Oifig na
nOibreacha Poiblí
Office of Public Works

Hydrology, Hydraulics & Coastal Processes

30th September 2024

Hydrometry and design flood estimation

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Office of Public Works

The Office of Public Works (OPW) is the lead State body for the coordination and implementation of Government policy on the management of flood risk in Ireland.

Key projects that require hydrometric programme support:

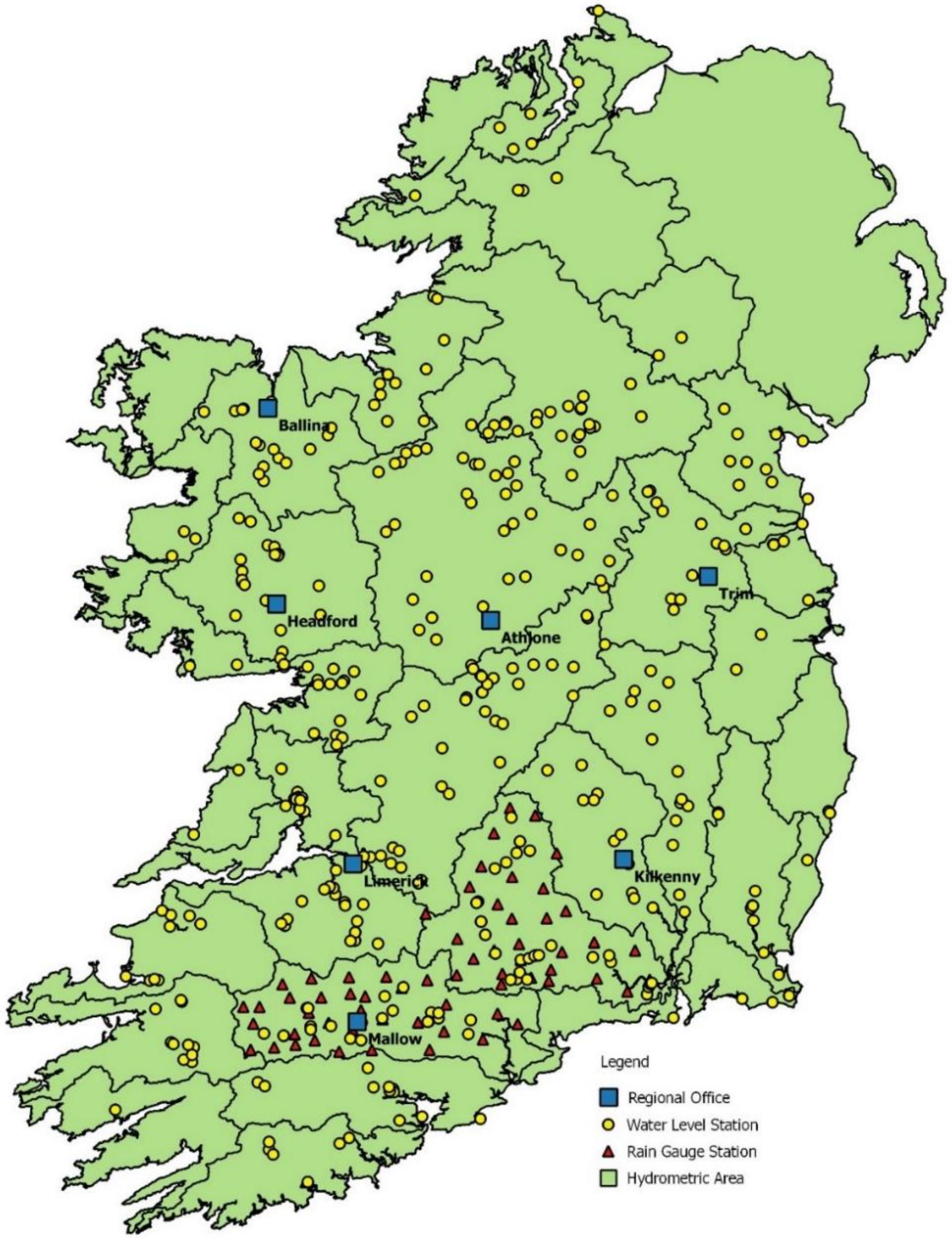
- Implementation of National Flood Risk Management Plans
- Establishment of National Flood Forecasting and Warning System (operated by Met Éireann)
- Determination of Flood Estimation Methodologies for Ireland (FSU and FEMI)

OPW Hydrometric Network

Current network:

- 537 surface water stations
  - *Water level (stage)*
  - *Water temperature*
- 73 rain gauge stations

  Rainfall
- 13 hydrometric teams
- Head Office - Headford
  - *Processing Unit*
  - *and National Archive*



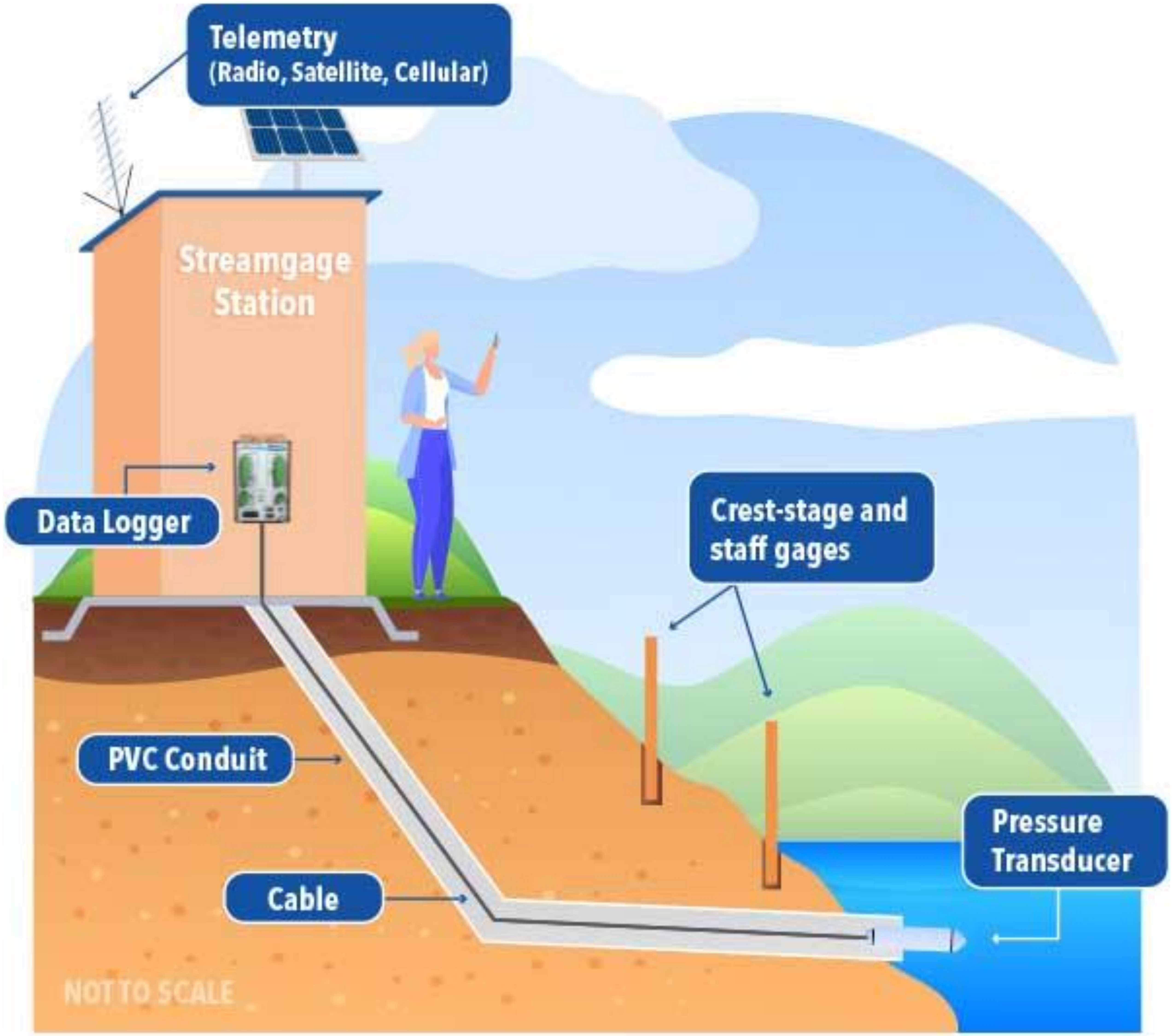
Typical water level (stage) station

Typically comprised of:

- Water level sensor
- Staff gauge
- Data logger
- Telemetry (sim, modem and antenna)

Power supply:

- Battery
- Solar panel



Typical water level (stage) station

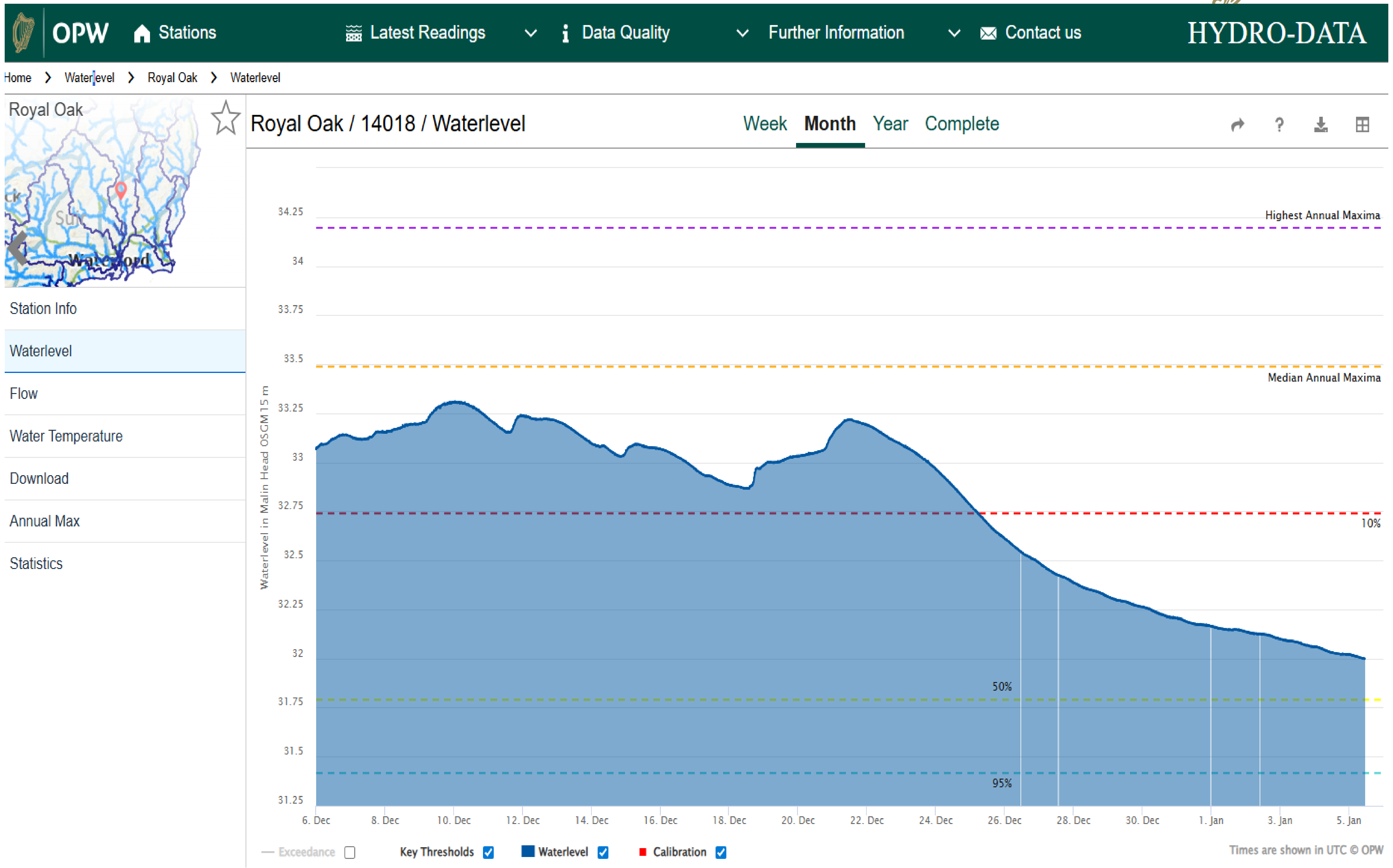
Typical hydrometric monitoring station – Brides Glen

Waded flow measurement with Acoustic Doppler Velocity Meter

Data collected by the Hydrometric Section

Water level (stage) is recorded:

- Typically at 15 minute intervals.
- 5 minute at tidal stations.



Station maintenance:

- Visited every 6 weeks.

Data disseminated in real-time via www.waterlevel.ie/hydro-data

Flow estimation

OPW discharge stations:

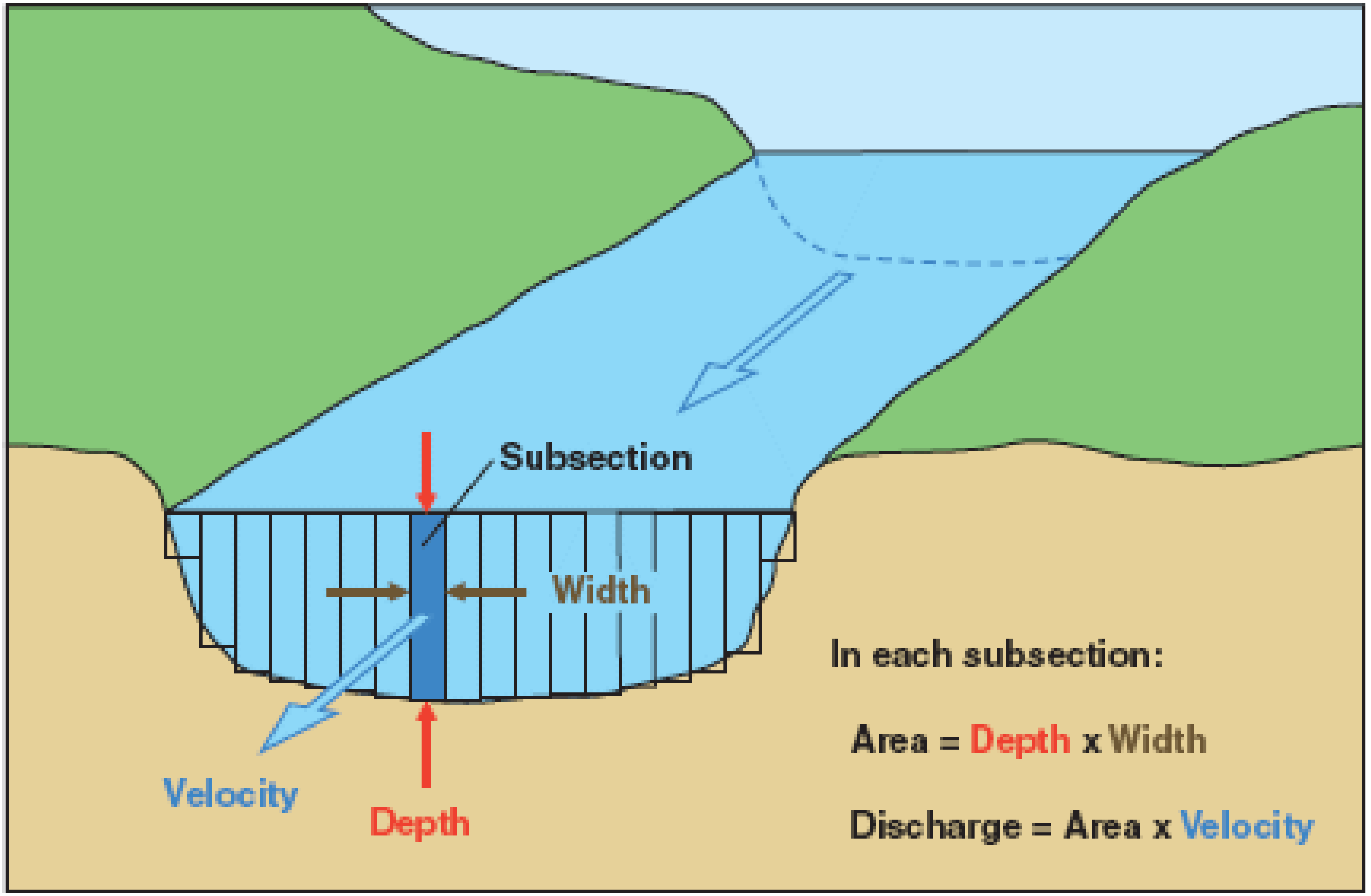
- generally area-velocity stations located on natural channels.
- Water level (stage) is converted to discharge (flow) by applying a stage-discharge relationship (rating).
- Rating is developed from spot flow measurements taken at different levels (stage).

Station 19101:
low flow (above).
flood flow (below).

Flow measurements?

