**Lab 3**

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The codes are available in this GitHub Repo: <https://github.com/mdfahimhasan/QEcoHydro/tree/master/Hyrdo_LU>

# Introduction

In this Lab, we develop a hydrologic model based on our works in the previous labs on the SVAT (Soil Vegetation Atmosphere Transfer Models) and simple conceptual hydrologic models. The previous SVAT model was focused on simulating evapotranspiration (ET) based on Penman\_Monteith (P-M) approach while incorporating a simple soil water balance module. In the next step, in our simple conceptual bucket hydrologic model, we upgraded the simple soil water balance module to a more conceptual bucket type system that was capable of simulating baseflow, quickflow, recharge, etc. However, in this model, the ET was estimated based on potential evapotranspiration (PET) and soil moisture ratio, which is not robust as P-M approach. In this new lab/model, we combine the strength of the previous models and develop a more all-around hydrologic model that incorporates P-M based ET simulation, conceptual three-layered soil storage simulation, and streamflow simulation (baseflow + quickflow). This model can simulate different canopy/land cover types, such as forest and grass. In addition, it can be used to simulate mixed land use scenarios.

The objective of this lab are –

1. Develop the hydrologic model.
2. Calibrate the model and understand which parameters are the most sensitive.
3. Simulate different land use scenarios with the calibrated models to understand how land use impacts different hydrologic fluxes.

# Study Area and Scenarios

We selected catchment 10 as a case study for this lab. Originally, this catchment has ~67% forest cover, ~24% savannas, and ~9% grasslands. However, we simplified/modified the land cover scenarios for calibration of the hydrologic model, its performance evaluation, parameters sensitivity analysis, and understanding impacts of land use change. In this lab we use the following two land use scenarios –

Scenario 1: 100% Forest. Used for calibrating the model.

Scenario 2: 70% Forest and 30% grasslands/shrubland.

Note that this hydrologic model has the capacity to incorporate more land cover types with some simple upgrades. Despite that, we limited our analysis to forest and grassland canopy types to keep things simple.

# Results

## Model Calibration and parameters decision

The model was calibrated qualitatively (based on plotting and visual judgement) using Budyko curve and total streamflow (Fig 1).

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| --- | --- |
|  |  |
| (a) | (b) |
| Fig 1: Model calibration using Budyko curve and daily streamflow. | |

We tested several parameters, such as maximum infiltration rate, maximum storage capacity of the unsaturated zone, time parameter for quick flow, and time parameter for base flow, to calibrate the model. We found that streamflow is the most sensitive maximum infiltration rate and Budyko plot is the most sensitive to maximum storage capacity of the unsaturated zone. Our final calibrated parameters are –

* maximum infiltration rate – 300
* maximum storage capacity of the unsaturated zone – 200
* time parameter for quick flow – 30
* time parameter for base flow – 1

We also checked some canopy specific parameters such as roughness height (z0), canopy specific constant (g0), and Canopy cover factor (gC) to see if they can affect streamflow simulation and Budyko curve, while keeping the other parameters constant. We found that ET is very sensitive to z0 and g0 (Fig 2); however, they didn’t affect streamflow or Budyko plot much. Therefore, we set the values z0 =1 and g0=1 based on Chen and Dudhia (2001).

These set of parameters were used to simulate Scenario 1 (100% Forest). To simulate Scenario 2, we introduced a set of canopy factors representing grasslands.

## Variation of fluxes depending on scenarios

We simulated two land use scenarios (detail in section 2) to understand how land use changes impact simulation of hydrologic fluxes. Fig 2 illustrates these differences.

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| --- | --- |
|  |  |
| (a) | (b) |
|  |  |
| (c) | (d) |
|  |  |
| (e) | (f) |
|  |  |
| (g) |  |

Fig 2: Changes in different hydrologic fluxes in two land use scenarios.

Fig 2(a) show changes in monthly streamflow due to land use changes. In both scenarios, there is high flow during the early and later months which can be explained by high precipitation in those months (Fig 2(g)). Streamflow in scenario 1 is of slightly higher magnitude than scenario 2. Scenario 1 has higher baseflow than scenario 2 (due to higher recharge). This is due to the spread of roots in the subsurface in forested land use which developed preferential flow paths for infiltration. Scenario 1 has more forest cover than scenario 2 which leads to more recharge and baseflow in scenario 1. In contrast, scenario 2 has more quickflow as less water can infiltrate the subsurface.

An interesting thing to notice is – scenario 1 has lower soil moisture storage than scenario 2 (Fig 2(f)) though scenario 1 has higher recharge. One way to explain that can be – higher contribution of baseflow to streamflow in scenario 1 is responsible for depletion of more soil moisture storage.

In both scenarios, ET is higher during the mid-year (Fig 2(e)) which is due to higher temperature and higher PET during these months. Despite low precipitation, higher ET leads to depletion of streamflow, recharge, and soil moisture storage in these months. Scenario 1 (with 100% forest) has more ET than scenario 2 (70% forest) which might be due to more canopy interception by more forests in scenario 1.

## Streamflow analysis

We plotted flow duration curve (Fig 3(a)) and flood frequency curve (Fig 3(b)) to further investigate the impacts of land use on streamflow.

The flow duration curve shows that the fully forested watershed (scenario 1) has a higher infiltration rate and lower surface runoff (Fig 2(b & d)), leading to a more moderated streamflow. Scenario 2 (with 30% grassland) has more surface runoff and lower infiltration, leading to less streamflow most of the time. However, at the far left of the graph, the lines converge or even cross, indicating that for the highest flows (likely during heavy rainfall), the difference between forest and grassland becomes less pronounced.

|  |  |
| --- | --- |
|  |  |
| (a) | (b) |

Fig 3: (a) Flow duration curve and (b) Flood frequency curve.

The flood frequency curve shows how likely it is to observe different magnitudes of annual maximum streamflow based on different land cover scenarios. In scenario 2 (70% forest, 30% grass), the annual maximum flow can exceed the fully forest scenario (scenario) at certain return periods, implying that land cover change could potentially lead to more extreme flood events.

# Discussion

In this lab, we developed a hydrologic model, calibrated it, and simulated different land cover scenarios. Simulation of different land cover scenarios revealed how land use changes can impact streamflow, recharge, ET, etc.

Model calibration using Budyko curve and daily streamflow highlighted the maximum infiltration rate and storage capacity of the unsaturated zone as the most sensitive parameters.

Our results showed that land cover significantly influences hydrologic processes. We found that 100% forested watershed has more streamflow, mostly contributed by baseflow, than mixed land cover (70% forest and 30% grass). In contrast, the mixed land cover scenario (Scenario 2) revealed a greater proportion of quickflow, suggesting that grassland reduces the catchment's capacity to infiltrate and promote baseflow, resulting in more immediate runoff. The flow duration curve and the flood frequency curves illustrate how the catchment will perform under different land use scenarios. The fully forested scenario will have more pronounced streamflow in general than scenario 2. However, during intense storms, both scenarios might behave similarly due to exceedance of infiltration capacity. The flood frequency curve shows that the mixed land cover (scenario 2) will have more extreme flow events than the fully forested scenario. This is contributed by a higher proportion of quickflow than baseflow in scenario 2. Overall, these analyses underscores how land cover changes can impact hydrologic responses of a watershed.