Hydrology of catchments, rivers and deltas (CIE5450)

Prof.dr.ir. Uhlenbrook

Lecture ‘Runoff’

Hydrology of Catchments, River Basins and Deltas

Part THREE – Introduction Runoff

Professor Stefan Uhlenbrook, PhD, MSc, habil.
Professor Dr. Ir. Hubert H.G. Savenije
Professor of Hydrology

UNESCO-IHE Institute for Water Education and
Delft University of Technology
The Netherlands

E-mail: s.uhlenbrook@unesco-ihe.org
s.uhlenbrook@tudelft.nl

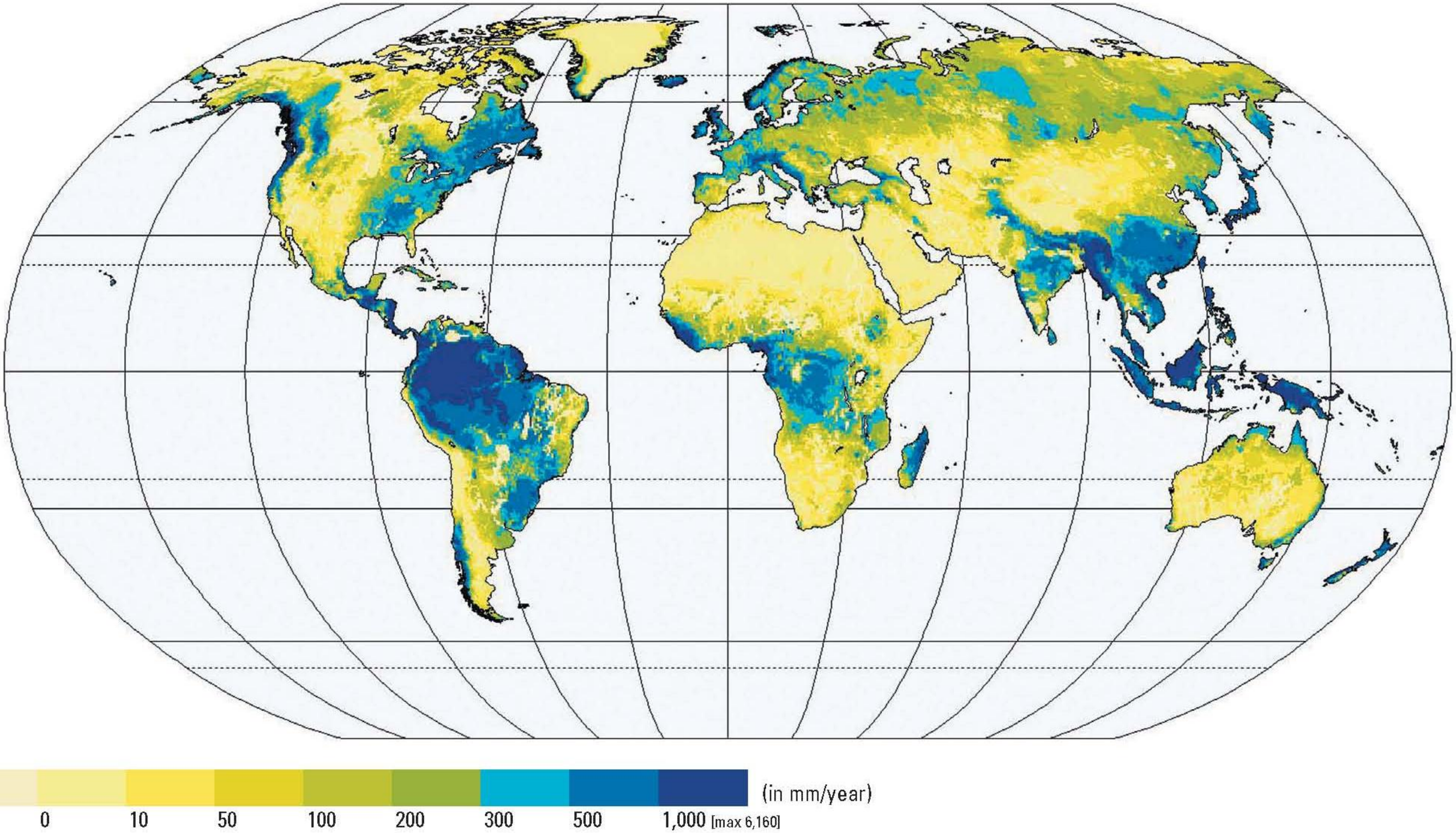
UNESCO-IHE Institute for Water Education

TU Delft Delft University of Technology

Long-term Mean Annual Runoff per Grid

(WWAP 2003)

$$P = R + E + dS/dt$$



The enormous variation in climate around the Earth leads to great variability in the streamflow, which is in line with the rainfall. This map shows similar patterns to map 4.1.

Source: Map prepared for the World Water Assessment Programme (WWAP) by the Centre for Environmental Research, University of Kassel, based on Water Gap Version 2.1.D, 2002.

Objectives of this Lecture

- Discharge measurement
- Interpreting the catchment response - discharge
- Hydrograph analysis
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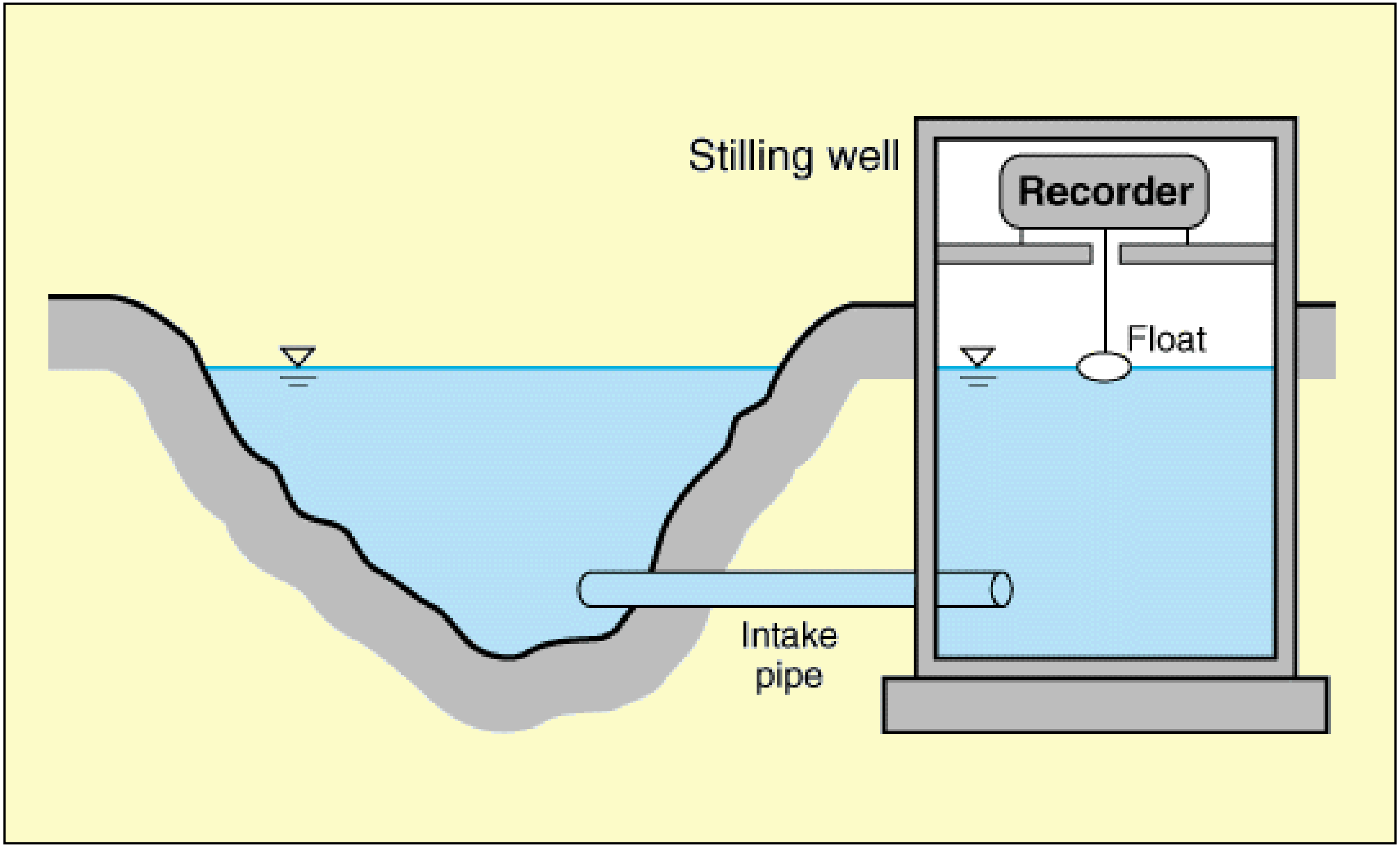
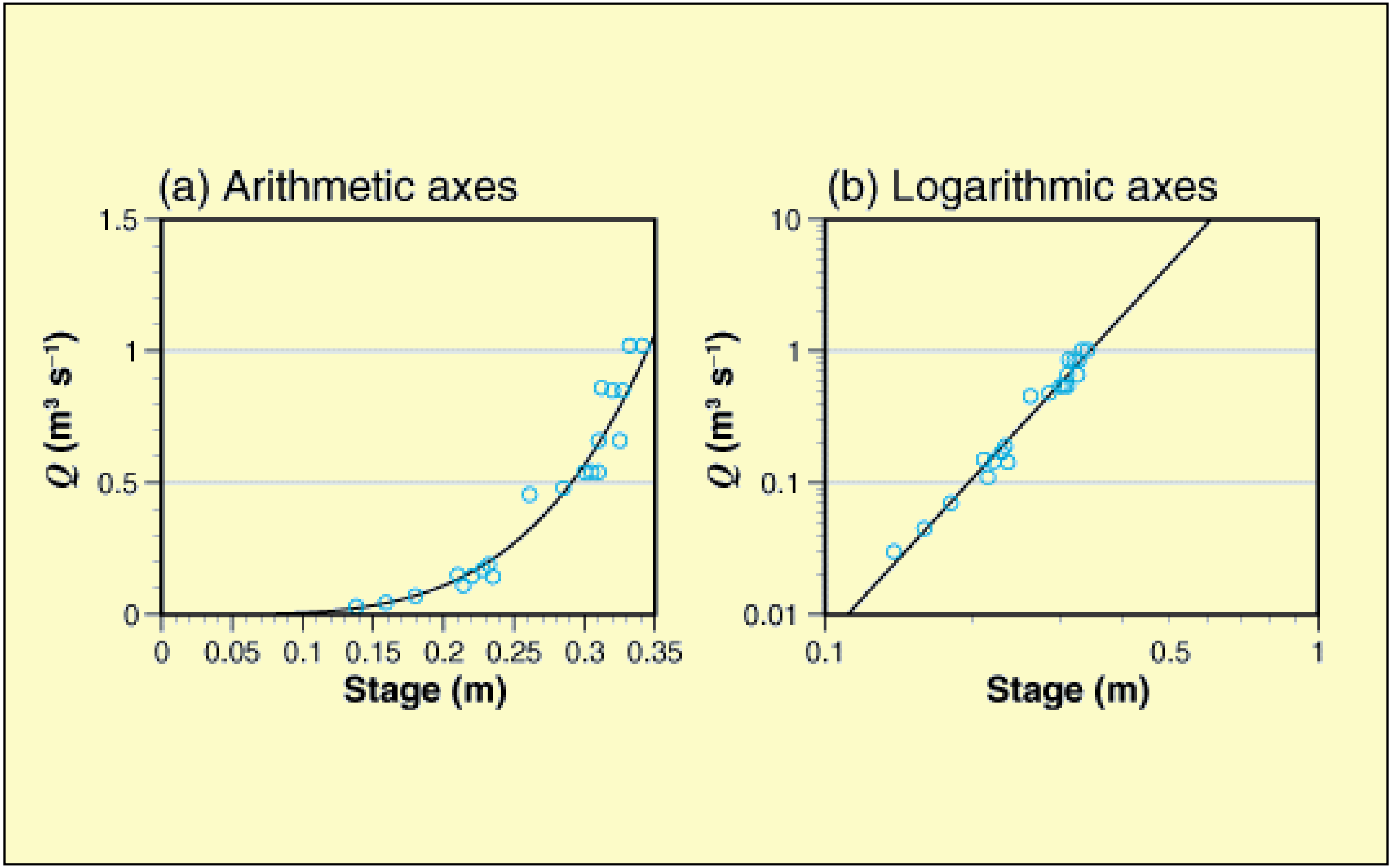
How do we measure the catchment response (discharge)? (cf. Hydraulics lectures)



