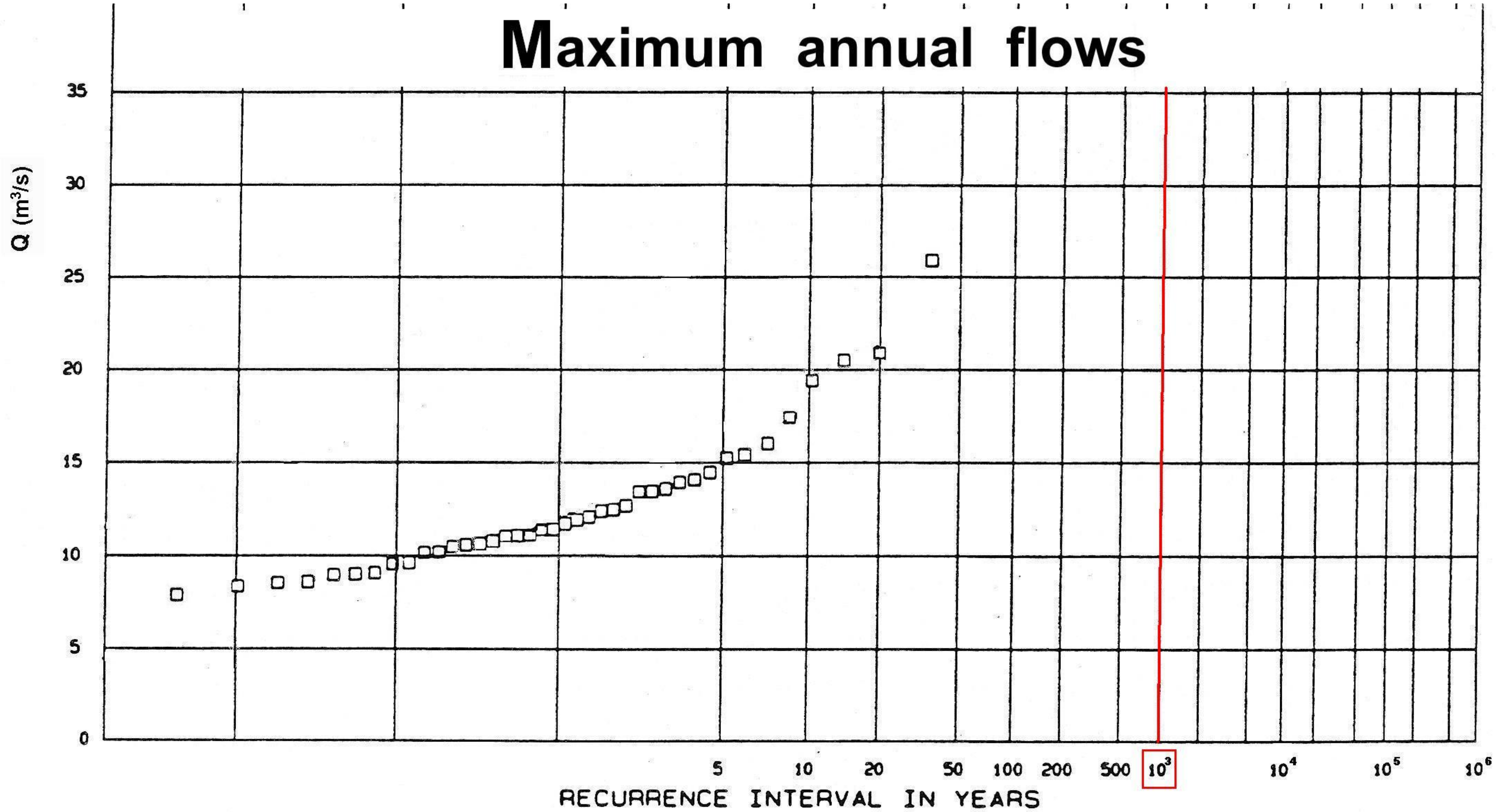
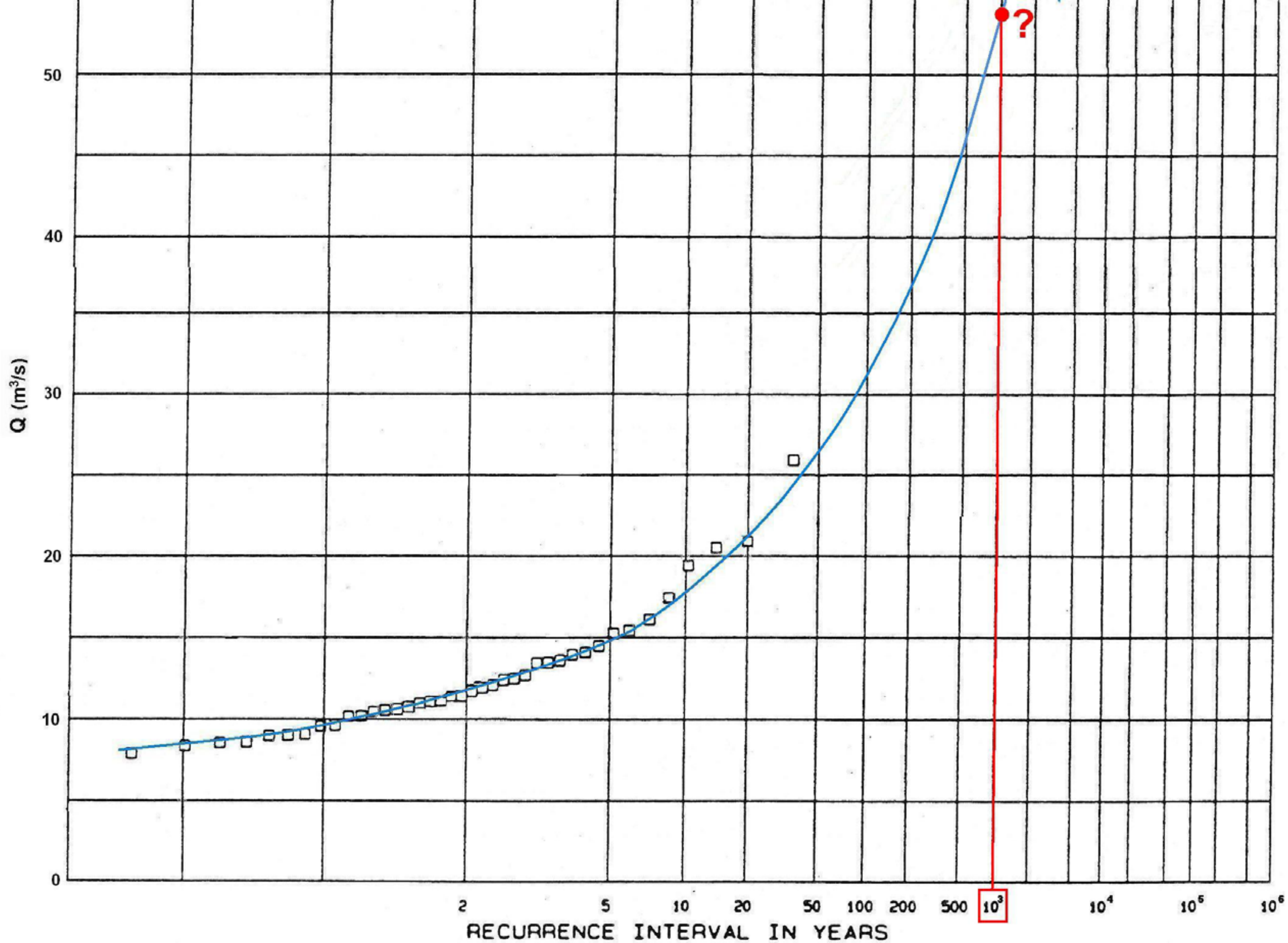
