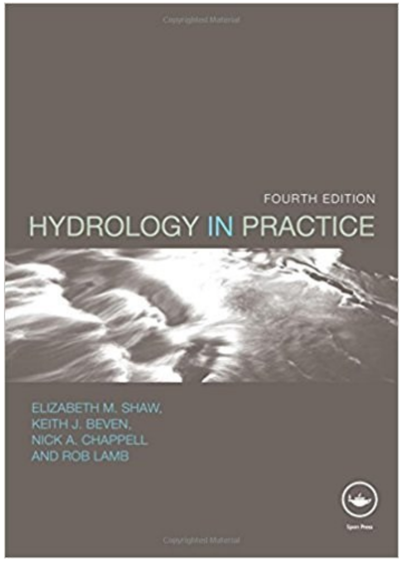
SWAP Practical 4: Flood risk

- Group A – 13:30-15:30, Monday 19 March
- Group B – 14:00-15:50, Wednesday 21 March
- Meet outside Ashworth Building, King's Buildings
- 1 hour visit on foot to Braid Burn
- Then data analysis & interpretation
- <u>Formative assessment (no hand-in)</u> with feedback sessions in Grant Lecture Theatre
  - 16:10-17:00 Tuesday 27 March OR
  - 16:10-17:00 Thursday 29 March