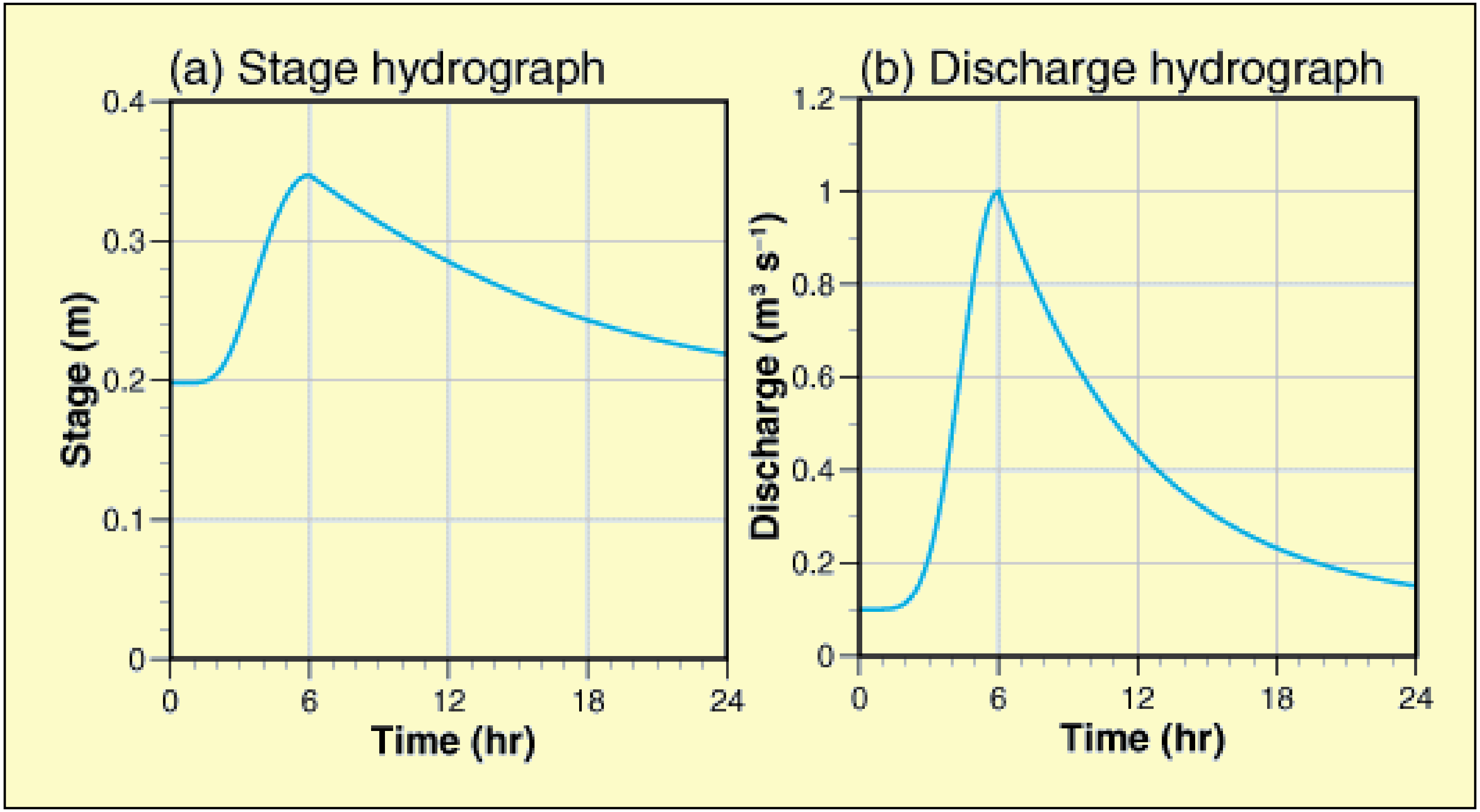
(Aus: Hornberger et al., 1998)

Rating curve



(Aus: Hornberger et al., 1998)

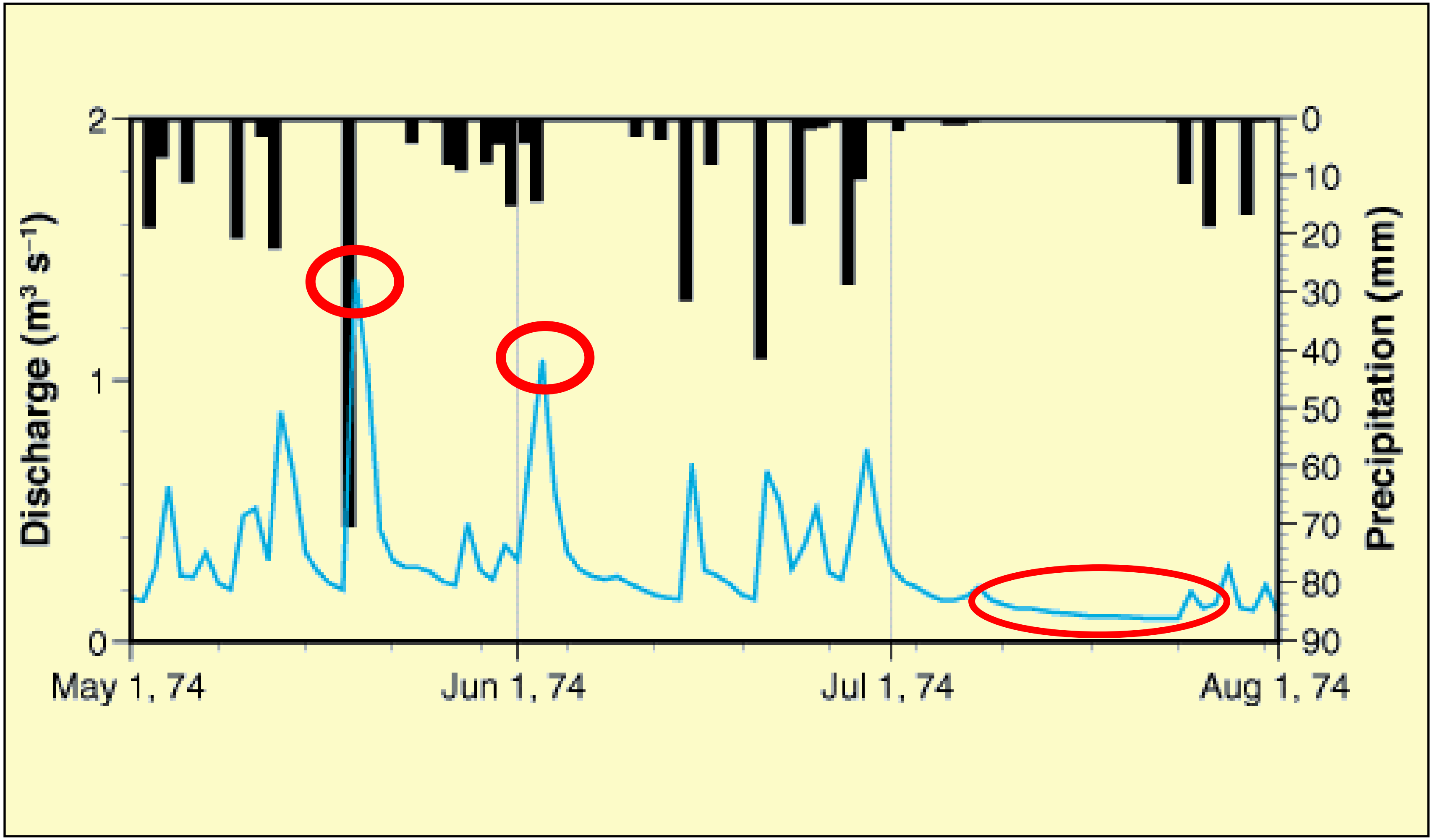
Application of rating curve to measured water levels at a gauge



(Aus: Hornberger et al., 1998)

Continuous measurement of discharges

(incl. floods and low flows)



(Aus: Hornberger et al., 1998)

Flow measuring structures

Principle: increase water velocity from sub-critical, via critical when passing the structure, to super-critical flow. This gives stable relationship between water depth and discharge.

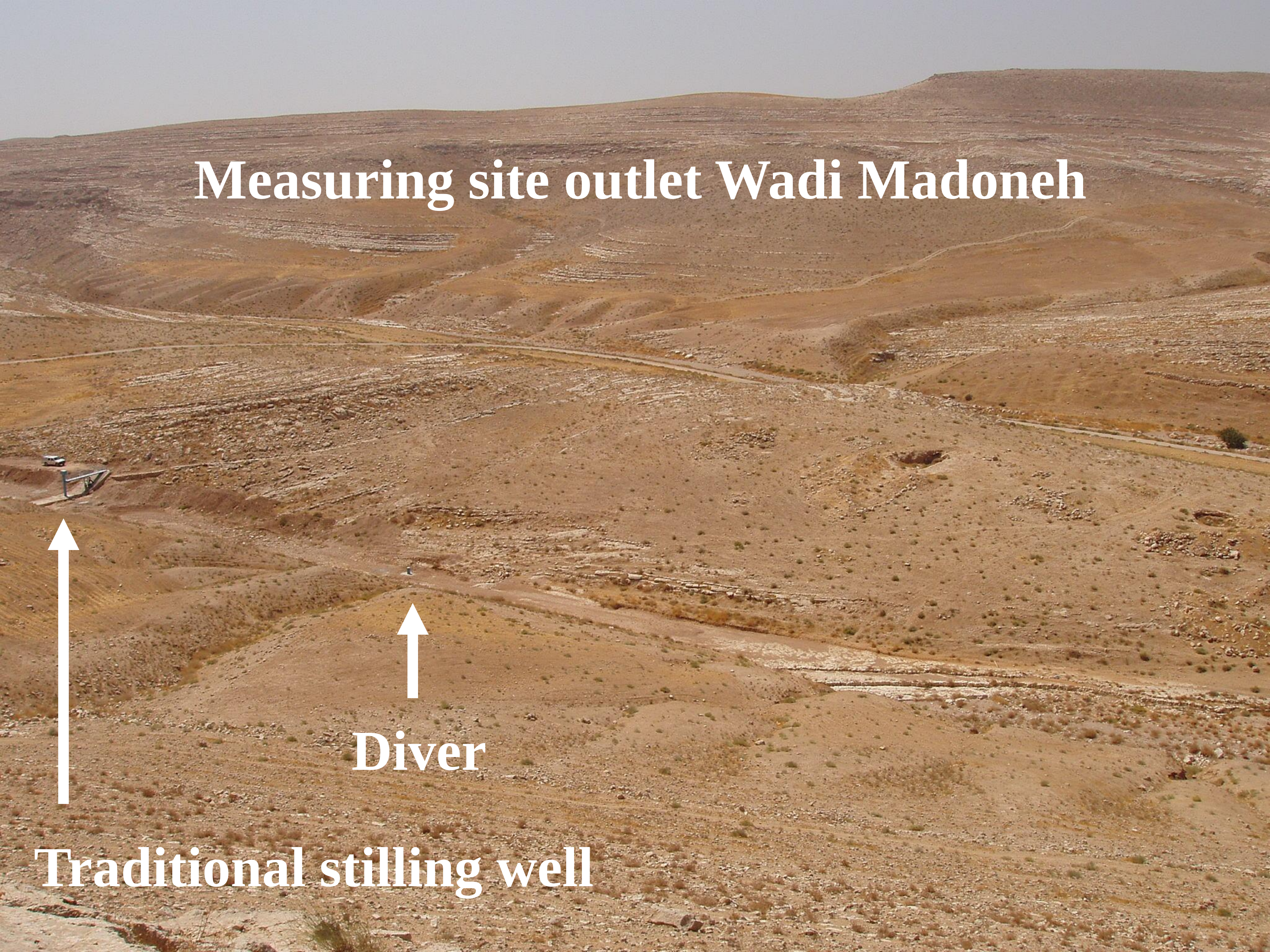
Weirs (e.g. broad-, sharp-, short-crested weirs)

General formula for rectangular weir

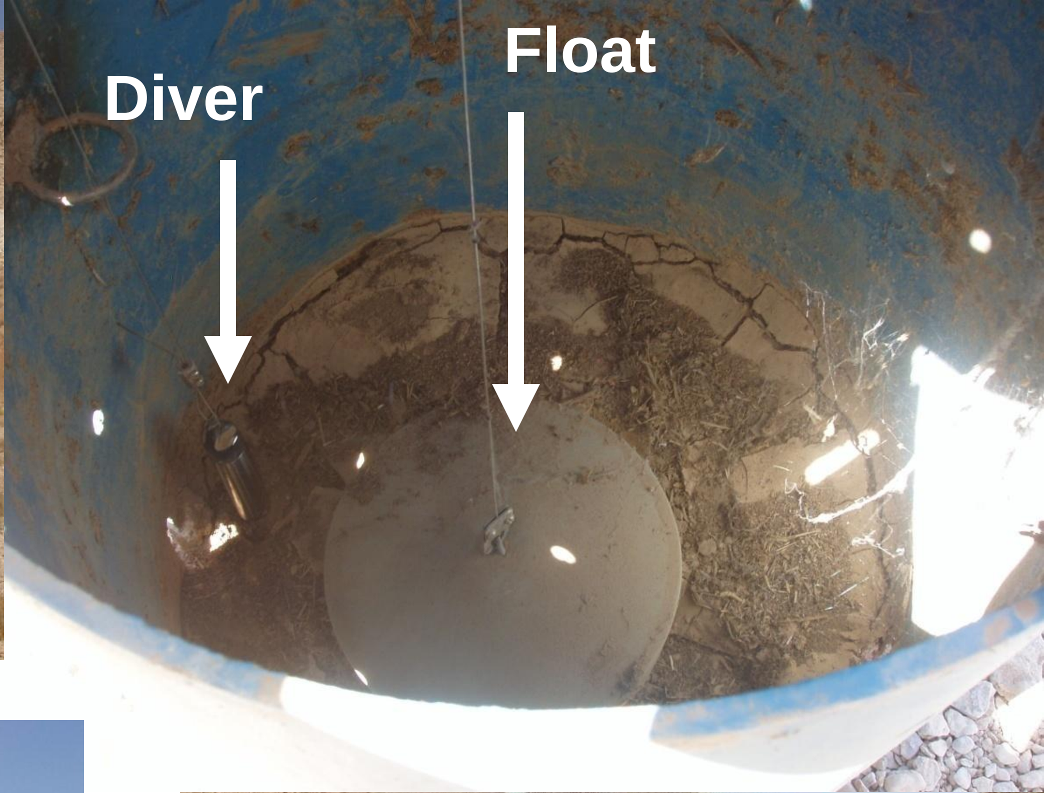
$$Q = k\, b\, H^{\frac{3}{2}}$$

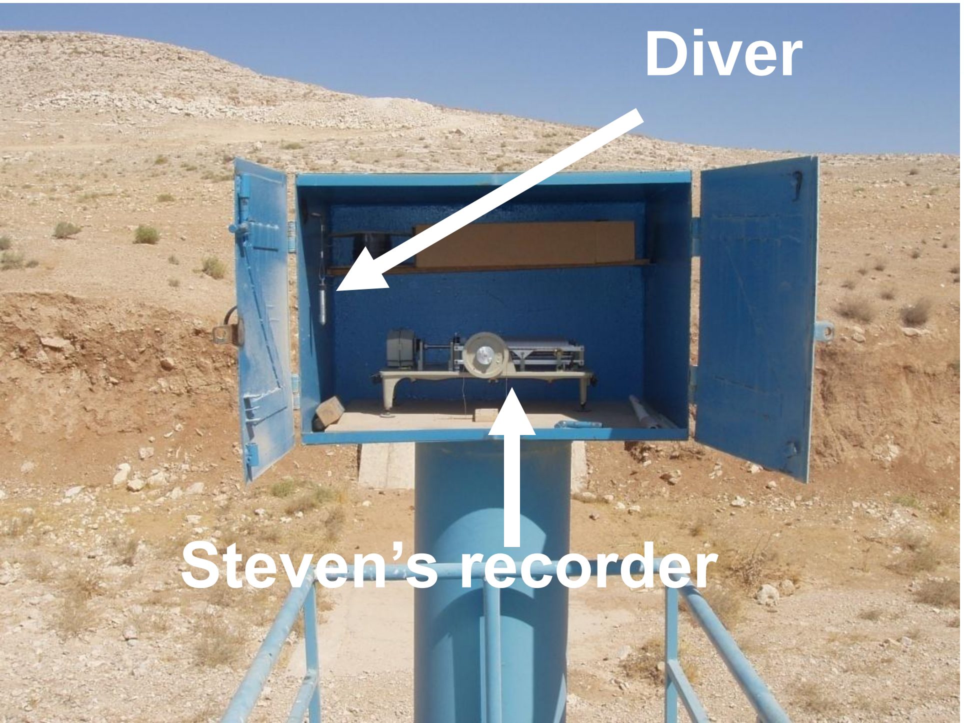
b width of weir
H water level upstream above crest
k coefficient depending on structure