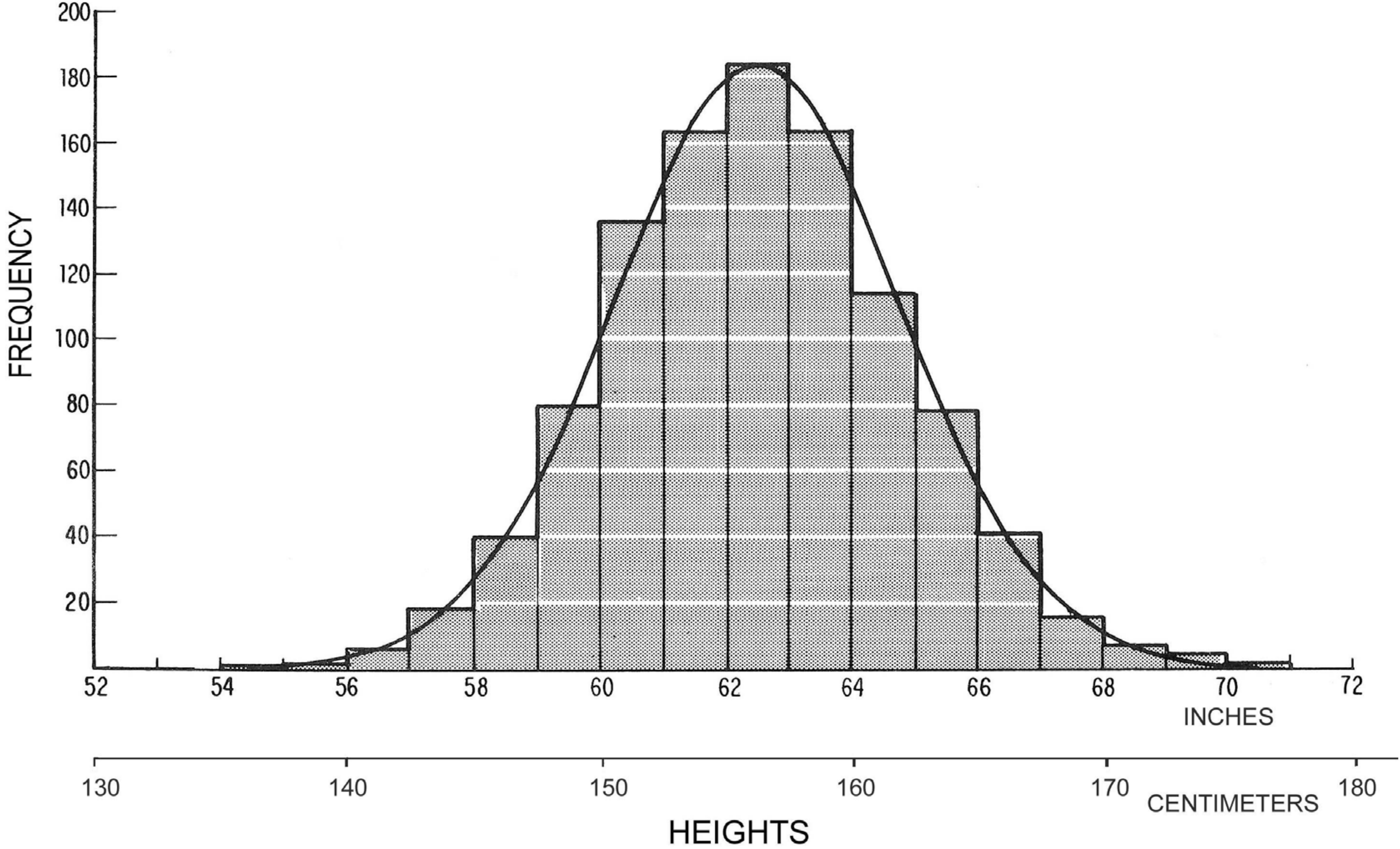

