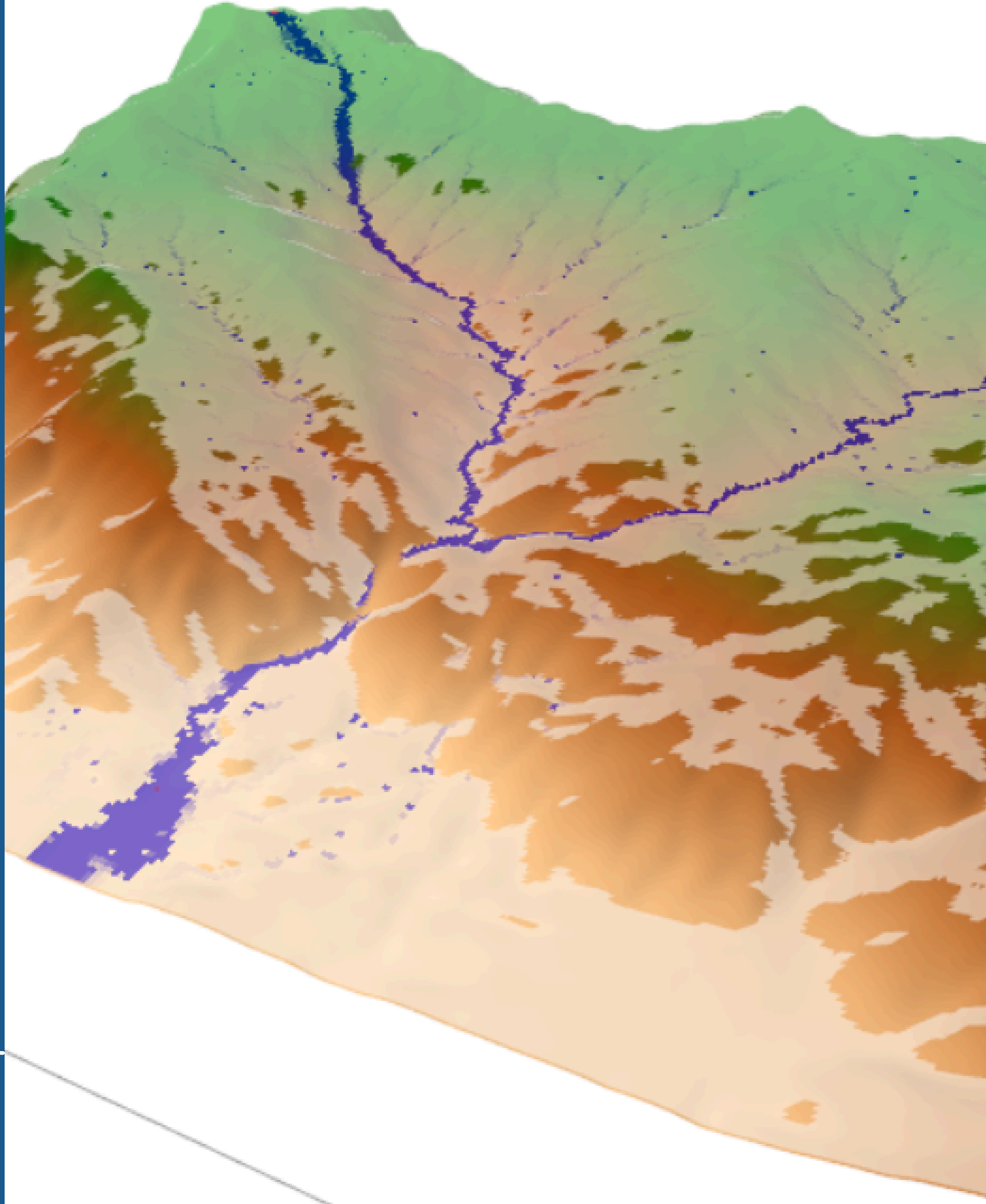
Geographical Agent-Based Modeling for Rainfall-Runoff Simulation

A Case Study of the Small Catchment Area of Bagmati River, Nepal

Presented By :
Upendra Oli
Rabina Twayana



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INTRODUCTION

- In recent years, Nepal has experienced increasing rainfall in many regions, leading to flooding even in areas with traditionally low precipitation.
- Understanding streamflow and runoff patterns is crucial to anticipate the peak river overflows that cause such flooding.
- The Bagmati River, a key contributor to urban flooding in Kathmandu during the monsoon, highlights the need to study the relationship between rainfall and water levels.

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Recent monsoon rainfall in Nepal heaviest in over 50 years

5 Oct 2024 by The Water Diplomat

Link: https://www.waterdiplomat.org/story/2024/10/recent-monsoon-rainfall-nepal-heaviest-over-50-years

Climate Change Amplified the Effects of Extreme Rainfall in Nepal

A new study indicates that rapid urbanization and deforestation also contributed to devastation caused by floods and landslides in 2024.

By Leslie Liang 18 December 2024

The city of Lalitpur, Nepal, was one of many affected by flooding associated with extreme monsoon rainfall in September 2024. Credit:

Link: https://eos.org/articles/climate-change-amplified-the-effects-of-extreme-rainfall-in-nepal

Research Question

How accurately can a rainfall runoff model simulate real-world hydrological dynamics through an agent-based modelling approach?

Objectives

Primary:

- To create an agent-based model capable of simulating rainfall runoff dynamics in the Bagmati river and validate its accuracy by comparing simulated outcomes with observed data.

Secondary:

- To advance our understanding of water flow dynamics and improve predictive capabilities in similar contexts.

