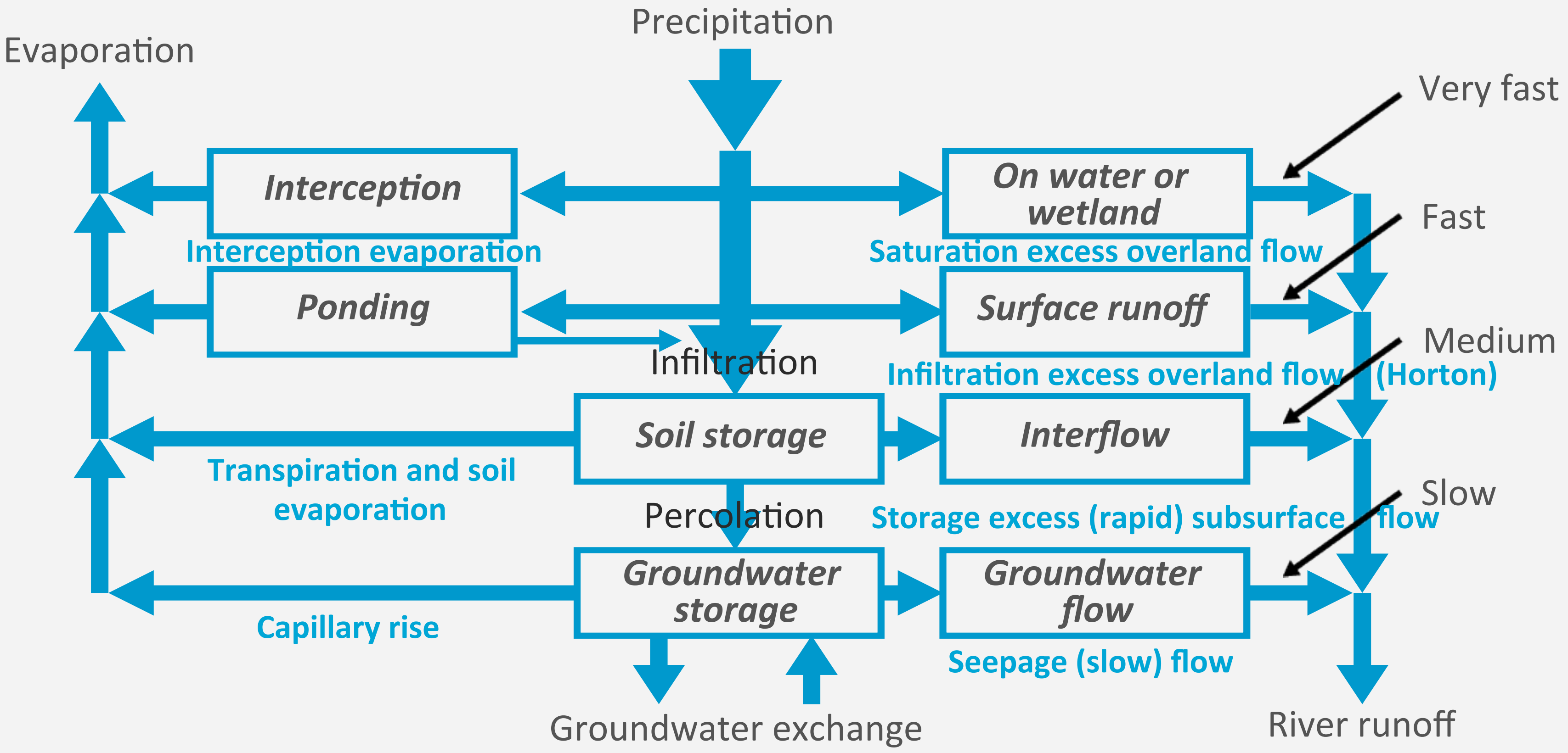
# GWC-4 Runoff Generation

*CTB3300WCx: Introduction to Water and Climate*

Prof.dr.ir. Hubert H.G. Savenije

# Runoff processes



# Runoff components

| | | | | |
|---|---|---|---|---|
| *Fast surface runoff* | = | *Precipitation* | - | ▪ *Interception*<br>▪ *Infiltration* |
| *Fast sub-surface runoff* | = | *Infiltration* | - | ▪ *Transpiration and soil evaporation*<br>▪ *Percolation* |
| *Base flow (seepage to surface water)* | = | *Percolation* | - | ▪ *Capillary rise* |

# River runoff

***Surface runoff*** *(fast and turbid)*

- Hortonian (infiltration excess) overland flow
- Saturation excess overland flow

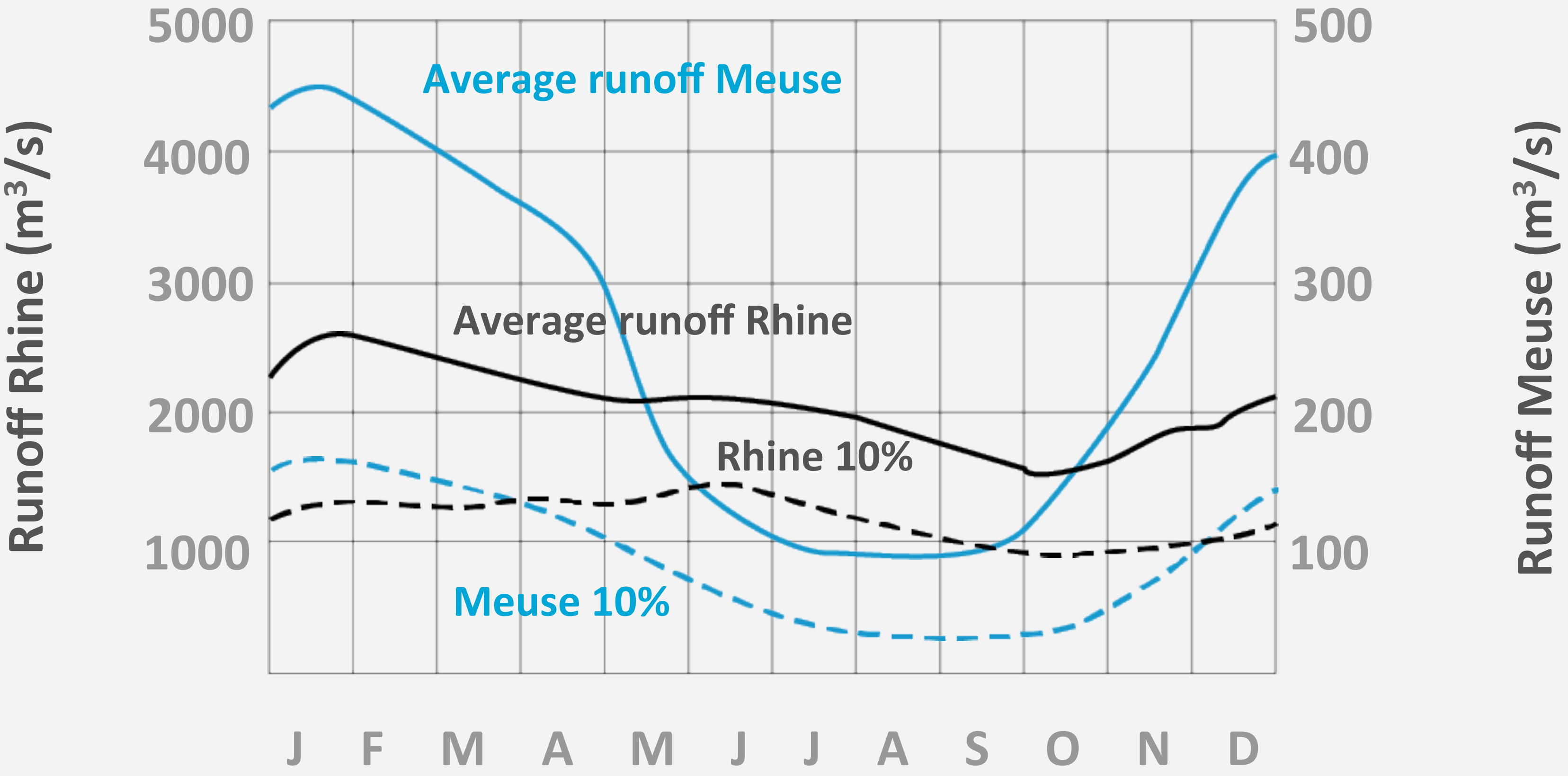
***Sub-surface runoff*** *(fast and mostly clear)*