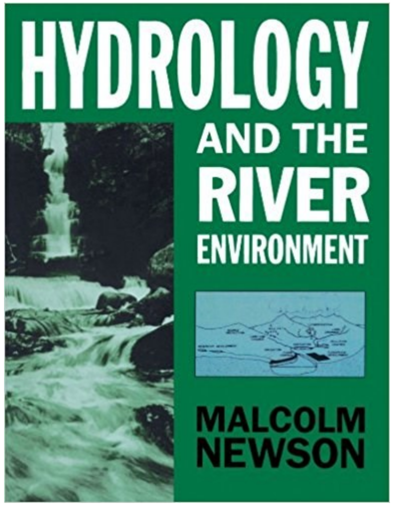
River flow measurement

Prof. Kate Heal

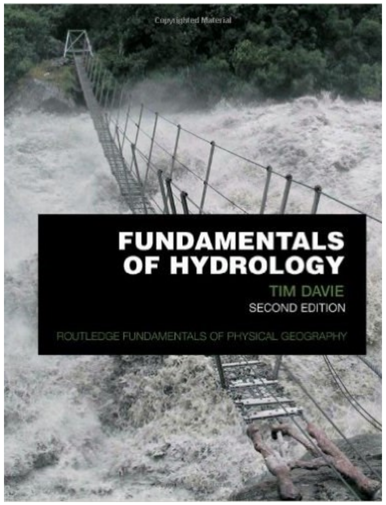
School of GeoSciences



Shaw et al. (4th Ed.) – River flow chapter



Newson – pp.20-26



Davie – pp.75-80

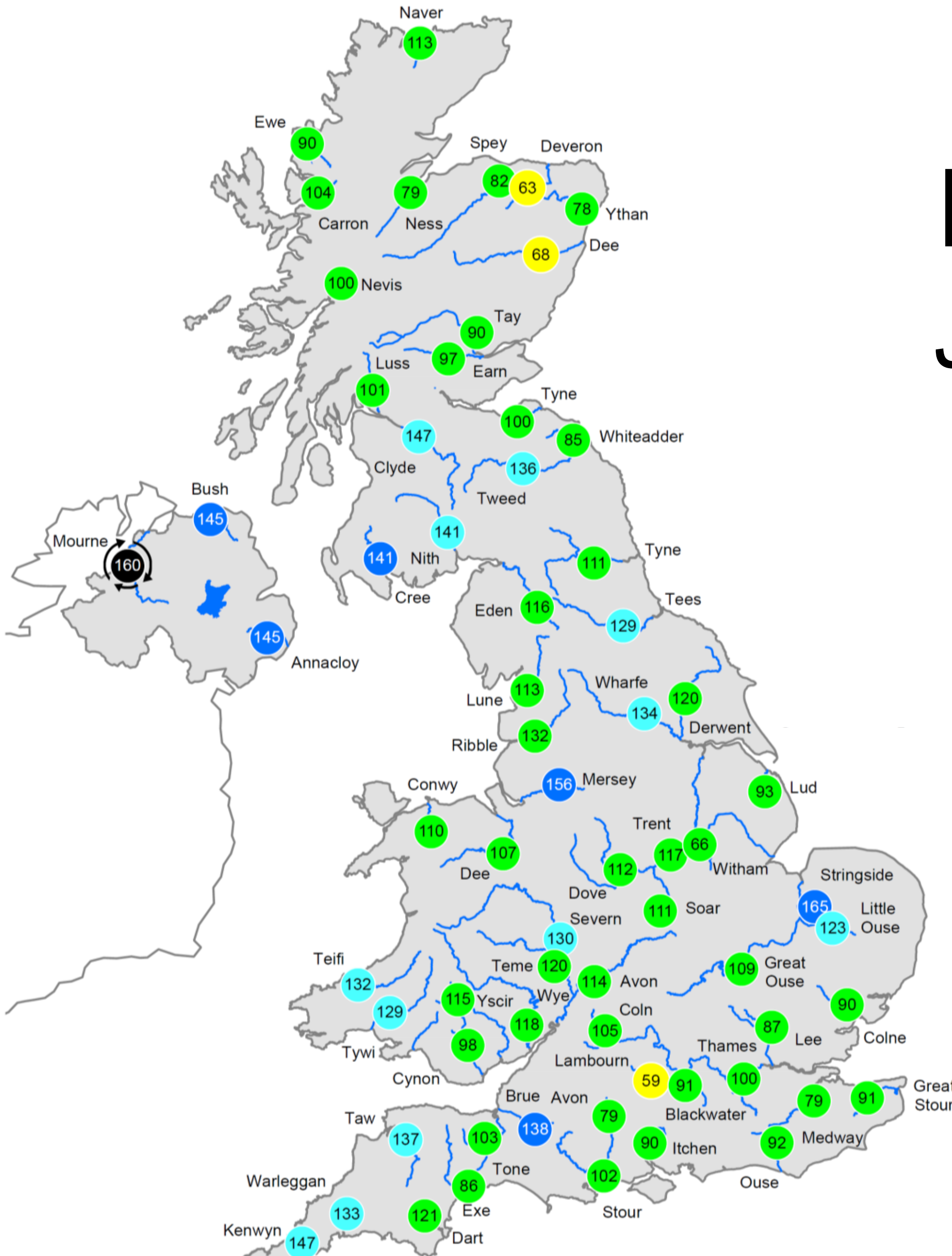
Soil, Water & Atmospheric Processes

Introduction

- Discharge/flow: volume of water passing a fixed point over certain period of time
- Units
  - $m^3 s^{-1}$ (cumecs)
  - $l s^{-1}$

- c.400 river flow stations in Scotland operated by SEPA
- National River Flow Archive http://nrfa.ceh.ac.uk

River flows
January 2018



Key

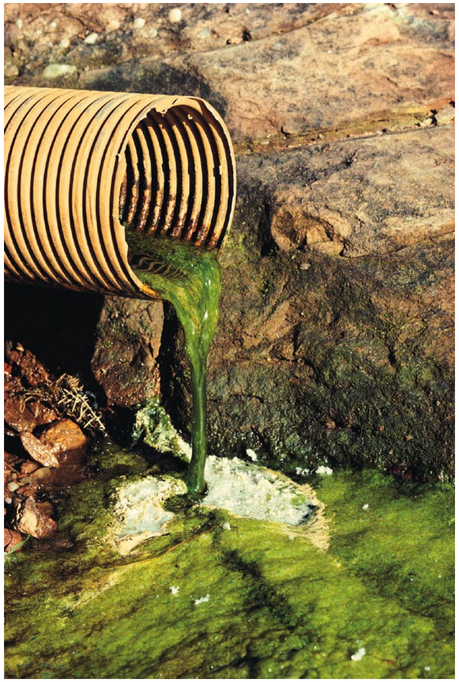
25 % of long-term average (record figure when circled)

- Exceptionally high flow
- Notably high flow
- Above normal
- Normal range
- Below normal
- Notably low flow
- Exceptionally low flow

*Based on ranking of the monthly flow**

Uses of river flow data

1. Water resource availability
2. Water quality: availability for diluting pollution
3. Flood warning
4. Basic hydrometric network
5. Ecology, geomorphology
6. Land use & climate change



eveningexpress.co.uk

Flow measurement techniques

- 5 main methods
- Choice of method depends on:
  - Size of river
  - Accuracy required
  - Available resources (time, money, human)

