User Guide: DRYP: a parsimonious model for DRYland regions water Partitioning.

April 28, 2021

1 INTRODUCTION: RUNNING DRYP

1.1 Introduction

DRYP v1.0 has been tested in Python 3.7.4. and runs in windows and Linux.

The following python packages must be installed in order to use DRYP:

Landlab 2.0. (see https://landlab.readthedocs.io/en/master/index.html)
Numpy 1.16.4
Pandas 0.25.1

DRYP can run in previous versions of python that are compatible with packages listed above.

DRYP comes with an example (GW_1D) in addition to the following python scripts:

DRYP_Gen_Func.py
DRYP_groundwater_EFD.py
DRYP_infiltration.py
DRYP_io.py
DRYP_model_list.txt
DRYP_Modflow.py
DRYP_rainfall.py
DRYP_routing.py
DRYP_soil_layer.py
run_DRYP_v1_0.py
run_model.py
test_dryp.py

The folder GW_1D contains all files required to run a simple integrated 1D model. Inside this folder a folder called 'input' as well as two files 'input.dmp' and 'settings.dmp' required to run the model are provided. All files provided in this folder can be read/modified using a notepad or other text editors.

To run DRYP:

1. Copy and paste the folder DRYP in a convenient location in your PC.

2. Open the file 'run_model.py' and change the name of the input file of the function 'run_DRYP(model_input_filename)' This function will call DRYP and its components.

3. Open the command line or any IDLE available in your PC and run the file previously edited ('run_model.py')

Details about the input files, model parameter files as well as simulation setting are specified in the following sections.
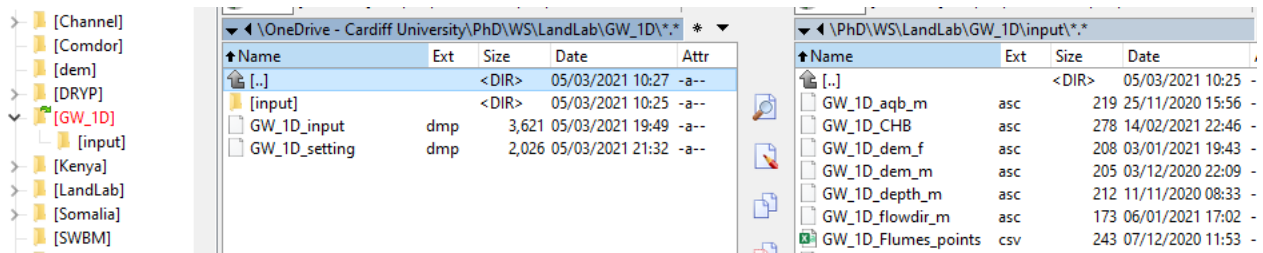
Figure 1: Location of the GW_1D example

For running the example copy and paste the folder GW_1D into the same directory of DRYP folder (see figure 1).

For model installation testing, run pytest command providing the location of the DRYP folder. A simple test file ('test_dryp.py') is provided in order to check the installation. For running the lossy flow accumulator using the cython transmission loses function, TransLoss function must be installed. The Transloss function should be installed using the "setup.py" file. This file is located in the folder components and it has to be installed into this directory.

The installation can be done using the python terminal using the following command:

python setup.py bould_ext --inplace

2   DATA INPUT FILE FORMAT

2.1   Forcing Data

The main driven variables of the model are the precipitation and evapotranspiration. Time variable parameters can be provided as gridded data in netcdf format or it can be provided as time series in '.csv' format. When provided as time series, the precipitation/evapotranspiration will be uniform for each time step.

The model will not interpolate/aggregate spatially or temporally any variable. Model grid size will depend entirely on datasets/maps provided as input files. The time step of precipitation/evapotranspiration has to be according to the time step specified in the model setting parameters.