Flumes and Gates


Measuring site outlet Wadi Madoneh
Diver
Traditional stilling well


Traditional
stilling well


Diver
Float


Diver
Steven's recorder


Stilling well Diver

Surface runoff measurement with a tipping bucket, South Africa

Blue Nile Gorge, Ethiopia, measurement of stage under the bridge (bedrock channel)

Discharge measurement with a flume, South Africa

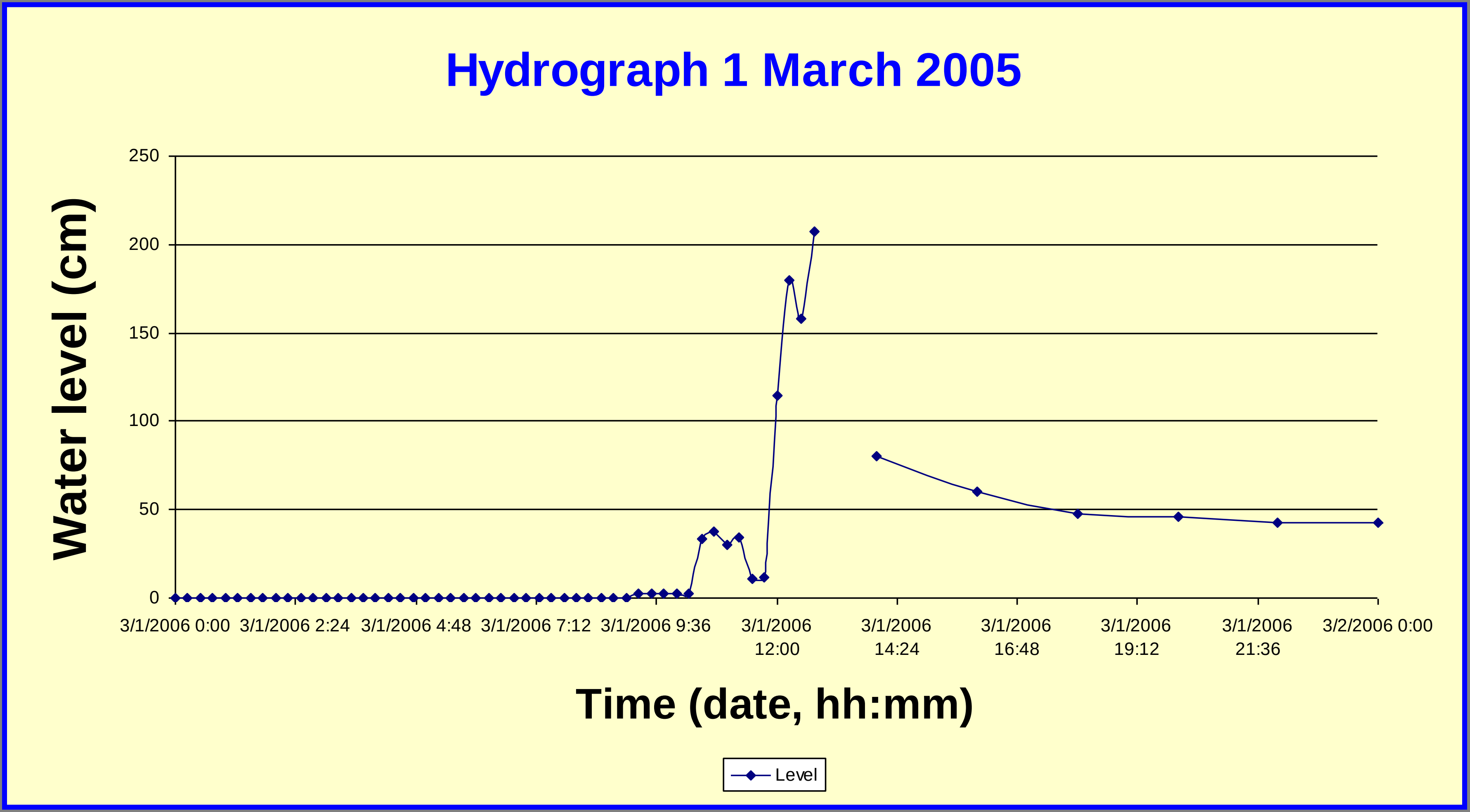
Discharge measurement, South Africa, from above

Discharge measurement, Tanzania

(Picture: R. K. Mutiibwa, 2005;)

(Pictures: M. Mul, March 2006)

Interrupted stage measurement due to a large flood – *How can we predict the peak discharge?*



(Mul et al. 2006)

Discharge measurement with flume in an emphemeral stream, Tanzania

…. that is not always that easy!

(The big flood in the HJ Andrews 1996)

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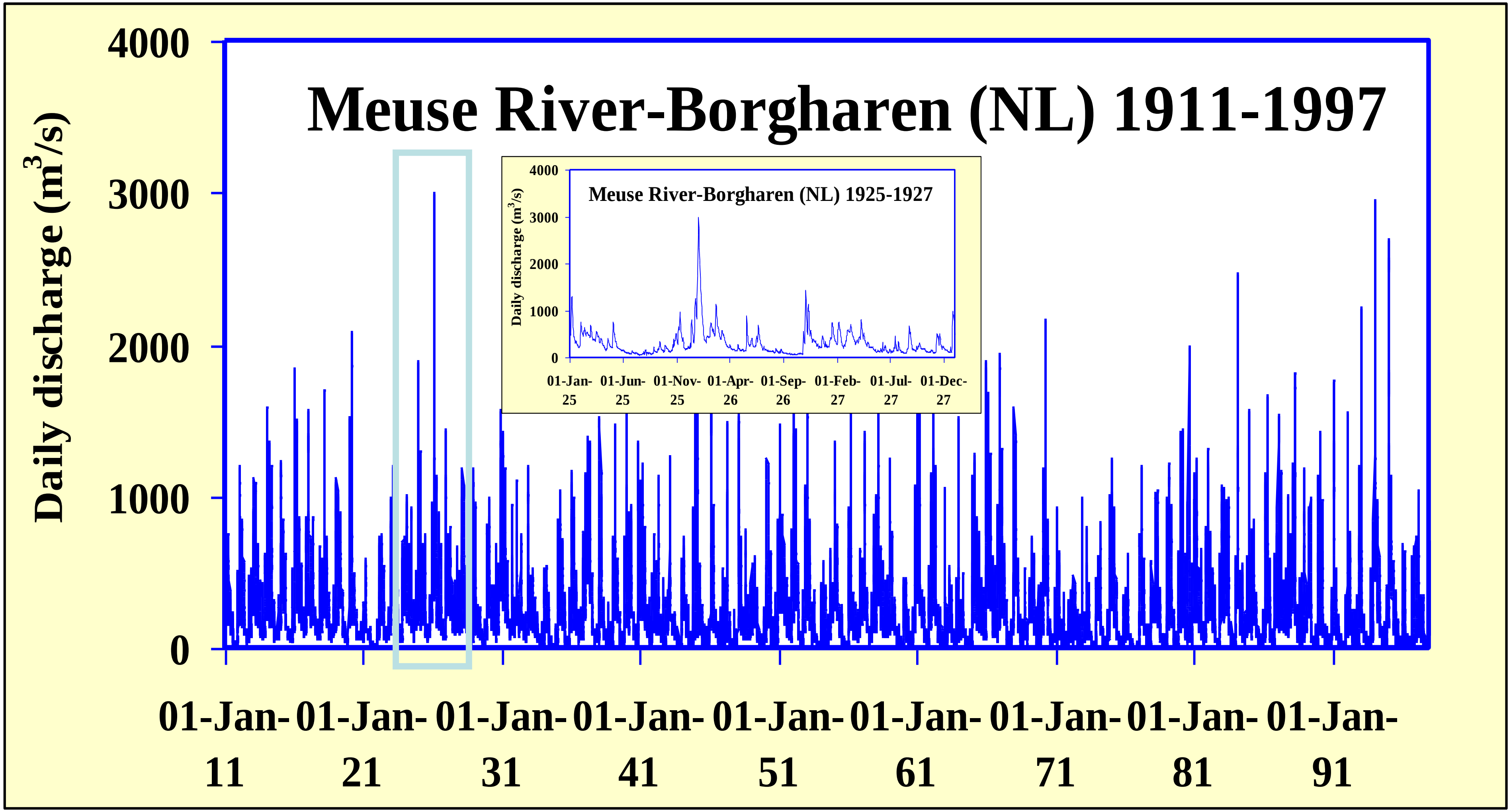
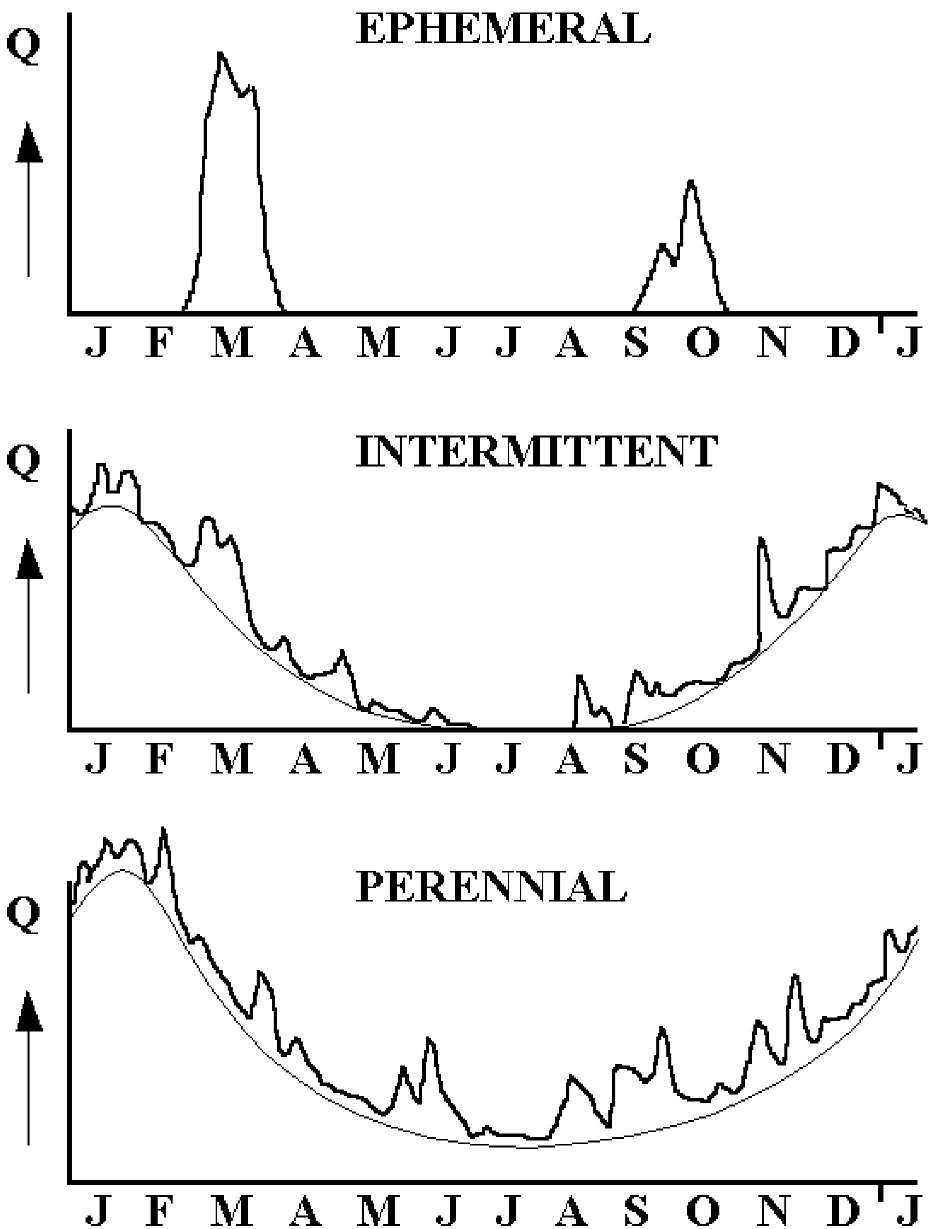
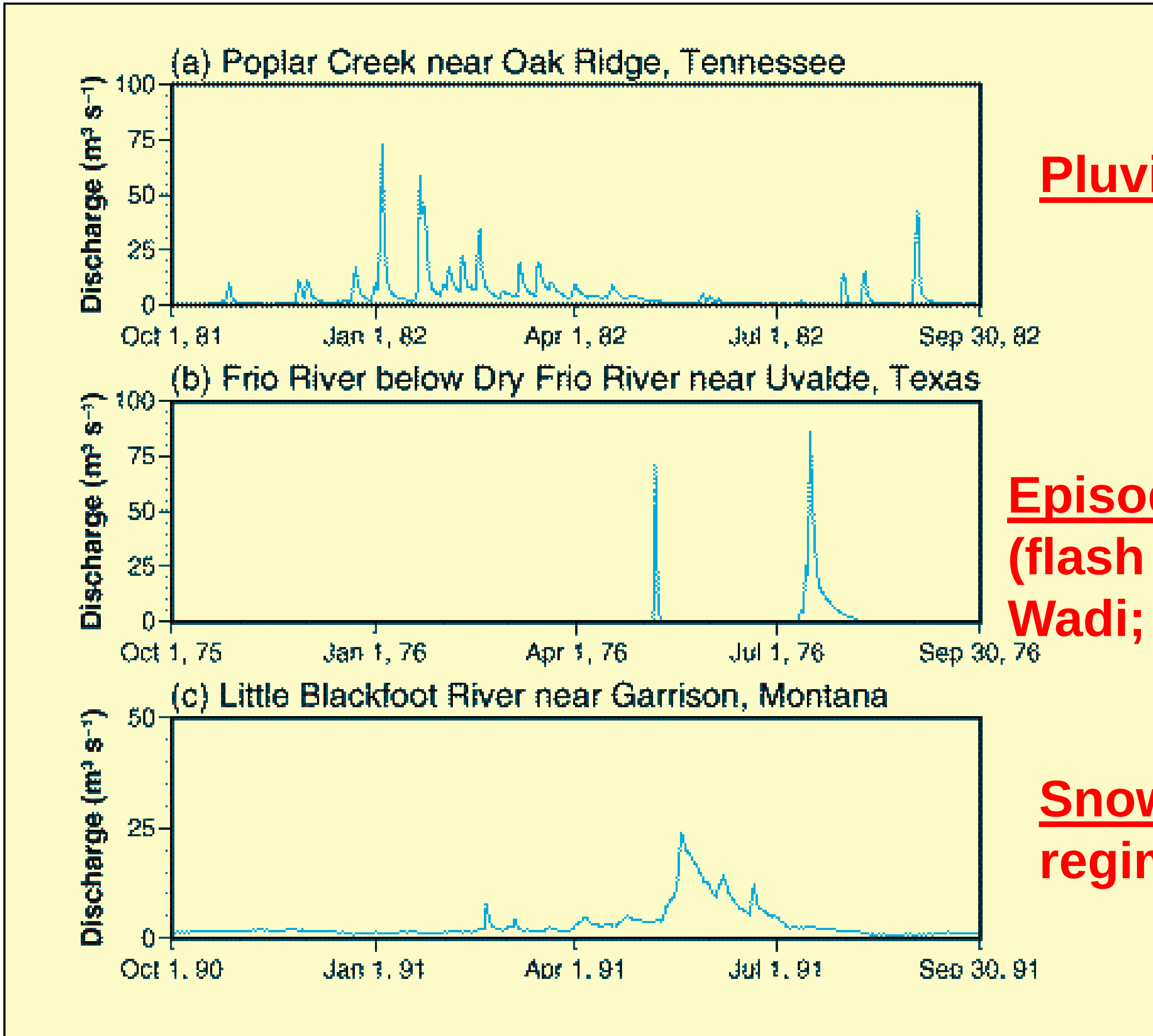
Analysis of catchment responses