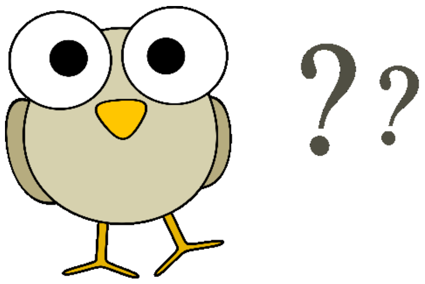
(1) Volumetric gauging

$$\text{Flow} = \frac{\text{Volume of water}}{\text{Time}}$$

- Most accurate method
- BUT limited to small flows
  - Drought conditions
  - Experimental plots
- <u>Example calculation</u>:
  - 10 litre bucket fills in 2 seconds
  - $Q = 10/2 = 5\ l\ s^{-1}$

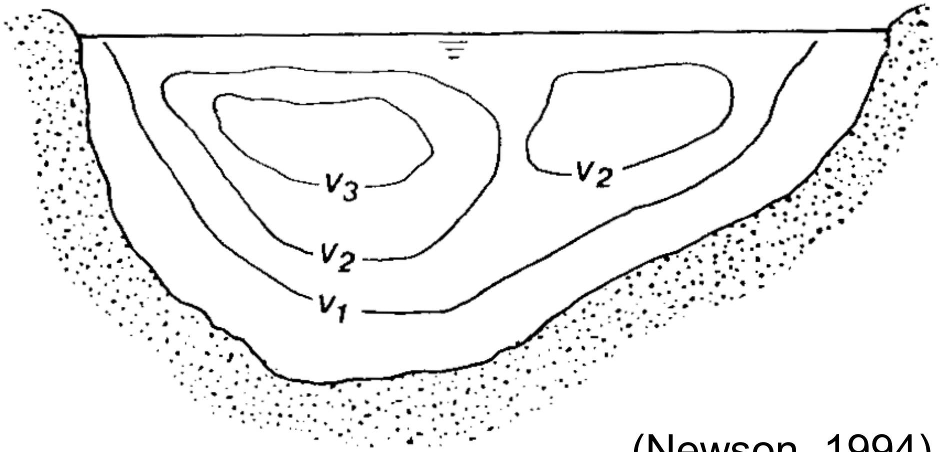
(2) Velocity-area method

- Q = mean velocity (V) x cross-sectional area of flow (A)
- Most widely-used method for one-off measurements
- BUT time-consuming
- Main problem is determination of average velocity



How to obtain average velocity from this?

Velocity contours:
v_1 is lowest, v_3 is highest



(Newson, 1994)

Measuring velocity

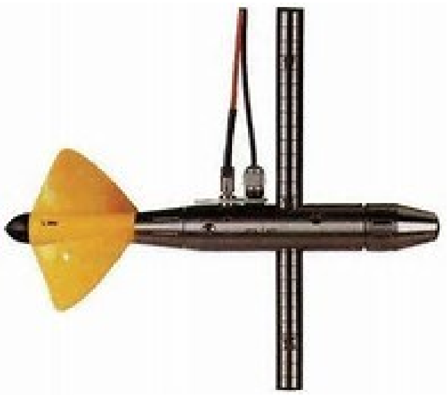
a) Floats

- Inexpensive, but poor accuracy
- Correction factor x 0.85

geohydromechsindia.com

b) Current meters

- Average velocity = velocity measured at 0.6 x water depth
- <u>Different types</u>
  - Propeller/bucket
  - Electromagnetic



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ott.com

Good for measuring low velocities

Captain McClean

River Garry, 1913

(Image courtesy of
Andrew Black)

Velocity-area example calculation, with a float

Amazon, Manaus, Brazil

- $Q = V \times A$
- $A = 2500 \text{ m} \times 60 \text{ m} = 150{,}000 \text{ m}^2$
- Float travels 500 m in 250 seconds
- => $V = 2 \text{ m s}^{-1}$
- x 0.85 correction factor, $V = 1.7 \text{ m s}^{-1}$
- $Q = 150000 \times 1.7 = 255{,}000 \text{ m}^3 \text{ s}^{-1}$

http://www.kqed.org/press/tv/cousteau/amazon/images/cousteau-amazon8.jpg

- Tay at Perth
  - Average flow = $170 \text{ m}^3 \text{ s}^{-1}$
  - Maximum flow = $2269 \text{ m}^3 \text{ s}^{-1}$ in January 1993
- Braid Burn
  - Average flow = $0.18 \text{ m}^3 \text{ s}^{-1}$
  - Maximum flow = $15.6 \text{ m}^3 \text{ s}^{-1}$ in April 2000

