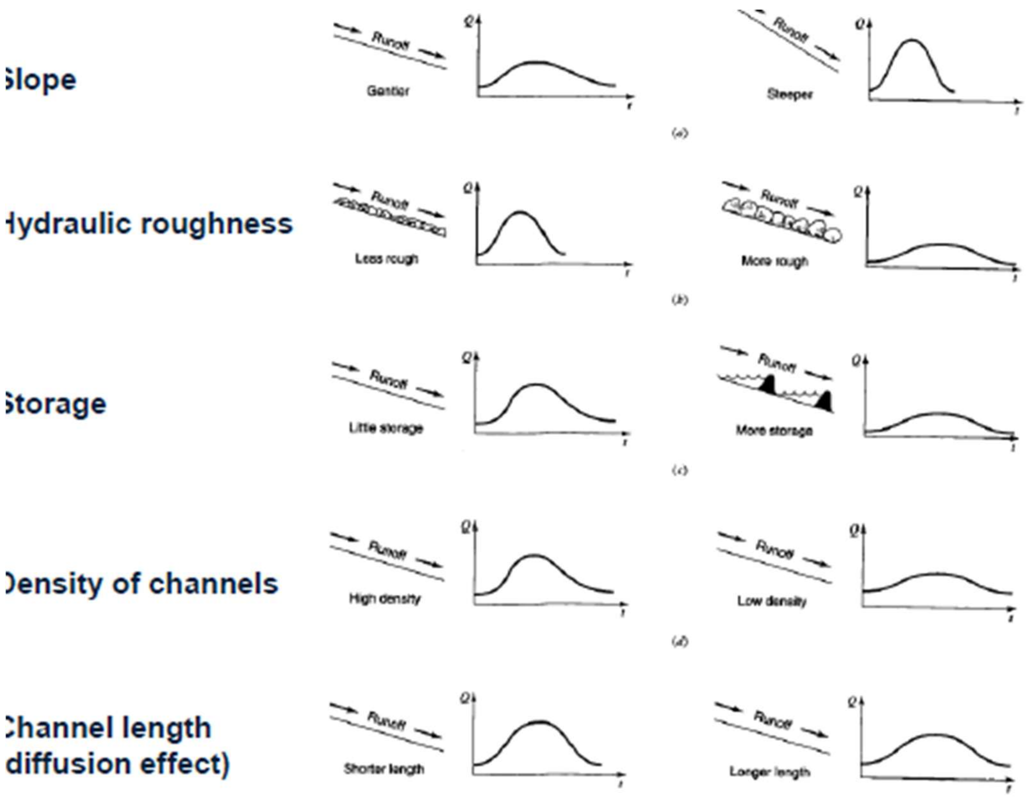
1.

(a) Students should mention at least four of the following catchment characteristics and then sketch their effect on the hydrograph as per figure below. One point shall be given for each catchment characteristic identified, for a possible total of 4 points.

- Size: More intense rainfalls are generally distributed over a relatively smaller area; a stream collecting water from a small catchment area is likely to give greater runoff intensity per unit area (a hydrograph with a big peak early on)
- Slope: If the surface slope is steep, water will flow quickly, and absorption and evaporation losses will be less, resulting in greater runoff.
- Storage: more storage along the catchment (reservoirs, natural lakes,wetlands), less pronounced the hydrograph peak, because surface runoff travelling downstream is slowed down by the storage
- Roughness: greater roughness will lead to lower runoff and a flatter hydrograph.
- Density: greater channel density can contribute to greater surface runoff as water finds an easy way to travel fast downstream. Low channel density typically means that water travels downstream more slowly, and thus the hydrograph will also be flatter.
- Geology: catchments underlain by highly permeable rocks (sandstone) tend to have flatter hydrographs, as more water infiltrates into the groundwater and contributes to baseflow, which is less variable than surface runoff. In catchments with impermeable soils (clays), we typically get hydrographs with more pronounced peaks in response to rainfall.