- Storage excess (rapid) subsurface flow (interflow)

***Base flow*** *(slow and clear)*

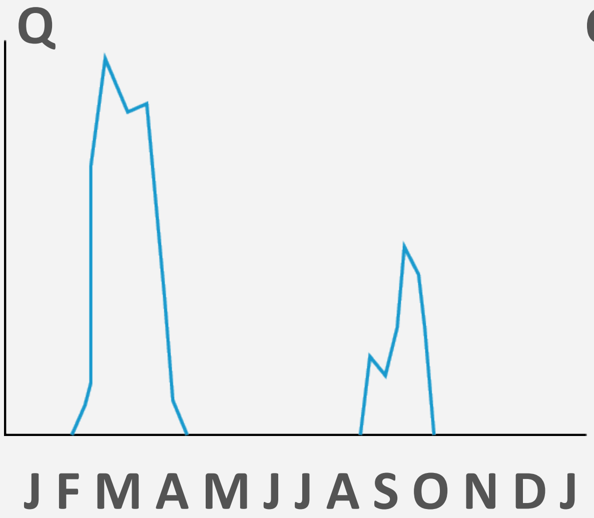
- Seepage flow to stream network

# Monthly runoff signatures

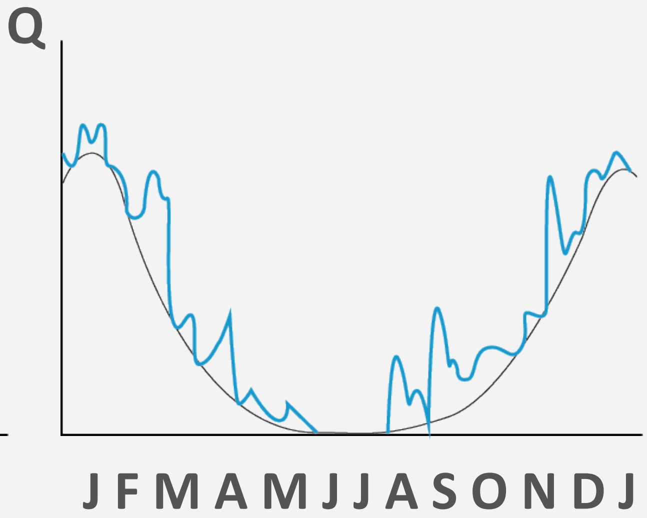


# Types of rivers

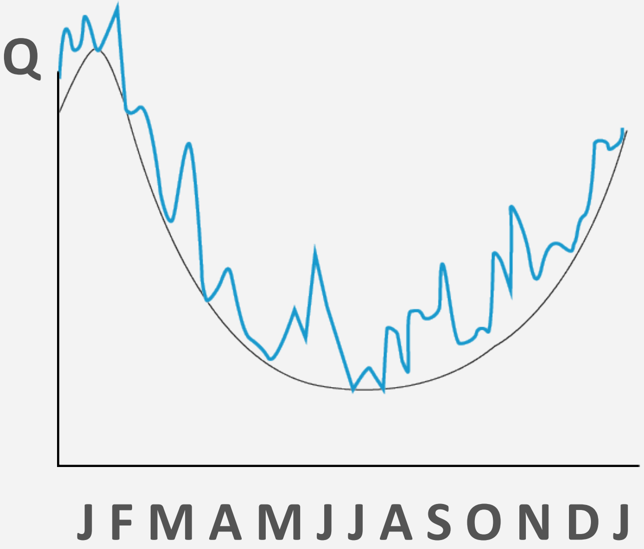
*Ephemeral (wadis)*




*Intermittent*

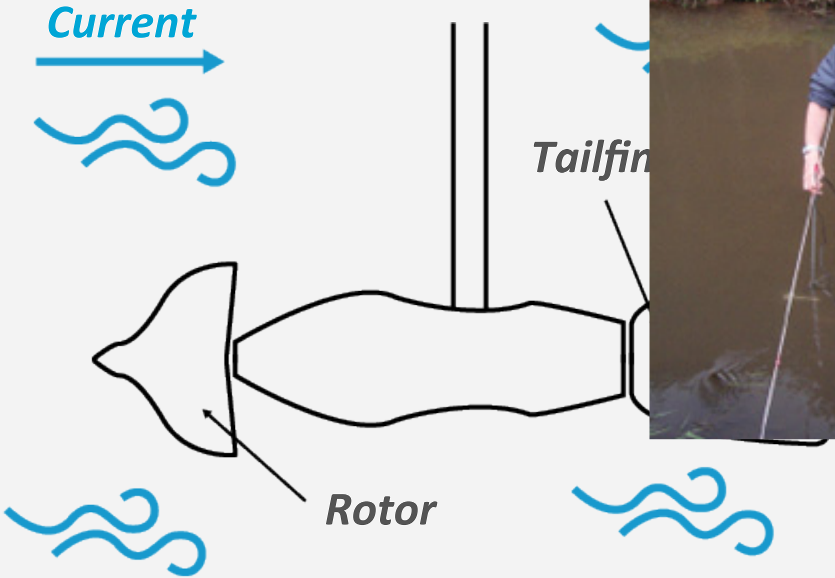


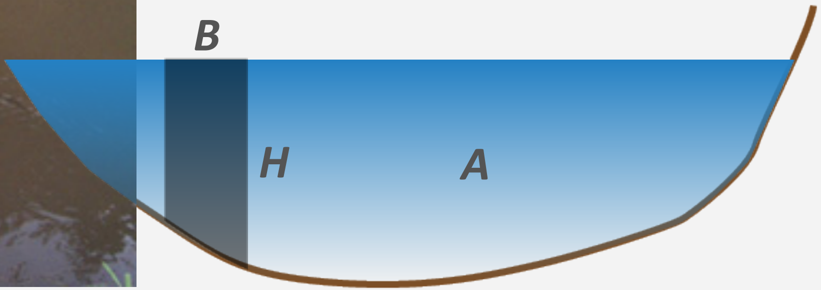

*Perennial*



# Discharge measurement

$$Q = \int v \, \mathrm{d}A = \iint v \, \mathrm{d}h \, \mathrm{d}b \approx \sum \bar{v} h \Delta b$$