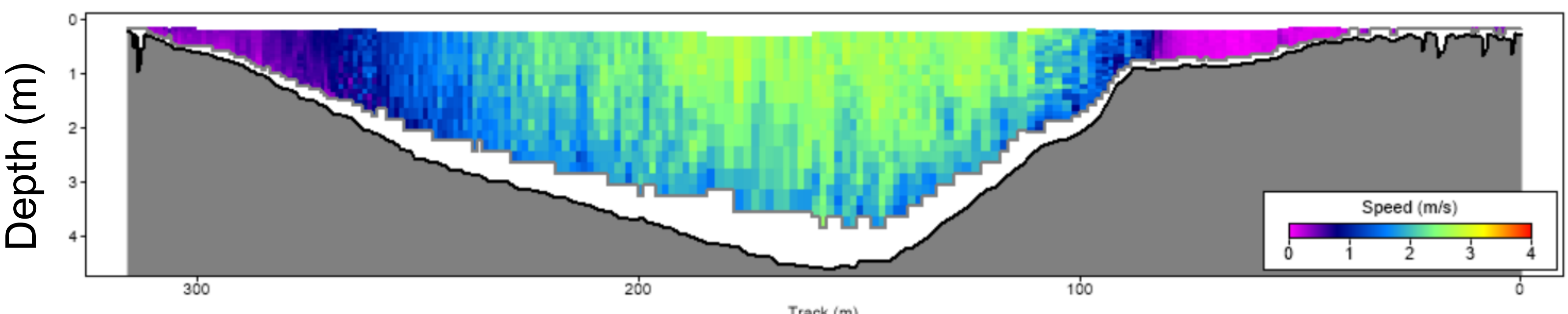
http://www.rampantscotland.com/week/graphics/tay_perth7740s.jpg

c) Doppler meters

- Acoustic pulse reflected off air bubbles/suspended matter
- Provides integrated velocity
- Combined depth measurements => direct determination of flow
- Installed at permanent stations or deployed across large rivers

www.rshydro.co.uk

ADCP unit



(Images courtesy of Lizzie Dingle)

d) Indirect estimation of flow velocity

E.g. Manning's equation

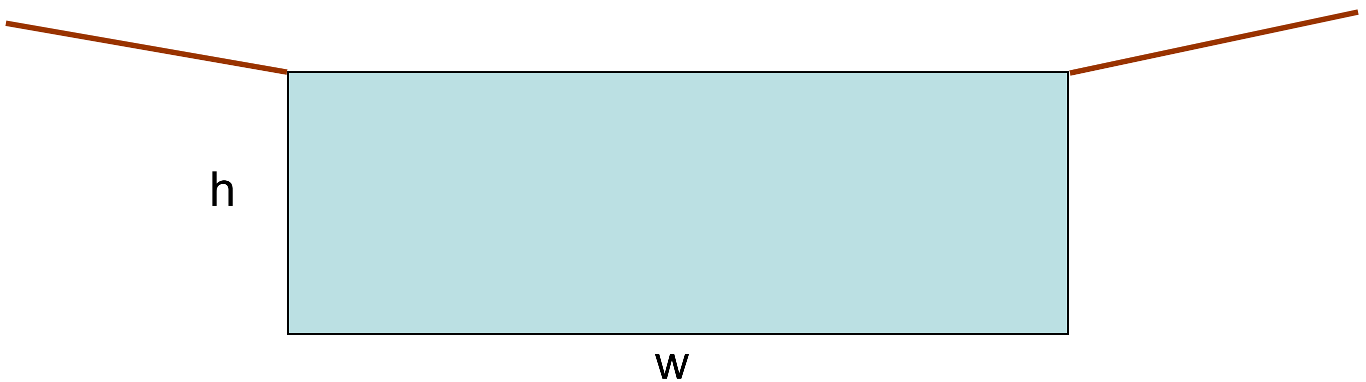
$$V = \frac{R^{\frac{2}{3}} S^{\frac{1}{2}}}{n}$$

