CIVE 625 – Quantitative Ecohydrology

Lab 3 – (Due Date: April 8th)

In this lab, our objective is to conduct hydrologic simulations that explore the impact of various types of land cover, focusing on forestation/deforestation/afforestation examples by manipulating land cover within our model, we aim to understand how different vegetation covers affect hydrologic patterns of interception, soil moisture, evapotranspiration, and runoff.

Lab 3 represents a significant upgrade from Lab 2, particularly in how we compute evapotranspiration (ET). Unlike before, we no longer rely on Potential Evapotranspiration (PET) as an input. Instead, we've shifted to a more advanced method using the Penman-Monteith Equation with a Jarvis scheme for surface resistance (Lab 1).

This change allows for a more detailed and accurate estimation of actual ET, moving away from more simplistic assumptions to capture the complexities of watershed behavior more effectively. By implementing this updated approach, we aim to better understand how changes in land cover affect ET dynamics and overall hydrological processes.

Lab instructions:

1 – Get familiarized with the hydrologic model (**Appendix 1 and 2**). Note that this is a different version than the one used in Lab 2. In this version we don't use the concept of potential evaporation. In fact, we use pretty much what we learned in Lab 1, i.e., a Penman-Monteith equation used for actual evapotranspiration, using several conductance types following a Jarvis type formulation while interception is also computed. Note that code Sections 1, 2.1 and 2.2 are the same as Lab 2.

2– Once a catchment is selected (2.3), get familiarized with its hydroclimatology. This section produces a few exploratory plots. **These figures should be included in your report**. Feel free to produce additional figures.

3- Simulation 1: After you selected a catchment (Section 2.3) and created an input matrix (Section 3.2), you will be able to manually adjust the parameters to obtain an adequate fit. This is not a consulting job! So, you don't have to calibrate your model to perfection. Visual assessment is fine. Note that several variables used in Lab1 are within the structure "vars", which is now an input to the model. You should adjust them accordingly to the vegetation type you are assuming in Simulation 1.

4- Simulation 2: In simulation 2, you will create an alternative scenario where the land use change in Simulation 1 is modified. Simulation 2 is divided into two simulations (2A

and 2B) representing 2 land cover types instead of only one. The weights A and B represent the percentage of the area taken by the land cover types used in simulation 1.

What you should do:

- Feel free to create any scenario you might want to explore! The code is originally written such that Simulation 1 (I used catchment #10) explores a catchment with 100% forest cover towards a split of 20% forest and 80% shrubs. This is just an example!
- Appendix 3 contains the actual land cover types in the 15 selected catchments. Use those values as broad guidelines, and feel free to assume different things when calibrating simulation 1 (E.g. if you picked a catchment that has 80% forest cover, feel free to simulate it first assuming only forest cover). Appendix 4 contains some parameters for different land cover types to be used based on your idealized experiment. Note that I assumed a different maximum infiltration rate PAR(1) in my shrub example.
- Once you decide on scenario 1 and scenario 2. Explore the results in the following manner.
    - Compare mean annual water balance results (E/P)
    - Compare the seasonal variations of Soil Water Storage (Su), Streamflow (QT), Recharge (R), Quickflow (QF) and Baseflow (QS), Total Evapotranspiration (Eta).
    - Compare the flow duration curve (FDC) and flood frequency curves (FFC) for each scenario. (code snippets for FDC and FFC are shown in appendix 5 and 6 respecively)
    - The code outputs all these variables in different ways, daily, monthly, annual, mean monthly, mean annual, etc. This is what the function **aggregate.m** is doing.
- Your report should include a clear description of the scenario you want to explore, as well as figures you used.
- As in any scientific report, your report should be brief but tackle the following points:
    - Introduction
    - Description of the scenarios and how you managed to impose those changes in the hydrologic model. What your choices were.
    - Results
        - Show your figures and describe them.
    - Discussion
        - Interpret the changes you see between scenarios one and two, providing your thoughts on each of the results shown

