User's Guide for Multi-Modular Penn State Integrated Hydrologic Model

User's Guide for MM-PIHM Version 1.0

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PennState

Contents

1 Overview

The Multi-Modular Penn State Integrated Hydrologic Model (MM-PIHM) is a multi-modular watershed model based on the Penn State Integrated Hydrologic Model. The first release of MM-PIHM (MM-PIHM Version 1.0) contains the source code for PIHM (Qu and Duffy 2007), PIHM with a surface heat flux module (Flux-PIHM; Shi et al. 2013), PIHM with surface heat flux and biogeochemistry modules (Flux-PIHM-BGC), and Flux-PIHM data assimilation system using the ensemble Kalman filter (Flux-PIHM-EnKF system; Shi et al. 2014).

PIHM is a spatially-distributed, physically-based hydrologic model. Flux-PIHM adds a land surface model [adapted from the Noah land surface model (Chen and Dudhia 2001)] to PIHM for the simulation of land surface processes. Flux-PIHM-BGC couples Flux-PIHM with a terrestrial ecosystem model [adapted from Biome-BGC (Thornton et al. 2002)] that enables the simulation of carbon and nitrogen cycles. The Flux-PIHM-EnKF system can be used for Flux-PIHM parameter and state estimation using data assimilation via the EnKF method (Evensen 1994). The source code for the reactive transport (RT) module and landscape evoluation (LE) module will be provided in future releases.

MM-PIHM is open source software and the development is coordinated via the MM-PIHM GitHub page (`https://github.com/PSUmodeling/MM-PIHM`).

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2 Installation

The source code provided in the MM-PIHM package can be used to compile excecutables for PIHM, Flux-PIHM, Flux-PIHM-BGC, and Flux-PIHM-EnKF.

MM-PIHM requires the SUNDIALS CVODE implicit solver. The SUNDIALS Version 2.2.0 source code, which contains CVODE Version 2.4.0, is provided with the MM-PIHM package for users' convenience. SUNDIALS (©2012–2014) is copirighted software produced at the Lawrence Livermore National Laboratory. A SUNDIALS copyright note can be found in the `sundials/shared` directory. If you have not previously installed CVODE Version 2.4.0, you need to run

```
$ make sundials
```

to install CVODE.

After CVODE is successfully installed, you can now install PIHM using

```
$ make pihm
```

To install other MM-PIHM members, run

```
$ make <model>
```

where `<model>` can be `flux-pihm`, `flux-pihm-bgc`, or `flux-pihm-enkf`.

The command

```
$ make clean
```

will clean the executbles and object files. Note that if you want to switch from one MM-PIHM model to another MM-PIHM model, you must `$ make clean` first.

A help message will appear if you run `$ make`:

```
Makefile for MM-PIHM

USAGE:

help:            Show this help
all:             Install sundials and compile PIHM
sundials:        Install sundials library
pihm:            Compile PIHM
flux-pihm:       Complile Flux-PIHM (PIHM with land surface module,
   adapted from Noah LSM)
```

```
rt-flux-pihm:    Complile RT-Flux-PIHM (Reactive Transport Flux PIHM
   ) for hydrogeochemical coupling.
flux-pihm-bgc:   Compile Flux-PIHM-BGC (Flux-PIHM with
   Biogeochemical module, adapted from Biome-BGC)
flux-pihm-enkf:  Compile Flux-PIHM-EnKF (Flux-PIHM EnKF system)
pihm-cycles:     Compile PIHM-Cycles (Flux-PIHM with crop module,
   adapted from Cycles)
clean:           Clean executables and objects

NOTE: Please always "make clean" when switching from one module to
   another!
```

3 Running MM-PIHM

After the installation, you can run MM-PIHM models using

```
$ ./<model> [-v] [-d] [-o] <project>
```

where `<model>` is the installed executable, `<project>` is the name of the project, and `[-vdo]` are optional parameters.

The optional `-v` parameter will turn on the verbose mode. The optional `-d` parameter will turn on the debug mode. The optional `-o` will let MM-PIHM write all model output variables in the `output` directory (this may overwrite existing model output files), instead of being saved in a separate directory named after the project and the system time when the simulation is executed (Section 5).

