Understanding Drainage Systems and Soil Water Flow: A Design Thinking Approach

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1. Introduction (Empathize Stage)

- **Objective**: Understand how **water moves through soil** and how we can **manage drainage** effectively.
- **Why it matters**:
  - Prevent **crop waterlogging** and **root damage**.
  - Improve **soil aeration**, **crop yield**, and **machinery access**.
  - Design efficient **surface** and **subsurface** drainage systems for sustainable agriculture.
- **Empathize with Stakeholders**:
  - Farmers need timely water removal.
  - Engineers need to design cost-effective systems.
  - Environmentalists need to protect groundwater quality.

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2. Key Concepts (Define Stage)

A. Drainage Coefficient

- **Definition**:
  The **Drainage Coefficient** is the **depth of water (in mm)** that must be removed from soil **within 24 hours** to prevent waterlogging.
- **Purpose**:
  - Guides the **design of drainage systems** (surface/subsurface).
  - Ensures that crops have **optimal soil moisture** without excess water.
- **Typical Values**:
  - 2 to 5 mm/day for field crops.
  - 5 to 10 mm/day for high-value crops (vegetables, orchards).

B. Principles of Flow Through Soils

- **Water moves through soil pores** under the action of:
  - **Gravity** (vertical movement downward)
  - **Capillary forces** (lateral and upward movement)
- **Flow depends on**:
  - Soil type (sand = fast; clay = slow)

    - Pore size and continuity
    - Water content (saturated vs unsaturated flow)

C. Darcy’s Law

- **Fundamental law** describing the **flow of water** through porous media (soils).
- **Mathematical Expression**:

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- **Mathematical Expression**:

$$Q = kA\frac{dh}{dl}$$

Where:

- Q = Discharge (volume/time, e.g., m^3/s)
- k = Hydraulic conductivity (m/s) – *soil permeability*
- A = Cross-sectional area perpendicular to flow (m^2)
- dh/dl = Hydraulic gradient (head loss per unit distance)

- **Interpretation**:
    - Flow rate is directly proportional to **hydraulic conductivity** and **hydraulic gradient**.
    - Sandy soils (high k) drain faster; clay soils (low k) drain slowly.

D. Infiltration Theory

- **Infiltration**: Process of **water entering the soil** from the surface.
- **Governing Factors**:
    - Soil texture (sand > silt > clay)
    - Initial moisture content
    - Surface conditions (crusting, compaction)
    - Vegetative cover
- **Infiltration Rate**:

    - Initially high when soil is dry.
    - Decreases and stabilizes at a constant rate over time.
- **Important for**:
    - Irrigation design
    - Flood management
    - Estimating runoff and drainage needs

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3. Surface and Subsurface Drainage Systems (Ideate Stage)

Surface Drainage Systems

- **Purpose**: Quickly remove **excess water** from the surface to prevent waterlogging.
- **Types**:
    - **Field drains** (shallow ditches)
    - **Bedding systems** (raised beds)
    - **Land grading** (sloping fields)
- **Design Principles**:
    - Adequate slope (~0.05% to 0.5%) to facilitate gravity flow.
    - Capacity based on drainage coefficient and rainfall data.

Subsurface Drainage Systems

- **Purpose**: Remove **excess water from root zone** below the surface.
- **Types**:
    - **Tile drains** (perforated pipes buried in soil)
    - **Mole drains** (channels formed without pipes)
- **Design Principles**:
    - **Spacing and depth** determined by soil permeability and drainage coefficient.
    - **Material selection** (PVC, clay pipes) must ensure durability.
    - **Outflow management** to prevent environmental contamination.

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4. Real-World Application (Prototype and Test Stage)

Crop/Region	Problem	Rheological/Drainage Solution
Rice fields	Water stagnation	Controlled surface drainage
Sugarcane on clay	Waterlogging, poor rooting	Subsurface tile drainage

Crop/Region	Problem	Rheological/Drainage Solution
Vegetable farms	High infiltration variability	Land grading and surface drains

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5. Quick Class Activity (Prototype Your Design)

Task:

- Design a **surface** or **subsurface** drainage plan for a farm given:
  - Soil type (clay or sandy)
  - Crop (rice, maize, vegetables)
  - Drainage coefficient (5 mm/day)
- Sketch layout, main drains, lateral drains, and outlets.

Discussion:

- What challenges do you anticipate?
- How would infiltration rate affect your design?

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6. Summary

- The **drainage coefficient** determines how much water needs to be removed daily.
- **Darcy's law** describes water movement through soil.
- **Infiltration theory** explains how water enters and moves in soil.
- **Surface drainage** removes water quickly from the field surface.
- **Subsurface drainage** controls water below the surface, improving crop root health.
- **Design Thinking** helps create practical, user-centered drainage solutions.