# Field work

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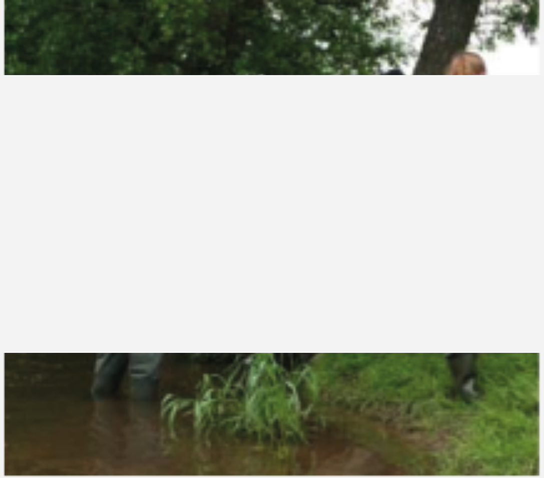
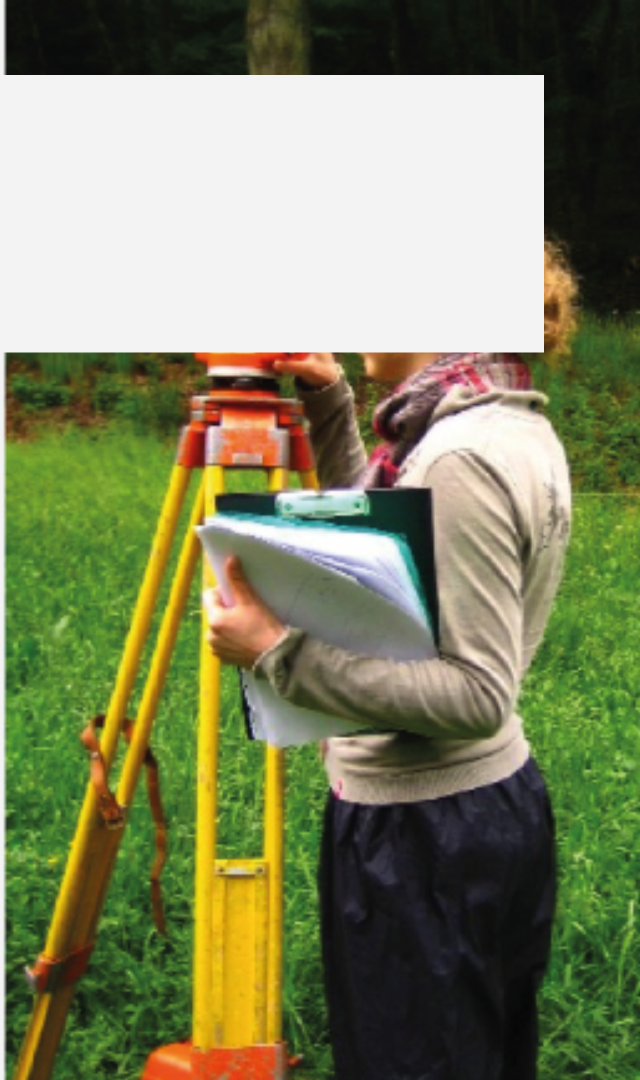
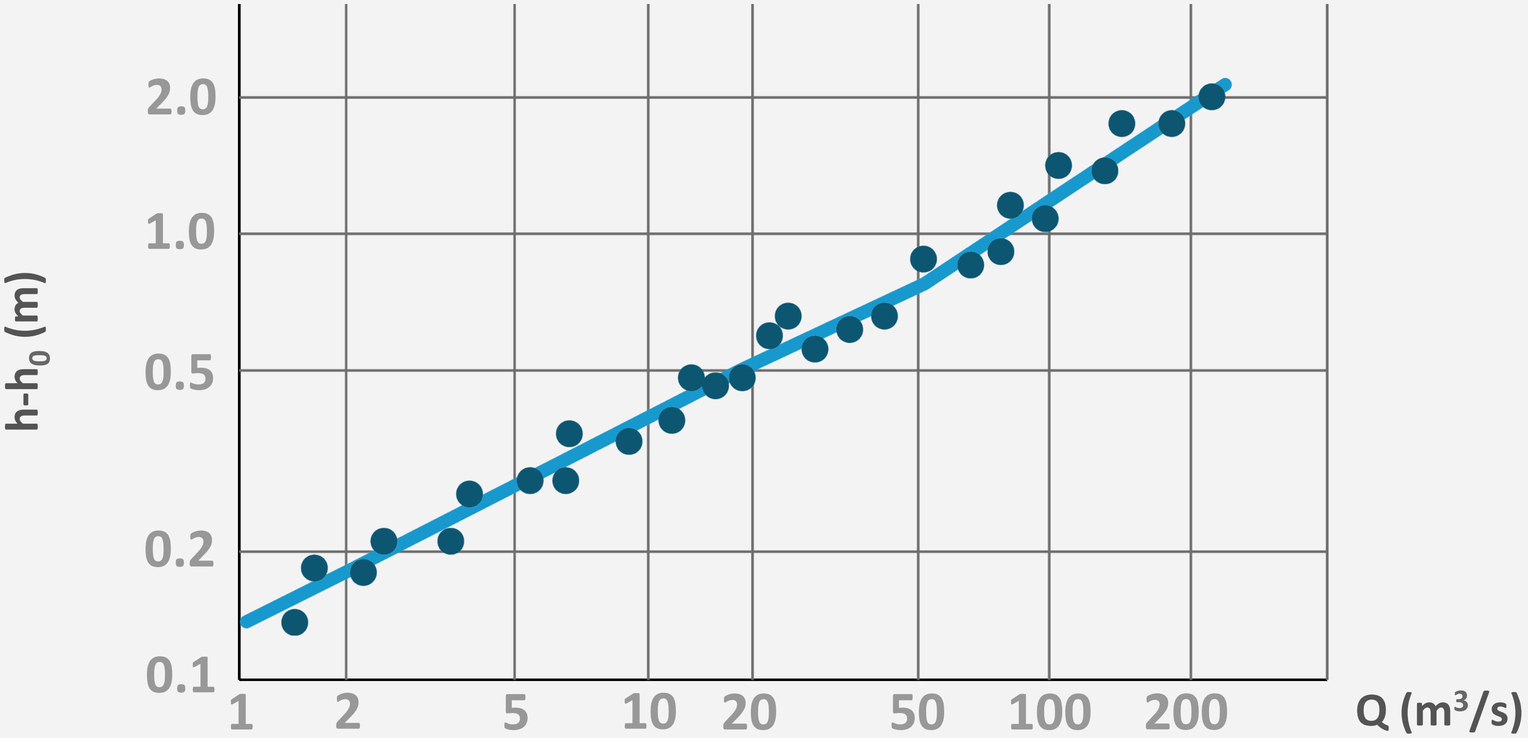




