-Raven in Sect. S3.8, as well as the regionally calibrated SWAT-Raven in Sect. S3.9, WATFLOOD-Raven in Sect. S3.10, MESH-CLASS-Raven in Sect. S3.11, MESH-SVS-Raven in Sect. S3.12, and GEM-Hydro-Watroute in Sect. S3.13.

S3.1 LSTM-lumped

The final LSTM model is an ensemble of 10 models with different random seeds. All models share the same architecture of 256 hidden states and use an input sequence length of 365. That is, a single day of discharge is predicted from a sequence of the previous 365 input time steps. We optimized the model parameters with an Adam optimizer (Kingma and Ba, 2015) on an loss function that approximates the NSE (Kratzert et al., 2019) for 20 epochs at a learning rate of $5 \times 10^{-4}$ and another 10 epochs.
Figure S2. The concept of non-dominance and dominance of multi-objective problems. The example of a two-dimensional calibration problem is chosen. Both objectives (x-axis and y-axis) are assumed to be minimized and hence the “Utopia” point is located at the origin for simplicity. For demonstration purposes the first objective is chosen to be \(1 - KGE_Q\) where \(KGE_Q\) is the model performance regarding streamflow and the second objective is set to be \(1 - KGE_{AET}\) where \(KGE_{AET}\) is the model performance regarding actual evapotranspiration.

The circle markers in each panel indicate one of the twelve models evaluated. (A) A model (dark gray marker) is dominating other models (light gray markers) if it is superior for all objectives. (B) A model is dominated by all models that are better in all objectives. (C) A model is non-dominated if it is not dominated by any model, i.e. all other models are worse in at least one of the objectives. (D) There might be several non-dominated models (red markers) which (E) form the so-called Pareto front (red line). To obtain results in Fig. 8 of the main manuscript the analysis is performed for each of the 212 catchments of the study. The number of times a model is part of the pareto front (red dot in panel E) is used as the measure in Fig. 8.

at a learning rate of \(1 \times 10^{-4}\). To regularize the model, we further applied dropout to the LSTM output with probability of 0.4 (Hinton et al., 2012). We stabilized the training procedure by clipping gradients to a maximum norm of 1 and initializing the LSTM forget gate with a bias of 3 (Gers et al., 1999).

The LSTM ingests the following input variables to predict daily discharge:

- daily meteorological forcings:
  - total precipitation,
  - minimum and maximum temperature,
  - mean downward solar flux,
  - specific humidity,
  - surface pressure,
  - u/v components of wind, and
potential evapotranspiration calculated following the Priestley-Taylor equation from the FAO-56 guidelines (Allen et al., 1998), using minimum and maximum temperature, solar radiation, latitude, elevation, and day of year as inputs and assuming that ground heat flux is zero at daily time steps (see also Newman et al., 2015)

**static basin characteristics:**

- in total 30 static input variables were used as inputs in the LSTM setup (Tab. S2)
- climatologic characteristics were calculated based on the calibration period (2000 to 2010)
- static features are fed into the LSTM at every time step alongside the meteorological forcings (see: Kratzert et al., 2019)

To ensure a model configuration that also works well in spatial validation, the LSTM hyperparameters (see Tab. S1) were tuned in a 5-fold cross-validation setting (Hastie et al., 2009) as follows: First, we randomly split the calibration basins into five partitions and trained each hyperparameter configuration on all combinations of four partitions. We repeated this process with three different random seeds and tested each setup on the corresponding remaining fifth partition. Second, we calculated the average KGE across all seeds for each basin in the partition that was not trained on and then took the median across all these basins. Finally, given the best hyperparameter configuration, we trained an ensemble of ten models with different random seeds on the full calibration period of all calibration basins combined and averaged their predictions.

The model was set up using the NeuralHydrology Python library in version 0.9.11-beta3 (Kratzert et al., 2022). The configuration files and scripts to reproduce the LSTM setup and training are available in the data repository (see A9_Scripts/MachineLearning) (Mai et al., 2022b).

**Table S1: The hyperparameters calibrated for the LSTM-lumped model.** The first three parameters are tested with the listed discrete values while the fourth parameter (epochs) was tested for a range of integer values in order to determine the best hyperparameter setting for this application. The best hyperparameter values found are highlighted in bold font. The parameter names are also the names of the NeuralHydrology configuration value. A brief description is given for each parameter.

| Parameter | Parameter value/range | Description |
|-----------|-----------------------|-------------|
| learning_rate | {0: 0.001}, {0: 0.005, 10: 0.001, 20: 0.0005}, {0: 0.001, 20: 0.0005, 30: 0.0001}, {0: 0.0005, 20: 0.0001, 30: 5e-05}, {0: 0.0001, 20: 5e-05, 30: 1e-05} | Learning rate schedule of the optimizer. E.g., 0: x, 10:y means learning rate x for epochs 0 to 9, learning rate y after epoch 9 |
| hidden_size | 64, 128, **256** | Number of LSTM cell states |
| batch_size | **64, 128, 256** | Number of samples per mini-batch during gradient descent |
| epochs | [3, 45]; **best: 30** | Number of training passes through the entire dataset (we evaluated every third epoch, so any value 3·k with k ∈ [1, 15] was evaluated) |
Table S2: **Static basin characteristic used for the LSTM-lumped model.** This lists the static basin characteristics exclusively derived from the common datasets (Sect. 2.2 of main manuscript) and used as input variables to the LSTM model. † Due to a data preprocessing mistake, only the average of the lower two soil layers from the soil dataset was considered for the soil related attributes.

| Attribute name                        | Description                                                                                                                                                                                                                                                                                                                                 |
|---------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| p_mean                                | Mean daily precipitation                                                                                                                                                                                                                                                                                                                                 |
| pet_mean                              | Mean daily potential evapotranspiration                                                                                                                                                                                                                                                                                                           |
| aridity                               | Ratio of mean PET to mean precipitation                                                                                                                                                                                                                                                                                                           |
| t_mean                                | Mean daily temperature, i.e., \((\text{daily}_{\text{min}} + \text{daily}_{\text{max}}) / 2\)                                                                                                                                                                                                                           |
| frac_snow                             | Fraction of precipitation falling on days with mean daily temperatures below 0°C                                                                                                                                                                                                                                                                 |
| high_prec_freq                        | Fraction of high-precipitation days \((\geq 5 \text{ times mean daily precipitation})\)                                                                                                                                                                                                                                                         |
| high_prec_dur                         | Average duration of high-precipitation events (number of consecutive days with \(\geq 5 \text{ times mean daily precipitation}\))                                                                                                                                                                                                         |
| low_prec_freq                         | Fraction of dry days \((< 1 \text{ mm d}^{-1} \text{ daily precipitation})\)                                                                                                                                                                                                                                                                     |
| low_prec_dur                          | Average duration of dry periods (number of consecutive days with daily precipitation \(< 1 \text{ mm d}^{-1}\))                                                                                                                                                                                                                                                                 |
| mean_elev                             | Catchment mean elevation                                                                                                                                                                                                                                                                                                                                 |
| std_elev                              | Standard deviation of catchment elevation                                                                                                                                                                                                                                                                                                         |
| mean_slope                            | Catchment mean slope                                                                                                                                                                                                                                                                                                                                 |
| std_slope                             | Standard deviation of catchment slope                                                                                                                                                                                                                                                                                                           |
| area_km2                              | Catchment area                                                                                                                                                                                                                                                                                                                                     |
| Temperate-or-sub-polar-needleleaf-forest | Fraction of land covered by “Temperate-or-sub-polar-needleleaf-forest”                                                                                                                                                                                                                                                                          |
| Temperate-or-sub-polar-grassland      | Fraction of land covered by “Temperate-or-sub-polar-grassland”                                                                                                                                                                                                                                                                                   |
| Temperate-or-sub-polar-shrubland      | Fraction of land covered by “Temperate-or-sub-polar-shrubland”                                                                                                                                                                                                                                                                                   |
| Temperate-or-sub-polar-grassland      | Fraction of land covered by “Temperate-or-sub-polar-grassland”                                                                                                                                                                                                                                                                                   |
| Mixed-Forest                          | Fraction of land covered by “Mixed-Forest”                                                                                                                                                                                                                                                                                                          |
| Wetland                               | Fraction of land covered by “Wetland”                                                                                                                                                                                                                                                                                                           |
| Cropland                              | Fraction of land covered by “Cropland”                                                                                                                                                                                                                                                                                                           |
| Barren-Lands                          | Fraction of land covered by “Barren-Lands”                                                                                                                                                                                                                                                                                                         |
| Urban-and-Built-up                    | Fraction of land covered by “Urban-and-Built-up”                                                                                                                                                                                                                                                                                                   |
| Water                                 | Fraction of land covered by “Water”                                                                                                                                                                                                                                                                                                                  |

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### S3.2 LBRM-CC-lumped

The Large Basin Runoff Model (LBRM) (Crowley II, 1983) was developed for applications to historical simulation and seasonal forecasting of the Great Lakes water balance. As such, prior to this study, it has primarily been evaluated for simulating whole-basin runoff into the lakes. It is a lumped conceptual model that simulates the propagation of rainfall to watershed outflow using a series of cascading tanks, with transfers between tanks represented through a mass balance coupled with linear reservoir concepts. Calibrated model parameters include linear and partial linear reservoir coefficients to represent transfer between the cascading tanks, as well as a base temperature parameter that controls the potential evapotranspiration and an upper soil zone capacity parameter. Since the initial development of LBRM, updates have included the integration of an approach to approximate the Clausius-Clapeyron to mitigate the oversensitivity of evapotranspiration to temperature identified by Lofgren et al. (2011). This update, referred to as LBRM-CC-lumped in this manuscript, demonstrated by Lofgren and Rouhana (2016) and implemented by Gronewold et al. (2017), was used for this study. LBRM-CC-lumped is currently in use as one of the models contributing guidance to the U.S. Army Corps of Engineers Detroit District’s contribution to the internationally coordinated 6-month water level forecast (Fry et al., 2020). Tab. S3 provides a list of all the LBRM-CC-lumped model parameters which were optimized for this study.

Table S3: The parameters calibrated for the LBRM-CC-lumped model. The table specifies the parameters calibrated for the LBRM-CC-lumped models. The “Param” column corresponded to the parameter definition with the Fortran source code, and “LBRM Params” corresponds to parameter names within the input file used for initiating model values for LBRM-CC-lumped. The parameters are uniformly distributed in the range given. The unit is specified for each parameter.
Table S3 – Continued from previous page

| Param. | Range             | Unit | LBRM Params                      |
|--------|-------------------|------|----------------------------------|
| AlpPer | $[3.0 \times 10^{-7}, 9.4]$ | 1/d | Linear Reservoir Coefficient (LRC) Percolation |
| AlpUEv | $[1.0 \times 10^{-12}, 9.9 \times 10^{-6}]$ | 1/m$^3$ | Partial LRC Upper Soil Zone Evaporation |
| AlpInt | $[1.0 \times 10^{-5}, 27.0]$ | 1/d | LRC Interflow                    |
| AlpDpr | $[1.0 \times 10^{-5}, 93.0]$ | 1/d | LRC Deep Percolation             |
| AlpLEv | $[1.0 \times 10^{-13}, 0.05]$ | 1/m$^3$ | Partial LRC Lower Soil Zone Evaporation |
| AlpGw  | $[1.0 \times 10^{-7}, 1.0]$ | 1/d | LRC groundwater                  |
| AlpSf  | $[0.02, 3.0]$       | 1/d | LRC surface flow                 |
| USZC   | $[1.8, 25.0]$       | cm  | Upper Soil Zone Capacity         |

S3.3 HYMOD2-lumped

HYMOD is a conceptual rainfall-runoff model introduced by Boyle et al. (2000). In this study, we use the modified lumped version of the HYMOD model, called HYMOD2. The model is referred to as “HYMOD2-lumped” in this study to follow the same naming convention for all models indicating whether models are lumped or distributed. The HYMOD2-lumped model is working in reliance on the probability distributed storage capacity concept proposed by Moore (1985), representing the vertical soil moisture accounting process. HYMOD is originally designed as a lumped model utilizing Nash cascade for horizontal routing and a leaky linear reservoir to represent baseflow.

The modified HYMOD2-lumped version used in this study contains an improved parameterization for the evaporation process as proposed by Roy et al. (2017). Since snow is an important factor driving the water cycle in the basins considered in this model intercomparison study, we also included the Degree Day Snow model (Martinec, 1975) and rain-snow-partitioning in the lumped version of HYMOD2. Potential evapotranspiration is derived from minimum and maximum temperature as well as the basin latitude using the Hargreaves-Samani method (Hargreaves and Samani, 1985).

The eleven parameters calibrated for this model are given in Tab. S4.

