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Engineering Fundamentals Stormwater

Open Drain / Open Channel Design

Introduction

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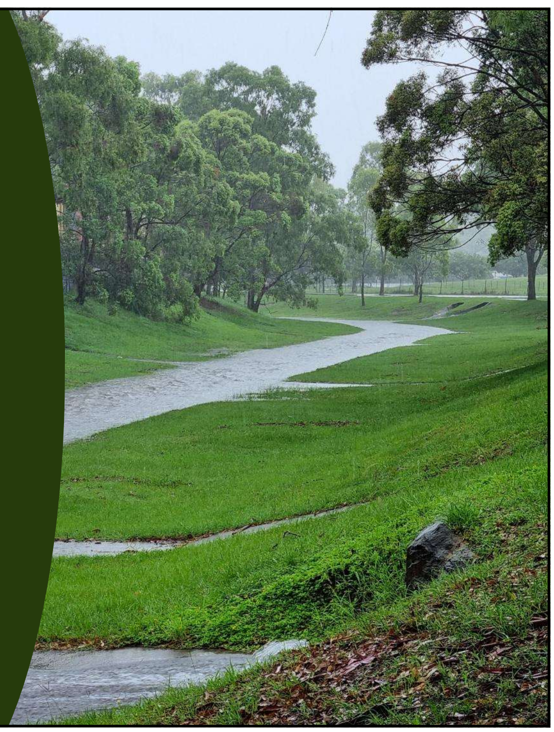
Open Drains (Channels)

Interchangeable terms: *Drains, Channels, Open Drains, Open Channels*

- Conduit or conveyance for water flow, either artificial or natural.
- Characterised by a free surface exposed to the atmosphere.
- Flow is driven by gravity and follows the path of least resistance.



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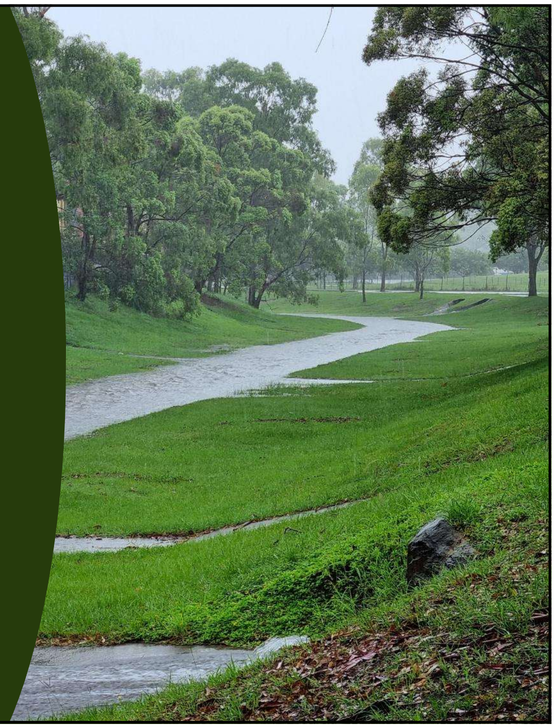
Design and Analysis Focus

- Emphasis on smaller natural streams, creeks, and constructed channels.

Exclusions:

- Larger systems (e.g. rivers, floodplains) are more complex.
- Requires specialised expertise in hydraulics and river engineering.



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Types of Open Channels

Table Drains:

- Located along the outer edge of road shoulders in cuts or shallow raised carriageways.
- Purpose: Collect and convey runoff from the pavement, shoulders, and batters to a suitable outfall (e.g. diversion drains or culverts).

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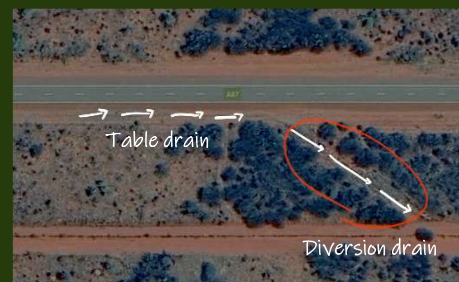
Types of Open Channels

Diversion Drains:

- Purpose: Redirect water collected in table drains to designated outlets, including side drains, creeks, or open countryside.
- Spacing: Must ensure flow in table drains does not exceed capacity.
- Key Features:
  - Redirect problematic flows to prevent excessive velocities.
  - Table drain blocks may be used downstream of confluences with diversion drains.