Maximum annual flows
Q (m3/s)
35
30
25
20
15
10
5
0
5
10
20
50
100
200
500
10^3
10^4
10^5
10^6
RECURRENCE INTERVAL IN YEARS

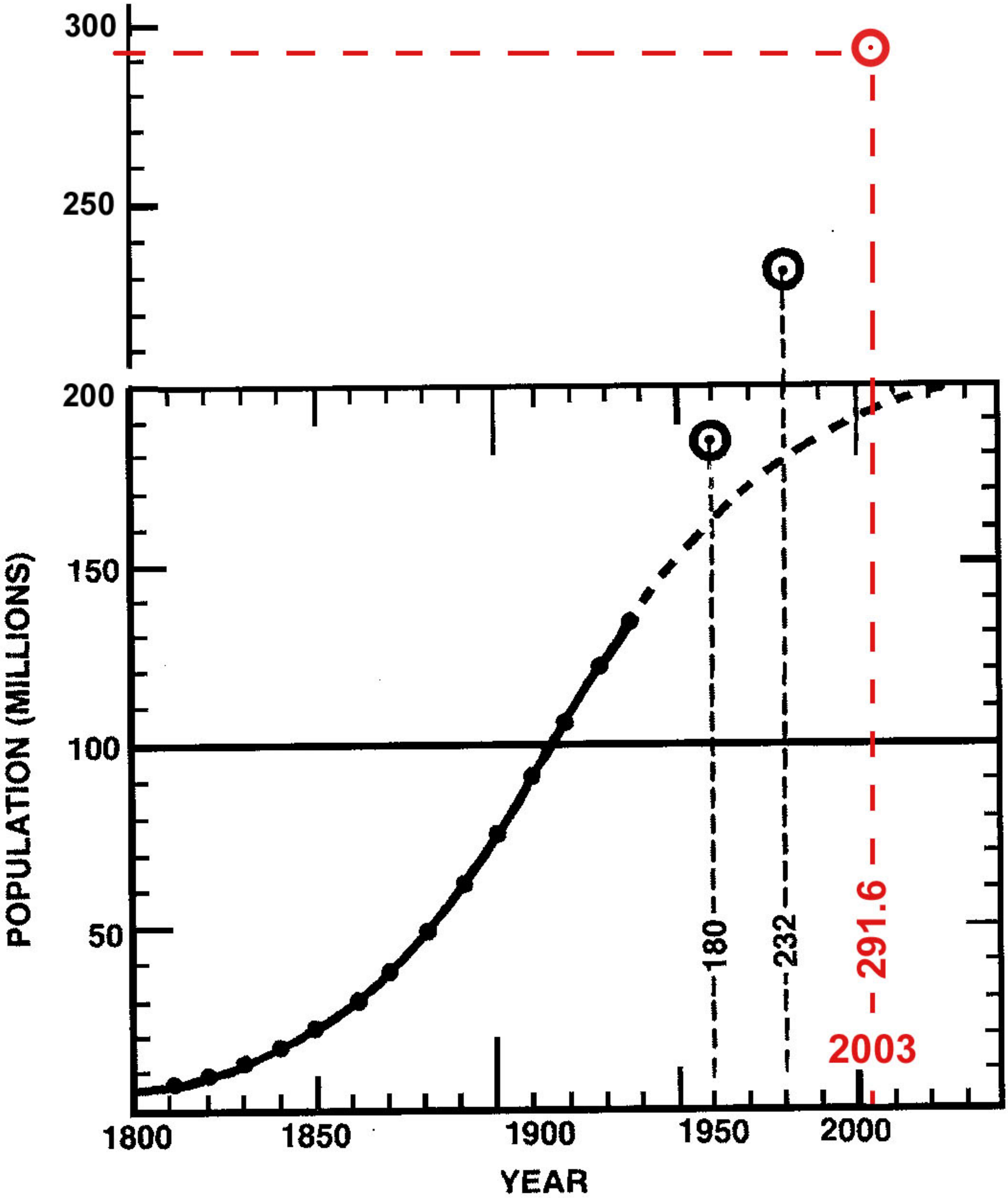

Q (m³/s)
50
40
30
20
10
0
?
2
5
10
20
50
100
200
500
10³
10⁴
10⁵
10⁶
RECURRENCE INTERVAL IN YEARS

Normal distribution fitted to the heights of 1052 mothers.

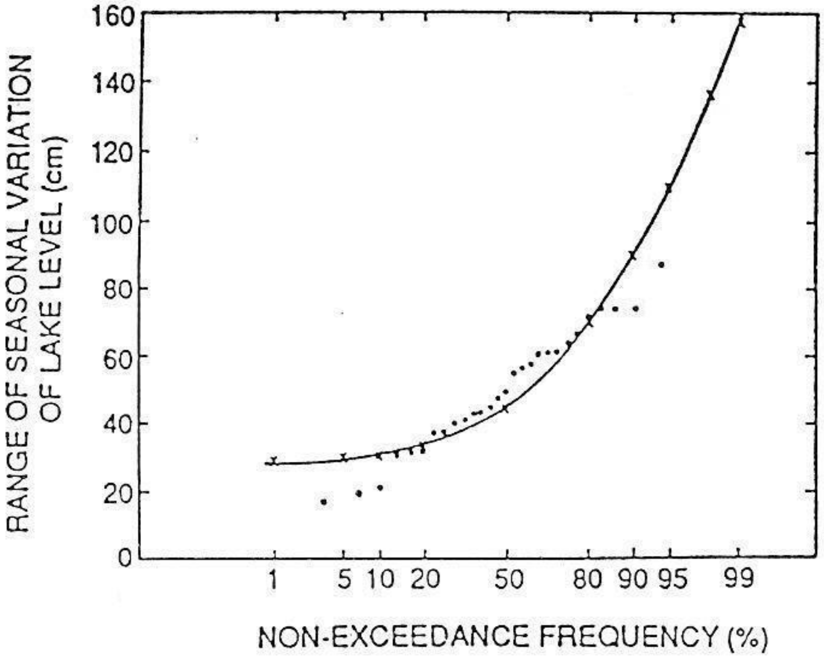
