OPEN CHANNEL GEOMETRY OPTIMIZATION INCORPORATING CLIMATE CHANGE TO MITIGATE ASSET LOSSES

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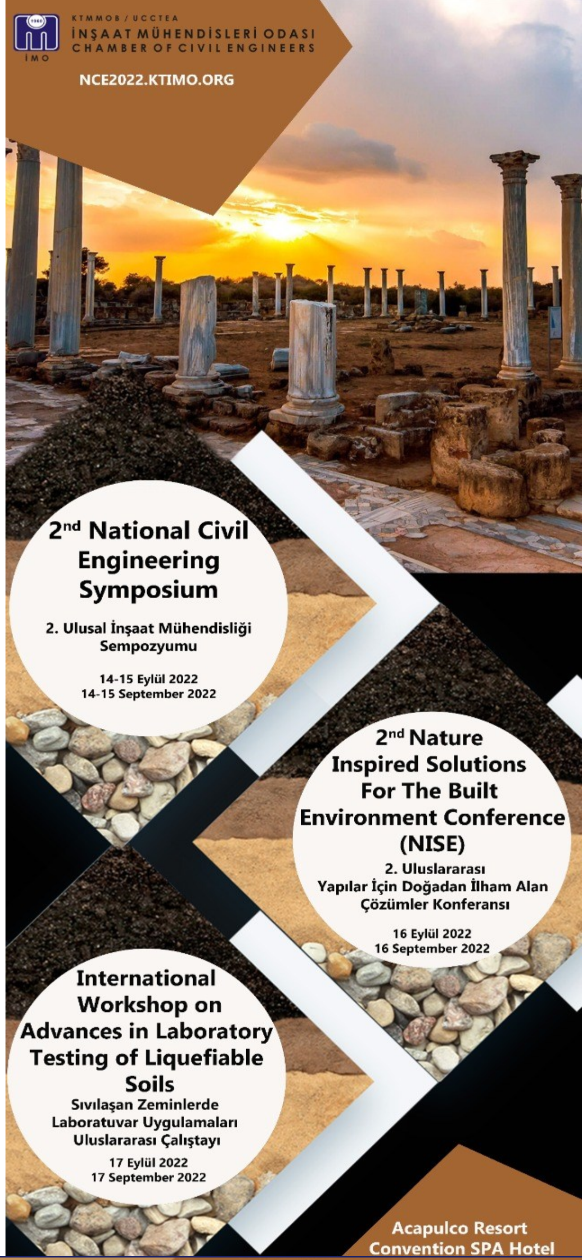

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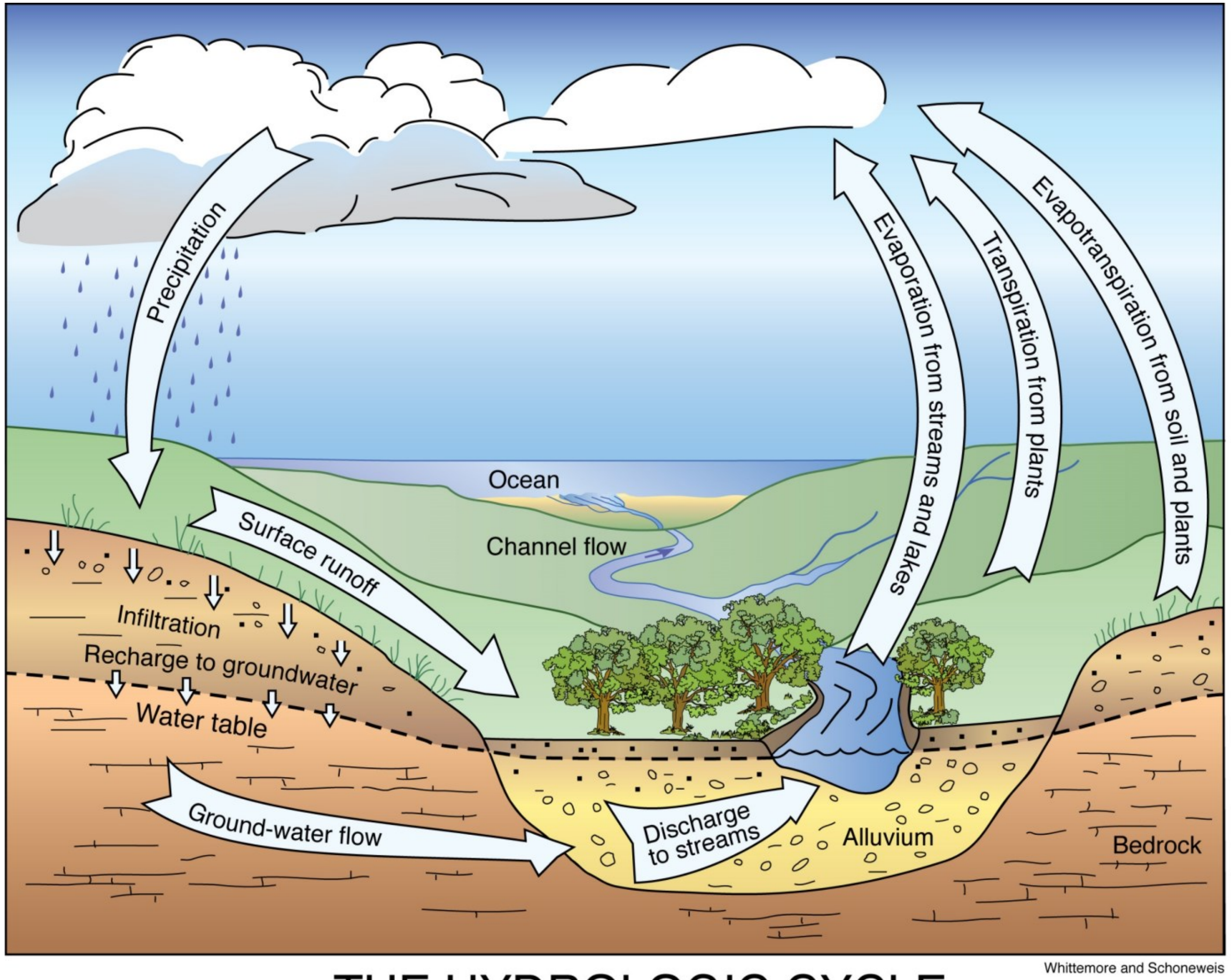
- *Story*
- *Challenge*
- *Open Channel Flow*
- *Channel Sections*
- *Optimisation*
- *Conclusion*

Story

Whole story is about understanding the Hydrologic Cycle.