V = average velocity

R = hydraulic radius (cross sectional area/wetted perimeter)

S = slope of water surface

n = Manning's roughness coefficient



Cross sectional area = h x w
Wetted perimeter = 2h + w

Artificially straightened stream, Wisconsin, USA

Boulder Creek, Colorado, USA

Table 2.5. Values of Manning's 'n' channel roughness parameter for various channel materials/configurations (Canadian National Committee International Hydrological Decade)

Type of channel and description	Minimum	Normal	Maximum
Excavated or Dredged			
Earth, straight and uniform			
Clean, recently completed	0.016	0.018	0.020
Gravel, uniform section, clean	0.022	0.025	0.030
With short grass, few weeds	0.022	0.027	0.033
Earth, winding and sluggish			
No vegetation	0.023	0.025	0.030
Dense weeds or aquatic plants in deep channels	0.030	0.035	0.040
Cobble bottom and clean sides	0.030	0.040	0.050
Natural streams			
Minor streams			
Streams on plain:			
Clean, winding, some pools and shoals	0.033	0.040	0.045
Sluggish reaches, weedy, deep pools	0.050	0.070	0.080
Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stages:			
Bottom—gravels, cobbles and few boulders	0.030	0.040	0.050
Bottom—cobbles with large boulders	0.040	0.050	0.070
Flood plains			
Short grass	0.025	0.030	0.035
Cultivated areas:			
No crop	0.020	0.030	0.040
Mature field crops	0.030	0.040	0.050
Trees:			
Dense willows, summer, straight	0.110	0.150	0.200
Heavy stand of timber, a few down trees, little undergrowth, flood stage below branches	0.080	0.100	0.120
Major streams			
Regular section with no boulders or brush	0.025	—	0.060
Irregular and rough section	0.035	—	0.100

Useful method for estimating flood flows

(3) Dilution gauging

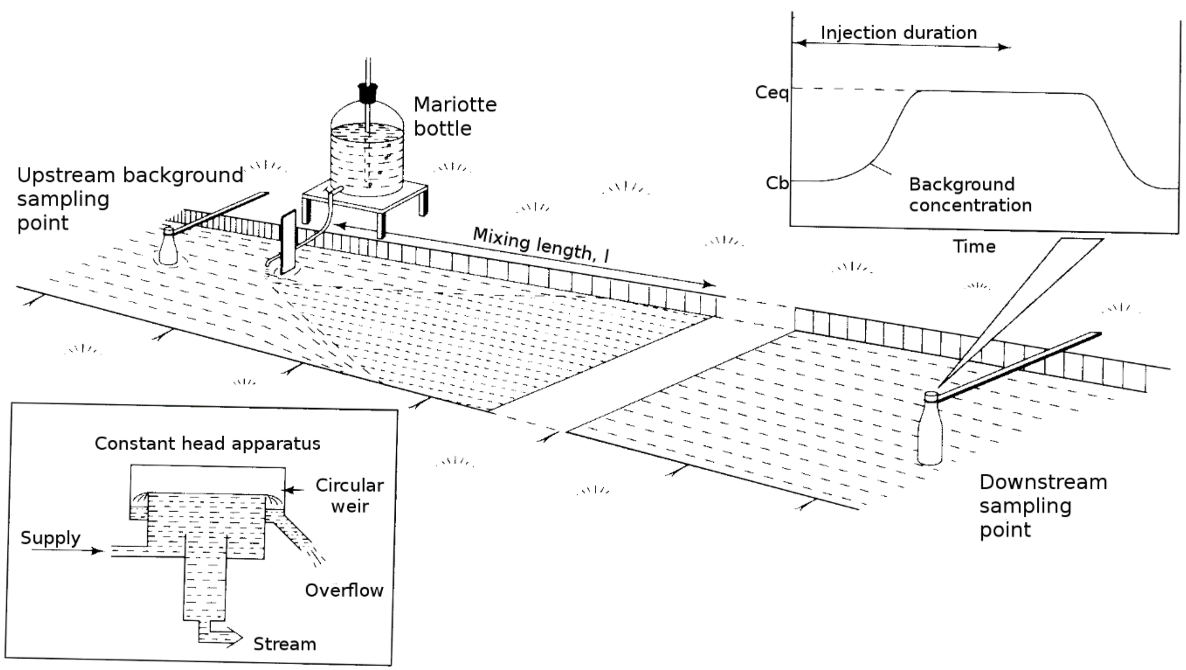
- Used where difficult to operate current meter
- Most accurate method for small streams
- <u>Tracers</u>: fluorescent dyes (e.g. rhodamine), salts (e.g. NaCl, KBr)

