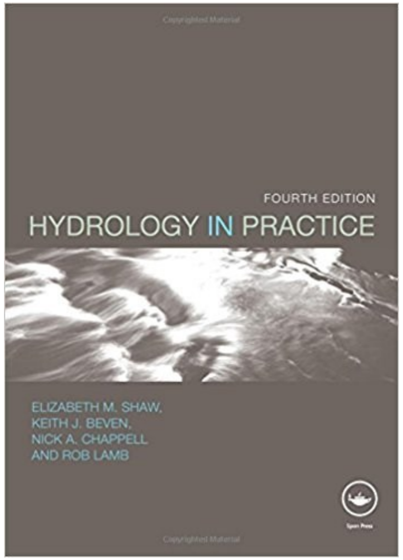
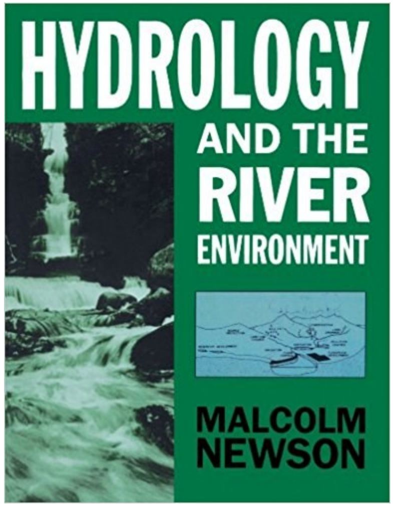
Flood hydrology and low flows



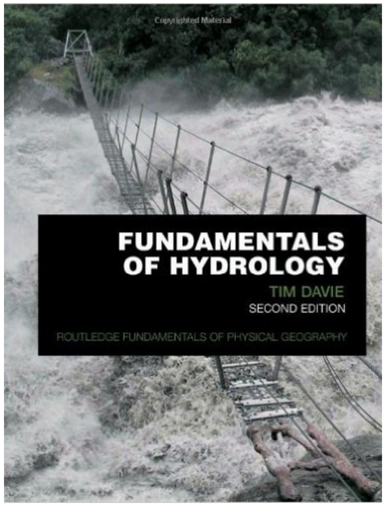
Shaw et al. (4th Ed.) – Chapter 11, Chapter 13 & pp.280-295