When MM-PIHM model runs, the model will look into the `input/<project>` directory for the input files (Section 4). The following message should appear for successful MM-PIHM runs:

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

            The Penn State Integrated Hydrologic Model

Output directory:  output/example.1603021343/
 Step = 2009-01-01 00:00
 Step = 2009-01-01 01:00
 Step = 2009-01-01 02:00
...
```

4 PIHM input files

PIHM input files are organized by projects. The input files for each project (except for the `vegprmt.tbl` file) should be put into the same directory, under `<PIHM_DIR>/input/<project>`, where `<PIHM_DIR>` is the directory in which PIHM is installed, and `<project>` is the name of the project. The `vegprmt.tbl` input file is provided with the source code, and is stored in the `input` directory. Each project may have a total of twelve input files, including eight required input files and four optional input files (Table 1).

Table 1: A list of PIHM input files.

File	File name	Purpose
Required:		
Mesh structure	`<project>.mesh`	Spatial information of nodes and irregular meshes
Element attribute	`<project>.att`	Attribute table defining different classes an element belongs to
Soil parameter	`<project>.soil`	Soil properties of different soil types
Vegetation parameter	`vegprmt.tbl`	Landcover properties of different landcover types
River	`<project>.riv`	Spatial, geometry and material properties of river channels
Meteorological forcing	`<project>.forc`	Meteorological forcing time series
Model control parameter	`<project>.para`	Control parameters (solver options, model modes, error control, etc.)
Calibration file	`<project>.calib`	Calibration coefficients
Optional:		
Geology parameter	`<project>.geol`	Geology properties of bedrock
Boundary condition	`<project>.ibc`	Boundary condition time series
Initial condition	`<project>.init`	Initial condition
Leaf area index file	`<project>.lai`	Leaf area time series

4.1 Mesh structure file

The mesh structure (`.mesh`) file is a required input file for PIHM. It provides the irregular mesh (triangular irregular network, or TIN) structure of the model domain. The mesh structure file consists of the element block and the node block. The element block describes the total number of elements, and the three vertex nodes and three neighbor elements of each trigular element. The node block describes the location and elevation of each node. A sample mesh structure file is provided in Appendix A.1. A description of the input variables can be found in Table 2.

Table 2: Description of the mesh structure input file.

Variable	Type	Description	Unit
Element block			
NUMELE	Integer	Total number of elements	-
INDEX	Integer	Element index	-
NODE[i]	Integer	The ith node of element	-
NABR[i]	Integer	The neighbor element on the ith edge [a]	-
Node block			
NUMNODE	Integer	Total number of nodes	-
INDEX	Integer	Node index	-
X	Double	x coordinate of node	m
Y	Double	y coordinate of node	m
ZMIN	Double	Bedrock elevation of node	m
ZMAX	Double	Surface elevation of node	m

[a] `0`: Boundary.

4.2 Element attribute file

The element attribute (`.att`) file is a lookup table which stores the attribute of each mesh element, including soil type, land cover type, meteorological forcing type, boundary condition type, etc. It allows efficient data storage. A sample element attribute file is provided in Appendix A.2. A description of the input variables can be found in Table 3.

Table 3: Description of element attribute file.

Variable	Type	Description	Unit
INDEX	Integer	Element index	-
SOIL	Integer	Soil class	-
GEOL	Integer	Geology class	-
LC	Integer	Land cover class	-
METEO	Integer	Meteorological forcing series	-
LAI	Integer	Leaf area index forcing series[a]	-
SS	Integer	Source/sink forcing series	-
BC[i]	Integer	Boundary condition type on Edge i	-

[a] `0`: NLCD climatological LAI will be used.

4.3 Soil parameter file

The soil parameter (`.soil`) file contains the hydraulic and thermal parameters of all soil classes, for both soil matrix and macropore, in the model domain. A sample soil parameter file is provided in Appendix A.3. A description of the input variables can be found in Table 4.

Table 4: Description of soil parameter file.

Variable	Type	Description	Unit
`INDEX`	Integer	Soil class index	-
`SILT`	Double	Silt percentage	%
`CLAY`	Double	Clay percentage	%
`OM`	Double	Organic matter percentage	%
`BD`	Double	Bulk density	g cm^{-3}
`KINF`	Double	Vertical saturated infiltration hydraulic conductivity[a]	m s^{-1}
`KSATV`	Double	Vertical saturated hydraulic conductivity[a]	m s^{-1}
`KSATH`	Double	Horizontal saturated hydraulic conductivity[a]	m s^{-1}
`MAXSMC`	Double	Porosity[a]	m^3 m^{-3}
`MAXSMC`	Double	Residual porosity[a]	m^3 m^{-3}
`ALPHA`	Double	van Genuchten soil parameter (related to the inverse of the air entry suction)[a]	m^{-1}
`BETA`	Double	van Genuchten soil parameter (measure of the pore-size distribution)[a]	Dimensionless
`MACHF`	Double	Horizontal area fraction of macropore	m^2 m^{-2}
`MACVF`	Double	Vertical area fraction of macropore	m^2 m^{-2}
`DMAC`	Double	Macropore depth	m
`QTZ`	Double	Quartz content[a]	100%
`DINF`	Double	Top soil layer across which infiltration is calculated	m
`KMACV_RO`	Double	Ratio between vertical macropore hydraulic conductivity and vertical saturated infiltration hydarulic conductivity	Dimensionless
`KMACH_RO`	Double	Ratio between horizontal macropore hydraulic conductivity and horizontal saturated hydarulic conductivity	Dimensionless

[a] `-999` indicates missing values and will be filled using pedotransfer functions.

4.4 Vegetation parameter file

The vegetation parameter (`vegprmt.tbl`) file contains the vegetation parameters corresponding to different landcover classes present in the model domain. This file is shared by all projects and the file should not be renamed. A sample vegetation parameter file is provided in Appendix A.4. A description of the input variables can be found in Table 5.

4.5 River file

The river (`.riv`) file provides description of the river channel properties. It consists of five blocks. The river attribute block describes the topographical information related to river segments (the