Two methods of dilution gauging

(1) Constant rate injection

$$Q = q \frac{(C_i - C_{eq})}{(C_{eq} - C_b)}$$

Q	=	discharge
q	=	rate of injection of tracer solution
C_i	=	concentrations of injected tracer
C_{eq}	=	downstream sampled concentration
C_b	=	base concentration of stream



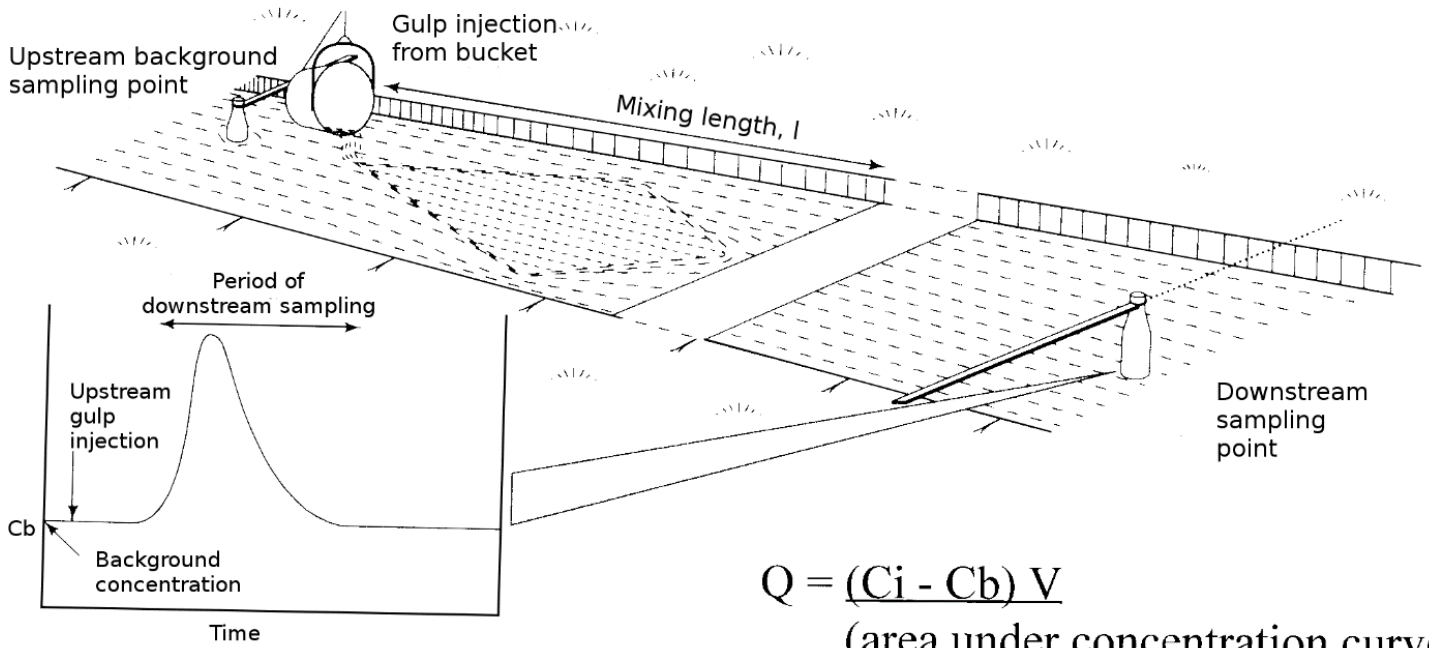
Advantage

easier to obtain background concentration

Disadvantage

more complicated injection procedure

(2) Gulp injection



$$Q = \frac{(C_i - C_b)\,V}{\text{(area under concentration curve)}}$$

Q	=	discharge
C_i	=	concentrations of injected tracer
C_b	=	base concentration of stream
V	=	volume of injected solution