Prof. Kate Heal

School of GeoSciences



Newson – Chapter 4



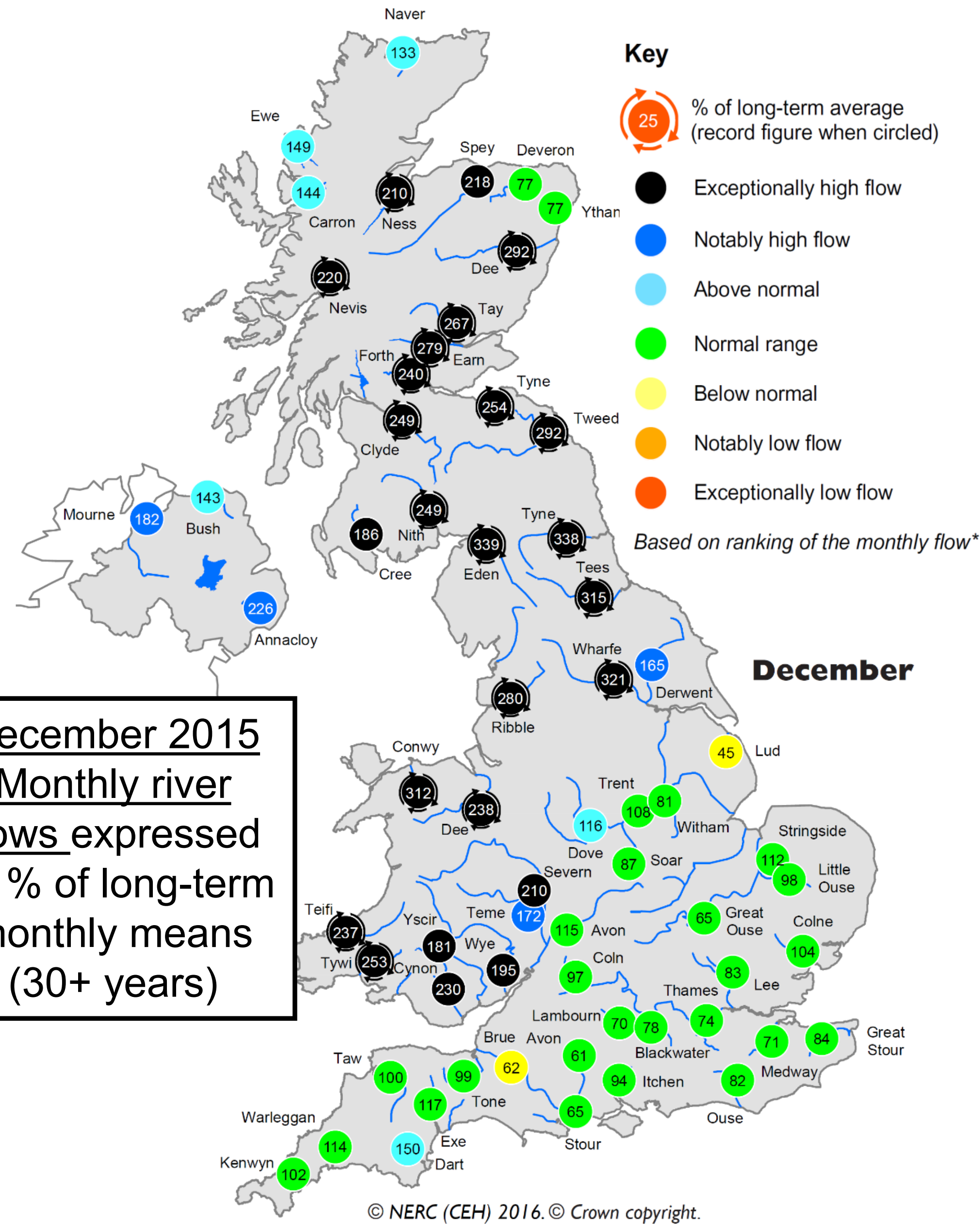
Davie – Chapter 7

Soil, Water & Atmospheric Processes

Recent floods in the UK – winter 2015/16

- New 24-hour UK rain record – 341.4 mm at Honister Pass
- West Coast railway line between Carlisle and Scotland out of action for 2 months
- Road bridges closed for several months in NW England
- > £1.3 billion damages to homes and businesses
- £100 million government funding released initially for assistance, flood protection

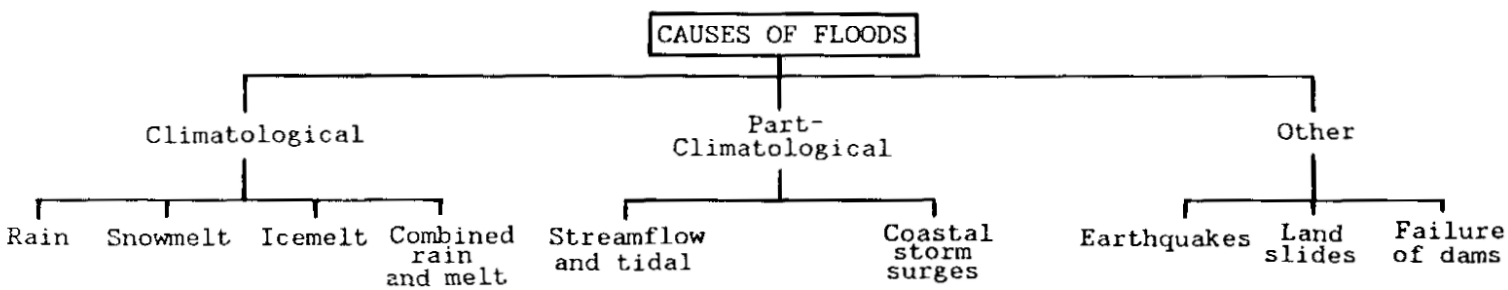
December 2015
Monthly river flows expressed as % of long-term monthly means (30+ years)