Table 5: Description of vegetation parameter (`vegprmt.tbl`) file.

Variable	Type	Description	Unit
`INDEX`	Integer	Land cover class	-
`SHDFAC`	Double	Green vegetation fraction	$m^2\ m^{-2}$
`DROOT`	Double	Rooting depth	m
`RS`	Double	Minimum stomatal resistance	$s\ m^{-1}$
`RGL`	Double	Parameter used in radiation stress function	$W\ m^{-2}$
`HS`	Double	Parameter used in vapor pressure dificit function	
`SNUP`	Double	Threshold water-equivalent snow depth that implies 100% snow cover	m
`LAIMIN`	Double	Minimum leaf area index through the year	$m^2\ m^{-2}$
`LAIMAX`	Double	Maximum leaf area index through the year	$m^2\ m^{-2}$
`EMISMIN`	Double	Minimum background emissivity through the year	Dimensionless
`EMISMAX`	Double	Maximum background emissivity through the year	Dimensionless
`ALBMIN`	Double	Minimum background albedo through the year	Dimensionless
`ALBMAX`	Double	Maximum background albedo through the year	Dimensionless
`ZOMIN`	Double	Minimum background roughness length through the year	m
`ZOMAX`	Double	Maximum background roughness length through the year	m
`ROUGH`	Double	Manning's roughness coefficient	$s\ m^{-1/3}$
`TOPT`	Double	Optimum transpiration air temperature	K
`CFACTR`	Double	Parameter used in the canopy interception calculation	Dimensionless
`RSMAX`	Double	Maximum stomatal resistance	$s\ m^{-1}$
`BARE`	Double	The land-use category representing bare ground	-
`NATURAL`	Double	The land-use category representing the non-urban portion of urban land-use points	-

upstream and downstrem nodes and the left and right bank elements), and river shape, material, boundary condition, and reservoir types. The shape and material blocks contain the parameters for different shape and material types. The boundary conditions and reservoir time series are provided in the boundary condition and reservoir blocks. A sample river file is provided in Appendix A.5. A description of the input variables can be found in Table 6.

4.6 Meteorological forcing file

The meteorological forcing (`.forc`) file contains the meteorological forcing for the model, including precipitation rate, air tempearature, relative humidity, surface wind speed, downward solar radiation, downward longwave radiation, and surface pressure. Note that the meteorological forcing file can contain multiple meteorological forcing time series. A sample meteorological forcing file is provided in Appendix A.6. A description of the input variables can be found in Table 7.

Table 6: Description of river (`.riv`) file.

Variable	Type	Description	Unit
Attribute block			
`NUMRIV`	Integer	Number of river segments	-
`INDEX`	Integer	River segment ID	-
`FROM`	Integer	From node ID	-
`TO`	Integer	To node ID	-
`DOWN`	Integer	Downstream segment ID	-
`LEFT`	Integer	Left element ID	-
`RIGHT`	Integer	Right element ID	-
`SHAPE`	Integer	Shape type	-
`MATL`	Integer	River bank and bed material type	-
`BC`	Integer	Boundary condition type	-
`RES`	Integer	Reservoir type	-
Shape block			
`SHAPE`	Integer	Number of shape types	-
`INDEX`	Integer	River shape type index	-
`DPTH`	Double	Depth of river	m
`OINT`	Double	Interpolation order[a]	Dimensionless
`CWID`	Double	Width coefficient[a]	Dimensionless
Material block			
`MATERIAL`	Integer	Number of material types	-
`INDEX`	Integer	River material type index	-
`ROUGH`	Double	Manning's roughness coefficient	s $m^{-1/3}$
`CWR`	Double	Discharge coefficient	Dimensionless
`KH`	Double	River bank hydraulic conductivity	m s^{-1}
`KV`	Double	River bed hydraulic conductivity	m s^{-1}
`BEDTHCK`	Double	River bed depth	m
Boundary condition block			
`BC`	Integer	Number of boundary conditions	-
Reservoir block			
`RES`	Integer	Number of reservoir time series	-

[a] Interpolation order (b) and width coefficient (a) are parameters defining relationship between river width and depth as $D = ax\left(\frac{W}{2}\right)^b$.

4.7 Control parameter file

The control parameter (`.para`) file consists of the model control block and the output control block. The model control block provides all the control parameters to the model, including solver options, model modes, parameters that govern model error, etc. The output control block controls which variables should be printed for output with what output interval. The output intervals have the unit of second. If the output interval for a variable is 0, the variable will not be printed for output.

Table 7: Description of meteorological forcing file.

Variable	Type	Description	Unit
METEO_TS	Integer	Index of meteorological forcing time series	-
WIND_LVL	Double	Height of wind speed observation	m
TIME	String	Time of forcing observation	-
PRCP	Double	Precipitation rate	kg m^2 s^{-1}
SFCTMP	Double	Surface air temperature	K
RH	Double	Relative humidity	%
SFCSPD	Double	Wind speed measured at WIND_LVL	m s^{-1}
SOLAR	Double	Downward solar radiation	W m^{-2}
LONGWV	Double	Downward longwave radiation	W m^{-2}
PRES	Double	Surface pressure	Pa

A sample control parameter file is provided in Appendix A.7. A description of the input variables can be found in Table 8.

4.8 Calibration file

The calibration (`.calib`) file contains the global calibration coefficient of key model parameters and climate scenario parameters. All calibration coefficients in the `.calib` file are the calibration multiplier to the original corresponding variables. The climate scenario parameters can be a multiplier or an offset. A sample `.calib` file is provided in Appendix A.8. A description of the variables can be found in Table 9.

Table 8: Description of `.para` input file.

Variable	Type	Description	Unit
INIT_MODE	Integer	Initialization mode[a]	-
ASCII_OUTPUT	Integer	ASCII output switch[b]	-
WRITE_IC	Integer	Write initial condition to file switch[c]	-
UNSAT_MODE	Integer	Unsaturation formulation[d]	-
SURF_MODE	Integer	Surface formulation[d]	-
RIV_MODE	Integer	River formulation[d]	-
SOLVER	Integer	CVODE solver type[e,f]	-
ABSTOL	Double	Absolute tolerance[f]	m
RELTOL	Double	Relative tolerance[f]	Dimensionless
INIT_SOLVER_STEP	Double	Initial time step[f]	s
MAX_SOLVER_STEP	Double	Maximum time step[f]	s
LSM_STEP	Integer	Land surface model (Evapotranspiration) time step[g]	s
START	String	Simulation start time	-