Scenarios

Following three scenarios were simulated after model calibration

Scenario 1

High Intensity Rainfall Event

Scenario 2

Medium Intensity Rainfall Event

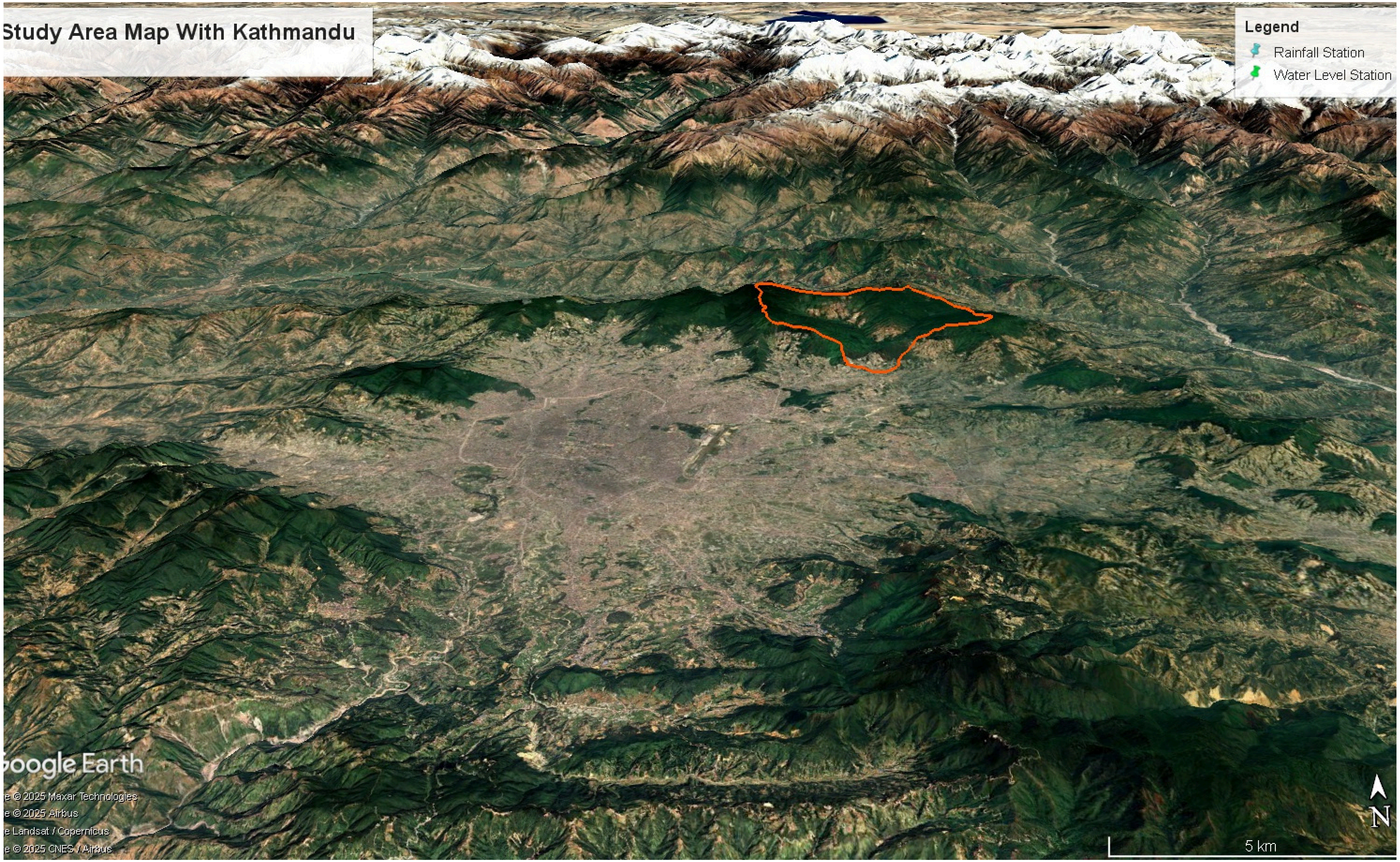
Scenario 3

Low Intensity Rainfall Event

Study Area

- Northern part of Kathmandu
- Covers the starting point of Bagmati River

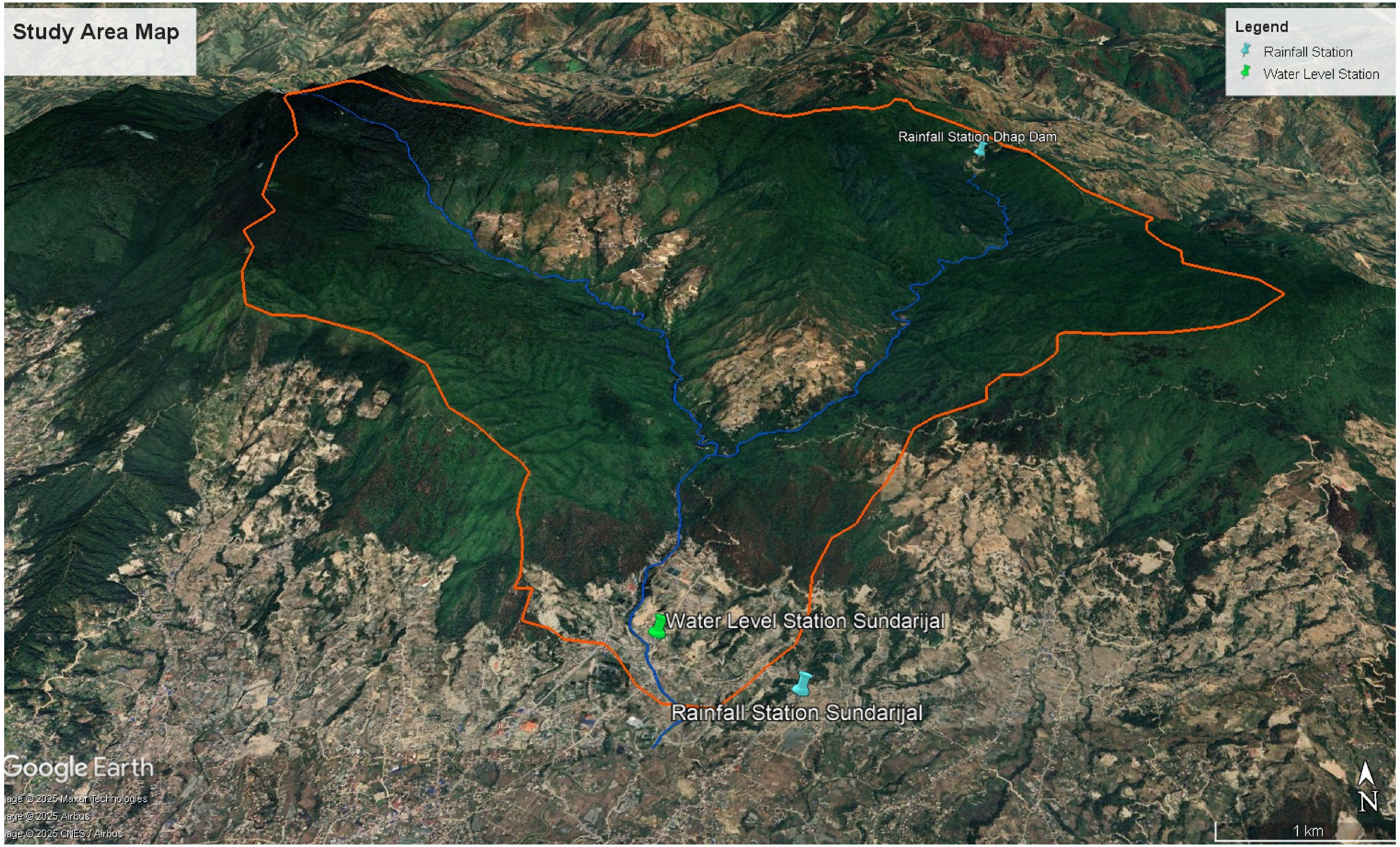
Study Area


Study Area Map With Kathmandu
Legend
Rainfall Station
Water Level Station
Google Earth
e © 2025 Maxar Technologies
e © 2025 Airbus
e Landsat / Copernicus
e © 2025 CNES / Airbus
5 km
N

Study Area

- Includes Rainfall Station and Water Level Station within catchment area
  - Rainfall Station Dhap Dam
  - Rainfall Station Sundarijal
  - Water Level Station Sundarijal

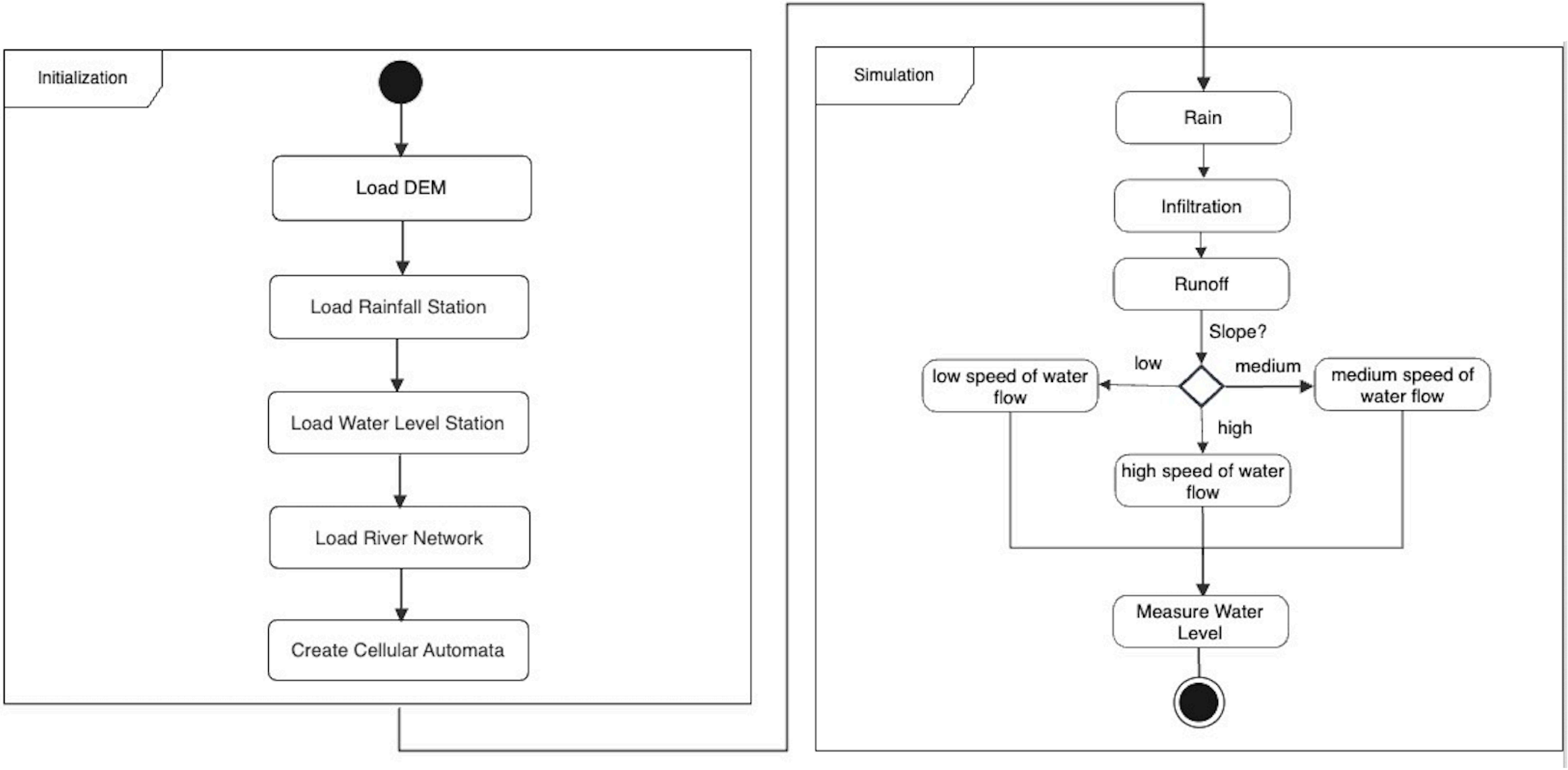
- Area: 38 km. sqare
- Area is small enough to run the simulation on laptop.



Data Preparation

- Digital Elevation Model:
  - 30m SRTM DEM downloaded from USGS website
- Precipitation and WaterLevel Data:
  - station and data were acquired from DHM (Department of hydrology and Meterology) web portal
- River Network:
  - HDX (Humanterian Data Exchange) portal
- Watershed Boundary:
  - Digitization on google earth

Methodology:



Development

Toy Model in GAMA Platform: Hydrological Model (Flood Simulation)

Stations

- Initialize Stations and load station data from files.
- Agent rainfall_station loads the data from file each hour and provides as input.
- Agent water_level_station measures the pixel value ie. water level.

Stabalization

Consider runoff situation where all water flows into the river. Keep raining until water level on the river is at a steady state. Then add real rainfall data to validate the model.

Water Flow

- Flow the water from higher value pixel to lower value pixel.
- Detailed description on next slide.

Experiments

Run the experiment with 3 displays

- Map
- Water Level Chart
- Rainfall Chart

Water Flow

One Flow Cycle Overview:

- Add rainfall data in all pixels equally
- List all neighbors
- Calculate Height of cell and neighboring cells
  - Height = Altitude + water_height
- Find Flow Cells
  - All neighboring cells with height less than current cell.
- Sort Flow Cells from lowest to highest height.
- Loop over Flow Cells
  - Finalize diffusion rate (amount of water that is hold in a cell while flowing) based on the slope
    - Diffusion rate on high slope: 0.3, medium: 0.6, high: 0.9
  - Find amount of water that will flow from one cell to a neighbor.
    - float water_flowing <- max([0.0, min([(height - flow_cell.height), water_height * diffusion_rate])]);
    - Used max between 0 or obtained value to ensure only positive values or zero values
    - Used minimum between height difference and amount of possible diffusible water for the controlled flow.
  - Reset height of the current cell and water flowing cell
    - water_height <- water_height - water_flowing;
    - flow_cell.water_height <- flow_cell.water_height + water_flowing;

Model Calibration

- A model was tested and validated with multiple iterations by testing rainfall and water level data measured on ground with the water level data measured on model with same amount of rainfall.