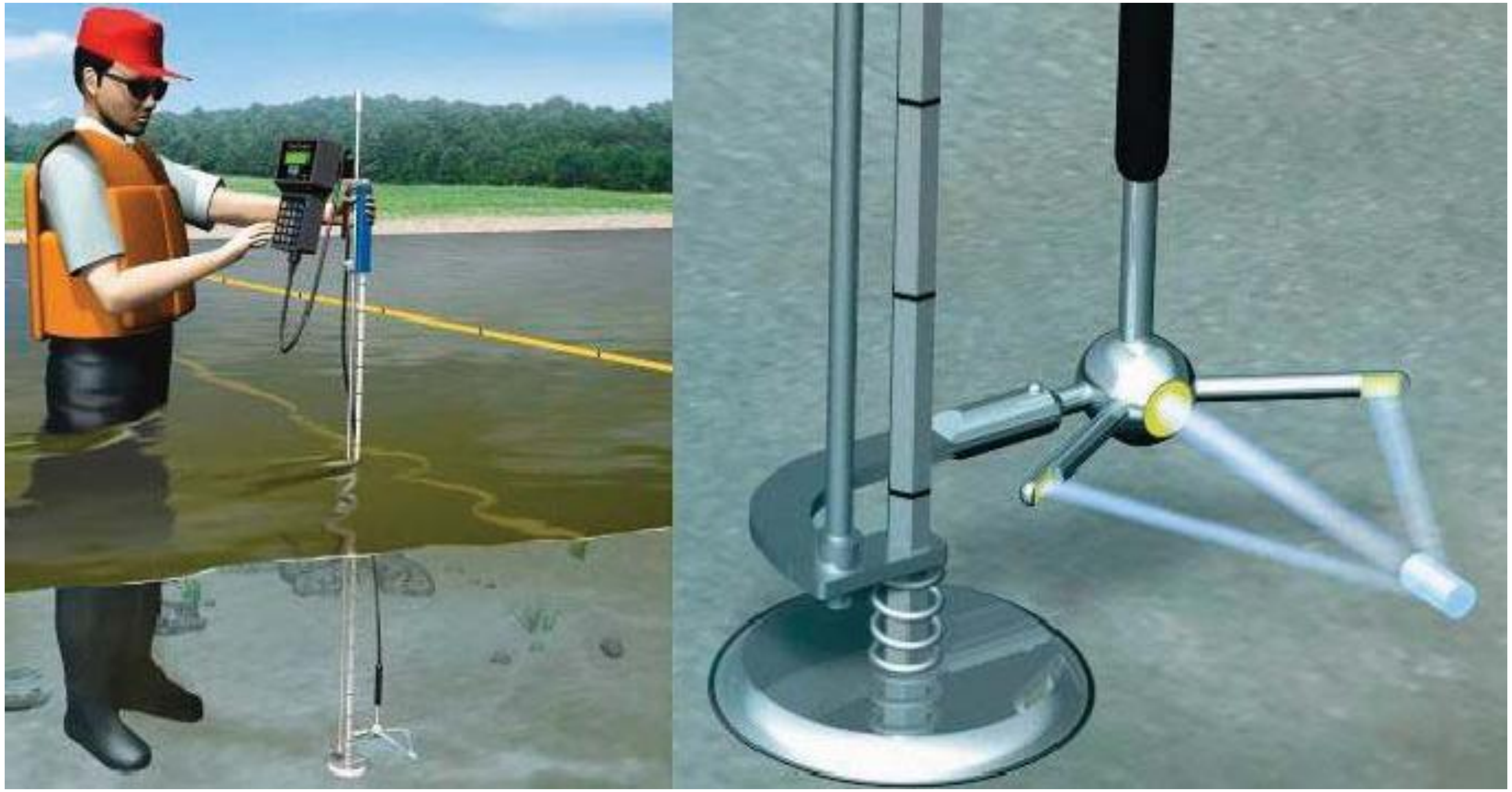
Flow measurement typically involves measuring:

- Water velocity
- Cross sectional area
- Q = V*A



Current-meter discharge measurements are made by determining the discharge in each subsection of a channel cross section and summing the subsection discharges to obtain a total discharge.

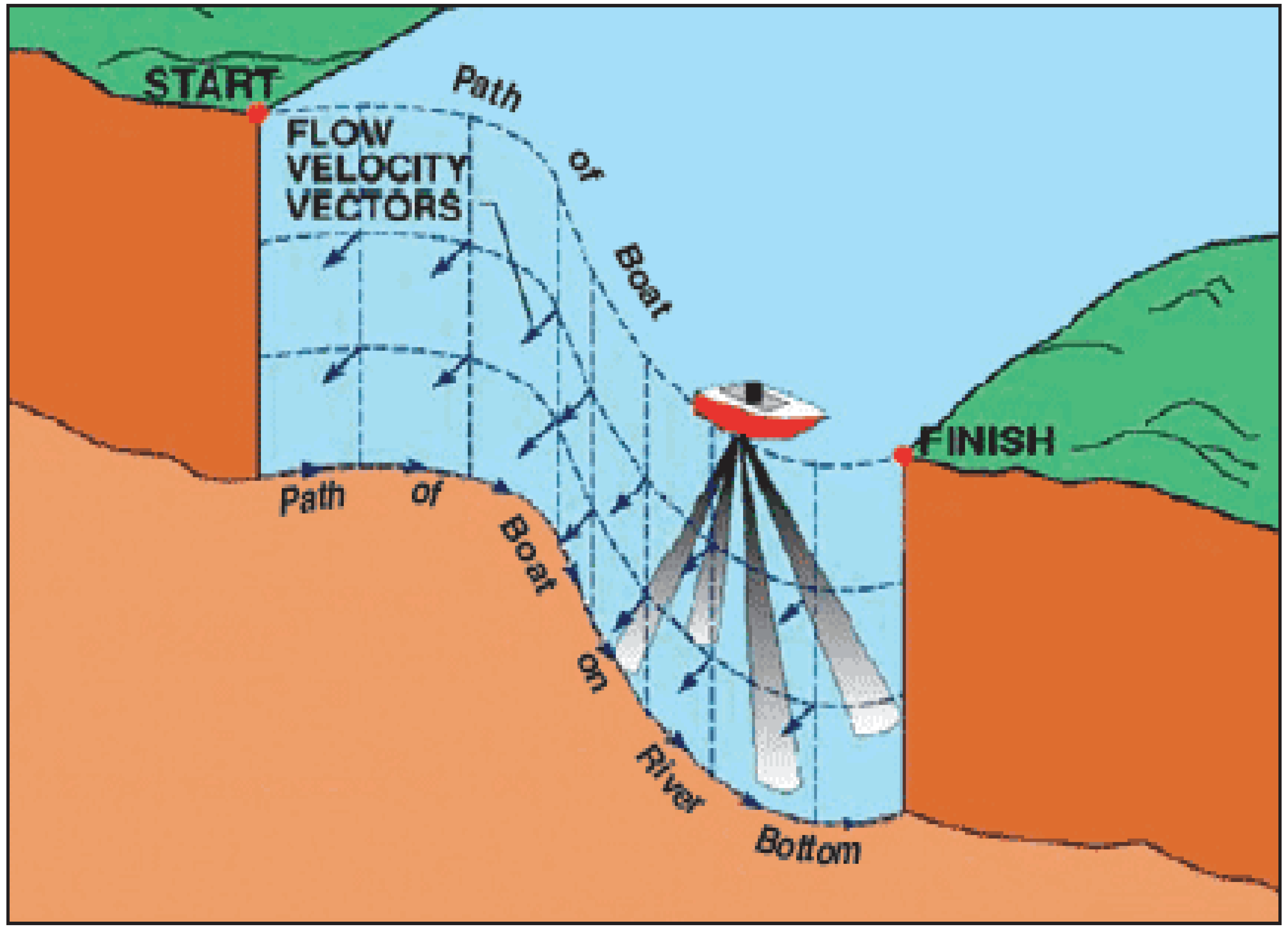
Point velocity measurement



Flow Tracker 2 Acoustic Doppler velocity meter (ADV)

Conventional current meter with impeller.

Modern flow measurement technology

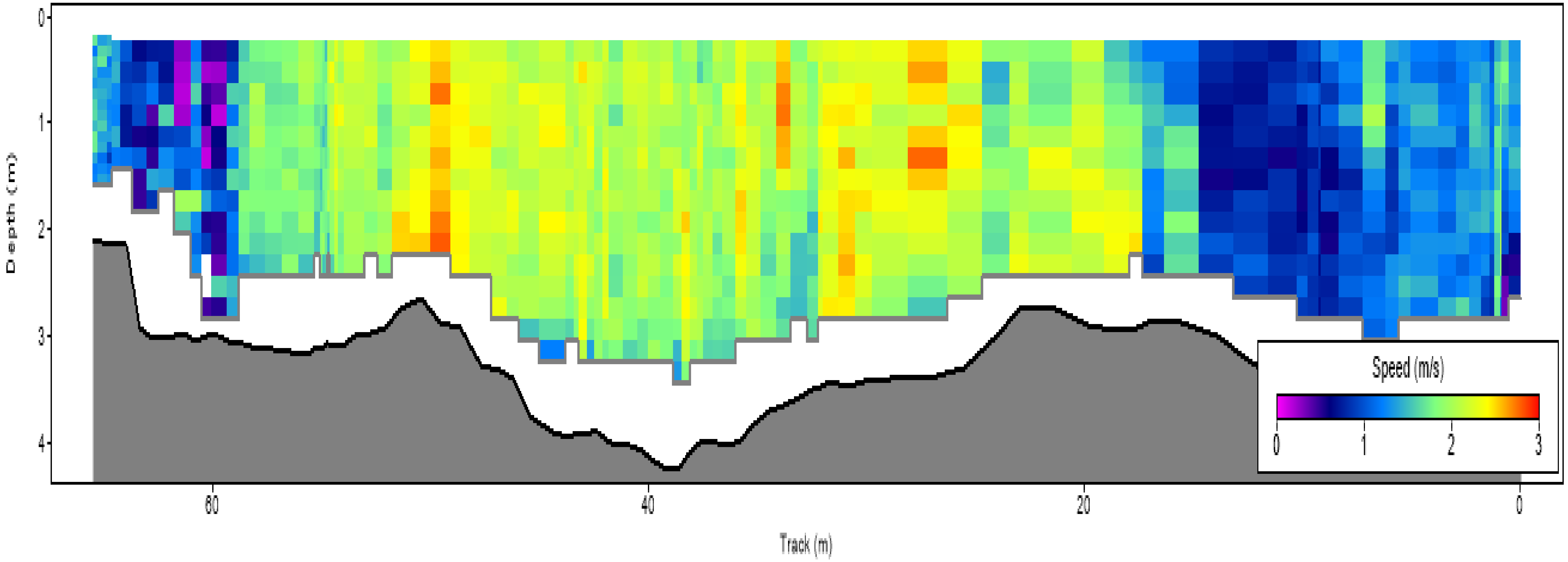


Acoustic Doppler current profiler (ADCP)

Acoustic Doppler Current Profiler (ADCP) mounted in a small watercraft, is used for measuring the discharge of a river. The ADCP acoustic beams are directed down into the water as it is guided across a river channel.

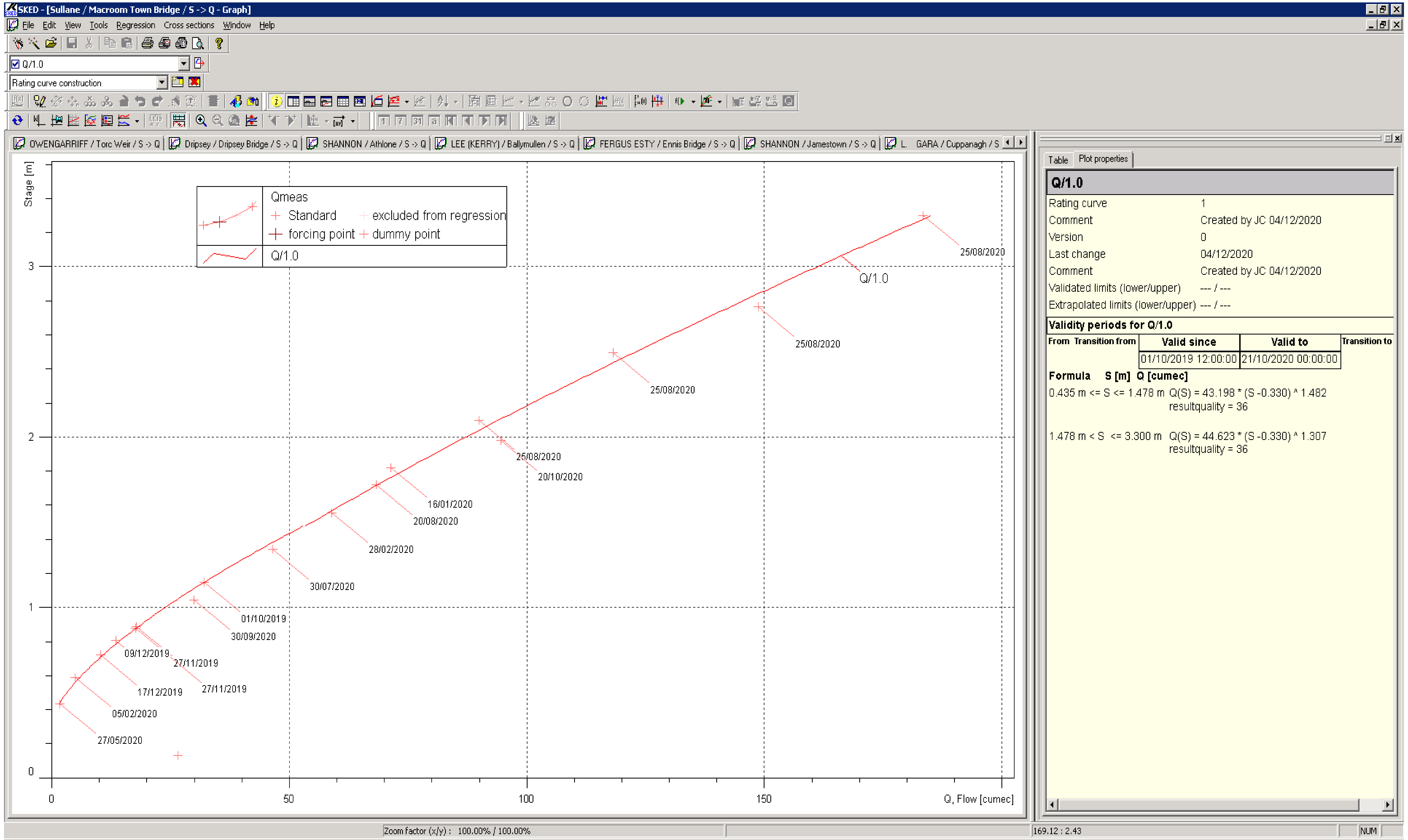
ADCP can be deployed from cableway (stationary or transect) or by remote control

Flow measurement



Transect taken at station 19101: Macroom Town Bridge

Flow estimation – rating



y-axis: water level (stage in m)

x-axis: discharge (flow in m/s^2)

For $0.435 \leq h \leq 1.478$

$$Q = 43.198\ (h-0.33)^{1.482}$$

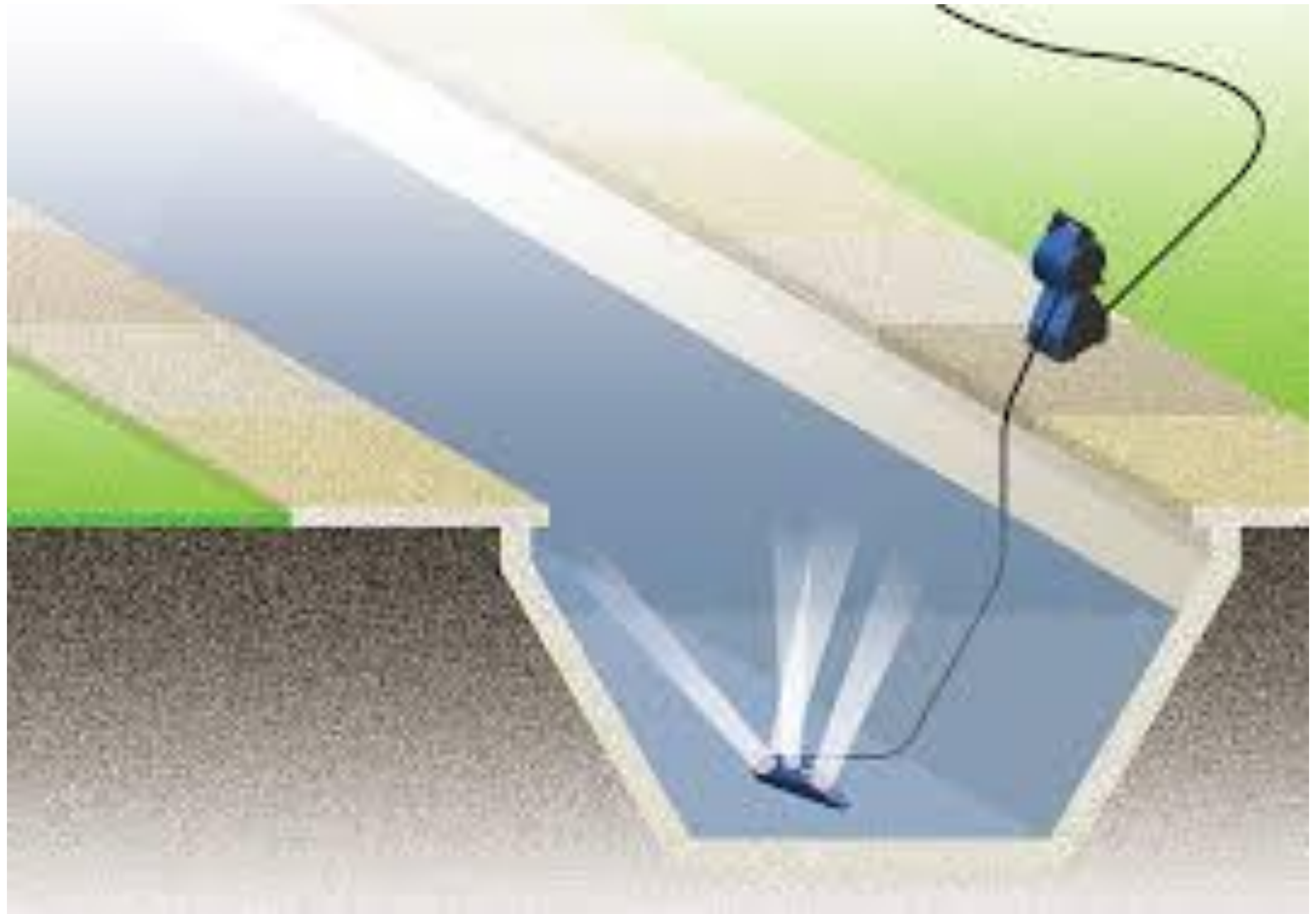
For $1.478 \leq h \leq 3.30$

$$Q = 44.623\ (h-0.33)^{1.307}$$

Station 19101: Plot of flow measurements showing stage-discharge relationship (rating).

