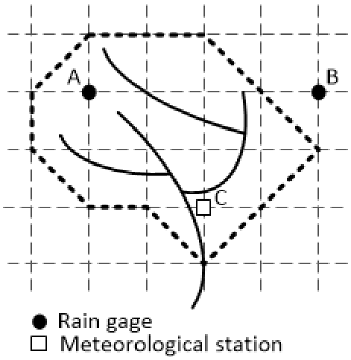
**INSTITUTO SUPERIOR TÉCNICO**
**Master of Environmental Engineering**
**Joint Master Programme on GroundWater and Global Change, Impacts and Adaptation**
**Hydrology, Environment and Water Resources**
**School year 2016/17 – Exam 1 – Duration: 2 hours**

*Each question is graded 2.0/20.0*

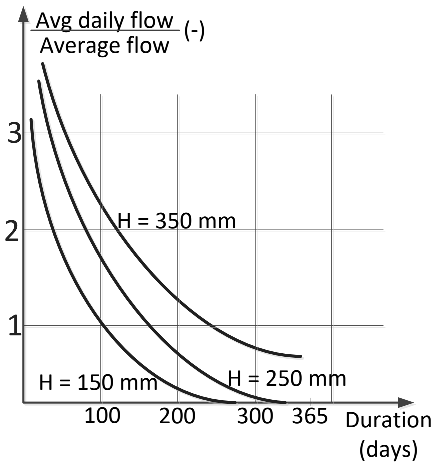
1. Consider the watershed on the right, with 1250 km$^2$. Also consider the 2 rain gages and the single meteorological station existing in the area. The average values of annual precipitation and annual evapotranspiration are shown in the table. Using the Thiessen method estimate the average annual precipitation over the watershed and compute the average daily discharge from the watershed, in m$^3$/s.

| Station | Precip (mm) | ET (mm) |
|---|---|---|
| A | 1200 | - |
| B | 1000 | - |
| C | 900 | 700 |




2. Evaporation from a water surface depends on a number of meteorological variables as expressed in the Penman equation. This equation estimates evaporation as a weighted average of two components, which are functions of the meteorological variables. What do these two major components represent and which meteorological variables are used to compute each one?

3. Consider the flow duration curves of a given region where a mini-hydropower plant is to be built. The watershed of the hydropower plant has 1450 km$^2$ and generates a discharge with an annual average of 16 m$^3$/s. Assuming that an ecological flow of 15% of the average flow has to be maintained in the river, downstream of the diversion, and that the plant has to work, on average, at least 200 days per year, estimate the minimum operating flow of the hydropower plant.




4. Consider the soil with the characteristics shown in the table, where a crop is irrigated once every week. At a given time, the crop has reached a growing stage which is associated with crop coefficient of 1.2. How much water (in mm) should be provided to the crop in a week when the weekly precipitation is 2 mm and the weekly potential evapotranspiration for a reference crop is 35 mm? For the same meteorological conditions, can the farmer provide twice that amount of water and irrigate only once every two weeks?

5. Consider the same soil from the previous question. During 20 minutes a rainfall event with an intensity of 60 mm/h generates superficial flow that starts immediately after the beginning of the precipitation and that totalizes 13 mm at the end of the event. Use the Green-Ampt model to estimate the soil moisture content at the beginning of the precipitation event.

| Parameter | Value |
|---|---|
| Soil depth, h (m) | 0,50 |
| Porosity, n (m/m) | 0,50 |
| Saturated soil water content, $\theta$s (m/m) | 0,46 |
| Field capacity, $\theta$cc (m/m) | 0,30 |
| Wilting point, $\theta$e (m/m) | 0,15 |
| Suction head (mm) | -40,0 |
| Hydraulic conductivity when saturated, Ks (mm/h) | 5,0 |