END	String	Simulation end time	-
MODEL_STEPSIZE	Integer	Model step size	s

[a] `0`: Relaxation mode (Model starts from saturation); `3`: Hot start mode (Model starts from the initial condition described in `.init` file.

[b] `0`: Do not print ASCII output/`1`: Print ASCII output.

[c] `0`: Do not write `.init` file/`1`: Last step of model output will be written into `.init` file.

[d] `1`: Kinematic/`2`: Diffusion.

[e] `2`: Iterative.

[f] See SUNDIALS manual for details.

[g] Must be larger than `MODEL_STEPSIZE`.

[h] Output will be turned of if set to 0.

Table 9: Description of `.calib` input file.

Variable	Type	Description	Unit
Calibration block			
KSATH	Double	Calibration coefficients for horizontal saturation conductivity	Dimensionless
KSATV	Double	Calibration coefficients for vertical saturation conductivity	Dimensionless
KINF	Double	Calibration coefficients for vertical infiltration saturation conductivity	Dimensionless
KMACSATH	Double	Calibration coefficients for horizontal macropore saturation conductivity	Dimensionless
KMACSATV	Double	Calibration coefficients for vertical macropore saturation conductivity	Dimensionless
DINF	Double	Calibration coefficients for infiltration depth	Dimensionless
DROOT	Double	Calibration coefficients for rooting depth	Dimensionless
DMAC	Double	Calibration coefficients for macropore depth	Dimensionless
POROSITY	Double	Calibration coefficients for porosity	Dimensionless
ALPHA	Double	Calibration coefficients for van Genuchten α	Dimensionless
BETA	Double	Calibration coefficients for van Genuchten β	Dimensionless
MACVF	Double	Calibration coefficients for vertical areal fraction of macopore	Dimensionless
MACHF	Double	Calibration coefficients for horizontal areal fraction of macopore	Dimensionless
VEGFRAC	Double	Calibration coefficients for vegetation fraction	Dimensionless
ALBEDO	Double	Calibration coefficients for albedo	Dimensionless
ROUGH	Double	Calibration coefficients for Manning's n for landcover	Dimensionless
PRCP	Double	Calibration coefficients for precipitation rate	Dimensionless
SFCTMP	Double	Calibration coefficients for surface air temperature	Dimensionless
EC	Double	Calibration coefficients for canopy evaporation	Dimensionless
ETT	Double	Calibration coefficients for total transpiration	Dimensionless
EDIR	Double	Calibration coefficients for soil evaporation	Dimensionless
ROUGH_RIV	Double	Calibration coefficients for river Manning's n	Dimensionless
KRIVH	Double	Calibration coefficients for river bank conductivity	Dimensionless
KRIVV	Double	Calibration coefficients for river bed conductivity	Dimensionless
BEDTHCK	Double	Calibration coefficients for river bed thickness	Dimensionless
RIV_DPTH	Double	Calibration coefficients for river depth	Dimensionless
RIV_WDTH	Double	Calibration coefficients for river width coefficient	Dimensionless
Climate scenario block			
PRCP	Double	Multiplier for precipitation forcing	Dimensionless
SFCTMP	Double	Offset for surface air temperature	K

5 PIHM output files

PIHM can store model output variables in both text and binary formats. Table 10 shows all available variables for output. The control for output can be found in the model control parameter file 4.7, where users can turn on/off output for desired variables as well as change the output intervals.

Table 10: Description of output variables.

Variable	Extension	Description	Unit
`SURF`	`surf`	Surface water level	m
`UNSAT`	`unsat`	Unsaturated water storage	m
`GW`	`gw`	Element groundwater level	m
`RIVSTG`	`stage`	River stage	m
`RIVGW`	`rivgw`	River groundwater level	m
`SNOW`	`snow`	Water-equivalent snow depth	m
`CMC`	`is`	Canopy interception	m
`INFIL`	`infil`	Infiltration rate	m s^{-1}
`RECHARGE`	`recharge`	Recharge rate	m s^{-1}
`EC`	`ec`	Canopy evaporation	m s^{-1}
`ETT`	`ett`	Total transpiration	m s^{-1}
`EDIR`	`edir`	Soil evaporation	m s^{-1}
`RIVFLX0`	`rivflx0`	Longitudinal flow to river	m^3 s^{-1}
`RIVFLX1`	`rivflx1`	Longitudinal flow from river	m^3 s^{-1}
`RIVFLX2`	`rivflx2`	Lateral overland flow to river from left	m^3 s^{-1}
`RIVFLX3`	`rivflx3`	Lateral overland flow to river from right	m^3 s^{-1}
`RIVFLX4`	`rivflx4`	Lateral groundwater flow to river from left	m^3 s^{-1}
`RIVFLX5`	`rivflx5`	Lateral groundwater flow to river from right	m^3 s^{-1}
`RIVFLX6`	`rivflx6`	Leakage flow from river to aquifer	m^3 s^{-1}
`RIVFLX7`	`rivflx7`	Longitudinal flow to river aquifer	m^3 s^{-1}
`RIVFLX8`	`rivflx8`	Longitudinal flow from river aquifer	m^3 s^{-1}
`RIVFLX9`	`rivflx9`	Lateral groundwater flow to aquifer from left	m^3 s^{-1}
`RIVFLX10`	`rivflx10`	Lateral groundwater flow to aquifer from right	m^3 s^{-1}
`SUBFLX`	`subflx[0-2]`	Subsurface water flux	m^3 s^{-1}
`SURFFLX`	`surflx[0-2]`	Surface water flux	m^3 s^{-1}

The default output format is binary, but ASCII output can be turned on in the model control parameter file (Section 4.7) if desired. The output files are stored in the `output/<project>.<time>/` directory by default, and are named as `<project>.<extension>.<fmt>`, where `<project>` is the name of the project, `<time>` is the system time when the simulation is executed, in the format of "yyyymmddHHMM", `<extension>` indicates the variable stored in the output file (Table 10), and `fmt` can be `dat` (for binary files) or `txt` (for ASCII files). Each output variable is stored in one output file, which contains the time series of all model grid elements, or river segments.

For the ASCII files, the first column of the output file is output time, in the format of "yyyy-mm-dd HH:MM". The time string is followed by output variables from the first element (or river channel segment) to the last element (or river channel segment). Appendix B shows a sample output file in ASCII format. Structure of the binary output files is similar to the ASCII files, except that the output time is stored as the seconds since the Unix epch, i.e., 00:00:00 UTC 1 January 1970, and the binary files stores the output variables (including the output time) as double-precision floting-point type.

A Sample input files

A.1 Sample mesh structure file

A sample mesh structure (`.mesh`) file is provided below, which can also be found in the `input/example/` directory in the MM-PIHM release.