APPENDIX 1: Lab_3.mat file description

Section 1: Load Data (Same as Lab 2)

In this section, data required for the hydrological analysis is loaded from CSV files. The data includes:

- **Q**: Streamflow data in millimeters (mm).
- **Dates**: Date information corresponding to the streamflow data.
- **Precip**: Precipitation data in mm.
- **e**: Vapor pressure data in kilopascals (kPa).
- **u2**: Wind speed data at 2 meters above the ground level in meters per second (m/s).
- **S_in**: Solar radiation data in Watts per square meter (W/m^2).
- **Temp**: Temperature data in Celsius.
- **Lat_Lon_A_Z**: Latitude, longitude, area, and elevation data.

Section 2.1: Generate Daily PET - Calculate Net Longwave (Same as Lab 2)

This section calculates the net longwave radiation using the provided solar radiation and temperature data. It also plots extraterrestrial solar radiation, clear sky solar radiation, and observed solar radiation over a specified period.

Section 2.2: Generate Daily PET (Same as Lab 2)

Here, the daily potential evapotranspiration (PET) is computed using the Penman-Monteith equation, which considers various meteorological factors such as net radiation, air temperature, vapor pressure deficit, and wind speed. The equation is solved to estimate PET in mm/day.

Section 2.3: Pick a Catchment

This section allows the user to select a specific catchment for further analysis by setting the variable *pick_catchment* to the desired catchment number.

Section 3.1: Mean Annual Analysis

This part of the code computes the mean monthly and mean annual values for precipitation, potential evapotranspiration, streamflow, and temperature. It also calculates two important ratios: Aridity Index (PHI) and actual evapotranspiration to precipitation ratio (E_P, or evaporative fraction). These ratios are used for further analysis and plotting.

Section 3.2: Run Hydrologic Model

This section initializes and prepares input data for running the hydrological model simulation. It sets up the required variables and parameters and defines the function to run the hydrological model.

Section 3.3: Simulation 1

In Simulation 1, the hydrological model is executed using parameters tailored for a forested land cover type. This section initiates the hydrological model by setting up the necessary input data, such as precipitation, potential evapotranspiration, vapor pressure, wind speed, solar radiation, temperature, and net longwave radiation. This data are obtained from the previously loaded datasets.

Additionally, specific variables related to the land cover type (in this case, forest) are defined. These variables include parameters such as the atmospheric pressure, the zero-plane displacement, the roughness length, and maximum stomatal conductance.

Once the parameters and variables are set up, the hydrological model (referred to as **toymodel_update**) is executed using the provided input data and parameters. After the model simulation is completed, the results are aggregated over time (e.g., monthly or annually), to provide summary statistics and metrics. These may include mean annual streamflow, mean monthly streamflow, water balance components, and other relevant hydrological variables. These simulated outputs are then compared with observed streamflow measurements, to assess the model's performance.

Section 3.4: Simulation 2

Simulation 2 is similar to Simulation 1 but involves running the model with parameters specific to both forest and your choice of land cover type land cover types. The outputs from these two simulations are combined using weighted averaging to generate a composite output representing both land cover types.

Section 3.5: Produce Final Figures

In this final section, various plots are generated to visualize the results of the hydrological model simulations. These plots include comparisons between simulated and observed streamflow, as well as other relevant hydrological variables. Additionally, summary statistics and Budyko plots may be generated for further analysis.