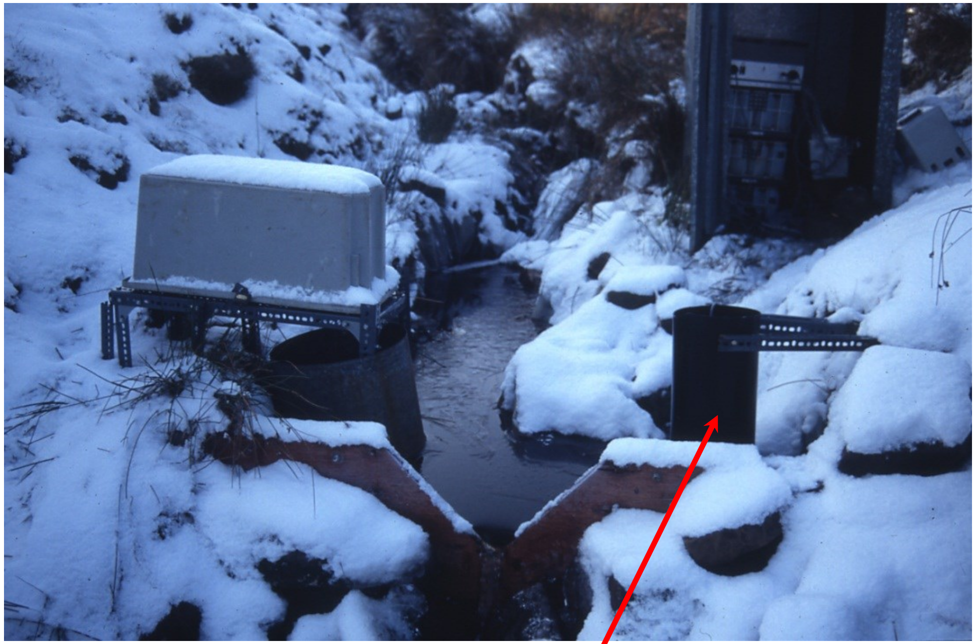
<u>Advantage</u> easier injection procedure

<u>Disadvantage</u> long monitoring time after injection to capture concentration curve

(4) Artificial control structures

Thin plate weirs

(e.g. 90^{o} V-notch weir)



Stilling well

Flumes

(4) Artificial control structures (cont.)

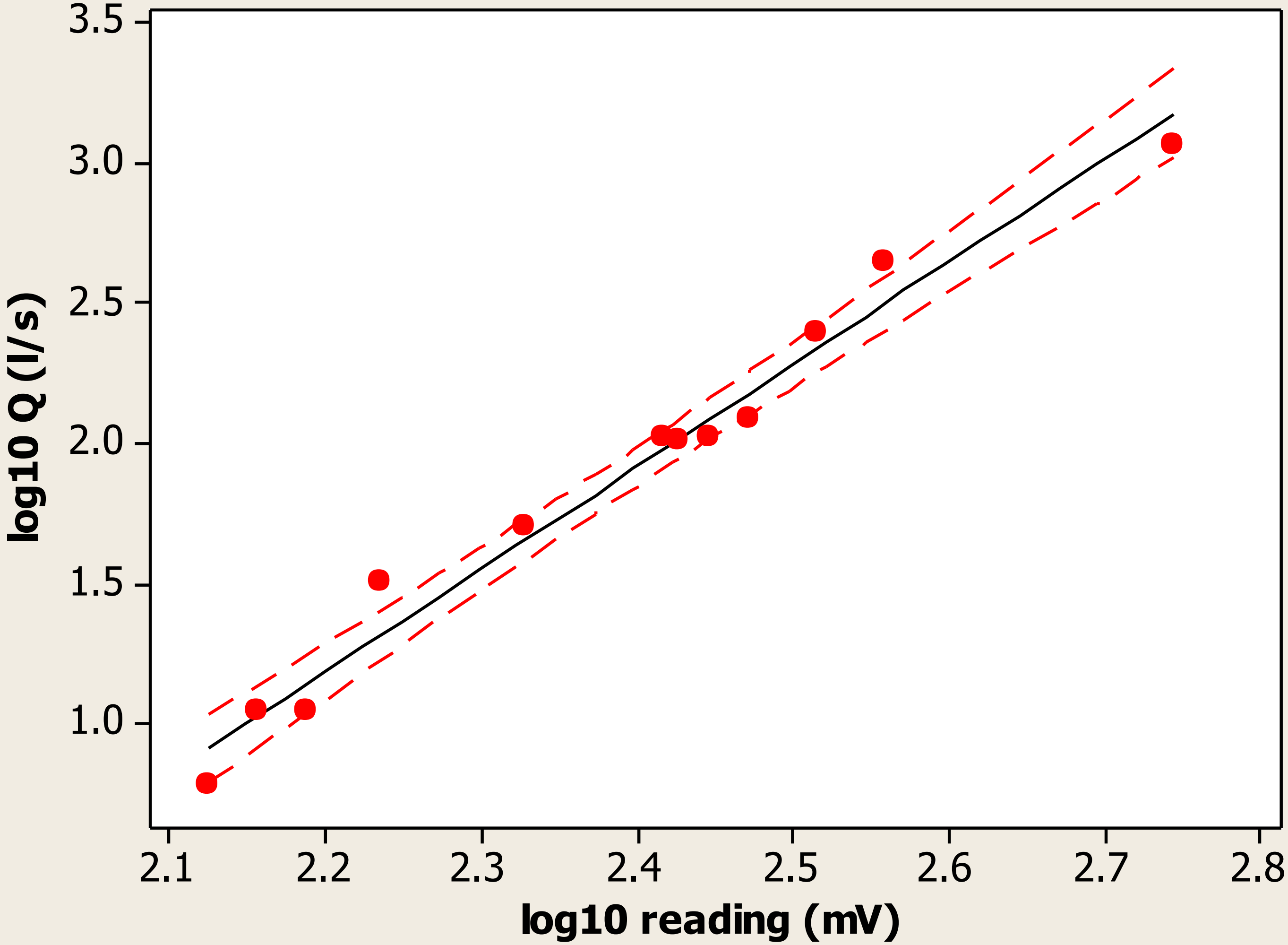
- Flow channelled through cross section of known dimensions
- Water depth over structure measured
- Q calculated from standard equations
- Need to check accuracy using velocity-area or dilution gauging methods
- Advantages:
  - Flow measurements quick and easy
  - Suitable for continuous flow monitoring
- Disadvantages:
  - Structures costly to install
  - Need for maintenance (debris accumulation, leakage)
  - Ecological impact

