# MARRMoT parameter ranges

Each model function in MARRMoT is accompanied by a file that specifies suitable sampling ranges for each parameter used in the model, that could be applied if the user chooses to pair MARRMoT with a calibration or parameter sampling procedure. This section gives the reasoning behind our choices of parameter ranges used within MARRMoT.

## Model-specific ranges versus generalised process-specific ranges

There are two different approaches to determining parameter ranges for model calibration or parameter sampling studies: (1) make a choice for appropriate parameter ranges per model, based on previous applications of the model, or (2) try to make consistent choices for all models based on literature (e.g. ensure that all ‘slow’ linear reservoirs, regardless of which model they are part of, have the same limits for the drainage time scale parameter). Generalization of parameter ranges across models is difficult because models use different flux formulations and thus different parameter values might be appropriate, even if the fluxes are intended to represent the same hydrologic process. On the other hand, using model-specific parameter ranges based on earlier studies might limit a model’s potential. Especially if the model has only been applied to a small number of places, published ‘appropriate’ parameter ranges might also reflect the climate or catchment characteristics of the few study catchments the model has been applied to. MARRMoT is intended as a model comparison framework. We thus attempt to generalize parameter ranges across all models in the framework, to facilitate fair comparison of different models. We try to err on the side of caution and intentionally set these ranges wide. Table 1 shows the parameter ranges used in MARRMoT and specifies in which model(s) each parameter range is used.