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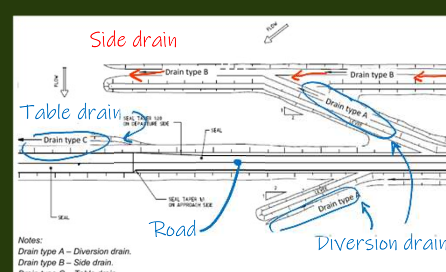
Types of Open Channels

Side Drains:

- Constructed to isolate roads from runoff generated in adjoining areas.
- Often designed as small levees when excavation is not feasible.



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Types of Open Channels

Catch Drains:

- Sometimes called cut-off drains; intercept surface water at the top of cut batters.
- Purpose:
  - Prevent rilling, erosion, or batter slope scour.
  - Convey water to outlets or road drainage systems.
- Specifications:
  - Typically 0.3 m deep, 2.0–2.5 m wide.
  - Not suitable for erodible soils (prone to levee failure or piping).

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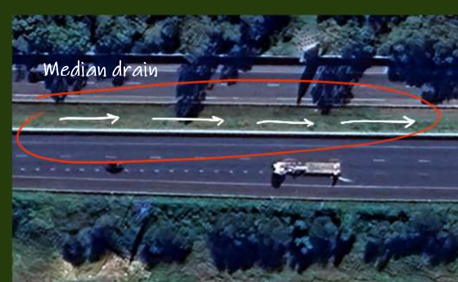
Types of Open Channels

Median Drains:

- Collect runoff from roadway medians and direct it to the drainage system.
- Limitations:
  - Safe slopes required for errant vehicles.
  - Steeper side slopes restrict capacity unless median is wide.
  - May incorporate grated pits and underground pipes.



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Types of Open Channels

Inlet or Outlet Drains:

- Convey water towards culvert inlets or away from culvert outlets.
- Features:
  - Use "daylighting" to construct at slopes until they meet the natural surface.
  - Critical for locations where culvert invert levels differ from the natural surface.

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Types of Open Channels

Batter Drains:

- Also known as slope drains, designed to remove stormwater from the batter top to reduce batter face scour.
- Spaced based on maximum flow width criteria.

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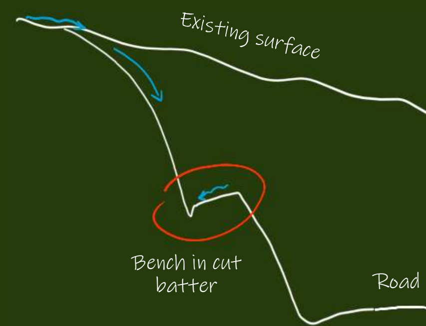
Types of Open Channels

Bench Drains:

- Constructed on a batter or natural slope to reduce erosion to batter faces.
- Purpose:
  - Minimise water in cuttings and improve sight distance on curves.
  - Direct water to suitable outlets.



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Types of Open Channels

Contour Drains:

- Also called contour banks; divert water along a gently sloped path to stable areas.
- Purpose:
  - Slow runoff to prevent erosion.
  - Direct flow to nearby stable areas at velocities that avoid damage.

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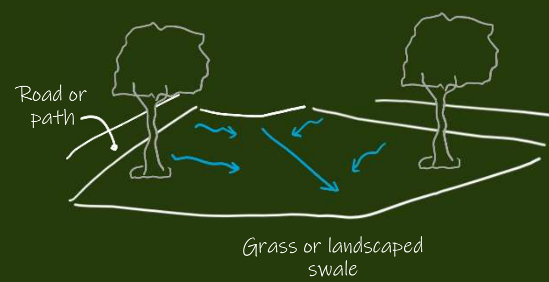
Types of Open Channels

Swales:

- Use vegetation to reduce flow velocities and promote sedimentation.
- Features:
  - Provide surface filtration.
  - Support biofilm growth for pollutant uptake.



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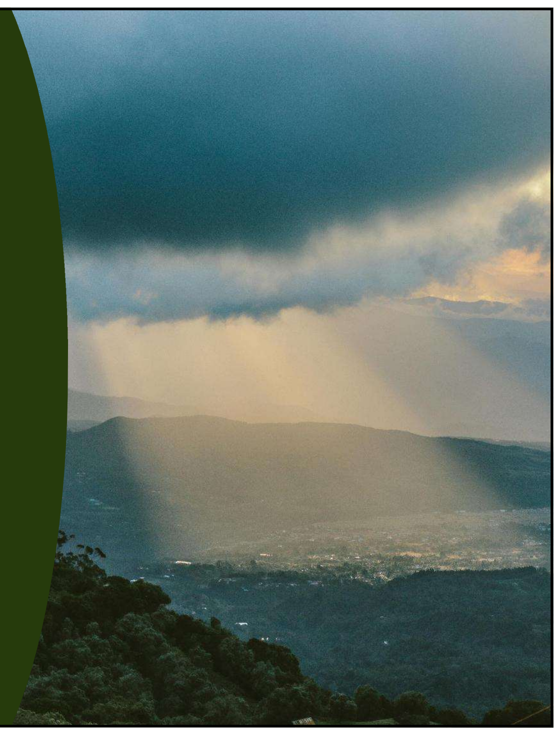
General Considerations

Hydrological Analysis:

- Determines discharge for the proposed open drain or channel design.
- May need to accommodate groundwater in some cases.