```
NUMELE  535
INDEX   NODE1   NODE2   NODE3   NABR1   NABR2   NABR3
1       139     6       179     239     112     238
2       50      49      46      45      4       23
3       16      249     248     442     439     440
4       50      46      48      30      77      2
5       256     257     205     455     453     452
...
531     237     297     212     375     371     420
532     131     298     121     470     201     204
533     295     298     268     204     475     526
534     218     299     217     499     383     225
535     281     299     291     225     515     518
NUMNODE  299
INDEX   X             Y             ZMIN     ZMAX
1       254488.5000   4505385.500   269.576  271.617
2       254469.5000   4505386.500   268.968  270.577
3       254381.5000   4505355.500   264.050  266.320
4       254375.0479   4505356.322   263.830  266.067
5       254356.9955   4505358.623   262.499  264.821
...
295     254523.0261   4505424.616   274.937  277.046
296     254437.0785   4505434.247   280.271  282.313
297     254583.3477   4505486.753   292.435  294.552
298     254535.7270   4505398.073   278.241  279.759
299     254598.6925   4505415.428   286.376  287.880
```

A.2 Sample element attribute file

A sample element attribute (`.att`) file is provided below, which can also be found in the `input/example` directory in the MM-PIHM release.

```
INDEX  SOIL  GEOL  LC  METEO  LAI  SS  BC0  BC1  BC2
1      5     0     5   1      1    0   0    0    0
2      1     0     5   1      1    0   0    0    0
3      1     0     5   1      1    0   0    0    0
4      2     0     4   1      1    0   0    0    0
5      2     0     4   1      1    0   0    0    0
...
531    1     0     4   1      1    0   0    0    0
532    1     0     4   1      1    0   0    0    0
533    3     0     4   1      1    0   0    0    0
534    1     0     4   1      1    0   0    0    0
535    1     0     4   1      1    0   0    0    0
```

A.3 Sample soil parameter file

A sample `.soil` file is provided on the next page, which can also be found in the `input/example` directory in the MM-PIHM release.