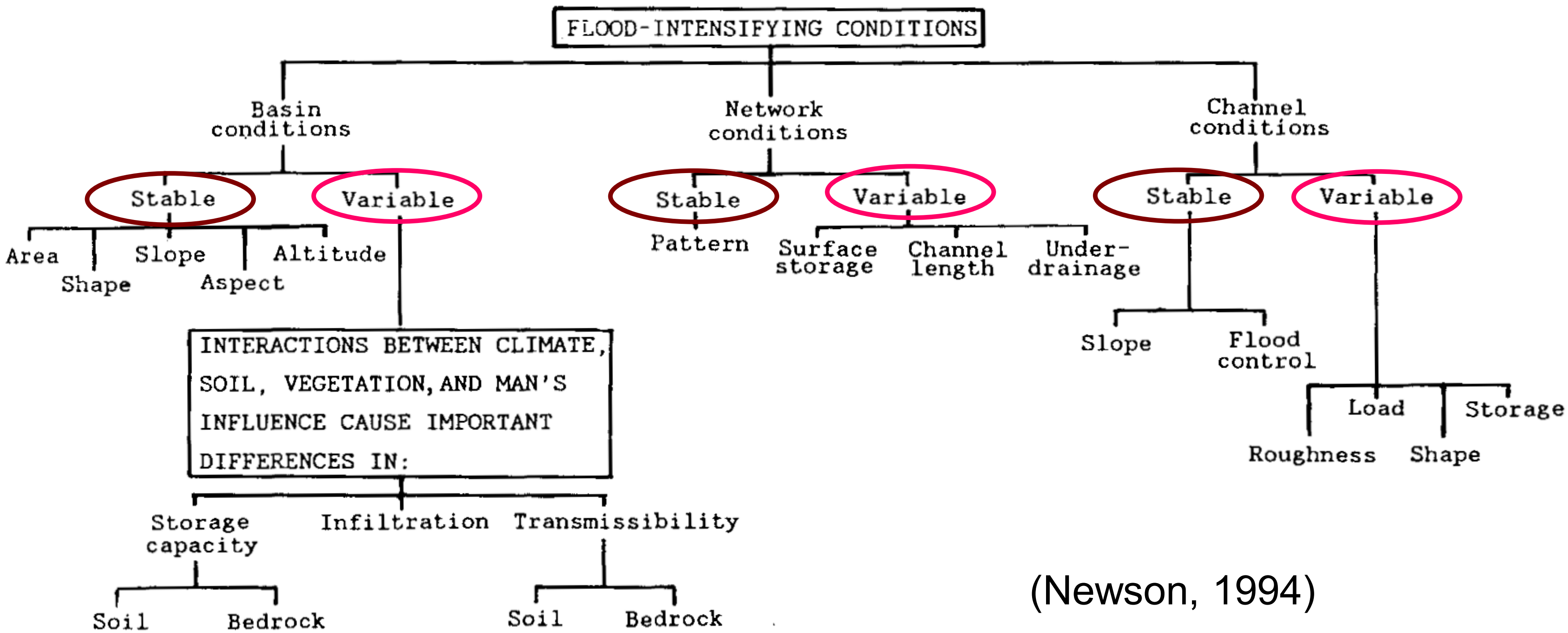
Definition of a flood

" a body of water which rises to overflow land that is not normally submerged"

http://floodlist.com/wp-content/uploads/2015/12/cumbria-floods-december-2015jpg



(Newson, 1994)



(Newson, 1994)

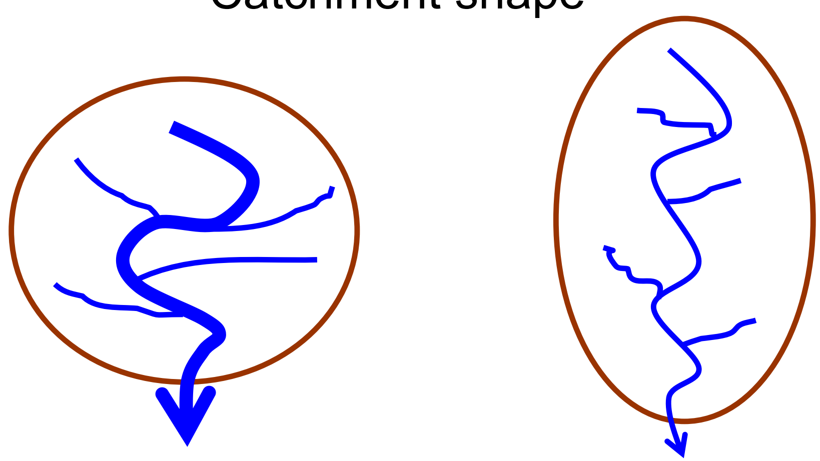
- Causes of most floods are complex
- Arise from combined effects of climate, geology, soil, vegetation and human influences

Flood intensifying conditions:
STABLE Basin conditions

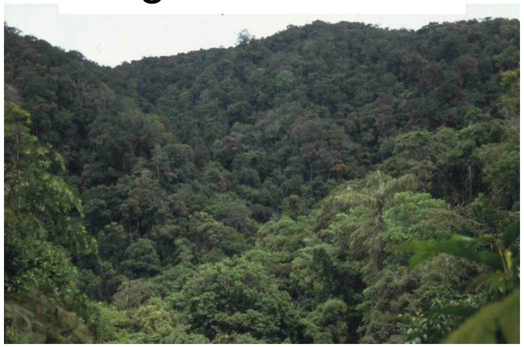
Catchment area

Topography

Catchment shape



Flood intensifying conditions: <u>VARIABLE Basin conditions</u>



Antecedent conditions

Flood intensifying conditions

Network conditions

Drainage network

Channel conditions

Channel characteristics

Human activities: river regulation

Managing flood risks - Design of flood protection structures

Megget Reservoir, largest earth dam in Scotland

Land use	*Acceptable return period (years)*
Floodplain grazing	3
Floodplain arable	10-25
Urban centres	200
Reservoirs in remote areas	150-1000
Reservoirs in populated areas	10 000