APPENDIX 2: SU_eq_mod

This function, **SU_eq_mod**, models soil and canopy water balance, evapotranspiration (ET), and energy balance within a vegetated area. It takes various inputs such as initial soil moisture (**Su_0**), precipitation (**Precip**), soil and vegetation parameters (**Sumax**, **alpha**, **beta**, **vars**), incoming shortwave radiation (**Sin**), net longwave radiation (**Lnet**), temperature (**Temp**), wind speed at 2 meters (**u2**), and actual vapor pressure (**e_actual**). The function calculates several key outputs including soil moisture (**S_dt**), canopy storage (**S_canopy**), interception loss (**E_int_mm**), transpiration (**E_tran_mm**), total evaporation (**E_total_mm**), rain not intercepted by the canopy (**rain_pass**), and aerodynamic (**r_a**) and surface (**r_s**) resistances. It employs several sub-functions for calculating saturated vapor pressure, aerodynamic resistance, and vegetation conductance, and uses the Penman-Monteith equation for ET calculations.

APPENDIX 3: Land Use types

MODIS Land-use types for the selected catchments

#	ENF	EBF	DBF	DBF	MF	CS	OS	WS	S	G	PW	C	UBL	C-NVM	PSI	B	WB
1	0%	0%	0%	0%	0%	0%	0%	0%	0%	44%	0%	56%	0%	0%	0%	0%	0%
2	99%	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
3	0%	0%	0%	21%	0%	0%	0%	6%	23%	0%	0%	11%	0%	39%	0%	0%	0%
4	0%	0%	0%	60%	0%	0%	0%	5%	11%	2%	0%	11%	0%	11%	0%	0%	0%
5	0%	5%	0%	54%	8%	0%	0%	31%	0%	1%	0%	0%	0%	0%	0%	0%	0%
6	0%	0%	0%	0%	0%	0%	0%	1%	45%	52%	0%	0%	1%	0%	0%	0%	0%
7	0%	0%	0%	0%	0%	0%	0%	0%	0%	50%	0%	50%	0%	0%	0%	0%	0%
8	0%	0%	0%	94%	5%	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%
9	88%	0%	0%	0%	1%	0%	0%	5%	2%	3%	2%	0%	0%	0%	0%	0%	0%
10	62%	3%	0%	0%	2%	0%	1%	21%	3%	8%	0%	0%	0%	0%	0%	0%	0%
11	0%	0%	0%	0%	0%	0%	0%	0%	72%	28%	0%	0%	0%	0%	0%	0%	0%
12	5%	0%	0%	0%	0%	0%	0%	14%	55%	24%	0%	0%	0%	0%	0%	2%	0%
13	0%	0%	0%	0%	0%	0%	44%	0%	8%	48%	0%	0%	0%	0%	0%	0%	0%
14	0%	0%	0%	0%	0%	7%	0%	21%	69%	3%	0%	0%	0%	0%	0%	0%	0%
15	29%	0%	0%	0%	0%	0%	0%	63%	5%	2%	0%	0%	0%	0%	0%	0%	0%

Description:

- **ENF**: Evergreen Needleleaf Forest
- **EBF**: Evergreen Broadleaf Forest
- **DBF**: Deciduous Broadleaf Forest
- **MF**: Mixed Forest
- **CS**: Closed Shrubland
- **OS**: Open Shrubland
- **WS**: Woody Savannas
- **S**: Savannas
- **G**: Grasslands
- **PW**: Permanent Wetlands
- **C**: Croplands
- **UBL**: Urban and Built-up Lands
- **C-NVM**: Cropland/Natural Vegetation Mosaic
- **PSI**: Permanent Snow and Ice
- **B**: Barren
- **WB**: Water Bodies
- **Unclassified**: Uncategorized land types

APPENDIX 4: Vegetation Parameterization

Vegetation Type	Albedo	Z0 (m)	g0_max (mm/s)
Broadleaf-evergreen trees	0.11	2.653	6.67
Broadleaf-deciduous trees	0.12	0.826	10.0
Broadleaf and needleleaf trees	0.12	0.8	8.0
Needleleaf-evergreen trees	0.1	1.089	6.67
Needleleaf-deciduous trees (larch)	0.11	0.854	10.0
Broadleaf trees with groundcover	0.19	0.856	14.29
Groundcover only	0.19	0.075	25.0
Broadleaf shrubs with groundcover	0.25	0.238	3.33
Broadleaf shrubs with bare soil	0.25	0.065	2.5
Dwarf trees/shrubs with groundcover (tundra)	0.16	0.05	6.67
Bare soil	0.12	0.011	1.0
Cultivations	0.19	0.075	25.0
Wetland	0.12	0.04	6.67
Dry coastal complex	0.19	0.075	2.5
Water	0.19	0.01	1.0
Glacial	0.8	0.011	1.0