- After finding the steady state of water level and running multiple iterations, finally found best fit for real data and modal data.

- Rainfall and water level data of Sept 28, 2024 from DHM was used where there was rainfall in overall area of the model. (shown on the right) ie. both rainfall stations at Dhap and Sundarijal witnessed the rainfall.

Date	Hour	Rainfall Dhapdam (mm)	Rainfall Sundarijal (mm)
27/9/2024	0	6	2.2
27/9/2024	1	6	2.2
27/9/2024	2	6	2.2
27/9/2024	3	6	2.2
27/9/2024	4	6	2.2
27/9/2024	5	6	2.2
27/9/2024	6	6	2.2
28/9/2024	0	1.6	2.2
28/9/2024	1	5.4	3
28/9/2024	2	13.8	8.2
28/9/2024	3	10	7
28/9/2024	4	7.2	4.6
28/9/2024	5	4.8	6
28/9/2024	6	5.2	6.2
28/9/2024	7	6.6	6
28/9/2024	8	8.4	7.6
28/9/2024	9	12	9.6
28/9/2024	10	10.4	8.6
28/9/2024	11	9.6	9.4
28/9/2024	12	6.6	5.4
28/9/2024	13	4	2.6
28/9/2024	14	1	0.8
28/9/2024	15	1	1.4
28/9/2024	16	3.8	3
28/9/2024	17	4.4	2.4
28/9/2024	18	1.2	1
28/9/2024	19	0.6	0
28/9/2024	20	0	0.2
28/9/2024	21	0	0
28/9/2024	22	0	0
28/9/2024	23	0	0

Date	Hour	Water Level (m)
27/9/2024	0	1.046
27/9/2024	1	1.046
27/9/2024	2	1.046
27/9/2024	3	1.046
27/9/2024	4	1.046
27/9/2024	5	1.046
27/9/2024	6	1.046
28/9/2024	0	1.046
28/9/2024	1	1.101
28/9/2024	2	1.18
28/9/2024	3	1.295
28/9/2024	4	1.366
28/9/2024	5	1.416
28/9/2024	6	1.378
28/9/2024	7	1.275
28/9/2024	8	1.184
28/9/2024	9	1.138
28/9/2024	10	1.134
28/9/2024	11	1.149
28/9/2024	12	1.106
28/9/2024	13	1.044
28/9/2024	14	1.02
28/9/2024	15	1.006
28/9/2024	16	0.977
28/9/2024	17	0.965
28/9/2024	18	0.948
28/9/2024	19	0.937
28/9/2024	20	0.927
28/9/2024	21	0.918
28/9/2024	22	0.908
28/9/2024	23	0.9

Model Stabilization | Calibration

Calibration Tests

Case 1: Existing Toy model

- float diffusion_rate <- 0.3;
- diffusion rate updated later based on slope. ie. 0.3, 0.6, 0.9

Case 2: Add existing water in the river to maintain water level.

- float constant_river_water_input <- 2.25;
- Two rivers combining to form another river. Calculated the contribution of each river to form combined river based on literature review.

Case 5: Reduce Low Resolution DEM Effect in Model

- float water_scale_factor <- 2.0;
- To reduce the effect of undulations due to low resolution DEM. eg. DEM included areas where we can see pond effects and until that pond is filled with water, water wont flow as it should. Hence, scaled the rainfall by 2 to reduce the effect.

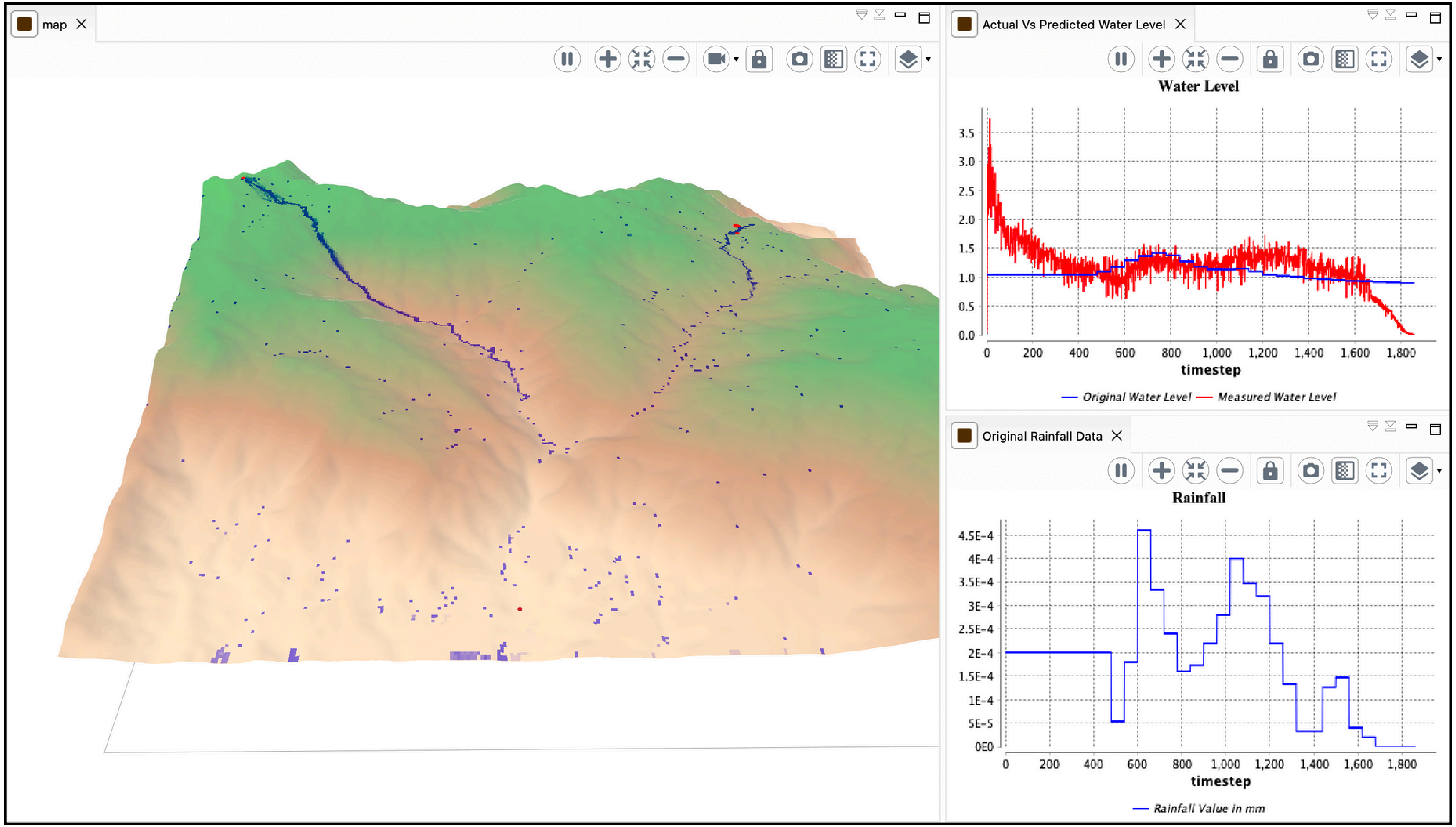
Case 3: Number of steps per hour

- int hour_steps <- 60;
- The steps were updated with hit and trial to adjust and match the measured water level on ground and model.

Case 4: Add Infiltration Coefficient

- float infiltration_coeff <- 0.005;
- considering 5% of infiltration as water level kept rising. The value was obtained by adjusting it to match the water level measured on ground and in the model. Since, the water level kept rising until very long time than expected and was not reducing even the rainfall stopped, this coefficient was introduced. It is assumed that even in case of runoff, there is a loss of water and certain amount of water is infiltrated or evaporated.