Table 1: Parameter ranges used in MARRMoT

| **Description** | **Min(lit)** | **Max(lit)** | **Min(used)** | **Max(used)** | **Reference(s)** | **Notes** | **Model** |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Snow parameters** | | | | | | | |
| Threshold temperature for snowfall (and melt, if not specified otherwise) [oC] | Table 3 | Table 3 | -3.0 | 5.0 | (Kienzle, 2008; Kollat et al., 2012) |  | 6, 12, 30, 31, 32, 34, 35, 37, 43, 44, 45 |
| Threshold interval width for snowfall [oC] | 0 | 7 | 0 | 17 | (Kienzle, 2008) | 0 is a physical limit | 37 |
| Threshold temperature for melt [oC] |  |  | -3.0 | 3.0 |  | Not easy to find any interval. Temperature for melt tends be treated as constant at 0 | 37, 43, 44 |
| Degree-day-factor for snow or ice melt [mm/oC/d] | 0 | Table 2 | 0 | 20 |  | 0 is a physical limit | 6, 12, 30, 31, 32, 34, 35, 37, 41, 43, 44, 45 |
| Water holding content of snow pack [-] | 0 | 0.8 | 0 | 1 | (Kollat et al., 2012) | 0 is a physical limit 1 is a physical limit | 37, 44 |
| Refreezing factor of retained liquid water [-] | 0 | 1 | 0 | 1 |  | 0 is a physical limit  1 is a physical limit | 37, 44 (given as fraction [0,1] of degree-day-factor) |
| Maximum melt rate due to ground-heat flux [mm/d] | 0 | 2 | 0 | 2 | (Schaefli et al., 2014) |  | 44 |
|  |  |  |  |  |  |  |  |
| **Interception parameters** | | | | | | | |
| Maximum store depth [mm] | 0 | Table 4 | 0 | 5 | (Chiew and McMahon, 1994; Gerrits, 2010) | 0 is a physical limit  Gerrits (2010, table 1.1) reports 3.8mm as maximum value used out of 15 studies. Chiew and McMahon (1994, table 3) report 5.6mm as a maximum value for 28 catchments | 2, 13, 15, 16, 18, 22, 23, 26, 34, 36, 39, 42, 44, 45 |
| Maximum intercepted fraction of precipitation [-] | 0 | 0.42 | 0 | 1 | (Gerrits, 2010) | 0 is a physical limit  1 is a physical limit  (Gerrits, 2010, table 1.1) reports 42% as maximum intercepted fraction out of 15 studies | 8, 23, 32, 35, 45 |
| Seasonal variation in LAI as fraction of mean |  |  | 0 | 1 |  | 0 is a physical limit | 22 |
| Timing of maximum Leaf Area Index [d] |  |  | 1 | 365 |  | Refers to days in a normal calendar year | 22, 32, 35 |
|  |  |  |  |  |  |  |  |
| **Depression store parameters** | | | | | | | |
| Maximum surface area contributing to store [-] | 0 | 1 | 0 | 1 |  | 0 is a physical limit 1 is a physical limit | 36, 45 |
| Maximum store depth [mm] | 0 | Table 5 | 0 | 50 | (Chiew and McMahon, 1994) | 0 is physical limit  50 is recommended in Chiew1994 | 36, 45 |
| Filling parameter [-] | 1 | 1 | 0.99 | 1 | (Chiew, 1990; Porter and McMahon, 1971) | Controls the shape of the depression store inflow flux but is usually set at 1 because no studies are (were?) available about how a depression store fills | 36 |
|  |  |  |  |  |  |  |  |
| **Infiltration parameters** | | | | | | | |
| Maximum loss [mm] | 0 | 400 | 0 | 600 | (Chiew et al., 2002) | Fig 11.11a shows calibrated parameter values for 339 catchments. Pattern indicates that limit was set at 400 | 18, 36 |
| Loss exponent [-] | 0 | 12 | 0 | 15 | (Chiew et al., 2002) | Fig 11.11a shows calibrated parameter values for 339 catchments. Pattern indicates that limit was set at 10 | 18, 36 |
| Maximum infiltration rate [mm/d] | Table 6 | Table 6 | 0 | 200 |  | Infiltration rates can be very high. However, to have a practical effect on modelling, (i.e. generate infiltration excess flow), Inf\_rate < P(t). Maximum daily P in CAMELS is 200 mm/d, so Inf\_rate is capped at 200mm/d in this work. | 15, 20, 23, 40, 44 |
| Infiltration decline non-linearity parameter [-] |  |  | 0 | 5 | (Sivapalan et al., 1996) | Very difficult to find information for (original paper mentions nothing) | 23, 43 |
|  |  |  |  |  |  |  |  |
| **Evaporation parameters** | | | | | | | |
| Plant-controlled maximum rate [mm/d] | 5.0 | 24.5 | 0 | 20 | (Chiew and McMahon, 1994) | Although the study reports an upper value of 24.5, the recommended range is capped at 20 (paper appendix) | 20, 36 |
| Wilting point as fraction of Soil moisture capacity | 0.1 | 0.25 | 0.05 | 0.95 | (Son and Sivapalan, 2007) | 0 is a physical limit but can break model equations 1 is a physical limit | 3, 4, 8, 9, 10, 12, 14, 15, 16, 19, 20, 21, 26, 31, 32, 34, 35, 37, 44 |
| Moisture constrained rate parameter |  |  | 0 | 1 |  | 0 is a physical limit 1 is a physical limit | 15 |