Classification of Rivers



Temporal unequal flow distribution



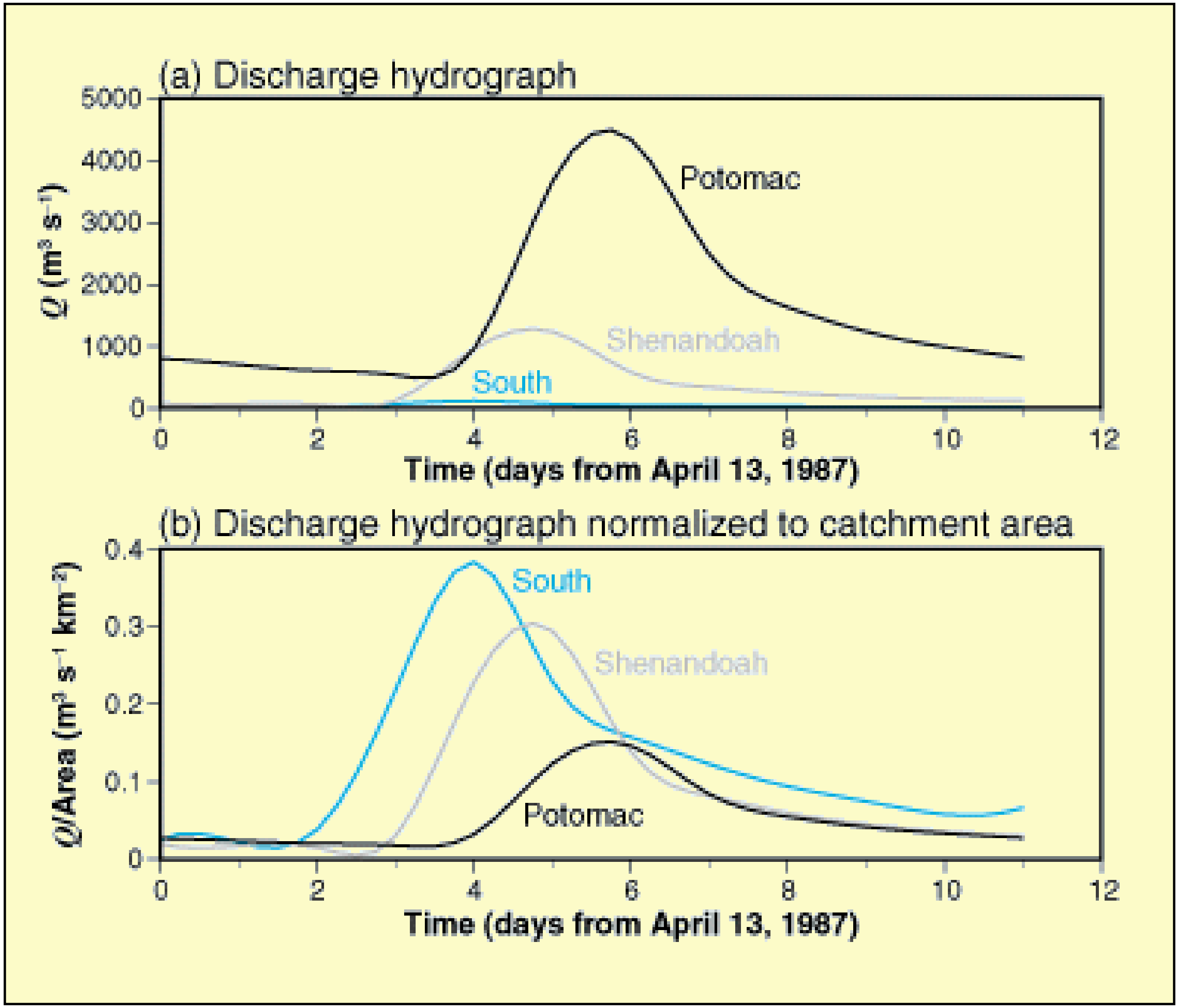
Pluvial regime

Episodic regime (flash floods in a Wadi; emphemeral)

Snow melt regime (nival)

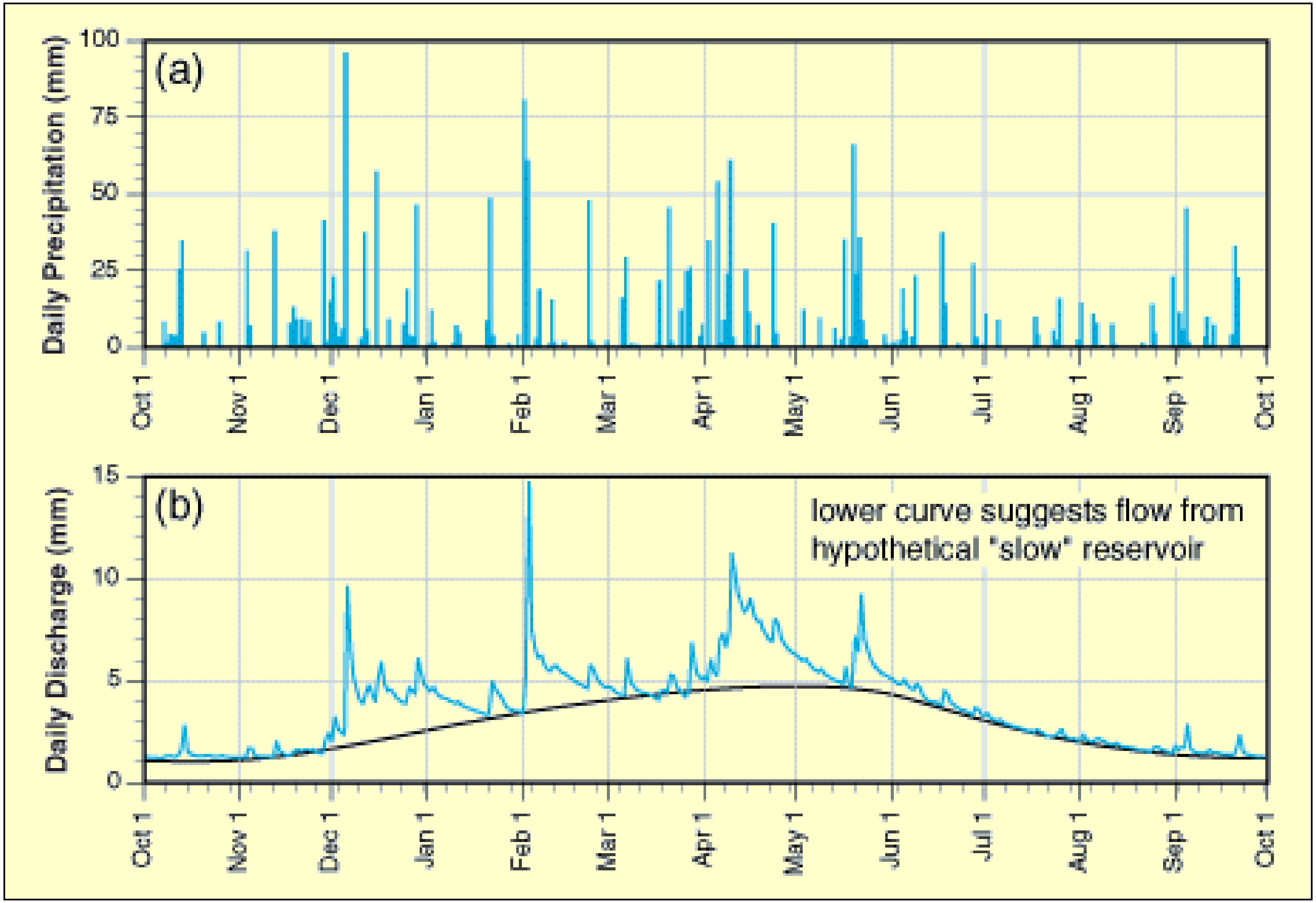
(Aus: Horn-berger et al., 1998)

Comparison of different catchment responses



(from: Hornberger et al., 1998)

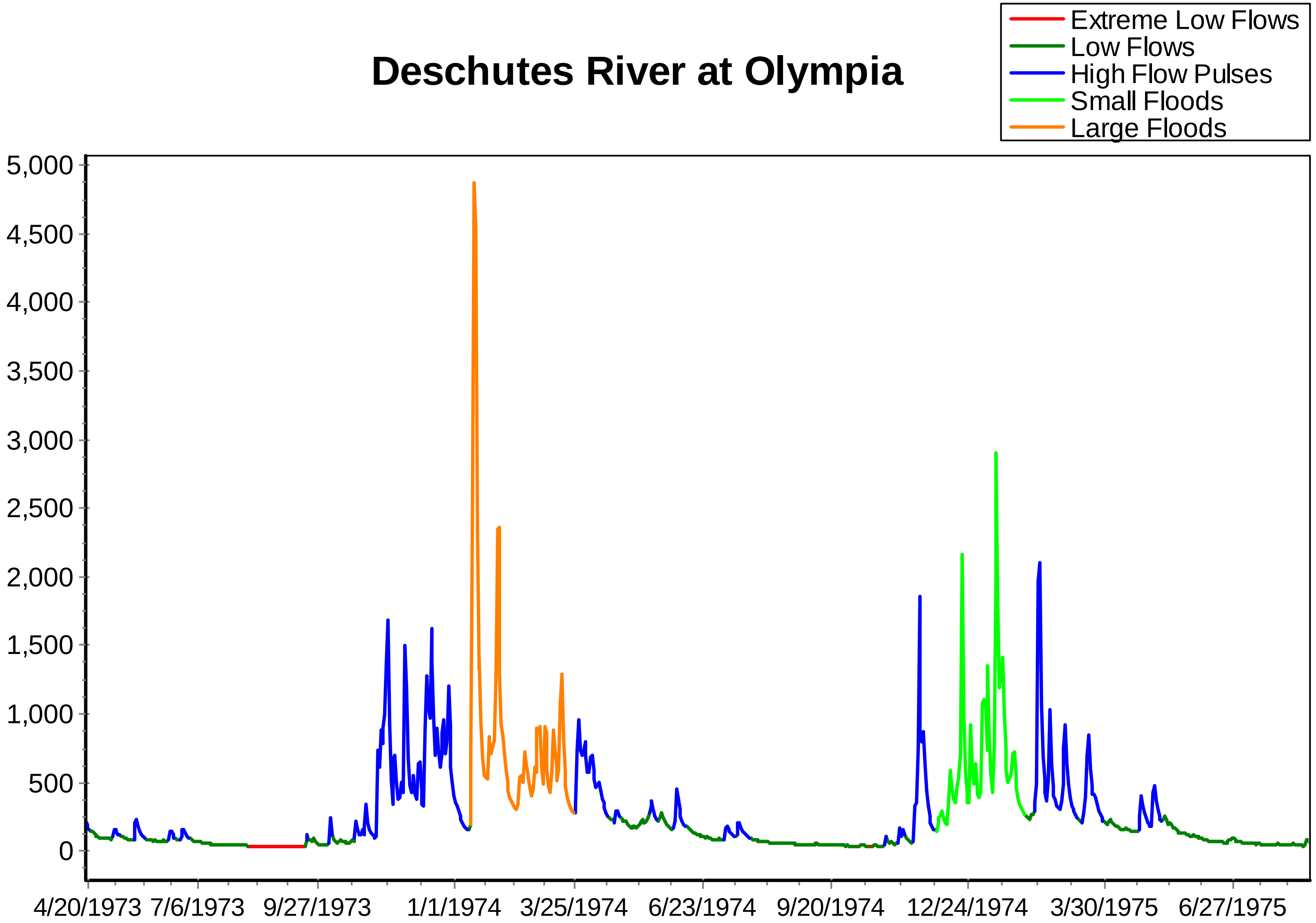
Response of two Runoff Components



(from: Hornberger et al., 1998)