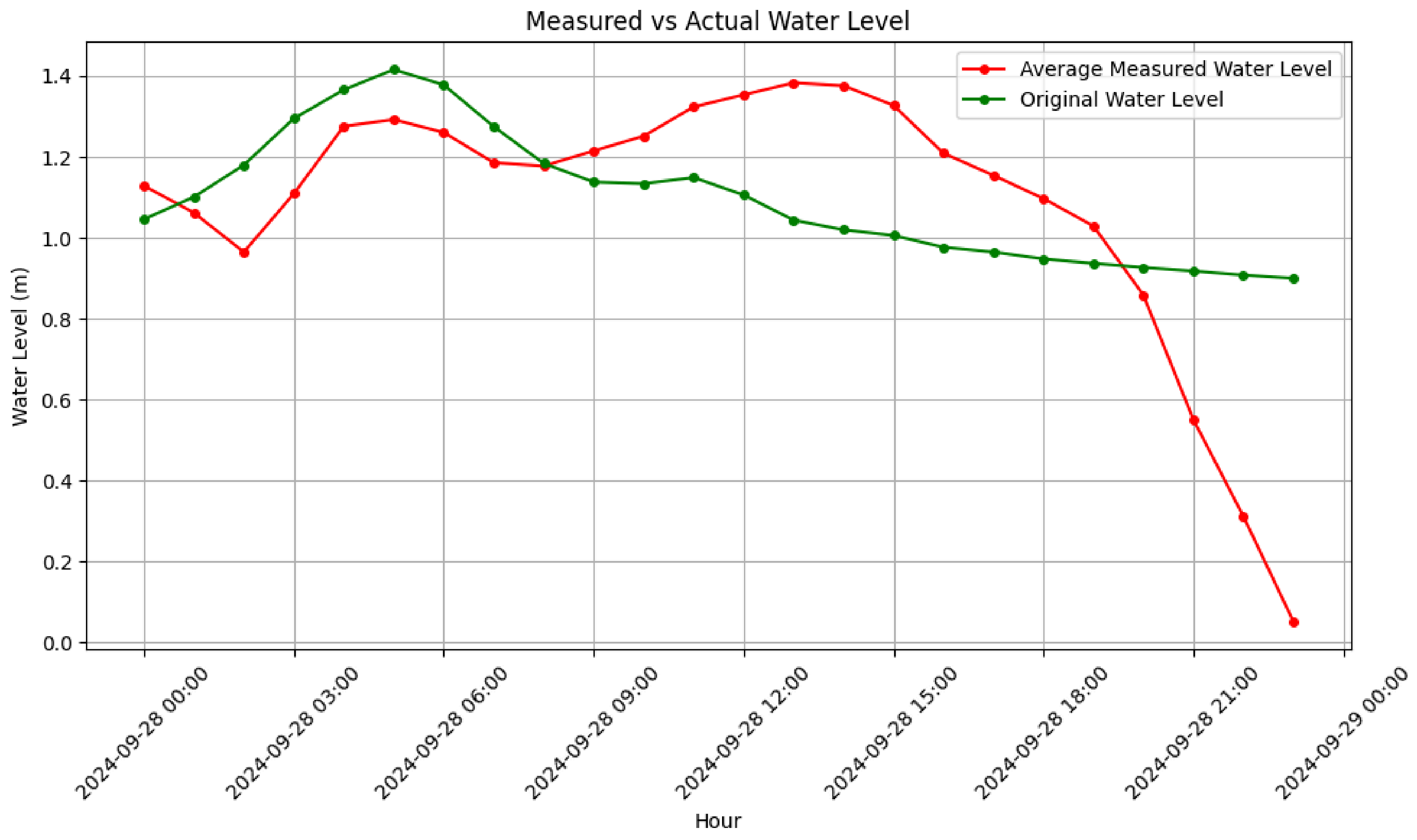
Calibration Results

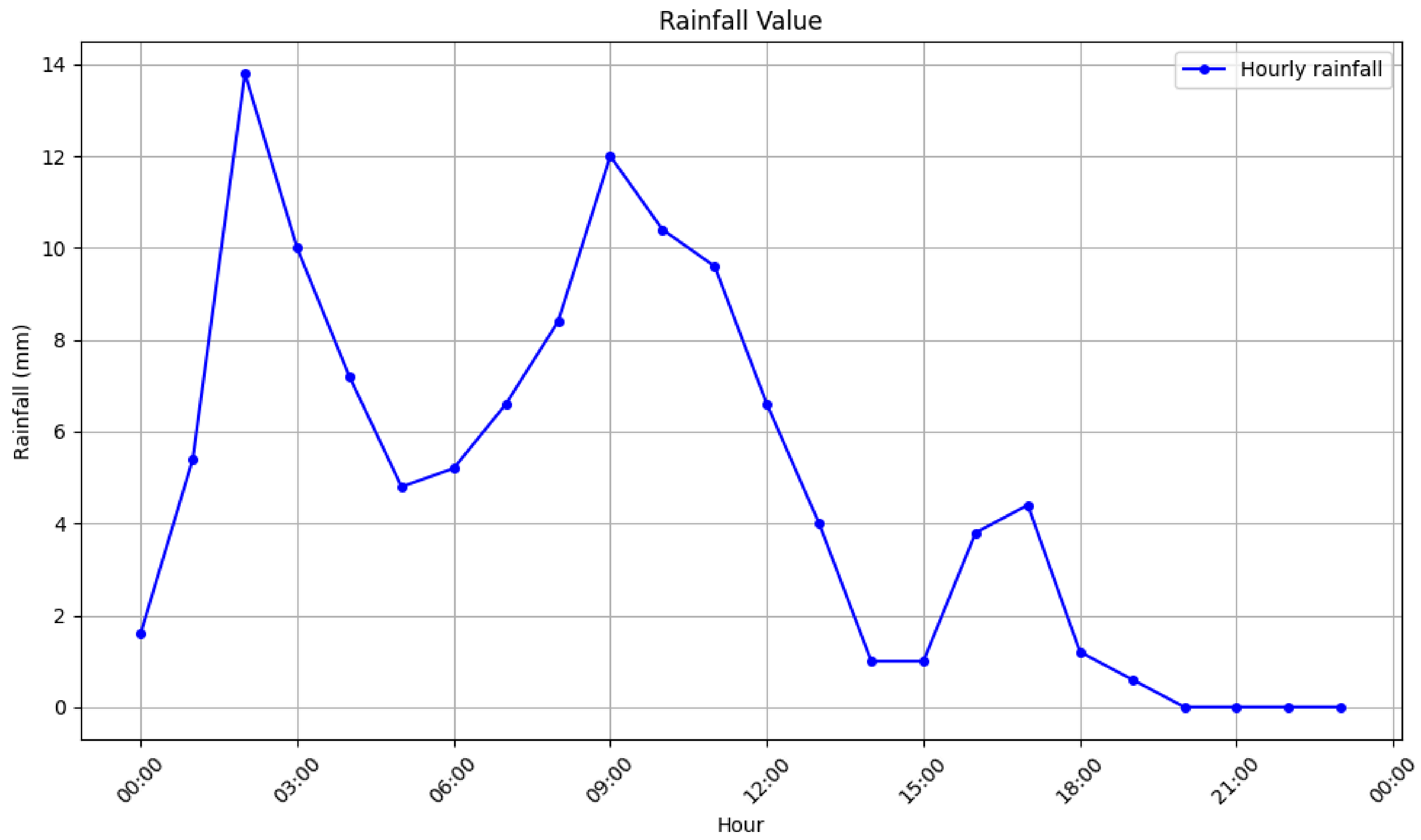


Model Validation (Quantitative Approach)

The following RMSE was observed after the validation of model with real observed water level data.