| Forest fraction for separate soil/vegetation evap | 0 | 1 | 0.05 | 0.95 |  | [0,1] are physical limits, but using these limits can result in divide-by-zero-errors in certain fluxes | 3, 4, 8, 16 |
| Phenology: minimum temperature where transpiration stops [oC] | -5 | -5 | 0 | -10 | (Ye et al., 2012) |  | 35 |
| Phenology: maximum temperature above which transpiration fully utilizes Ep [oC] | 10 | 10 | 1 | 20 | (Ye et al., 2012) | The setup of minimum and maximum temperature used in Ye et al. (2012) is here changed to a minimum temperature + temperature range (Tmax = Tmin + Trange) to avoid overlap in parameter values | 35 |
| Evaporation reduction with depth coefficient [-] | 0.083 | 1 | 0 | 1 | (Penman, 1950; Tan and O’Connor, 1996) | 0 is a physical limit 1 is a physical limit | 17, 23, 25, 40 |
| Shape parameter for evaporation reduction in a deficit store |  |  | 0 | 1 | (Moore and Bell, 2001) | This uses a sigmoid function to determine a fraction of Ep to evaporate. Values >1 make the transition very steep | 39 |
| Evaporation non-linearity coefficient [-] |  |  | 0 | 10 | (Sivapalan et al., 1996) | Very difficult to find information for. Assumption made to be in line with other non-linearity coefficients. | 23, 43 |
|  |  |  |  |  |  |  |  |
| **Soil moisture parameters** | | | | | | | |
| Maximum store depth [mm] | 1 | Table 7 | 1 | 2000 |  | 0 is a physical limit | 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46 |
| Capillary rise [mm/d] | 0 | Table 10 | 0 | 4 |  | 0 is a physical limit SMHI gives a default value of 1 mm/d for use with HBV. We use a wider range here | 13, 15, 37, 38 |
| Percolation rate [mm/d] | 0 | Table 9 | 0 | 20 | (Bethune et al., 2008) | Some modelling studies report very large percolation rates (100 mm/d). Bethune et al (2008) report ~11mm/d from field observations. | 21, 26, 34, 37, 39, 44, 45 |
| Percolation fraction [-] | 0.013 | 0.533 | 0 | 1 | (Ye et al., 2012) table 1 | 0 is a physical limit  1 is a physical limit  Fraction of current storage directed towards slow pathways | 14, 22, 23, 24, 27, 30, 31, 32, 35, 45 |
| Recharge nonlinearity [-] | 0 | 7 | 0 | 10 | (Kollat et al., 2012) | Also seen as a soil depth distribution | 5, 22, 33, 37 |
| Soil depth distribution [-] | 0 | Table 8 | 0 | 10 |  | For cases where the soil depth is not considered constant. Most studies limit this to 0-2.5 but this seems based on a single source (Wagener et al., 2004) which is UK only. Thus we use a wider range here | 2, 13, 15, 21, 22, 26, 28, 29, 34 |
| Porosity [-] | 0.35 | 0.5 | 0.05 | 0.95 | (Son and Sivapalan, 2007) | [0,1] are theoretical physical limits, but no (0) porosity and full (1) porosity are not sensible: there would be no soil moisture or soil respectively | 10, 19 |
| Gamma distribution for topographic indices - phi | 0.4 | 3.5 | 0.1 | 5 | (Clark et al., 2008) |  | 14 |
| Gamma distribution for topographic indices - chi | 2 | 5 | 1 | 7.5 | (Clark et al., 2008) |  | 14 |
| Fraction area with permeable soils |  |  | 0 | 1 | (Crooks and Naden, 2007) | 0 is a physical limit  1 is a physical limit | 46 |
| Fraction area with semi-permeable soils |  |  | 0 | 1 | (Crooks and Naden, 2007) | 0 is a physical limit  1 is a physical limit | 46 |
| Fraction area with impermeable soils |  |  | 0 | 1 | (Crooks and Naden, 2007) | 0 is a physical limit  1 is a physical limit | 46 |
| Variable contributing area scaling [-] |  |  | 0 | 5 | (Sivapalan et al., 1996) | Very difficult to find information about this. Assumption made | 23 |
| Variable contributing area non-linearity [-] |  |  |  |  | (Sivapalan et al., 1996) | See: **soil depth distribution** above | 23 |
| Fraction of D50 that is D16 [-] |  |  | 0.01 | 0.99 |  | Note: re-writing of D16 parameter in (Fukushima, 1988) | 42 |
| Variable contributing area equation inflection point [-] | -0.5 | 0.5 | -0.5 | 0.5 | (Jayawardena and Zhou, 2000) |  | 28 |
|  |  |  |  |  |  |  |  |
| **Groundwater parameters** | | | | | | | |
| Leakage coefficient [-] | 0.07 | 0.13 | 0 | 0.5 | (Chiew and McMahon, 1994) | 0 is physical limit  0.5 is recommended in the paper’s appendix | 36 |
| Leakage rate [mm/d] |  |  |  |  |  | **See: percolation rate** above |  |