(b) A duration curve is a graph showing the fraction (percent) of time that the magnitude of a given variable is exceeded.

Step 1: Sort (rank) average daily discharges for period of record from the largest value to the smallest value, involving a total of n values.

Step 2: Assign each discharge value a rank (M), starting with 1 for the largest daily discharge value.

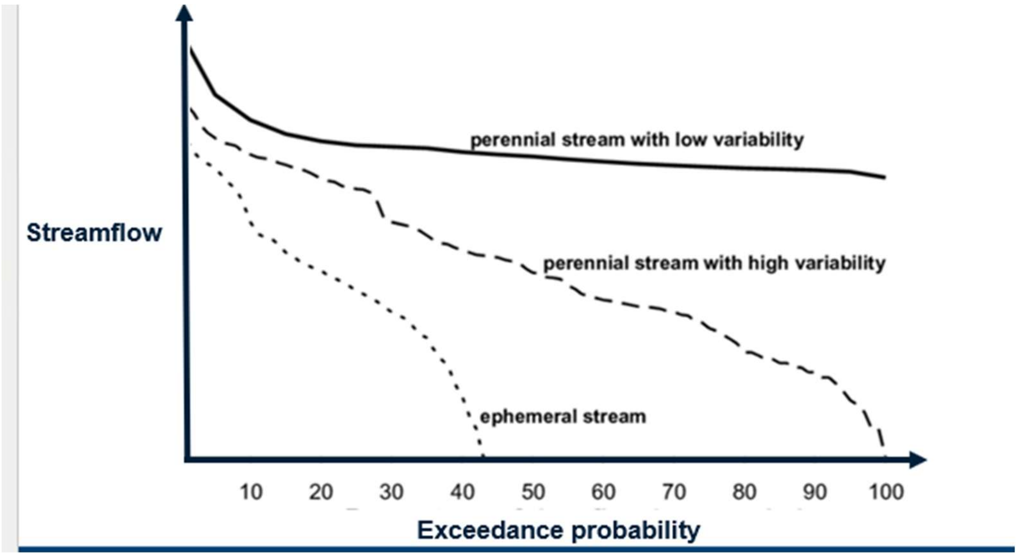
Step 3: Calculate exceedance probability (P) as follows:

$P = 100 * [M / (n + 1)]$

P = the probability that a given flow will be equaled or exceeded (% of time)

M = the ranked position on the listing (dimensionless)

n = the number of events for period of record (dimensionless)



(c)

Hour	**Rainfall** P	**Interception** L	**Throughfall** P_g	**Infiltration** I	**Runoff** R
1	15.0	1.0	14.0	9.3	4.7
2	20.0	1.0	19.0	8.2	10.8
3	20.0	1.0	19.0	7.4	11.6
4	5.0	1.0	4.0	4.0	0.0

Infiltration capacity of the soil (f) is highest at the onset of rain and decreases to a constant, because rainwater can both fill the voids between soil particles (storage) and seep through the soil. At the beginning, the soil is drier, so it has a higher capacity to store rainwater. Once soil is saturated, the storage stops, and only seepage is possible, so f becomes a constant.

2. (a)

i) In a saturated granular medium at any given point.

Pore water pressure 'P' is the water pressure at that point. When there is no water flow, this would be the hydrostatic pressure (in kPa).

Pressure head 'h' is the height to which water would rise in a stand pipe inserted to that location. It is measured in m.

$$h = P/\gamma_w$$

Potential head $\bar{h}$ is defined as the pressure head above a datum.

$$\bar{h} = h + y$$

where 'y' is the elevation head above the datum. It is +ve if the point is above the datum and -ve if the point is below the datum. [10%]

b) In a soil layer, the level to which water is present is called the water table, if there is no ground water flow.

However, when there is ground water flow occuring through the soil due to seepage, the water surface is called the phreatic surface.