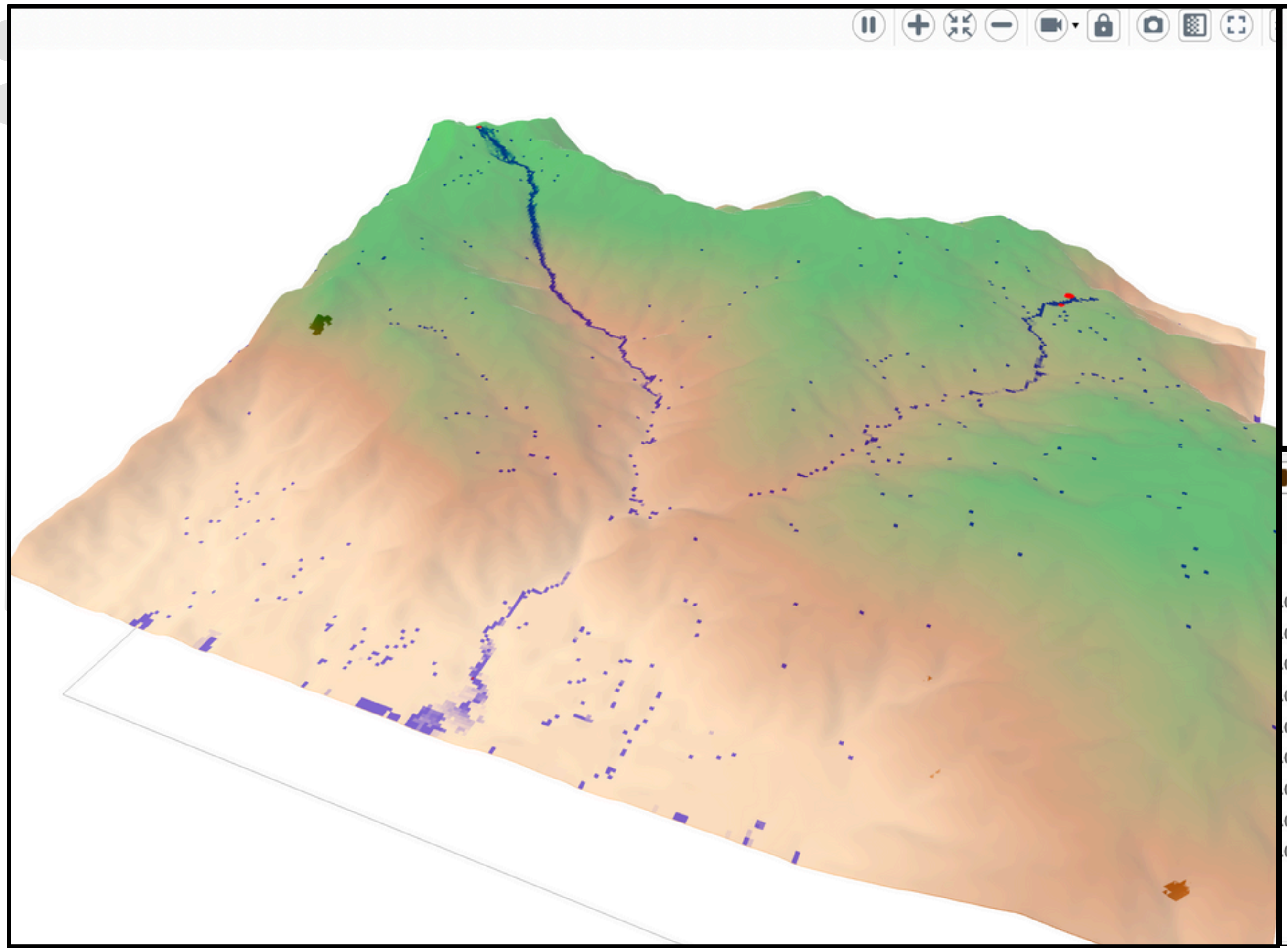
RMSE: 0.0326m

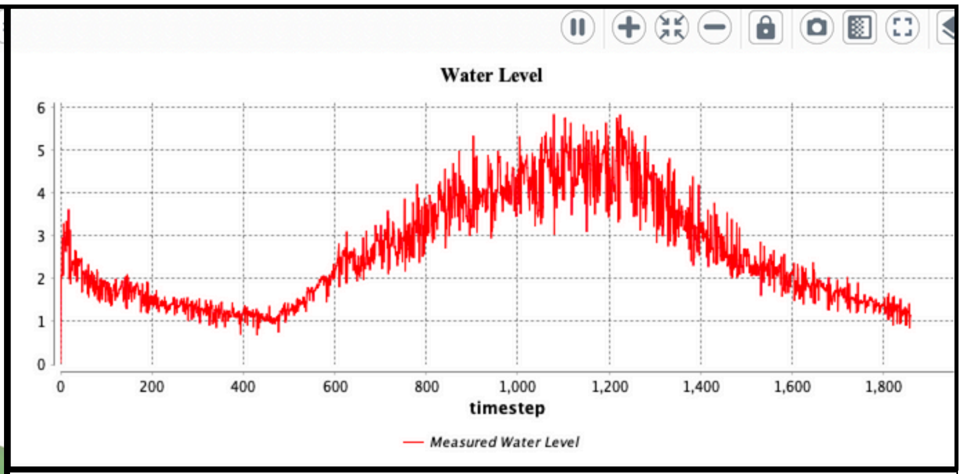


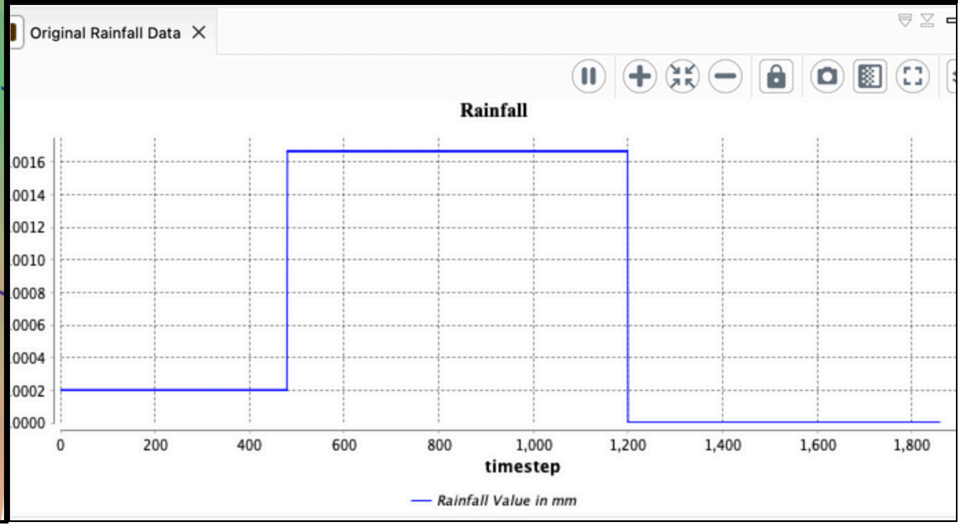


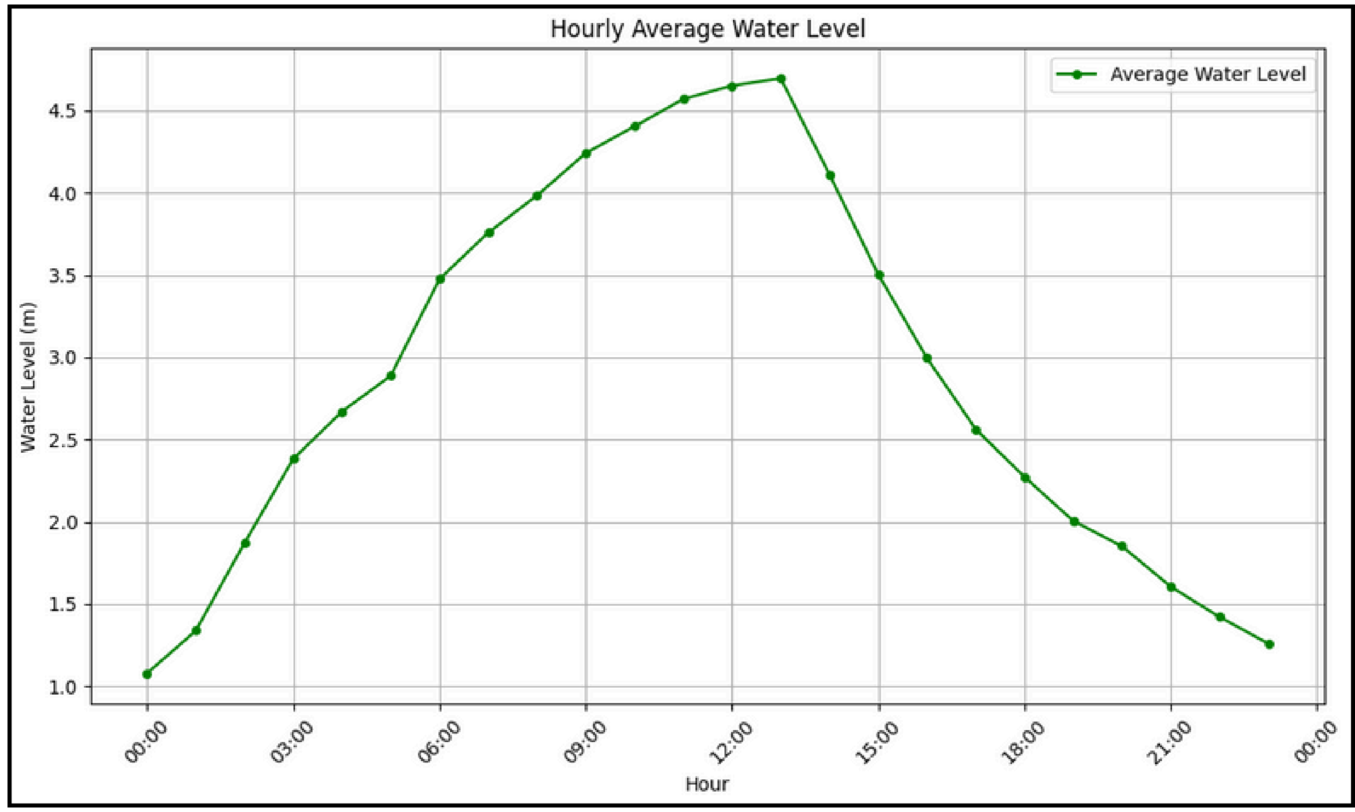
Scenerio 1: Extreme Rainfall Event

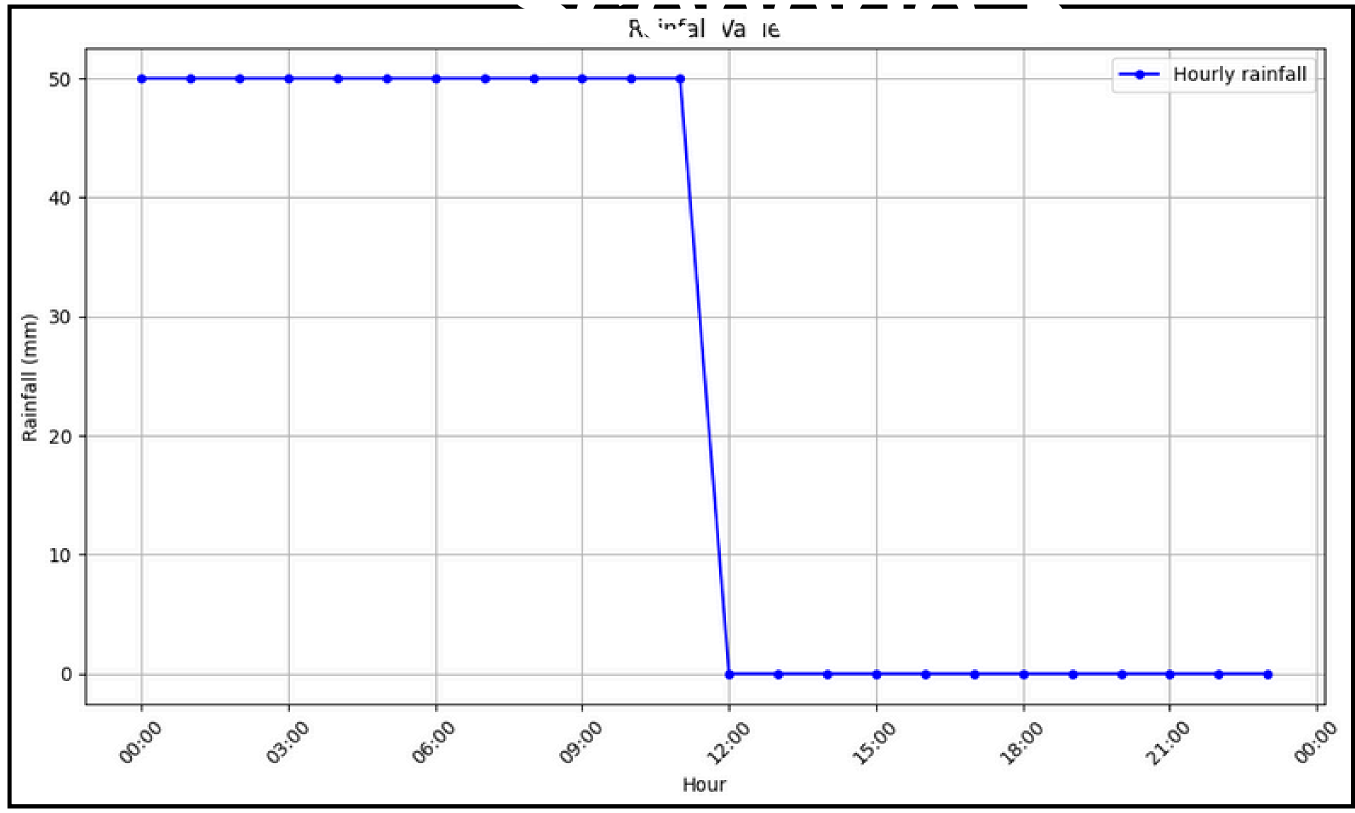
- 50mm per hour precipitation for 12 hour