Table S4: The parameters calibrated for the HYMOD2-lumped model. The table specifies the eleven parameters calibrated for the HYMOD2-lumped models. The parameters are uniformly distributed in the range given. A brief description of the parameter as well as its unit is specified.

| Param. | Range        | Unit | Parameter description                      |
|--------|--------------|------|-------------------------------------------|
| H      | $[100, 5000]$ | mm   | Height of soil moisture accounting tank    |
| B      | $[0.01, 2.0]$ | -    | Distribution function shape parameter      |

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Table S4 – Continued from previous page

| Param. | Range    | Unit | Parameter description                      |
|--------|----------|------|-------------------------------------------|
| α      | [0.01, 1.0] | -    | Quick-slow split parameter                 |
| Nq     | [1, 6]    |      | Number of quickflow routing tanks          |
| Ks     | [0.001, 0.95] | mm/d | Slowflow routing tanks rate parameter      |
| Kq     | [0.05, 0.95] | mm/d | Quickflow routing tanks rate parameter     |
| Kmax   | [0.0, 1.0] | mm/d | Upper limits for resistance to ET flux K    |
| γ      | [0, 1]    |      | Lower limits for resistance to ET flux K as Kmin = γ Kmax |
| BE     | [0.01, 1.95] |      | Power coefficient                          |
| DDF    | [0.0, 10.0] | mm/d/°C | Degree day factor (DDF) for snowmelt       |
| Tbase  | [−2.0, 2.0] | °C   | Base temperature for melt calculation in DDF model |

105 S3.4 GR4J-lumped

The GR4J model (Perrin et al., 2003) is a lumped water balance model that relates runoff to rainfall and evapotranspiration using daily data while the model contains two stores and originally has four parameters (X₁ to X₄). The GR4J parameter X₁ denotes the production store capacity, parameter X₂ is the inter-catchment exchange coefficient, X₃ is the routing store capacity, and X₄ is the unit hydrograph time constant. GR4J is used in concert with CemaNeige (Valéry et al., 2014) for the handling of snow. GR4J and CemaNeige are fully emulated within the Raven modeling framework (Craig et al., 2020) and used as such in this study. The parameters, their ranges and where these parameters are located in a Raven setup is listed in Table S5. Please note that parameter x₅ for an estimate of annual average snow is usually not part of the CemaNeige model but was added here as Raven requires an estimate and none was at hand. Two additional parameters for rain-snow partitioning were added as only precipitation forcings instead of rain and snow forcings were available.

Table S5: The parameters calibrated for the GR4J-lumped model. The parameters are uniformly distributed in the range given. The Raven table and parameter name can be used to locate the parameter in the Raven setup files.

| Param. | Range    | Unit | Raven table            | Parameter name                                      |
|--------|----------|------|------------------------|-----------------------------------------------------|
| GR4J parameters:                                |                                                  |
| x₁     | [0.01, 2.5] | m    | SoilProfiles           | thickness top soil layer (GR4J X₁)                   |
| x₂     | [−15.0, 10.0] | mm/d | SoilParameterList      | GR4J_X2                                              |
| x₃     | [10.0, 700.0] | mm   | SoilParameterList      | GR4J_X3                                              |
| x₄     | [0.0, 10.0] | d    | LandUseParameterList   | GR4J_X4                                              |

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Table S5 – Continued from previous page

| Param. | Range     | Unit          | Raven table       | Parameter name                |
|--------|-----------|---------------|-------------------|-------------------------------|
|        |           |               | GlobalParameter   | AvgAnnualSnow                 |
| $x_5$  | [1.0, 30.0] | mm            |                    |                               |
| $x_6$  | [0.0, 1.0] | l/d           | GlobalParameter   | AirSnowCoeff                  |
| $x_7$  | [2.0, 8.0] | mm/d/°C       | LandUseParameterList | MELT_FACTOR            |

Rain-snow partitioning:

| Param. | Range     | Unit | Raven table       | Parameter name                |
|--------|-----------|------|-------------------|-------------------------------|
|        |           |      | GlobalParameter   | RAINSNOW_TEMP                 |
| $x_8$  | [-3.0, 3.0] | °C   |                    |                               |
| $x_9$  | [0.5, 6.0] | °C   | GlobalParameter   | RAINSNOW_DELTA                |

S3.5 HMETS-lumped

HMETS is a very simple, yet efficient, lumped conceptual hydrological model simulating all main hydrological processes including snow accumulation and snowmelt (Martel et al., 2017). HMETS us setup through the Raven hydrologic modeling framework which is able to fully emulate the original HMETS implementation. The parameters calibrated for HMETS are listed in Table S6.

Table S6: The parameters calibrated for the HMETS-lumped model. The parameters are uniformly distributed in the range given. The Raven table and parameter name can be used to locate the parameter in the Raven setup files. A two-layer soil model was used here. The TOPSOIL is the upper soil layer while PHREATIC is the lower soil layer. The two Raven parameters, SNOW_SWI_MAX and MAX_MELT_FACTOR, are derived using a sampled parameter ($x_6$, $x_7$) and SNOW_SWI_MIN and MIN_MELT_FACTOR, respectively, to make sure that one parameter is always larger than the other.

| Param. | Range     | Unit          | Raven table       | Parameter name                |
|--------|-----------|---------------|-------------------|-------------------------------|
| $x_1$  | [0.3, 20.0] | -             | LandUseParameterList | GAMMA_SHAPE               |
| $x_2$  | [0.01, 5.0] | -             | LandUseParameterList | GAMMA_SCALE                |
| $x_3$  | [0.5, 13.0] | -             | LandUseParameterList | GAMMA_SHAPE2              |
| $x_4$  | [0.15, 1.5] | -             | LandUseParameterList | GAMMA_SCALE2             |
| $x_5$  | [0.0, 20.0] | mm/d/°C       | LandUseParameterList | MIN_MELT_FACTOR           |
| $x_6$  | [0.0, 20.0] | mm/d/°C       | LandUseParameterList | MAX_MELT_FACTOR = MIN_MELT_FACTOR + $x_6$ |
| $x_7$  | [-2.0, 3.0] | °C            | LandUseParameterList | DD_MELT_TEMP              |
| $x_8$  | [0.01, 0.2] | l/mm          | LandUseParameterList | DD_AGGRADATION            |
| $x_9$  | [0.0, 0.1] | frac          | GlobalParameter   | SNOW_SWI_MIN               |

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Table S6 – Continued from previous page

| Param. | Range       | Unit     | Raven table       | Parameter name                       |
|--------|-------------|----------|-------------------|--------------------------------------|
| $x_{10}$ | [0.01, 0.3] | frac     | GlobalParameter   | SNOW_SWI_MAX = SNOW_SWI_MIN + $x_{10}$ |
| $x_{11}$ | [0.005, 0.1] | l/mm     | GlobalParameter   | SWI_REDUCT_COEFF                      |
| $x_{12}$ | [-5.0, 2.0] | °C       | LandUseParameterList | DD_REFREEZE_TEMP                      |
| $x_{13}$ | [0.0, 5.0]  | mm/d°C   | LandUseParameterList | REFREEZE_FACTOR                       |
| $x_{14}$ | [0.0, 1.0]  | -        | LandUseParameterList | REFREEZE_EXP                          |
| $x_{15}$ | [0.0, 3.0]  | -        | SoilParameterList  | PET_CORRECTION TOPSOIL               |
| $x_{16}$ | [0.0, 1.0]  | -        | LandUseParameterList | HMETS_RUNOFF_COEFF                    |
| $x_{17}$ | [0.00001, 0.02] | l/d | SoilParameterList  | PERC_COEFF TOPSOIL                    |
| $x_{18}$ | [0.0, 0.1]  | l/d      | SoilParameterList  | BASEFLOW_COEFF TOPSOIL               |
| $x_{19}$ | [0.00001, 0.01] | l/d | SoilParameterList  | BASEFLOW_COEFF PHREATIC              |
| $x_{20}$ | [0.0, 0.5]  | m        | SoilProfiles       | thickness TOPSOIL                     |
| $x_{21}$ | [0.0, 2.0]  | m        | SoilProfiles       | thickness PHREATIC                    |
| $x_{22}$ | [-3.0, 3.0] | °C       | GlobalParameter    | RAINSNOW_TEMP                         |
| $x_{23}$ | [0.5, 6.0]  | °C       | GlobalParameter    | RAINSNOW_DELTA                        |

S3.6 Blended-lumped

The lumped Blended Model is a hydrologic model defined within the Raven hydrologic modeling framework (Craig et al., 2020). The Blended Model uses the weighted average of several chosen process implementations for key processes to simulate streamflow instead of using one single parametrization per process.

As an example, a (simplified) blended model could be defined as:

$$f_{\text{shared}}(x, w) = (w_{d1} D_1 + w_{d2} D_2) \cdot (w_{e1} E_1 + w_{e2} E_2 + w_{e3} E_3) + (w_{f1} F_1 + w_{f2} F_2)$$

(S1)

with

$$w_{d1} + w_{d2} = 1$$

(S2)

$$w_{e1} + w_{e2} + w_{e3} = 1$$

(S3)

$$w_{f1} + w_{f2} = 1$$

(S4)

where $D_1$ and $D_2$ could be, for instance, be two options for one process. For example, deriving infiltration could be performed once using the infiltration definition of HMETS ($D_1$) and once derived as defined in the HBV model ($D_2$). The infiltration outputs $D_1$ and $D_2$ are then weighted using $w_{d1}$ and $w_{d2}$ to derive the infiltration estimate Raven will use for the...
remainder of the simulation. A detailed description of all processes and process options as well as a model flowchart can be found in the Supplementary Material of Mai et al. (2020) and in the Raven documentation (Craig et al., 2020).

The Blended Model was introduced by Mai et al. (2020), analysed in calibration mode by Chlumsky et al. (2021), and deployed across North America by Mai et al. (2022a). The exact same model setup was employed here. It uses three different options \( M_i \) for the infiltration process, three options \( N_i \) for quickflow, two options \( O_i \) for evaporation, two options \( P_i \) for baseflow, and three options \( Q_i \) for snow balance. All other processes, i.e., convolution of surface runoff \( R_1 \) and delayed runoff \( S_1 \), potential melt \( T_1 \), percolation \( U_1 \), rain–snow partitioning \( V_1 \), and precipitation correction \( W_1 \), are used with one fixed process option. The remaining processes also have only one option, but none of them contains tunable parameters. They are merged to a “remaining” process \( X_1 \), which will never appear in the sensitivity analysis because it is constant. When the first option of each of the processes \( M_1, N_1, O_1, P_1, Q_1, R_1, S_1, T_1, U_1, V_1, W_1, \) and \( X_1 \), is chosen and parameter \( x_{35} \) is set to zero, the Raven setting emulates the HMETS model (Martel et al., 2017) perfectly. All other combinations are unnamed models.

Details of process options and parameters can be found in Appendix C (Tables C1 and C2) in Mai et al. (2020). The list of parameters is added to the Supplementary Material herein (Table S7) for the convenience of the readers.

Table S7: The parameters calibrated for the Blended-lumped model. The parameters are uniformly distributed in the range given. The Raven table and parameter name can be used to locate the parameter in the Raven setup files. A three-layer soil model was used here, with the third (groundwater) layer being of infinite depth. The TOPSOIL is the upper soil layer while PHREATIC is the lower soil layer. The three Raven parameters, FIELD\_CAPACITY TOPSOIL, SNOW\_SWI\_MAX, and MAX\_MELT\_FACTOR, are derived using a sampled parameter \( (x_{10}, x_{14}, \) and \( x_{25} ) \) and SAT\_WILT TOPSOIL, SNOW\_SWI\_MIN, and MIN\_MELT\_FACTOR, respectively, to make sure that one parameter is always larger than the other. The baseflow coefficients, BASEFLOW\_COEFF TOPSOIL and PHREATIC, are derived from parameters \( x_4 \) and \( x_{11} \) to allow a logarithmic sampling. This table is taken from Mai et al. (2020) (Appendix C Table C2 therein) and augmented by the weight generating parameters \( (r_1 \) to \( r_8 ) \) that are used to describe the model structure.

| Param. | Range | Unit | Raven table | Parameter name |
|--------|-------|------|-------------|----------------|
| **Infiltration:** | | | | |
| \( x_1 \) | \([0.0, 1.0]\) | - | LandUseParameterList | HMETS\_RUNOFF\_COEFF |
| \( x_2 \) | \([0.1, 3.0]\) | - | SoilParameterList | B\_EXP TOPSOIL |
| \( x_3 \) | \([0.5, 3.0]\) | - | SoilParameterList | HBV\_BETA TOPSOIL |
| **Quickflow:** | | | | |
| \( x_4 \) | \([-5.0, -1.0]\) | 1/d | SoilParameterList | BASEFLOW\_COEFF TOPSOIL \( = 10.0^{x_4} \) |
| \( x_5 \) | \([0.0, 100.0]\) | mm/d | SoilParameterList | MAX\_BASEFLOW\_RATE TOPSOIL |
| \( x_6 \) | \([0.5, 2.0]\) | - | SoilParameterList | BASEFLOW\_N TOPSOIL |
| \( x_7 \) | \([5.0, 10.0]\) | m | TerrainClasses | TOPMODEL\_LAMBDA |