(After Snedecor and Cochran, *Statistical Methods*, 1980)



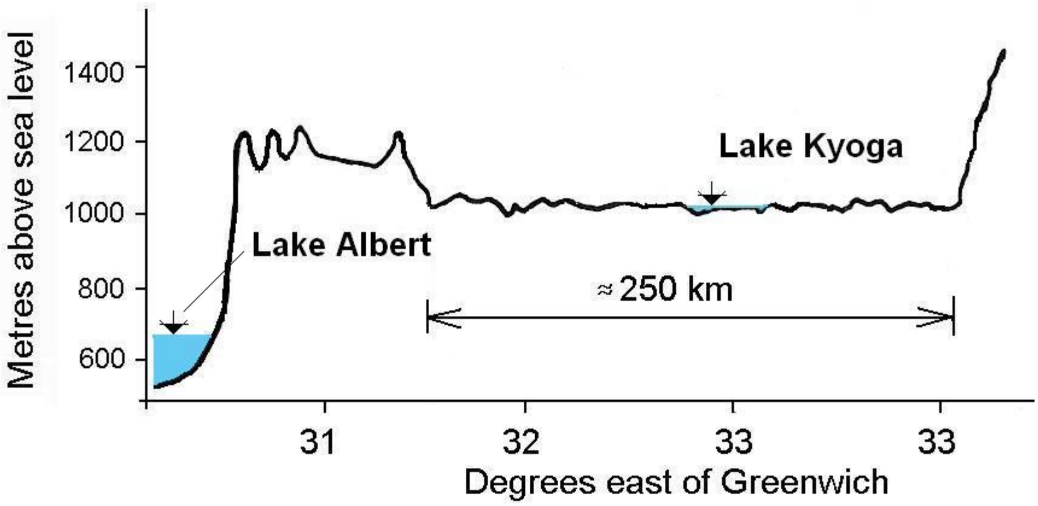
". . . It is more recently, only after the census of 1910, that the curve seemed to be finding its turning point, or point of inflection; and only now, since 1940, ***we can say with full confidence*** ***that it has done so . . ."***