What is the flood size?
Flood frequency analysis

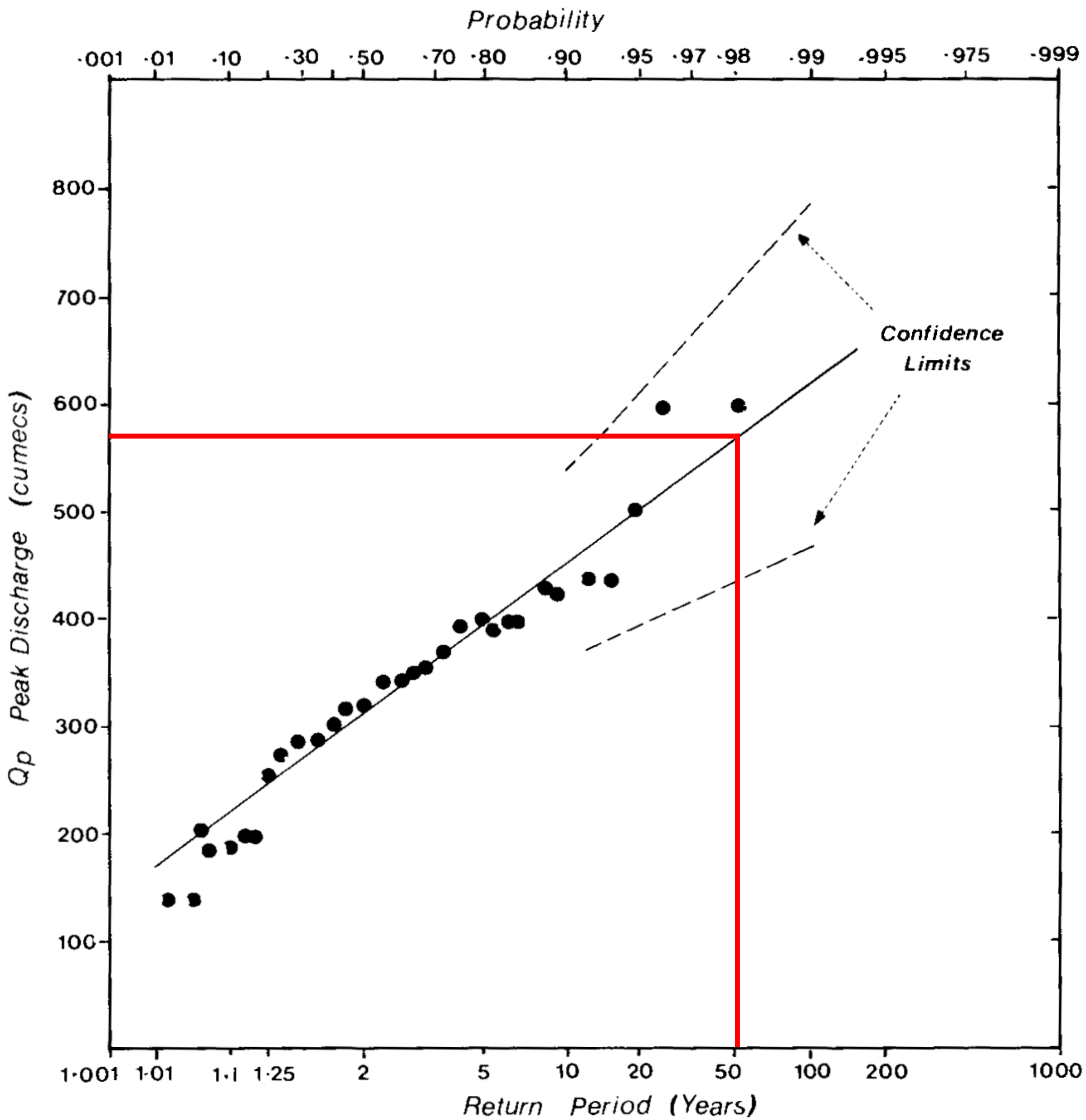
- Return period (recurrence interval) of a flood is how often a flood of a particular magnitude will be exceeded ON AVERAGE
- E.g. Return period of 50 years
- Now re-expressed as annual exceedance probability (AEP) = % probability of occurrence in a particular year
  - Return period of 100 years = 1% probability of occurrence in any one year
- Long time series of river flow data
- Annual peak flows ranked highest to lowest
- Return period of each peak flow calculated using Weibull's formula:

$$\boxed{\text{Return period (in years)} = \frac{n+1}{m}}$$

n = number of years of record (in the total dataset available)

m = rank

Flood frequency analysis



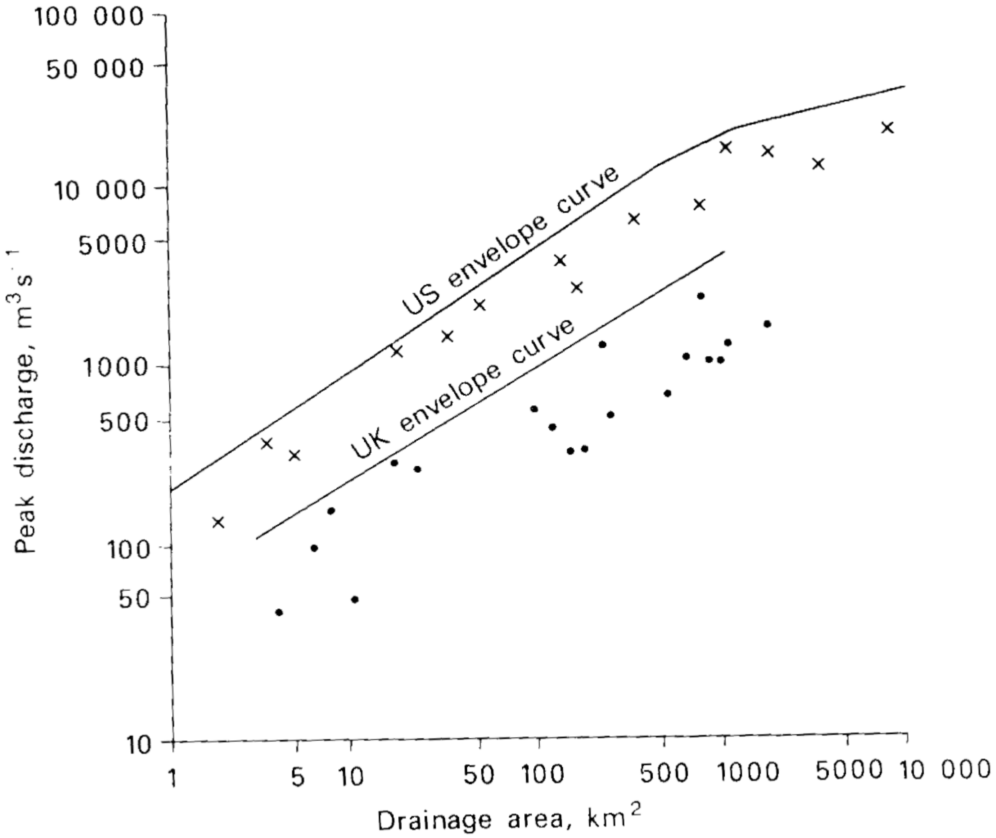
(Newson, 1994)