For netcdf datasets, a variable representing time has to be specified with name 'time' Time has to be defined as numeric values but it should include a time units and the calendar. Names of variables must be specified as 'pre' for precipitation and 'pet' for evapotranspiration. The model will not recognise any other name specified for the last variables. The netCDF4 API for python can be used to create input files for the model. The following is an example of a variable defined created as netCDF4 file in python that can be read by DRYP:

```
dataset = Dataset(fname_out, 'w', format='NETCDF4_CLASSIC')
dataset.createDimension('time', None)
dataset.createDimension('lon', columns)
dataset.createDimension('lat', rows)
dataset.createDimension('grid', grid size)
lat = dataset.createVariable('lat', np.float64, ('lat',))
lon = dataset.createVariable('lon', np.float64, ('lon',))
time = dataset.createVariable('time', np.float64, ('time',))
pre = dataset.createVariable('pre', np.float32,('time','grid'))
time.units = 'hours since 1980-01-01 00:00:00'
time.calendar = 'gregorian'
```

For dataset provided as time series in csv files, columns must be label as 'Date' for time and 'pre' and 'ETo' for precipitation and evapotranspiration, respectively.

```
Date,pre,ETo
01/01/2000 00:00,0,0
01/01/2000 01:00,0,0
01/01/2000 02:00,0,0
01/01/2000 03:00,0,0
```

2.2 Model Parameters

A list of parameters required for each component is presented below:

Surface component:

- Digital elevation model (DEM), required

- River network (values greater than zero are considered as river), if not available all cells are considered rivers

- Flow direction in landlab format (ID of receiving node following landlab indexing), if no available, Landlab will automatically find the direction of flow based on the DEM.

- Drainage area, it can specified as the model domain for the catchment. Default value is 1.0.

Subsurface component:

- Rooting depth in mm, default value 1000mm

- Wilting Point (θ_{wp}), default value 0.1

- field capacity (θ_{fc}), default value 0.15

- Porosity, n_e, default value 0.35

- Standard deviation of the saturated hydraulic conductivity, σ

- Infiltration at saturated conditions, (K_{sat}) in mm/h

- Water content at residual capacity, θ_r

- Exponent of the water retention function, b default value 2.

- Suction head, ψ, default value 300mm

Groundwater component

- Aquifer saturated hydraulic conductivity, Ks_{GW}, default value 1 [m/h]

- Aquifer specific yield, Ks_{GW}, default value 0.01 [-]

- Groundwater model domain, optional, in case that groundwater catchment is different than surface catchment.

- Initial water table, default value is specified at 1 meter below the rooting depth.

- Head boundary conditions

- Flux boundary conditions

- Bottom stream bed elevation, default value: z - 5m

Parameters can be provided as numerical values or as maps. When maps are provided, they must be raster files. An example of the raster format for a 3 x 3 grid size map is shown below.

```
ncols         3
nrows         3
xllcorner     574361
yllcorner     3502989
cellsize      1000
NODATA_value  -99999
```

```
825.233 860.3439 864.650
825.233 860.3439 864.650
825.233 860.3439 -99999
```

Maps specifying boundary conditions must have as nodata values -9999, any other value will be assumed as boundary conditions.

Filenames of parameters required for the model must be included in the input file. If a filename is not provided, default values will be considered. The input file must be a plain text file. This file must start with 'drylandmodel' in the first line (see example below), omitting the first line will stop the simulation.