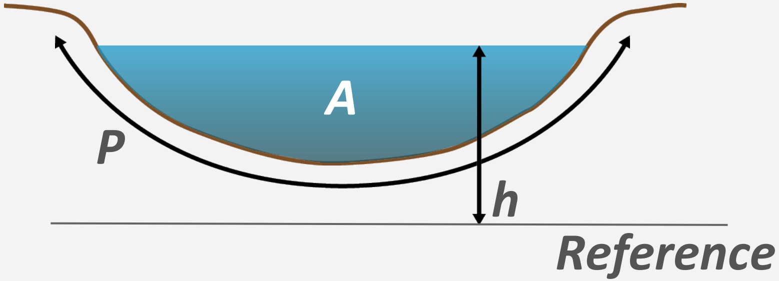
# Rating curve



# Rating curves

$$Q = a(h - h_0)^b \qquad \text{or} \qquad \log Q = \log a + b \log(h - h_0)$$

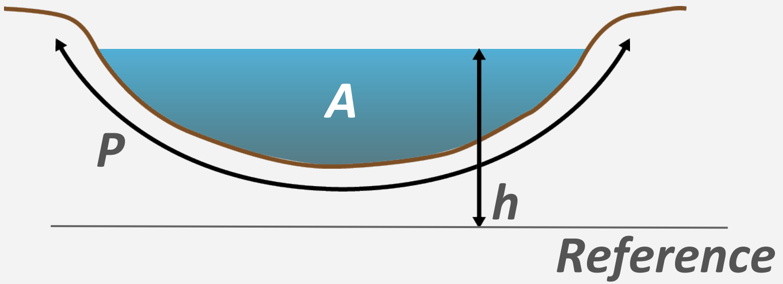
$R = A / P$

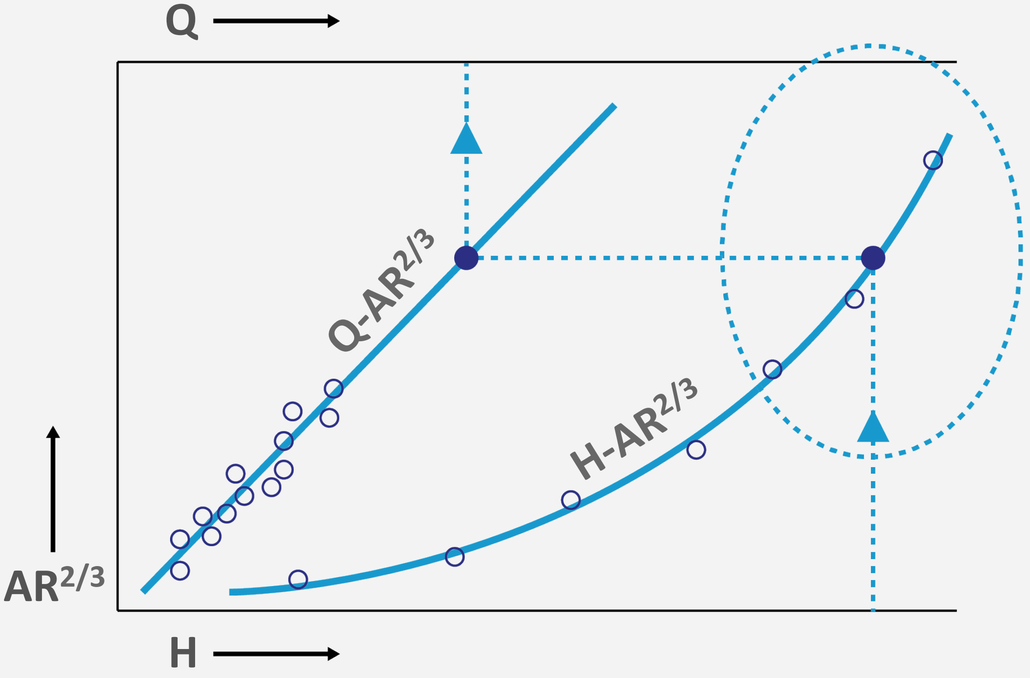



*Manning:*

$$Q = A\bar{v} = \frac{1}{n} A R^{\frac{2}{3}} \sqrt{S} = \frac{1}{n} \sqrt{S} * BhR^{\frac{2}{3}} \approx a(h - h_0)^b$$