(5) Rated sections

- Same principle as control structures but <u>used where control structures impractical</u>
- Requires stable channel cross section
- Calibration curve (<u>ratings curve</u>) constructed from measurements of water level (<u>stage</u>) made at same time as flow measured (by velocity-area or dilution gauging)
- Once ratings curve constructed, Q can be estimated simply by measuring stage
- <u>Disadvantages</u>:
  - Long time to complete ratings curve
  - Need to redo ratings curve when channel cross section changes
  - Ratings curve only valid for measured flows

Ratings curve for Cultullich Burn, Griffin Forest 2000

log10 (Q) (l/s) = - 6.853 + 3.655 log10 (reading)



A measure of water depth

Summary of applicability of different flow measurement methods

Reach/flow conditions	Practical advantages or constraints
VOLUMETRIC Narrow flow-width or pipe; culvert; waterfall to concentrate flow. Drought flows only in larger catchments.	Simple and effective for small flows.
VELOCITY/AREA Uniform flow, straight reach. Avoid boulder or cobble beds where possible. Avoid eroding or depositing sections. Downstream control desirable, e.g. bridge or weir.	Current metering may be time-consuming. Problems in navigable rivers. Encourages frequent visits to station.
WEIRS Interrupts flow—unsuitable for low gradients where water *backs up and risks flooding. Unsuitable for sediment-*laden flows—merely fills up weir pool. Straight reach, good fall.	Simple construction and simple formulae *(H = stage) (B = width) 'V' notch* (90^0) $Q = 2.5H^{5/2}$. Rectangular $Q = 3.33BH^{3/2}$.
FLUMES Solves the sediment transport problem. Can suffer abrasion damage in sediment-laden flows. Suitable for low gradients. Straight reach.	Formulae more complex and flow conditions can become unsuited to calibration. Sensible to make field calibration.
DILUTION Requires calculation of reach length and conditions to give good mixing. Suited to rough upland channels but not fall-pool reaches.	Getting equipment to site may be a problem or power for continuous measurements.
ALL None suited to very small diffuse flows or very large tidal flows; innovations include electromagnetic velocity measurement and ultrasonic discharge gauges.	All require careful attention to links with the recording system. All subject to vandalism.

(Newson, 1994)