THE HYDROLOGIC CYCLE

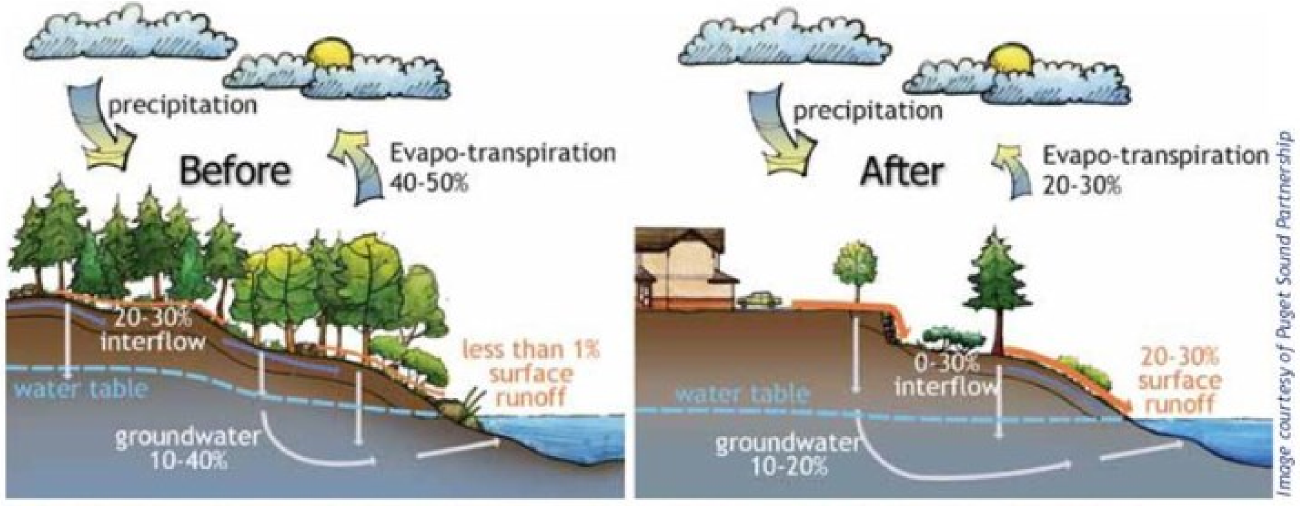
Is it manageable?

Yes! Indeed!

Story

Surface Runoff (**SR**, also known as overland flow) is the flow of water occurring on the ground surface when excess rainwater, stormwater, meltwater, or other sources, can no longer sufficiently rapidly infiltrate in the soil.

Factors Affecting the **SR**;
Type of precipitation (rain, snow, sleet, etc.)
Rainfall intensity,
Rainfall amount,
Rainfall duration,
Distribution of rainfall over the watersheds, and
Density of the hardstanding areas.



Is it manageable?

Yes! Indeed!