The soil above the phreatic surface can be dry or saturated (but under suction pressures) depending on the capillary rise and the air entry value for the soil. [10%]

c) The earth dam given is anisotropic as $K_h \neq K_v$.

$$K_v = 2.4 \times 10^{-6} \text{ m/s}$$

$$K_h = 9.6 \times 10^{-6} \text{ m/s}.$$

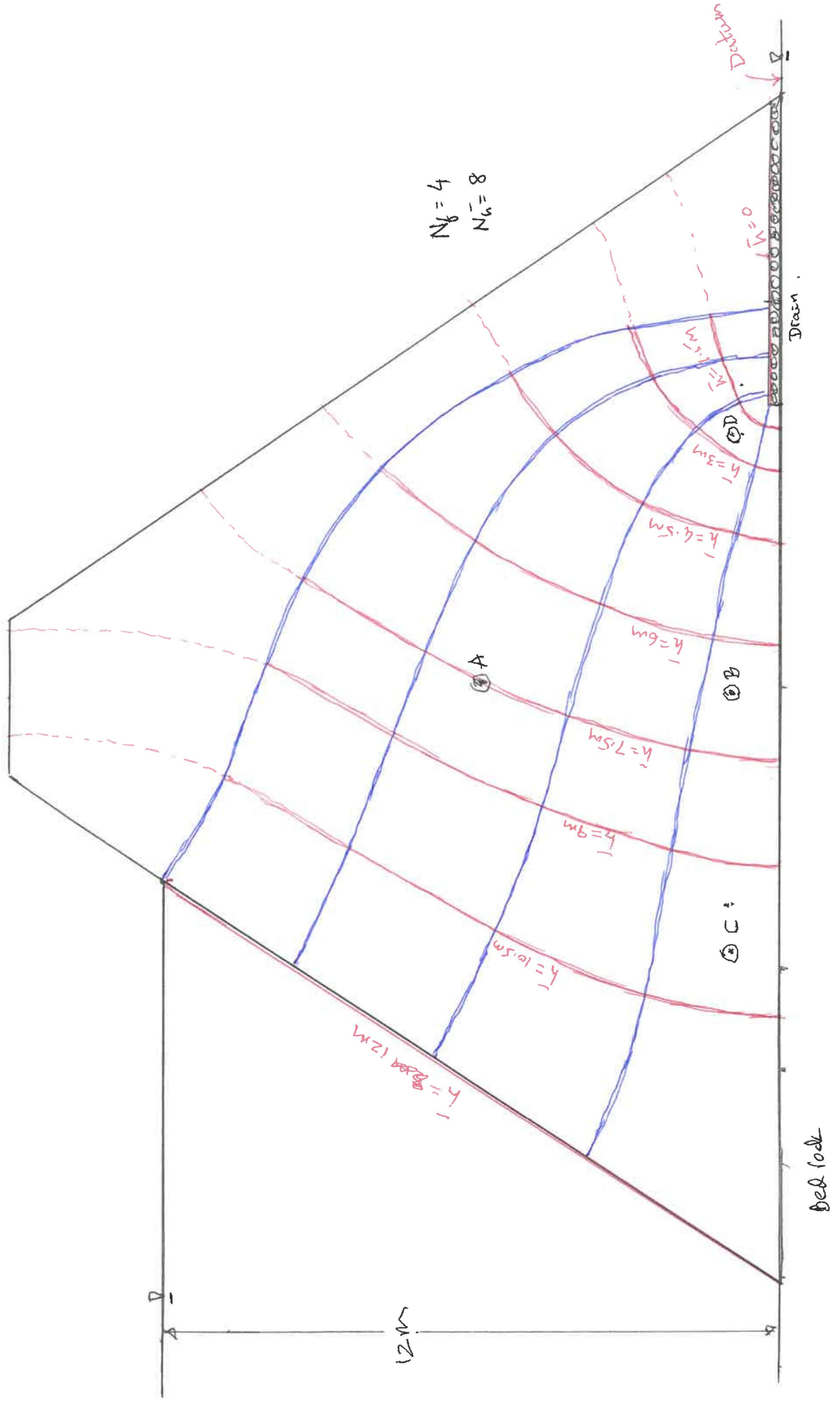
$$\therefore \text{Anisotropy ratio } \alpha = \sqrt{\frac{K_h}{K_v}} = \sqrt{\frac{9.6}{2.4}} = \sqrt{4} = 2.$$

So we must construct the geometry of the earth dam by scaling the x axis down by a factor of 2.