Continued on next page
| Param. | Range         | Unit   | Raven table         | Parameter name                        |
|--------|---------------|--------|---------------------|---------------------------------------|
|        |               |        |                     |                                       |
| Evaporation:                               |       |                    |                                       |
| $x_8$  | [0.0, 3.0]    | -      | SoilParameterList   | PET_CORRECTION TOPSOIL                |
| $x_9$  | [0.0, 0.05]   | frac   | SoilParameterList   | SAT_WILT TOPSOIL                      |
| $x_{10}$ | [0.0, 0.45]  | frac   | SoilParameterList   | FIELD_CAPACITY TOPSOIL =              |
|        |               |        |                     | SAT_WILT TOPSOIL + $x_{10}$          |
|        |               |        |                     |                                       |
| Baseflow:                                  |       |                    |                                       |
| $x_{11}$ | $[−5.0, −2.0]$ | 1/d   | SoilParameterList   | BASEFLOW_COEFF PHREATIC = $10.0^{x_{11}}$ |
| $x_{12}$ | [0.5, 2.0]    | -      | SoilParameterList   | BASEFLOW_N PHREATIC                  |
|        |               |        |                     |                                       |
| Snow balance:                              |       |                    |                                       |
| $x_{13}$ | [0.0, 0.1]    | frac   | GlobalParameter     | SNOW_SWI_MIN                          |
| $x_{14}$ | [0.01, 0.3]   | frac   | GlobalParameter     | SNOW_SWI_MAX = $=$                   |
|        |               |        |                     | SNOW_SWI_MIN + $x_{14}$               |
| $x_{15}$ | [0.005, 0.1]  | 1/mm   | GlobalParameter     | SWI_REDUCT_COEFF                      |
| $x_{16}$ | $[−5.0, 2.0]$ | °C     | LandUseParameterList| DD_REFREEZE_TEMP                      |
| $x_{17}$ | [0.0, 1.0]    | -      | LandUseParameterList| REFREEZE_EXP                          |
| $x_{18}$ | [0.0, 5.0]    | mm/d/°C | LandUseParameterList | REFREEZE_FACTOR                       |
| $x_{19}$ | [0.0, 0.4]    | frac   | GlobalParameter     | SNOW_SWI                             |
|        |               |        |                     |                                       |
| Convolution (surface runoff):              |       |                    |                                       |
| $x_{20}$ | [0.3, 20.0]   | -      | LandUseParameterList| GAMMA_SHAPE                           |
| $x_{21}$ | [0.01, 5.0]   | -      | LandUseParameterList| GAMMA_SCALE                           |
|        |               |        |                     |                                       |
| Convolution (delayed runoff):              |       |                    |                                       |
| $x_{22}$ | [0.5, 13.0]   | -      | LandUseParameterList| GAMMA_SHAPE2                          |
| $x_{23}$ | [0.15, 1.5]   | -      | LandUseParameterList| GAMMA_SCALE2                          |
|        |               |        |                     |                                       |
| Potential melt:                           |       |                    |                                       |
| $x_{24}$ | [1.5, 3.0]    | mm/d/°C | LandUseParameterList| MIN_MELT_FACTOR                       |
| $x_{25}$ | [0.0, 5.0]    | mm/d/°C | LandUseParameterList| MAX_MELT_FACTOR = $=$               |
|        |               |        |                     | MIN_MELT_FACTOR + $x_{25}$            |
| $x_{26}$ | $[−1.0, 1.0]$ | °C     | LandUseParameterList| DD_MELT_TEMP                          |
| $x_{27}$ | [0.01, 0.2]   | 1/mm   | LandUseParameterList| DD_AGGRADATION                        |
|        |               |        |                     |                                       |
| Percolation:                              |       |                    |                                       |
| $x_{28}$ | [0.00001, 0.02]| 1/d   | SoilParameterList   | PERC_COEFF TOPSOIL                    |
| $x_{35}$ | [0.0, 0.02]   | 1/d    | SoilParameterList   | PERC_COEFF PHREATIC                  |

Continued on next page
S3.7 Blended-Raven

The Blended-Raven model is the same as the Blended-lumped model setup using the common subbasin discretization provided through the common routing product. The parameters calibrated are the ones calibrated for the Blended-lumped model (Table S7 augmented by the routing specific parameters listed in Table S8.)
Table S8: **The parameters calibrated for the Blended-Raven model.** The parameters are uniformly distributed in the range given. The Raven table and parameter name can be used to locate the parameter in the Raven setup files. Only the routing parameters are explicitly listed while all the other parameters are the same as given in the table for the Blended-lumped model to avoid duplication.

| Param. | Range | Unit | Raven table | Parameter name |
|--------|-------|------|-------------|----------------|
| All parameters $x_1$ to $x_{35}$ and $r_1$ to $r_8$ used for Blended-lumped (Tab. S7) |
| **Routing:** |
| $x_{36}$ | $[-1.0, 1.0]$ | - | SBGroupPropertyMultiplier | MANNINGS_N = 5.0$^{x_{36}}$ |
| $x_{37}$ | $[0.1, 2.0]$ | - | SBGroupPropertyMultiplier | RESERVOIR_CREST_WIDTH |

### S3.8 VIC-Raven

In GRIP-GL, the VIC and Raven routing model are coupled to simulate rainfall-runoff processes in the Great Lakes region. The VIC Image Driver of version 5.1.0 is used, and Raven is employed as a routing module for VIC. It should be noted that the drainage from the bottom soil layer in VIC is named as “baseflow” (Gao et al., 2010); however, this is a misnomer that implies water directly enters the streams without being delayed in storage (Li et al., 2015). Thus, we use the term “recharge” instead of “baseflow” to represent this flux component in this context, which is consistent with the terminology used in Raven (Craig et al., 2020; Craig, 2022).

In GRIP-GL, VIC model is built at the RDRS-v2 forcing grid-cells with a resolution of 15 km by 15 km. VIC requires DEM, soil, and land cover data for its parameterization. The input data for VIC are the sub-daily meteorological drivers from the RDRS-v2 forcing data set, i.e., precipitation, air temperature, atmospheric pressure, incoming shortwave radiation, incoming longwave radiation, vapor pressure and wind speed. The VIC-generated (quick) runoff and recharge fluxes at the grid-cell scale are firstly aggregated into the sub-watershed scale, and then routed to the catchment outlet in terms of in-catchment routing and river channel routing processes.

Raven routing module consists of in-catchment routing and channel routing processes. VIC-generated runoff is firstly simulated by an in-catchment routing process, which employs a Gamma unit hydrograph to represent the time delay between runoff and reaching the stream. It then employs channel routing using the diffusive wave method to simulate flood wave propagation through the reach. Baseflow is simulated using a linear storage model to delay the recharge component. If catchments contain lakes, the lake release is solved by a two-parameter lake-type reservoir model in Raven. The routing network for the Raven routing module is produced by BasinMaker (Han, 2021; Han et al., 2021), and inputs for routing are subbasin-averaged runoff and baseflow generated by VIC.

VIC has nine parameters for calibration and Raven routing module has five parameters for catchments with lakes and four parameters for catchments without lakes for calibration (Tab. S9). These parameters are calibrated simultaneously using DDS
optimization algorithm (i.e., the VIC and Raven are coupled in calibration, and the outputs of VIC are used as inputs for Raven routing). The KGE is employed as the calibration objective. The optimization is repeated for 20 trials, each with 1,000 calibration iterations, and the best results out of 20 are reported.

Table S9: The parameters calibrated for the VIC-Raven model. The parameters are uniformly distributed in the range given. The unit and a brief description of each parameter is given. The parameters are grouped into the nine parameters of the VIC land-surface scheme and the five parameters calibrated for the Raven routing.

| Param. | Range       | Unit | Parameter description                                      |
|--------|-------------|------|-----------------------------------------------------------|
| VIC Land-Surface Scheme:                  |
| infilt | (0, 5]      | -    | Parameter used to describe Variable Infiltration Curve; higher values will produce more runoff |
| Ds     | (0, 1]      | -    | Fraction of Dsmax parameter at which non-linear recharge occurs |
| Dsmax  | (0, 30]     | mm/d | Maximum velocity of recharge for each grid cell          |
| Ws     | (0, 1]      | -    | Fraction of maximum soil moisture where non-linear recharge occurs |
| d1     | [0.01, 0.5] | m    | Depth of top layer                                       |
| d2     | [0.01, 2.0] | m    | Depth of first layer                                     |
| d3     | [0.5, 3.0]  | m    | Depth of second layer                                    |
| expt   | [3, 30]     | -    | Exponent parameter of Brooks-Corey relationship          |
| Ksat   | [100, 1200] | mm/d | Saturated hydraulic conductivity for each layer           |
| Raven Routing:                           |
| Mcoeff | [0.2, 5.0]  | -    | Multiplier to calibrate Manning’s n                      |
| Bcoeff | [0.1, 0.999]| l/d  | Baseflow coefficient k                                   |
| Shape  | [1.1, 11.0] | -    | Shape parameter of the gamma unit hydrograph              |
| Tpeak  | [0.2, 2.0]  | d    | Time to peak parameter; used to estimate scale parameter of gamma unit hydrograph |
| Cwidth | [0.5, 1.5]  | -    | Multiplier to calibrate crest width in the lake-like reservoir model; parameter ignored if catchment has no lakes |

S3.9 SWAT-Raven

SWAT simulated vertical flux (total runoff) were fed to the lake and river routing product (Han et al., 2020), integrated into the Raven modelling framework (Craig et al., 2020), to route the both the vertical flux. The integrated SWAT-Raven model was
then calibrated by calibrating SWAT-related and Raven-related parameters simultaneously within the given range as shown in Tab. S10.

Table S10: **The parameters calibrated for the SWAT-Raven model.** The parameters are uniformly distributed in the range given. The unit and a brief description of each parameter is given. The parameters are grouped into the 17 parameters of the SWAT model and the two parameters calibrated for the Raven routing.

| Param.          | Range    | Unit | Parameter description                                                                 |
|-----------------|----------|------|---------------------------------------------------------------------------------------|
| **SWAT related:** |          |      |                                                                                       |
| SFTMP           | [−5, 5]  | °C   | Snow fall temperature                                                                  |
| SMTMP           | [−5, 5]  | °C   | Snowfall melt base temperature                                                         |
| SMFMX           | [2, 10]  | mm/°C/d | Maximum melt rate for snow during the year                                            |
| SMFMN           | [2, 10]  | mm/°C/d | Minimum melt rate for snow during the year                                           |
| TIMP            | [0, 1]   | -    | Snow pack temperature lag factor                                                      |
| CN2             | [−20, 20]| %    | Percent change of initial SCS runoff curve number for moisture condition II [-]      |
| GW_DELAY        | [1, 180]| d    | Groundwater delay time                                                                |
| ALPHA_BF        | [0.01, 1]| -    | Base flow alpha factor                                                                |
| GWQMN           | [10, 1000]| mm  | Threshold depth of water in the shallow aquifer required for return flow to occur     |
| GW_REVAP        | [0.02, 0.2]| -  | Groundwater revap. coefficient                                                        |
| REVAPMN         | [10, 1000]| mm | Threshold depth of water in the shallow aquifer for ‘revap’ to occur                  |
| SURLAG          | [0.1, 24]| d    | Surface runoff lag time                                                               |
| ESCO            | [0.5, 1] | -    | Soil evaporation compensation factor                                                  |
| EPCO            | [0, 1]   | -    | Plant uptake compensation factor                                                       |
| OV_N            | [0.01, 0.25]| -  | Manning’s n value for overland flow                                                   |
| SOL_K           | [−20, 20]| %    | Percent change of initial soil hydraulic conductivity [mm/d]                          |
| SOL_AWC         | [−20, 20]| %    | Percent change of initial soil available water storage capacity [-]                  |
| **Raven Routing:** |          |      |                                                                                       |
| w               | [0.25, 4.0]| -  | Multiplier to adjust crest width of reservoir/lake                                    |
| n               | [0.25, 4.0]| -  | Multiplier to adjust Manning’s coefficient                                             |
S3.10 WATFLOOD-Raven

WATFLOOD simulated gridded vertical fluxes (runoff and recharge to lower zone storage) were fed to the lake and river routing product (Han et al., 2020), integrated into the Raven modelling framework (Craig et al., 2020), to route the both vertical fluxes. The integrated WATFLOOD-Raven model was then calibrated by using WATFLOOD-related and Raven-related parameters simultaneously within the given range as shown in Tab. S11.

Table S11: The parameters calibrated for the WATFLOOD-Raven model. The parameters are uniformly distributed in the range given. The unit and a brief description of each parameter is given. The parameters are grouped into the eleven parameters of the WATFLOOD model and the six parameters calibrated for the Raven routing.

| Param.   | Range         | Unit     | Parameter description                               |
|----------|---------------|----------|-----------------------------------------------------|
| WATFLOOD related: |            |          |                                                     |
| fm       | [0.05, 0.5]   | mm/°C/h  | Melt factor                                         |
| base     | [-5, 5]       | °C       | Base temperature                                    |
| rec      | [0.01, 10]    | -        | Interflow coefficient                               |
| ak       | [0.01, 10]    | -        | Infiltration coefficient in bare ground            |
| akfs     | [0.001, 1]    | -        | Infiltration coefficient in snow covered ground     |
| retn     | [50, 1000]    | mm       | Upper zone retention                                |
| ak2      | [0.01, 1]     | -        | Recharge coefficient in bare ground                |
| ak2fs    | [0.001, 0.1]  | -        | Recharge coefficient in snow covered ground        |
| r3       | [1, 50]       | -        | Overland flow roughness coefficient in bare ground  |
| r3fs     | [1, 10]       | -        | Overland flow roughness coefficient in snow covered ground |
| fpet     | [1, 20]       | -        | Interception evaporation factor                     |
| Raven Routing: |          |          |                                                     |
| w        | [0.25, 4.0]   | -        | Multiplier to adjust crest width of reservoir/lake  |
| n        | [0.25, 4.0]   | -        | Multiplier to adjust Manning’s coefficient          |
| γ-shape  | [1, 10]       | -        | Gamma unit hydrograph shape parameter               |
| γ-scale  | [1, 10]       | -        | Gamma unit hydrograph scale parameter               |
| bf_k     | [10^-5, 1]    | 1/d      | Baseflow coefficient                                |
| bf_n     | [1, 5]        | 1/d      | User specified soil parameter                       |
S3.11 MESH-CLASS-Raven

The integrated MESH-CLASS-Raven model was then calibrated by using MESH-CLASS-related and Raven-related parameters simultaneously within the given range as shown in Tab. S12.