| Level compared to channel level [mm] | -2.8 | 3.9 | -10 | +10 | (Chiew and McMahon, 1994) | Range recommended in appendix of the paper | 36 |
| Base flow rate at no deficit [mm/d] | 0 | 201.6 | 0.1 | 200 | (Beven, 1997) | Based on Table 2 (Beven, 1997) | 14, 23 |
| Baseflow deficit scaling parameter [-] |  |  | 0 | 1 |  | 0 is a physical limit 1 is a physical limit | 14, 23 |
|  |  |  |  |  |  |  |  |
| **Flow distribution parameters** | | | | | | | |
| Interflow and saturation excess | 0 | 1 | 0 | 1 |  | 0 is a physical limit 1 is a physical limit | 18, 36 |
| Preferential recharge | 0 | 2 | 0 | 1 | (Chiew and McMahon, 1994) | 0 is a physical limit Later paper sets this limit to 1 | 18, 25, 36, 46 |
| Surface/groundwater division |  |  | 0 | 1 |  | 0 is a physical limit 1 is a physical limit | 13, 17, 33 |
| Fast and slow flow | 0 | 1 | 0 | 1 |  | 0 is a physical limit 1 is a physical limit | 21, 26, 29, 34, 46 |
| Groundwater recharge and interflow | 0.05 | 0.3 | 0 | 1 | (Son and Sivapalan, 2007) | 0 is a physical limit 1 is a physical limit | 10, 11, 20, 40 |
| Infiltration and direct runoff | 0.161 | 0.422 | 0 | 1 | (Tan and O’Connor, 1996) | 0 is a physical limit 1 is a physical limit | 40 |
| Impervious and infiltration area |  |  | 0 | 1 |  | 0 is a physical limit 1 is a physical limit | 28, 33, 45 |
| Contributing area to overland flow |  |  | 0 | 1 |  | 0 is a physical limit 1 is a physical limit | 39, 45 |
| Tension water and free water |  |  | 0 | 1 |  | 0 is a physical limit 1 is a physical limit | 33 |
| Threshold for overland flow generation | 0 | <1 | 0 | 0.99 | (Nielsen and Hansen, 1973) | 0 is a physical limit 1 is a physical limit | 41 |
| Threshold for overland flow generation | 0 | <1 | 0 | 0.99 | (Nielsen and Hansen, 1973) | 0 is a physical limit 1 is a physical limit | 41 |
| Channel and land division |  |  | 0 | 1 |  | 0 is a physical limit 1 is a physical limit | 42 |
| Throughfall/stem flow division |  |  | 0 | 1 |  | 0 is a physical limit 1 is a physical limit | 42 |
| Glacier/non-glacier precipitation |  |  | 0 | 1 |  | 0 is a physical limit 1 is a physical limit | 43 |
|  |  |  |  |  |  |  |  |
| **Flow time scales and shape parameters** | | | | | | | |
| Fast reservoir time scale [d-1] | 0.05 | Table 12 | 0 | 1 |  | 0 is a physical limit | 12, 21, 24, 26, 28, 29, 30, 31, 32, 33, 34, 35, 37, 39, 41, 42, 43, 44, 46 |
| Slow reservoir time scale [d-1] | 0.01 | Table 11 | 0 | 1 |  | 0 is a physical limit | 2, 3, 4, 6, 8, 10, 13, 15, 16, 17, 18, 19, 20, 21, 22, 24, 25, 26, 28, 29, 30, 31, 32, 33, 34, 35, 37, 39, 40, 41, 42, 43, 44, 46 |
| Flow non-linearity S^x [-] | 0 | Table 13 | 1 | 5 |  |  | 4, 9, 10, 11, 16, 19, 22, 23, 37, 39, 42, 44, 45 |
| Flow reduction (S/X) [mm] | 5 | 40 | 1 | 50 | (Son and Sivapalan, 2007) |  | 9 |
| Exponential shape parameter [mm-1] |  |  | 0 | 2 | (Moore and Bell, 2001) | Very difficult to find documentation for | 39 |
|  |  |  |  |  |  |  |  |
| **Routing** | | | | | | | |
| Routing delay to fast flow [d] | 0 | 1 | 1 | 5 | (Fenicia et al., 2008) |  | 5, 21, 26, 34 |
| Routing delay to slow flow [d] | 0 | 8 | 1 | 15 |  |  | 5, 7, 21, 26, 34 |
| Routing delay [d] | 1 | Table 14 | 1 | 120 | (Kollat et al., 2012) | 1 is the limit (water shouldn’t speed up) 120 because it seems very high | 13, 15, 16, 21, 37, 39, 40 |
| Routing store depth [mm] | 1 | 300 | 1 | 300 | (Perrin et al., 2003) |  | 7, 20, 39, 45 |
| Gamma function, number of Nash cascade reservoirs [-] | 0.75 | 9.79 | 1 | 10 | (Tan and O’Connor, 1996) | 0 would mean no routing, so slightly above that | 40 |
|  |  |  |  |  |  |  |  |
| **Water exchange parameters** | | | | | | | |
| Coefficient 1 [-] | 0.005 | 0.54 | 0 | 1 | (Chiew and McMahon, 1994) | Although the study only reports values up to 0.54, an upper range of 1 is recommended in the study’s appendix | 36 |
| Coefficient 2 [-] | 0.01 | 0.29 | 0 | 1 | (Chiew and McMahon, 1994) | Although the study only reports values up to 0.29, an upper range of 1 is recommended in the study’s appendix | 36 |
| Coefficient 3 [-] | 0 | 13 | 0 | 100 | (Chiew and McMahon, 1994) | Although the study only reports values up to 13, an upper range of 100 is recommended in the study’s appendix | 36 |
| Water exchange coefficient [mm/d] | -10 | 14 | -10 | 15 | (Perrin et al., 2003; Santos et al., 2017) | Parameter x2 in GR4J model | 7 |