Flood frequency plot (*Gumbel distribution*) => estimate size of design flood

What to do when limited/no flow data available?

Flood estimation

1. <u>Envelope curves</u>



(after Shaw, 1994)

BUT rely entirely on observed data

2. Flood Estimation Handbook (FEH) for the UK

Uses flow data and catchment characteristics to estimate QMED (median annual maximum flow, return period 2 years)

$$QMED = 8.3062\ AREA^{0.8510}\ 0.1536^{\frac{1000}{SAAR}}\ FARL^{3.4451}\ 0.0460^{BFIHOST^2}$$

AREA = catchment area (km^2)

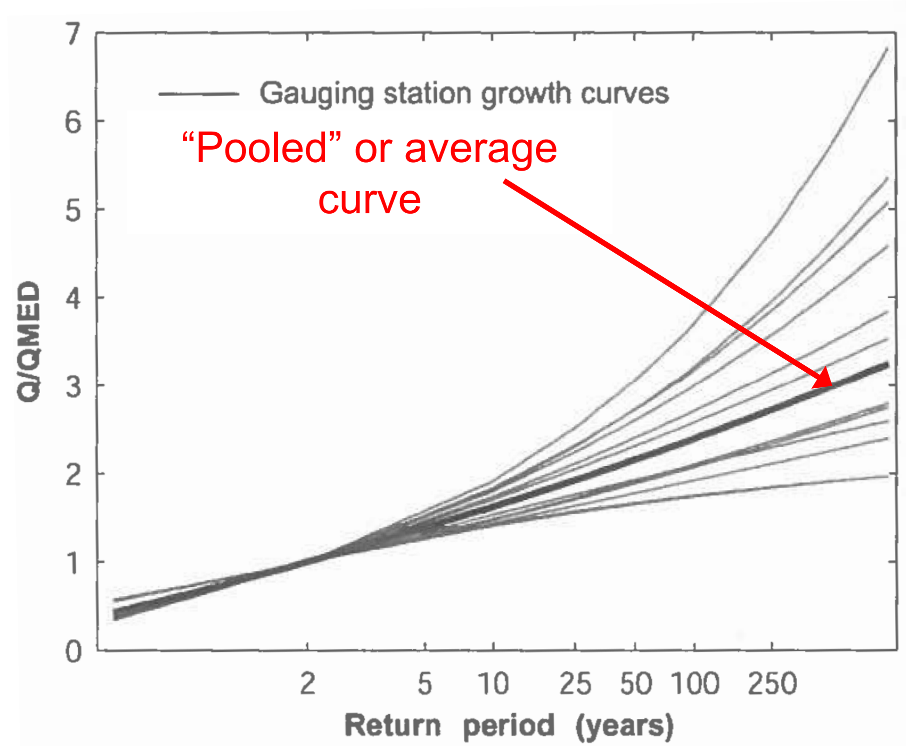
SAAR = standard-period (1961-90) average annual rainfall (mm)

FARL = index of flood attenuation due to reservoirs/lakes (1.0 = no attenuation)

BFIHOST = baseflow index derived using the HOST (Hydrology Of Soil Types) classification

Then conduct flood frequency analyses using similar catchments with flow data => pooled growth curve