Alternative ADCP deployments

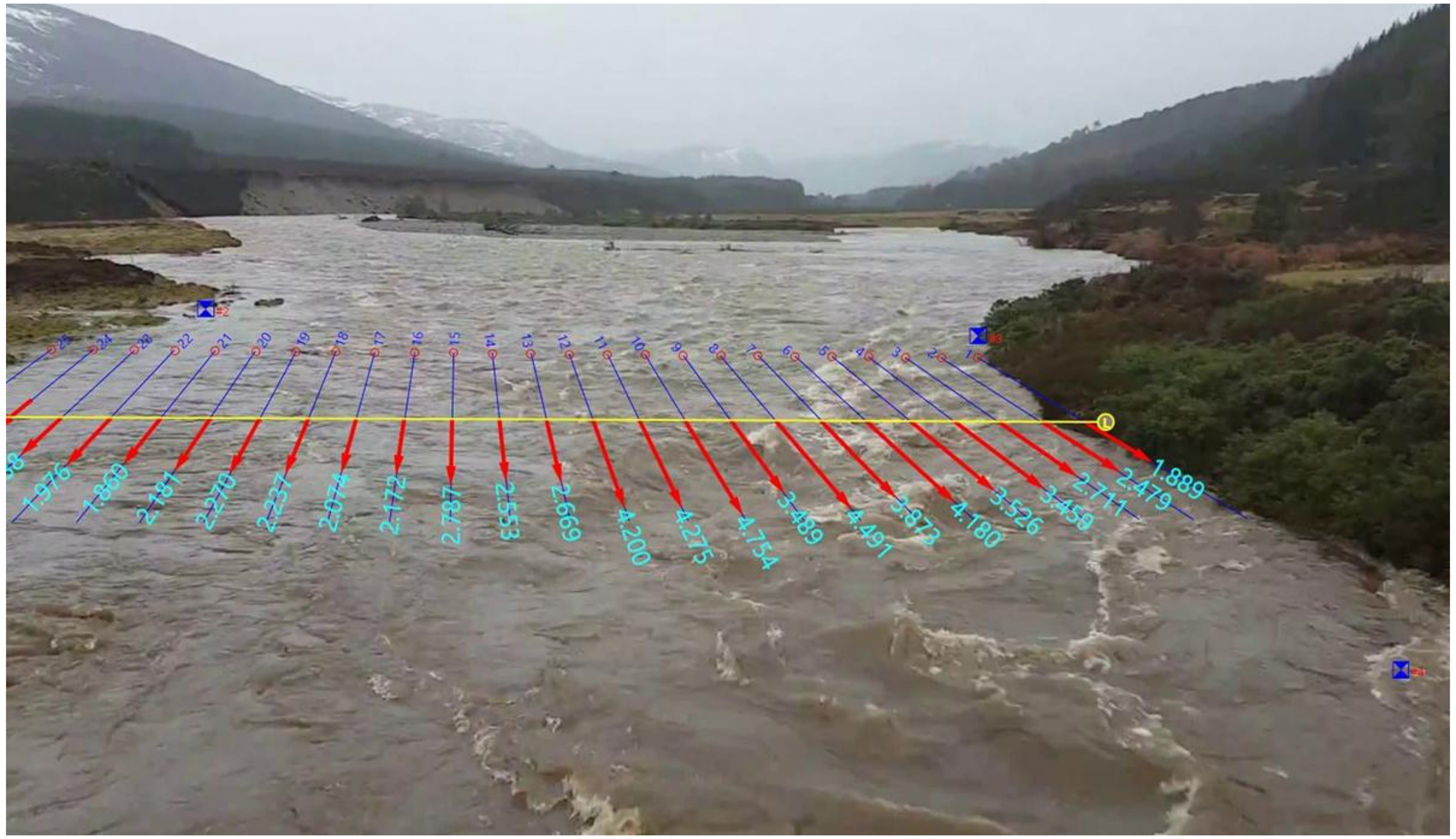
Side mounted ADCP



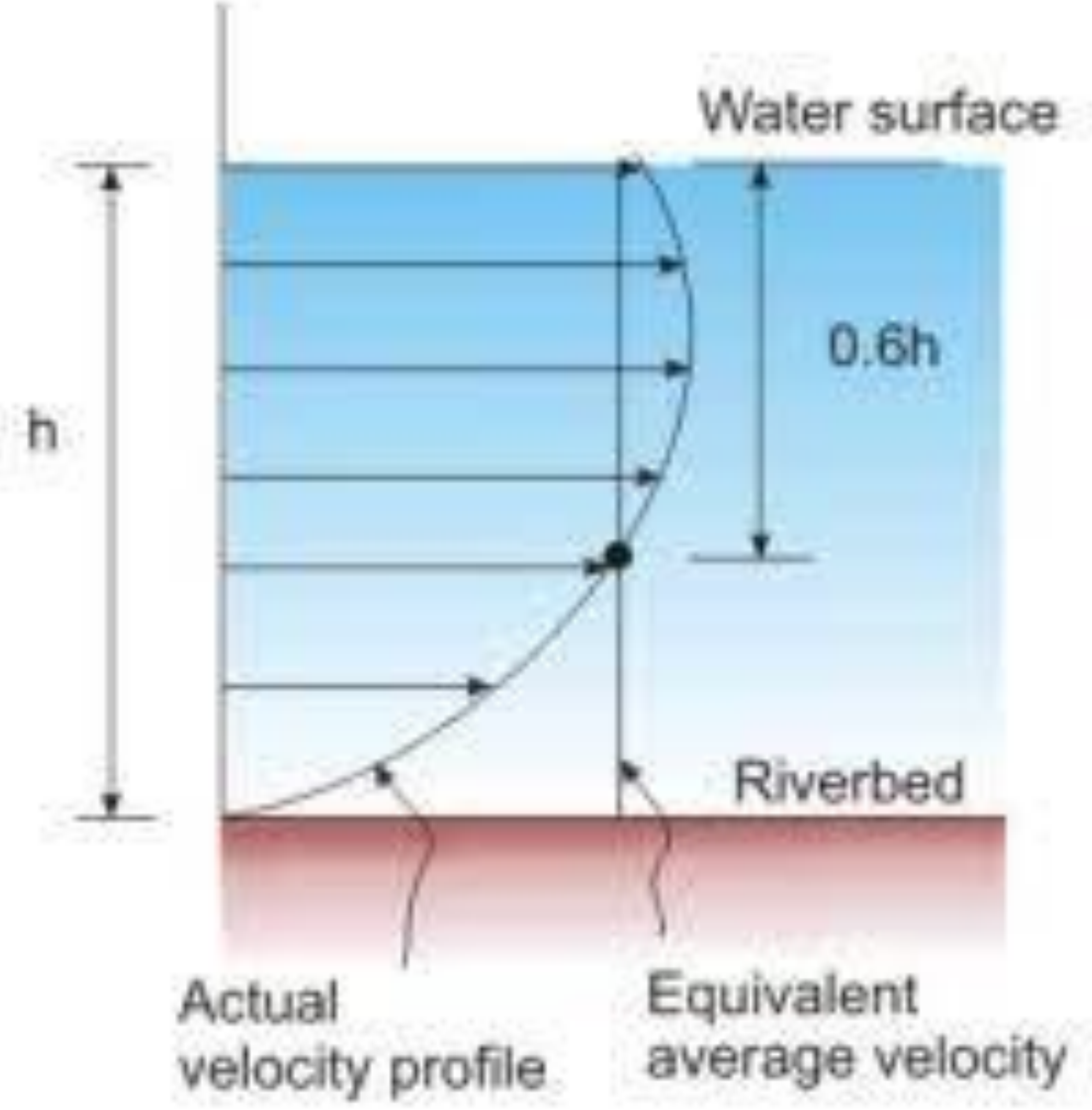
Bed mounted ADCP

Emerging technology – Surface Velocity

Image Velocimetry (IV) from drone or fixed camera footage



SV radar gun



Surface Velocity – alpha co-efficient relates surface velocity to average velocity and a default value of 0.857 is typically used.

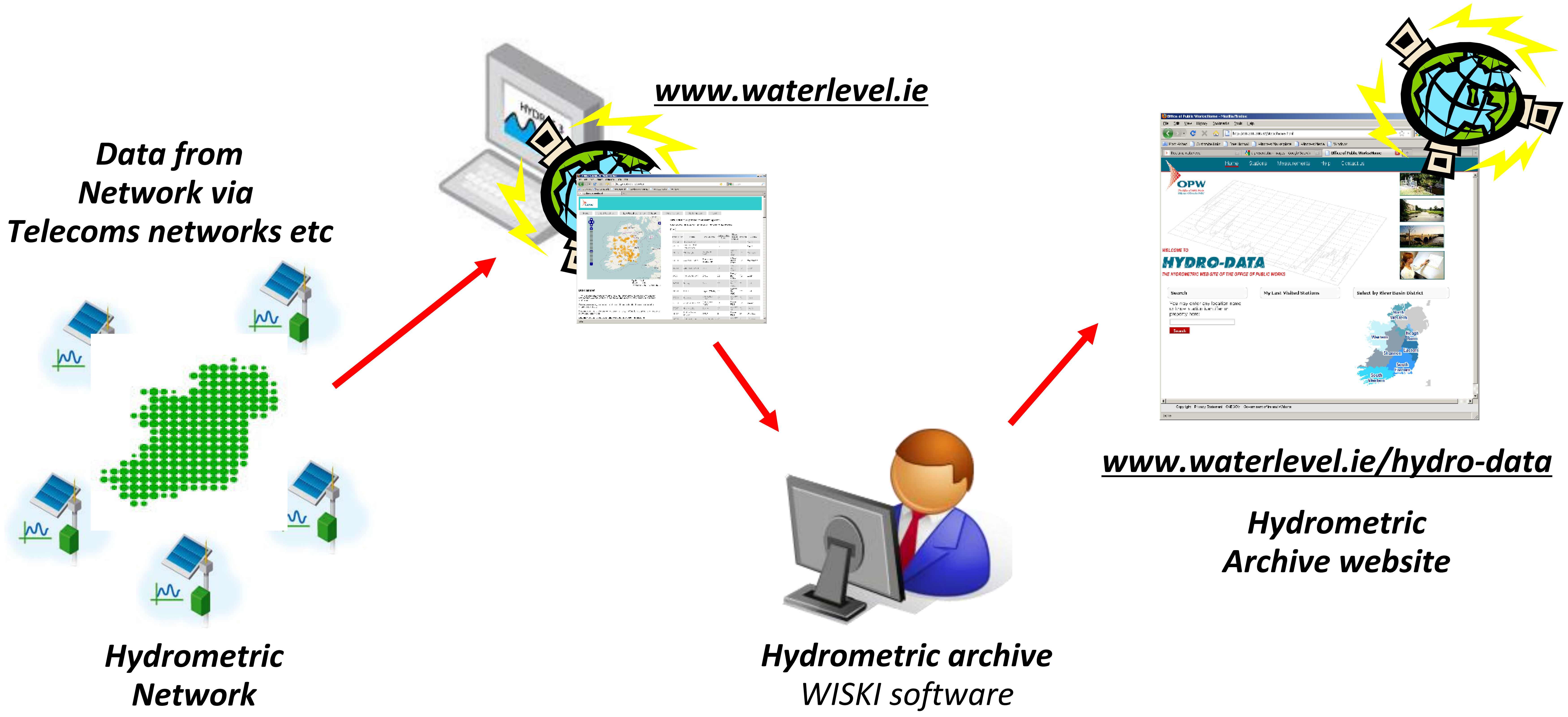
Some common issues

- accessibility of the site under all conditions of flow;
- aquatic weed growth in the watercourse;
- stability of the watercourse bed and embankments;
- influence of submergence of the gauging site due to downstream impounding structures (lakes, dams, weirs);
- potential of vandalism;
- blockage to downstream structures;
- availability of communication links;
- potential stream losses in karst areas;

high velocities and turbulence;

- width of channel;

Data management and transfer

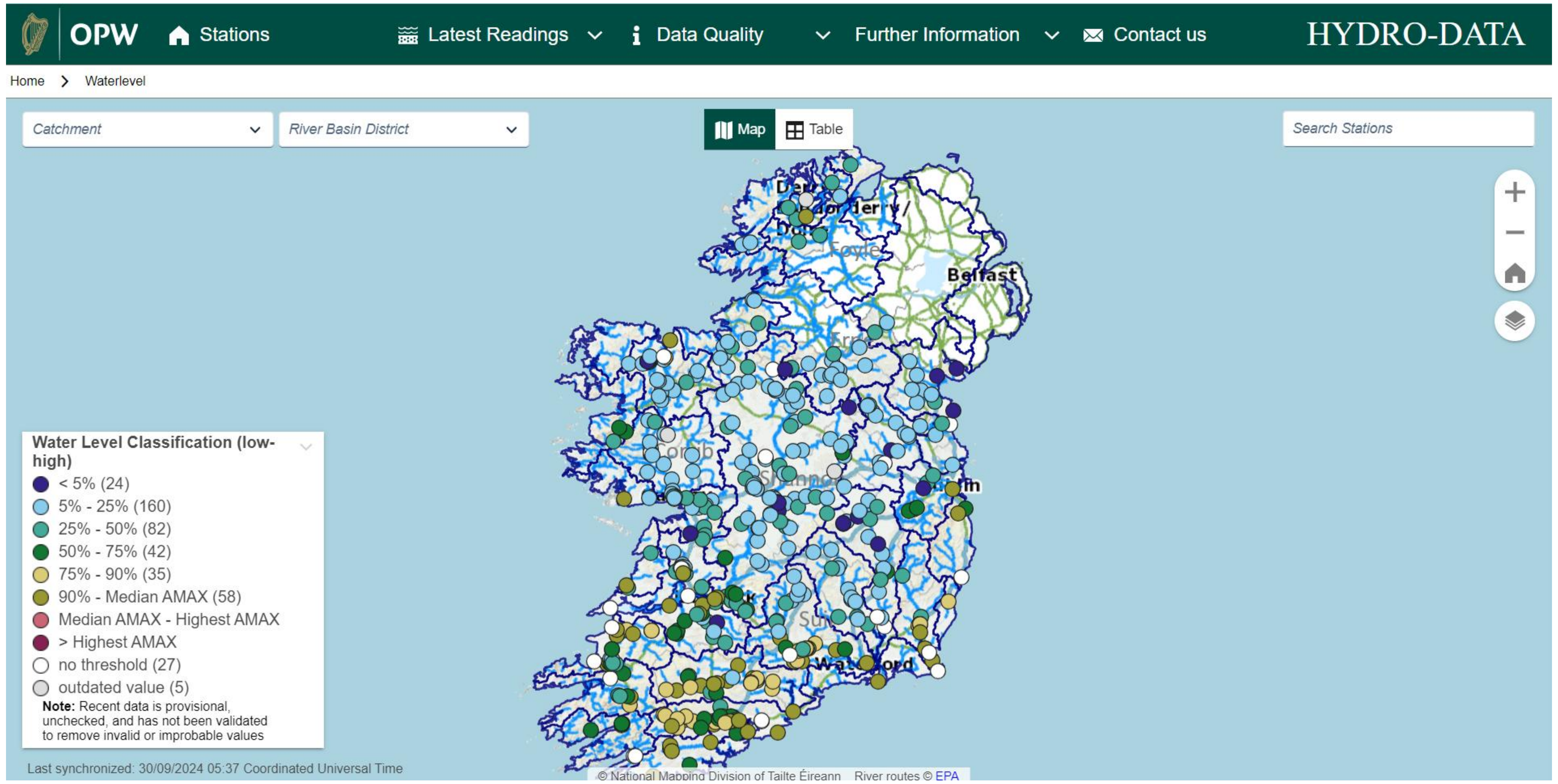


Hydro-data website (WISKI web)

Data available includes:

- Instantaneous data (WL+Q)
- Daily mean data (WL+Q)
- Percentile data (WL+Q)
- **Annual maxima series (WL+Q)**
- Station meta data
- Mapping

www.waterlevel.ie/hydro-data



Gauge Quality Classifications for extreme flood estimation

Stations are classified as either:

(a) Suitable for QMED only (63 stations)

