Hydrology & Fluvial Geomorphology

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Course Plan

Day 1: Introduction and Overview
- Water cycle – Globally & Locally
- River shapes and forms
- River behaviour
- Closer look at river hydraulics and sediment dynamics

Day 2: Fieldwork on the Braid Burn
- Collection of field data: Flow and particle analysis

Day 3: Analysis and modelling of results
- Hydraulic calculations
- Modelling of peak flows

Hydrological Interactions

1. Stream Discharge (Q) = climate controlled
   - rainfall
   - snowmelt
   - groundwater discharge

2. Discharge = volume of water flow per unit time (cubic metres per second) [m³ s⁻¹]

Important Variables

Catchment Water Budget:

Input mechanism into surface water process: atmospheric precipitation

Precipitation = Runoff + Interception + Storage

- Interception = evapotranspiration + evaporation + infiltration
- Storage = groundwater and/or snow pack and ice

Important Variables: Precipitation

Release of moisture by the atmosphere (rain, snow)

Amount defined by region, climate and season
- Storm cycle intensity – volume of precipitation per unity time (intensity)
- Recurrence interval – ‘chance’ of a storm of given intensity occurring during a set time period (e.g. 1 in 100 years)
  - Typically the greater the magnitude (intensity) the less the frequency of it occurring
- Duration – length of an individual storm event
  - High intensity, long duration storms will result in the greatest amount of geomorphological change
**Important Variables: Interception & Evapotranspiration**

- Interception of rainfall by plants, leaves, groundcover prior to reaching the ground
  - "energy dissipate" in terms of rain fall impact on landscape (reduces erosion rates)
- Evapotranspiration: atmospheric evaporation of moisture directly from plant tissue and/or intake of moisture into plant system prior to reaching ground surface
  - Foliage Evaporation = function of air temp. and humidity
  - Amount of interception = function of:
    - type and species of plant cover
    - density of foliage/plant cover
- Approximating Regional interception
  - Measure total precipitation for drainage basin
  - Measure total stream discharge at mouth of basin
  - difference = interception + evaporation
  - generally difficult to measure

**Important Variables: Infiltration**

- Water/precipitation that seeps into soil/subsurface rock
- Infiltration function of:
  - vegetative cover
  - soil permeability & porosity
  - angle of slope
  - moisture content of soil

**Porosity and permeability**

- Porosity: ratio, in %, of the volume of void space to the total volume of sediment or rock

- Permeability: the degree of interconnectedness between pore spaces and fractures within a rock or sediment deposit. A measure of the capacity of a porous material to transmit fluids

**Surface Water Flow: Hierarchy**

**Rills and rivulets**: small scale channels of surface runoff (cm wide and cm deep)
- found on upper portions of hillslopes
- servicing runoff only during precipitation events

**Gullies**: medium scale channels of runoff (on scale of sub-metre to metres in width and depth)
- upper to lower portions of hillslopes
- servicing runoff only during precipitation events
Surface Water Flow: Hierarchy

- **Open Stream channels** (scale of metres to 10s of metres)
  - major sites of surface runoff
  - In humid areas, sites of year round
  - may be ephemeral in arid areas

Surface Water Flow: Hierarchy

- **Overland Sheet Flow**
  - sheets of runoff freely flowing, unchannelized over the landscape
  - common during saturated ground conditions or very intensive rainfall events

Open Channel Flow – Closer Look

- We are concerned with **open channel flow** in this lecture.
- From direct experience we know that open channels (rivers) have a **variety** of shapes & forms.
- Why do these forms occur?
- What similarities can we see that allows us to group these forms together?

River Shape & Form

- Rivers come in a variety of shapes and sizes
- Examples include:
  - Straight
  - Meandering
  - Braided
  - Anastomosing
  - Bedrock Channels

Straight Channel

- Alluvial deposits
- Bars
- Direction of flow

Meandering Channel

- Floodplain
- Ox-bow Lakes
**Meandering Channel**
- High sinuosity, large channel systems
- Finer sediment load (compared with Braided) – dominated by silt and clay
- Migration of pattern across floodplain
  - Coarse cross-bedding in deposits
  - Fine silt / mud dominated ‘overbank’ deposits
  - High suspended load content
  - Coarse channel/pointbar deposits (alluvium)

**Braided Channels**
- Network of low-sinuosity channels separated by mid-channel bars/islands
- Bedload dominated (sand and gravel)
- Found in:
  - Glacial outwash plains (sandur)
  - Distal (furthest) reaches of alluvial fans
  - Mountainous drainage systems
- Typically has:
  - Minimal vegetative cover
  - High runoff
  - High rate of sediment supply

**Anastomosing Channels**
- Hybrid form: similarities to meandering and braided morphologies
  - Multiple channel stream
  - Low gradient
  - Narrow, deep channels
  - Laterally stable banks
  - Therefore typically highly vegetated, evolved ecosystems

**Bedrock Channels**
- Highly-energetic environments
  - High flow velocities
  - Not associated with sediment deposits
  - Channels are laterally unstable
  - Channel patterns occupy floodplain

**Anastomosing Channels**
- Channels are laterally stable
  - Channels patterns occupy floodplain
Why do we have different channel patterns?