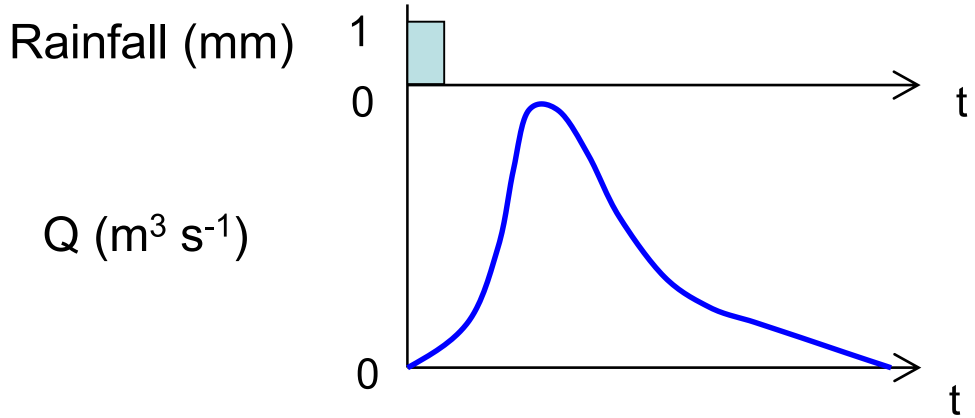
(Shaw *et al*., 2011)



Rainfall-runoff modelling

Unit hydrographs

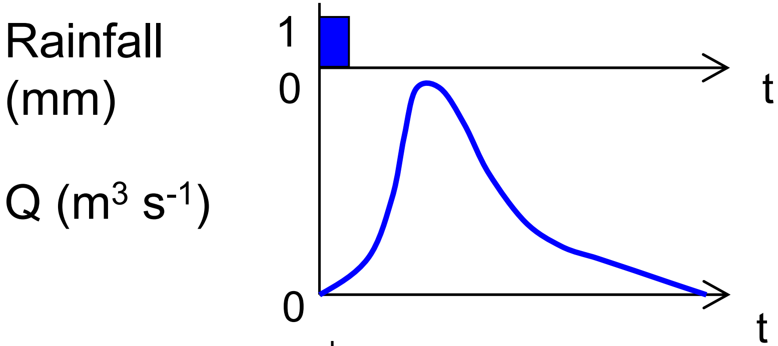
- Characteristic storm hydrograph for a catchment
- A unit hydrograph of 1 hour duration = hydrograph of direct runoff resulting from 1 mm depth of effective rainfall falling uniformly over the whole catchment for 1 hour.

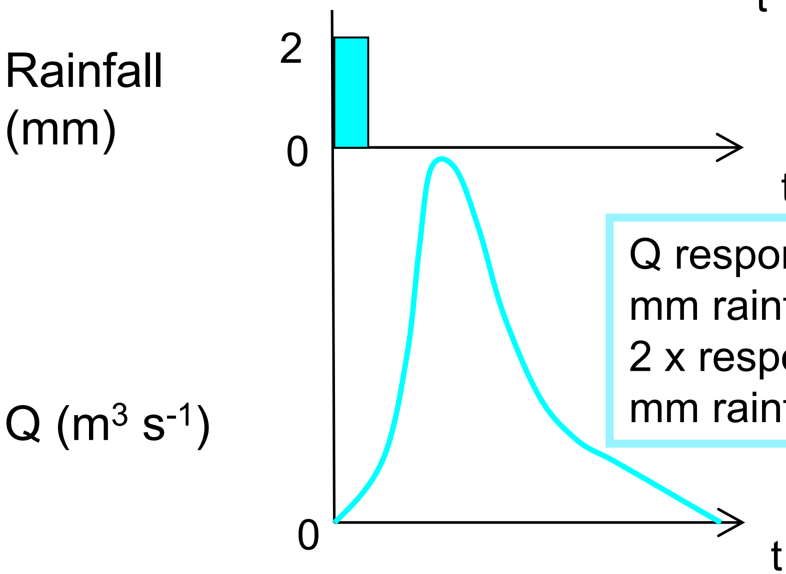


- Effective rainfall: rainfall that reaches the river channel
- Quickflow: unit hydrographs only consider the quickflow runoff component; not baseflow

Unit hydrograph assumptions

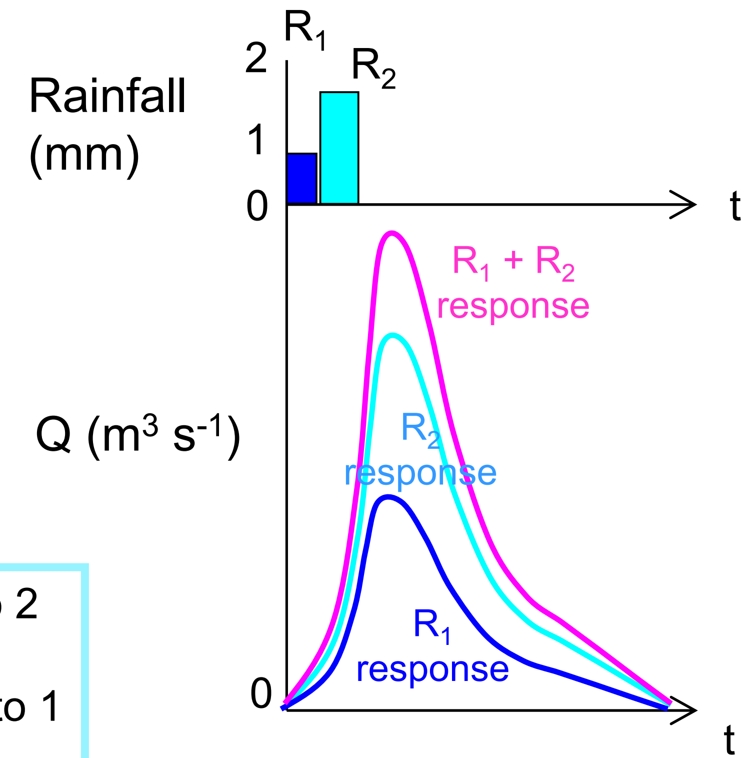
a) Direct relationship between effective rainfall and quickflow