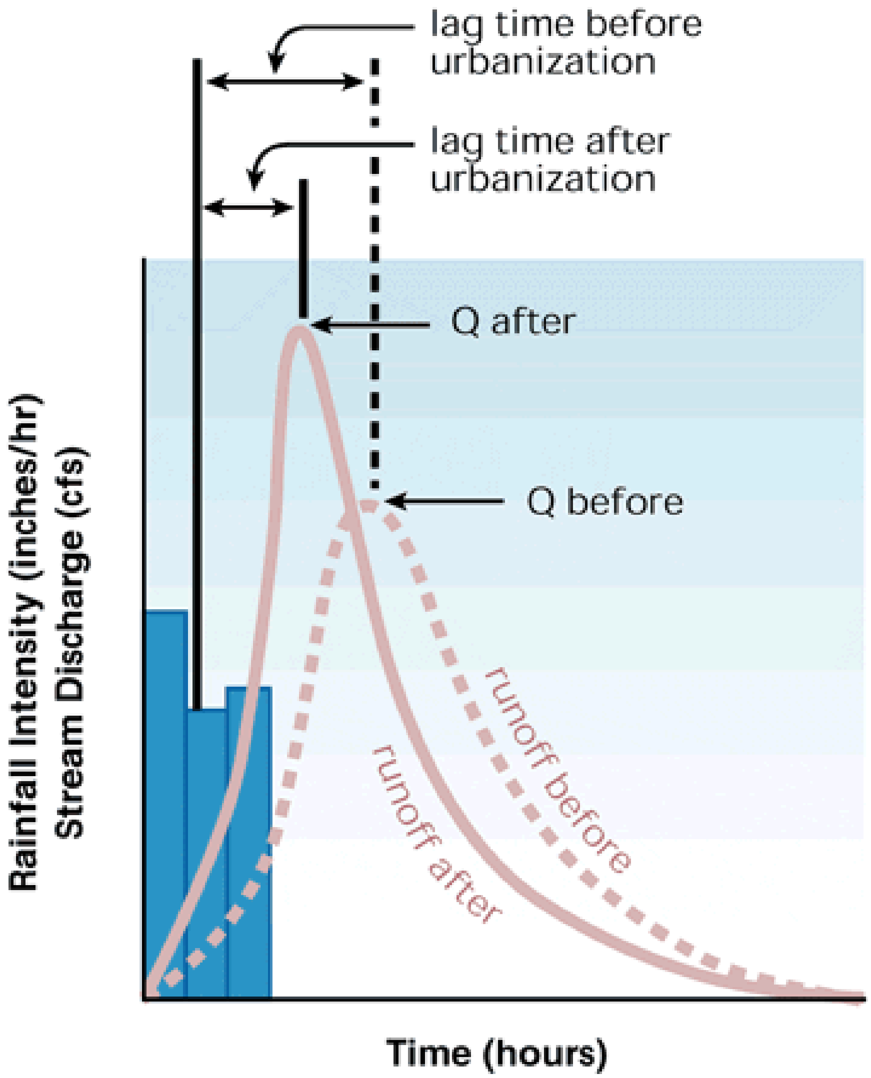
Story

Hardstanding areas, increases impermeable surfaces that quickens the flush discharges after a storm as surface runoff.

All hardstanding areas, in developed regions, are normally drain into **channels** those are designed to transmit stormwater.

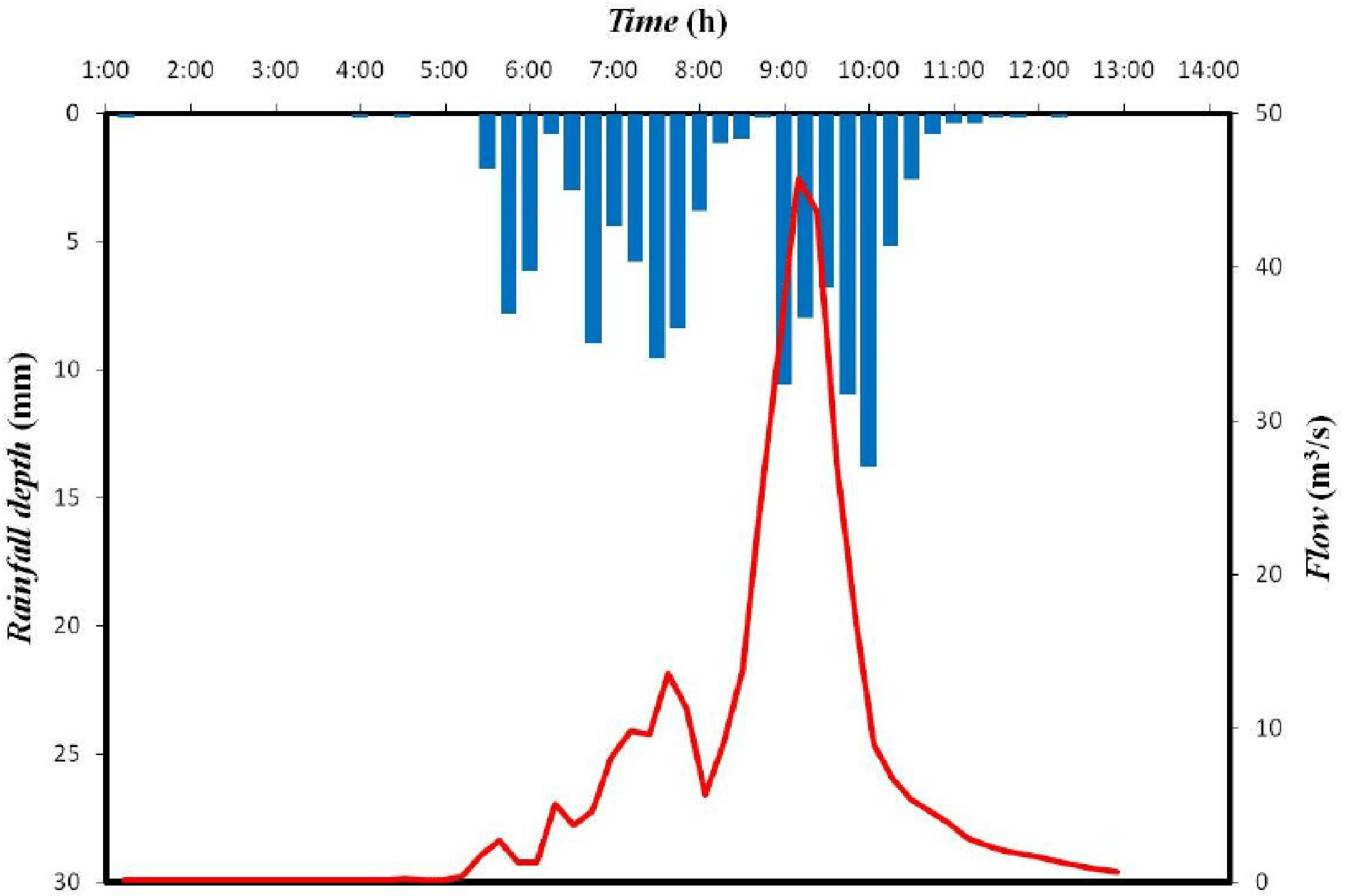
Is it manageable?

Yes! Indeed!



A typical hydrograph

Story



Hyetograph, shows how much it has rained, usually recorded/measured in mm (or kg) *CAN ALSO BE FORCASTED*.

Hydrograph, shows rate of flow (called discharge), usually measured in m^3/s *CAN ALSO BE ESTIMATED.*

Challenge

… here is to understand the crucial term called **CLIMATE CHANGE**.

NOT THE GLOBAL WARMING!