# Stevens' method




Extrapolation

$$Q = cAR^{\frac{2}{3}} \qquad [L^3 / T]$$

# Exceptional circumstances

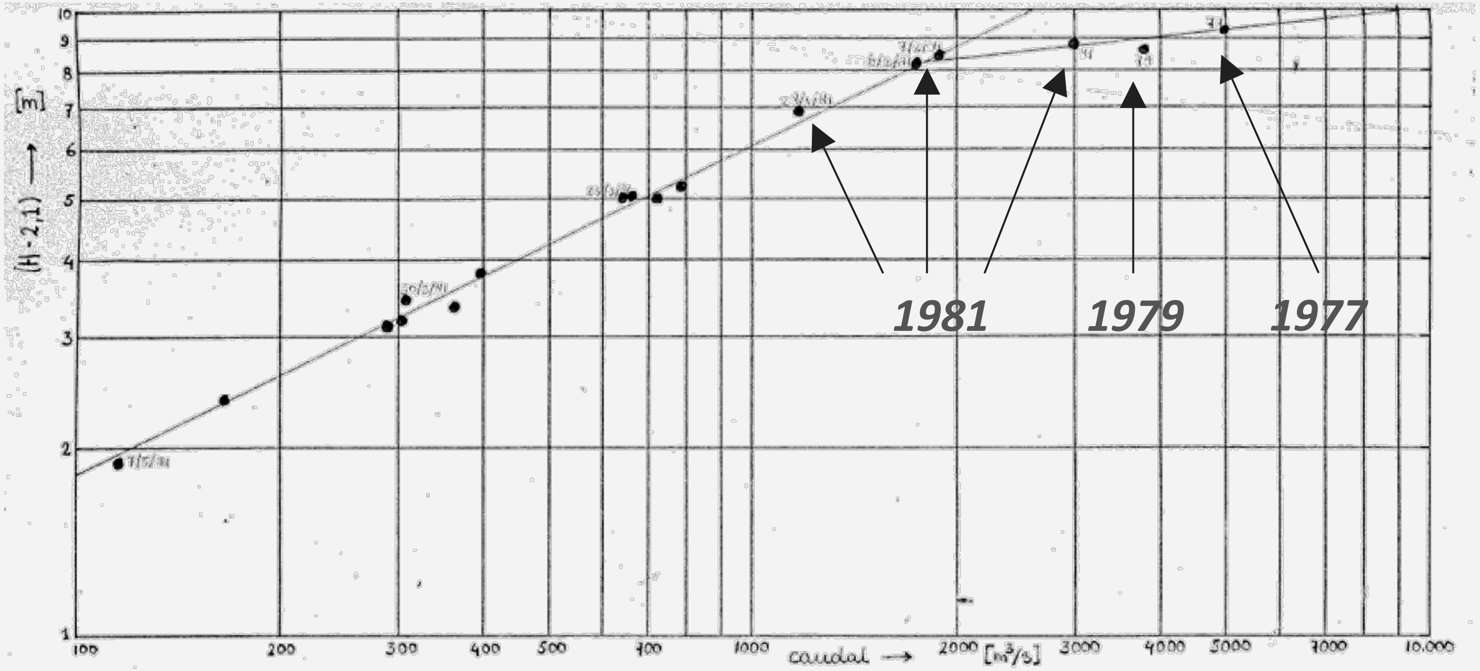
***Bangladesh***

- Bank overtopping
- Backwater effects

***Mozambique***

- Bank overtopping

# Rating curve Limpopo river

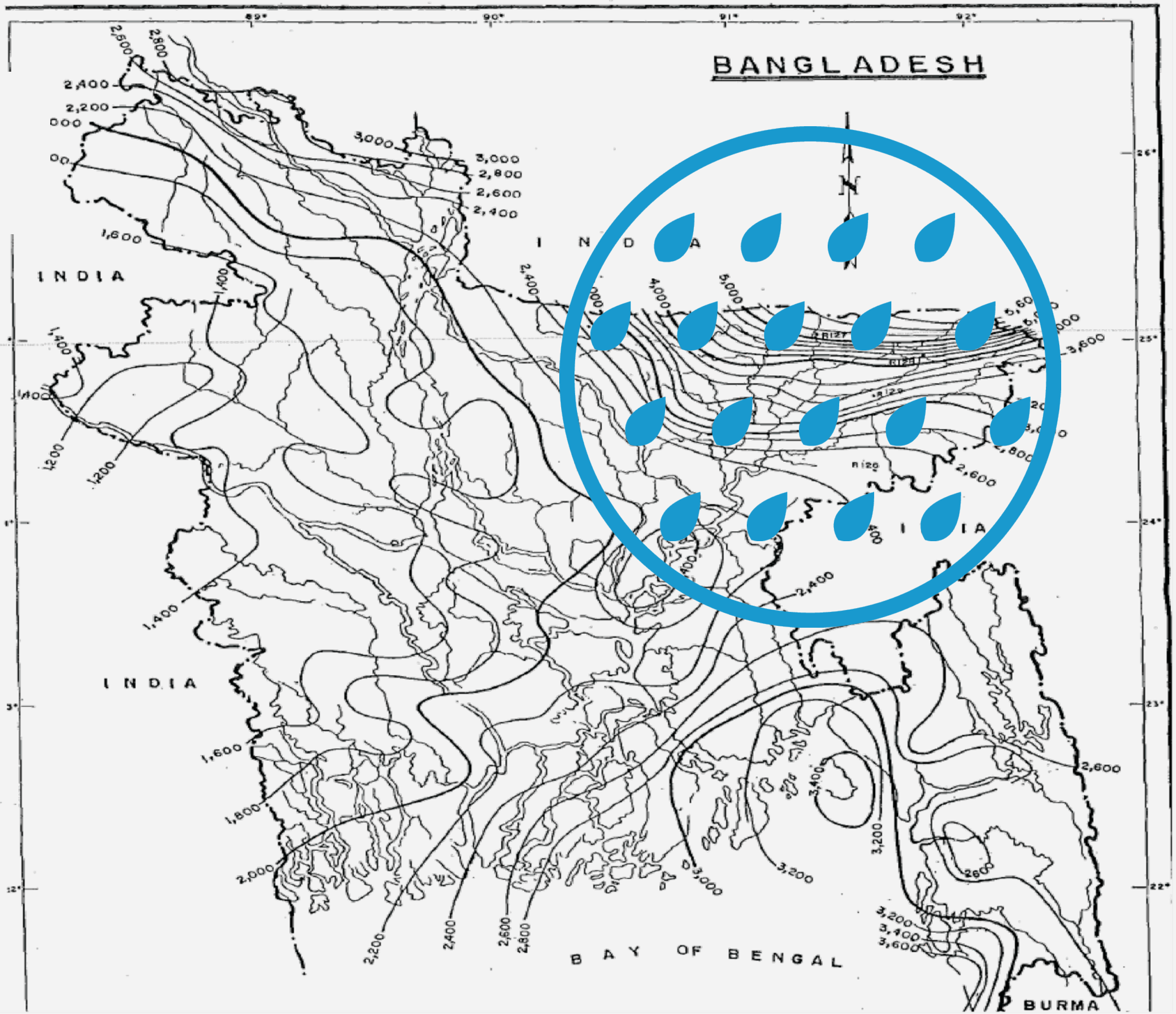



Sicacate Curva de Vazão Figura 6a

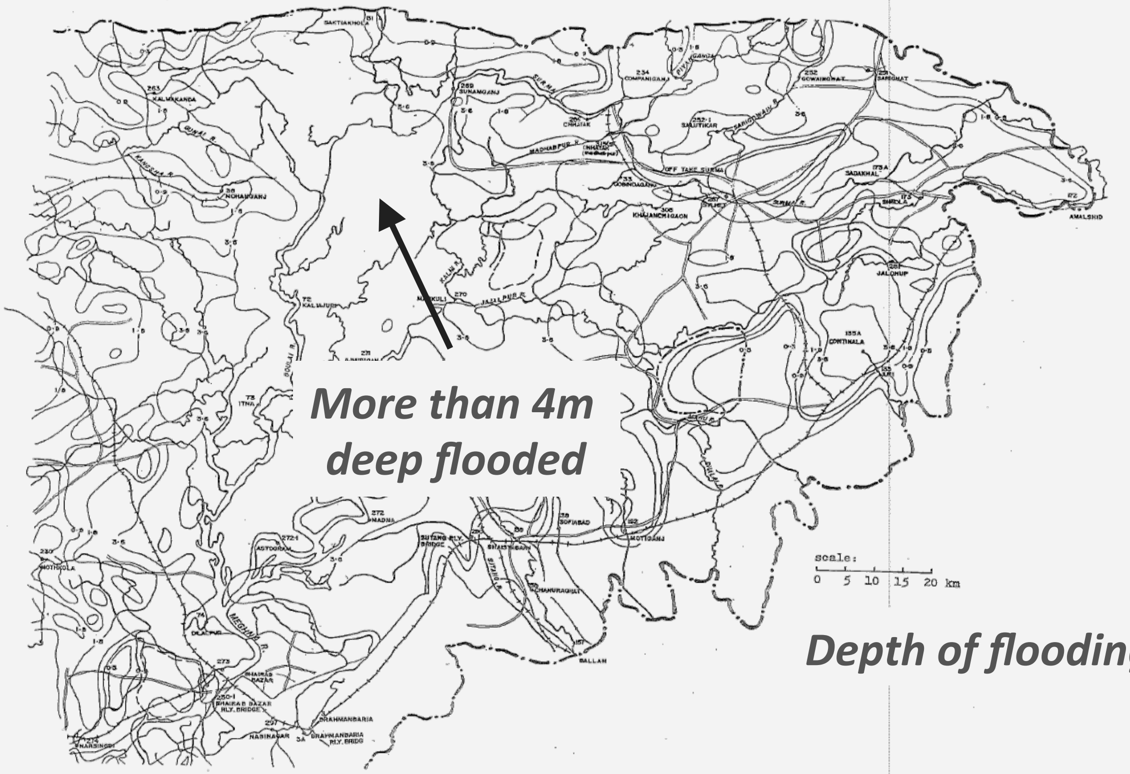
primeiro ramo : Log Q = 1,507 + 1,899 Log (H-2,1) H ≤ 10,3 m