Table S12: The parameters calibrated for the MESH-CLASS-Raven model. The parameters are uniformly distributed in the range given. The unit and a brief description of each parameter is given. The parameters are grouped into the 14 parameters of the MESH-CLASS model and the 6 parameters calibrated for the Raven routing.

| Param. | Range          | Unit | Parameter description                                           |
|--------|----------------|------|-----------------------------------------------------------------|
| MESH-CLASS related (all parameters per GRU): |
| DRN    | [0.001, 5.0]   | -    | Soil drainage index                                            |
| DDEN   | [1.0, 150.0]   | -    | Drainage density                                                |
| KSAT   | [1 x 10^{-11}, 1 x 10^{-2}] | m/s  | Saturated hydraulic conductivity                               |
| QA50   | [1.0, 100.0]   | W/m^2| Reference value of incoming shortwave radiation                |
| ROOT   | [0.001, 5.0]   | m    | Annual maximum rooting depth of vegetation category             |
| RSMN   | [10, 450]      | s/m  | Minimum stomatal resistance of vegetation category              |
| SDEP   | [0.001, 4.0]   | m    | Soil permeable depth                                           |
| WFR2   | [0.01, 2.0]    | -    | Channel roughness coefficient                                   |
| SAND   | [0.0, 100.0]   | %    | Percentage sand content                                        |
| CLAY   | [0.0, 100.0]   | %    | Percentage clay content                                        |
| XSLP   | [0.0001, 1.0]  | %    | Average overland slope                                         |
| ZSLN   | [0.01, 1.0]    | m    | Limiting snow depth below which coverage is less than 100%     |
| ZPLS   | [0.01, 1.0]    | -    | Maximum water ponding depth for snow-covered areas              |
| ZPLG   | [0.01, 1.0]    | -    | Maximum water ponding depth for snow-free areas                |
| Raven Routing: |
| w      | [0.1, 5.0]     | -    | Multiplier to adjust crest width of reservoir/lake             |
| n      | [0.1, 5.0]     | -    | Multiplier to adjust Manning’s coefficient                     |
| γ-shape| [1.0, 10.0]    | -    | Gamma unit hydrograph shape parameter                          |
| γ-scale| [1.0, 10.0]    | -    | Gamma unit hydrograph scale parameter                          |
| bf_k   | [1 x 10^{-5}, 1.0] | 1/d  | Baseflow coefficient                                           |
| bf_n   | [1.0, 5.0]     | 1/d  | User specified soil parameter                                  |
S3.12 MESH-SVS-Raven

The MESH-SVS-Raven model was calibrated by using MESH-SVS-related and Raven-related parameters simultaneously within the given range as shown in Tab. S13. Most of the calibrated parameters correspond to coefficients that are used to multiply the actual corresponding Model parameter values. This is done in order to limit the number of free parameters during calibration, while being able to change the actual parameter values over the full domain and maintain a spatial variability and coherence for the actual field of parameter values across the domain. This approach has already proven effective in the sense that model performances could be significantly improved compared to the default version of the model, that the issue of parameter value equifinality was limited, and that model robustness was satisfying. See for example the studies of Gaborit et al. (2015), Gaborit et al. (2017), and Mai et al. (2021), where some models were calibrated based on multiplying coefficients instead of actual parameter values. One other advantage of such an approach is that none of the MESH-SVS-Raven free parameters used in calibration are tied to a specific calibration or validation basin, but are applied to the whole region at once. Therefore, no spatial parameter transfer is required for the validation basins, as long as they are included in the region of interest. Among the MESH-SVS-Raven parameters, only the “RICK”, “FLZCOEFF”, “PWRC”, “GASH” and “GASC” parameters (see Tab. S13) correspond to actual model parameter values, but here they correspond in the model to values that are fixed over the whole region where the model is applied.

In order to use different parameter values for the agricultural and more natural areas (like grassland, forests, etc.), two different multipliers were used both for the horizontal and vertical model conductivities, as well as for the evapotranspiration resistance multipliers (see Tab. S13). This was done because of the artificial tile drains that are often installed in agricultural areas of the Great-Lakes basin (see Valayamkunnath et al., 2020). These tile drains allow to prevent the crops from being flooded by quickly removing water that infiltrated into the soil column, but lead to significantly higher peak flows at the outlet of agricultural basins, in comparison to their natural regime. Because these tile drains are not explicitly represented in MESH-SVS-Raven, their effect on simulated flows was represented by allowing hydraulic conductivity values to be significantly increased in the model, as suggested by De Schepper et al. (2015). This is why higher ranges were allowed for the hydraulic conductivity multiplier values associated with agricultural areas, compared to the natural areas (see Tab. S13). However, since MESH-SVS-Raven cannot simulate processes separately for these two types of areas inside a grid-cell (SVS soil parameters are valid over the whole grid cell), the actual multiplier value used to adjust SVS horizontal or vertical hydraulic conductivity consists of a weighted average of the agricultural and “natural” multiplier values, based on the fraction of the grid-cell covered with agricultural cover, and the rest of the pixel that is assumed as being “natural”, in the sense that it is assumed not to contain any tile drains. The same was done for the evapotranspiration resistance multipliers, in order to give SVS some flexibility by using different adjustments in agricultural and other (natural) areas, for these parameters.

Finally, because we rely here on multiplicative coefficients to adjust the actual parameter values, some restrictions had to be imposed on the final (after adjustment) actual model parameter values, to ensure that they could not go beyond values with physical meaning. For example, the Albedo final values have a maximum of 1, the 50% root depth values have to stay below the 95% root depth values (minus 5cm to ensure numerical stability), and the three soil moisture thresholds, namely the wilting
point, the field capacity and the saturation were respectively constrained below fractions of 0.5, 0.75 and 0.95. Because they were adjusted all together by the same multiplier, their relative order remained unchanged after adjustment and did not need to be constrained.

Table S13: The parameters calibrated for the MESH-SVS-Raven model. The parameters are uniformly distributed in the range given. The unit and a brief description of each parameter is given. The parameters are grouped into the 17 parameters of the MESH-SVS model and the 6 parameters calibrated for the Raven routing. Most of these parameters correspond to multiplying coefficients. See text for more details.

| Param.       | Range          | Unit | Parameter description                                                                 |
|--------------|----------------|------|---------------------------------------------------------------------------------------|
| **MESH-SVS related:**                                                                                                                                   |
| MLTM         | [0.5,4]        | -    | Snowmelt rate divider                                                                  |
| BMOD         | [0.5,4]        | -    | Slope of retention curve multiplier                                                    |
| WMOD         | [0.1,3]        | -    | Soil moisture thresholds multiplier                                                    |
| PMOD         | [0.1,5]        | -    | Soil water suction near saturation multiplier                                           |
| GRKMO_N      | [0.2,5]        | -    | Horizontal hydraulic conductivity multiplier (natural areas)                           |
| GRKMO_A      | [0.2,40]       | -    | Horizontal hydraulic conductivity multiplier (agricultural areas)                      |
| KASMO_N      | [0.2,5]        | -    | Vertical hydraulic conductivity multiplier (natural areas)                              |
| KASMO_A      | [0.1,40]       | -    | Vertical hydraulic conductivity multiplier (agricultural areas)                        |
| RICK         | [0,1]          | -    | Weight given to new evaporation formulation over bare ground                           |
| EVM_N        | [0.2,5]        | -    | Evapo-transpiration resistance multiplier (natural areas)                              |
| EVM_A        | [0.2,9]        | -    | Evapo-transpiration resistance multiplier (agricultural areas)                        |
| SUMOD        | [0.1,5]        | -    | Sublimation resistance multiplier                                                     |
| RTMOD        | [0.1,3]        | -    | 95% root depth multiplier                                                             |
| DMOD         | [0.1,4]        | -    | 50% root depth multiplier                                                             |
| LMOD         | [0.2,4]        | -    | Leaf-Area Index multiplier                                                            |
| AMOD         | [0.1,5]        | -    | Albedo multiplier                                                                     |
| ZMOD         | [0.2,5]        | -    | Surface Roughness multiplier                                                          |
| **Raven Routing:**                                                                                                                                      |
| FLZCOEFF     | [1.0 × 10^{-8},1.0 × 10^{-3}] | -   | Baseflow equation multiplicative parameter                                             |
| PWRC         | [1.5,7]        | -    | Baseflow equation power parameter                                                     |
| R1NC         | [0.1,9]        | -    | Manning values multiplier                                                             |
| GASH         | [1,32]         | -    | Gamma Unit Hydrograph shape parameter                                                 |
| GASC         | [1,6]          | -    | Gamma Unit Hydrograph scale parameter                                                 |
| LACRWD       | [1.0 × 10^{-3},1.0 × 10^{3}] | -   | Lakes’ outlet width multiplier                                                        |
The GEM-Hydro-Watroute model was not calibrated directly, because it is too expensive in terms of computation time. For example, a 10-year open-loop simulation with GEM-Hydro-Watroute over the whole Great-Lakes watersheds is about a 100 times slower than a MESH-SVS-Raven similar run. This is due to several reasons. Despite the surface component of GEM-Hydro-Watroute (named GEM-Surf) is heavily parallelized (with MPI, where a domain grid can be split into numerous subgrids during computation) and can for example perform simulations over very large domains (even global simulations) in an efficient manner, it currently relies on 24-h integration cycles, leading to a lot of time being spent in Input/Output (I/O) processes, and in model jobs being submitted for each day of simulation on ECCC supercomputers, with the job sometimes waiting in a queue. In contrast, the surface component of MESH-SVS-Raven (namely MESH-SVS), which is also parallelized with an MPI approach, is run with a single model integration over the full period, such that less time is therefore spent in I/O and job submission processes. Therefore, a MESH simulation is actually much faster than a GEM-Surf one, when running over grids with a limited number of points, like this is the case for the six regions of the Great-Lakes domain used here, with a 10 km resolution. In this study, the MESH-SVS simulation was about 40 times faster than the GEM-Surf simulation, over one of the six regions and the 10 km resolution considered here, despite both models were run here on the same CPUs, with 10 CPUs for MESH-SVS. Using 4 CPUs for GEM-Surf was close to the optimum in this case: if asking for more CPUs, the job could wait more time in the queue during submission. For MESH-SVS, computation time may be further improved with using more CPUs, but probably not to a significant degree, since the six regions used here do not contain a high number of 10 km grid points (the maximum is 4455 grid-points for the Lake Superior region, while the minimum is 2132 for the Ottawa River region). Therefore, it is very challenging to calibrate GEM-Hydro-Watroute directly already because of its surface component.

Regarding the routing component of GEM-Hydro-Watroute (Watroute), it is also much slower than the Raven routing scheme. First, Watroute is a grid-based model that has a 1 km resolution in GEM-Hydro-Watroute, and that is not parallelized. In the ECCC National Surface and River Prediction System (NSRPS; Durnford et al., 2021) that relies on the GEM-Hydro-Watroute model, the routing Watroute component is however implemented separately for each of six main Canadian Watersheds that it currently covers in the NSRPS system, leading to a parallelization of the model by separate model setups. In opposition, Raven is a subbasin-based routing model. Therefore, it generally includes much less subbasin objects than there are 1 km grid points inside a given watershed. Raven to Watroute comparisons performed as part of collaborative University of Waterloo-ECCC research projects showed that Raven is about 30 times faster than Watroute, over a 60,000 km² watershed, with a 6-h Raven time-step and the detailed Raven version, which had 2635 objects compared to Watroute’s 122,441 grid points included in the basin. But this ratio is based on the model computing time only. However, running Watroute inside of GEM-Hydro-Watroute also implies a pre-processing phase of GEM-Surf outputs, which can be even more time-consuming than the model runtime itself. When including Watroute’s pre-processing time, Raven was about 130 times faster than Watroute, for the basin described above. However, when comparing Watroute to Raven runtimes on the Lake Huron region of this GRIP-GL project, Raven was able to perform the 10-y calibration period in 130s, while it took about 55h to do the same for Watroute, which
represents a ratio of about 1500. It is true that in this case, Watroute was running over the full Lake Huron watershed, while Raven was only simulating the calibration and validation basins, which in total, represent about half of the Lake Huron region. Moreover, during these 55h of the total Watroute runtime, about 76% was spent on the pre-processing, highlighting where the emphasis should be put in order to decrease Watroute computation time. It was noticed that Watroute pre-processing time could be improved significantly, following some previous tests. But even if considering only Watroute true model computation time over half of Lake Huron region, Raven would still be about 200 times faster than Watroute in this case. The difference with the ratio of 30 mentioned above probably comes from the fact that the common Raven setup used for GRIP-GL does not correspond to the most possible detailed version of the model, because lakes smaller than 5 km$^2$ were removed from the setup, allowing to significantly reduce the total number of subbasins in the Raven setup used for GRIP-GL. Nevertheless, the Raven setup used here proved to be able to simulate hydrographs at gauge locations in a very satisfactory manner during this project.