Challenge… (in understanding the Climate Change)

5 effects of climate change

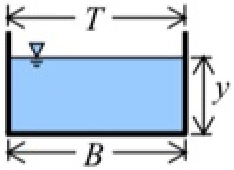
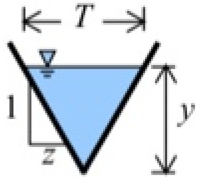
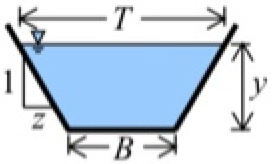
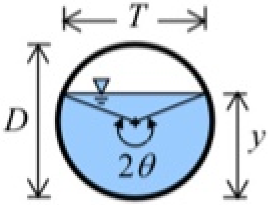
frequent and intense

- drought,
- storms,
- heat waves,
- rising sea levels,
- melting glaciers and,
- warming oceans.

Open Channel Flow

Channel geometries may differ but all transmitting water with a free surface.

EVEN IN PIPE SECT

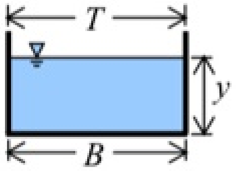
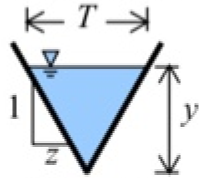
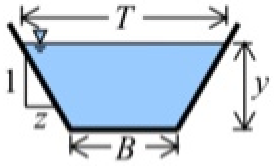
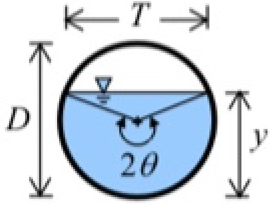
Section	Area A	Top width T	Wetted perimeter P
 Rectangular	By	B	$B+2y$
 Triangular	zy^2	$2zy$	$2y\sqrt{1+z^2}$
 Trapezoidal	$By+zy^2$	$B+2zy$	$B+2y\sqrt{1+z^2}$
 Circular	$\frac{D^2}{8}(2\theta-\sin 2\theta)$	$D\sin\theta$	θD

Optimum Section

Main source of the flow in all geometries is the **gravity**!

Amongst all, most economical solution is the one giving the maximum discharge for the selected section.

APPLICABILITY IS A CONSTRAINT

Section	Area A	Top width T	Wetted perimeter P
 Rectangular	By	B	$B+2y$
 Triangular	zy^2	$2zy$	$2y\sqrt{1+z^2}$
 Trapezoidal	$By+zy^2$	$B+2zy$	$B+2y\sqrt{1+z^2}$
 Circular	$\frac{D^2}{8}(2\theta-\sin 2\theta)$	$D\sin\theta$	θD

Open Channel Flow Velocity

Antoine de

Chezy

$$V = C\sqrt{R_h S_o}$$

V is average velocity [m/s]
C is the Chezy coefficient
R_h is the hydraulic radius (*A*/*P*) [m]
S_0 is the hydraulic gradient

Philippe - Robert

Gauckler – Manning

$$V = \frac{k}{n} R_h^{2/3} S_o^{1/2}$$

V is average velocity [m/s]
k is the conversion factor between SI and Imperial
n is the Gauckler-Manning coefficient
R_h is the hydraulic radius (*A*/*P*) [m]
S_0 is the hydraulic gradient

Open Channel Flow Velocity and Discharge

General expression for the mean velocity in an open channel flow is

$$V = kR_h^a S^b$$

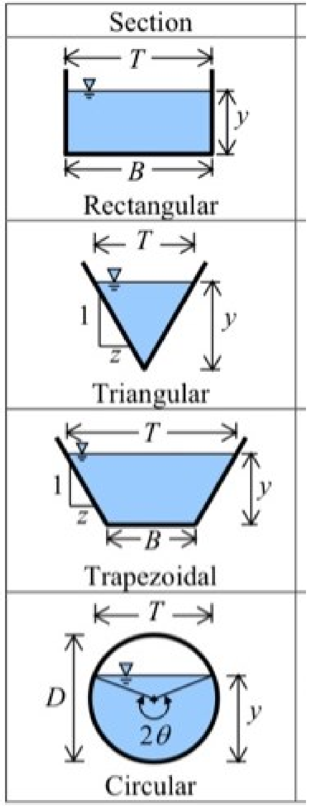
or based on the continuity, the discharge in an open channel flow is

$$Q = AkR_h^a S^b$$

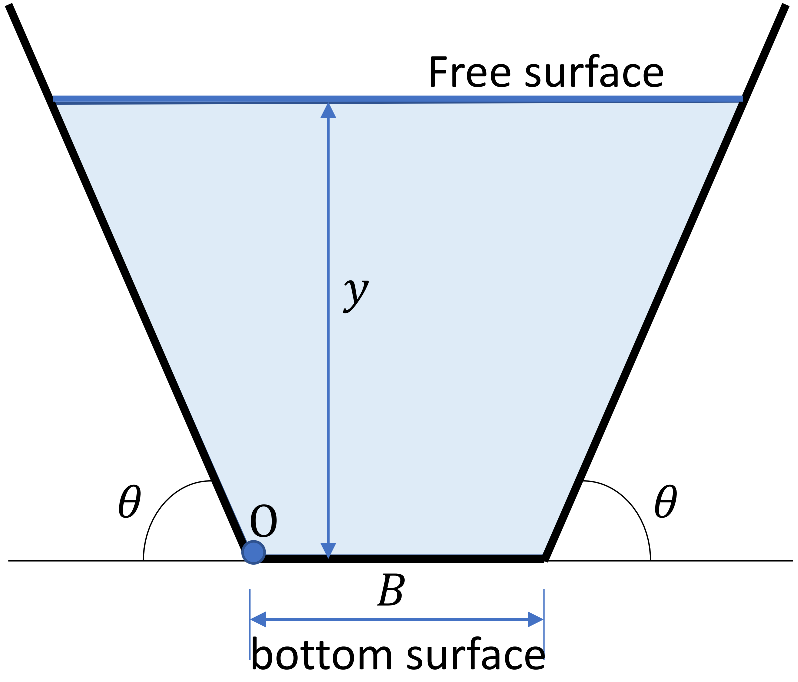
V is average velocity [m/s]
k is the flow resistance factor
A is the cross-sectional area [m^2]
a and *b* are hydraulic components