Note:

- Albedo represents the reflectivity of the surface.
- Z0 is the roughness length.
- g0_max is Maximum stomatal conductance

Adapted from:

Chen, F., & Dudhia, J. (2001). Coupling an Advanced Land Surface–Hydrology Model with the Penn State–NCAR MM5 Modeling System. Part I: Model Implementation and Sensitivity. *Monthly Weather Review*, *129*(4), 569-585.

APPENDIX 5: Flow Duration Curve (FDC)

```
% Assuming OUT_1 and OUT_2 are structures containing flow data QT for simulations 1
and 2

% Extracting flow data for simulation 1
QT_1 = OUT_1.QT;

% Extracting flow data for simulation 2
QT_2 = OUT_2.QT;

% Sorting flow data in ascending order
QT_1_sorted = sort(QT_1, 'ascend');
QT_2_sorted = sort(QT_2, 'ascend');

% Calculating permanence
permanence = (length(QT_1):-1:1) / length(QT_1);

% Plotting the flow duration curves
figure(4)
clf(4)
set(gcf, 'Position', [488.0000 577.8000 827.4000 184.2000])

semilogy(permanence, QT_1_sorted, '-k', 'LineWidth', 1, 'Color', color1); hold on
semilogy(permanence, QT_2_sorted, '-r', 'LineWidth', 1, 'Color', color2); hold on
legend(legend1, legend2); legend boxoff; ylabel('Q (mm/d)'); xlabel('% of Time
Exceeded'); axis([0 1 10^-4 20])
```

APPENDIX 6: Flood Frequency Curve (FFC)

```
% Find unique years in the data
unique_years = unique(year(Dates));

% Initialize matrices to store annual maximum flows for both simulations
annual_max_flows_1 = zeros(length(unique_years), 1);
annual_max_flows_2 = zeros(length(unique_years), 1);

% Iterate over each unique year
for i = 1:length(unique_years)
    % Find indices corresponding to the current year in the Dates array
    indices_year_1 = find(year(Dates) == unique_years(i) & QT_1 >= 0);
    indices_year_2 = find(year(Dates) == unique_years(i) & QT_2 >= 0);

    % Extract streamflow data for the current year
    streamflow_year_1 = QT_1(indices_year_1);
    streamflow_year_2 = QT_2(indices_year_2);

    % Calculate the annual maximum flow for the current year
    annual_max_flows_1(i) = max(streamflow_year_1);
    annual_max_flows_2(i) = max(streamflow_year_2);
end

% Sort the annual maximum flows in descending order for both simulations
sorted_max_flows_1 = sort(annual_max_flows_1, 'descend');
sorted_max_flows_2 = sort(annual_max_flows_2, 'descend');

% Calculate exceedance probability and return periods
n_years = length(unique_years);
exceedance_prob = (1:n_years) / n_years;
return_periods = 1 ./ exceedance_prob;

% Plotting the flood frequency curve
figure(6)
clf(6)
set(gcf, 'Position', [488.0000 473.0000 583.4000 289.0000])

plot(return_periods, sorted_max_flows_1, 'o-k', 'Color', color1); hold on % Log-log
scale for better visualization
plot(return_periods, sorted_max_flows_2, 'o-r', 'Color', color2); % Log-log scale for
better visualization
legend(legend1, legend2);
xlabel('Return Period (years)');
ylabel('Annual Maximum Streamflow (mm/d)');
grid on;
```