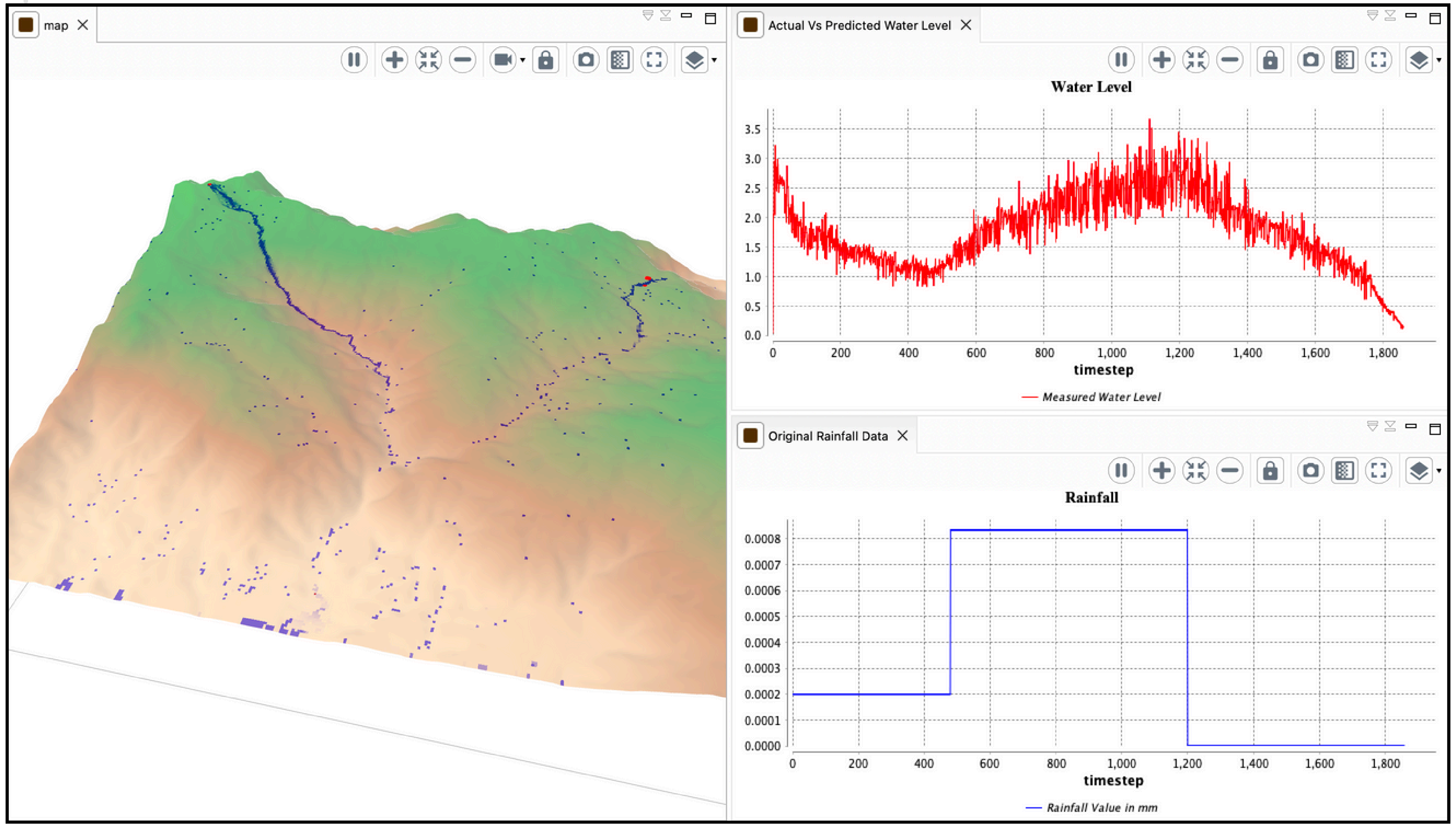


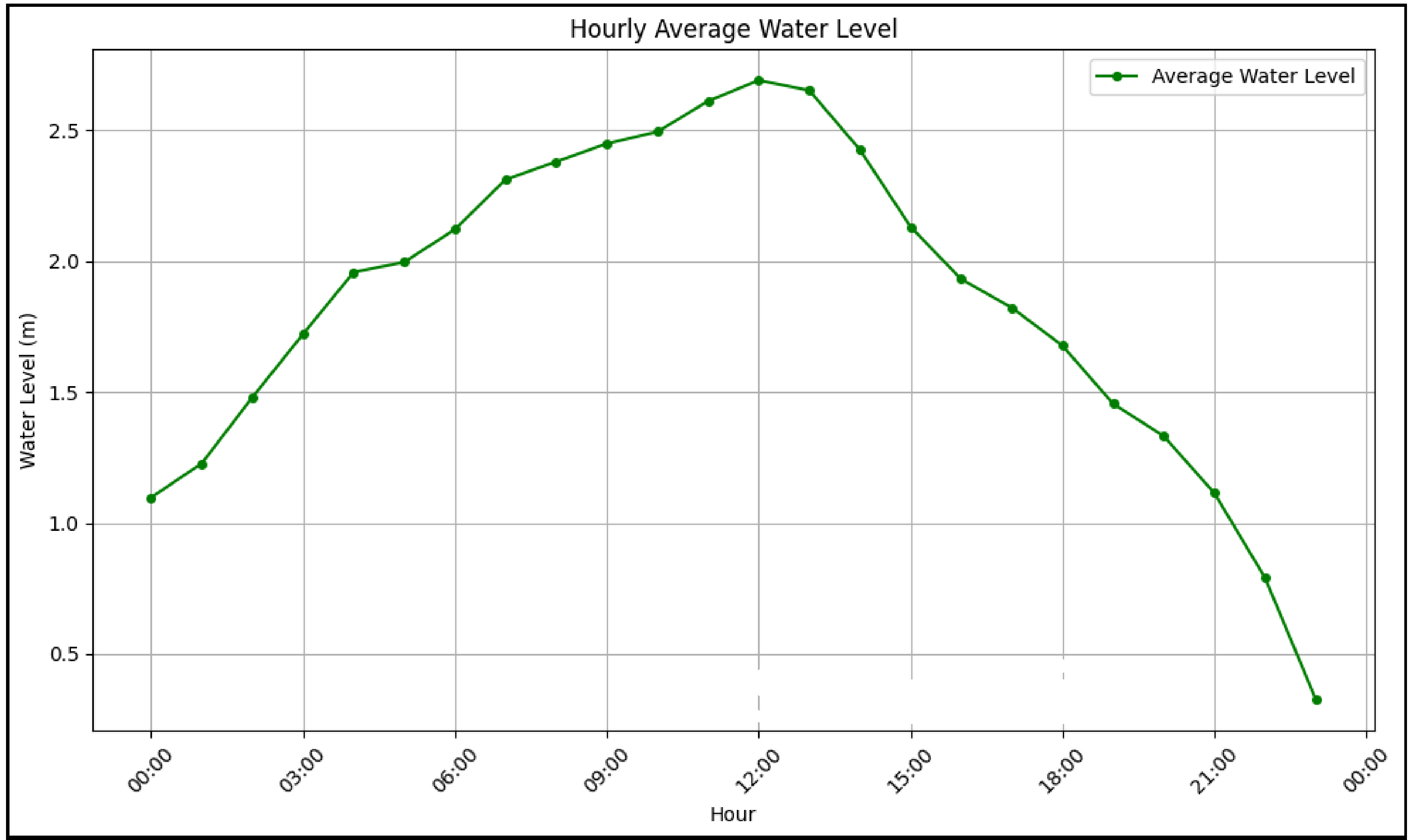


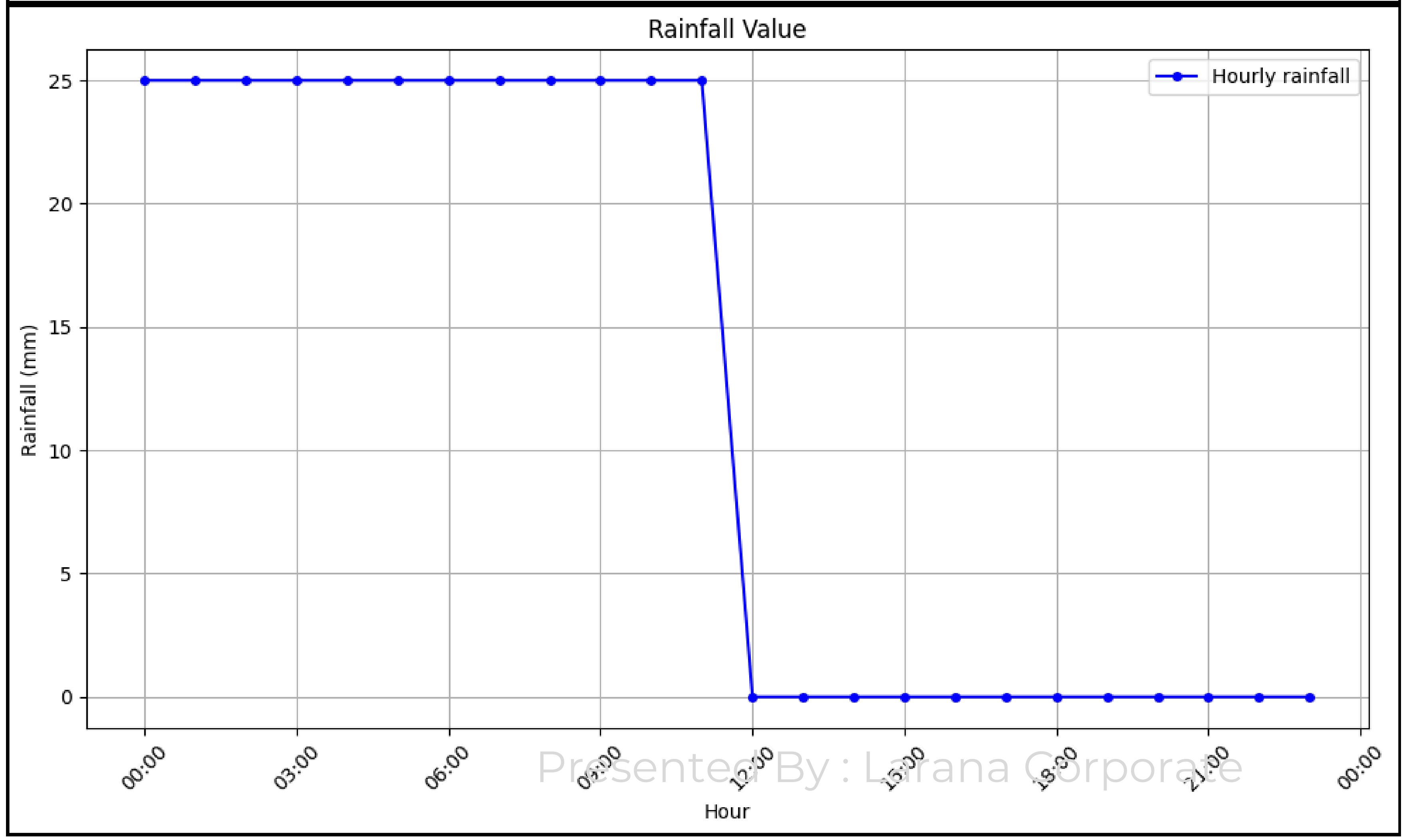


Scenerio 2: Medium Rainfall Event

- 25mm per hour precipitation for 12 hour