Q is discharge [m^3/s]
R_h is the hydraulic radius or hydraulic mean depth
S is the channel slope

Channel Section



Simply setting the origin to be at O;



$$Area\ A = \int_0^y \int_{ycot(\pi-\theta)}^{ycot\theta+B} dxdy$$

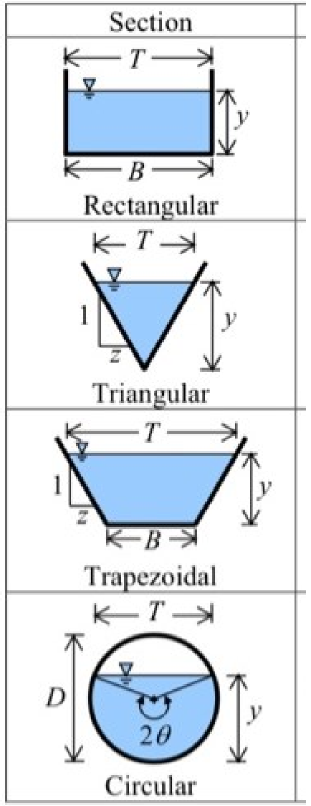
where; $ycot(\pi - \theta) \leq x \leq ycot\theta + B$

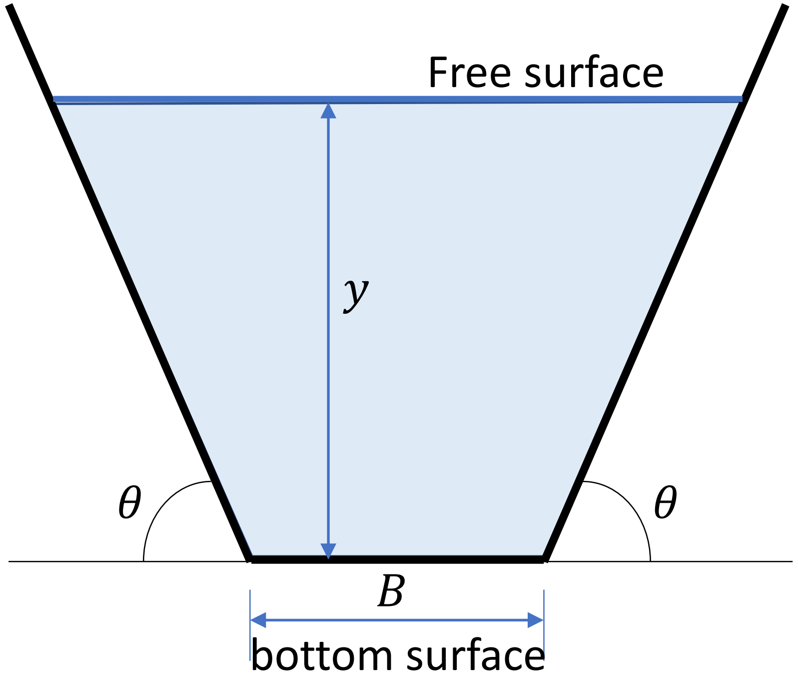
since; $cot(\pi - \theta) = -cot\theta$

Therefore; $\mathrm{A} = By + y^2 * cot\theta$

and $\mathrm{P} = B + 2y * csc\theta$

Channel Section

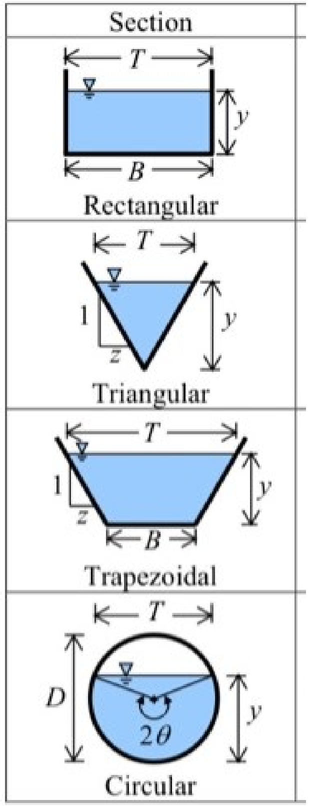


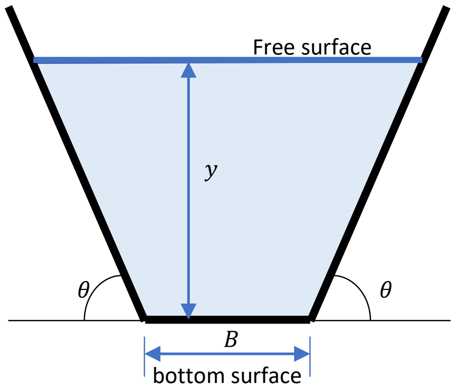


Hydraulic, R_h becomes;

$$R_h = \frac{A}{P} = \frac{By + y^2 * cot\theta}{B + 2y * csc\theta}$$

Channel Section Optimisation



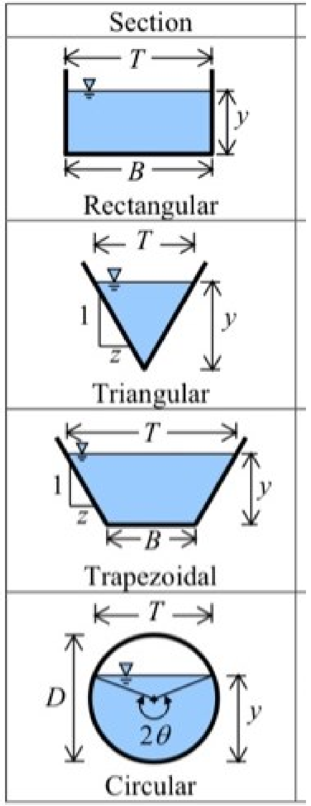


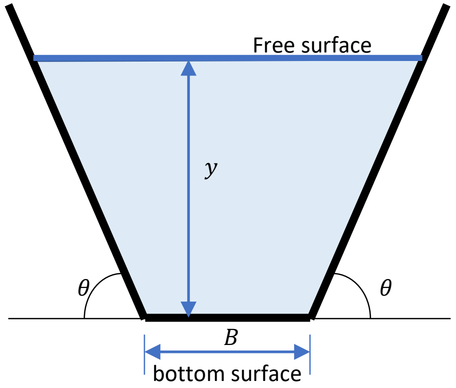
y can never be zero! to maintain an area for the flow. So; $y \neq 0$.