Table 2: Literature-based ranges for snowmelt parameter “degree-day-factor”

|  |  |  |
| --- | --- | --- |
| **Degree-day factor for snowmelt [mm/degree C/d]** | **Min** | **Max** |
| Table 2 (Seibert, 1997) | 1 | 10 |
| Table 1 (Kollat et al., 2012) | 0 | 20 |
| Table A3 (Seibert and Vis, 2012) | 1 | 10 |

Table 3: Literature-based ranges for snowmelt parameter “threshold temperature for snowfall”

|  |  |  |
| --- | --- | --- |
| **Threshold temperature for snowfall [degree C]** | **Min** | **Max** |
| Table 2 (Seibert, 1997) | -2.5 | 2.5 |
| Table 1 (Kollat et al., 2012) | -3.0 | 3.0 |
| Table 2 (Kienzle, 2008) *Note: always coupled with a snow interval [10,17]* | 1.1 | 4.5 |
| Table A3 (Seibert and Vis, 2012) | -1.5 | 2.5 |

Table 4: Literature-based ranges for interception parameter "maximum interception capacity"

|  |  |  |
| --- | --- | --- |
| **Interception bucket [mm]** | **Min** | **Max** |
| Figure 11.11a (Chiew et al., 2002) | 0 | 5 |
| Table 3 (Chiew and McMahon, 1994) | 0.5 | 5.6 |
| Table 1.1 (Gerrits, 2010) | 0 | 3.8 |
| Table 2 (Son and Sivapalan, 2007) |  | 0.4 |

Table 5: Literature-based ranges for depression parameter "maximum depression capacity"

|  |  |  |
| --- | --- | --- |
| **Depression bucket [mm]** | **Min** | **Max** |
| Table 3 (Chiew and McMahon, 1994) | 1 | 100 |
| Table 1 (Amoah et al., 2013) | 5 | 110 |

Table 6: Literature-based ranges for infiltration parameter "maximum infiltration rate"

|  |  |  |
| --- | --- | --- |
| **Infiltration rate** | **Min** | **Max** |
| Figure 2 (Assouline, 2013) [mm/d] | 40 | 100 |
| Table 3.3 (Jones, 1997) [mm/h] | 6 | 76 |
| Table 3 (Cerdà, 1996) [mm/h] | 50 | 770 |

Table 7: Literature-based ranges for soil moisture parameter "maximum soil moisture capacity"

|  |  |  |
| --- | --- | --- |
| **Soil moisture bucket [mm]** | **Min** | **Max** |
| Figure 11.11b (Chiew et al., 2002) | 0 | 500 |
| Table 3 (Chiew and McMahon, 1994) | 65 | 400 |
| Table 2 (Seibert, 1997) | 50 | 500 |
| Table 1 (Rusli et al., 2015) | 100 | 800 |
| Table 1 (Kollat et al., 2012) | 0 | 2000 |
| Table A3 (Seibert and Vis, 2012) | 50 | 500 |
| Table 3 (Sun et al., 2015) | 1 | 500 |

Table 8: Literature-based ranges for soil moisture parameter "soil depth distribution non-linearity"

|  |  |  |
| --- | --- | --- |
| **Soil depth distribution [-]** | **Min** | **Max** |
| Table 3 (Sun et al., 2015) | 0 | 2 |
| Figure 9 (Lamb, 1999) | 0 | 2.5 |
| Table 4 (Bulygina et al., 2009) | 0 | 2.5 |
| Figure 4.12(Wagener et al., 2004) | 0 | 2 |
| Page 700(Sivapalan and Woods, 1995) |  | 4.03 |
| Figure 4 (Huang et al., 2003) Note: estimated values, ~97% < 6 | 0 | 11.5 |

Table 9: Literature-based ranges for percolation parameter "maximum percolation rate"

|  |  |  |
| --- | --- | --- |
| **Percolation rate [mm/d]** | **Min** | **Max** |
| Table 2 (Seibert, 1997) | 0 | 6 |
| Table 1 (Rusli et al., 2015) | 0.1 | 5 |
| Table 1 (Kollat et al., 2012) | 0 | 100 |
| Figure 3 (Bethune et al., 2008) | 0 | 10.4 |
| Table A3 (Seibert and Vis, 2012) | 0 | 3 |