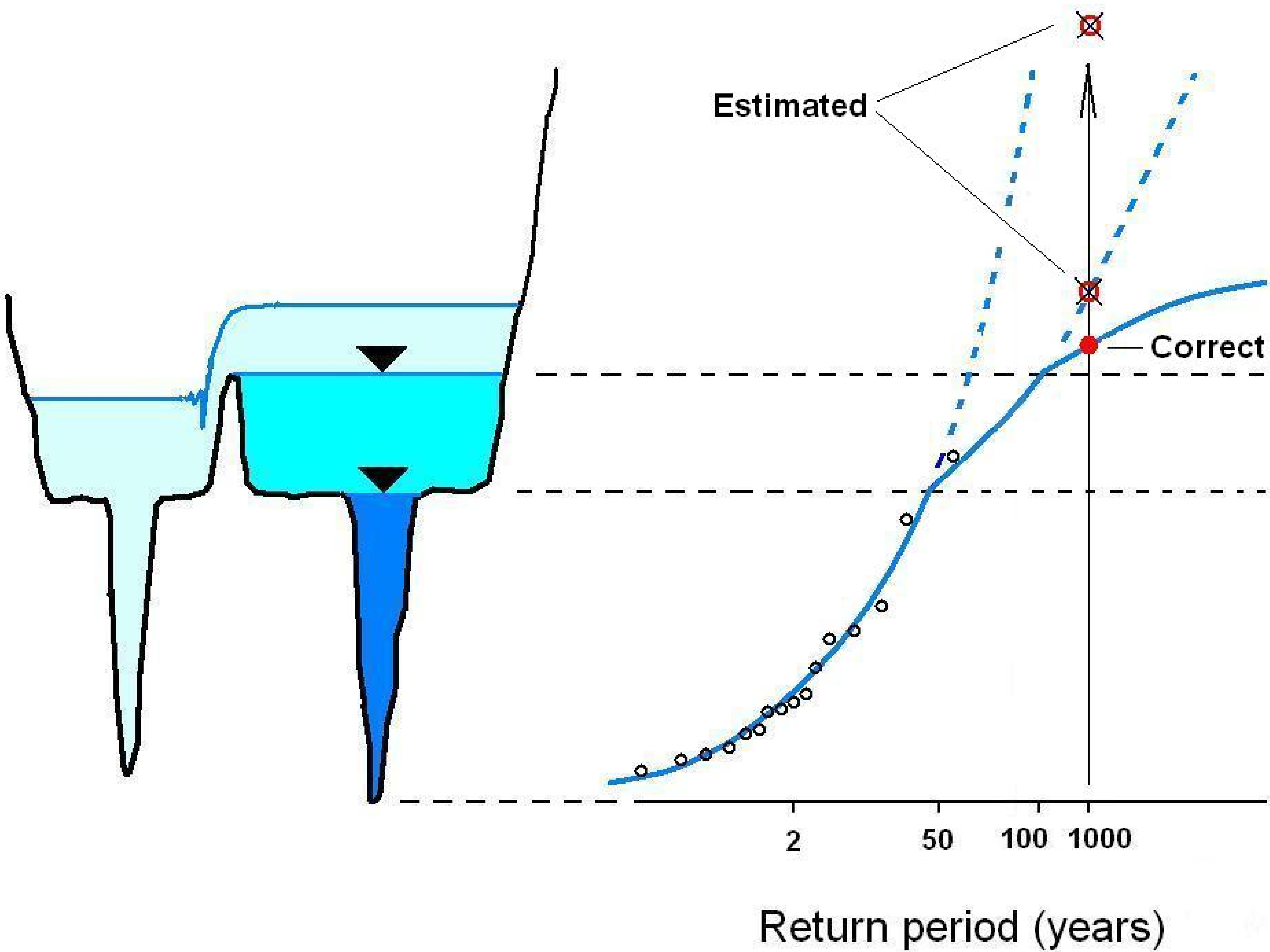
Conjectural population of the United States [Thompson, 1942]; double circles show the actual population in 1960 and 1980. and in 2003



Empirical distribution of annual water level fluctuations in a large and shallow equatorial lake, with the "best fit" of a "theoretical probability distribution"



Petawawa River
Trout Lake
Shah L
Dan L
Grassy Bay
Misty L
Pocket L
Southworth L
Otterslide Lake
McLAUGHLIN
Timberwolf L
McIntosh Ck
Swallow L
Little Otterslide L
Wenona L
McIntosh Lake
Hunter L
Magpie L
Sunbeam L
Straight Shore Lake
Ink L
Willow L
Burnt Island Lake
HUNTER
Alder L
Brûlé L
Tom Thomson L
Littledoe Lake
Pathfinder L
Iris L
Potter Lake
Brown Lake
Furrow Lake
Linda L
Little Joe L
Tepee L
Boys and Girls Camp
Loft L
Potter Creek
Owl L
East End L
Raven Lake
Polly L
Rainbow Lake
Joe Island
Joe L
Canisbay L
Canoe Lake
Bruce L
Otterpaw L
Tern L
East River
Boys Camp
Public Docks
Marsh Hare L
Source L
Algonquin Park
Nature Museum
West Harry Lake
Guide L
PECK
Canoe Lake
Girls Camp
Lupus Lake
Ouse L
Tanamakoon Lake
Girls Camp
Cache Lake
Smoke Lake
Public Docks
Outfitting Store
Restaurant
Drummer L
Mossy L
Panther L
Bonita Lake
Public Docks
Little Island Lake
Hilliard L
Oak L
Namakootchie
Lookout
1400
1500
1600
1700
1379
1382
1469