However, as mentioned in the main part of this study, GEM-Hydro-Watroute computation time is generally not an issue when it comes to perform large-scale forecasts, where the lead-time is generally limited to about 16 days. GEM-Hydro-Watroute can still perform 10 years open-loop runs over large watersheds in a reasonable time (about 7 to 10 days), given that this type of simulations is generally not needed frequently and that tests needed for model development can be done over shorter periods and smaller domains. It has also to be mentioned that Watroute pre-processing time is not linearly correlated with the size of the domain, and large domains can have a pre-processing time quite similar to the one of small domains. However, this computation time is definitely an issue when it comes to model calibration. Despite different approaches have been tried in the past to calibrate GEM-Hydro-Watroute (see main part of the manuscript), in this study the idea is to emulate GEM-Surf with MESH-SVS, and to replace Watroute by Raven during calibration. This is done because using a detailed routing model is still wanted in order to be able to compute streamflow performances even for small watersheds. Moreover, it is assumed that most of the bias and dynamics of streamflow simulations are controlled by the surface component, and not by the routing model, despite the latter can of course control the timing of peak flows and the dynamics of flow recessions, through the Manning and baseflow parameters, for example.

Therefore, as part of this work, the SVS-related parameters that were calibrated with MESH-SVS-Raven were transferred directly to SVS in GEM-Hydro-Watroute. For the routing parameters, only the calibrated baseflow parameters were directly transferred to GEM-Hydro-Watroute afterwards. Indeed, Watroute does not rely on the Gamma Unit Hydrograph convolution to route surface runoff to the streams, and does not rely on the same lake outflow equation than Raven (thus, not all lakes are explicitly represented in Watroute), and the default Manning values in Watroute are not computed the same way as in Raven. However, because Watroute default Manning values may not be optimal, especially in conjunction with the calibrated baseflow parameters, they were manually tuned afterwards over each of the six regions, by using multiplicative coefficients applied to the default (spatially varying) values (see Tab. S14), similarly to what was done during the Raven calibration. For this, a few trials (about 4 to 6 generally) were realized by running Watroute over 2 years of the calibration period, when forced by the calibrated GEM-Surf version and when using the calibrated baseflow parameters. To do so, Watroute’s pre-processing therefore only had to be done once, and a two-year Watroute run without the pre-processing only took about 2.5h. The final multiplicative coefficients retained to adjust Watroute’s original (default) Manning values, after these manual adjustments, range between
0.5 and 2 across the six regions, with the value of 1 (original Watroute Manning values remain unchanged) being retained for three out of the six regions. A limited sensitivity of the simulated flow performances to the adjusted Manning values moreover confirmed the stronger importance of the LSS parameters compared to the routing scheme (especially Manning values) parameters used here, which only control the timing of simulated streamflow to some degree, and not its general bias.

The approach employed here to calibrate GEM-Hydro-Watroute by emulating the surface component of GEM-Surf with MESH-SVS and employing the faster routing scheme Raven in place of Watroute during calibration seemed relevant, as long as the two models could produce similar streamflow simulations. For this reason and during this project, all subgrid-scale lakes were neglected when simulating the surface with MESH-SVS or GEM-Surf. Indeed, with GEM-Surf (see Bernier et al., 2011), a total of five different types of surfaces can be simulated, including land, water, and urban areas, which are the three different types of surfaces present in the Great-Lakes region. However, with the current version of MESH, only the land type can be simulated when using the SVS LSS. Work is under way to integrate additional GEM-Surf routines in MESH, in order to represent the other types of surfaces that GEM-Surf can simulate. Note that in the current GEM-Hydro-Watroute model used for hydrology simulations at ECCC, urban areas are not yet represented with the urban component of GEM-Surf, but are represented with SVS directly, assuming a fixed ratio of 33% imperviousness for urban cover, based on Gaborit et al. (2013). But because of this, and in order to obtain GEM-Surf and MESH-SVS simulations that are as close as possible to favor parameter transfer between the two, the subgrid-scale lakes were neglected in GEM-Surf, which means that any grid-cell having a fraction of water lower than 100% was in fact assumed to contain 100% of land instead. This resulted in almost 100% of the calibration/validation basins studied here to be covered at 100% by land in both MESH-SVS and GEM-Surf. In terms of streamflow impact, neglecting these subgrid-scale lakes in GEM-Surf only has a minor effect on GEM-Hydro-Watroute simulations across the Great Lakes, probably because of the relatively small role that lake evaporation plays in the overall water balance of the terrestrial watersheds of the Great Lakes (i.e., with the exception of the five Great Lakes themselves). Moreover, since land evapotranspiration rates are generally similar to overlake evaporation in this region, replacing water surfaces with land surfaces does not have a strong impact on the resulting streamflow simulations in this region (not shown here).

However, strong differences were noticed for some flow gauges, between the simulations obtained with the default versions of MESH-SVS-Raven and GEM-Hydro-Watroute. For some gauges, these differences were partly due to the fact that the Raven basin delineation was different than one used for Watroute. However, strong delineation differences between the two models was quite rare and only affected a few of the total 212 calibration/validation basins used in this project. Of course, differences can arise from the different routing models themselves, because they might not represent the same river and lake network, and because they might not represent the same processes: for example, Raven uses a Gamma Unit Hydrograph convolution approach in order to route the surface runoff generated by the LSS, into the closest stream. In Watroute, surface runoff is assumed to enter the stream of the current grid-cell instantaneously, and the fact that Watroute assumes that a stream is present in every grid-cell can, to some degree, represent an approximation of the transport of surface/subsurface runoff between its source and an actual stream. However, these routing model differences should only affect streamflow timing, and not the general streamflow bias, for basins having close delineation boundaries between the two routing schemes. This affirmation
is especially true given that subgrid-scale lakes were neglected in the MESH-SVS and GEM-Surf surface simulations of this project (see above). Therefore, evaporation losses from lakes and rivers were not taken into account in both the Raven and Watroute simulations performed here, because such losses, when coupling Watroute or Raven to MESH-SVS or GEM-Surf, are included in the aggregated surface runoff of a surface grid cell. Surface runoff over land can however not be negative with SVS, because the evapotranspiration losses are already removed from the SVS vegetation and soil storage compartments. And the main difference that can arise between Raven and Watroute simulations, when forced by the same surface fluxes and in terms of general flow bias, is due to the treatment of evaporation in the routing scheme. Therefore, in this case, because no evaporation loss is provided to either routing scheme, and because they both close their water balance almost perfectly, the routing schemes can not be responsible for strong differences regarding their flow simulations’ biases (again, assuming that they have similar delineations for a given watershed, which is generally the case here).

Regarding MESH-SVS and GEM-Surf simulations, differences existing between the two are well known and were already noticed during the GRIP-E project (see Mai et al., 2021). However, these differences were generally small and both models still produced very similar flow simulations in this case. After investigation, it was found that there was an issue regarding the reading of vegetation cover fractions from the geophysical file, in MESH-SVS-Raven. As a consequence, MESH-SVS did not use the correct vegetation cover during GRIP-GL, and seems to have assigned the same vegetation fractions for all points inside a region, based on one of the points of the region. This issue did not occur during GRIP-E, because it is related to the new NetCDF format used in GRIP-GL for the MESH geophysical input file. This is a strong problem for the approach used here, because SVS vegetation classes are associated to specific vegetation parameters. Therefore, the calibrated parameters related to vegetation properties (like LAI, stomatal resistance, root dephts, etc; see Tab. S13) that were obtained with MESH-SVS-Raven were not optimal for GEM-Hydro-Watroute.

This probably explains the strong flow bias differences between the default versions of the two models, for some regions, as well as most of the strong loss of performance when transferring the SVS and some routing parameters that were calibrated with MESH-SVS-Raven, into GEM-Hydro-Watroute. But despite this issue, the approach employed here to calibrate GEM-Hydro-Watroute seems promising, in view of the results obtained in this study. The fact that the parameters calibrated with MESH-SVS-Raven, when transferred into GEM-Hydro-Watroute, could still generally improve upon the default version of the model, is probably due to the fact the calibrated SVS parameters related to soil processes, for example hydraulic conductivity, were more appropriate than the default values used in GEM-Hydro, especially for agricultural areas with tile drains, that are not represented explicitly in the model, yet. However, work is under way to fix the issue mentioned above, as well as revising the strategy for some calibration parameters, and restart all MESH-SVS-Raven calibrations, GEM-Hydro simulations, and the auxiliary variables’ evaluation, in order to come up with a calibration strategy for GEM-Hydro-Watroute, that would allow to improve or maintain the performances regarding surface fluxes and auxiliary variables, in view of being able to couple a GEM-Hydro-Watroute model that was calibrated by targeting streamflow performances, with an atmospheric model, which is the long-term goal of this work.
Table S14: **The parameters manually tuned for the GEM-Hydro-Watroute model.** Some of the parameters calibrated with MESH-SVS-Raven were transferred into GEM-Hydro-Watroute, and the Watroute Manning values were then further manually tuned afterwards. See text for more details.

| Param. | Range  | Unit | Parameter description       |
|--------|--------|------|----------------------------|
| MULN   | [0.2, 5]| -    | Manning values multiplier   |

S4  **Model performance for streamflow in KGE components**

The following figures show the model performance for the three Kling-Gupta efficiency (KGE) components of variability ($KGE_\alpha$; Fig. S3), bias ($KGE_\beta$; Fig. S4) and correlation ($KGE_r$; Fig. S5). The components are transformed in a way that all have their optimal (maximal) value at 1 similar to the overall KGE for better comparability. The metrics are defined in the main manuscript (Eq. 1 to 3). All the component performance values can be visualized on the project website (www.hydrohub.org/grip-gl/maps_streamflow.html).

S5  **Streamflow gauging stations**

Table S15 contains the list of the 212 gauging stations including their area, region they are located in, objectives they were selected for, and whether they were used for calibration or validation.
Figure S3. Model performance (variability) regarding streamflow. The performance is shown for (A) the 141 calibration stations and (B) the 71 validation locations for the calibration period. The results for the validation period of the calibration and validation sites are shown in panels (C) and (D), respectively. In summary, panel (B) shows spatial validation, panel (C) shows temporal validation, and panel (D) shows spatio-temporal validation across the locations (x-axis) and the 13 models (y-axis). The locations are grouped according to their location within the six watersheds (vertical black lines) of Lake Erie (ERI), Lake Huron (HUR), Lake Michigan (MIC), Lake Ontario (ONT), Ottawa River (OTT), and Lake Superior (SUP). The horizontal black lines separate the machine-learning based global LSTM model from the models that are calibrated locally and the models that are calibrated per region. The performance is quantified using the component $\alpha$ of the Kling-Gupta efficiency (KGE$\alpha$) which determines the relative variability of the simulations and observations. The median KGE$\alpha$ performance of each model for each of the four evaluation scenarios is added as labels to each panel. The thresholds for medium, good, and excellent performance classifications are added as labels to the colorbar. The performance regarding KGE can be found in Fig. 3 in the main manuscript. For the spatial distribution of these results as well as the simulated and observed hydrographs please refer to the website (www.hydrohub.org/grip-gl/maps_streamflow.html).
**Figure S4. Model performance (bias) regarding streamflow.** The performance is shown for (A) the 141 calibration stations and (B) the 71 validation locations for the calibration period. The results for the validation period of the calibration and validation sites are shown in panels (C) and (D), respectively. In summary, panel (B) shows spatial validation, panel (C) shows temporal validation, and panel (D) shows spatio-temporal validation across the locations (x-axis) and the 13 models (y-axis). The locations are grouped according to their location within the six watersheds (vertical black lines) of Lake Erie (ERI), Lake Huron (HUR), Lake Michigan (MIC), Lake Ontario (ONT), Ottawa River (OTT), and Lake Superior (SUP). The horizontal black lines separate the machine-learning based global LSTM model from the models that are calibrated locally and the models that are calibrated per region. The performance is quantified using the component $\beta$ of the Kling-Gupta efficiency ($\text{KGE}_\beta$) which determines the bias between simulations and observations. The median $\text{KGE}_\beta$ performance of each model for each of the four evaluation scenarios is added as labels to each panel. The thresholds for medium, good, and excellent performance classifications are added as labels to the colorbar. The performance regarding KGE can be found in Fig. 3 in the main manuscript. For the spatial distribution of these results as well as the simulated and observed hydrographs please refer to the website (www.hydrohub.org/grip-gl/maps_streamflow.html).
Figure S5. Model performance (correlation) regarding streamflow. The performance is shown for (A) the 141 calibration stations and (B) the 71 validation locations for the calibration period. The results for the validation period of the calibration and validation sites are shown in panels (C) and (D), respectively. In summary, panel (B) shows spatial validation, panel (C) shows temporal validation, and panel (D) shows spatio-temporal validation across the locations (x-axis) and the 13 models (y-axis). The locations are grouped according to their location within the six watersheds (vertical black lines) of Lake Erie (ERI), Lake Huron (HUR), Lake Michigan (MIC), Lake Ontario (ONT), Ottawa River (OTT), and Lake Superior (SUP). The horizontal black lines separate the machine-learning based global LSTM model from the models that are calibrated locally and the models that are calibrated per region. The performance is quantified using the component $r$ of the Kling-Gupta efficiency (KGE$_r$) which determines the Pearson correlation between the simulations and observations. The median KGE$_r$ performance of each model for each of the four evaluation scenarios is added as labels to each panel. The thresholds for medium, good, and excellent performance classifications are added as labels to the colorbar. The performance regarding KGE can be found in Fig. 3 in the main manuscript. For the spatial distribution of these results as well as the simulated and observed hydrographs please refer to the website (www.hydrohub.org/grip-gl/maps_streamflow.html).
Table S15: **Streamflow gauges used in this study.** The 212 streamflow gauges are given including their gauge ID either specified by Water Survey Canada or U.S. Geological Survey and their name. The drainage area upstream of each gauge is specified as derived by the routing product. The region specifies in which of the six watersheds comprising the great Lakes the watershed is located in (ERI=Lake Erie, HUR=Lake Huron, MIC=Lake Michigan, SUP=Lake Superior, ONT=Lake Ontario, OTT=Ottawa River). The objective for each basin is assigned to be 1 if the watershed is of low-human impact while it is assigned to 2 if the gauge station is most downstream to one of the five lakes or the Ottawa River. Calibration basins (141) are specified with ‘Cal’ and validation basins (71) are specified with ‘Val’ in the column ‘Cal/Val’. Furthermore, the mean elevation and average annual runoff of each basin is given.