Table 10: Literature-based ranges for capillary rise parameter "maximum capillary rise rate"

|  |  |  |
| --- | --- | --- |
| **Capillary rise [mm/d]** | **Min** | **Max** |
| Table 1 (Rusli et al., 2015) | 0.1 | 1 |
| Default value (SMHI, 2004) | 1 | 1 |
| Figure 3 (Bethune et al., 2008) | 0 | 0.06 |

Table 11: Literature-based ranges for flow parameter "slow flow time scale"

|  |  |  |
| --- | --- | --- |
| **Slow flow time scale [d-1]** | **Min** | **Max** |
| Figure 11.11b (Chiew et al., 2002) | 0 | 0.3 |
| Table 2 (Son and Sivapalan, 2007) | 2.4e-5 | 0.1 |
| Table 2 (Seibert, 1997) | 0.001 | 0.1 |
| Table 1 (Rusli et al., 2015) | 0.0005 | 0.1 |
| Table 1 (Kollat et al., 2012) | 0.00005 | 0.05 |
| Table A3 (Seibert and Vis, 2012) | 0.001 | 0.15 |
| Table 3 (Sun et al., 2015) | 0.001 | 0.5 |

Table 12: Literature-based ranges for flow parameter "fast flow time scale"

|  |  |  |
| --- | --- | --- |
| **Fast flow time scale [d-1]** | **Min** | **Max** |
| Table 2 (Seibert, 1997) | 0.05 | 0.5 |
| Table 1 (Rusli et al., 2015) | 0.05 | 0.8 |
| Table 1 (Kollat et al., 2012) | 0.01 | 1 |
| Table A3 (Seibert and Vis, 2012) | 0.01 | 0.4 |
| Table 3 (Sun et al., 2015) | 0.5 | 1.2 |

Table 13: Literature-based ranges for flow parameter "flow non-linearity"

|  |  |  |
| --- | --- | --- |
| **Flow non-linearity** | **Min** | **Max** |
| Table 3 (Lidén and Harlin, 2000) – non-linearity shape = S^(1+var) | 0 | 3 |
| Table 1 (Son and Sivapalan, 2007) – non-linearity shape = S^(1/var) | 0.45 | 0.50 |
| Table 3 (Jothityangkoon et al., 2001) | 0.5 | 0.5 |

Table 14: Literature-based ranges for routing parameter "routing delay"

|  |  |  |
| --- | --- | --- |
| **Routing delay [d]** | **Min** | **Max** |
| Table 2 (Seibert, 1997) | 1 | 5 |
| Table 1 (Kollat et al., 2012) | 24 | 120 |
| Table 3 (Lidén and Harlin, 2000) | 1 | 4 |
| Table 1 (Perrin et al., 2003) | 0.5 | 4 |
| Table A3 (Seibert and Vis, 2012) | 1 | 7 |
| Table 2 (Atkinson et al., 2003) *Note: converted from a flow speed of 0.5m/s and catchment area of 47km2* |  | <1 |
| Table 3 (Goswami and O’Connor, 2010) | 12 | 36 |
| Table 2 (Vinogradov et al., 2011) *Note: approximated from flow velocities and catchment sizes* | 0.01 | 4 |

**References**

Amoah, J. K. O., Amatya, D. M. and Nnaji, S.: Quantifying watershed surface depression storage: determination and application in a hydrologic model, Hydrol. Process., 27(17), 2401–2413, doi:10.1002/hyp.9364, 2013.

Assouline, S.: Infiltration into soils: Conceptual approaches and solutions, Water Resour. Res., 49(4), 1755–1772, doi:10.1002/wrcr.20155, 2013.

Atkinson, S. E., Sivapalan, M., Woods, R. A. and Viney, N. R.: Dominant physical controls on hourly flow predictions and the role of spatial variability: Mahurangi catchment, New Zealand, Adv. Water Resour., 26(3), 219–235, doi:10.1016/S0309-1708(02)00183-5, 2003.

Bethune, M. G., Selle, B. and Wang, Q. J.: Understanding and predicting deep percolation under surface irrigation, Water Resour. Res., 44(12), 1–16, doi:10.1029/2007WR006380, 2008.

Beven, K.: TOPMODEL: a critique, Hydrol. Process., 11(9), 1069–1085, doi:10.1002/(SICI)1099-1085(199707)11:9<1069::AID-HYP545>3.0.CO;2-O, 1997.