Highest Gauged Flow (HGF) is less than QMED

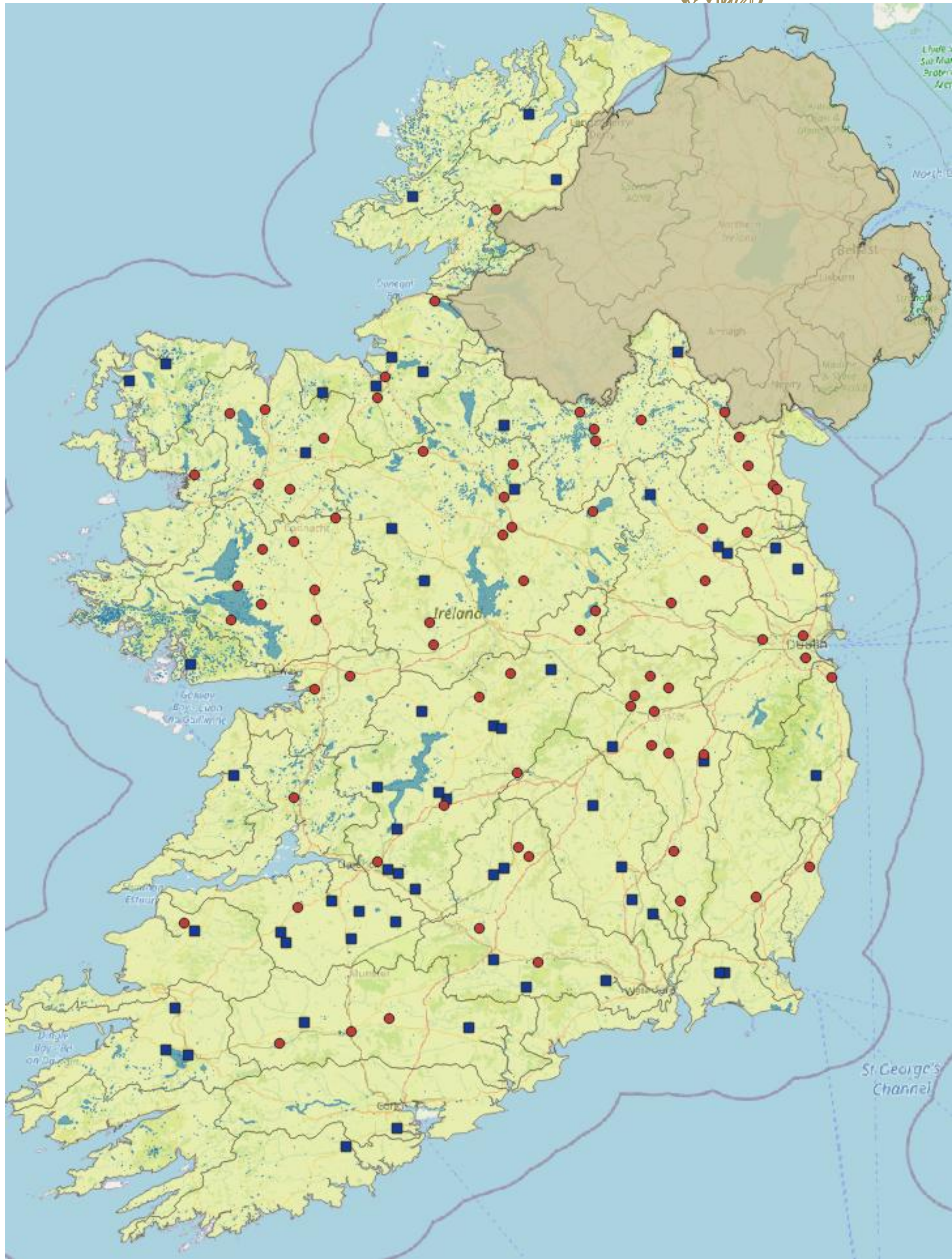
Characteristics of the site indicate that measurement of high flows could be compromised (eg. Backwatering or bypassing at high flows)

Or

(b) Suitable for QMED and Pooling (73 stations)

Highest Gauged Flow (HGF) ≥ QMED

Good channel geometry for high flow estimation



Calculation of design flood magnitudes

To calculate a design flood Q_T of return period T, two items are required:

(a) The median of the Annual Maximum Series (QMED)

- At gauged sites, estimated from the observed Amax data
- At ungauged locations, from equations based on catchment descriptors

and

(b) The T-year return period growth factor (X_T)

- At gauged sites, by fitting a curve to observed Amax data
- At ungauged locations, by selecting a curve based on hydrologically similar catchments

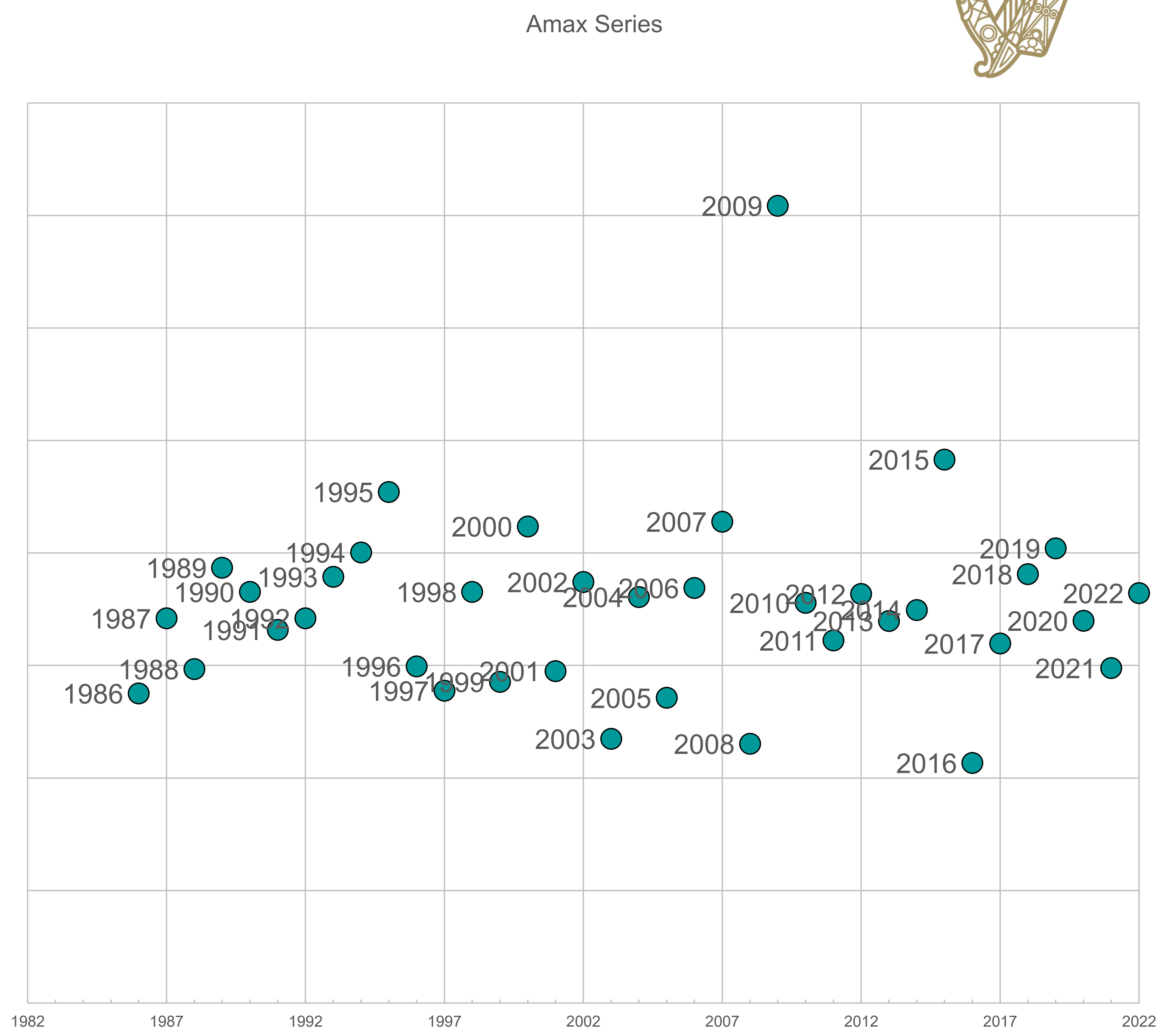
The greatest uncertainty is in the estimation of QMED

The Median Annual Maximum Flood (QMED)

QMED from Annual Maxima

Hydrometric Year	Date	Waterlevel (mOD Poolbeg)	Staff Gauge Reading (m)	Estimated Flow (m^3/s)	Notes
1986	19/12/1986	37.421	1.900	55.039	
1987	19/01/1988	37.691	2.170	68.364	
1988	26/10/1988	37.511	1.990	59.347	
1989	07/02/1990	37.861	2.340	77.361	
1990	06/01/1991	37.781	2.260	73.069	
1991	06/01/1992	37.651	2.130	66.314	
1992	12/06/1993	37.691	2.170	68.364	
1993	27/02/1994	37.831	2.310	75.740	
1994	31/01/1995	37.911	2.390	80.094	
1995	29/11/1995	38.101	2.580	90.840	
1996	20/02/1997	37.521	2.000	59.834	
1997	09/01/1998	37.431	1.910	55.511	
1998	05/01/1999	37.781	2.260	73.069	
1999	25/12/1999	37.541	2.020	57.081	
2000	06/11/2000	38.071	2.550	84.719	
2001	05/02/2002	37.581	2.060	59.007	
2002	14/11/2002	37.891	2.370	74.827	
2003	05/02/2004	37.321	1.800	46.965	
2004	08/01/2005	37.841	2.320	72.170	
2005	31/03/2006	37.481	1.960	54.241	
2006	04/12/2006	37.871	2.350	73.760	
2007	17/08/2008	38.086	2.565	85.567	
2008	13/12/2008	37.301	1.780	46.087	
2009	19/11/2009	**38.973**	3.452	141.718	
2010	07/02/2011	37.821	2.300	71.119	
2011	25/10/2011	37.691	2.170	64.442	
2012	19/01/2013	37.851	2.330	72.699	
2013	31/12/2013	37.759	2.238	67.900	
2014	14/11/2014	37.797	2.276	69.866	
2015	31/12/2015	38.276	2.755	96.600	
2016	04/03/2017	37.299	1.778	42.7	
2017	22/01/2018	37.757	2.236	63.9	
2018	11/08/2019	37.994	2.473	76.2	
2019	25/02/2020	38.078	2.557	80.8	
2020	20/01/2021	37.837	2.316	68.0	
2021	21/02/2022	37.669	2.148	59.5	
2022	06/08/2023	37.931	2.410	72.9	

Rank	Estimated Flow (m3/s)
1	141.72
2	96.60
3	90.84
4	85.57
5	84.72
6	80.81
7	80.09
8	77.36
9	76.22
10	75.74
11	74.83
12	73.76
13	73.07
14	73.07
15	72.86
16	72.70
17	72.17
18	71.12
19	69.87
20	68.36
21	68.36
22	67.95
23	67.90
24	66.31
25	64.44
26	63.89
27	59.83
28	59.54
29	59.35
30	59.01
31	57.08
32	55.51
33	55.04
34	54.24
35	46.97
36	46.09
37	42.68

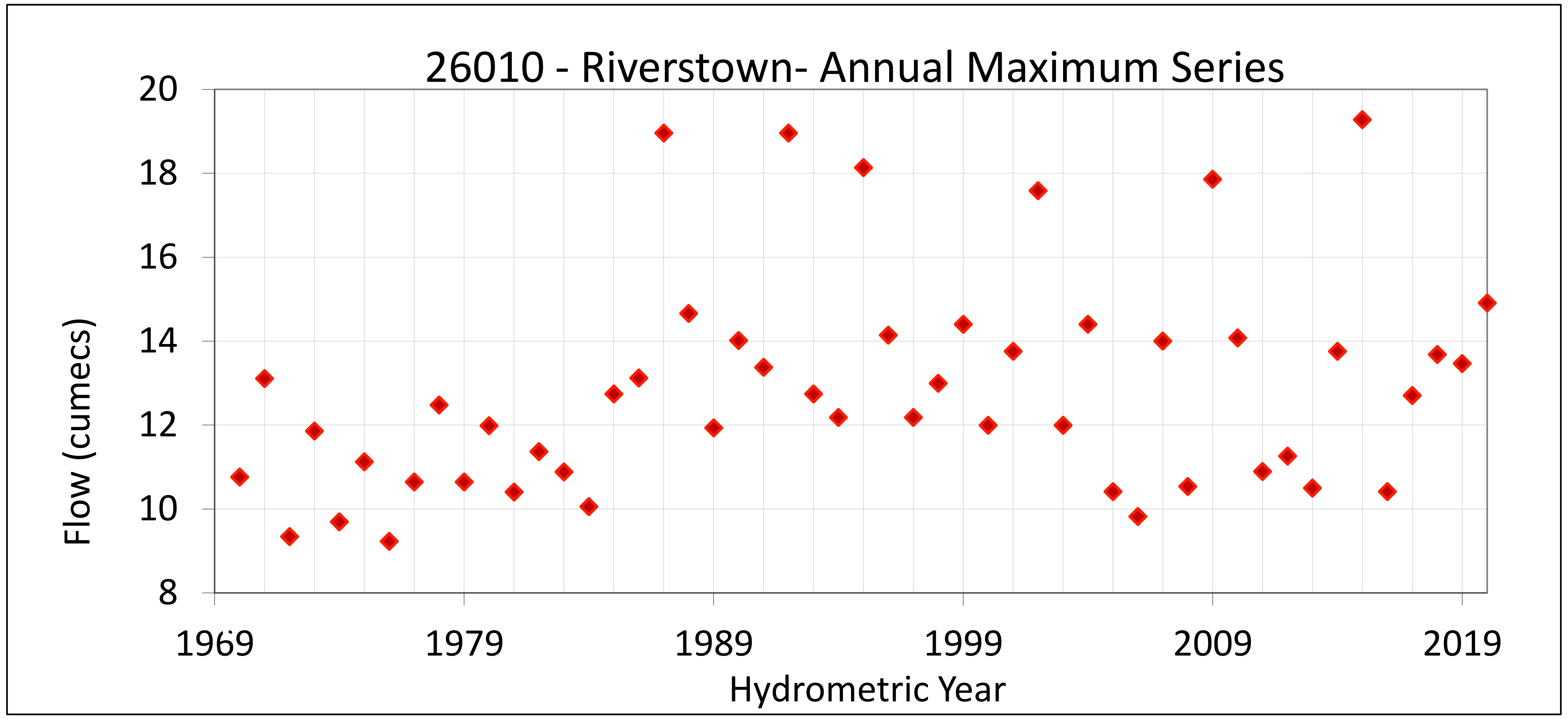


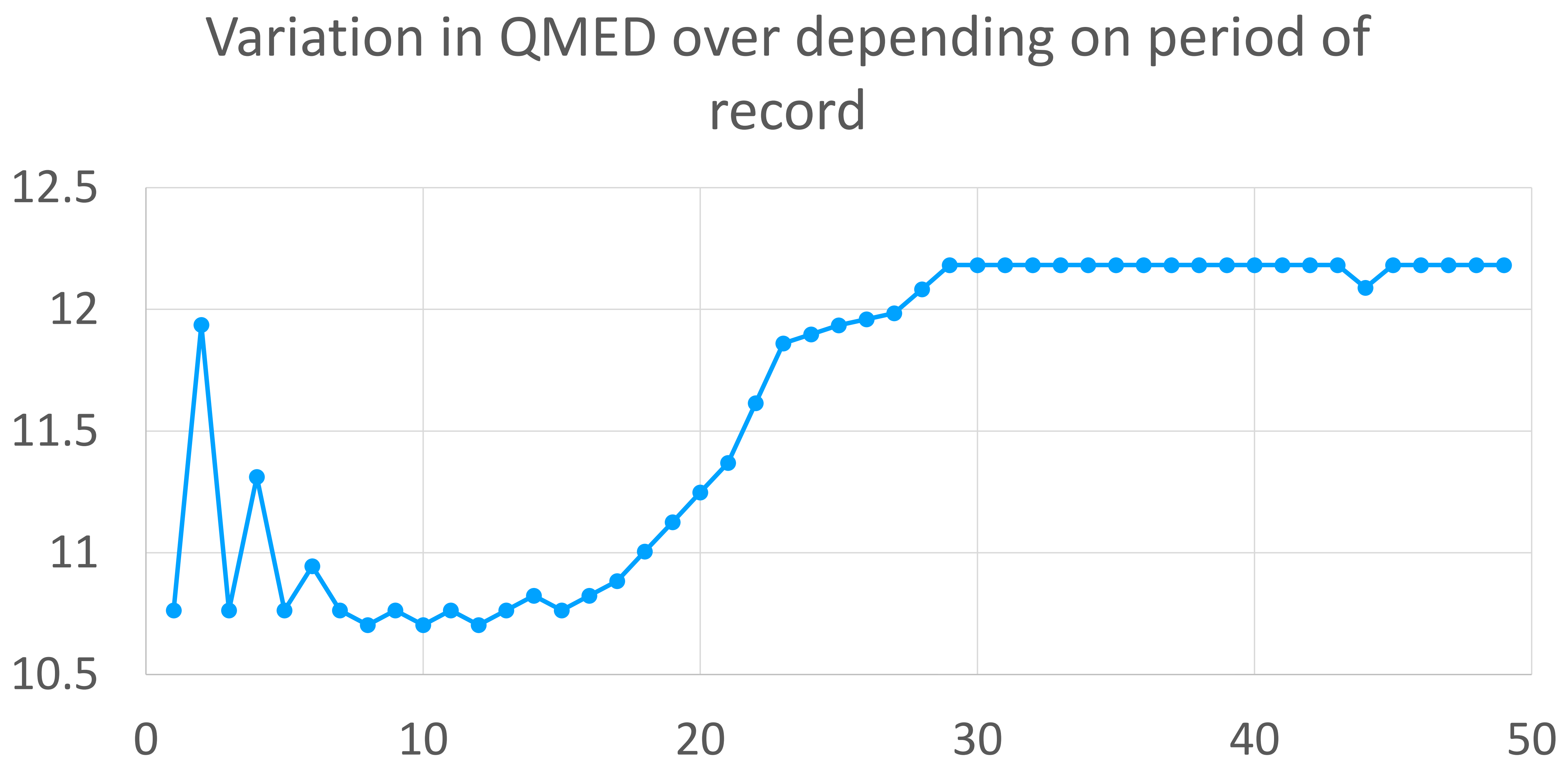
Median of the Annual Maximum Series = 69.87m^3/s