| Gauge ID | Name                                              | Derived Area [km²] | Region | Obj. | Cal/Val | Elev. [m] | Avg. Annual Runoff [mm] |
|---------|---------------------------------------------------|--------------------|--------|------|---------|-----------|------------------------|
| 02AB006 | KAMINISTIQUIA RIVER AT KAMINISTIQUIA               | 6576               | SUP    | 2    | Val     | 299       | 282                    |
| 02AB017 | WHITEFISH RIVER AT NOLALU                         | 229                | SUP    | 1,2  | Cal     | 321       | 295                    |
| 02AB021 | CURRENT RIVER AT STEPSTONE                        | 404                | SUP    | 1,2  | Val     | 333       | 335                    |
| 02AC001 | WOLF RIVER AT HIGHWAY NO. 17                      | 634                | SUP    | 1,2  | Cal     | 184       | 305                    |
| 02AC002 | BLACK STURGEON RIVER AT HIGHWAY NO. 17            | 2733               | SUP    | 1,2  | Cal     | 188       | 268                    |
| 02AD010 | BLACKWATER RIVER AT BEARDMORE                     | 718                | SUP    | 1    | Cal     | 288       | 353                    |
| 02AD012 | NIPIGON RIVER AT ALEXANDER GS                     | 25112              | SUP    | 2    | Val     | 165       | 515                    |
| 02AE001 | GRAVEL RIVER NEAR Cavers                          | 624                | SUP    | 1,2  | Val     | 240       | 392                    |
| 02BA003 | LITTLE PIC RIVER NEAR COLDWELL                    | 1378               | SUP    | 1,2  | Cal     | 195       | 364                    |
| 02BA006 | STEEL RIVER BELOW SANTOY LAKE                     | 1219               | SUP    | 1,2  | Val     | 196       | 384                    |
| 02BB003 | PIC RIVER NEAR MARATHON                           | 4214               | SUP    | 1,2  | Cal     | 189       | 365                    |
| 02BB004 | CEDAR CREEK NEAR HEMLO                            | 214                | SUP    | 2    | Cal     | 297       | 319                    |
| 02BC004 | WHITE RIVER BELOW WHITE LAKE                      | 4129               | SUP    | 2    | Val     | 306       | 352                    |
| 02BC006 | Pukaskwa River BELOW FOX RIVER                    | 454                | SUP    | 2    | Cal     | 348       | 472                    |
| 02BD002 | MICHIPICOTEN RIVER AT HIGH FALLS                  | 5104               | SUP    | 2    | Cal     | 193       | 381                    |
| 02BD007 | MAGPIE RIVER NEAR WAWA                            | 1979               | SUP    | 2    | Val     | 262       | 401                    |
| 02BE002 | MONTREAL RIVER NEAR MONTREAL RIVER HARBOUR        | 3369               | SUP    | 2    | Val     | 256       | 392                    |
| 02BF001 | BATCHAWANA RIVER NEAR BATCHAWANA                  | 1225               | SUP    | 1,2  | Cal     | 220       | 541                    |
| 02BF002 | GOULAIS RIVER NEAR SEARCHMONT                    | 1181               | SUP    | 1    | Cal     | 298       | 477                    |
| 02BF014 | GOULAIS RIVER NEAR KIRBYS CORNER                  | 1826               | SUP    | 2    | Val     | 189       | 539                    |
| 02CA007 | THESSALON RIVER NEAR POPLAR DALE                  | 255                | HUR    | 2    | Val     | 211       | 483                    |

*Continued on next page*
| Gauge ID | Name                                             | Derived Area [km²] | Region | Obj. | Cal/Val | Elev. [m] | Avg. Annual Runoff [mm] |
|---------|--------------------------------------------------|--------------------|--------|------|---------|-----------|-------------------------|
| 02CB003 | AUBINADONG RIVER ABOVE SESABIC CREEK             | 1481               | HUR    | 1,2  | Cal     | 347       | 362                     |
| 02CC005 | LITTLE WHITE RIVER NEAR BELLINGHAM               | 1954               | HUR    | 2    | Cal     | 218       | 406                     |
| 02CD001 | SERPENT RIVER AT HIGHWAY NO. 17                  | 1252               | HUR    | 2    | Cal     | 178       | 464                     |
| 02CE002 | AUX SABLES RIVER AT MASSEY                       | 1276               | HUR    | 2    | Val     | 170       | 420                     |
| 02CF007 | WHITSON RIVER AT CHELMSFORD                      | 244                | HUR    | 1,2  | Cal     | 265       | 347                     |
| 02CF010 | ONAPING RIVER NEAR LEVACK                       | 1651               | HUR    | 2    | Val     | 306       | 221                     |
| 02CF011 | VERMILION RIVER NEAR VAL CARON                   | 701                | HUR    | 1,2  | Val     | 278       | 398                     |
| 02DB005 | WANAPITEI RIVER NEAR WANUP                       | 3318               | HUR    | 2    | Cal     | 220       | 375                     |
| 02DC012 | STURGEON RIVER AT UPPER GOOSE FALLS              | 1281               | HUR    | 1    | Cal     | 256       | 406                     |
| 02DD010 | FRENCH RIVER AT DRY PINE BAY                     | 18222              | HUR    | 2    | Cal     | 184       | 449                     |
| 02EA005 | NORTH MAGNETAWAN RIVER NEAR BURKS FALLS          | 325                | HUR    | 1    | Cal     | 309       | 593                     |
| 02EA011 | MAGNETAWAN RIVER NEAR BRITT                      | 2633               | HUR    | 2    | Cal     | 178       | 509                     |
| 02EA018 | MAGNETAWAN RIVER NEAR EMSDALE                    | 397                | HUR    | 1    | Val     | 332       | 586                     |
| 02EB011 | MOON RIVER AT HIGHWAY NO. 400                    | 4527               | HUR    | 2    | Cal     | 209       | 182                     |
| 02EB014 | OXTONGUE RIVER NEAR DWIGHT                      | 571                | HUR    | 1    | Cal     | 324       | 576                     |
| 02EC002 | BLACK RIVER NEAR WASHAGO                        | 1451               | HUR    | 1    | Cal     | 208       | 514                     |
| 02EC003 | SEVERN RIVER AT SWIFT RAPIDS                     | 5793               | HUR    | 2    | Cal     | 194       | 317                     |
| 02EC011 | BEAVER RIVER NEAR BEAVERTON                     | 300                | HUR    | 1    | Val     | 227       | 347                     |
| 02EC018 | PEFFERLAW BROOK NEAR UDORA                      | 348                | HUR    | 1    | Cal     | 229       | 290                     |
| 02EC019 | BLACK RIVER NEAR VANKOUGHNET                    | 385                | HUR    | 1    | Val     | 275       | 588                     |
| 02ED003 | NOTTAWASAGA RIVER NEAR BAXTER                   | 1295               | HUR    | 1    | Cal     | 189       | 270                     |
| 02ED015 | MAD RIVER AT AVENING                             | 255                | HUR    | 1    | Cal     | 238       | 505                     |
| 02ED024 | North River at the Falls                        | 249                | HUR    | 1,2  | Cal     | 171       | 259                     |
| 02ED027 | Nottawasaga River near Edenvale                 | 2735               | HUR    | 2    | Val     | 163       | 324                     |
| 02ED029 | INNISFIL CREEK NEAR ALLISTON                    | 457                | HUR    | 1    | Cal     | 202       | 226                     |
| 02ED032 | WILLOW CREEK NEAR MINESING                      | 228                | HUR    | 1    | Val     | 192       | 351                     |
| 02ED101 | NOTTAWASAGA RIVER NEAR ALLISTON                 | 337                | HUR    | 1    | Cal     | 222       | 315                     |
| 02ED102 | Boyne River at Earl Rowe Park                   | 239                | HUR    | 1    | Cal     | 211       | 313                     |
| 02FA001 | SAUBLE RIVER AT SAUBLE FALLS                    | 927                | HUR    | 2    | Cal     | 144       | 538                     |
Table S15 — Continued from previous page

| Gauge ID | Name                                      | Derived Area [km²] | Region | Obj. Cal/ Val | Elev. [m] | Avg. Annual Runoff [mm] |
|----------|-------------------------------------------|--------------------|--------|---------------|-----------|------------------------|
| 02FA004  | Sauble River at Allenford                 | 349                | HUR    | 1 Val         | 217       | 532                    |
| 02FB009  | BEAVER RIVER NEAR CLARKSBURG              | 586                | HUR    | 2 Cal         | 225       | 510                    |
| 02FB010  | BIGHEAD RIVER NEAR MEAFORD               | 310                | HUR    | 2 Cal         | 228       | 590                    |
| 02FC001  | SAUGEEN RIVER NEAR PORT ELGIN            | 3758               | HUR    | 2 Cal         | 191       | 540                    |
| 02FC016  | SAUGEEN RIVER ABOVE DURHAM               | 348                | HUR    | 1 Val         | 360       | 492                    |
| 02FE008  | Middle Maitland River near Belgrave      | 673                | HUR    | 1 Val         | 309       | 489                    |
| 02FE009  | SOUTH MAITLAND RIVER AT SUMMERHILL       | 388                | HUR    | 1 Cal         | 262       | 559                    |
| 02FE010  | BOYLE DRAIN NEAR ATWOOD                  | 209                | HUR    | 1 Val         | 353       | 456                    |
| 02FE013  | MIDDLE MAITLAND RIVER ABOVE ETHEL        | 402                | HUR    | 1 Val         | 354       | 473                    |
| 02FE015  | Maitland River at Benmiller              | 2558               | HUR    | 2 Cal         | 213       | 500                    |
| 02FF002  | AUSABLE RIVER NEAR SPRINGBANK            | 804                | HUR    | 2 Val         | 201       | 407                    |
| 02GA010  | NITH RIVER NEAR CANNING                  | 973                | ERI    | 1 Cal         | 248       | 391                    |
| 02GA018  | NITH RIVER AT NEW HAMBURG                | 543                | ERI    | 1 Cal         | 331       | 385                    |
| 02GA038  | NITH RIVER ABOVE NITHBURG                | 322                | ERI    | 1 Cal         | 357       | 441                    |
| 02GA047  | SPEED RIVER AT CAMBRIDGE                 | 782                | ERI    | 1 Val         | 267       | 365                    |
| 02GB001  | GRAND RIVER AT BRANTFORD                 | 5149               | ERI    | 2 Cal         | 189       | 388                    |
| 02GB007  | FAIRCHILD CREEK NEAR BRANTFORD           | 389                | ERI    | 1,2 Val       | 196       | 309                    |
| 02GC002  | KETTLE CREEK AT ST. THOMAS               | 334                | ERI    | 1,2 Cal       | 205       | 355                    |
| 02GC007  | BIG CREEK NEAR WALSINGHAM               | 573                | ERI    | 2 Cal         | 183       | 398                    |
| 02GC010  | BIG OTTER CREEK AT TILLSONBURG          | 393                | ERI    | 1 Val         | 207       | 388                    |
| 02GC026  | Big Otter Creek near Calton             | 681                | ERI    | 2 Val         | 181       | 418                    |
| 02GD004  | MIDDLE THAMES RIVER AT THAMESFORD       | 297                | ERI    | 1 Cal         | 268       | 412                    |
| 02GE003  | THAMES RIVER AT THAMESVILLE             | 4498               | ERI    | 2 Cal         | 171       | 416                    |
| 02GE007  | MCGREGOR CREEK NEAR CHATHAM             | 213                | ERI    | 1,2 Val       | 161       | 333                    |
| 02GG002  | Sydenham River near Alvinston           | 712                | ERI    | 1 Cal         | 195       | 349                    |
| 02GG003  | Sydenham River at Florence              | 1155               | ERI    | 1,2 Cal       | 176       | 336                    |
| 02GG006  | BEAR CREEK NEAR PETROLIA                | 238                | ERI    | 1 Cal         | 194       | 365                    |
| 02GG009  | BEAR CREEK BELOW BRIGDEN                | 520                | ERI    | 1,2 Cal       | 187       | 334                    |
| 02GG013  | BLACK CREEK NEAR BRADSHAW               | 219                | ERI    | 1,2 Val       | 183       | 386                    |