segundo ramo : Log Q = -4,498 + 8,471 Log (H-2,1) H > 10,3 m

# Bangladesh

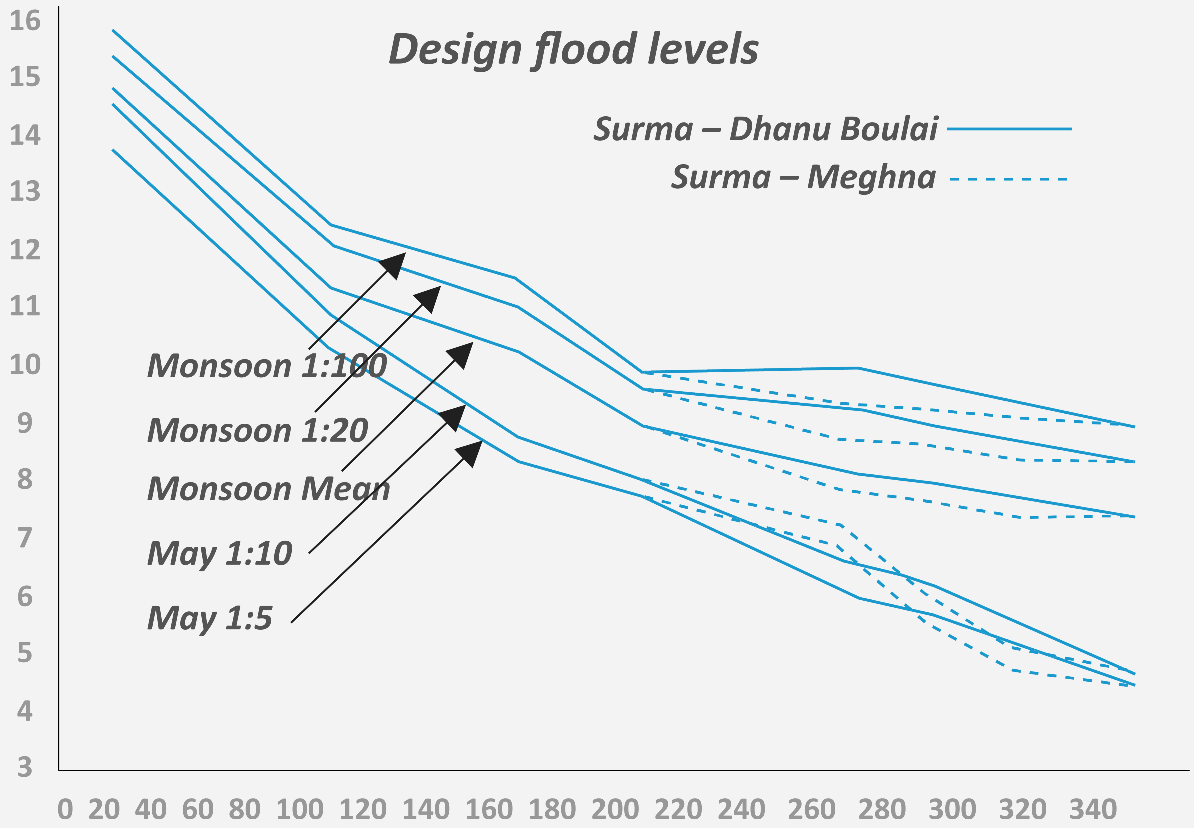


# Flooding of Sylhet area

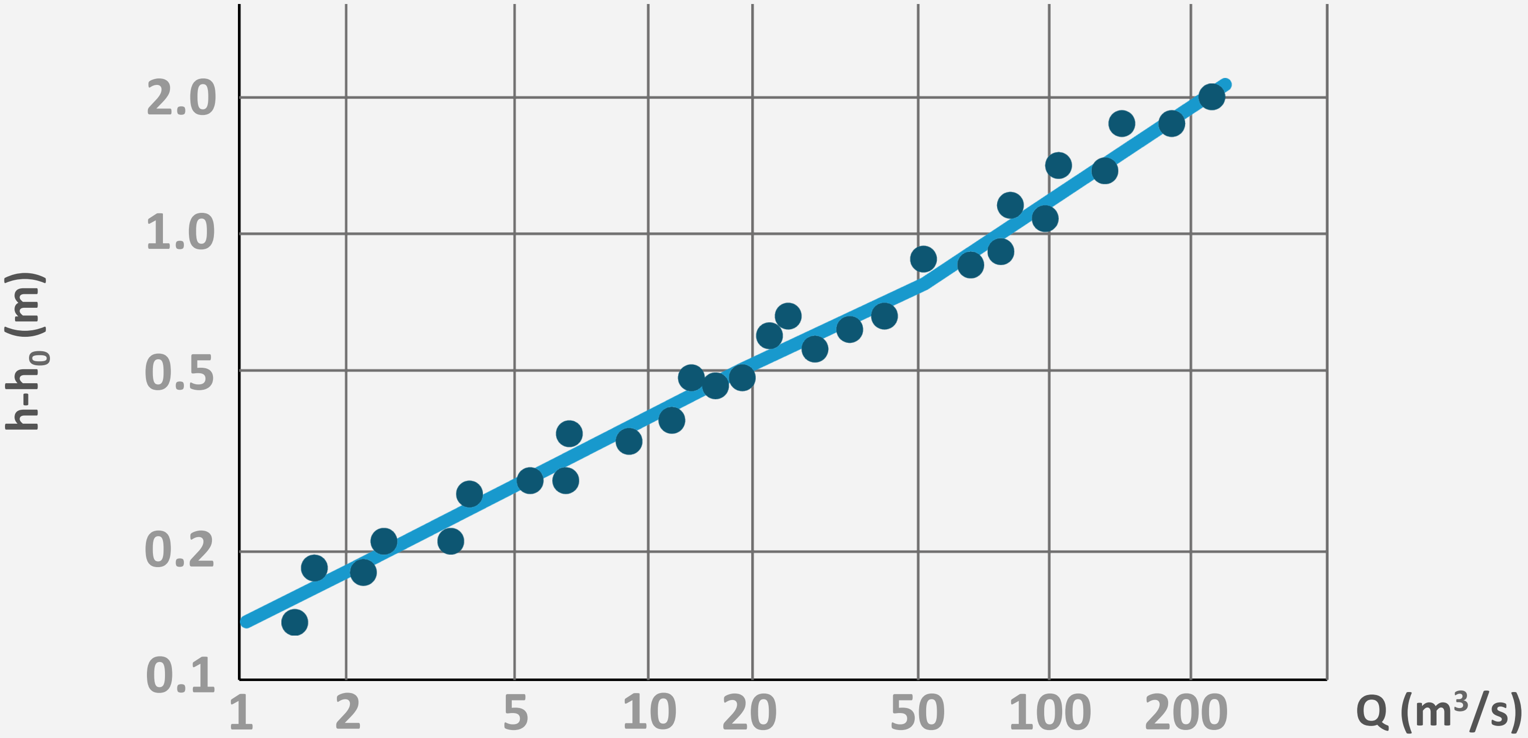



*Depth of flooding*

# Backwater effect of Ganges and Bramaputhra



# Effects on rating curve



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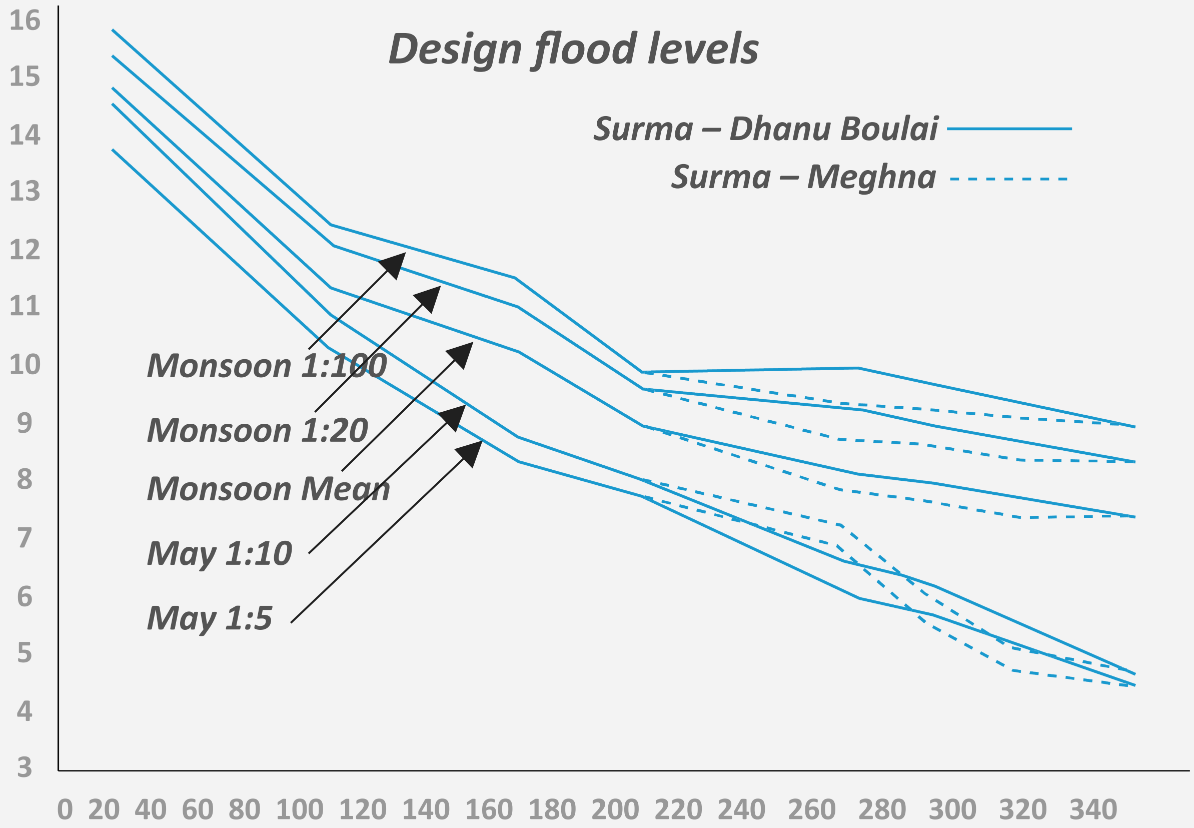