Use x axis scale as 1 cm = 2 m

y axis scale as 1 cm = 1 m.

As the dam has 'no air entry' soil above the phreatic surface remains saturated



$N_f = 4$
$N_d = 8$
Datum
$h = 0$
Drain
$h = 1.5m$
D
$h = 3m$
$h = 4.5m$
$h = 6m$
A
B
$h = 7.5m$
$h = 9m$
C
$h = 10.5m$
$h = 12m$
Bed rock
12m

Seepage flow through the dam

$$Q = \sqrt{K_h K_v}\ \Delta h\ \frac{N_f}{N_d}.$$

$$= \sqrt{2.4\times10^{-6} \times 9.6\times10^{-6}} \times 12 \times \frac{4}{8}$$

$$= 2.9976\times10^{-5}\ m^3/s\ /m = 2589.93 \text{ litres/day/m}.$$

[30%]

1 d) $\rho_{sat} = 1830\ kg/m^3 \therefore$ Unit weight $= \gamma_{sat} = \cancel{17.95}\ 18.3\ kN/m^3$ taking $\gamma_w = 10\ kN/m^3$

Pore water pressures from flow net.

At A : $\bar{h} = 7.5m$ $\bar{y} = 6m$ above datum

$\hat{h} = \bar{h} - y = 7.5 - 6.0 = 1.5m \Rightarrow p_A = 15\ kPa$.

At B = $\bar{h} = 6.75m$ $y = 1m \Rightarrow h = 5.75m \Rightarrow p_B = 57.5\ kPa$.

At C = $\bar{h} = 10m$ $y = 1m$ $h = 9m \Rightarrow p_C = 90\ kPa$

At D $\bar{h} = 2.25m$ $y = 1m$ $h = 1.25m \Rightarrow p_D = 12.5\ kPa$.

$\therefore$ Hydraulic gradient $i_{C-D} = \frac{10 - 2.25}{20} = 0.3875$

Total Stress at

A $\Rightarrow \sigma_{vA} = \gamma_{sat} \times (15-6) = 164.7\ kPa$ $\therefore \sigma'_{vA} = 164.7 - 15 = 149.7\ kPa$.

B $\rightarrow \sigma_{vB} = \gamma_{sat}\ (15-1) = 256.2\ kPa$ $\therefore \sigma'_{vB} = 256.2 - 57.5 = 198.7\ kPa$

C $\rightarrow \sigma_{vC} = \gamma_{sat} \times 8.7 = 159.21\ kPa$ $\therefore \sigma'_{vC} = 159.21 - 90 = 69.21\ kPa$

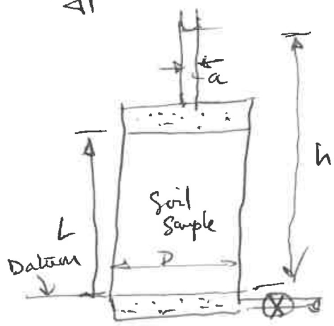
D $\Rightarrow \sigma_{vD} = \gamma_{sat} \times 8.7 = 159.21\ kPa$ $\therefore \sigma'_{vD} = 159.21 - 12.5 = 146.71\ kPa$

[35%]

1e) If the dam was to be constructed as 'isotropic' then the dam geometry will not be scaled differently for x and y directions. ($K_h = K_v$) Therefore the flow lines will be longer through the dam. This would mean that the seepage flow through the dam will reduce.

[15%]

a) Falling head permeameter :- This apparatus is used for determining the hydraulic conductivity K' of a fine grained soils like silts & clays. The experiment starts by opening the outlet of the sample and starting a stop watch. The height of water, ie head is measured above a datum at different times. The outflow from the sample need not be collected or measured.