```
NUMSOIL  5
INDEX  SILT   CLAY   OM    BD    KINF       KSATV      KSATH      MAXSMC  MINSMC  ALPHA  BETA   MACHF  MACVF  DMAC  QTZ
1      41.67  14.44  4.02  1.15  9.098E-5   1.625E-5   1.202E-5   0.3698  0.0370  8.80   1.240  0.01   0.01   1.0   0.25
2      33.90  15.85  3.44  1.53  1.516E-4   1.862E-5   9.802E-6   0.4032  0.0403  6.45   1.212  0.01   0.01   1.0   0.25
3      33.90  15.85  3.44  1.49  9.833E-5   1.086E-5   2.263E-5   0.4247  0.0425  6.50   1.258  0.01   0.01   1.0   0.25
4      39.70  19.86  3.66  1.64  1.506E-5   6.762E-6   3.047E-5   0.4179  0.0418  5.34   1.260  0.01   0.01   1.0   0.25
5      39.70  19.86  3.66  1.48  8.281E-5   3.705E-5   6.962E-5   0.4928  0.0493  5.82   1.220  0.01   0.01   1.0   0.25
DINF      0.10
KMACV_RO  100.0
KMACH_RO  1000.0
```

A.4 Sample vegetation parameter file

A sample vegetation parameter (`vegprmt.tbl`) file is provided below, which can also be found in the `input` directory in the MM-PIHM release.