# Extreme discharge

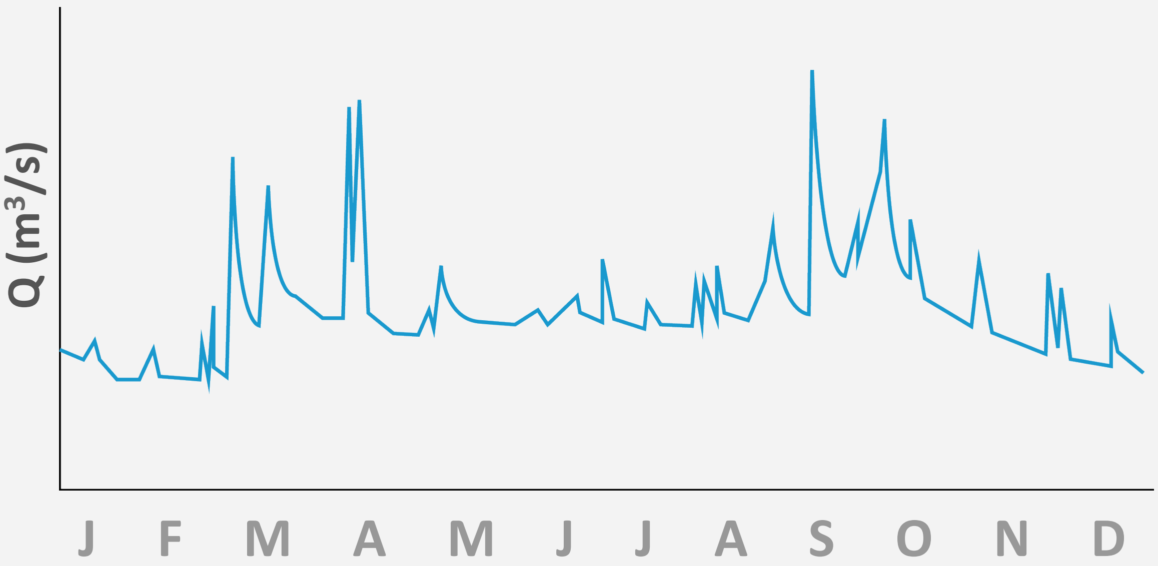
***Duration curves → Frequency curves***

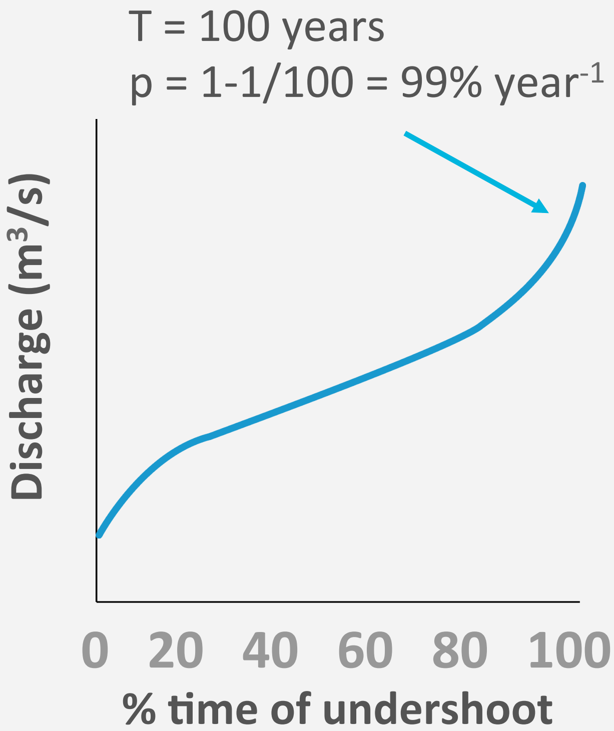
***Extreme value distribution for floods***

- Annual maxima

***Gumbel extreme values analysis (flood frequency analysis)***

# Duration curve



# Gumbel (1891-1966) extreme values analysis

***For the purpose of:***

- Design discharge
- Design dike level
- Design of culvert or bridge capacity

# Extreme flood levels

# Gumbel assumption

*“**Assuming** a phenomenon is **normally distributed**, then the **extremes** follow the **Gumbel distribution**”*

**BUT**

*This **seldom** holds true*

# Additional Gumbel assumptions

- *Series is homogeneous*
- *Series is stationary*
- *Series is long enough (seldom true)*

# Gumbel equation

$$q = P(Q \leq x) = 1 - p = \exp(-\exp(-y)) = \mathrm{e}^{-\mathrm{e}^{-y}}$$

$$p = P(Q > x) = 1 - \exp(-\exp(-y)) = 1 - \mathrm{e}^{-\mathrm{e}^{-y}}$$

$$y = -\ln(-\ln(q)) = -\ln(-\ln(1 - p)) = -\ln\left(-\ln\left(1 - \frac{1}{T}\right)\right)$$

***Reduced variate of Gumbel:*** $y = a(x - b)$

# Analogy with normal distribution

$$q = P\left(x < X\right) = \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{X} \mathrm{e}^{-\frac{1}{2}t^2}\,\mathrm{d}t$$

***Reduced variate of Gauss:***

$$t = \frac{X-\mu}{\sigma} = \frac{1}{\sigma}\left(X-\mu\right)$$

***Reduced variate of Gumbel:***

$$y = a\left(x-b\right) \approx \frac{1}{S}\left(x - X_m\right)$$

# How to do Gumbel analysis

- *Determine the anual extreme occurrences*
- *This gives N extreme values for N years*
- *Ranking from large to small with rank number* $m$
- *Calculate the frequency of occurrence using the "plotting position"*

# Plotting position

$$p = \frac{m}{N+1}$$

$$T = \frac{N+1}{m}$$

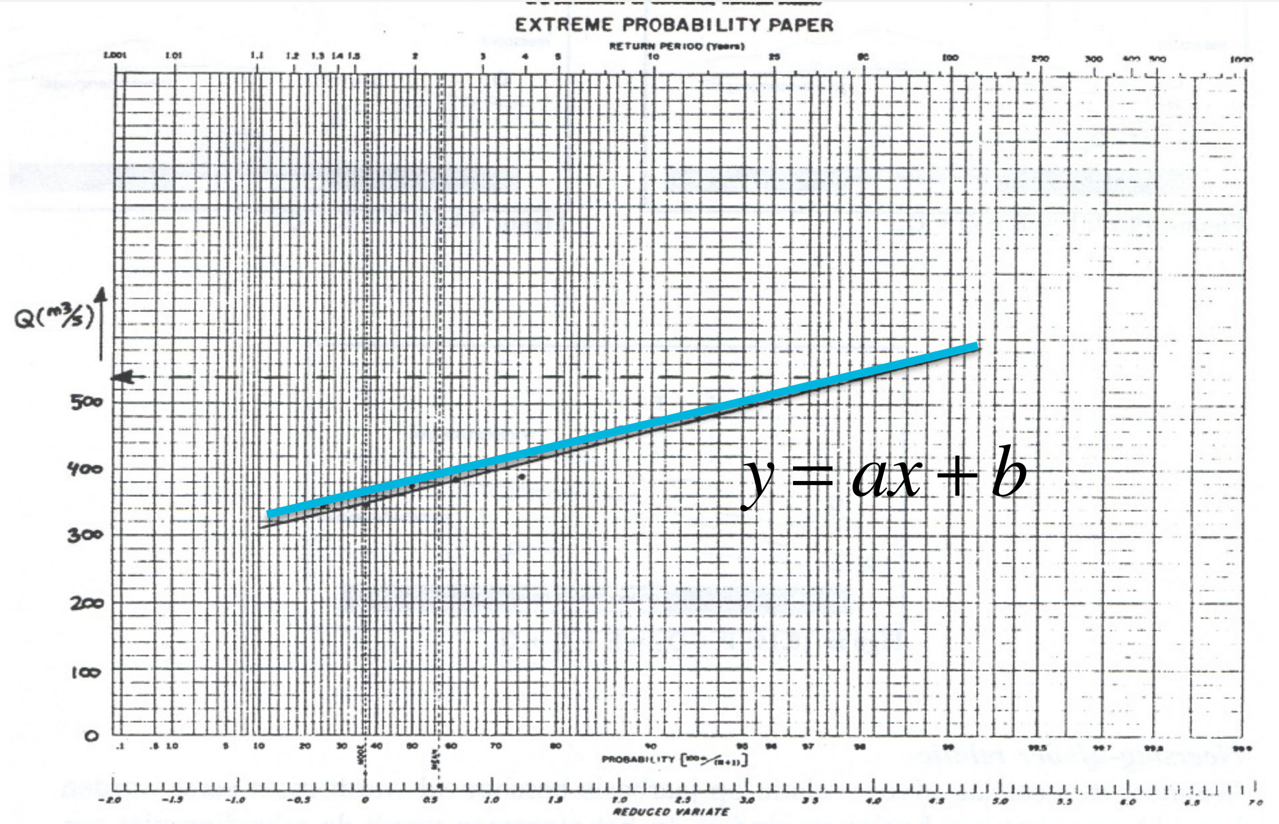
*p: probability of exceedence ($yr^{-1}$)*
*T: frequency scale (yr)*
*N: number of years of observation (yr)*
*m: rank number (-)*