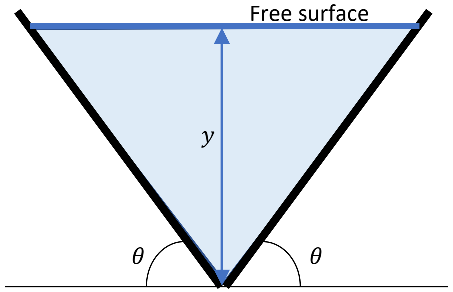
Setting $B = 0$ converts the section area into a **TRIANGULAR** channel.

Setting $\theta = 90^{\circ}$ converts the section in rectangular channel.

Channel Section Optimisation







$For\ simplicity,\ and\ minimizing\ the\ wetted\ perimeter,$
$let's\ consider\ a\ Trigular\ Cross\ Section$

Wetted Perimeter

$$P = \lim_{B \to 0}(B + 2y * csc\theta) = 2y * csc\theta$$

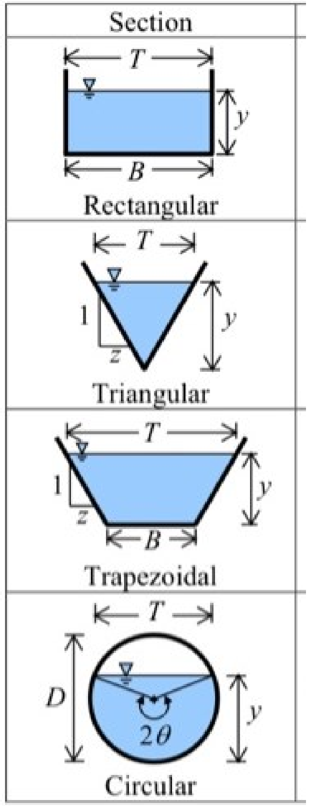
Area

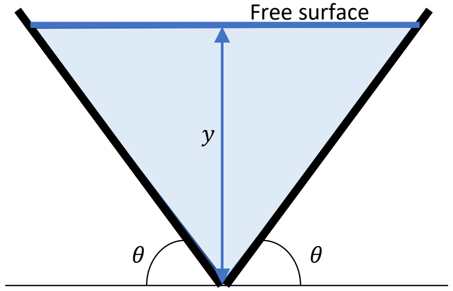
$$A = \lim_{B \to 0}(By + y^2 * cot\theta) = y^2 * cot\theta$$

Hydraulic Radius becomes

$$R_h = \frac{A}{2y * csc\theta} = \frac{A}{2\left[\sqrt{\frac{A}{cot\theta}}\right] csc\theta}$$

Channel Section Optimisation





$$For\ an\ optimum\ channel\ slope$$

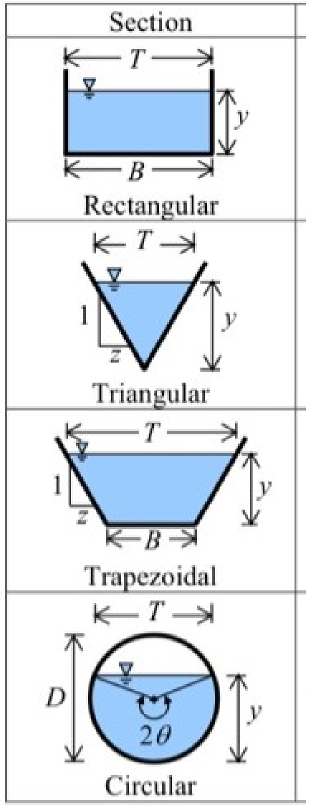
Minimum required area needs to be maintained so the denominator needs to be minimized in the Hydraulic Radius equation. So denominator needs to be differentiated w.r.t. θ

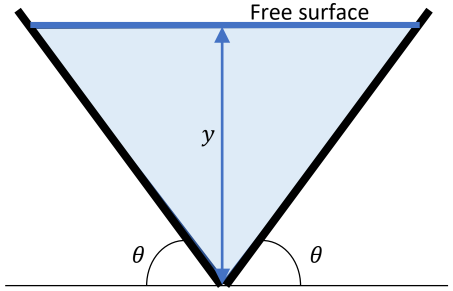
$$\frac{\partial}{\partial\theta}\left[2\left[\sqrt{\frac{A}{cot\theta}}\right]csc\theta\right] = 2\sqrt{A}\,\frac{\partial}{\partial\theta}\left[\frac{csc\theta}{\sqrt{cot\theta}}\right] = 0$$

Since $A \neq 0$

Therefore $$\frac{\partial}{\partial\theta}\left[\frac{csc\theta}{\sqrt{cot\theta}}\right] = 0$$