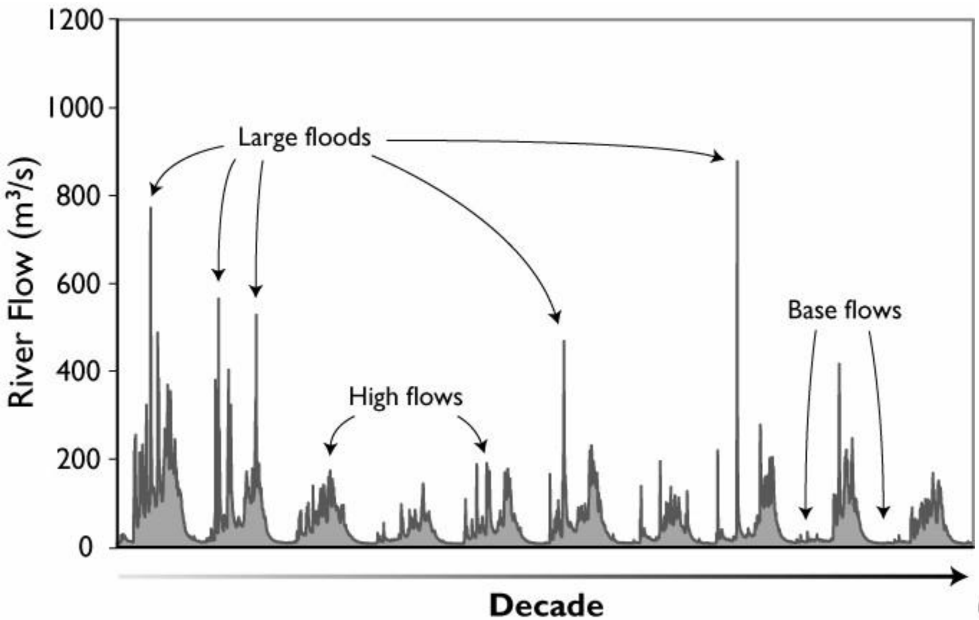
Interpretations of Discharge Variations to Describe the Hydrological Regime

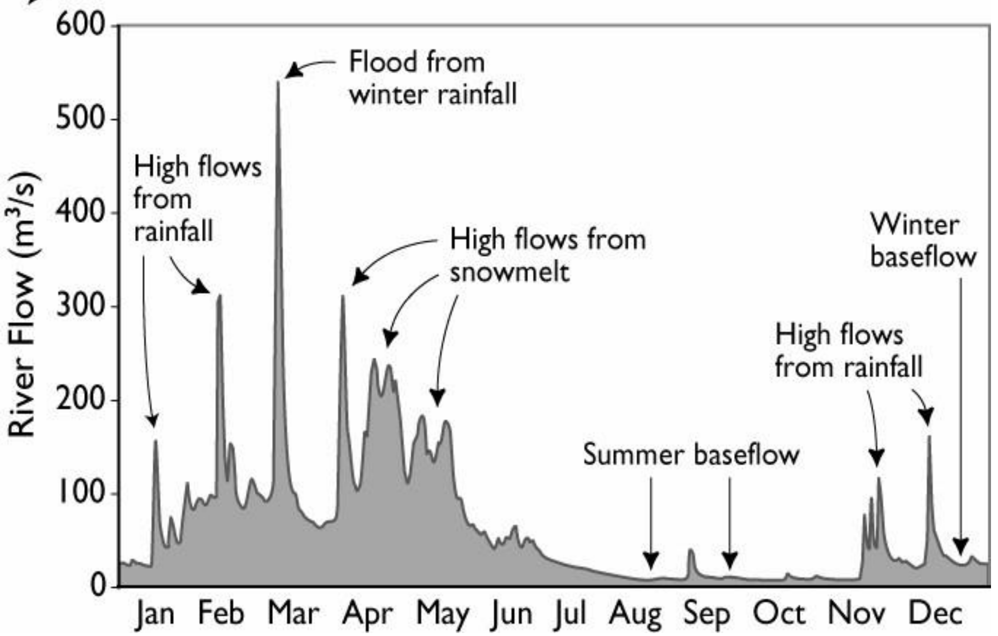
Crucial input for Environmental Flow Assessment



(Richter et al., 2006)

Examples for Annual and Long-term Flow Variability

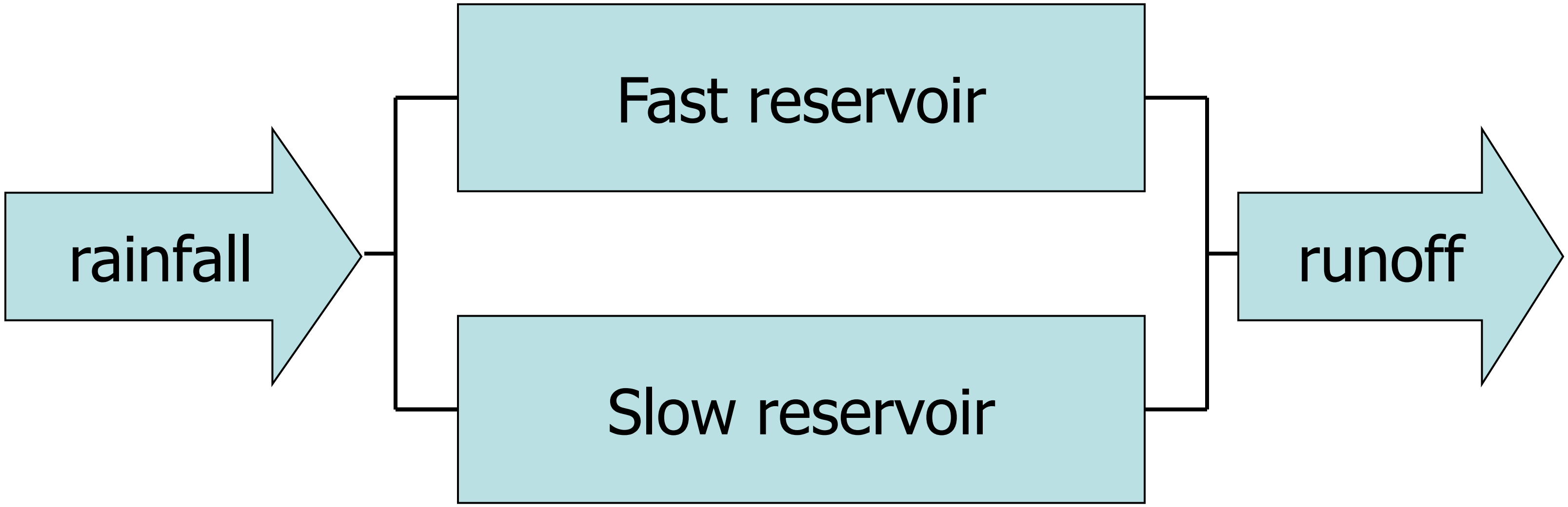




(Richter et al. 1996)

Final Remark on the Link Discharge –Stream Chemistry:

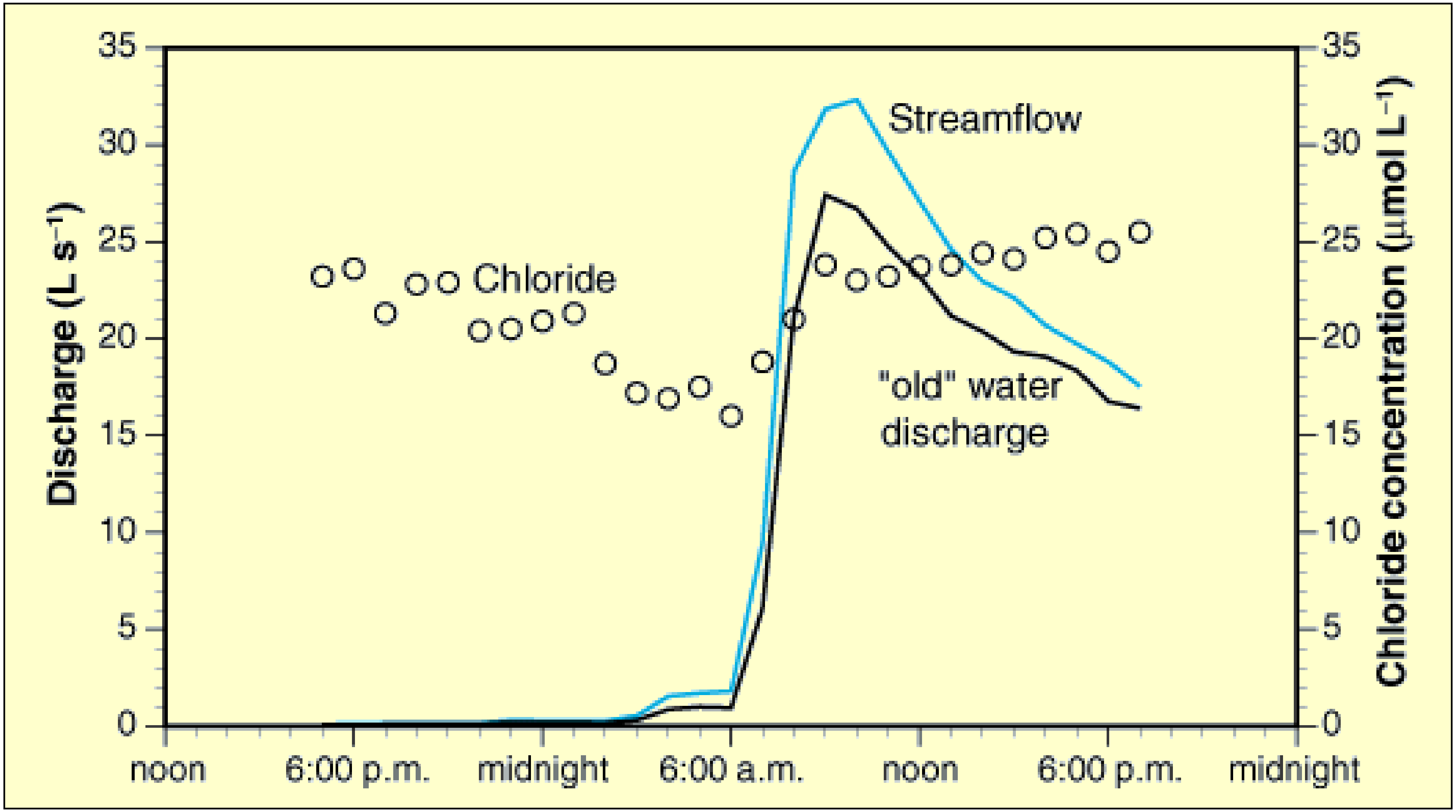
Response of two Runoff Components



Different runoff dynamics and different hydrochemistry

Implications for Hydrochemistry

(different runoff components have different hydo-chemical composition)



(from: Hornberger et al., 1998)

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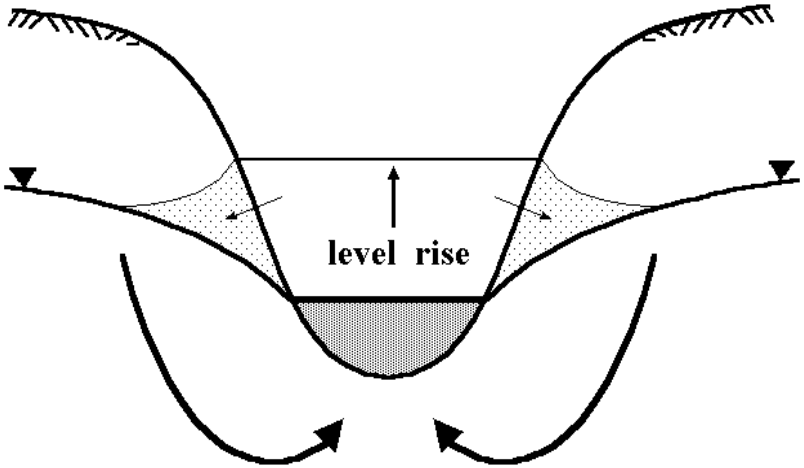
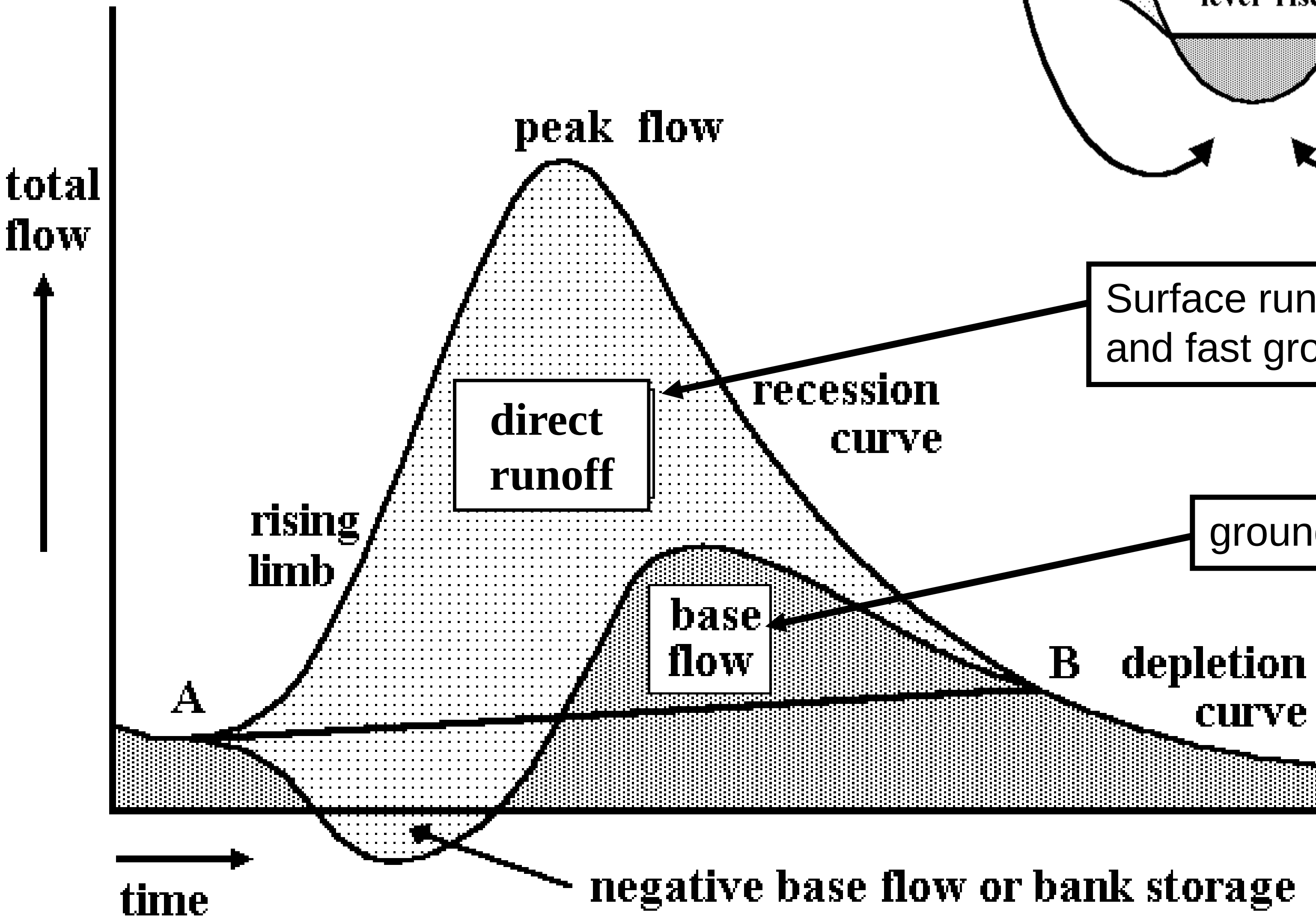
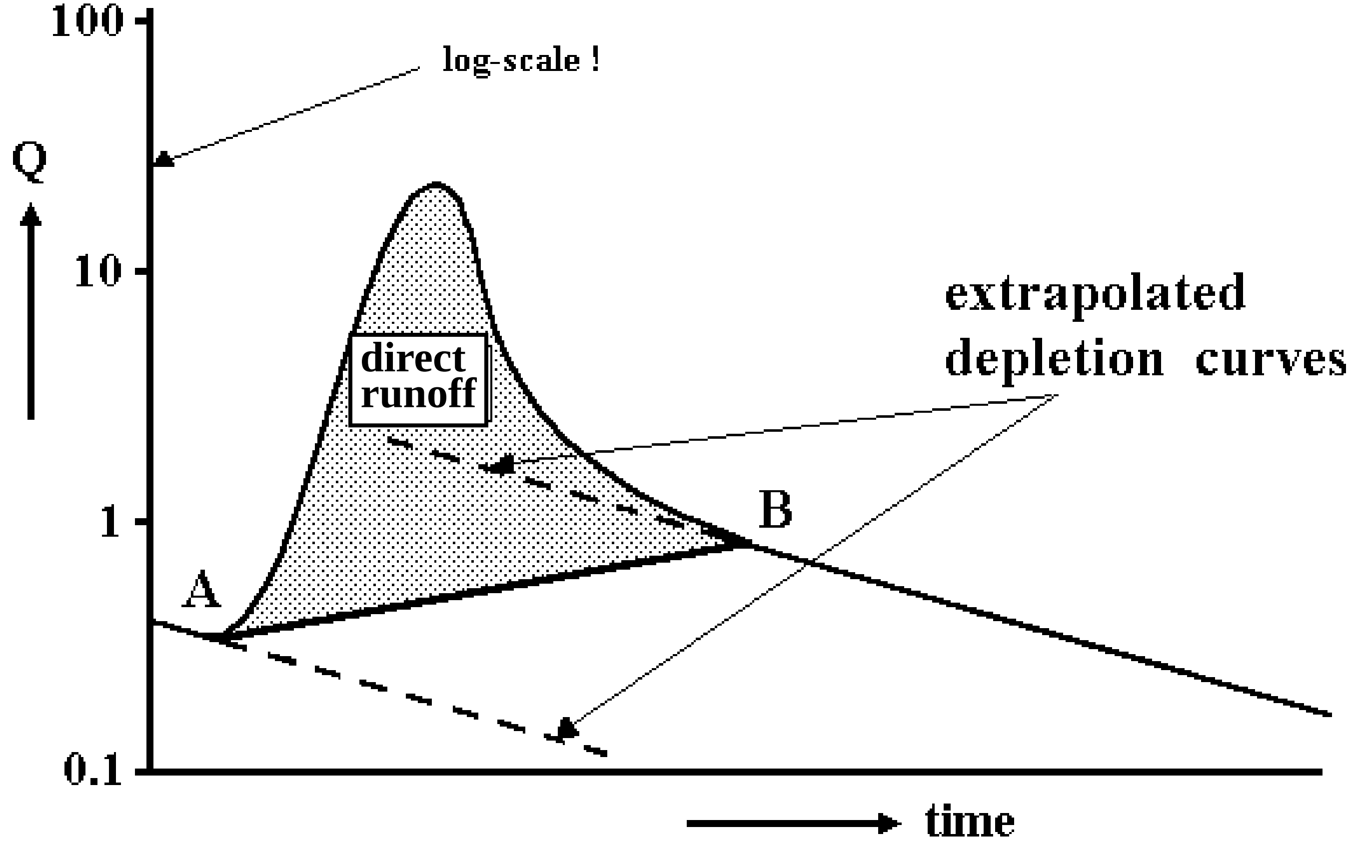
Base flow separation