Q response to 2 mm rainfall = 2 x response to 1 mm rainfall

b) Superposition



c) Relationship between effective rainfall and quickflow does not change over time

BUT relationship between effective rainfall and quickflow depends may vary seasonally and can depend on antecedent conditions

Taking account of climate change in flood protection

Until recently assumed 20% increase in river flows due to climate change

NOW region-specific peak river flow allowances in England & Wales

www.gov.uk/guidance/flood-risk-assessments-climate-change-allowances

River basin district	Allowance category	Total potential change anticipated for the '2020s' (2015 to 2039)	Total potential change anticipated for the '2050s' (2040 to 2069)	Total potential change anticipated for the '2080s' (2070 to 2115)
South East	Upper end	25%	50%	105%
	Higher central	15%	30%	45%
	Central	10%	20%	35%
Thames	Upper end	25%	35%	70%
	Higher central	15%	25%	35%
	Central	10%	15%	25%

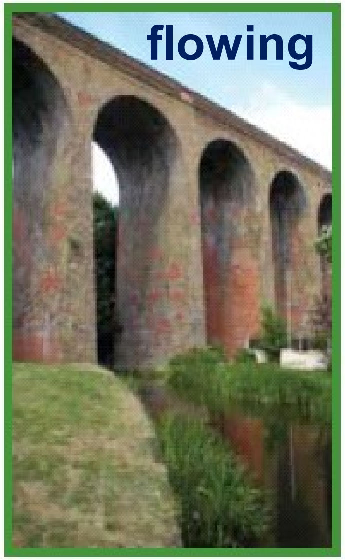
Upper end = 90th percentile
Higher central = 70th percentile
Central = 50th percentile

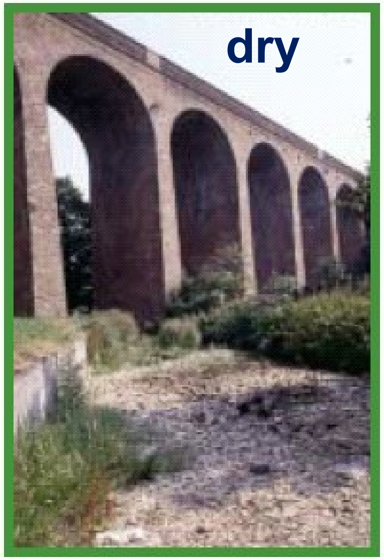
If the higher allowance (70th percentile) is 15%, current scientific evidence suggests there is 70% chance that peak flows will increase by less than 15%, and 30% chance that flows will increase by more than 15%

Low flows

- <u>Notable UK droughts</u>: e.g. 1995
- <u>Definition of a low flow</u>:
  - 95% exceedance flow on a flow duration curve (Q95)
  - But also interested in length of low flows and consecutive low flows (e.g. mean annual minimum 10-day flow)
- <u>Impacts of low flows</u>:
  - Availability of water resources
  - Degradation of water quality
  - Severe impact on aquatic ecosystems
- Increasing interest in Ecological Flows