```
NUMLC   20
INDEX   SHDFAC  DROOT  RS     RGL    HS     SNUP   LAIMIN  LAIMAX  EMISMIN  EMISMAX  ALBMIN  ALBMAX  ZOMIN   ZOMAX   ROUGH
1       0.70    0.6    125.0  30.0   47.35  0.08   5.00    6.40    0.950    0.950    0.12    0.12    0.50    0.50    0.070
2       0.95    0.6    150.0  30.0   41.69  0.08   3.08    6.48    0.950    0.950    0.12    0.12    0.50    0.50    0.070
3       0.70    0.6    150.0  30.0   47.35  0.08   1.00    5.16    0.930    0.940    0.14    0.15    0.50    0.50    0.070
4       0.80    0.6    100.0  30.0   54.53  0.08    1.85   3.31    0.930    0.930    0.16    0.17    0.50    0.50    0.070
5       0.80    0.6    125.0  30.0   51.93  0.08   2.80    5.50    0.930    0.970    0.17    0.25    0.20    0.50    0.060
6       0.70    0.4    300.0  100.0  42.00  0.03   0.50    3.66    0.930    0.930    0.25    0.30    0.01    0.05    0.045
7       0.70    0.4    170.0  100.0  39.18  0.035  0.60    2.60    0.930    0.950    0.22    0.30    0.01    0.06    0.045
8       0.70    0.4    300.0  100.0  42.00  0.03   0.50    3.66    0.930    0.930    0.25    0.30    0.01    0.05    999.9
9       0.50    0.4    70.0   65.0   54.53  0.04   0.50    3.66    0.920    0.920    0.20    0.20    0.15    0.15    999.9
10      0.80    0.4    40.0   100.0  36.35  0.04   0.52    2.90    0.920    0.960    0.19    0.23    0.10    0.12    0.040
11      0.60    0.1    70.0   65.0   55.97  0.015  1.75    5.72    0.950    0.950    0.14    0.14    0.30    0.30    999.9
12      0.80    0.4    40.0   100.0  36.25  0.04   1.56    5.68    0.920    0.985    0.17    0.23    0.05    0.15    0.040
13      0.10    0.05   200.0  999.0  999.0  0.04   1.00    1.00    0.880    0.880    0.15    0.15    0.50    0.50    0.010
14      0.80    0.4    40.0   100.0  36.25  0.04   2.29    4.29    0.920    0.980    0.18    0.23    0.05    0.14    999.9
15      0.00    0.05   999.0  999.0  999.0  0.02   0.01    0.01    0.950    0.950    0.55    0.70    0.001   0.001   999.9
16      0.01    0.05   999.0  999.0  999.0  0.02   0.10    0.75    0.900    0.900    0.38    0.38    0.01    0.01    0.035
17      0.00    0.0    100.0  30.0   51.75  0.01   0.01    0.01    0.980    0.980    0.08    0.08    0.0001  0.0001  0.035
18      0.60    0.4    150.0  100.0  42.00  0.025  0.41    3.35    0.930    0.930    0.15    0.20    0.30    0.30    999.9
19      0.60    0.4    150.0  100.0  42.00  0.025  0.41    3.35    0.920    0.920    0.15    0.20    0.15    0.15    999.9
20      0.30    0.1    200.0  100.0  42.00  0.02   0.41    3.35    0.900    0.900    0.25    0.25    0.05    0.10    999.9
TOPT      298.0
CFACTR    0.5
RSMAX     5000.0
BARE      16
NATURAL   14
```

A.5 Sample river file

A sample river (`.riv`) file is provided below, which can also be found in the `input/example` directory in the MM-PIHM release.

```
NUMRIV  20
INDEX   FROM   TO    DOWN   LEFT   RIGHT   SHAPE   MATL   BC   RES
1       1      2     2      118    162     1       1      0    0
2       2      97    3      153    160     1       1      0    0
3       97     93    4      120    155     1       1      0    0
4       93     52    5      148    151     2       1      0    0
5       52     57    6      71     98      2       1      0    0
6       57     60    7      8      80      2       1      0    0
7       60     3     8      51     85      2       1      0    0
8       3      4     9      9      57      2       1      0    0
9       4      5     10     7      31      3       1      0    0
10      5      140   11     240    241     3       1      0    0
11      140    63    12     110    245     3       1      0    0
12      63     139   13     270    273     3       1      0    0
13      139    6     14     1      238     3       1      0    0
14      6      7     15     93     314     4       1      0    0
15      7      55    16     28     84      4       1      0    0
16      55     8     17     75     76      4       1      0    0
17      8      41    18     54     65      4       2      0    0
18      41     43    19     15     63      4       2      0    0
19      43     9     20     58     59      4       2      0    0
20      9      10    -3     17     66      4       2      0    0
SHAPE   4
INDEX   DPTH   OINT   CWID
1       0.1    1      1.5
2       0.3    1      1.5
3       0.4    1      1.5
4       0.4    1      1.5
MATERIAL  2
INDEX   ROUGH   CWR   KH         KV         BEDTHCK
1       0.04    0.6   6.962E-5   3.705E-5   0.11
2       0.04    0.6   6.962E-5   3.705E-5   1.00
BC   0
RES  0
```

A.6 Sample meteorological forcing file

A sample meteorological forcing file is provided below. It is the same as the `input/example/example.forc` file in the MM-PIHM release.