Need to understand:

- Water in motion (catchment hydrology, local hydraulics) – affects rates of discharge (Q)
- Influence of the landscape: e.g. catchment topography (gradient), geology (substrate)

From large-scale to small-scale

- We’ve looked at a larger-scale (planform) view of channel morphology
- Difficult to fully characterise (e.g. how do we make large-scale measurements?)
- Rivers also adjust their cross-sectional form in response to changes in Q
- Measurements are undertaken using cross-sections of points along a channel and then combining them to understand the overall nature of the channel
- This is called ‘at-a-station’ research

Energy: Thought experiment

- Unreleased object
  - High Ep
  - No Ek
  - Equilibrium
- Object falling under gravity
  - Ep converted mostly to Ek
  - Some loss through heat to air resistance (friction)
- Dis-equilibrium
- 1st Law of Thermodynamics: ‘Energy can neither be created nor destroyed’
- Energy therefore converted to perform work
- Stationary object
  - No (relative) Ep
  - No Ek
  - Equilibrium

Energy in River Channels

- Therefore:
  - Ep converted to Ek as water drops under force of gravity
  - Ek is expended/dissipated largely through friction:
    - Internal shear between water molecules
    - External shear with channel bottom and sides
  - Velocity of flow is controlled by frictional shear:
    - This is defined by how rough the channel bottom and sides are.
    - Roughness coefficient (n)
Effects of Friction on Velocity

Which other factors affect velocity?
- We know that roughness \((n)\) can reduce the velocity of a river...
- What other factors can you think of that will either speed-up or reduce the river's velocity?
  - Its cross-sectional area?
  - The gradient of the section?

Manning's Equation
- Average velocity in the channel is therefore directly proportional to:
  - Hydraulic Radius \((R)\)
  - Slope (Gradient) of the Section \((S)\)
- \(Q\) is inversely proportional to:
  - Roughness \((n)\)

\[ \bar{u} \propto \frac{S^2 \times R^2}{n} \]
which gives:

\[ \bar{u} = \frac{S^{2+3} \times R^{0.12}}{n} \]

Calculating Discharge
If we know the average velocity (metres per second) through a cross section, discharge is easy to calculate:

Continuity Equation:

\[ Q = A \times \bar{u} \]

Where:
- \(Q\) = discharge (metres cubed per second)
- \(A\) = cross sectional area (metres squared)
- \(\bar{u}\) = average velocity in section (metres per second)
Sediment supply to rivers, a function of:
- Relief (increased relief, increased energy, increased erosion rates)
- Hillslope lithology: dictates sediment composition
- Climate: influences weathering and vegetation
- Vegetation cover: acts to stabilise forces acting on hillslope

Types of Sediment Load
- Dissolved load: dissolved ions in solution
- Flotation load (organic debris/litter)
- Suspended load:
  - Fine sediment carried within fluid
  - Dependent on water velocity and grain size
  - Coarser the sediment, the greater velocity required to entrain the particles in the fluid
- Bedload – very coarse sediment transported along the channel bottom by increased shear forces during high discharges

Stream capacity vs. Stream competence

Capacity: the potential load that a stream can transport (volume of material per unit area)

Competence: the largest particle diameter that the stream is capable of transporting given its velocity and shear force

Calculating Competence

Once we know the shear stress on the channel bed, we can also use the following equation to calculate the largest particle that this shear stress can move:

\[ D_{max} = \frac{\tau}{0.08 \times g \times (\rho_{Sediment} - \rho_{Water})} \]

where:
- \( D_{max} \) = Maximum diameter of particle that can be moved (m)
- \( \tau \) = Shear Stress (N)
- \( g \) = Acceleration due to gravity (9.8 m/s²)
- \( \rho_{Sediment} \) = Density of Sediment (1000 kg m⁻³)
- \( \rho_{Water} \) = Density of Water (1000 kg m⁻³)
- \( \rho_{Sediment} \) = Density of Silica (2650 kg m⁻³)

Calculating Competence

\[ \tau = \rho \times g \times R \times S \]

where:
- \( \tau \) = Shear Stress (N)
- \( \rho \) = Density of Water (1000 kg m⁻³)
- \( g \) = Acceleration due to gravity (9.8 m/s²)
- \( R \) = Hydraulic Radius
- \( S \) = Surface Water Slope

Remarks...

- We will be using these equations after we undertake our fieldwork on Friday at the Braid Burn.
- You don’t need to memorise them; they will be automatically calculated for you in the spreadsheet we will use.
- You just need to understand what they show and how they work.
- Time for a break! 😊