Estimated
Correct
2
50
100
1000
Return period (years)

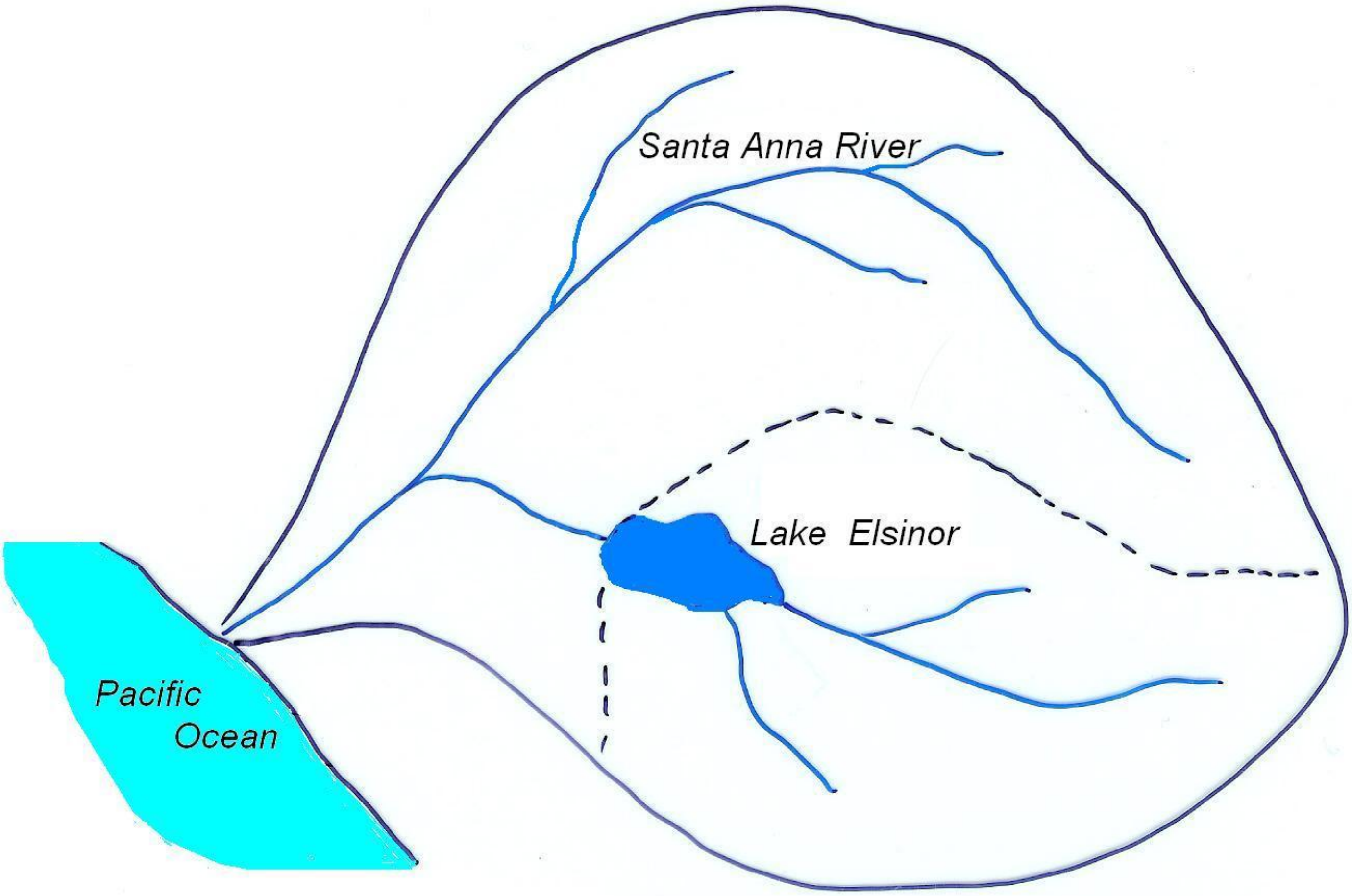
COMMON SENSE AND OTHER HERESIES