```
METEO_TS  1  WIND_LVL  10.0
TIME              PRCP        SFCTMP  RH     SFCSPD  SOLAR   LONGWV  PRES
TS                kg/m2/s     K       %      m/s     W/m2    W/m2    Pa
2008-01-01 00:00  0.00047200  272.35  83.88  2.62    0.00    227.36  97614.16
2008-01-01 01:00  0.00047200  271.94  84.75  1.75    0.00    224.42  97625.35
2008-01-01 02:00  0.00047200  270.75  90.53  2.77    0.00    231.55  97628.40
2008-01-01 03:00  0.00047200  270.82  90.02  3.79    0.00    231.40  97576.52
2008-01-01 04:00  0.00047200  270.50  90.83  5.17    0.00    239.81  97439.20
2008-01-01 05:00  0.00000000  271.52  86.02  5.98    0.00    243.08  97374.10
2008-01-01 06:00  0.00000000  273.24  79.50  7.58    0.00    274.33  97226.61
2008-01-01 07:00  0.00000000  273.32  79.67  8.68    0.00    293.40  97098.44
2008-01-01 08:00  0.00000000  273.72  79.88  7.34    0.00    312.25  96976.38
2008-01-01 09:00  0.00000000  274.11  80.50  8.51    0.00    304.58  96836.00
2008-01-01 10:00  0.00000000  275.16  80.41  3.81    0.00    317.05  96845.16
2008-01-01 11:00  0.00000000  275.23  82.25  6.28    0.00    312.86  96840.07
2008-01-01 12:00  0.00041700  273.64  93.53  7.34    0.00    292.23  96808.54
2008-01-01 13:00  0.00005600  273.20  96.97  7.32    39.98   250.54  96784.12
2008-01-01 14:00  0.00000000  273.29  97.47  8.18    262.38  258.77  96836.00
2008-01-01 15:00  0.00002800  274.35  93.10  8.80    126.15  296.00  96891.95
2008-01-01 16:00  0.00000000  275.59  67.40  8.43    119.58  300.35  96859.40
2008-01-01 17:00  0.00000000  275.35  62.29  8.21    117.95  300.32  96792.26
2008-01-01 18:00  0.00000000  275.27  62.89  8.67    107.57  302.44  96813.62
2008-01-01 19:00  0.00000000  274.77  65.81  8.94    109.47  293.69  96846.17
2008-01-01 20:00  0.00000000  274.28  69.28  9.24    77.09   287.17  96860.41
2008-01-01 21:00  0.00000000  274.12  68.07  10.15   21.79   277.67  96881.78
2008-01-01 22:00  0.00000000  273.69  67.75  9.38    0.00    293.64  96920.43
2008-01-01 23:00  0.00000000  273.15  69.57  10.38   0.00    285.67  96931.62
2008-01-02 00:00  0.00000000  272.75  70.72  9.69    0.00    289.00  96979.43
```

A.7 Sample control parameter file

A sample control parameter file is provided below. It is the same as the `input/example/example.para` file in the MM-PIHM release.

```
INIT_MODE         0
ASCII_OUTPUT      1
WRITE_IC          0
UNSAT_MODE        2
SURF_MODE         2
RIV_MODE          2
SOLVER            2
ABSTOL            1E-4
RELTOL            1E-3
INIT_SOLVER_STEP  5E-5
MAX_SOLVER_STEP   60
LSM_STEP          900
START             2009-05-01 00:00
END               2009-11-01 00:00
MODEL_STEPSIZE    60
SURF              3600
UNSAT             3600
GW                3600
RIVSTG            3600
RIVGW             3600
SNOW              3600
CMC               3600
INFIL             3600
RECHARGE          3600
EC                3600
ETT               3600
EDIR              3600
RIVFLX0           3600
RIVFLX1           3600
RIVFLX2           3600
RIVFLX3           3600
RIVFLX4           3600
RIVFLX5           3600
RIVFLX6           3600
RIVFLX7           3600
RIVFLX8           3600
RIVFLX9           3600
RIVFLX10          3600
SUBFLX            3600
SURFFLX           3600
```

A.8 Sample calibration file

A sample calibration file is provided below. It is the same as the `input/example/example.calib` file in the MM-PIHM release.

```
KSATH      5.0
KSATV      3.5
KINF       5.0
KMACSATH   10.0
KMACSATV   0.25
DINF       1.0
DROOT      1.0
DMAC       1.6
POROSITY   0.78
ALPHA      1.0
BETA       1.14
MACVF      10.0
MACHF      10.0
VEGFRAC    1.0
ALBEDO     1.0
ROUGH      1.0
EC         1.0
ETT        1.0
EDIR       1.0
ROUGH_RIV  1.0
KRIVH      1.0
KRIVV      1.0
BEDTHCK    1.0
RIV_DPTH   1.0
RIV_WDTH   1.0
########################
# Scenario             #
########################
PRCP       1.0
SFCTMP     0.0
```

B Sample output files

A sample output file is provided below.

```
"2009-05-01 01:00"  2.230311  2.226720  2.786549  2.963137  ...  2.194498
"2009-05-01 02:00"  2.256147  2.248865  2.804228  2.999801  ...  2.172541
"2009-05-01 03:00"  2.242130  2.233259  2.766913  2.991224  ...  2.156478
"2009-05-01 04:00"  2.231134  2.218965  2.722830  2.970623  ...  2.141306
"2009-05-01 05:00"  2.222300  2.206838  2.681986  2.931470  ...  2.128164
...
```

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