R&D Internship at FluxGen | Round 1 Assignment

GUIDELINES:

1. Please ensure that **all questions from all three problems** are answered.
2. Compile your responses in a **single Word document**, clearly indicating the correct problem number and question number for each answer.
3. Convert your Word document to **PDF format** and **upload it directly to the Google Form** - https://forms.gle/LpPQNvPFP2L8pA636
4. **Submission deadline: Tuesday, 13th January at 10:00 AM (IST)**.
5. The Google Form will close automatically at the deadline, so we recommend submitting a little in advance to avoid any last-minute issues.
6. Once submitted, responses **cannot be edited**, so please review both your Google Doc and form submission carefully before submitting.
7. For each problem, structure your response as:

   a. My understanding of the problem
   (restate in your own words, identify the core challenge)

   b. Key physical principles involved
   (list the physics/math concepts relevant to this scenario)

   c. My approach
   (step-by-step logic, not code)

   d. Assumptions & limitations
   (what are you assuming? where might your approach fail?)

   e. Validation strategy
   (how would you verify your solution is correct?)

PROBLEM 1: THE INCOMPLETE GEOMETRY (Complexity: Foundation)

Skills Assessed: Spatial reasoning, interpolation logic, uncertainty handling

SCENARIO: You are tasked with estimating the total storage capacity of an irregularly shaped underground reservoir. You have cross-sectional depth measurements at 40 survey points, but these points only cover 65% of the reservoir's footprint. The remaining 35% is inaccessible due to structural obstructions.

QUESTIONS:

1. What mathematical approaches would you use to estimate the volume of the unmeasured 35%? Explain why simple averaging would be inadequate.

2. The reservoir walls are known to be naturally formed (not engineered). How does this physical characteristic influence your interpolation strategy?

3. How would you quantify the uncertainty in your final volume estimate?What additional information would reduce this uncertainty?

PROBLEM - 2 : THE SPECTRAL DISCREPANCY

Skills Assessed: Multi-spectral imagery, spatial datasets, early warning logic, validation frameworks.

SCENARIO: You are using satellite-based multi-spectral imagery to monitor a specific biological parameter (represented by a "Greenness Index") across a network of 50 small water bodies.

- Satellite readings show a 40% increase in the "Greenness Index" across all 50 sites over 7 days.
- Your early warning system triggers an "Algae Bloom Risk" alert for the entire region.
- Manual field reports from 5 of these sites (the only ones accessible) show the water is clear.

QUESTIONS:

1. List three non-biological factors (atmospheric or optical) that could cause a satellite to see "green" when the water is actually clear. How would you use different "bands" of light (e.g., Near-Infrared) to prove it's an error?
2. If 5 sites are clear, but the other 45 are unverified, how do you mathematically decide whether to "cancel" the alert for the whole region or keep it for the unverified 45? Describe your spatial weighting logic.
3. Design a "Validation Framework" that sits between the raw satellite data and the user alert. What specific "secondary data" (e.g., weather or temperature) would the model check before it is allowed to send a high-risk notification?

PROBLEM - 3 : THE BALANCING ACT

Skills Assessed: Systems thinking, mass-balance, first-principles modeling, catchment dynamics.

SCENARIO: You are modeling a "Closed-System" watershed consisting of an **Inlet Stream**, a **Primary Lake**, and an **Outlet**.

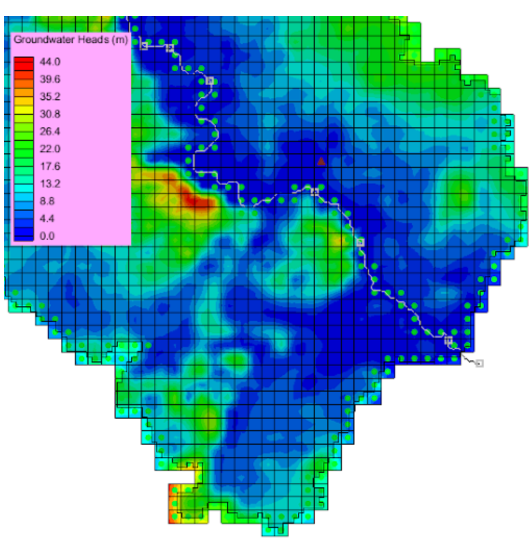
- **Input:** You have a rain gauge at the Inlet.
- **Output:** You have a flow-meter at the Outlet.
- **The Observation:** After a heavy rainfall, your rain gauge shows 1,000 units of water entered the system. Your Lake Level sensor shows the lake rose by only 400 units. Your Outlet sensor shows only 200 units left the system.
- **The Gap:** 400 units of water are "missing" from your mass-balance equation.
- Model the dynamics of the system to form a twin and optimise the solution/system build