Scammonden reservoir, West Yorkshire



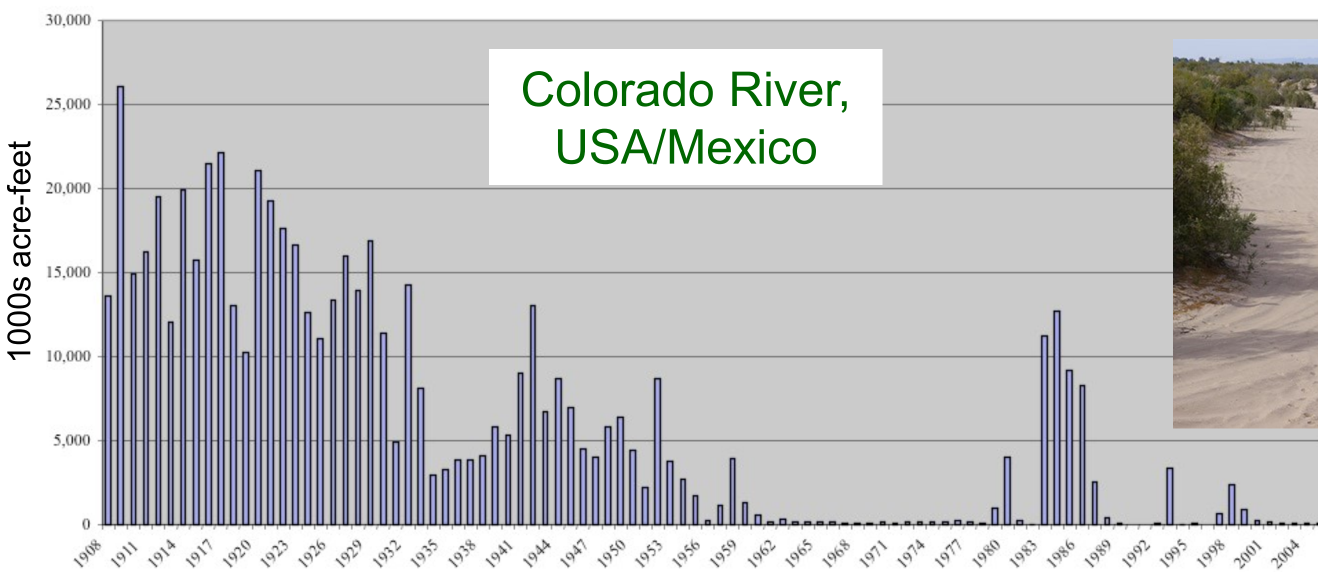


River Darent, Kent

The State of England's Chalk Rivers, Environment Agency, 2004

Causes of low flows

- Regional scale
  - Balance between precipitation and evapotranspiration
- Catchment scale factors
  1. Geology and soil
  2. Afforestation
  3. Water use and abstraction



Sources: International Boundary and Water Commission, "Western Water Bulletin: Flow of the Colorado River and Other Western Boundary Streams and Related Data" (annual); http://www.ibwc.state.gov/wad/ddqsibco.htm; and US Geological Survey. 1954. Compilation of Records of Surface Waters of the United States through September 1950: Part 9. Colorado River Basin. Geological Survey Water-Supply Paper 1313. (pp. 709-729).

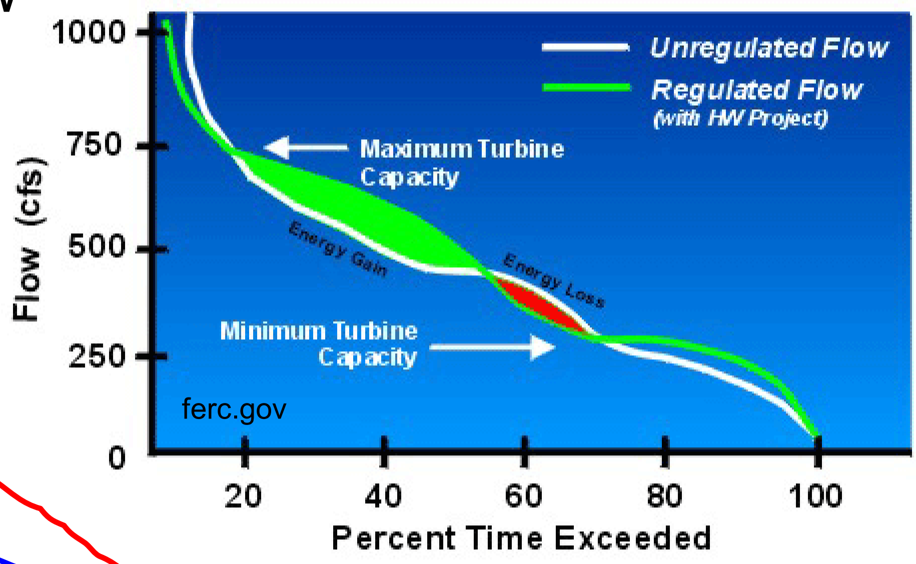
Images of delta in Mexico - before and after pulse flow, March 2014

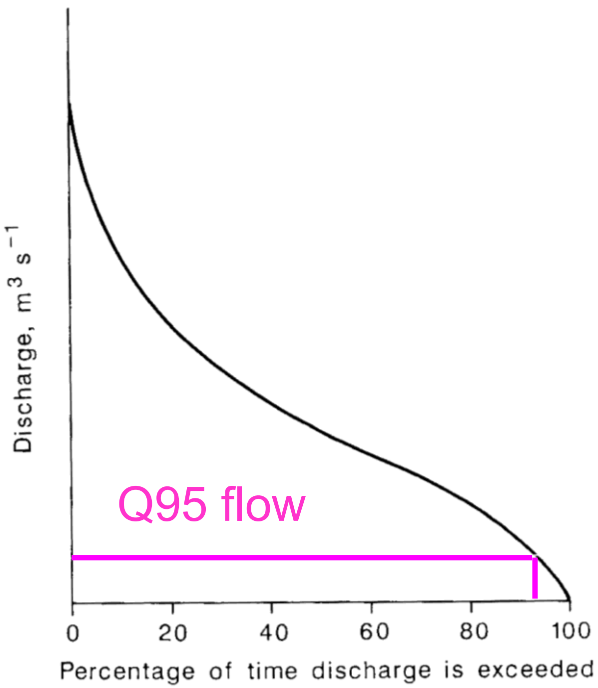
Hydrological analysis of low flows

- Low flows neglected by hydrologists
- Difficult to obtain reliable river low flow data

1. Return periods of low flows
2. Flow duration curves

Effect of flow regulation for hydropower on flow duration curves





(Jones, 1997)