Importance of Long Records

26010 Riverstown

- How many years does it take to get a good estimate of QMED?
- Using Amax series estimate QMED for the first 1, 2, 3, 4…years
- 29 years for 26010 Riverstown to stabilise on a value for QMED
- Need to identify good locations quickly and dump poor locations that show little or no promise





Calculation of Design Flood Magnitudes (Gauged Sites)

To calculate a design flood Q_T of return period T, two items are required:

(a) The median of the Annual Maximum Series (QMED)

- At gauged sites, estimated from the observed Amax data

and

(b) The T-year return period growth factor (X_T)

- At gauged sites, by fitting a curve to observed Amax data

- Design flood magnitudes are calculated from the product of the two

$$Q_T = QMED \cdot X_T$$

The greatest uncertainty is in the estimation of QMED

Statistics

First, some statistical measures:

(a) The mean (also known as the average)

(b) The median

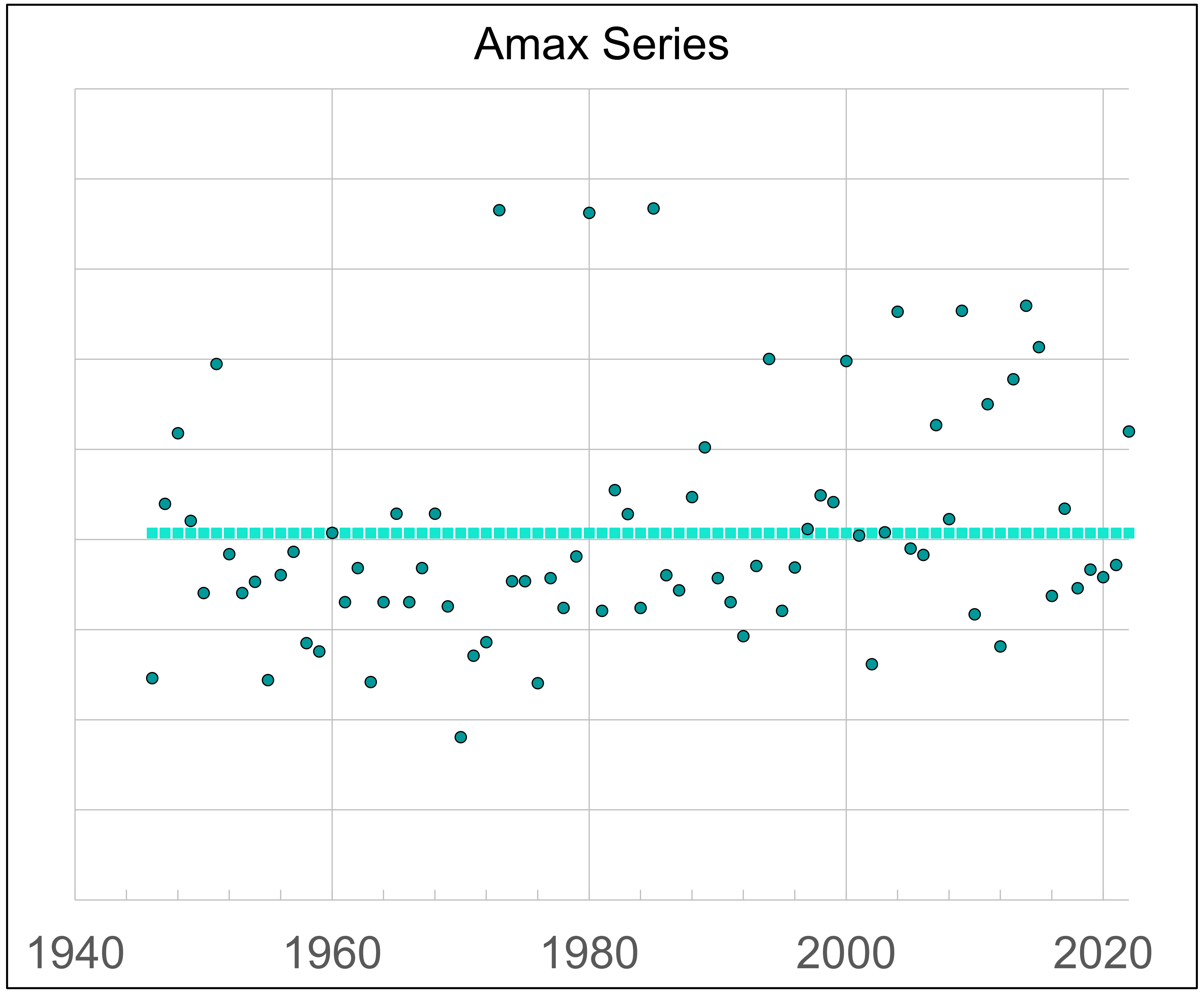
(c) Standard Deviation - the amount of variation of the values of a variable about its mean

(d) Coefficient of variation (CV) - the ratio of the standard deviation σ to the mean μ

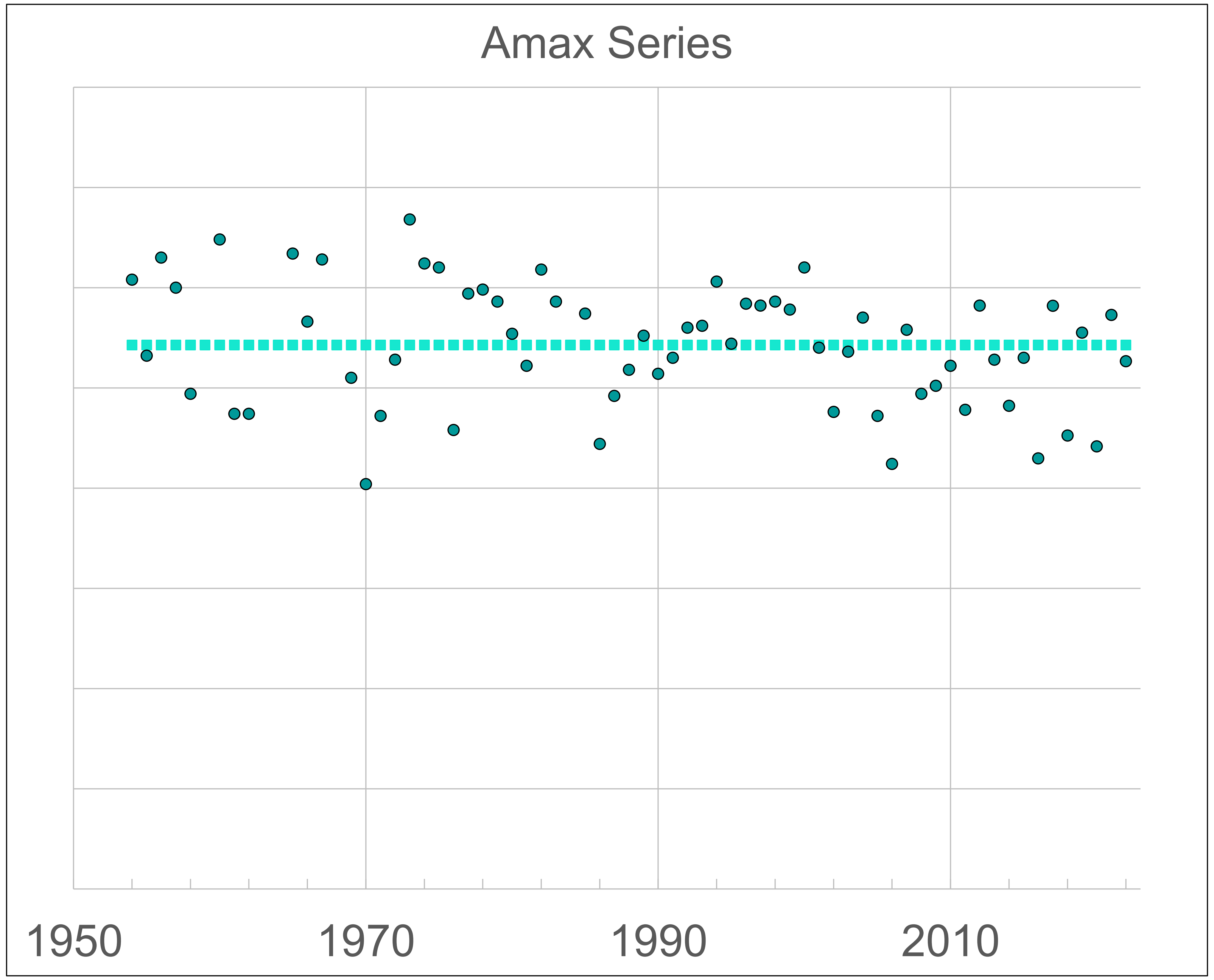
$$CV = \frac{standard\ deviation}{mean} = \frac{\sigma}{\mu}$$

Statistics

(d) Coefficient of Variation (CV)



High CV

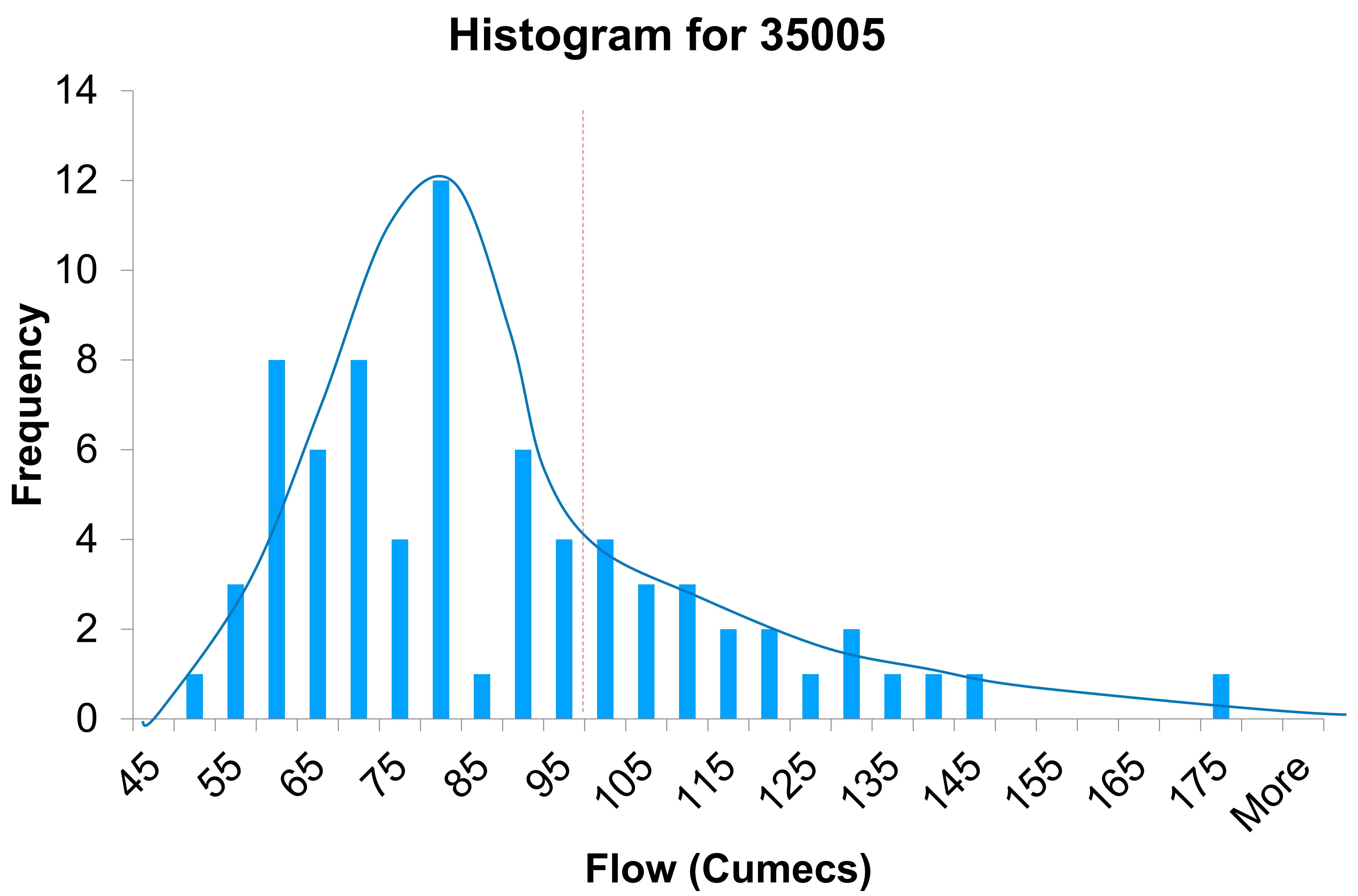


Low CV

Statistics

(e) Skewness

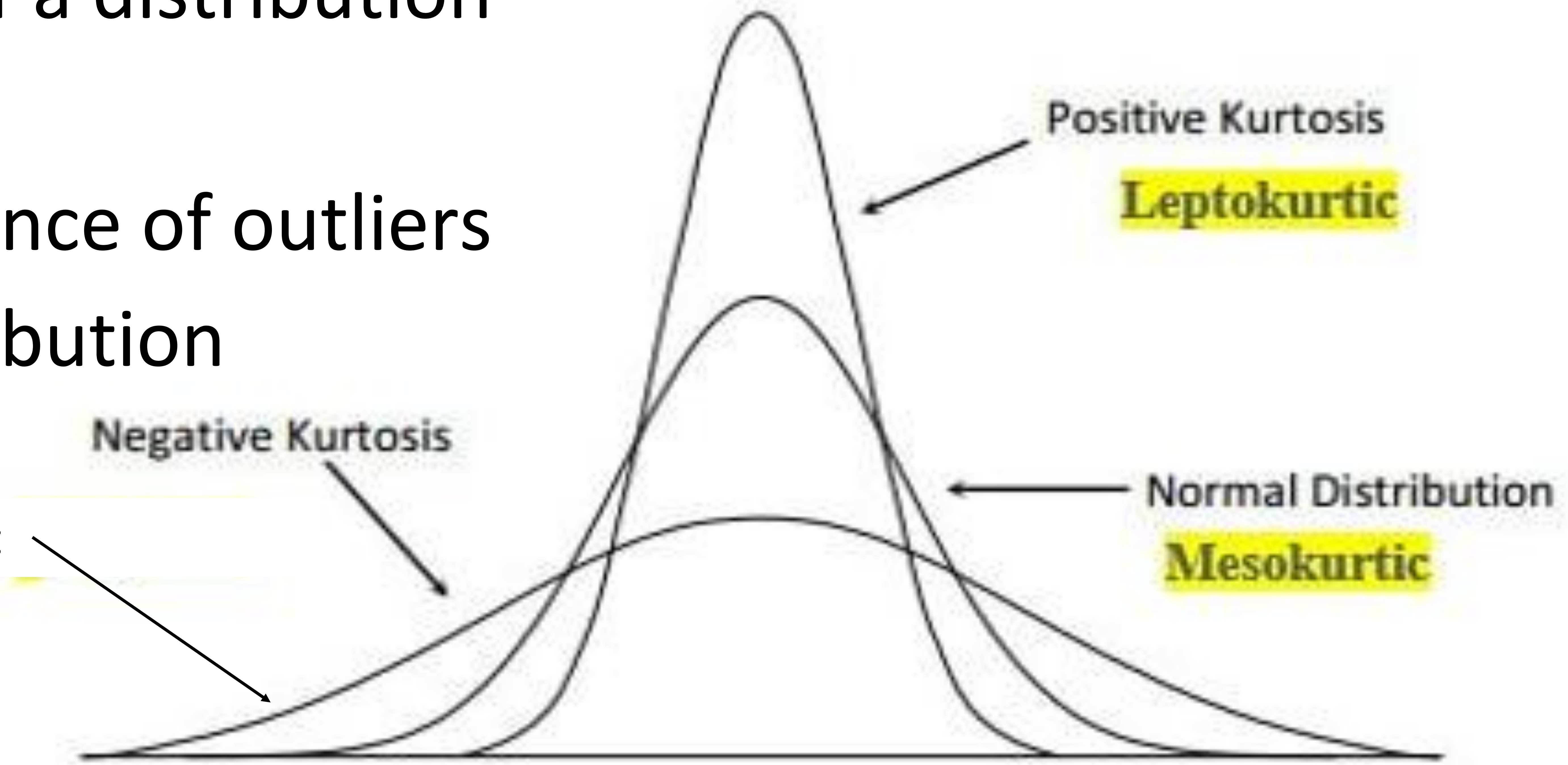
a measure of the asymmetry of a distribution



(f) Kurtosis

a measure of the ‘flatness’ of a distribution

refers to the degree of presence of outliers (extreme values) in the distribution



Statistics

L-moments

For flood frequency analysis at gauged sites, we use must fit a best fit curve to the Amax data from the gauge.

We use what are called L-Moments to find the best fit curve.