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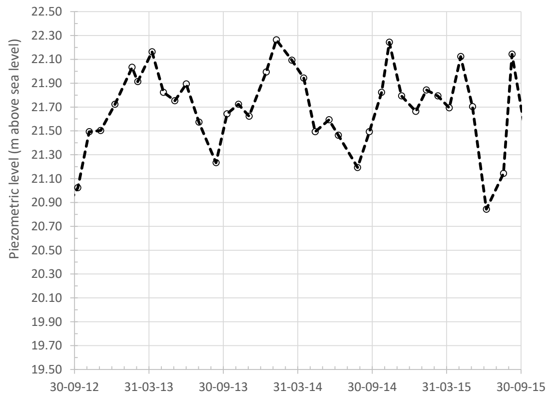
6. Considering that the following figure represents the annual fluctuation of the piezometric level in an unconfined sandy aquifer located in a region of Portugal with average annual rainfall of 850 mm, calculate the groundwater recharge for the year 2014. For the calculations you use a value of specific yield (Sy) of the equal to 0,15.




7. Identify, the main factors that influence the hydrological response of a watershed to a single and short precipitation event, briefly explaining in what way each one affects the response.

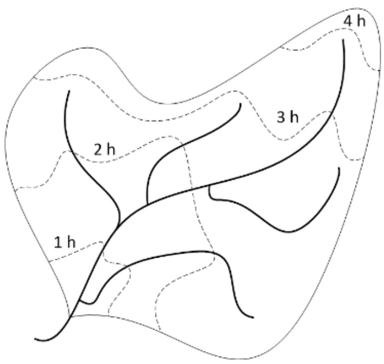
8. On a given day, a riverine town suffers a flood when the precipitation over the watershed upstream of the town and the discharge of a nearby river presents the following records.
   a. Estimate the time of concentration of the watershed, in hours.
   b. Estimate the area of the watershed, in km$^2$.
   c. Estimate the unit hydrograph of the watershed.

| Time interval (h) | 0-0.5 | 0.5-1.0 | 1.0-1.5 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Precipitation (mm) | 20 | 50 | 10 | | | | | | | | |
| Time (h) | 0 | 0.5 | 1.0 | 1.5 | 2.0 | 2.5 | 3.0 | 3.5 | 4.0 | 4.5 | 5.0 |
| Discharge (m3/s) | 0 | 100 | 450 | 950 | 1400 | 1110 | 630 | 320 | 140 | 20 | 0 |

9. The flow record of the river cross section referred in the previous question has the statistics presented in the table. Assuming a log-normal distribution, estimate average recurrence period of the flood described in the previous question and check if it exceeds 50 years, the minimum threshold accepted by insurance companies to pay for the flood damages.

| | Q | LnQ |
|---|---|---|
| N | 35 | 35 |
| Average | 685 m$^3$/s | 6,41 |
| Standard deviation | 345 m$^3$/s | 0,49 |
| Skewness coefficient | 1,35 | -0,15 |

10. Consider a watershed with 300 km$^2$, depicted in the figure, with isochrones. The watershed lies in an area where the precipitation depth-duration-frequency curve for a recurrence period of 100 years is $P = 15D^{0,35}$, with P in mm and D in minutes. Using the rational formula, estimate the peak flood flow for the same recurrence period assuming a uniform precipitation, an infiltration of 20% and a peak flow attenuation of 30% resulting from water detention in the watershed.




**Useful formulas:**

Standard normal:

| p | 0.01 | 0.05 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 | 0.95 | 0.99 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| z | -2.33 | -1.64 | -1.28 | -0.84 | -0.52 | -0.25 | 0.00 | 0.25 | 0.52 | 0.84 | 1.28 | 1.64 | 2.33 |

Green & Ampt:

$$F = K_s t + \frac{b}{K_s} \ln\left(1 + \frac{K_s \cdot F}{b}\right) \qquad b = -K_s \Psi_f (\theta_s - \theta_i) \qquad t_e = \frac{(-\Psi_f)(\theta_s - \theta_i)}{p\left(\frac{p}{K_s} - 1\right)} \quad , p > K_s$$