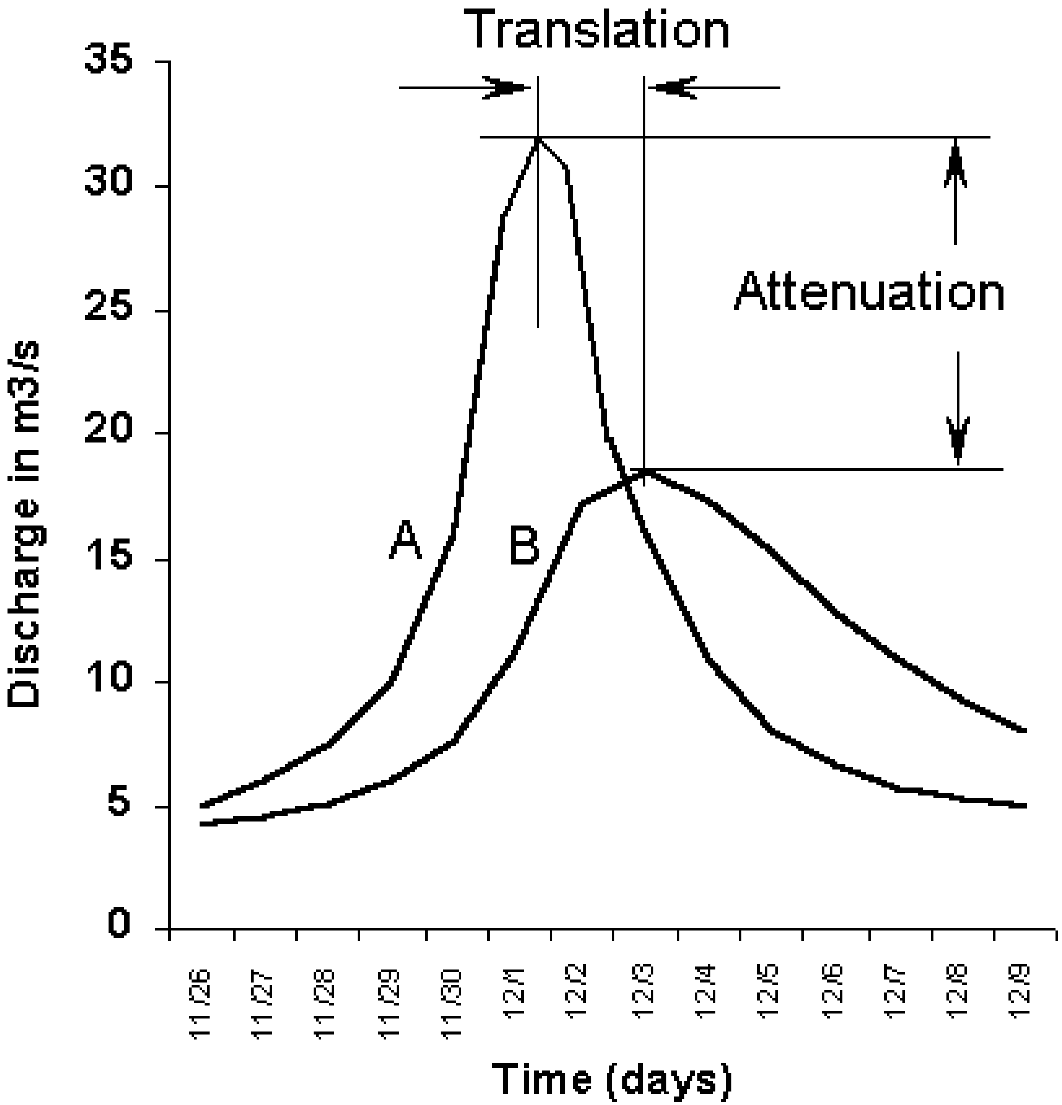
Base flow separation



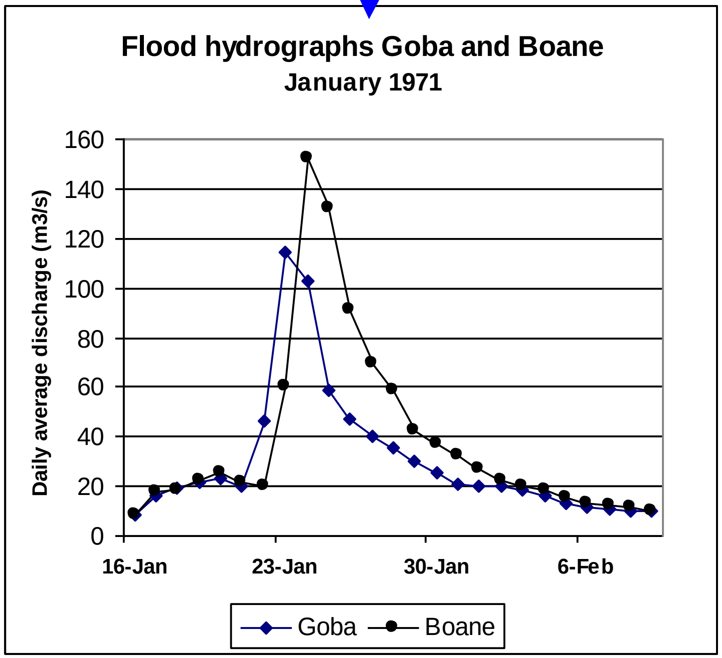
Depletion curve: $Q_t = Q_0\, e^{-\frac{t-t_0}{K}}$

Translation and attenuation of a flood wave

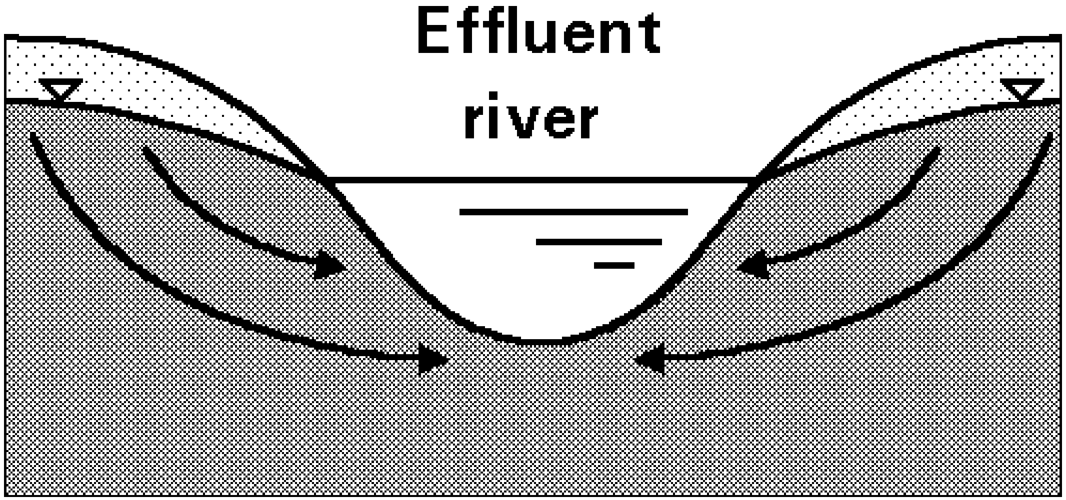
Assuming lateral in- and outflows between A and B are negligible

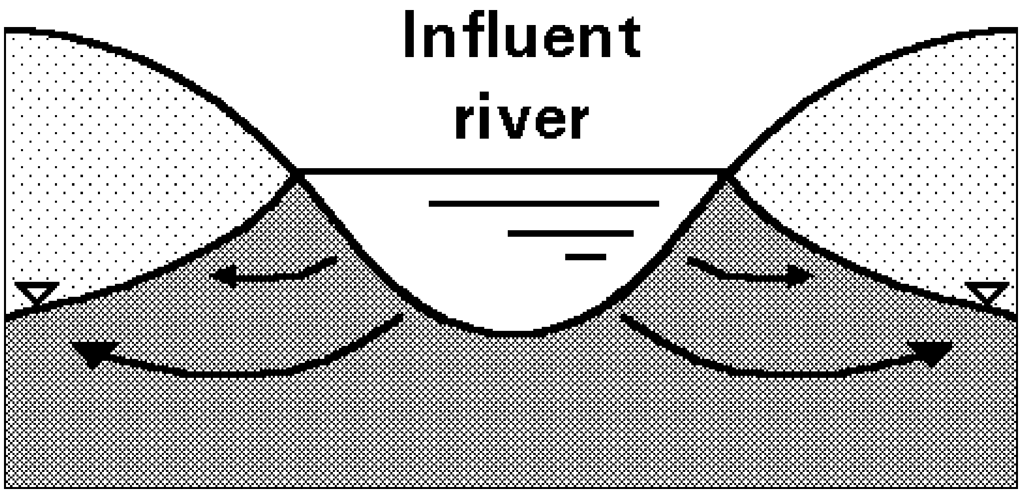


Lateral inflow
NOT negligible!