They are :

- L-mean (t_1)
- L-CV (t_2)
- L-skewness (t_3)
- L-Kurtosis (t_4)

L-moments are calculated from the Amax data and are used to fit a growth curve to the Amax data

Selection of flood frequency Curve

How to choose the curve that fits the best

We use standard plots known as L-moment ratio:

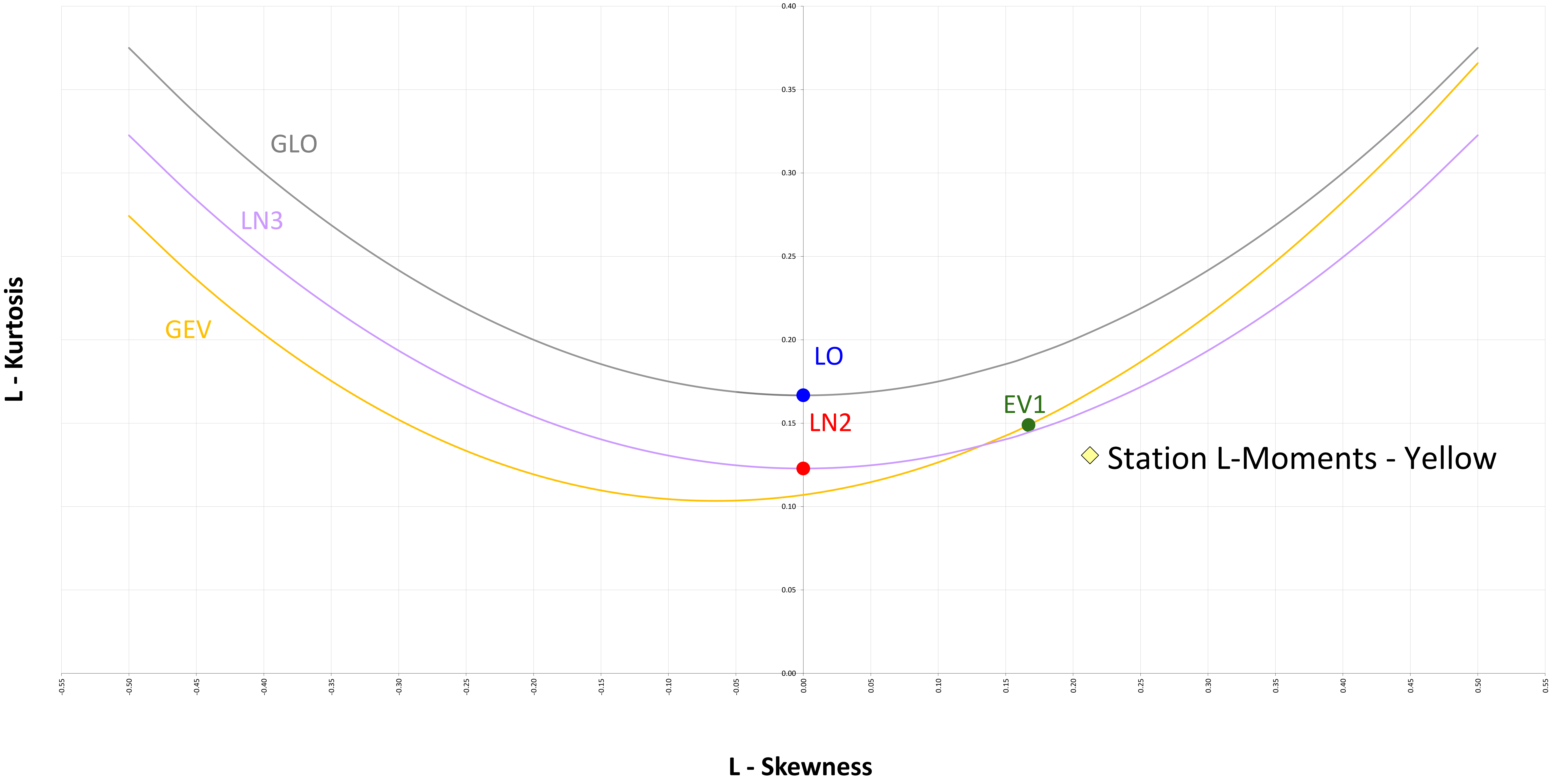
Plot of - L-Kurtosis Vs L-Skewness

6 families of curves are used in Ireland:

2- parameter curves: EV1, LN2 and LO

3-parameter curves: GEV, LN3 and GLO

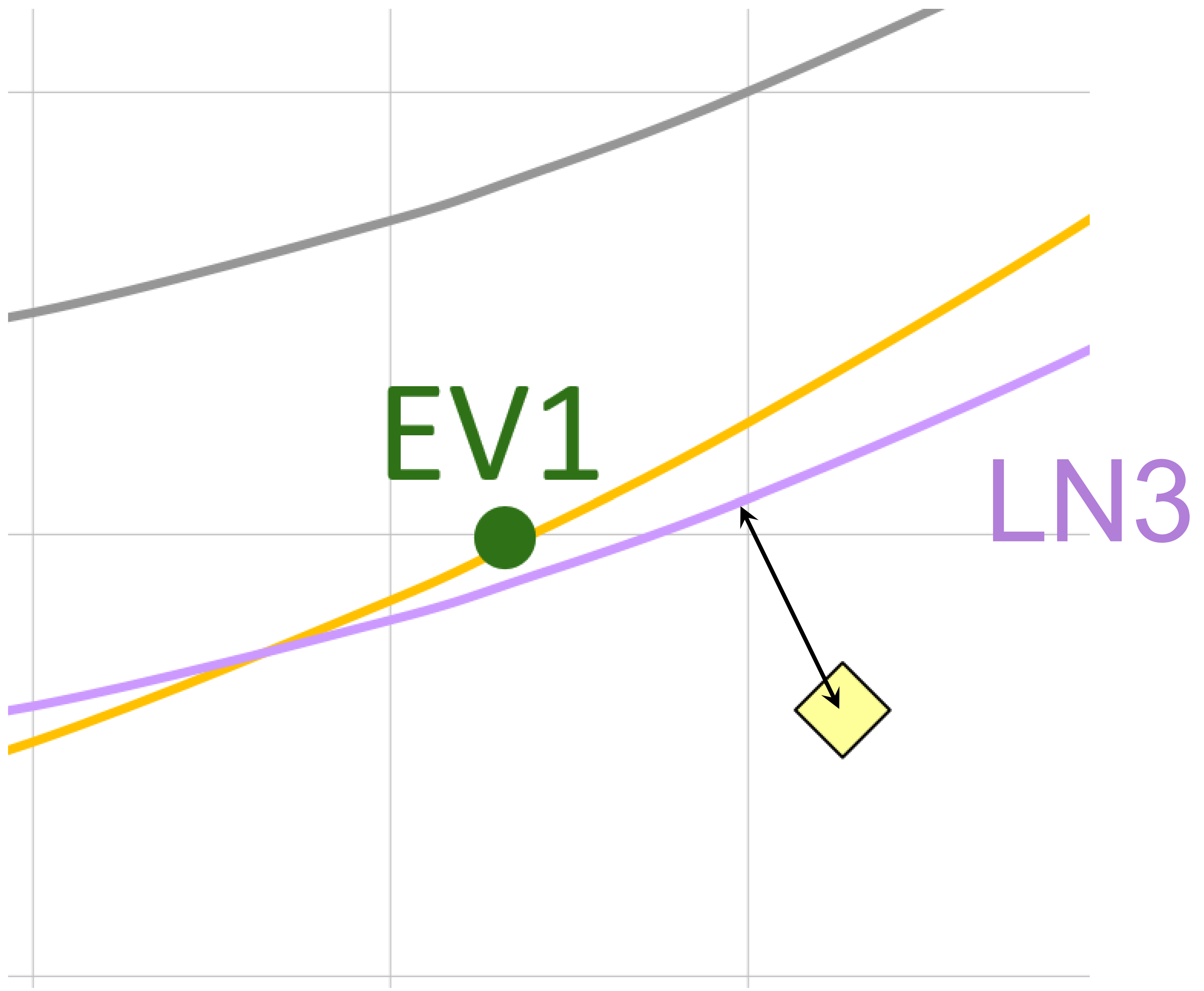
Two and Three Parameter Moment Ratio Diagram



Choice of best fit flood frequency distribution:

- The L-moment ratio for the subject site (yellow diamond) is compared to the standard curves

- In this example the L-moment ratio is closest to the LN3 curve (purple)



2-Parameter Flood Frequency Curves

EV1: $$Q_T = \xi + \alpha\left[-ln\left(-ln\left(1 - {}^{1}/_{T}\right)\right)\right]$$

LO: $$Q_T = \xi + \alpha\, ln(T - 1)$$

LN2: $$Q_T = exp\left[\mu + \sigma\, \phi^{-1}\left(1 - {}^{1}/_{T}\right)\right]$$

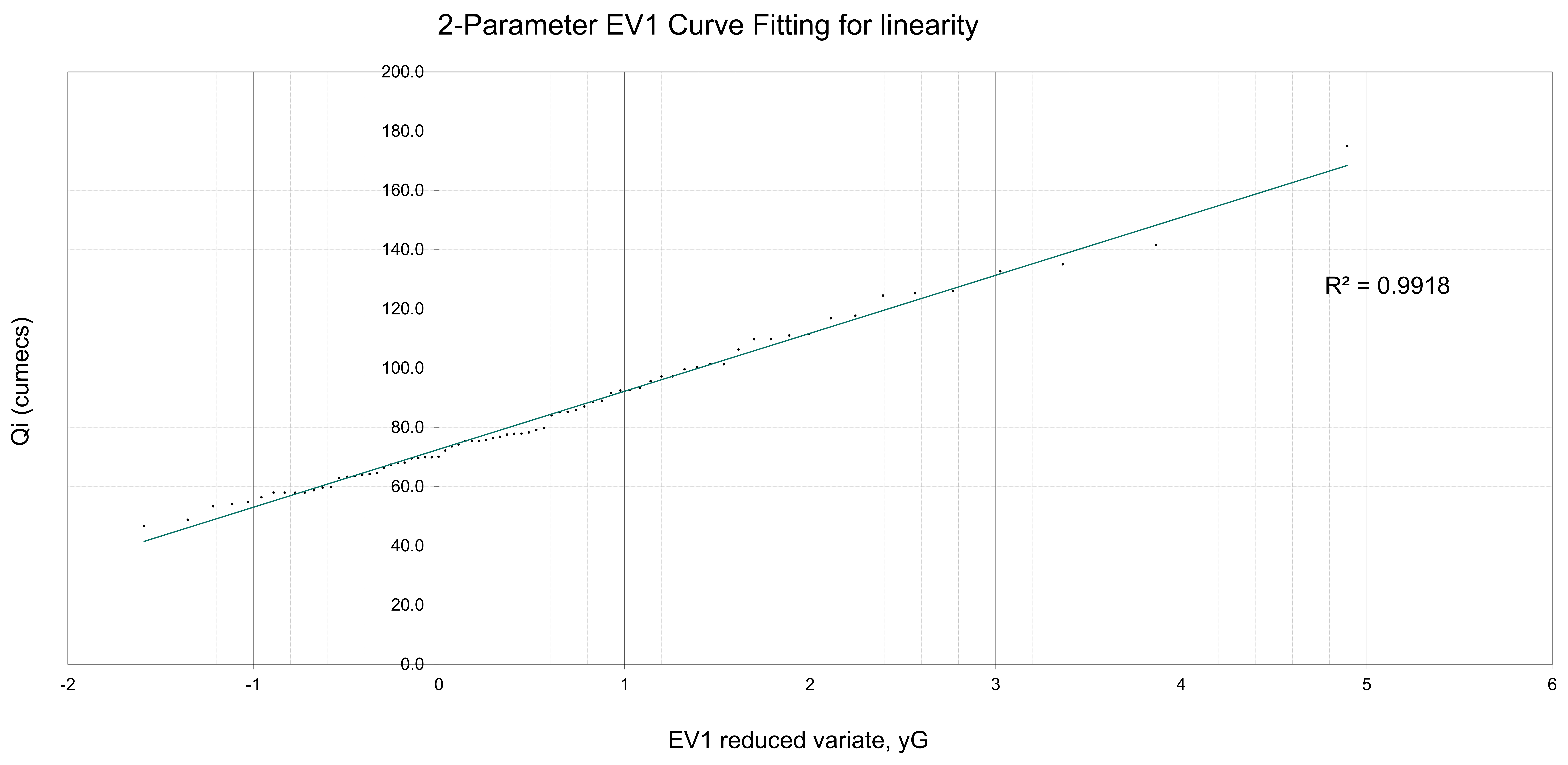
3-Parameter Flood Frequency Curves

GEV: $$Q_T = \xi + \frac{\alpha}{k}[e^{-ky}]$$

GLO: $$Q_T = \xi + \frac{\alpha}{k}[1 - (T-1)^{-k}]$$

LN3: $$Q_T = exp[\mu + \sigma\, \phi^{-1}(1 - {}^{1}/_{T})]$$

2- Parameter Flood Frequency Curves



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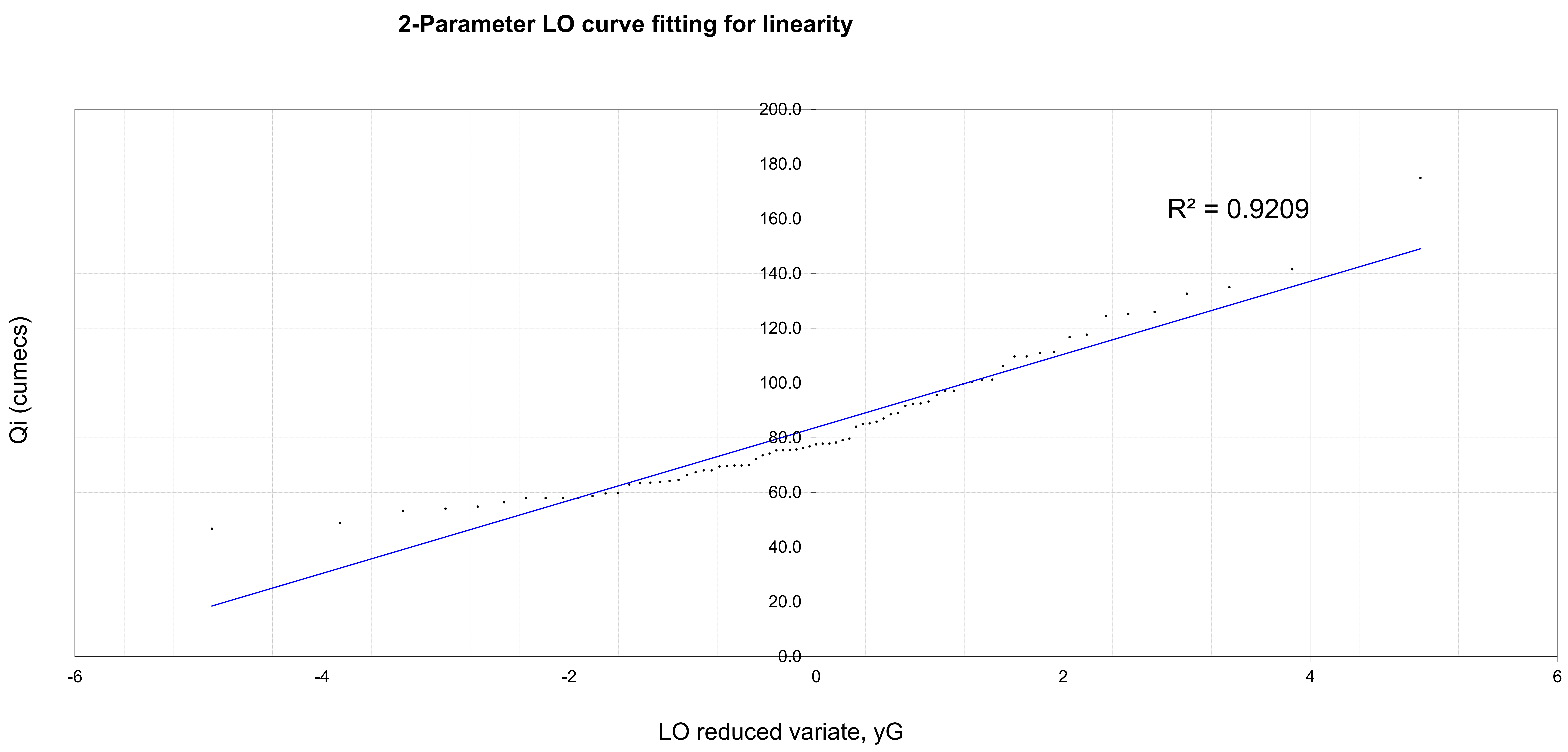