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General Considerations

Hydraulic Analysis:

- Channel shape - side batters, slope, width, depth
- Surface treatment



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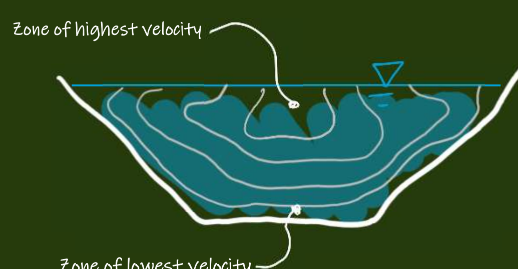
Fundamentals of Open Channel Flow

Velocity Distribution:

- Velocity is non-uniform across the cross-section.
- Slowest near the bed and banks due to friction.
- Highest velocity occurs near the surface in deeper sections.
- Iso-velocity contours illustrate velocity distribution.



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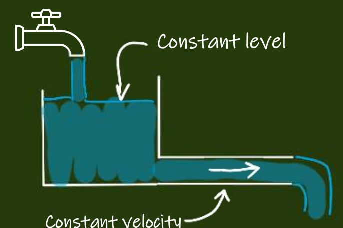
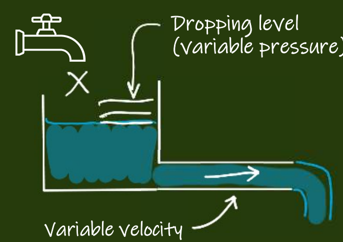
Fundamentals of Open Channel Flow

Types of Flow

- Steady Flow:
  - Flow rate (and velocity) does not change over time at a given point.
- Unsteady Flow:
  - Flow rate (and velocity) changes over time at a given point.



Steady flow



Unsteady flow

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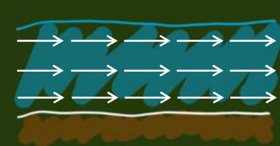
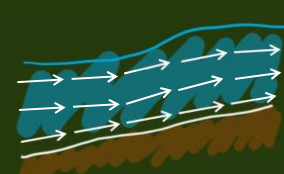
Fundamentals of Open Channel Flow

Types of Flow

- Uniform Flow:
  - Depth remains constant along the channel.
  - Requires consistent cross-section, slope, and roughness.
- Non-Uniform (Varied) Flow:
  - Depth changes along the channel length (rapid or gradual).



Uniform flow



Non-Uniform flow

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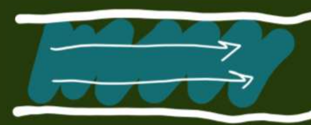
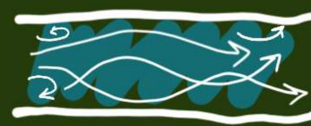
Fundamentals of Open Channel Flow

States of Flow:

- Laminar Flow:
  - Water moves in smooth, parallel paths (rare in natural channels).
- Turbulent Flow:
  - Water moves irregularly, creating white-water conditions (common in nature).



Laminar flow



Turbulent flow

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Fundamentals of Open Channel Flow

Assumptions:

- Steady flow: Flow rate remains constant over time at a given point.
- Uniform flow: Flow depth remains constant across all cross-sections.
- Velocity is averaged across the cross-section.
- Flow is laminar.

Limitations:

- If assumptions are invalid, a more detailed hydraulics analysis is required.

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Fundamentals of Open Channel Flow

Normal Depth:

- The flow depth in a channel under normal conditions.
- Determined using Manning's Equation.

Normal Velocity:

- The flow velocity in a channel under normal conditions.
- Determined using Manning's Equation.

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Manning's Roughness Coefficient

Natural Channels:

- Values depend on vegetation and channel characteristics.