Channel Section Optimisation





$$Solving\ for\ the\ previous\ equation$$

$$-csc^2\theta + sec^2\theta = 0$$

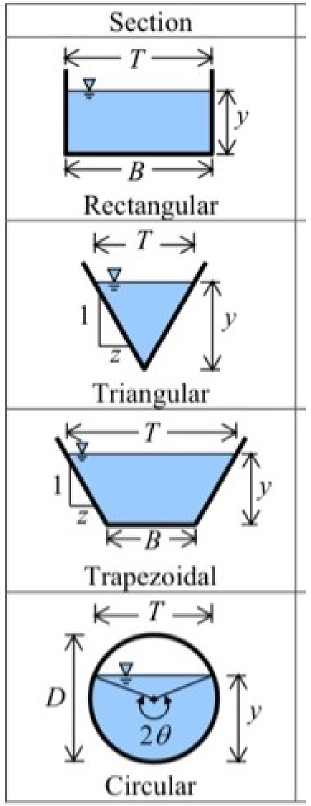
Therefore;

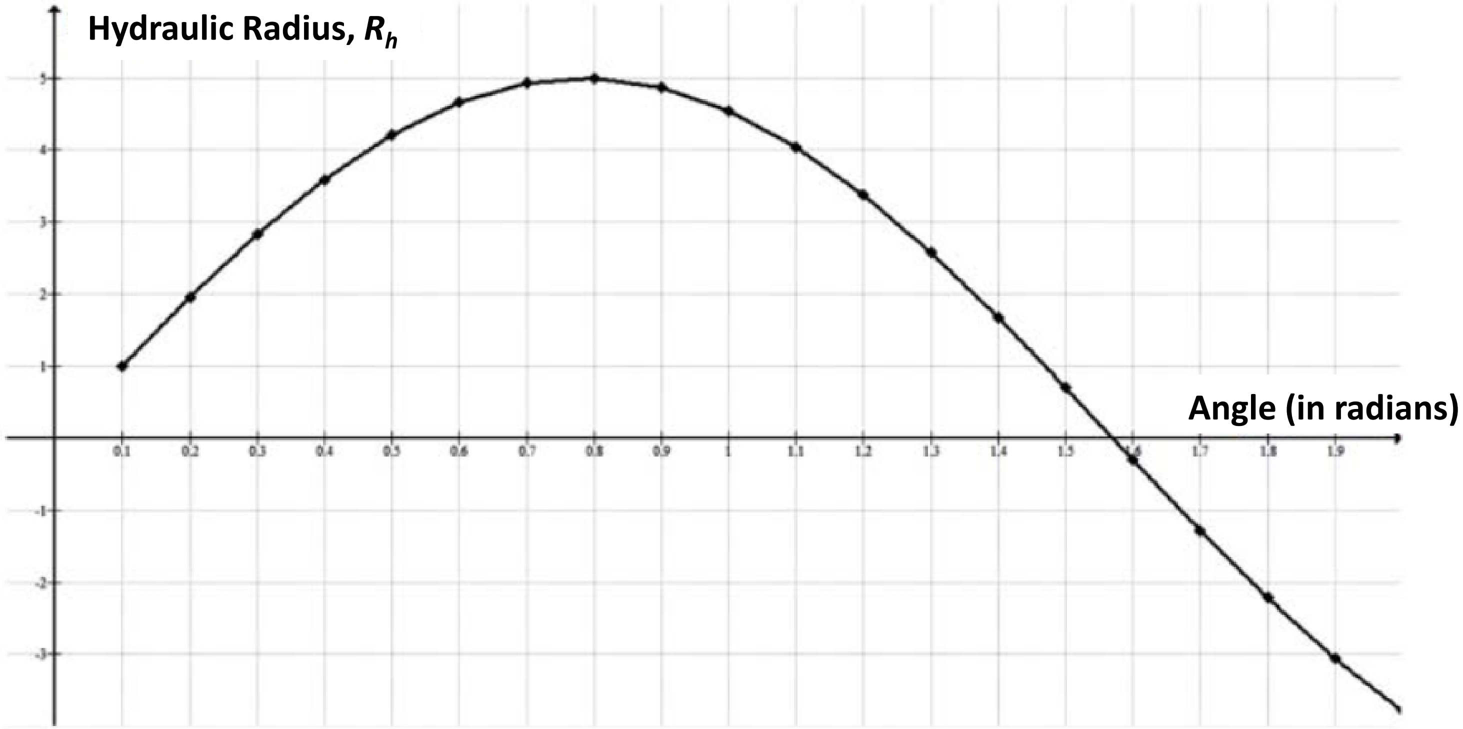
$$cos\theta = sin\theta \Rightarrow \theta = \frac{\pi}{4}$$

The most economical triangular channel therefore needs to have side slopes to be 45°.

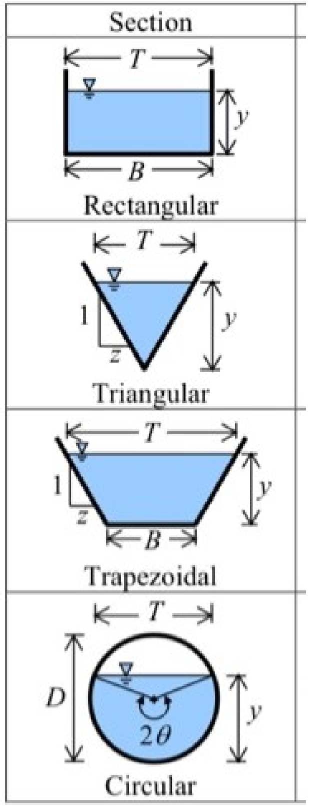
Channel Section Optimisation

Graphical representation of the above calculations also indicating the turning point of the curve at $\theta = \frac{\pi}{4} = 0{,}785398 \ldots$