The crossectional area of the tube is 'a'. The area ratio between soil sample and the tube.

$$A_r = \frac{\pi D^2/4}{a}$$

This area ratio needs to be quite large (>1000) for the falling head permeameter to be effective [10%]

b) Let us assume a small change in head dh, occurs in a time dt.

Volume of water $= a\,dh$. flow rate $Q = a\frac{d\bar{h}}{dt}$ → ①

The same volume of water has to flow through the soil sample.

$$\therefore \quad Q = KiA = K\frac{\pi D^2}{4} \times \frac{\bar{h}}{L} \rightarrow ②$$

Equating ① and ②

$$K\frac{\pi D^2}{4} \times \frac{\bar{h}}{L} = a\frac{d\bar{h}}{dt}$$

$$K\frac{\pi D^2}{4aL}\,dt = \frac{d\bar{h}}{\bar{h}}$$ ⇒ Integrating both sides $K\frac{\pi D^2}{4aL}\int dt = \int\frac{d\bar{h}}{\bar{h}}$

If at t_1 the head $= \bar{h}_1$

& at t_2 the head $= \bar{h}_2$

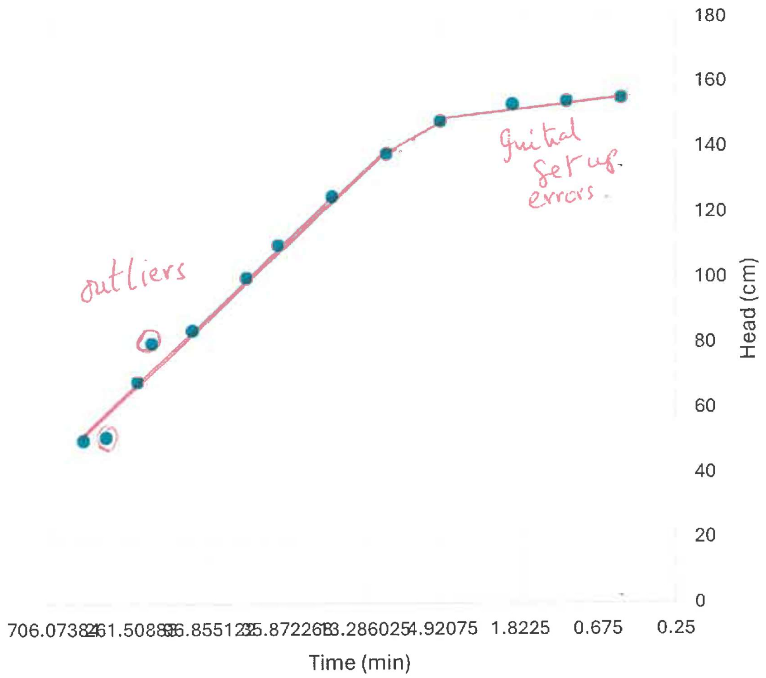
$$\therefore \quad K\frac{\pi D^2}{4aL}\int_{t_1}^{t_2} dt = \int_{\bar{h}_1}^{\bar{h}_2}\frac{d\bar{h}}{\bar{h}} \Rightarrow K\frac{\pi D^2}{4aL}(t_2 - t_1) = \ln\frac{\bar{h}_2}{\bar{h}_1}$$

$$\therefore \quad K = \frac{4aL}{\pi D^2}\,\frac{1}{(t_1 - t_2)}\,\ln\frac{\bar{h}_1}{\bar{h}_2}$$

[15%]

c) Plot the data on a semi-log scale & identify initial setup errors and outliers. Find the slope of the best fit line, ignoring outliers.

$$\text{Slope} \simeq \frac{\ln 88}{480-10} = 9.526 \times 10^{-3}\ \text{cm/min} = \cancel{1.588e{-}6\ \text{m/s}} = 1.588 \times 10^{-6}\ \text{m/s}.$$



$$\therefore\ K = \frac{4aL}{\pi D^2}\left[\frac{1}{t_2-t_1}\ln\frac{h_1}{h_2}\right] \leftarrow \text{slope of the line}$$

$$K = \frac{4 \times \pi d^2/4}{\pi D^2}\, L \times \text{slope} = \frac{8^2}{50.8^2} \times \frac{100}{1000} \times 1.588 \times 10^{-6}.$$

$$K = 3.937 \times 10^{-9}\ \text{m/s}.$$

This hydraulic conductivity is quite low and is indicative of clay sample. So falling head apparatus is the right apparatus. A constant head permeameter cannot be used in this case.