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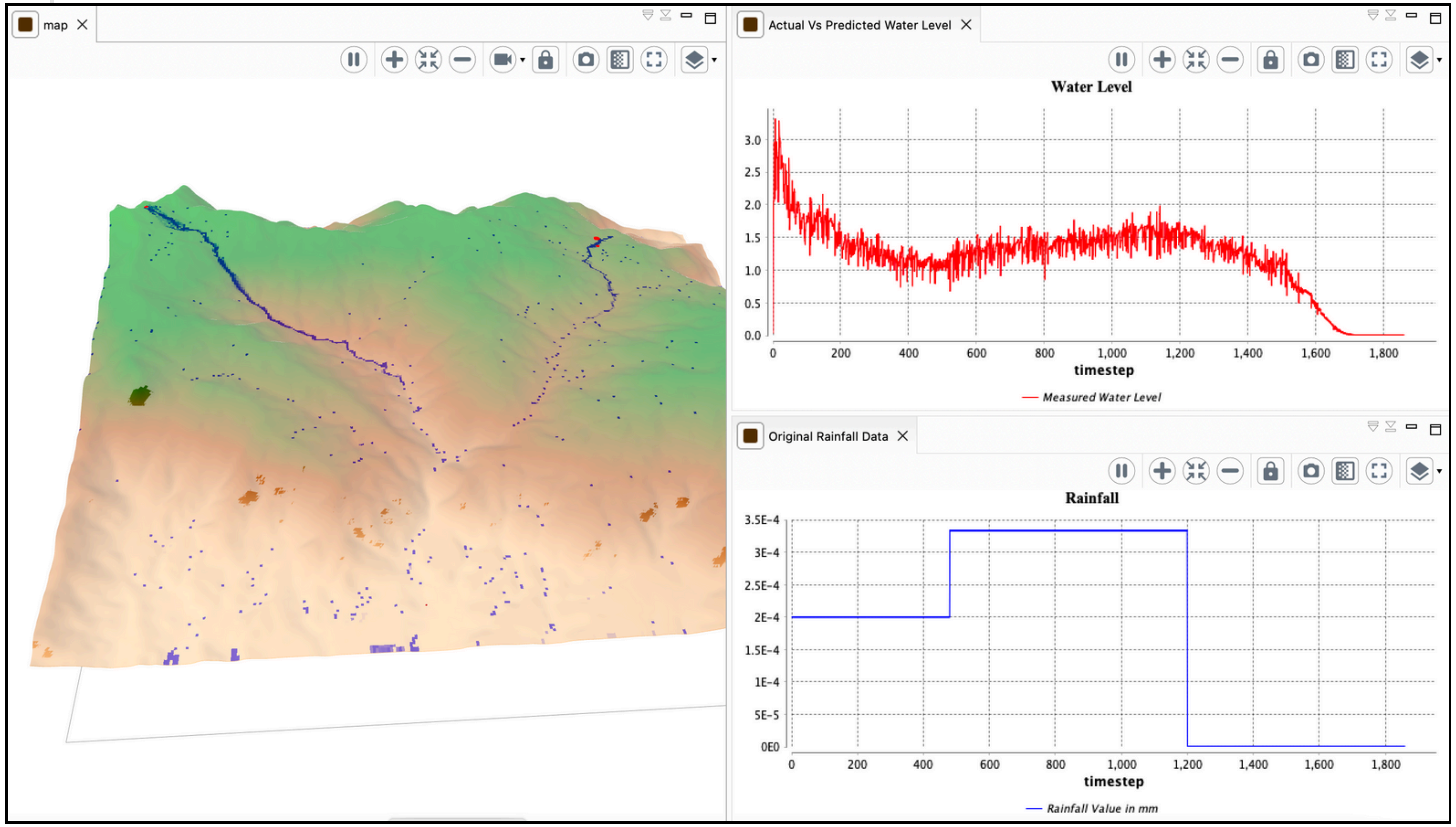
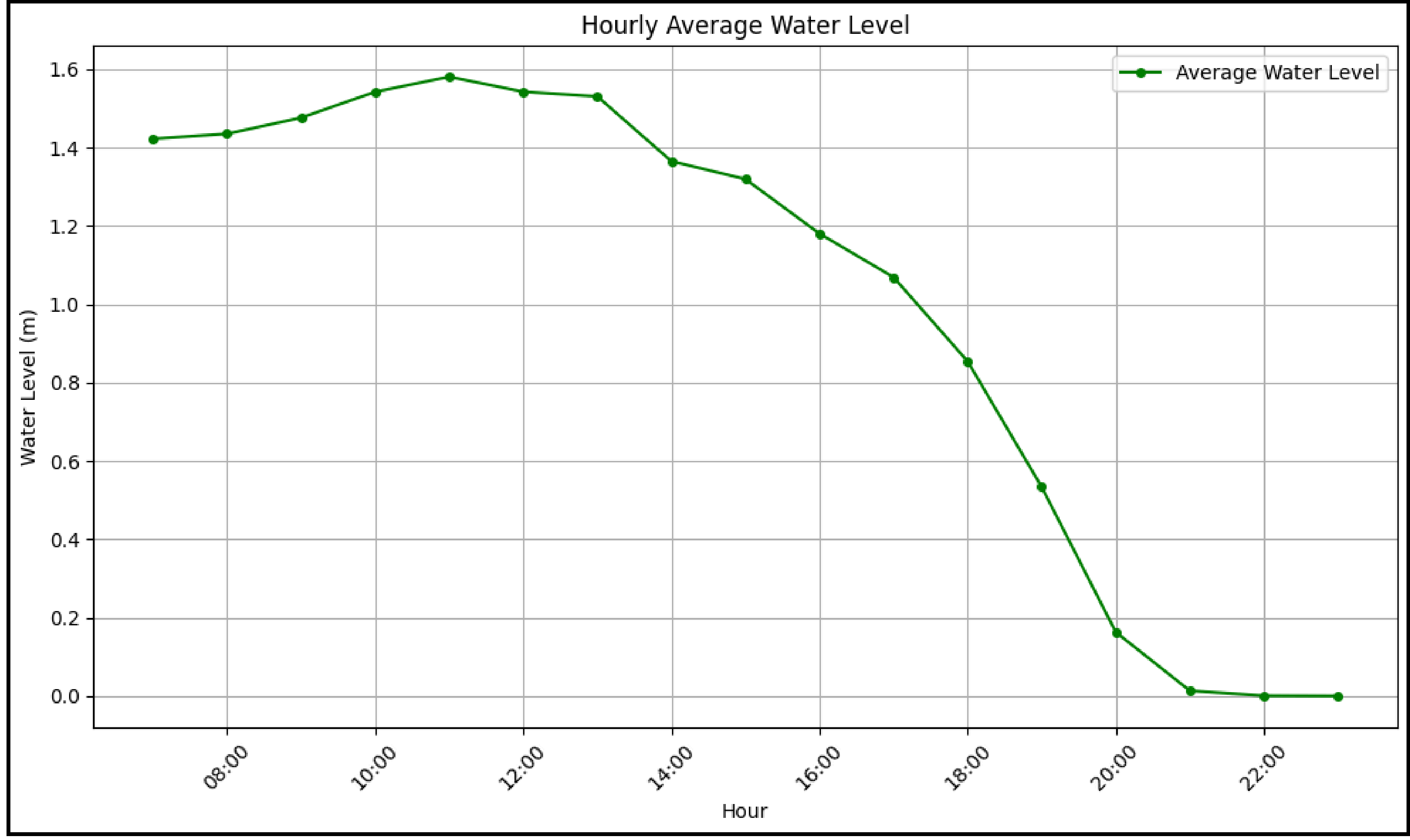
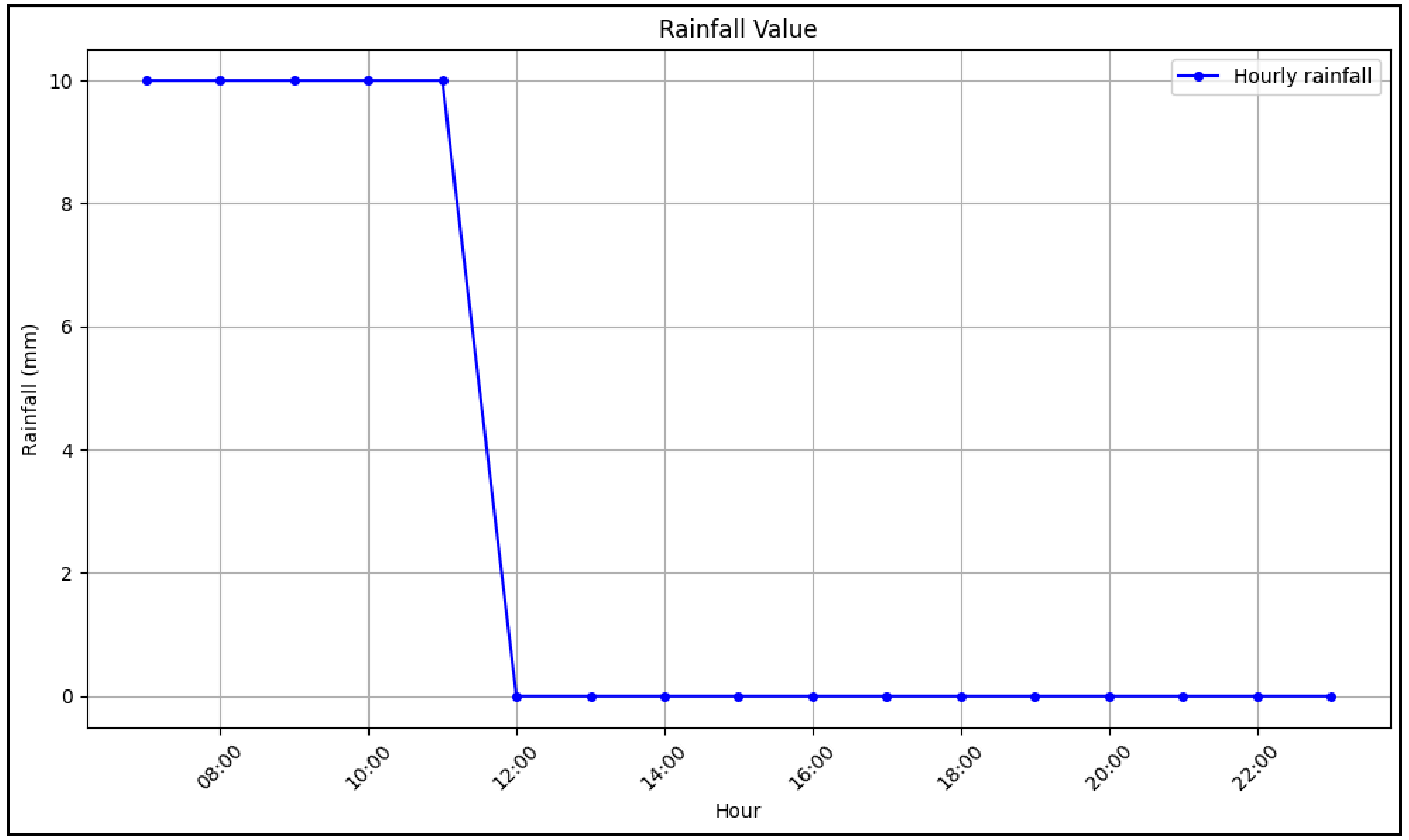
Scenerio 3: Low Rainfall Event