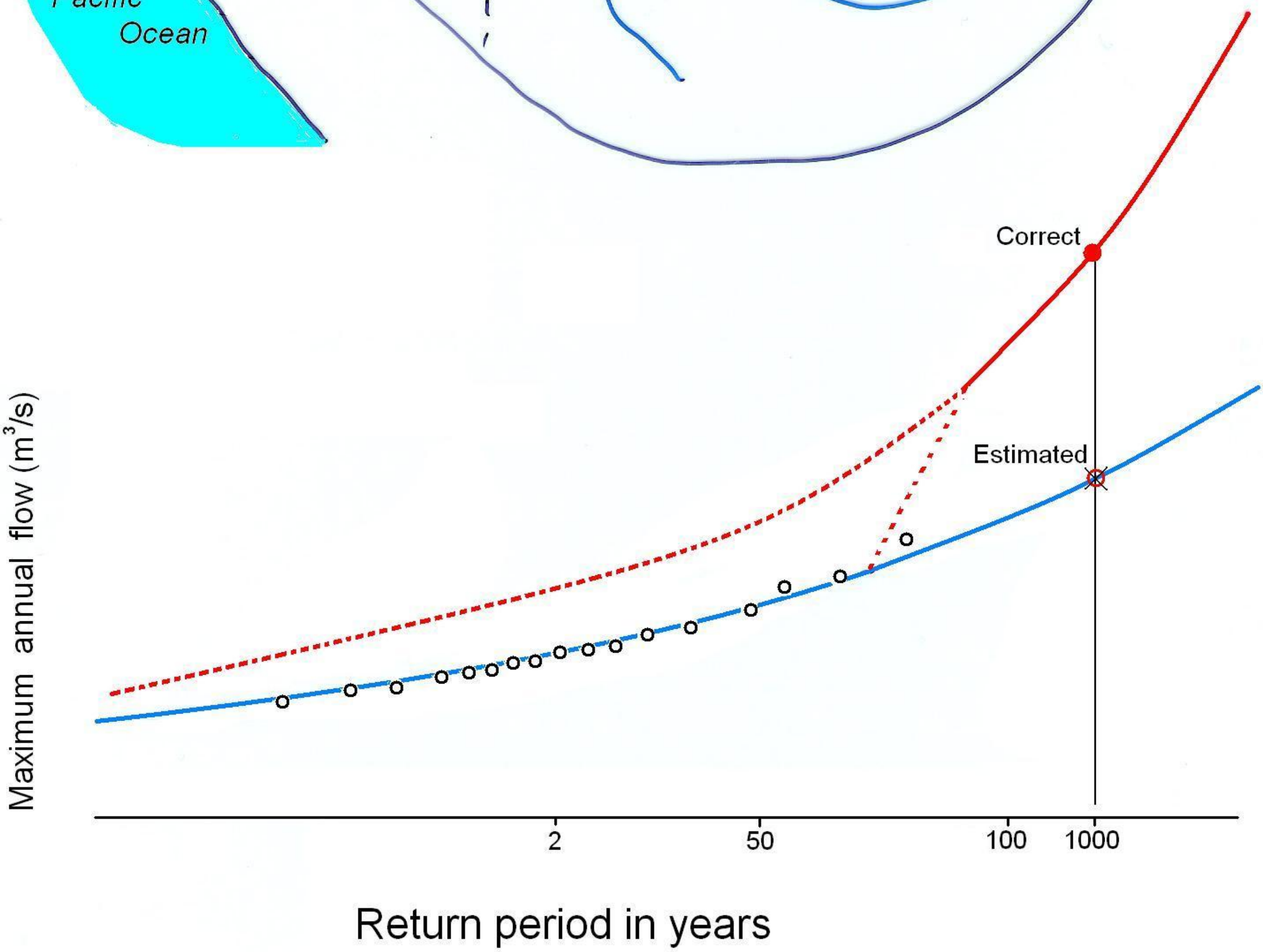
Selected Papers on Hydrology and Water Resources Engineering