Simple diagrams to illustrate:

- Water flow through soil (arrows through pores)
- Surface drainage cross-section
- Subsurface drainage layout with tile pipes
- Infiltration curve (rate vs time)

Task: Design a surface or subsurface drainage plan for a farm given: Soil type (clay or sandy) Crop (rice, maize, vegetables) Drainage coefficient (5 mm/day) Sketch layout, main drains, lateral drains, and outlets

Task:

Design a **Drainage System** for a farm based on:

Parameter	Given Value
Soil Type	Clay or Sandy
Crop	Rice, Maize, Vegetables
Drainage Coefficient	5 mm/day

Solution Plan

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1. Analyze Soil Type and Crop Needs

Soil Type	Characteristics	Drainage Need
Clay Soil	Poor infiltration, slow drainage	Needs **Subsurface drainage**
Sandy Soil	High infiltration, fast drainage	Needs **Surface drainage** mainly

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2. Decide Drainage System Based on Soil and Crop

Soil-Crop Combination	Recommended System
Clay soil + Rice	Controlled Subsurface Drainage (water table management)
Clay soil + Maize/Vegetables	Aggressive Subsurface Drainage (deep root zones need dry soil)
Sandy soil + Rice/Maize/Vegetables	Surface Drainage (remove occasional ponding quickly)

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3. Drainage Layout Design Components

- **Main Drains**: Collect water from entire field and discharge to outlet.
- **Lateral Drains**: Collect water from smaller field sections and lead to main drain.
- **Outlet**: Point of safe discharge (river, ditch, pond).

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4. Basic Drainage Design Assumptions

- **Drainage Coefficient**: 5 mm/day → about 5 liters/m^2/day needs to be removed.
- **Drain Depth (for subsurface)**:
  - 1.2 to 1.5 m deep for clay soils.
- **Drain Spacing**:
  - Clay soil (subsurface): 15–30 meters apart.
  - Sandy soil (surface drains): 40–60 meters apart.
- **Drain Slope**:
  - 0.05% to 0.1% minimum slope for effective gravity flow.

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5. Sketch Description

Here’s how the **layout** would look:

(For Clay Soil with Subsurface Drainage for Vegetables or Maize)

Field Boundary

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|                     |
|  Lateral Drain   Lateral Drain   Lateral Drain  |
|   (15–20m apart)   (15–20m apart)    (15–20m apart)    |
|   ||         ||         ||      |
|   ||         ||         ||      |
|    ↓          ↓          ↓       |
|         Main Collector Drain (running across field)  |
|             ↓                    |
|              Outlet to water channel           |
└─────────────────────────────────────────────────────────┘
```

(For Sandy Soil with Surface Drainage for Rice/Vegetables)

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Field Boundary
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                       |
 Raised Bed    Shallow Surface Drain   Raised Bed |
(2–3m wide)    (shallow furrow)      (2–3m wide) |
   / \\            / \\             / \\        |
 Water flows along shallow furrows toward main drain      |
                  ↓                              |
         Main Surface Drain to Outlet                   |
└──────────────────────────────────────────────────────────┘
```

Summary for Field Implementation:

Item	Clay Soil (Subsurface)	Sandy Soil (Surface)
Lateral Drain Spacing	15–20 m	40–60 m (shallow furrows)
Main Drain Depth	1.2–1.5 m below ground	Shallow depression
Drainage Flow Slope	0.05% to 0.1%	0.1%–0.3% for surface
Outlet	Controlled outlet (e.g., check structures for rice)	Simple open discharge

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Design Thinking Reflection:

- **Empathize**: Farmer needs easy operation and minimum waterlogging.
- **Define**: Need to remove 5 mm/day of excess water efficiently.
- **Ideate**: Chose appropriate surface/subsurface system.
- **Prototype**: Sketch the plan.
- **Test**: Adjust spacing and depth in real field based on soil tests and field slopes.

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How to Calculate Drainage Coefficient

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1. Understand what "5 mm/day" means:

- **Drainage Coefficient (Dc)** = **depth of water** to be removed from the field **per day**.
- 5 mm/day means:
  → We need to remove **5 millimeters** thickness of water from **every square meter** of land surface **per day**.

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2. Convert Millimeters to Liters

- 1 mm of water over 1 m² = **1 liter** of water.

Because:

Volume=Area×Depth

Area = 1 m²
Depth = 1 mm = 0.001 m
Thus,

$$\text{Volume} = 1\ m^2 \times 0.001\ m = 0.001\ m^3$$

□ Therefore:

$1\ m^3 = 1000$ liters

$0.001\ m^3 = 1$ L

1 mm/day = 1 liter/m²/day

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3. Apply for 5 mm/day

- **5 mm/day** = 5 × 1 liter/m²/day
- Thus:

5 liters per square meter per day\

Every **1 m²** of land needs to drain **5 liters** of water **each day**.

Summary

Given Drainage Coefficient	**Water to be Removed**
1 mm/day	1 liter/m²/day
5 mm/day	5 liters/m²/day
10 mm/day	10 liters/m²/day

Quick Formula:

$$\text{Water to Remove (liters/m}^2\text{/day)} = \text{Drainage Coefficient (mm/day)}$$

Real-Life Meaning:

If a farmer has **1 hectare** (10,000 m²) of clay field, and drainage coefficient is **5 mm/day**, then:

$$5 \text{ liters/m}^2\text{/day} \times 10{,}000 \text{ m}^2 = 50{,}000 \text{ liters/day}$$

Thus, **50,000 liters/day** of excess water must be removed from that hectare every day!