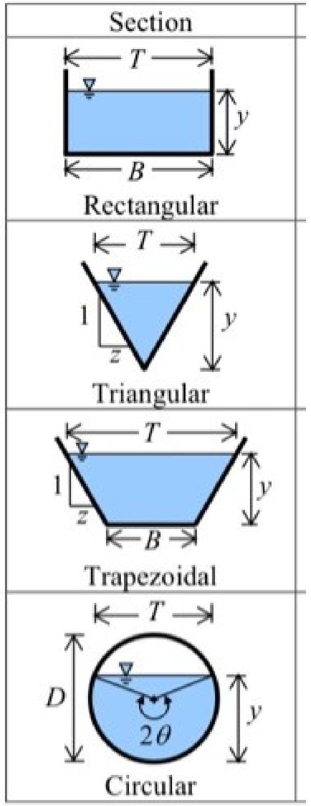


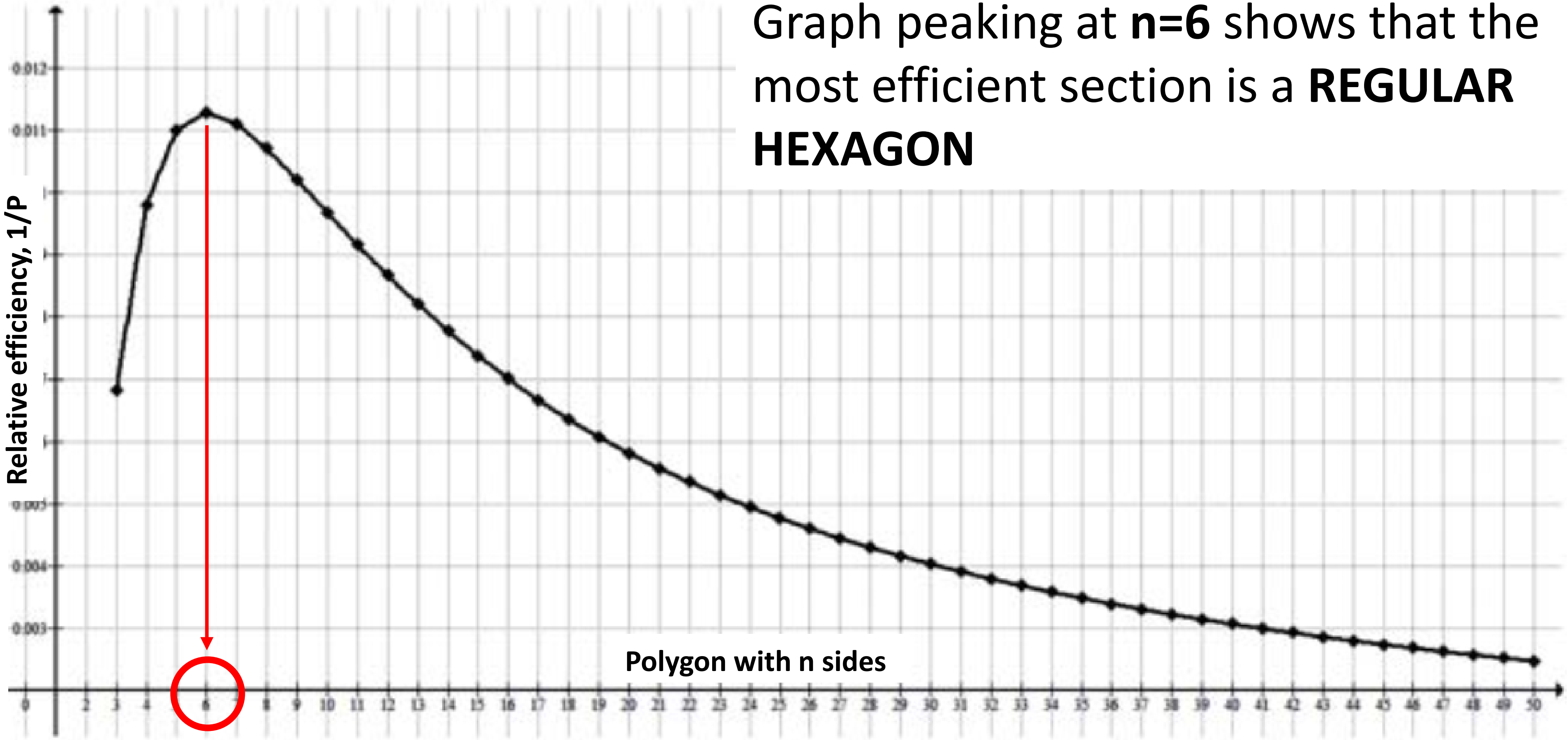
Channel Section Optimisation



- Using similar approaches and calculations efficiency of regular trapezoidal channel sections with different side slope angles, θ
- Using different number of sides of a regular polygon
- Using efficiency of different sections by employing wetted perimeter, P, as the main parameter

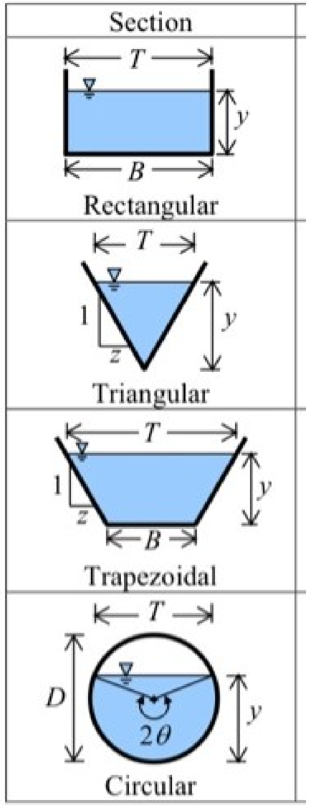
Channel Section Optimisation





Graph peaking at **n=6** shows that the most efficient section is a **REGULAR HEXAGON**

Conclusion



- It is very well know that the best hydraulic section for a flow conformity is a circular section!

- Its engineers duty to find the **OPTIMUM** solution!

- Considering the applicability and minimizing the cost of construction, the **MOST EFFICIENT** section is the half regular hexagon, that is **TRAPEZOIDAL SECTION**.


THANKS FOR LISTENING
TO MY PRESENTATION