QUESTIONS:

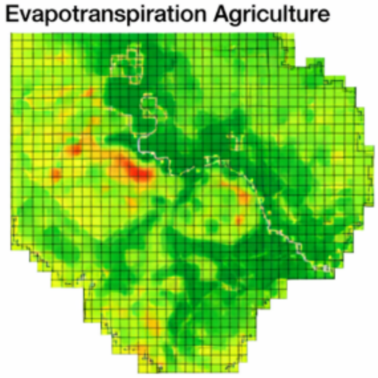
1. Using first-principles, where are the 400 units? Categorize your answers as: (a) Storage within the environment, (b) Natural loss, or (c) Sensor/Measurement error.
2. The rainfall happened at Hour 0, but the Outlet didn't show an increase until Hour 12. How would you mathematically model this "delay"? Why is this delay critical for an early warning system?
3. If the temperature rose by 10°C during this event, how would that physically change your calculation of "Volume" versus "Mass"? How do you ensure your "Digital Twin" doesn't mistake a temperature-driven expansion for an actual increase in water quantity?

PROBLEM - 4: Case Study on Spatial–Mathematical Modeling of Groundwater Head Dynamics

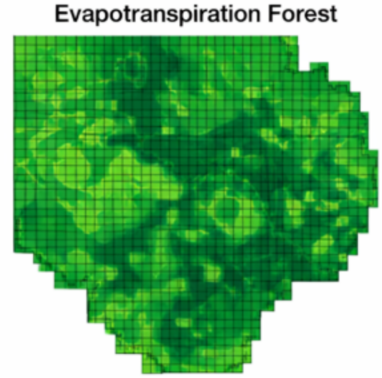
four groundwater consumption sources
(Agriculture, Built-up, Forest, Water bodies)

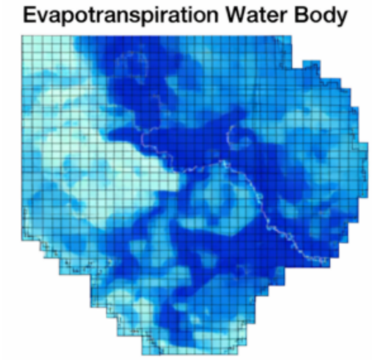


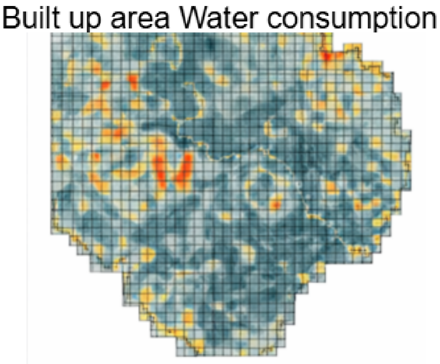
Evapotranspiration Agriculture



Evapotranspiration Forest







Aim: To develop a **math-based spatial system model** that solves groundwater head dynamics and quantifies the **spatial dependency of four groundwater consumption sources** (Agriculture, Built-up, Forest, Water bodies). The model identifies and projects **impact gradients around zones of interest/critical zones (red triangle annotations)**.

Approach: A grid-based domain is used to solve groundwater head variation using **cell-to-cell interaction mechanics**. For each grid cell, **radial and Cartesian influence functions** propagate consumption effects forward in space, ensuring **net downstream impacts are preserved**. Each of the four sources is represented as an independent but interacting consumption field.

Model Logic:

- Groundwater head gradients are computed per cell.
- Source-specific consumption functions modify local and neighboring cells.
- Interaction gradients are accumulated to reflect **realistic spatial coupling**.
- Interest zone points (red triangle) are evaluated for **multi-source dependency and sensitivity**.

Outcome: The model produces **four spatial interaction gradients**, revealing how combined consumption patterns drive groundwater stress. This mirrors real hydro-spatial dynamics and supports identification.