# Peak table

| datum: | Q in m$^3$/s | datum: | Q in m$^3$/s | datum: | Q in m$^3$/s |
|---|---|---|---|---|---|
| 01-02-69 | 340 | 17-01-72 | 140 | 15-04-74 | 343 |
| 17-02-69 | 57 | 02-02-72 | 180 | 20-04-74 | 357 |
| 24-02-69 | 324 | 04-03-72 | 50 | 08-05-74 | 222 |
| 26-02-69 | 110 | 27-03-72 | **345** | 16-05-74 | 120 |
| 02-03-69 | **343** | 23-01-73 | 214 | 04-01-75 | 245 |
| 09-03-69 | 280 | 14-03-73 | **339** | 12-01-75 | 211 |
| 12-03-69 | 50 | 24-09-73 | 256 | 17-01-75 | 245 |
| 29-03-69 | 342 | 02-01-74 | 267 | 13-03-75 | 56 |
| 15-04-69 | 112 | 18-01-74 | 53 | 24-03-75 | 68 |
| 30-04-69 | 95 | 21-01-74 | 48 | 03-04-75 | 95 |
| 06-01-70 | **387** | 14-02-74 | 80 | 14-04-75 | 102 |
| 23-02-71 | **376** | 15-03-74 | 281 | 21-05-75 | 269 |
| 03-01-72 | 211 | 20-03-74 | **383** | 14-11-75 | **431** |
| 08-01-72 | 299 | 24-03-74 | 163 | 15-12-75 | 319 |

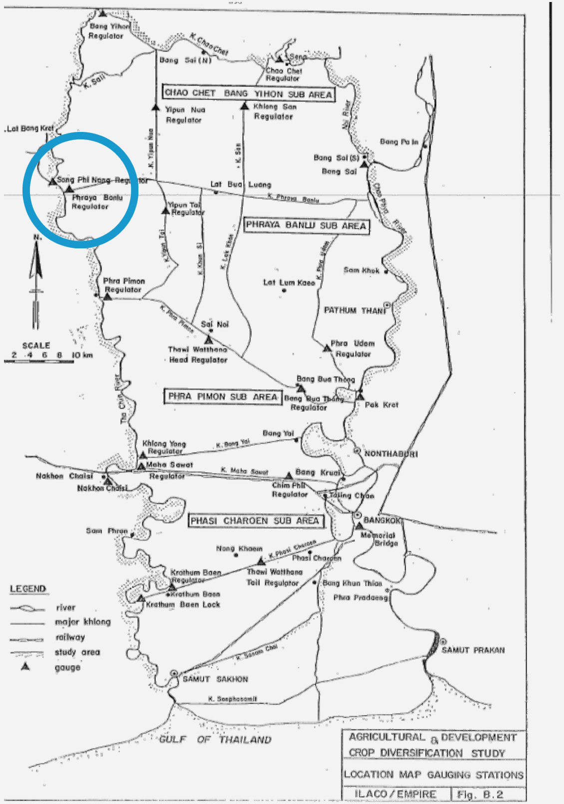
# Gumbel paper

| $i$ | $Q$ in m$^3$/s | $T$ |
|---|---|---|
| 1 | 431 | 8 |
| 2 | 387 | 4 |
| 3 | 383 | 2.67 |
| 4 | 376 | 2 |
| 5 | 345 | 1.6 |
| 6 | 343 | 1.33 |
| 7 | 339 | 1.14 |

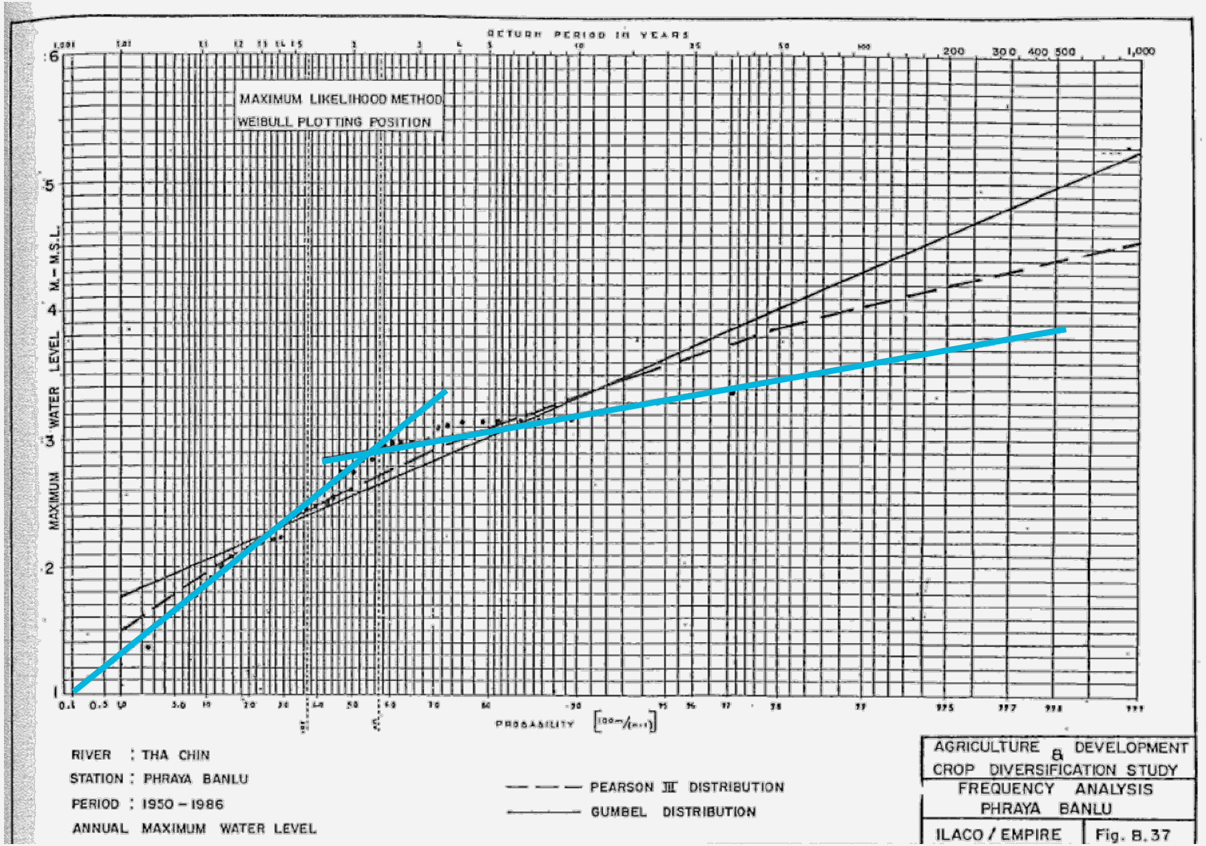


# Thailand 2011

# Phraya Banlu



# Gumbel graph



# Probability of occurrence

*What is the **probability** that within a period of **n** years the **design discharge** of once in **T** years occurs?*

$$P_n = 1 - \left(1 - \frac{1}{T}\right)^n$$

# Be critical

***Because observation series are generally:***

- Not normally distributed
- Too short
- Not homogeneous
- Not stationary

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