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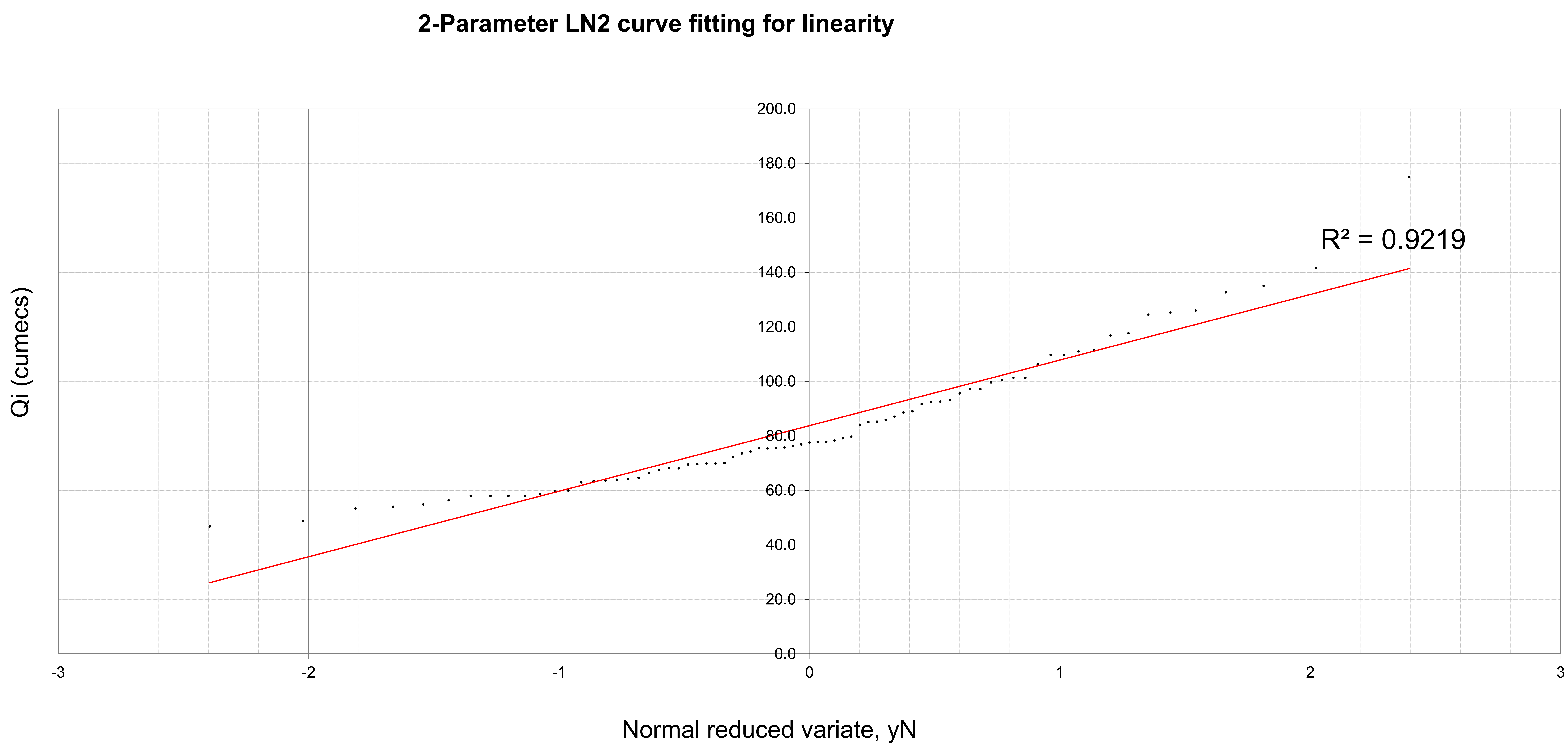

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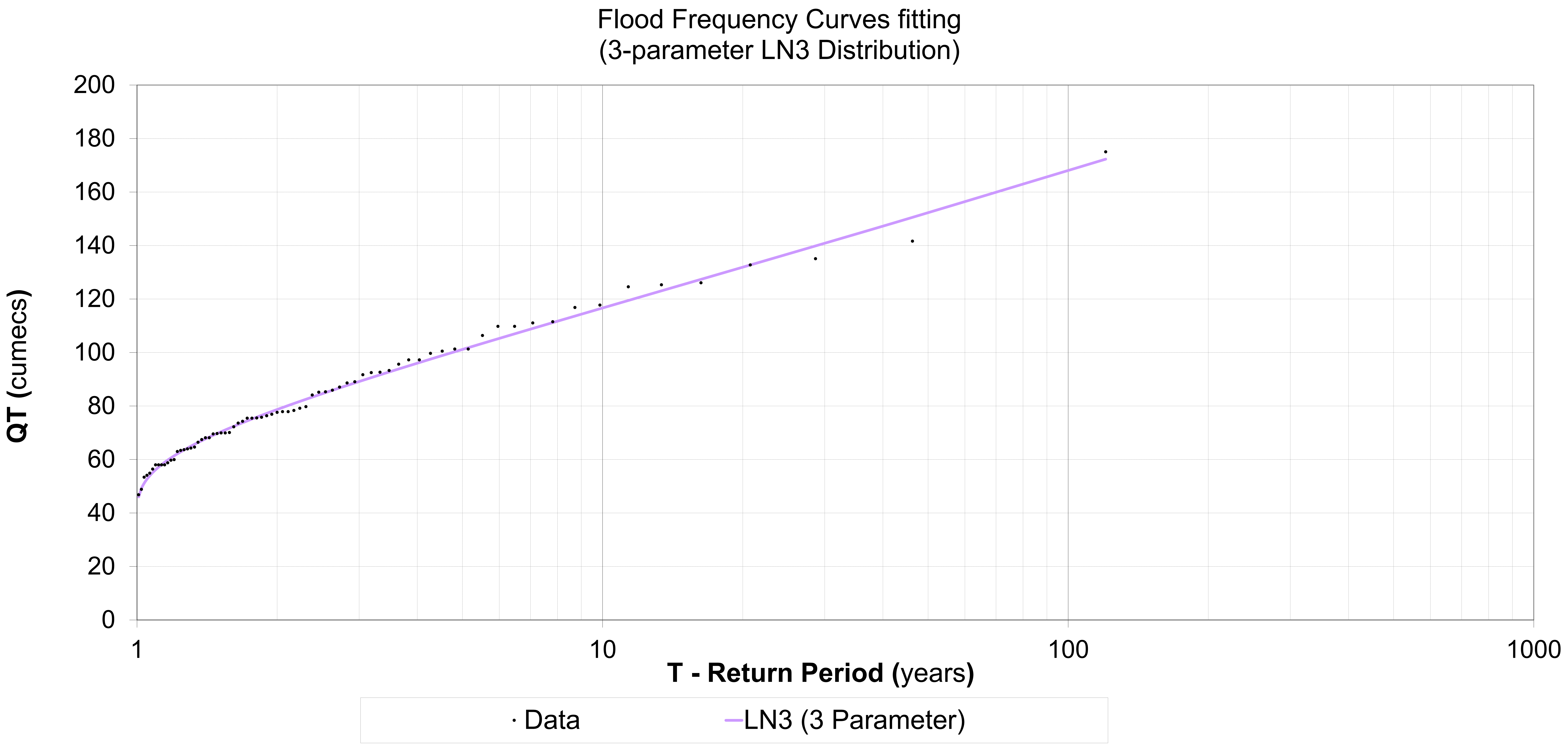

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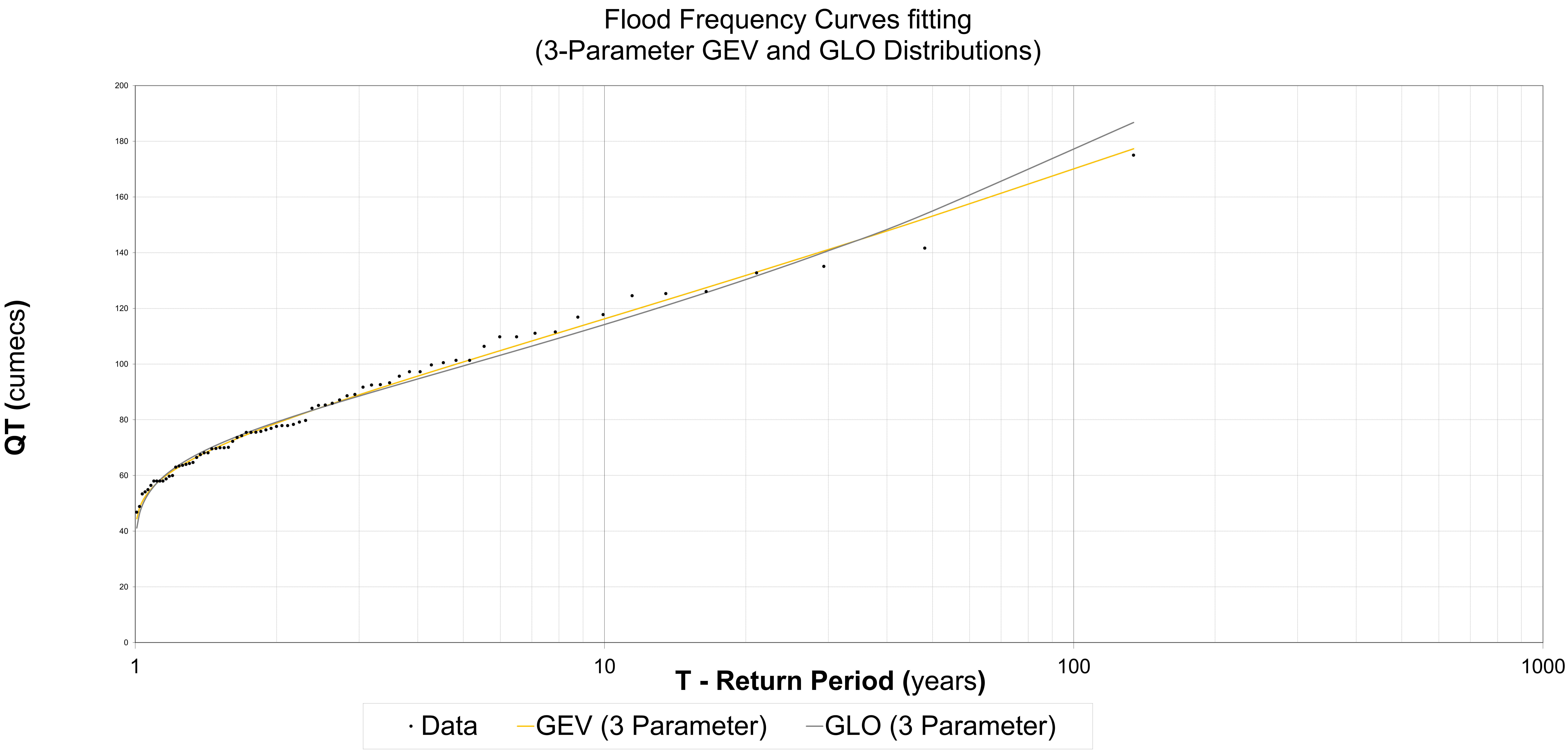


Flood Estimation at ungauged sites

- At ungauged sites, we don't have any flow Data (no Amax data)

- $Q_T = QMED \times X_T$

- QMED is calculated from a 7-variable equation

- X_T is calculated using pooled flood frequency analysis.

Flood Estimation at ungauged sites

<u>Physical Catchment Descriptors</u>

- AREA - Catchment Area
- SAAR - Standard Period Average Annual Rainfall
- BFIsoil - Baseflow Index derived from Soils
- FARL - Flood Attenuation from Reservoirs and Lakes
- DRAIND - Drain Density
- S1085 - Mainstream Slope
- ARTDRAIN2 - Arterial Drainage Index
- URBEXT - Proportion of Urban Landcover Extent

Estimation of QMED – ungauged locations

a) 7-variable QMEDrural equation

$$\mathbf{QMEDrural} = 3.117 \times 10^{-6} \times AREA^{1.07} \times BFIsoil^{-1.342} \times SAAR^{1.351} \times FARL^{2.419} \times DRAIND^{0.273} \times S1085^{0.185} \times (1 + ARTDRAIN2)^{0.53}$$

b) Adjustment Factor (ADJFAC) - from a nearby or similar gauged catchment)

$$\mathbf{ADJFAC} = \frac{QMEDgauged}{QMEDrural}$$

c) Pivotal Site Adjustment

$$\mathbf{QMEDadjusted} = QMEDrural \times ADJFAC$$

d) Adjustment for Urbanisation

$$\mathbf{QMED} = \boldsymbol{QMEDadjusted} \times (\mathbf{1} + \boldsymbol{URBEXT})^{\mathbf{1.482}}$$

Estimation of flood growth factors – ungauged locations

a) Form a pooling group based on hydrological similarity (Dij)

$$\boldsymbol{D_{ij}} = \sqrt{0.5\left(\frac{LnAREA_i - LnAREA_j}{1.3382}\right)^2 + 1.52\left(\frac{LnSAAR_i - LnSAAR_j}{0.2144}\right)^2 + 1.24\left(\frac{LnDRAIND_i - LnDRAND_j}{0.3819}\right)^2}$$

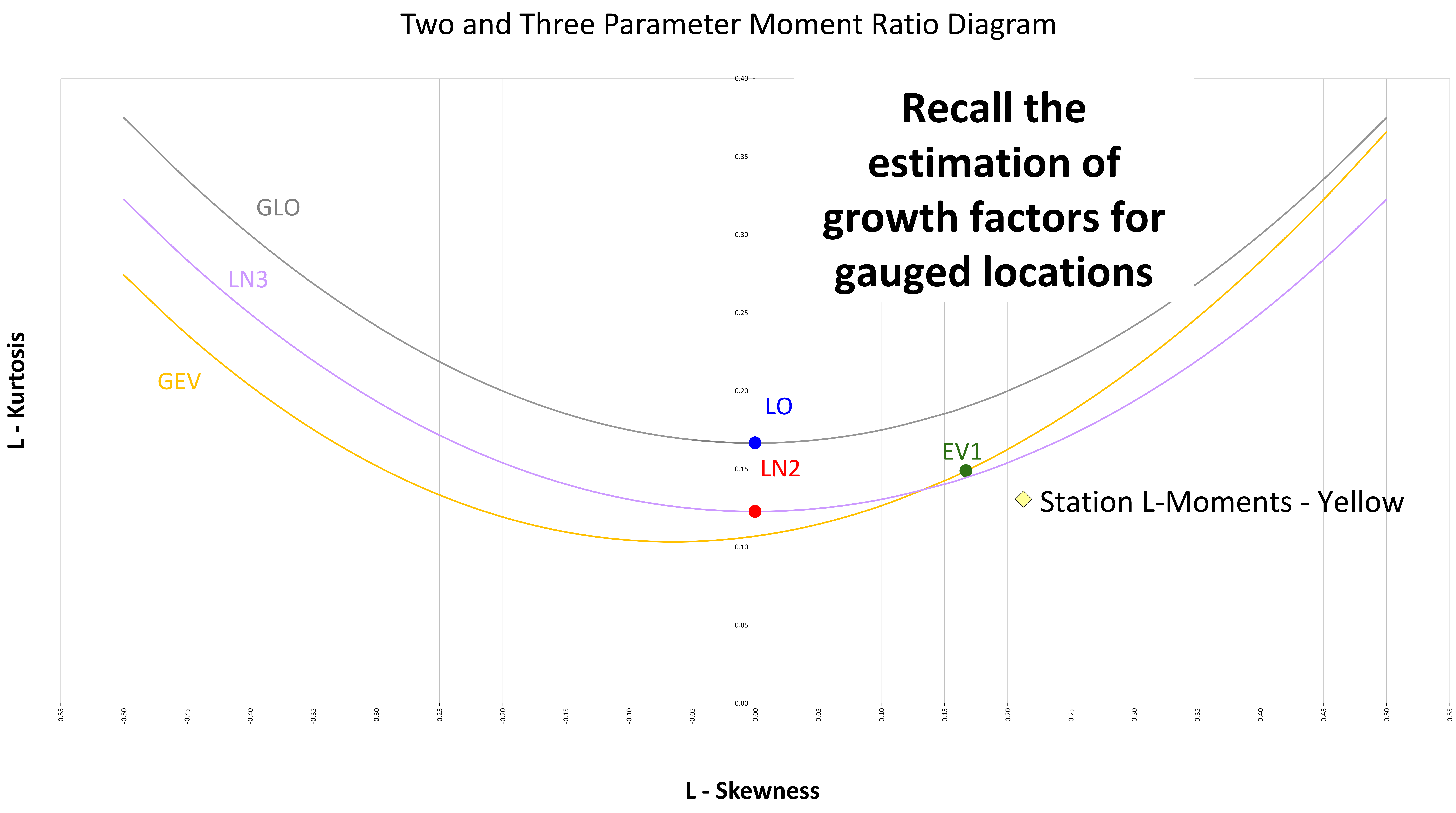
Estimation of flood growth factors – ungauged locations