Bulygina, N., Mcintyre, N. and Wheater, H.: Conditioning rainfall-runoff model parameters for ungauged catchments and land management impacts analysis, Hydrol. Earth Syst. Sci, 13, 893–904, doi:10.5194/hessd-6-1907-2009, 2009.

Cerdà, A.: Seasonal variability of infiltration rates under contrasting slope conditions in southeast Spain, Geoderma, 69(3-4), 217–232, doi:10.1016/0016-7061(95)00062-3, 1996.

Chiew, F. and McMahon, T.: Application of the daily rainfall-runoff model MODHYDROLOG to 28 Australian catchments, J. Hydrol., 153(1-4), 383–416, doi:10.1016/0022-1694(94)90200-3, 1994.

Chiew, F. H. S.: Estimating groundwater recharge using an integrated surface and groundwater model, University of Melbourne., 1990.

Chiew, F. H. S., Peel, M. C. and Western, A. W.: Application and testing of the simple rainfall-runoff model SIMHYD, in Mathematical Models of Small Watershed Hydrology, edited by V. P. Singh and D. K. Frevert, pp. 335–367, Water Resources Publications LLC, USA, Chelsea, Michigan, USA., 2002.

Clark, M. P., Slater, A. G., Rupp, D. E., Woods, R. a., Vrugt, J. a., Gupta, H. V., Wagener, T. and Hay, L. E.: Framework for Understanding Structural Errors (FUSE): A modular framework to diagnose differences between hydrological models, Water Resour. Res., 44(12), doi:10.1029/2007WR006735, 2008.

Crooks, S. M. and Naden, P. S.: CLASSIC: a semi-distributed rainfall-runoff modelling system, Hydrol. Earth Syst. Sci., 11(1), 516–531, doi:10.5194/hess-11-516-2007, 2007.

Fenicia, F., Savenije, H. H. G., Matgen, P. and Pfister, L.: Understanding catchment behavior through stepwise model concept improvement, Water Resour. Res., 44(1), doi:10.1029/2006WR005563, 2008.

Fukushima, Y.: A model of river flow forecasting for a small forested mountain catchment, Hydrol. Process., 2(2), 167–185, 1988.

Gerrits, M.: The role of interception in the hydrological cycle, edited by PhD thesis, Technische Universiteit Delft, Netherlands., 2010.

Goswami, M. and O’Connor, K. M.: A “monster” that made the SMAR conceptual model “right for the wrong reasons,” Hydrol. Sci. J., 55(6), 913–927, doi:10.1080/02626667.2010.505170, 2010.

Huang, M., Liang, X. and Liang, Y.: A transferability study of model parameters for the variable infiltration capacity land surface scheme, J. Geophys. Res., 108(D22), 8864, doi:10.1029/2003JD003676, 2003.

Jayawardena, A. W. and Zhou, M. C.: A modified spatial soil moisture storage capacity distribution curve for the Xinanjiang model, J. Hydrol., 227(1-4), 93–113, doi:10.1016/S0022-1694(99)00173-0, 2000.

Jones, J. A. A.: Global Hydrology: Processes, Resources and Environmental Management, Routledge., 1997.

Jothityangkoon, C., Sivapalan, M. and Farmer, D. .: Process controls of water balance variability in a large semi-arid catchment: downward approach to hydrological model development, J. Hydrol., 254(1-4), 174–198, doi:10.1016/S0022-1694(01)00496-6, 2001.

Kienzle, S. W.: A new temperature based method to separate rain and snow, Hydrol. Process., 22(26), 5067–5085, doi:10.1002/hyp.7131, 2008.

Kollat, J. B., Reed, P. M. and Wagener, T.: When are multiobjective calibration trade-offs in hydrologic models meaningful?, Water Resour. Res., 48(3), n/a–n/a, doi:10.1029/2011WR011534, 2012.

Lamb, R.: Calibration of a conceptual rainfall-runoff model for flood frequency estimation by continuous simulation, Water Resour. Res., 35(10), 3103–3114, doi:10.1029/1999WR900119, 1999.

Lidén, R. and Harlin, J.: Analysis of conceptual rainfall-runoff modelling performance in different climates, J. Hydrol., 238(3-4), 231–247, doi:10.1016/S0022-1694(00)00330-9, 2000.

Moore, R. J. and Bell, V. A.: Comparison of rainfall-runoff models for flood forecasting. Part 1: Literature review of models, Environment Agency, Bristol., 2001.