Continued on next page
| Gauge ID | Name                                                      | Derived Area [km²] | Region | Obj. | Cal/Val | Elev. [m] | Avg. Annual Runoff [mm] |
|---------|-----------------------------------------------------------|--------------------|--------|------|---------|-----------|------------------------|
| 02HA006 | TWENTY MILE CREEK AT BALLS FALLS                          | 320                | ONT 1,2| Cal  | 149     | 353       |                        |
| 02HA007 | WELLAND RIVER BELOW CAISTOR CORNERS                       | 205                | ERI    | 2    | Cal     | 176       | 345                    |
| 02HB011 | BRONTE CREEK NEAR ZIMMERMAN                               | 221                | ONT 2  | Val  | 161     | 338       |                        |
| 02HB029 | CREDIT RIVER AT STREETSVILLE                              | 792                | ONT 1,2| Val  | 149     | 369       |                        |
| 02HC003 | HUMBER RIVER AT WESTON                                     | 834                | ONT 2  | Cal  | 120     | 287       |                        |
| 02HC024 | DON RIVER AT TODMORDEN                                    | 344                | ONT 2  | Cal  | 76      | 428       |                        |
| 02HC025 | HUMBER RIVER AT ELDER MILLS                               | 291                | ONT 1  | Val  | 158     | 275       |                        |
| 02HC030 | ETOBICOKE CREEK BELOW QUEEN ELIZABETH HIGHWAY             | 192                | ONT 1,2| Cal  | 91      | 427       |                        |
| 02HC049 | Duffins Creek at Ajax                                     | 284                | ONT 1,2| Cal  | 76      | 354       |                        |
| 02HD012 | Ganaraska River above Dale                               | 243                | ONT 1,2| Cal  | 105     | 435       |                        |
| 02HF002 | GULL RIVER AT NORLAND                                    | 1730               | ONT 2  | Val  | 269     | 517       |                        |
| 02HF003 | BURNT RIVER NEAR BURNT RIVER                              | 1270               | ONT 2  | Cal  | 265     | 495       |                        |
| 02HJ003 | OUSE RIVER NEAR WESTWOOD                                  | 292                | ONT 2  | Cal  | 189     | 339       |                        |
| 02HK003 | CROWE RIVER AT MARMORA                                    | 1892               | ONT 2  | Cal  | 158     | 402       |                        |
| 02HL001 | MOIRA RIVER NEAR FOXBORO                                  | 2673               | ONT 2  | Cal  | 84      | 386       |                        |
| 02HL003 | BLACK RIVER NEAR ACTINOLITE                               | 413                | ONT 1  | Cal  | 155     | 415       |                        |
| 02HL004 | SKOOTAMATTA RIVER NEAR ACTINOLITE                          | 672                | ONT 1  | Cal  | 150     | 397       |                        |
| 02HL005 | MOIRA RIVER NEAR DELORO                                   | 308                | ONT 1  | Cal  | 189     | 431       |                        |
| 02HL008 | CLARE RIVER NEAR BOGART                                   | 315                | ONT 1  | Val  | 142     | 414       |                        |
| 02HM003 | SALMON RIVER NEAR SHANNONVILLE                            | 989                | ONT 2  | Cal  | 83      | 420       |                        |
| 02HM007 | Napanee River at Camden East                              | 782                | ONT 2  | Cal  | 119     | 416       |                        |
| 02HM010 | SALMON RIVER AT TAMWORTH                                  | 588                | ONT 1  | Val  | 154     | 414       |                        |
| 02JB013 | KINOJEVIS (RIVIERE) A 0.3 KM EN AMONT DU PONT-ROUTE A CLERICY | 2531               | OTT 1  | Val  | 262     | 478       |                        |
| 02JC008 | BLANCHE RIVER ABOVE ENGLEHART                             | 1801               | OTT 1  | Cal  | 204     | 425       |                        |
| 02JE027 | AMABLE DU FOND RIVER AT KIOSK                             | 706                | OTT 1  | Val  | 291     | 504       |                        |
| 02KC018 | INDIAN RIVER AT PEMBROKE                                  | 497                | OTT 1  | Val  | 120     | 376       |                        |
| 02KD002 | YORK RIVER NEAR BANCROFT                                  | 846                | OTT 1  | Val  | 335     | 513       |                        |
| 02KF005 | OTTAWA RIVER AT BRITANNIA                                 | 89925              | OTT 2  | Val  | 53      | 446       |                        |

Continued on next page
| Gauge ID | Name                                      | Derived Area [km$^2$] | Region | Obj. | Cal/Val | Elev. [m] | Avg. Annual Runoff [mm] |
|---------|-------------------------------------------|------------------------|--------|------|---------|-----------|------------------------|
| 02KF011 | CARP RIVER NEAR KINBURN                   | 266                    | OTT    | 1    | Cal     | 87        | 389                    |
| 02LA004 | RIDEAU RIVER AT OTTAWA                    | 4058                   | OTT    | 2    | Cal     | 45        | 380                    |
| 02LA006 | KEMPTVILLE CREEK NEAR KEMPTVILLE         | 415                    | OTT    | 2    | Cal     | 93        | 395                    |
| 02LA007 | JOCK RIVER NEAR RICHMOND                  | 456                    | OTT    | 1,2  | Cal     | 80        | 400                    |
| 02LB005 | SOUTH NATION RIVER NEAR PLANTAGENET SPRINGS | 3819                  | OTT    | 2    | Cal     | 33        | 430                    |
| 02LB007 | SOUTH NATION RIVER AT SPENCERVILLE        | 277                    | OTT    | 1    | Val     | 89        | 435                    |
| 02LB008 | BEAR BROOK NEAR BOURGET                   | 427                    | OTT    | 1    | Cal     | 55        | 461                    |
| 02LB032 | RIGAUD RIVER NEAR ST. EUGENE              | 301                    | OTT    | 1,2  | Val     | 42        | 621                    |
| 02LC008 | NORD (RIVIERE DU) A 4.8 KM EN AMONT DU PONT DU C.N. A SAINT-JEROME | 1161                  | OTT    | 2    | Val     | 88        | 684                    |
| 02LC029 | ROUGE (RIVIERE) EN AMONT DE LA CHUTE MCNEIL | 5530                  | OTT    | 2    | Val     | 131       | 631                    |
| 02LD005 | PETITE NATION (RIVIERE DE LA) AU PONT A 1.6 KM EN AMONT DE RIPON | 1254                  | OTT    | 1,2  | Val     | 158       | 559                    |
| 02LE024 | LIEVRE (RIVIERE DU) A 2.2 KM EN AMONT DU PONT-ROUTE 311 A LAC-SAINT-PAUL | 4568                  | OTT    | 2    | Val     | 240       | 594                    |
| 02LE025 | KIAMIKA (RIVIERE) A CHUTE-SAINT-PHILIPPE  | 882                    | OTT    | 2    | Val     | 239       | 602                    |
| 02LG005 | GATINEAU (RIVIERE) AUX RAPIDES CEIZUR     | 6923                   | OTT    | 1,2  | Val     | 221       | 572                    |
| 04010500 | PIGEON RIVER AT MIDDLE FALLS NR GRAND PORTAGE MN | 1561                  | SUP    | 2    | Cal     | 238       | 265                    |
| 04015330 | KNIFE RIVER NEAR TWO HARBORS MN            | 217                    | SUP    | 1,2  | Val     | 183       | 350                    |
| 04024000 | ST. LOUIS RIVER AT SCANLON MN              | 8964                   | SUP    | 2    | Cal     | 301       | 233                    |
| 04024430 | NEMADJI RIVER NEAR SOUTH SUPERIOR WI      | 1127                   | SUP    | 1,2  | Cal     | 188       | 296                    |
| 04027000 | BAD RIVER NEAR ODANAH WI                  | 1527                   | SUP    | 1,2  | Cal     | 222       | 356                    |
| 04027500 | WHITE RIVER NEAR ASHLAND WI               | 735                    | SUP    | 2    | Cal     | 226       | 302                    |
| 04029990 | Montreal River at Saxon Falls near Saxon WI | 693                    | SUP    | 2    | Cal     | 282       | 426                    |
| 04031000 | BLACK R NR BESSEMER MI                    | 510                    | SUP    | 1,2  | Cal     | 357       | 427                    |
| 04040000 | ONTONAGON R NR ROCKLAND MI                | 3491                   | SUP    | 2    | Cal     | 200       | 315                    |
| 04040500 | STURGEON RIVER NEAR SIDNAW MI             | 477                    | SUP    | 1    | Cal     | 378       | 392                    |
| 04041500 | STURGEON RIVER NEAR ALSTON MI             | 904                    | SUP    | 2    | Cal     | 233       | 380                    |
| 04044724 | Au Train River at Forest Lake MI          | 233                    | SUP    | 2    | Cal     | 182       | 422                    |

Continued on next page
| Gauge ID | Name                                          | Derived Region | Obj. | Cal/ Val | Elev. | Avg. Annual Runoff [mm] |
|----------|-----------------------------------------------|----------------|------|----------|-------|-------------------------|
| 04045500 | TAHQUAMENON RIVER NR TAHQUAMENON PARADISE MI  | SUP            | 1,2  | Cal      | 186   | 383                     |
| 04056500 | MANISTIQUE RIVER NR MANISTIQUE MI             | MIC            | 1,2  | Cal      | 189   | 440                     |
| 04057510 | STURGEON RIVER NR NAHMA JUNCTION MI           | MIC            | 1,2  | Val      | 190   | 330                     |
| 04059000 | ESCANABA RIVER AT CORNELL MI                  | MIC            | 2    | Cal      | 221   | 272                     |
| 04059500 | FORD RIVER NR HYDE MI                         | MIC            | 1,2  | Cal      | 198   | 249                     |
| 04066500 | PIKE RIVER AT AMBERG WI                       | MIC            | 1    | Cal      | 265   | 256                     |
| 04067500 | MENOMINEE RIVER NEAR MCALLISTER WI            | MIC            | 2    | Cal      | 175   | 267                     |
| 04067958 | Peshtigo River near Wabeno WI                 | MIC            | 1    | Cal      | 306   | 277                     |
| 04069500 | PESHTIGO RIVER AT PESHTIGO WI                 | MIC            | 2    | Val      | 172   | 263                     |
| 04071765 | Oconto River near Oconto WI                   | MIC            | 2    | Cal      | 170   | 242                     |
| 04072150 | Duck Creek near Howard WI                     | MIC            | 2    | Cal      | 169   | 199                     |
| 04074950 | WOLF RIVER ATLANGLADE WI                      | MIC            | 1    | Cal      | 383   | 290                     |
| 04084500 | FOX R AT RAPIDE CROCHE DAM NEAR WRIGHTSTOWN WI | MIC          | 2    | Val      | 152   | 258                     |
| 04085200 | KEWAUNEE RIVER NEAR KEWAUNEE WI               | MIC            | 1,2  | Cal      | 181   | 205                     |
| 04085427 | MANITOWOC RIVER AT MANITOWOC WI               | MIC            | 2    | Cal      | 169   | 219                     |
| 04086000 | SHEBOYGAN RIVER AT SHEBOYGAN WI               | MIC            | 2    | Cal      | 171   | 275                     |
| 04087000 | MILWAUKEE RIVER AT MILWAUKEE WI                | MIC            | 2    | Cal      | 153   | 287                     |
| 04087120 | MENOMONEE RIVER AT WAUWATOSA WI               | MIC            | 2    | Val      | 186   | 350                     |
| 04087240 | ROOT RIVER AT RACINE WI                       | MIC            | 2    | Cal      | 159   | 311                     |
| 04093000 | DEEP RIVER AT LAKE GEORGE OUTLET AT HOBART IN | MIC            | 2    | Cal      | 155   | 421                     |
| 04096015 | Galien River near Sawyer MI                   | MIC            | 2    | Val      | 165   | 380                     |
| 04101500 | ST. JOSEPH RIVER AT NILES MI                  | MIC            | 2    | Cal      | 188   | 355                     |
| 04101800 | DOWAGIAC RIVER AT SUMNERVILLE MI              | MIC            | 2    | Cal      | 177   | 413                     |
| 04102500 | PAW PAW RIVER AT RIVERSIDE MI                 | MIC            | 2    | Cal      | 178   | 424                     |
| 04102700 | SOUTH BRANCH BLACK RIVER NEAR BANGOR MI       | MIC            | 2    | Cal      | 189   | 452                     |
| 04102776 | Middle Branch Black River near South Haven MI | MIC            | 1,2  | Val      | 186   | 446                     |
| 04108660 | Kalamazoo River at New Richmond MI            | MIC            | 2    | Val      | 147   | 403                     |
| 04119000 | GRAND RIVER AT GRAND RAPIDS MI                | MIC            | 2    | Cal      | 162   | 311                     |
| 04121970 | Muskegon River near Croton MI                 | MIC            | 2    | Cal      | 206   | 314                     |