First ~~Each~~ drop of water will take $\simeq \frac{0.1}{3.937 \times 10^{-9}}$ s ~~&~~ a very long time! Also the flow rate through sample will be very small.

[35%]

d) Using Fourier's law.

$$H = -\lambda A \frac{\partial T}{\partial x}.$$

Power to heat $= VI = 24 \times 0.25 = 6$ watts.

$$A = \frac{\pi}{4} \times \left(\frac{50.8}{1000}\right)^2 = 2.0268 \times 10^{-3} \text{ m}^2.$$

$$\frac{\partial T}{\partial x} = \frac{(75^\circ - 10^\circ)}{0.1} = 650.$$

$$6 = \lambda \times 2.0268 \times 10^{-3} \times 650$$

$$\therefore \lambda = 4.55 \text{ W/m/K}.$$

This is reasonable for a saturated clay. [20%]

e) Volumetric heat capacity $VHC = \rho C_p$.

$\cancel{\rho} = \gamma_{sat} = 17.5$ kN/m³.

$\rho_{sat} = 1783.89$ kg/m³.

$C_p = 1.5$ kJ/kg/°K.

$\therefore VHC = 1783.89 \times 1.5 = 2675.84$ kJ/m³/°K.

Thermal diffusivity $\alpha = \frac{\lambda}{VHC} = \frac{4.55}{2675.84}$

$= \underline{\underline{1.7 \times 10^{-3}}}$ m²/s.

[20%]

4.

(a)

In a mild slope channel, the critical water depth is lower than the normal water depth, so the uniform flow is subcritical.

In a steep slope channel, the critical water depth is higher than the normal water depth, so the uniform flow is supercritical.

(b) The flow over the weir is supercritical, so the flow speed is only dependent on the water depth and the weir geometry. Therefore, the flow rate is only a function of the water depth, given the weir shape is fixed. By calibrating the relationship between the flow rate and the water depth, we can find the flow rate by measuring the water depth.

(c) Argue by contradiction. The flow should be uniform beyond certain distances upstream and downstream of the midpoint. As explained in the lecture notes, the water depth variation caused by the slope change is governed by the gradually varied flow equation. We will not be able to recover the normal depth sufficiently away from the midpoint, if the flow is either sub-critical or super-critical at the midpoint.

(d)

(i)

$A = bh + mh^2 = 22 \times 8 + 2 \times 8^2$ =304 m^2

$P_h = b + 2h\sqrt{1+m^2} = 22 + 2 \times 8 \times \sqrt{5}$ = 57.78 m

$R_h = \frac{A}{P_h} = 304/57.78$= 5.26 m

Manning: $U = \frac{1}{n} {R_h}^{2/3} {S_b}^{1/2} = \frac{1}{0.015} \times 5.26^{2/3} \times \left(\frac{100}{1270000}\right)^{1/2}$ = 1.8 m/s

$Q = UA = 1.8 \times 304$= 544 m^3/s,

(ii)

$$C = \frac{1}{n} {R_h}^{1/6} = 7.8 \ln\left(\frac{12R_h}{k_s}\right)$$

$$\frac{1}{0.015} \times 5.26^{1/6} = 7.8 \ln\left(\frac{12 \times 5.26}{k_s}\right)$$

$$87.92 = 7.8 \ln\left(\frac{12 \times 5.26}{k_s}\right)$$

k_s = 8 x 10^{-4} m = 0.8 mm