Nielsen, S. A. and Hansen, E.: Numerical simulation of he rainfall-runoff process on a daily basis, Nord. Hydrol., (4), 171–190, doi:https://doi.org/10.2166/nh.1973.0013, 1973.

Penman, H. L.: the Dependence of Transpiration on Weather and Soil Conditions, J. Soil Sci., 1(1), 74–89, doi:10.1111/j.1365-2389.1950.tb00720.x, 1950.

Perrin, C., Michel, C. and Andréassian, V.: Improvement of a parsimonious model for streamflow simulation, J. Hydrol., 279(1-4), 275–289, doi:10.1016/S0022-1694(03)00225-7, 2003.

Porter, J. W. and McMahon, T. A.: Application of a catchment model in southeastern Australia, J. Hydrol., 24(1-2), 121–134, doi:10.1016/0022-1694(75)90146-8, 1971.

Rusli, S. R., Yudianto, D. and Liu, J. tao: Effects of temporal variability on HBV model calibration, Water Sci. Eng., 8(4), 291–300, doi:10.1016/j.wse.2015.12.002, 2015.

Santos, L., Thirel, G. and Perrin, C.: State-space representation of a bucket-type rainfall-runoff model: a case study with State-Space GR4 (version 1.0), Geosci. Model Dev. Discuss., 1–22, doi:10.5194/gmd-2017-264, 2017.

Schaefli, B., Nicotina, L., Imfeld, C., Da Ronco, P., Bertuzzo, E. and Rinaldo, A.: SEHR-ECHO v1.0: A spatially explicit hydrologic response model for ecohydrologic applications, Geosci. Model Dev., 7(6), 2733–2746, doi:10.5194/gmd-7-2733-2014, 2014.

Seibert, J.: Estimation of Parameter Uncertainty in the HBV Model, Nord. Hydrol., 28(1982), 247–262, doi:10.2166/nh.1997.015, 1997.

Seibert, J. and Vis, M. J. P.: Teaching hydrological modeling with a user-friendly catchment-runoff-model software package, Hydrol. Earth Syst. Sci., 16(9), 3315–3325, doi:10.5194/hess-16-3315-2012, 2012.

Sivapalan, M. and Woods, R. A.: Evaluation of the effects of general circulation models’ subgrid variability and patchiness of rainfall and soil moisture on land surface water balance fluxes, Hydrol. Process., 9(5-6), 697–717, doi:10.1002/hyp.3360090515, 1995.

Sivapalan, M., Ruprecht, J. K. and Viney, N. R.: Water and salt balance modelling to predict the effects of land-use changes in forested catchments. 1. Small catchment water balance model, Hydrol. Process., 10(3), 1996.

SMHI: Integrated Hydrological Modelling System (IHMS) Manual Version 4.5, 2004.

Son, K. and Sivapalan, M.: Improving model structure and reducing parameter uncertainty in conceptual water balance models through the use of auxiliary data, Water Resour. Res., 43(1), doi:10.1029/2006WR005032, 2007.

Sun, W., Ishidaira, H., Bastola, S. and Yu, J.: Estimating daily time series of streamflow using hydrological model calibrated based on satellite observations of river water surface width: Toward real world applications, Environ. Res., 139, 36–45, doi:10.1016/j.envres.2015.01.002, 2015.

Tan, B. Q. and O’Connor, K. M.: Application of an empirical infiltration equation in the SMAR conceptual model, J. Hydrol., 185(1-4), 275–295, doi:10.1016/0022-1694(95)02993-1, 1996.

Vinogradov, Y. B., Semenova, O. M. and Vinogradova, T. A.: An approach to the scaling problem in hydrological modelling: The deterministic modelling hydrological system, Hydrol. Process., 25(7), 1055–1073, doi:10.1002/hyp.7901, 2011.

Wagener, T., Wheater, H. S. and Gupta, H. V.: Rainfall-Runoff Modelling in Gauged and Ungauged Catchments, edited by T. K. Wei, Imperial College Press., 2004.

Ye, S., Yaeger, M., Coopersmith, E., Cheng, L. and Sivapalan, M.: Exploring the physical controls of regional patterns of flow duration curves - Part 2: Role of seasonality, the regime curve, and associated process controls, Hydrol. Earth Syst. Sci., 16(11), 4447–4465, doi:10.5194/hess-16-4447-2012, 2012.