Artificial Channels:

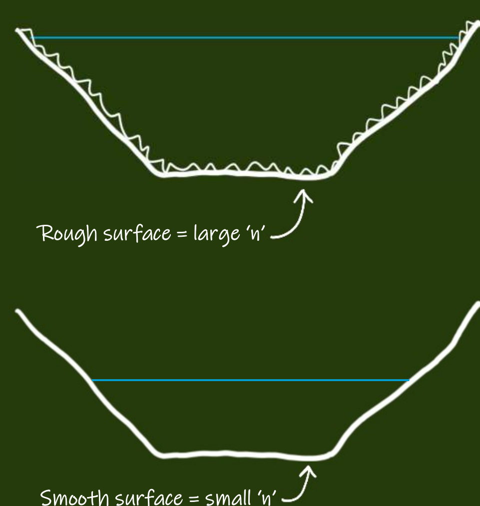
- Determined by lining roughness.

Grassed Channels:

- Use vegetative retardance curves when hydraulic radius < 1m.

Rock Lined Channels

- Determined by rock size, shape



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Manning's Equation

$$V = (1/n)R^{2/3}S^{1/2}$$

$$\mathrm{R} = A/P$$

V Average (normal) velocity (m/s)
R Hydraulic radius (m)
A Cross-sectional area of flow (m^2)
P Wetted perimeter (m)
S Slope of energy line (m/m)
(Assumed to equal slope of channel bed)
n Manning's roughness coefficient

Note: Manning's equation is unsuitable for irregular channel shapes.

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Continuity Equation

$$\mathrm{Q} = V\mathrm{A}$$

$$Q_1 = Q_2 \quad \text{or} \quad V_1A_1 = V_2A_2$$

Assumes no additions or subtractions to flow between sections e.g. $Q_1 = Q_2$.

Q Flow rate (m^3/s)
V Average (normal) velocity (m/s)
A Cross-sectional area of flow (m^2)

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Determine the flow rate and velocity for a channel flowing full.

- 1:4 batters
- 2.5m base width
- 0.5m deep
- 1% slope
- n = 0.035 (typical for grass)

Using Manning's equation, we can calculate the velocity.

$$V = 1/n\, R^{2/3}\, S^{1/2}$$

Then, we can apply the continuity equation to calculate the flow rate.

$$Q = VA$$

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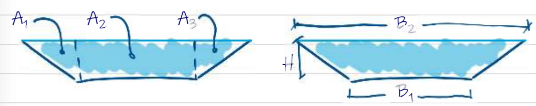
$$V = 1/n\, R^{2/3}\, S^{1/2}$$

But we need to calculate the hydraulic radius, which is

$$R = A / P$$

So, let's analyse the channel shape to obtain the area and wetted perimeter.

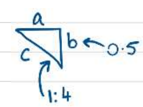
We are assuming the channel will flow full so the flow area will include the total channel area.



$A = A1 + A2 + A3$

Or trapezoidal area formula, $A = ½ \times (B_1 + B_2) \times H$

Batter slope to calculate dimensions of channel and Pythagoras to calculate hypotenuse:



$a^2 + b^2 = c^2$

$b = 0.5$ depth at 1:4 = $0.5 * 4 = 2.0$m

$c = \sqrt{a^2 + b^2} = \sqrt{0.5^2 + 2^2} = 2.062$m

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$A = ½ \times (B_1 + B_2) \times H$

$A = 0.5 \times (2.5 + 6.5) \times 0.5 = 2.250m^2$

Let's look at the wetted perimeter (where water interfaces with the channel surface)

P = side slope dimension + base + side slope dimension

$P = 2.062 + 2.5 + 2.062 = 6.623$m

Now we can calculate the hydraulic radius

$R = A / P = 2.250 / 6.623 = 0.340$m

We're ready for Manning's equation!

We can calculate the velocity of flow, when the channel is full

$V = 1/n\, R^{2/3}\, S^{1/2}$

$V = 1/0.035 \times 0.340^{2/3}\, 0.010^{1/2}$

$V = 1.391$m/s

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Finally, we can calculate the flow rate based on the velocity and cross-sectional area of the channel

$Q = VA = 1.391 \times 2.250 = 3.130m^3/s$

Remember, $1m^3$ of water is equal to 1,000 litres.

So this channel, flowing full, can convey $3.130m^3/s$ or 3,130L/s.

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Here are common topics we encounter in the industry:

- Channel lining solutions – geotextile, rock, grass, vegetation, concrete
- Hydraulic jumps – when supercritical flows occur in your channel
- Stage-Discharge curves
- Tailwater conditions
- Design criteria: D*V, erosive velocities, self-cleaning velocity, freeboard

If these sound familiar but you're not 100% confident, get in touch and we can deliver a technical workshop:

- Have your questions answered
- Run through hand-calculations
- Explore real-world examples
- Problem solve within a group

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Book a workshop!

- 💡 Managers save time while upskilling their team
- 💡 Increase staff engagement
- 💡 Achieve Professional Development goals
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