Continued on next page
| Gauge ID | Name                                                   | Derived Area [km$^2$] | Region | Obj. | Cal/Val | Elev. [m] | Avg. Annual Runoff [mm] |
|---------|--------------------------------------------------------|-----------------------|--------|------|---------|----------|------------------------|
| 04122200 | WHITE RIVER NEAR WHITEHALL MI                          | 1090                  | MIC 1,2| Cal  | 187     | 387      |
| 04122500 | PERE MARQUETTE RIVER AT SCOTTVILLE MI                  | 1805                  | MIC 1,2| Cal  | 153     | 393      |
| 04124000 | Manistee River near Sherman MI                         | 2297                  | MIC 1  | Cal  | 251     | 434      |
| 04125460 | Pine River at High School Bridge nr Hoxeyville MI     | 645                   | MIC 1  | Cal  | 255     | 415      |
| 04125550 | Manistee River near Wellston MI                        | 3586                  | MIC 2  | Val  | 200     | 421      |
| 04126740 | Platte River at Honor MI                              | 341                   | MIC 2  | Cal  | 167     | 346      |
| 04126970 | Boardman R above Brown Bridge Road nr Mayfield MI     | 386                   | MIC 1,2| Cal  | 249     | 295      |
| 04133501 | Thunder Bay River at Herron Road near Bolton MI       | 1461                  | HUR 2  | Val  | 196     | 280      |
| 04136000 | Au Sable River near Red Oak MI                         | 2937                  | HUR 1  | Cal  | 293     | 245      |
| 04137500 | Au Sable River near Au Sable MI                        | 4622                  | HUR 2  | Cal  | 175     | 265      |
| 04142000 | RIFLE RIVER NEAR STERLING MI                          | 795                   | HUR 2  | Cal  | 205     | 361      |
| 04159492 | Black River near Jeddo MI                             | 1147                  | ERI 2  | Cal  | 195     | 225      |
| 04159900 | Mill Creek near Avoca MI                              | 470                   | ERI 2  | Val  | 212     | 214      |
| 04160600 | BELLE RIVER AT MEMPHIS MI                              | 383                   | ERI 2  | Cal  | 218     | 247      |
| 04165500 | CLINTON RIVER AT MORAVIAN DRIVE AT MT. CLEMENS MI      | 1852                  | ERI 2  | Cal  | 168     | 320      |
| 04166500 | RIVER ROUGE AT DETROIT MI                             | 479                   | ERI 2  | Cal  | 186     | 294      |
| 04168400 | Lower River Rouge at Dearborn MI                      | 272                   | ERI 2  | Val  | 173     | 396      |
| 04174500 | HURON RIVER AT ANN ARBOR MI                           | 1826                  | ERI 2  | Cal  | 236     | 255      |
| 04176500 | RIVER RAISIN NEAR MONROE MI                           | 2822                  | ERI 2  | Cal  | 177     | 280      |
| 04177000 | OTTAWA RIVER At UNIVERSITY OF TOLEDO TOLEDO OH         | 336                   | ERI 2  | Cal  | 178     | 297      |
| 04185000 | Tiffin River at Stryker OH                            | 988                   | ERI 1  | Cal  | 203     | 324      |
| 04193500 | MAUMEE R AT WATERVILLE OH                             | 16393                 | ERI 2  | Cal  | 162     | 345      |
| 04195500 | PORTAGE R AT WOODVILLE OH                             | 1099                  | ERI 2  | Val  | 181     | 365      |
| 04196800 | Tymochtee Creek at Crawford OH                        | 663                   | ERI 1  | Cal  | 215     | 369      |
| 04197100 | Honey Creek at Melmore OH                            | 390                   | ERI 1  | Cal  | 242     | 379      |
| 04198000 | SANDUSKY R NR FREMONT OH                              | 3122                  | ERI 2  | Cal  | 184     | 351      |
| 04199000 | HURON R AT MILAN OH                                   | 915                   | ERI 2  | Cal  | 180     | 383      |
| 04199500 | VERMILION R NR VERMILION OH                           | 663                   | ERI 2  | Cal  | 186     | 404      |
| 04200500 | BLACK R AT ELYRIA OH                                  | 983                   | ERI 2  | Cal  | 174     | 380      |
| Gauge ID | Name                                      | Derived Area [km^2] | Region | Obj. Val | Cal Elev | Avg. Annual Runoff [mm] |
|---------|-------------------------------------------|---------------------|--------|----------|----------|-------------------------|
| 04201500 | ROCKY R NR BEREAL OH                       | 696                 | ERI    | 2 Val    | 206      | 501                     |
| 04208000 | CUYAHOGA R AT INDEPENDENCE OH              | 1990                | ERI    | 2 Cal    | 181      | 538                     |
| 04209000 | CHAGRIN R AT WILLOUGHBY OH                 | 622                 | ERI    | 2 Val    | 195      | 639                     |
| 04212100 | GRAND R NR PAINESVILLE OH                  | 1822                | ERI    | 2 Cal    | 176      | 535                     |
| 04213000 | CONNEAUT C AT CONNEAUT OH                  | 497                 | ERI    | 2, Cal 1 | 160      | 608                     |
| 04213500 | CATTARAUGUS CREEK AT GOWANDA NY            | 1169                | ERI    | 2 Cal    | 233      | 640                     |
| 04214500 | BUFFALO CREEK AT GARDENVILLE NY           | 382                 | ERI    | 2 Val    | 191      | 548                     |
| 04215000 | CAYUGA CREEK NR LANCASTER NY              | 255                 | ERI    | 2 Cal    | 212      | 570                     |
| 04215500 | CAZENOVIA CREEK AT EBENEZER NY            | 347                 | ERI    | 2 Cal    | 189      | 702                     |
| 04218000 | TONAWANDA CREEK AT RAPIDS NY              | 895                 | ERI    | 2 Cal    | 156      | 476                     |
| 04218518 | ELLICOTT CREEK BELOW WILLIAMSVILLE NY     | 232                 | ERI    | 2 Cal    | 160      | 636                     |
| 04220045 | OAK ORCHARD CREEK NEAR SHELBY NY          | 385                 | ONT    | 2 Val    | 175      | 366                     |
| 04221000 | GENESEE RIVER AT WELLSVILLE NY            | 762                 | ONT    | 1 Cal    | 443      | 479                     |
| 04224775 | CANASERAGA CREEK ABOVE DANSVILLE NY       | 248                 | ONT    | 1 Cal    | 199      | 396                     |
| 04231600 | GENESEE RIVER AT FORD STREET BRIDGE ROCHESTER NY | 6338                 | ONT    | 2 Cal    | 125      | 417                     |
| 0423205010 | Irondequoit Cr abv Blossom Rd nr Rochester NY | 363                 | ONT    | 2 Cal    | 83       | 354                     |
| 04249000 | OSWEGO RIVER AT LOCK 7 AT OSWEGO NY        | 13221               | ONT    | 2 Val    | 51       | 522                     |
| 04250200 | Salmon River at Pineville NY              | 644                 | ONT    | 2 Cal    | 139      | 1189                    |
| 04250750 | SANDY CREEK NEAR ADAMS NY                 | 373                 | ONT    | 2 Val    | 159      | 740                     |
| 04256000 | INDEPENDENCE RIVER AT DONNATTSBURG NY     | 229                 | ONT    | 1,2 Cal  | 306      | 838                     |
| 04258000 | Beaver River at Croghan NY                | 754                 | ONT    | 2 Cal    | 248      | 814                     |
S6 Common set of donor basins

The seven locally calibrated models (LBRM-CC-lumped, HYMOD2-lumped, GR4J-lumped, HMETS-lumped, Blended-lumped, Blended-Raven, and VIC-Raven) needed to specify a so-called donor basin for each of the 71 validation locations. The donor basin is a basin that was calibrated. The calibrated parameter set of the donor basin is then used to run the model deriving streamflow at the validation location. All models used the mapping of donor basins given in Table S16. The mapping approach is explained in the main manuscript (Sect. 2.4).

Table S16: Donor basin mapping. The Table specifies the donor basin for each validation location. These donor basins are used by all locally calibrated models. The table also specifies the reason for the donor basin to be selected.

| Validation Basin | Donor Basin | Reason Selected          |
|------------------|-------------|--------------------------|
| 02AB006          | 02AB017     | closest basin centroids   |
| 02AB021          | 02AC001     | closest basin centroids   |
| 02AD012          | 02AD010     | nested basins             |
| 02AE001          | 02AD010     | closest basin centroids   |
| 02BA006          | 02BA003     | closest basin centroids   |
| 02BC004          | 02BB004     | closest basin centroids   |
| 02BC006          | 02BB004     | closest basin centroids   |
| 02BD007          | 02BD002     | closest basin centroids   |
| 02BE002          | 02BF001     | closest basin centroids   |
| 02BF014          | 02BF002     | nested basins             |
| 02CA007          | 02BF002     | closest basin centroids   |
| 02CE002          | 02CD001     | closest basin centroids   |
| 02CF010          | 02DB005     | closest basin centroids   |
| 02CF011          | 02CF007     | closest basin centroids   |
| 02EA018          | 02EA011     | nested basins             |
| 02EC011          | 02EC003     | nested basins             |
| 02ED027          | 02ED003     | nested basins             |
| 02ED032          | 02ED024     | closest basin centroids   |
| 02FA004          | 02FA001     | nested basins             |
| 02FC016          | 02FC001     | nested basins             |
| 02FE008          | 02FE015     | nested basins             |
| 02FE010          | 02FE015     | nested basins             |
| 02FE013          | 02FE015     | nested basins             |
| 02FF002          | 02GG002     | closest basin centroids   |
| 02GA047          | 02GB001     | nested basins             |

Continued on next page
| Validation Basin | Donor Basin | Reason Selected       |
|------------------|-------------|-----------------------|
| 02GB007          | 02GC007     | closest basin centroids|
| 02GC010          | 02GC007     | closest basin centroids|
| 02GC026          | 02GC007     | closest basin centroids|
| 02GE007          | 02GG003     | closest basin centroids|
| 02GG013          | 02GG009     | closest basin centroids|
| 02HB011          | 02HC030     | closest basin centroids|
| 02HB029          | 02HC030     | closest basin centroids|
| 02HC025          | 02HC003     | nested basins         |
| 02HF002          | 02EB014     | closest basin centroids|
| 02HJ003          | 02HK003     | closest basin centroids|
| 02HL008          | 02HL001     | nested basins         |
| 02HM010          | 02HL004     | closest basin centroids|
| 02JB013          | 02JC008     | closest basin centroids|
| 02JE027          | 02EA005     | closest basin centroids|
| 02KC018          | 02HL004     | closest basin centroids|
| 02KD002          | 02HF003     | closest basin centroids|
| 02KF005          | 02JC008     | nested basins         |
| 02LB007          | 02LB005     | nested basins         |
| 02LB032          | 02LB005     | closest basin centroids|
| 02LC008          | 02LB008     | closest basin centroids|
| 02LC029          | 02LB008     | closest basin centroids|
| 02LD005          | 02LB008     | closest basin centroids|
| 02LE024          | 02LB008     | closest basin centroids|
| 02LE025          | 02LB008     | closest basin centroids|
| 02LG005          | 02LB008     | closest basin centroids|
| 04015330         | 04024000    | closest basin centroids|
| 04041500         | 04040500    | nested basins         |
| 04057510         | 04044724    | closest basin centroids|
| 04069500         | 04067958    | nested basins         |
| 04084500         | 04074950    | nested basins         |
| 04087120         | 04087240    | closest basin centroids|
| 04096015         | 04101800    | closest basin centroids|
| 04102776         | 04102700    | closest basin centroids|
| 04108660         | 04102700    | closest basin centroids|
| 04125550         | 04124000    | nested basins         |

Continued on next page
| Validation Basin | Donor Basin | Reason Selected          |
|------------------|-------------|--------------------------|
| 04133501         | 04137500    | closest basin centroids  |
| 04159900         | 04160600    | closest basin centroids  |
| 04168400         | 04176500    | closest basin centroids  |
| 04195500         | 04198000    | closest basin centroids  |
| 04201500         | 04200500    | closest basin centroids  |
| 04209000         | 04208000    | closest basin centroids  |
| 04214500         | 04215000    | closest basin centroids  |
| 04220045         | 04218000    | closest basin centroids  |
| 04249000         | 0423205010  | closest basin centroids  |
| 04250750         | 04250200    | closest basin centroids  |
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