b) Pooling Group - showing L-moment weighted by record length

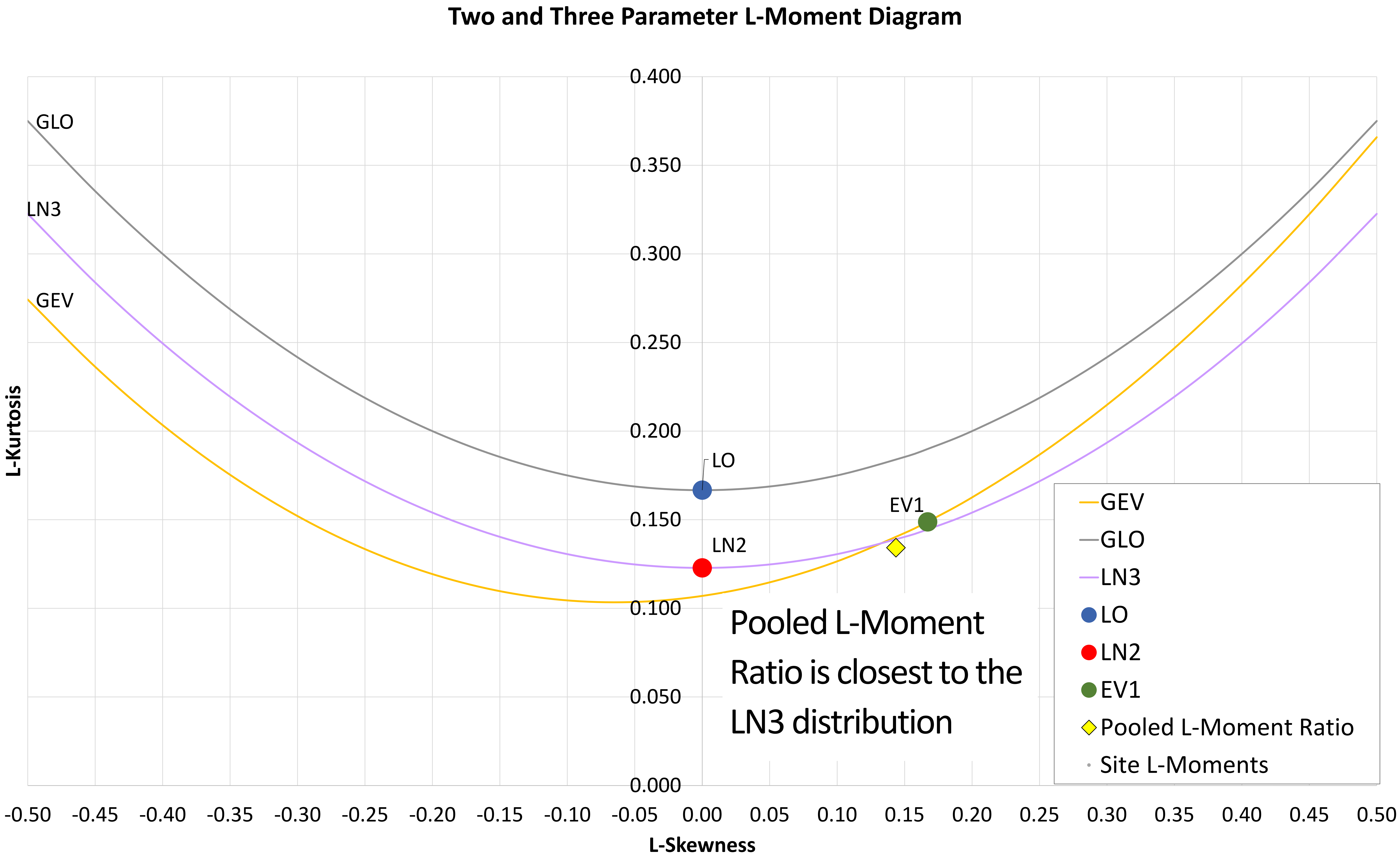
Ranking	station no.	similarity measure Dij	No. of Yrs of data	Pooling Years Count	t2 L-CV	t3 L-Skewness	t4 L-Kurtosis	n*t2	n*t3	n*t4
1	9037	0.000	24	24	0.342	0.305	0.100	8.216	7.314	2.392
2	6033	0.662	47	71	0.232	0.093	0.137	10.893	4.388	6.437
3	6013	0.729	48	119	0.150	0.040	0.050	7.200	1.920	2.400
4	9001	0.731	66	185	0.245	0.207	0.139	16.165	13.683	9.205
5	10021	0.822	41	226	0.244	0.244	0.126	10.016	9.991	5.156
6	16001	0.901	51	277	0.129	0.000	0.108	6.597	0.009	5.503
7	36031	0.921	25	302	0.151	0.291	0.215	3.778	7.268	5.375
8	11001	0.959	51	353	0.150	0.185	0.240	7.659	9.446	12.221
9	7006	1.039	37	390	0.125	0.050	0.118	4.640	1.851	4.377
10	6014	1.123	48	438	0.143	0.231	0.197	6.848	11.091	9.473
11	36018	1.147	68	**506**	0.156	0.216	0.194	10.629	14.702	13.180
12	15001	1.149	57	563	0.169	0.023	0.092	9.610	1.299	5.218
13	24005	1.256	35	598	2.670	0.471	0.447	93.456	16.479	15.645
14	7002	1.260	44	642	0.148	-0.027	0.083	6.506	-1.178	3.665
15	26019	1.334	69	711	0.140	0.268	0.190	9.649	18.514	13.126
					Average of weighted L-Moments/no. of years **= Pooled L-moment Ratio**			**0.185**	**0.144**	**0.134**

5T rule (in yellow)

100 year return period required hence 5 x 100 = 500 years of data


Two and Three Parameter Moment Ratio Diagram
Recall the estimation of growth factors for gauged locations
GLO
LN3
GEV
LO
LN2
EV1
Station L-Moments - Yellow
L - Kurtosis
L - Skewness
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
-0.55
-0.50
-0.45
-0.40
-0.35
-0.30
-0.25
-0.20
-0.15
-0.10
-0.05
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
0.55

Estimation of flood growth factors – ungauged locations



Estimation of flood growth factors – ungauged locations

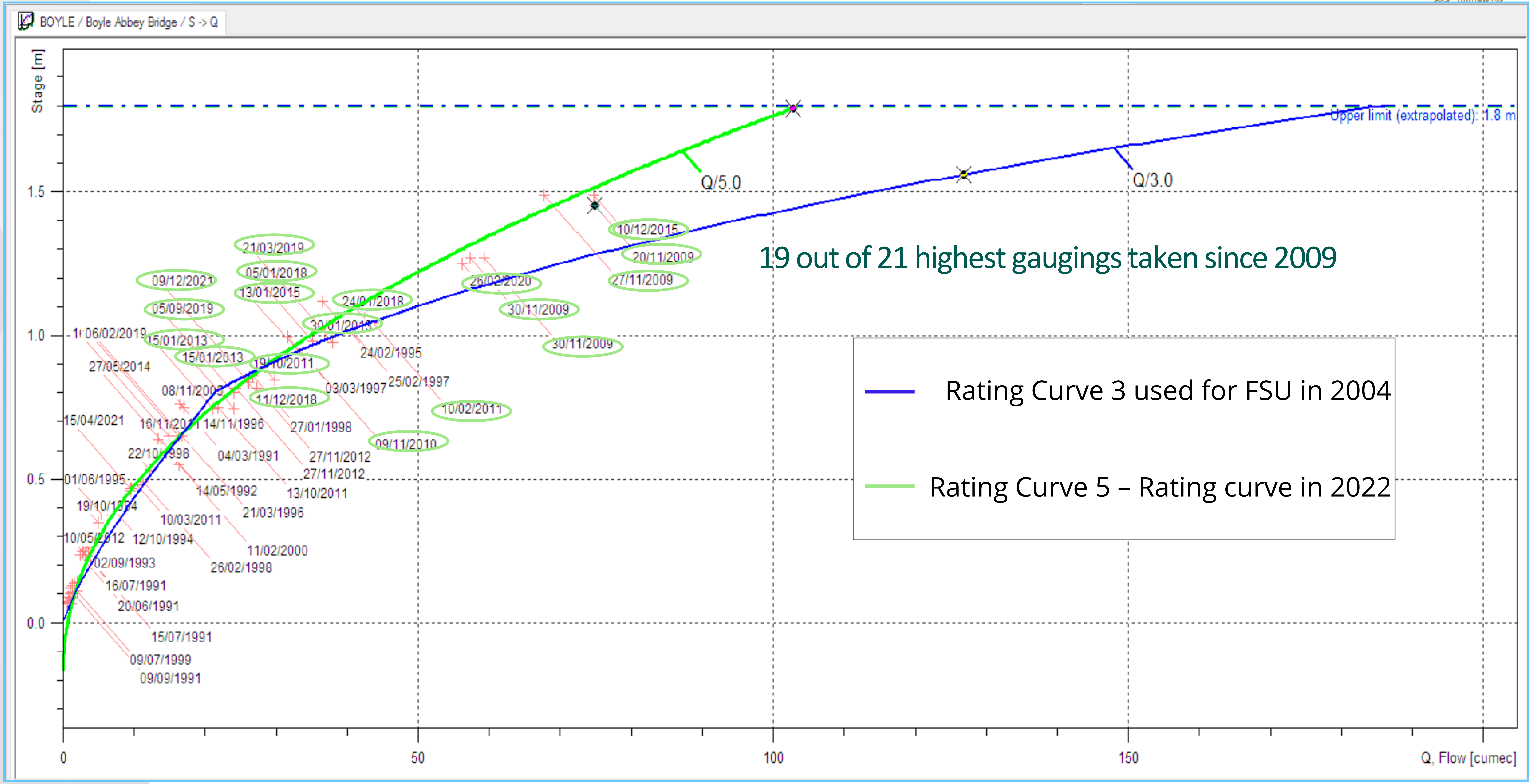
b) Growth Factors

LN3		
Return Period (T)	**Growth Factors**	**Design Flows**
1.3	0.783	21.744
2	1.000	27.779
5	1.240	34.455
10	1.363	37.853
20	1.462	40.612
25	1.491	41.408
30	1.513	42.031
35	1.531	42.541
50	1.572	43.668
100	1.644	45.676

Why collect Spot Flow Gaugings?

- To create rating curves (especially for newer gauges on Flood Relief Schemes)
- To give greater confidence in low and high flow estimates
- Enables improved Annual Maxima (Amax) estimates
- Improved flood growth curves
- Confidence in rating curve accuracy is hugely important for estimating high flows, especially for flood forecasting
- Enables improved Median Annual Maximum estimates (QMED)

Greater confidence in high flow estimates



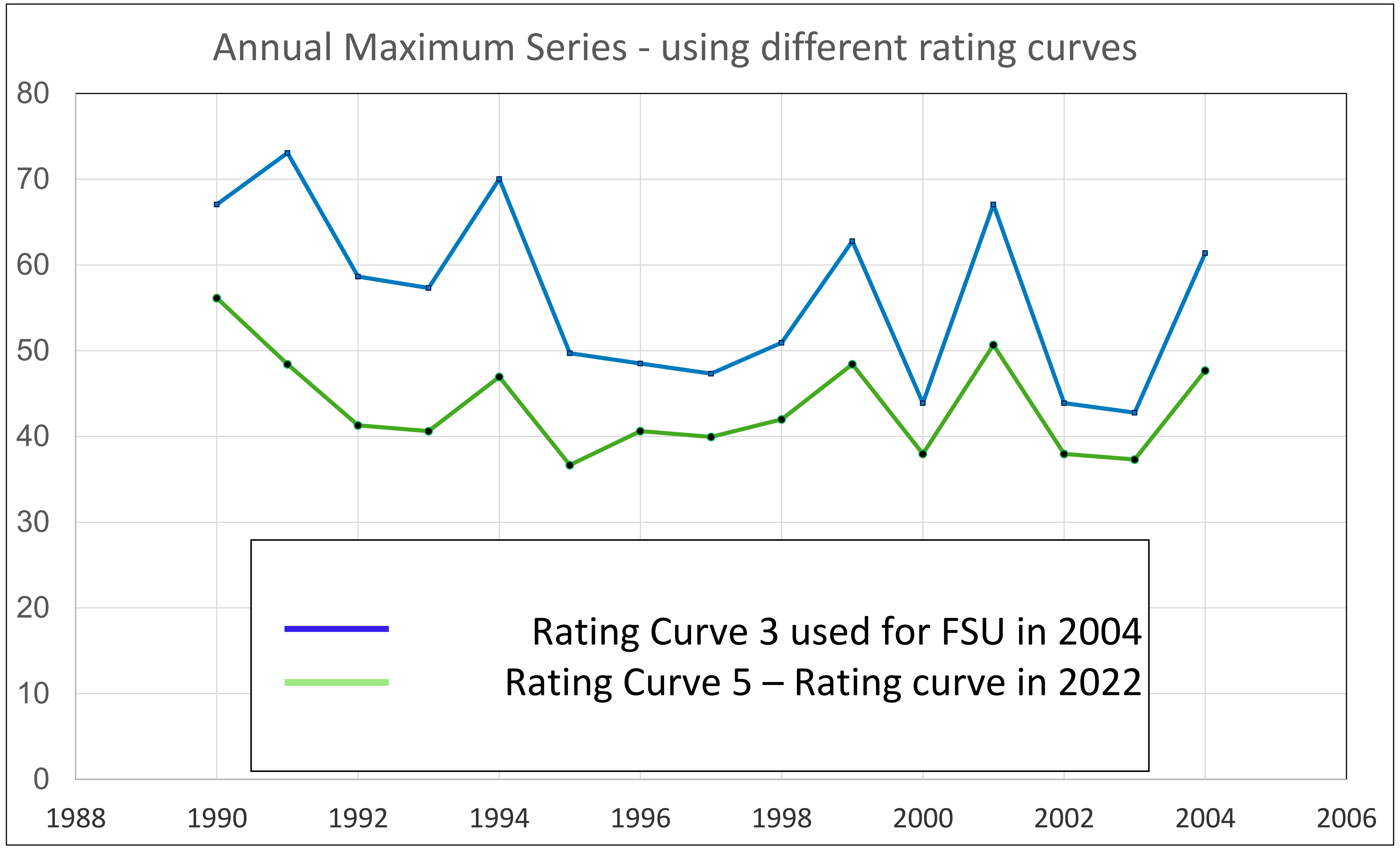
Improves Annual Maxima (Amax) Series

26108 Boyle Abbey Bridge on the Boyle

- RC 3 was the Rating Curve in 2004 used for the FSU
- Q = 8.3138*(h-0.08)^1.7599

- RC 5 was the Rating Curve used in 2022 for FEMI
- Q = 25*(h+0.1)^2.1

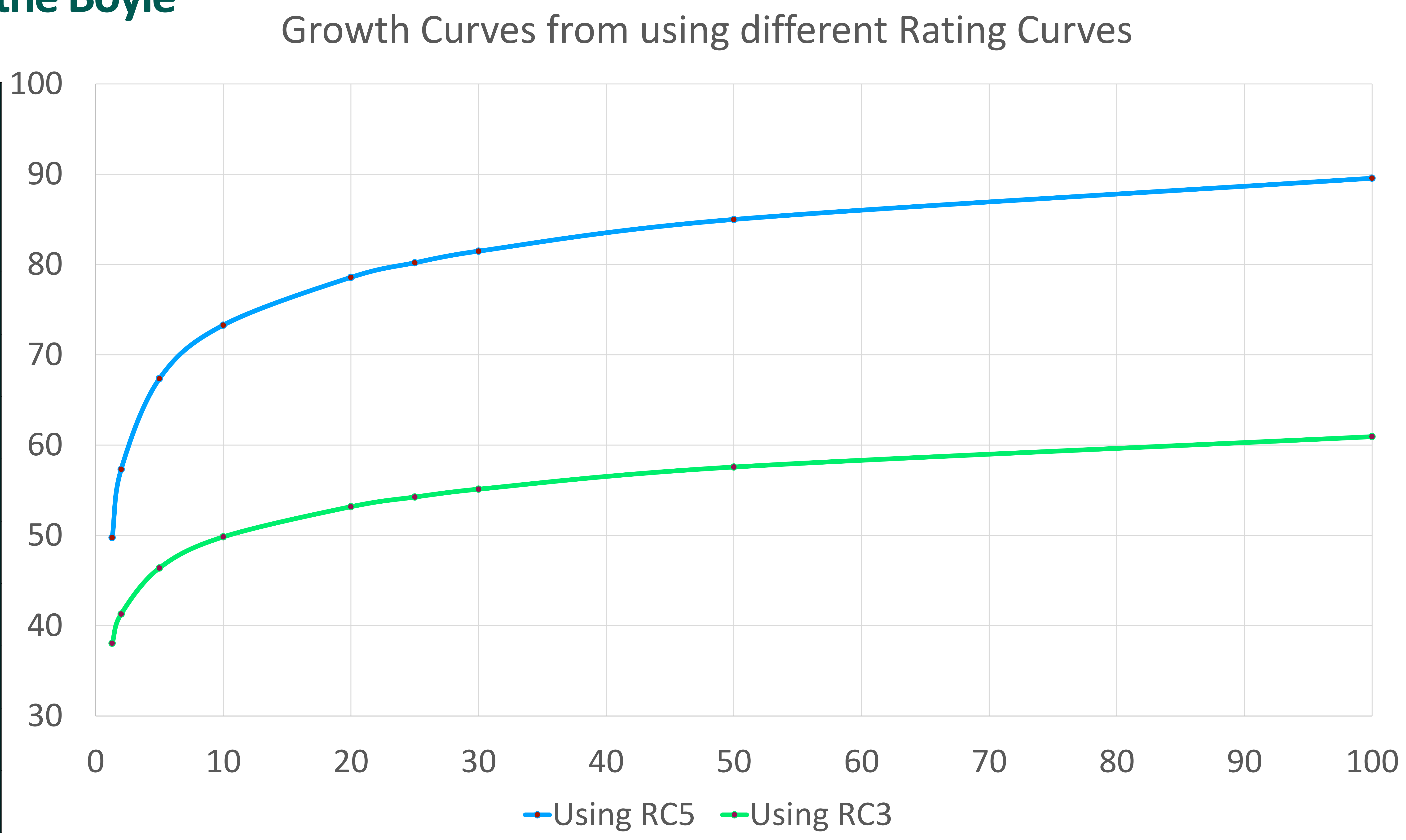
- QMED 2004 = 57.32
- QMED 2022 = 41.3
- Overestimates by 39% if using the older rating curve



Improved Flood Growth Curves

26108 Boyle Abbey Bridge on the Boyle

Return Period (T)	*Using RC3*	*Using RC5*
1.3	*49.765*	*38.060*
2	*57.316*	*41.298*
5	*67.359*	*46.395*
10	*73.290*	*49.836*
20	*78.581*	*53.177*
25	*80.192*	*54.246*
30	*81.483*	*55.119*
50	*84.993*	*57.573*
100	***89.556***	***60.935***



- Difference in Q100 of 28.6 Cumecs (equivalent to 50% over-prediction using RC3)

Most critical data required for Design Flood Estimation

- Lots of High Flow spot gaugings – The Holy Grail!
- Long period of record (if the station will not be in place for a long period of time then why bother?)
- Means of identifying problems in high flows that have been extrapolated beyond HGF
- Early identification of stations that will only ever be just water level sites will save resources for Hydrometric Section and Hydrology (no time wasted on spending years of taking measurements)
- Good record keeping on high flow measurements that will explain any unusually high or low gaugings. (e.g. tree blocking bridge, storage of water on flood plains, by passing of the gauge during a flood)
- Very good collaboration between Hydrometric section and Hydrology section