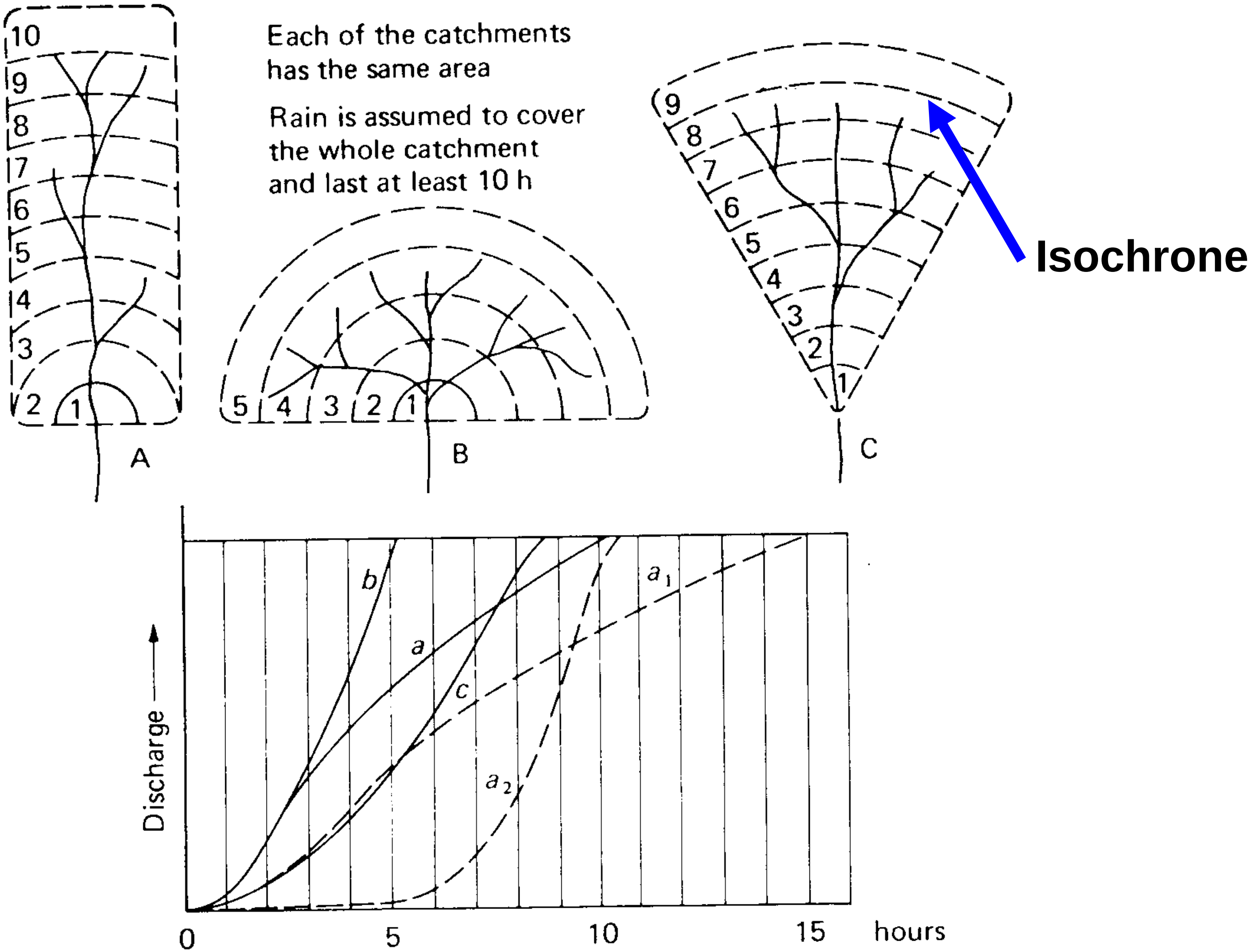
Influent and effluent streams





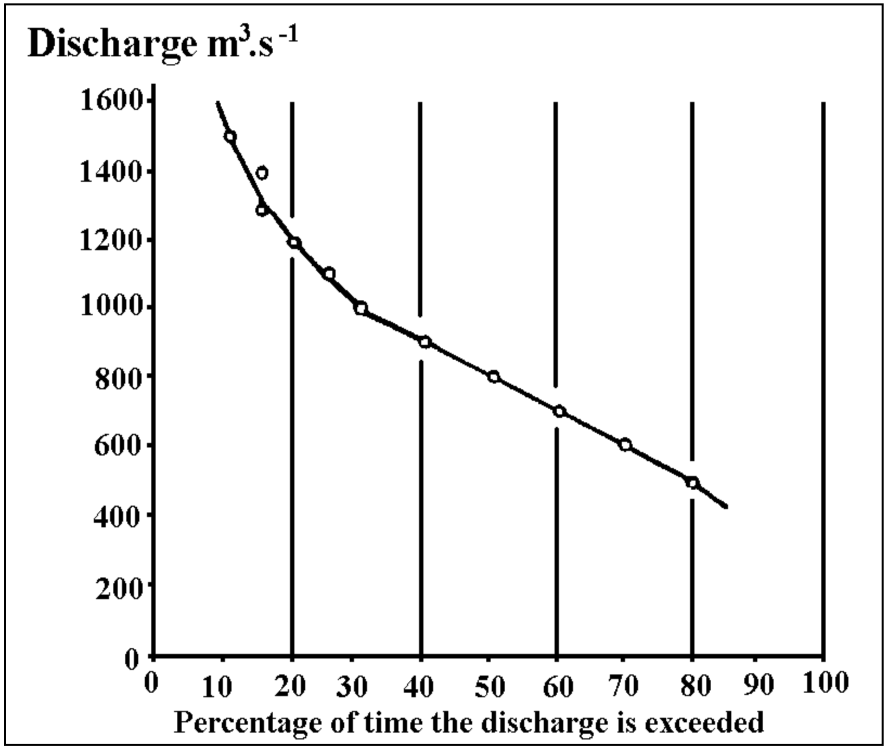
Example: The effect of shape on catchment response

(after Wilson, 1983)

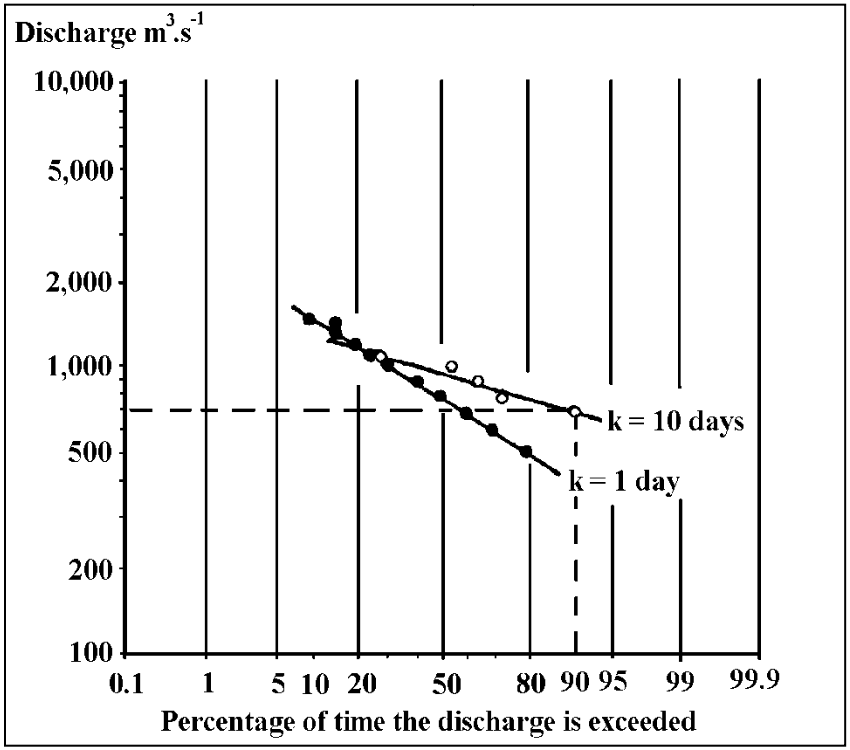


Flow Duration Curve (FDC)

All flow values in decreasing order to interpret exceedance values and flow variability



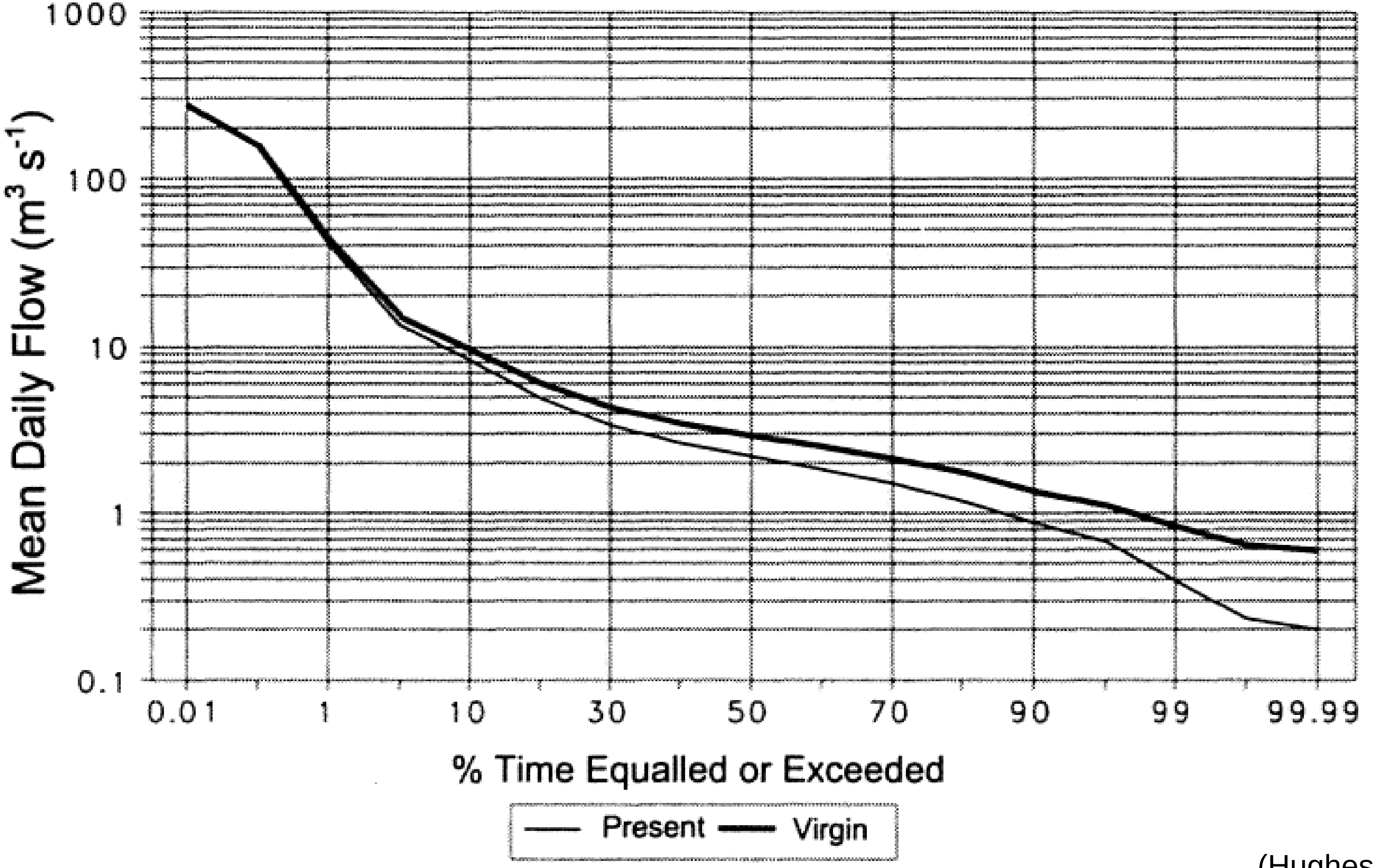
Flow duration curve for the example discussed in the course note



Flow duration curve with log-values on both axes for flow durations of k = 1 day and k = 10 days (average)

Note, the FDC is <u>not</u> a probability curve to estimate e.g. the 100 year flood!

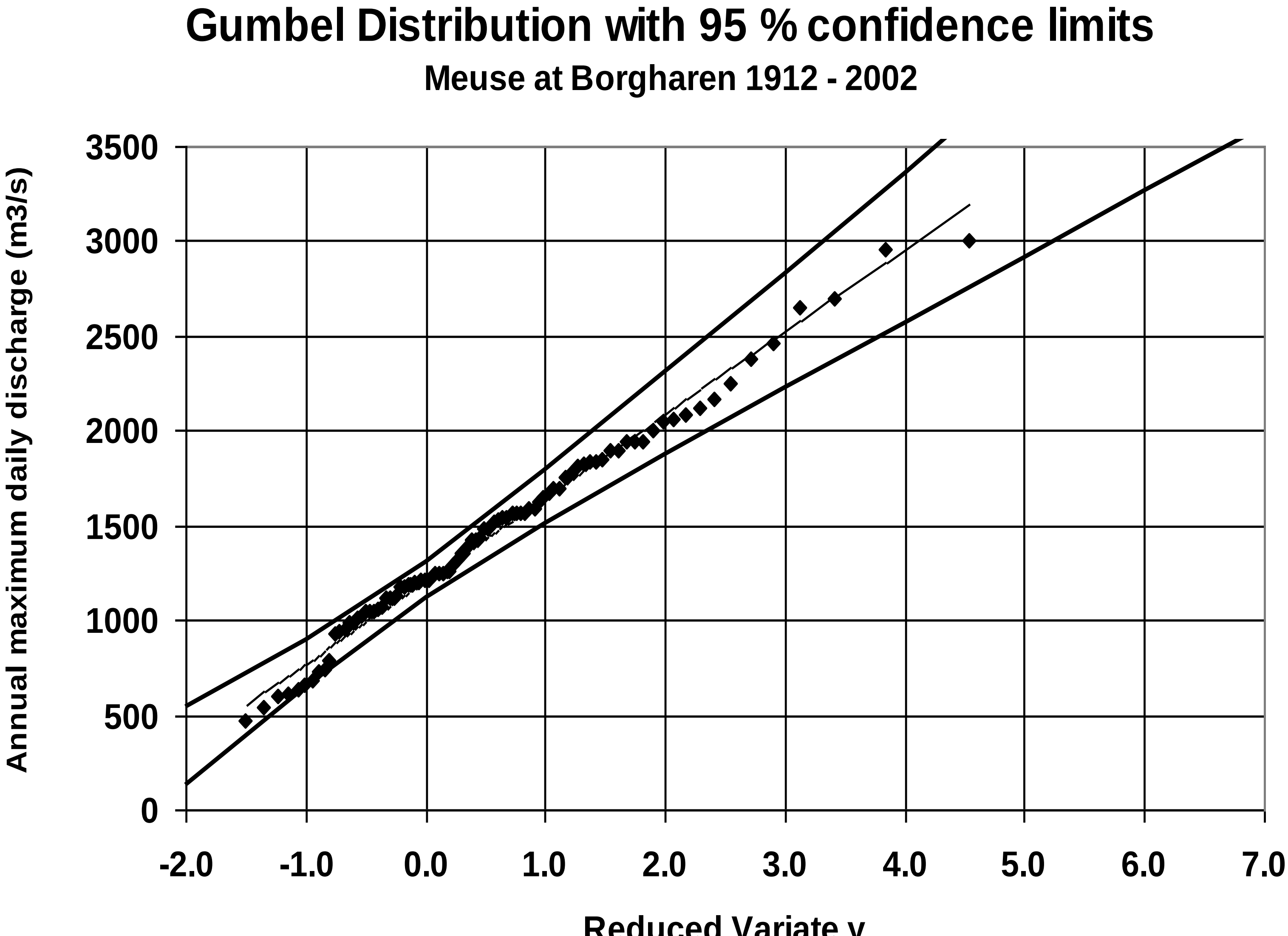
Example for the **flow duration curve** for a river in South Africa and the simulated flow duration curve for the same catchment under complete natural ('virgin') conditions