- 10mm per hour precipitation for 12 hour







Discussion and Conclusion

- **Low Resolution DEM** used which might have affected the accuracy at some extent
- **limited** number **of ground precipitation stations** may also reduce the model's accuracy, as varying precipitation patterns across the area cannot be fully represented
- **Other factors** like infiltration, evapotranspiration, land cover type, human made structures like Dams in between might affect the flow of water that might lead to some discrepancies in result.

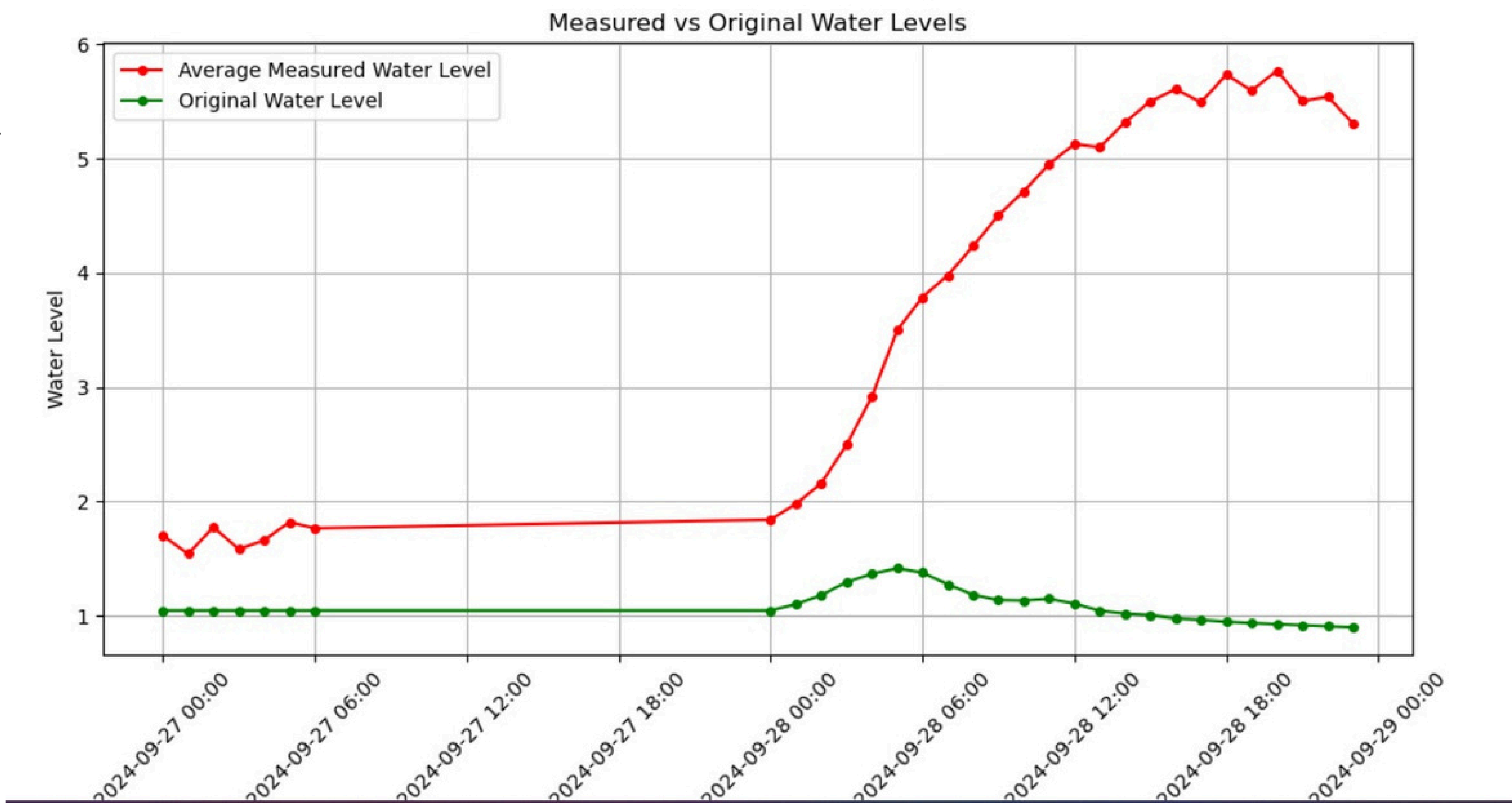
- The simulation helped to understand how rainfall interacts with the terrain and contributes to streamflow dynamics.
- The incorporation of a spatial perspective provides additional value by identifying rain flow patterns and terrain-specific behaviours which enhances the model's contextual applicability.

References

- Dhital, Y. P., Kayastha, R. B., & Eslamian, S. (2018). *Precipitation and Discharge Pattern Analysis: A Case Study of Bagmati River Basin, Nepal*. Journal of Flood Engineering, 9(1).
- Jiang, Y., Liu , C., Li , X., Liu , L., & Wang, H. (2015). *Rainfall-runoff modeling, parameter estimation and sensitivity analysis in a semiarid catchment*. Environmental Modelling & Software, 67, 72-88.
- Department of Water Resources and Irrigation. (2023). *Environmental Impact Assessment of Nagmati Dam Project. Gaurighat, Guheshwori, Kathmandu*: Department of Water Resources and Irrigation, Nagmati Dam Project.

Thank You!!!

When we don’t add Infiltration cofficient



Parameters:

float diffusion_rate <- 0.3;
float constant_river_water_input <- 2.25;
float infiltration_coeff <- 0.00;
float water_scale_factor <- 0.0;
int hour_steps <- 60;