Filenames provided in the input file must be written in each line specified in the example, changes will result in simulation errors or wrong variables being read (e.g. if the file 'GW_1D_dem_m.asc' is written in line 5, python will raise an exception error).

```
─────────────────────────── input_file ───────────────────────────
 1  drylandmodel
 2  Model name ------------------------------------(1):
 3  test
 4  ================ TERRAIN COMPONENTS ================
 5  Topography (DEM)-------------------------------(4):
 6  test/input/test_dem_m.asc
 7  Cell factor area ------------------------------(6):
 8  test/input/test_area_m.asc
 9  Flow Direction (fd)----------------------------(8):
10  test/input/test_flowdir_m.asc
11  Boundary conditions (check CHB) ---------------(10):
12  test/input/test_chb.asc
13  Basin Mask (catchment) ------------------------(12):
14  test/input/test_mask_m.asc
15  River length ----------------------------------(14):
16  test/input/test_riv_m.asc
17  River width -----------------------------------(16):
18  none
19  River bottom elevation ------------------------(18):
20  none
21  ================ SURFACE COMPONENTS ================
22  Vegetation type Kc ----------------------------(21):
23  none
24  Soil land use ---------------------------------(23):
25  none
26  Other -----------------------------------------(25):
27  none
28  =========== SOIL AND SUBSURFACE PARAMETERS =========
29  Soil porosity: porosity -----------------------(28):
30  test/input/test_rawls_ne.txt
31  Theta residual --------------------------------(30):
32  test/input/test_rawls_theta_r.txt
33  Available Water content (AWC) -----------------(32):
34  test/input/test_rawls_awc.txt
35  Wilting Point (wp) ----------------------------(34):
36  test/input/test_rawls_wp.txt
37  Soil Depth (D) --------------------------------(36):
38  test/input/test_depth_m.asc
39  Soi particle distribution parameter (b) -------(38):
40  test/input/test_rawls_n.txt
41  Soil suction head -----------------------------(40):
42  test/input/test_rawls_phi.txt
43  Saturated hydraulic conductivity --------------(42):
44  test/input/test_rawls_ks.txt
45  sigma_Ksat ------------------------------------(44):
46  test/input/test_rawls_sigma_ks.txt
```

```
47  Initial soil water content --------------------(46):
48  none
49  Other -------------------------------------(48):
50  none
51  === GROUNDWATER PARAMETER AND BOUNDARY CONDITIONS ===
52  Groundwater Boundary condition (domain) --------(51):
53  test/input/test_mask_m.asc
54  Aquifer Sat. Hydraulic Conductivity (Ksat_aq) --(53):
55  test/input/test_rawls_ks1.txt
56  Specific Yield---------------------------------(55):
57  none
58  Initial Conditions Water table elevation -------(57):
59  test/input/test_wte_ini.asc
60  Flux Boundary Conditions ----------------------(59):
61  None
62  Head Boundary Conditions ----------------------(61):
63  test/input/test_CHB1.asc
64  Other------------------------------------------(63):
65  none
66  ============== METEOROLOGICAL DATA =================
67  Precipitation ---------------------------------(66):
68  test/input/Pre_60m_00_05_10_sin.csv
69  Potential Evapotranspiration ------------------(68):
70  test/input/Pre_60m_p00_e00.csv
71  Water abstractions file -----------------------(70):
72  none
73  Other -----------------------------------------(72):
74  none
75  ======== RESULTS AND OUTPUT DIRECTORIES ============
76  Discharge point results -----------------------(75):
77  test/input/test_Flumes_points.csv
78  Soil point results output ---------------------(77):
79  test/input/test_SM_points.csv
80  Groundwater point results ---------------------(79):
81  test/input/test_well_point_m.csv
82  Folder location results -----------------------(81):
83  test/output
84  Other -----------------------------------------(83):
85  none
86  Other -----------------------------------------(85):
87  none
88  MODEL PARAMETER SETTINGS FILE -----------------(87):
89  test/setting_test.dmp
```

If information related anthropogenic interactions such as Water abstractions and irrigation are available, it must be provided in line 72. Information can be provided in netCDF format in order to take into account the spatial variability, if a csv file is provided a uniform rate will be applied over the entire model domain. Additionally, information must be specified with the following codes:

Table 1: Code and Name of variables for input datasets of anthropogenic fluxes

code	variable
ASW	Surface component: River abstractions
AUZ	Unsaturated component: Irrigation
ASZ	Saturated component: Groundwater abstractions

For the groundwater component, boundary conditions have to be specified as head boundary and flux boundary conditions in lines 61 and 63, respectively. A raster file of head/flux must be provided if boundary conditions are considered in the model. The raster file must have as non boundary condition values of -9999, otherwise it will be assumed as head/flux condition. If no file is provided, zero flux

boundary conditions will be assumed.

Additionally, a simulation settings file must also be provided. This file should contain parameters that control the simulations such as simulation period, format of input files as well as the activation of model components such as groundwater flow.