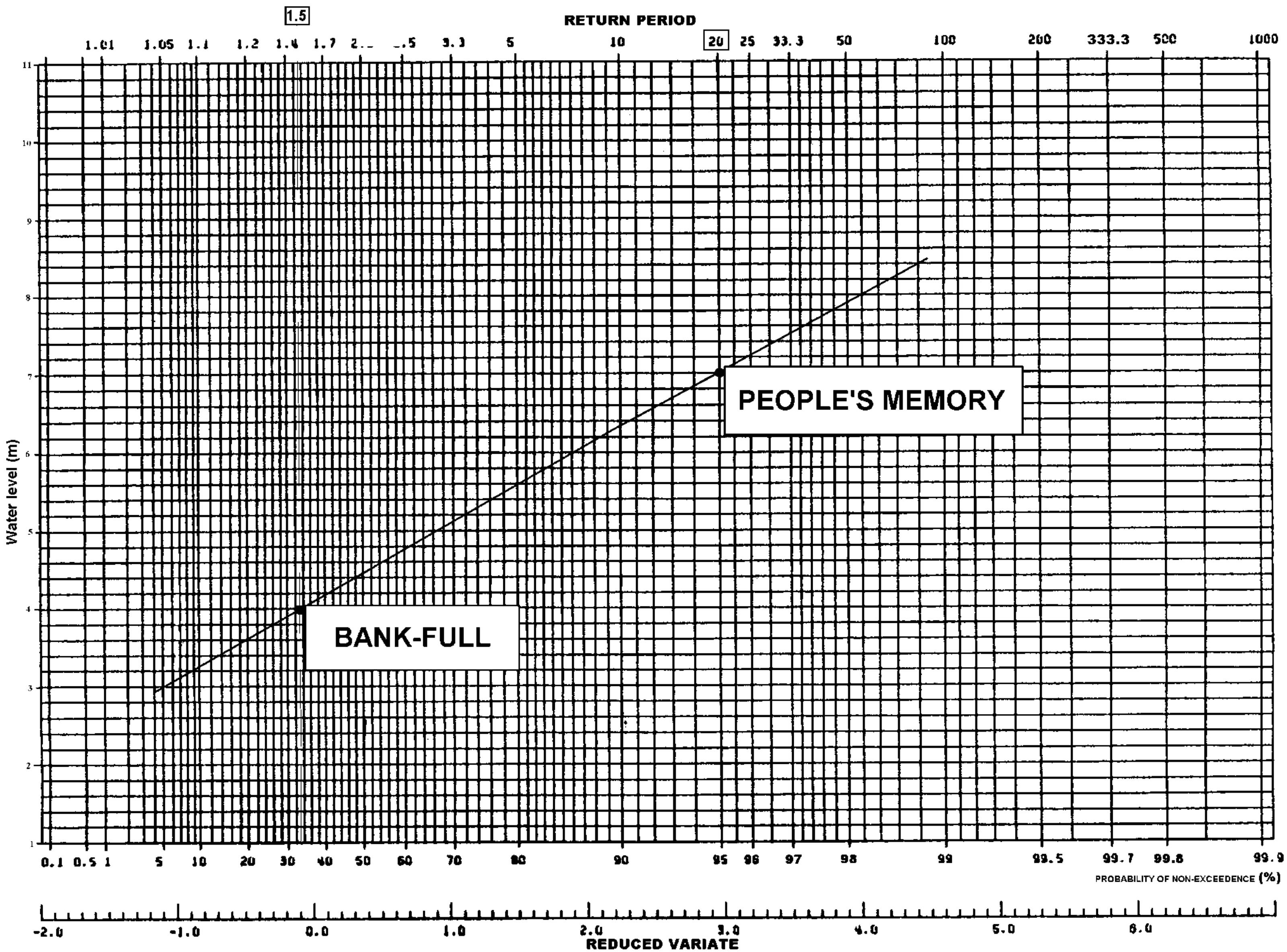
(Hughes, 2000)

Extreme value distributions

(see Workshop on Hydrology; exercises)



Gumbel distribution based on field observation and interviews



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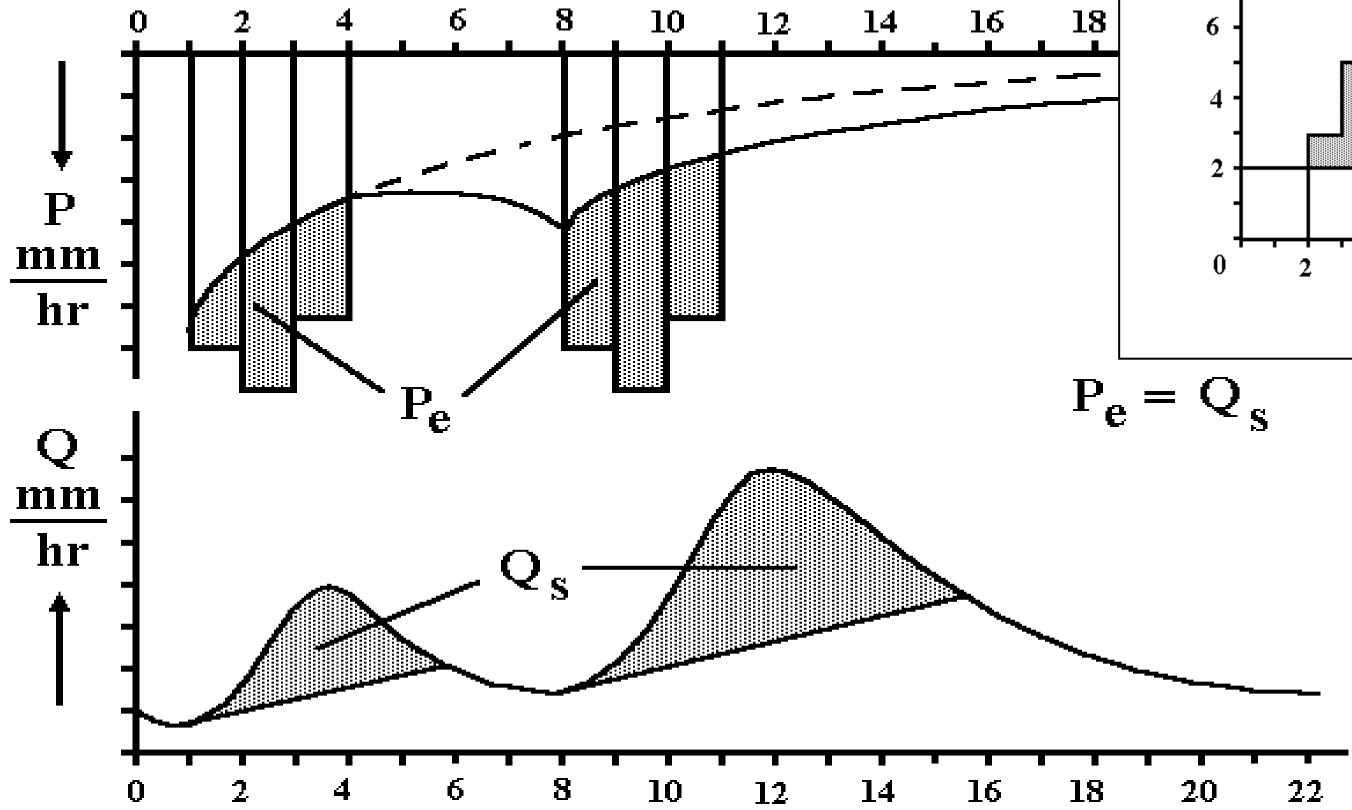
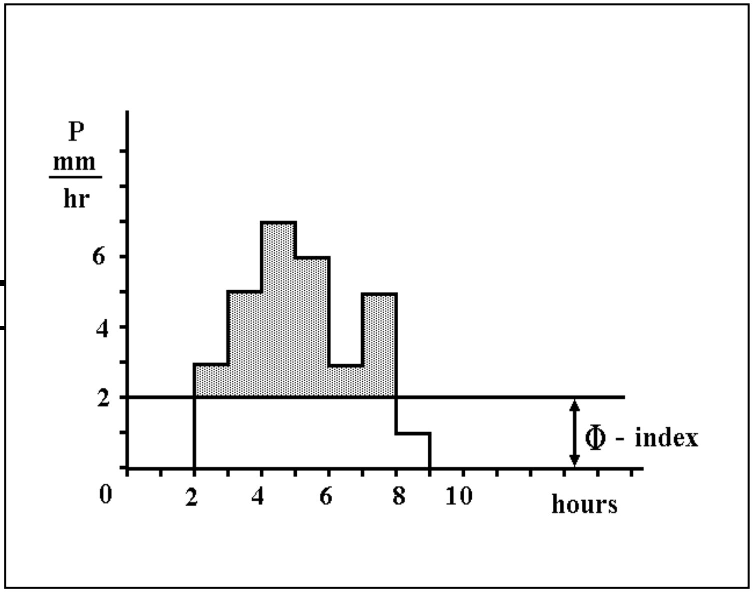
The effect of infiltration (and other!) losses on the effective precipitation and direct runoff





Runoff coefficient, *RF*: $\boldsymbol{RF = Pe/P = Qs/P}$

Simple, lumped black box models to estimate peak discharge

Example #1: The rational method (Mulvaney, 1850):

- Crude estimate of peak flow, often used for urban drainage and small catchments (<15 km^2)
- Uniform rainfall with constant rate *i* (from IDF) over time t_c
- Entire catchment area *A* contributes to runoff

$$Q_p = C\, i\, A$$

- *C* is the runoff coefficient
- *tc* is the time of concentration can be estimated with Kirpich formula, where L is the maximum length of the catchment and S is the slope of the catchment over distance L:

$$t_c = 0.015 \left(\frac{L}{\sqrt{S}} \right)^{0.8}$$

Type of drainage area	Runoff coefficient
Sandy soil	0.05 - 0.20
Heavy soil	0.13 - 0.35
Business	0.50 - 0.95
Residential	0.25 - 0.75
Industrial	0.50 - 0.90
Streets	0.75 - 0.95
Roofs	0.75 - 0.95
Forests	0.10 - 0.60
Pastures	0.10 - 0.60
Arable land	0.30 - 0.80

Example #2: Time-area method

Catchment is divided in *n* sub-areas by isochrones

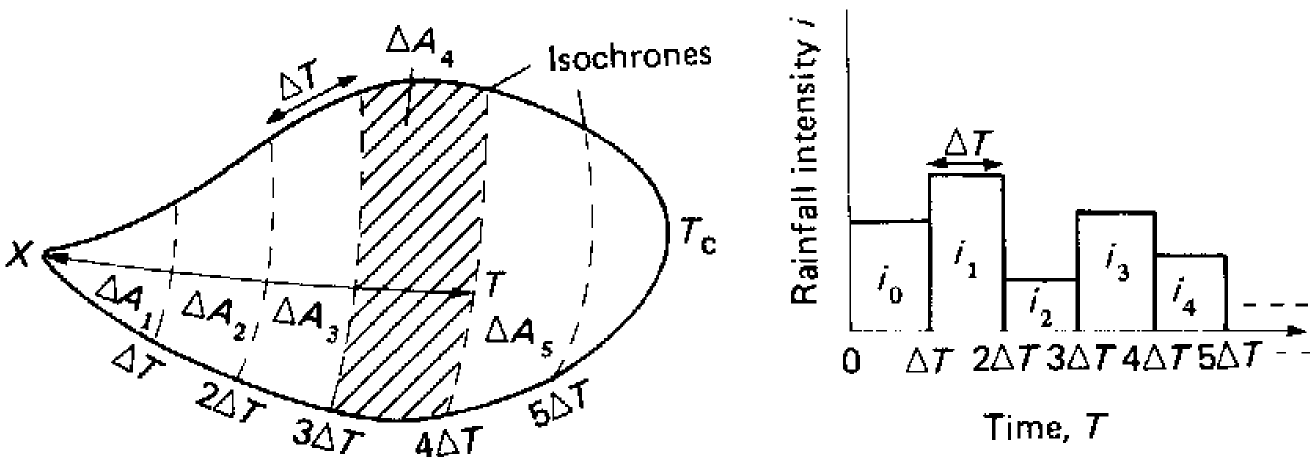
- Each sub-area A_k has effective rainfall rate i_k (k=1…n)

$$Q_T = \sum_{k=1}^{T} i_{T-k} \Delta A_k$$

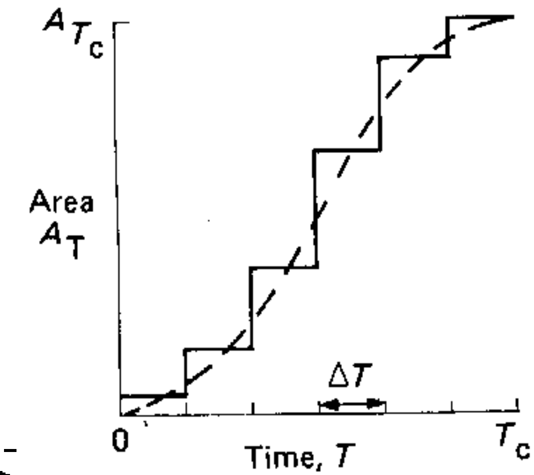
When $T \geq T_c$, the peak flow is (note that $n = T_c/\Delta T$):

$$Q_p = \sum_{k=1}^{n} i_{n-k} \Delta A_k$$

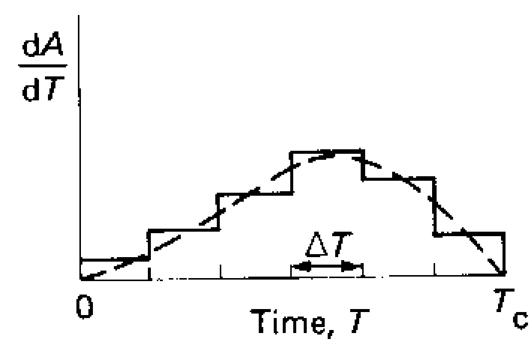
Time-area method (cont'd):



(a) Rainfall bar graph and catchment showing isochrones of travel time



(b) Time-area curve



(c) Time-area-concentration curve

From: Shaw (1988)

Take Home Messages

- Rating curves are valid over a certain range of water levels and have to be updated regularly; there are many different types of gauges
- Know the different catchment response types and use the right terminology
- Hydrograph separation according to runoff dynamics
- Estimation and interpretation of depletion curve
- A flow duration curve uses all the flow data, an extreme value distribution often only one value per year (i.e. annual max and POT method)
- Hydrograph separation may be used to estimate effective precipitation or the Φ-index (constant loss rate)
- Know about simple black-box methods to estimate runoff peaks
- There is a link between runoff dynamics and hydro-chemistry of the stream