Simulation settings file is a plain text document file, which has to include in the first line the following text 'DWAPM_SET', as it is shown in the example below, omitting the first line will will stop the simulation. Lines with numerical values are allowed to change, but they can not be displaced by adding a new line. The change of position of lines will result in errors or will stop the simulation.

```
                                                        simulation_setting_file
 1   DWAPM_SET
 2   ======== SIMULATION PERIOD AND TIME STEP ==========
 3   Initial date for simulation (YYYY MM DD) ........(2)
 4   2000 1 1
 5   Initial date for simulation (YYYY MM DD) ........(4)
 6   2004 1 3
 7   OF Time step - dt_Pre (min) - (1440 for daily)...(8)
 8   60
 9   UZ Time step - dt_Pre (min) - (1440 for daily)..(10)
10   60
11   SZ Time step - dt_Pre (min) - (1440 for daily)..(12)
12   60
13   ============= MODEL READING OPTIONS ================
14   Read Precipitation from NETCF file..............(13)
15   0 60
16   Read Evapotranspiration from NETCF file.........(15)
17   0 60
18   Read Abstractions from NETCF file ..............(17)
19   0
20   =============== MODEL COMPONENTS ====================
21   Inf.- 0: Scheeke 1: Philips 2: Up_GA 3: Mod_GA..(20)
22   1
23   Run surface routing ----------------------------(22)
24   0
25   Run Groundwater-Enable Type: 0-Unc 1-func 2-Con-(26)
26   1 1
27   Run OF linear reservoir: 1 active 0 disable.....(26)
28   0
29   Run UZ linear reservoir: 1 active 0 disable.....(28)
30   0
31   =============== OUTPUT OPTIONS ===================
32   Show simulation times 1 active 0 disable .......(31)
33   0
34   Save state rasults in netcf files..............(33)
35   1
36   Temporal aggregation results (eg. 3M Y H).......(35)
37   6M
38   Plot maps and the end of the period.............(37)
39   0
40   Save maps as raster at the end of the period....(39)
41   0
42   Print daily maps................................(41)
43   0
44   Print simulation time...........................(43)
45   0
46   ============= MODEL PARAMETERS FACTORS ============
47   Runoff partition parameter (kdt-Sheeke).........(46)
48   1.0
49   Soil Depth factor - kDroot (mm) ................(48)
50   1.0
```

```
51  Available Water Content factor - kAWC ..........(50)
52  1.0
53  Infiltration rate factor - kKsat ...............(52)
54  0.004
55  Heterogeneity factor - k_sigma - (Upscaled GA)..(54)
56  1.0
57  Transmission losses - Kch (m/h) ................(56)
58  10.52967
59  Decay discharge - T - (hours)...................(58)
60  0.1512967
61  Channel width parameter (pe-not activated)......(60)
62  1
63  Aquifer saturated hydraulic conductivity........(62)
64  1.250
65  Aquifer specific yield factor...................(64)
66  1.00
```

Information related to simulation period should be specified as the initial and final date of the simulation and must be specified in lines 4 and 6. Date must be specified as integers separated by spaces (e.g. 2001 1 9), zero on the left side is not allowed and will stop the simulation (e.g 2001 01 19, will raise an error).

Simulation time step of the surface component must be specified in line 10. Time has to be specified in minutes, with a maximum time step of one day. Time step must be an integer, and values must be rational fraction of the hour (e.g 20 min is allowed but 25 will stop the simulation) when sub-hourly time step is set. In case of hourly time steps, it must be a rational fraction of the day (e.g. 180 min (3h) is allowed but 300 min (5h) will result in errors).

For groundwater component, the simulation time step must be specified on line 12. Time step has to be an integer value, and should be specified in hours.

The format of precipitation/evapotranspiration and water abstraction files must be specified in lines 15, 17 and 19, respectively, A value of 1 represent grids in netcdf format, whereas a value of zero represent comma-separated formats. Time frequency of model input files should be specified along with the file format parameter. Time frequency should be specified in minutes (see example below). If frequency is not provided, DRYP will assume a default value of 60 min.

```
13  ============ MODEL READING OPTIONS ================
14  Read Precipitation from NETCF file..............(15)
15  0 60
16  Read Evapotranspiration from NETCF file.........(17)
17  0 720
18  Other...........................................(19)
19  0 60
```

DRYP has four types of infiltration methods implemented which has to be specified in line 22. The following codes can be chosen depending on the infiltration approach adopted:

    0: Schaake model,
    1: Philip's equation,
    2: Upscaled Green and Ampt,
    3: Modified Green and Ampt method.

For groundwater, three different approaches for running the groundwater component have been added to DRYP:

    0: Variable transmissivity, fully unconfined conditions,
    1: Constant transmissivity,
    2: Transmissivity function,

The groundwater components can be activated or disabled in line 26, a value of 1 enable the groundwater component whereas a value of 0 disables it. The groundwater approach is specified along with the activation code of the groundwater component as shown in the example below:

```
25  Run Groundwater-Enable Type: 0-Unc 1-func 2-Con-(26)
26  1 1
```

in case that the approach is not specified, the "variable transmissivity", option 0, is used as default approach.

Line 27 is currently disabled.

To save model results as netCDF files, lines 33 and 35 needs to be modified. A value of 1 in line 33 will activate the option save, whereas line 35 is used to specify the aggregation frequency. Frequency should be specified as integer and an string character. Accepted character are D for days, M for months and Y for years, an example is specified below:

```
32  Save state rasults in netcf files...............(33)
33  1
34  Temporal aggregation results (eg. 3M Y H).......(35)
35  6M
```

A set of parameters that globally modify the model parameters are also specified in the simulation settings file. Values are scale factors of the following parameters:

line 48: kdt, for water partitioning of the Shaake infiltration approach,
line 50: kDroot, for rooting depth,
line 52: kAWC, for available water content,
line 54: kKsat for the saturated hydraulic conductivity of the soil,
line 56: kSigma, for the standard deviation of the saturated hydraulic conductivity of the Modified Green and Ampt approach,
line 58: kKch, for infiltration rates in the channel,
line 60: kT for decay parameter of discharge,
line 62: kKaq for aquifer saturated hydraulic conductivity,
line 64: kSy for aquifer specific yield factor,

3   DRYP RESULTS

Output variables for each model component are summarised below:

Surface component

- Runoff

- Infiltration rate

- Flow accumulation

- Transmission losses

Subsurface component:

- Water content (θ)

- Actual evapotranspiration (AET)

- Percolation

Groundwater component:

- Recharge (percolation + transmission losses)

- Water table elevation

By default, DRYP saves all results in the directory specified in the line 83 of the input parameter file (see section 2). Filename of the result files start with the name of the model (line 2, input files), followed by the following codes:

Table 2: Suffix of model result files stored by DRYP

Code	Variable
avg:	average results over the active model domain
THT:	Soil moisture [-]
PET:	Potential evapotranspiration [L T^{-1}]
AETr:	Actual evapotranspiration for river [L T^{-1}]
AET:	Actual evapotranspiration [L T^{-1}]
INF:	Infiltration rate [L T^{-1}]
EXS:	Infiltration excess [L T^{-1}]
RCH:	Recharge [L T^{-1}]
Dis:	Discharge [L T^{-1}]
BFL:	Baseflow [L T^{-1}]
QFL:	Baseflow [L^3 T^{-1}]
wte:	Water table elevation [L]

DRYP will automatically save the average fluxes and water content of model compartments. Results are saved at time steps specified for the surface component.

Average results are saved in a comma separated file that can be opened in microsoft excel or any text editor. The document contains the following information which is specified by codes for each variable in the first line:

- pre: precipitation,

- rch: recharge,

- dis: discharge,

- aet: actual evapotranspiration,

- usz: soil water content,

- gws: groundwater storage,

Result at specific locations of each model component can be obtained by providing a list of coordinates. Coordinate files should be specified in a comma separated format (e.g. .csv) with column heads specified as `Nort` and `East` for the y and x, respectively. If a coordinate is not inside the model domain, the simulation will stop. Coordinate files must be specified in the following lines of the input file:

line 77: File of coordinates for surface component,
line 79: File of coordinates for unsaturated zone,
line 81: File of coordinates for saturated zone,

Point result files are named with the model name (see 2.2) as prefix followed by the codes specified in table 2. Point result files store a number of variables variables depending on the component. A list of model variables for each component is specified below:

Point result files are time series with the first column specified as time with head 'Date'. The number of columns of result files depend on the number of points specified in the coordinate files defined above. Columns are label depending on the component and variable (see 3) followed by number starting by zero (e.g. for discharge, the file model_name_Dis.txt will contain the following columns, 'Date' for time and 'OF_0', 'OF_1', .. etc. for discharge values)

Table 3: Variables stored in point result files and codes of each variable, for filename see table 2

code	variable
Surface component	
OF	Discharge
TL	Transmission losses
EXS	infiltration excess
Unsaturated zone	
SM	soil moisture
AET	actual evapotranspiration
RCH	recharge, diffuse and foccused recharge
Saturated zone	
WT	water table elevation