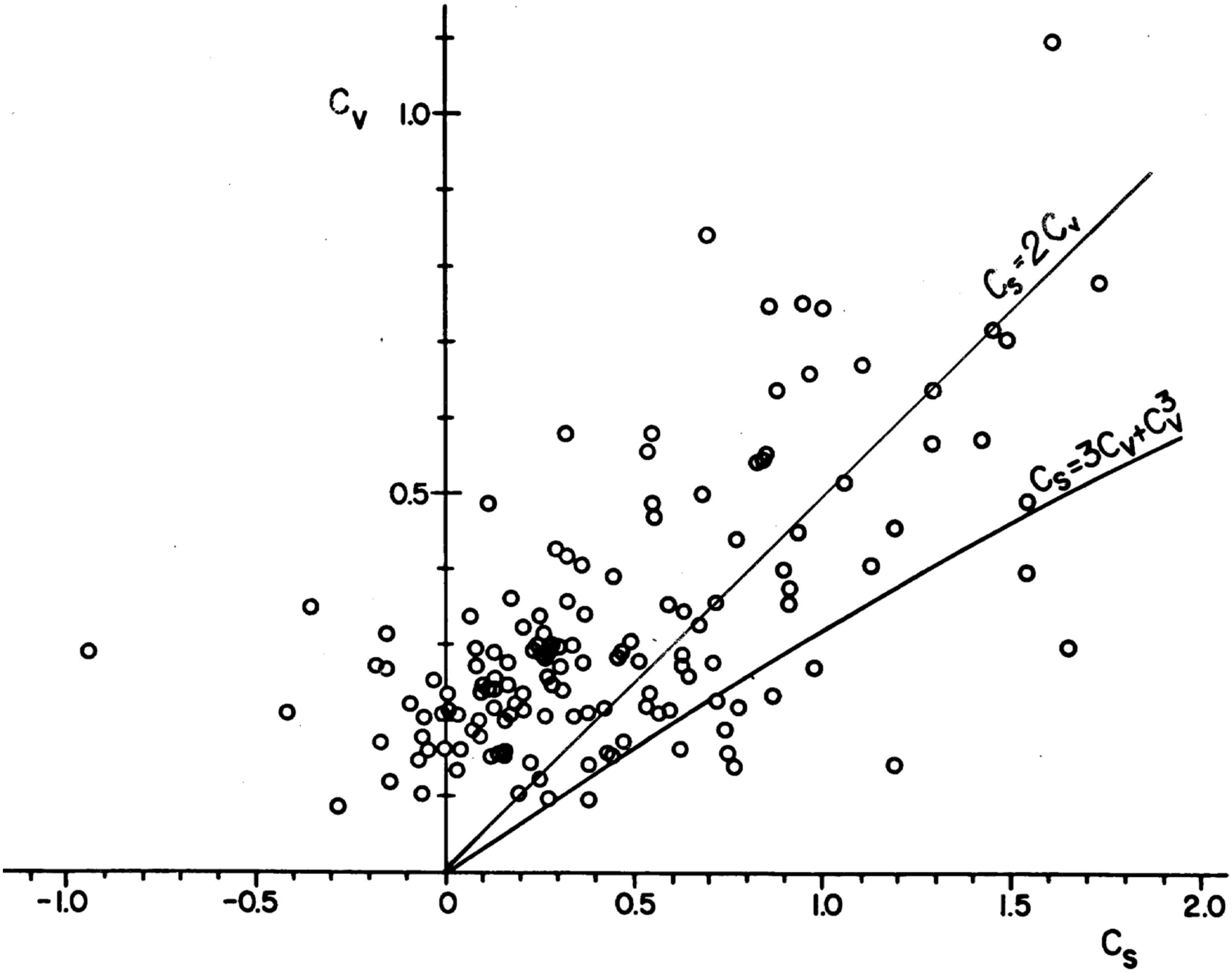
by Vít Klemeš

Edited by C. David Sellars

Santa Anna River Basin







C_v
1.0
0.5
-1.0
-0.5
0
0.5
1.0
1.5
2.0
C_s
$C_s = 2C_v$
$C_s = 3C_v + C_v^3$

TABLE 4. First serial correlation coefficients for the eight most negatively skewed series of annual runoff from the 140 samples compiled by Yevjevich (1963)

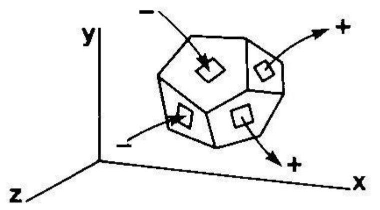
River	Station	Country	Number of years	Coeff. of skewness	First serial correl. coeff.
St. Lawrence	Ogdensburg	U.S.A., Canada	97	-0.286	0.705
Missouri	Sioux City	U.S.A. (Iowa)	58	-0.187	0.590
Arkansas	Salida	U.S.A. (Colorado)	47	-0.407	0.377
Beaver	Beaver	U.S.A. (Utah)	43	-0.360	0.483
Quinault	Quinault Lake	U.S.A. (Washington)	46	-0.176	0.189
Spray	Banff	Canada (Alberta)	45	-0.942	0.438
Garonne	Mas d'Argenais	France	42	-0.156	0.738
Birs	Muenchenstein	Switzerland	41	-0.156	0.168

CONSERVATION OF MASS

CONSERVATION OF MOMENTUM

FLUID MECHANICS

$$\oiint_A \rho V\cdot dA + \frac{\partial}{\partial t}\iiint_S \rho\, ds = 0$$



$$\oiint_A V(\rho V\cdot dA) + \frac{\partial}{\partial t}\iiint_S V(\rho\, ds) = \oiint_A dF + \iiint_S dB$$

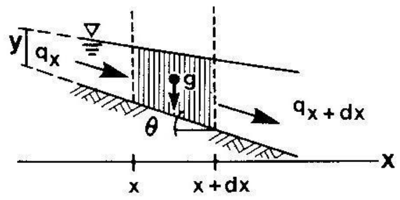
HYDRAULICS

constant $\rho \rightarrow$ conservation of volume

$$\frac{\partial (Vy\ z)}{\partial x}\, dx + \frac{\partial (y\ z)}{\partial t}\, dx = 0$$

$$\frac{\partial (Vy)}{\partial x} + \frac{\partial y}{\partial t} = 0$$

$$V\frac{\partial y}{\partial x} + y\frac{\partial V}{\partial x} + \frac{\partial y}{\partial t} = 0$$



constant mass (ρ and volume) $\rightarrow$ conservation of acceleration

$$g\frac{\partial y}{\partial x} + V\frac{\partial V}{\partial x} + \frac{\partial V}{\partial t} = -\frac{\tau_0}{\rho y} + g\theta \quad \text{DYNAMIC WAVE}$$

$$\left.\begin{array}{r}\dfrac{\tau_0}{\rho y} = g\theta \rightarrow \tau_0 = \rho g y \theta \\ \tau_0 = cV^2\end{array}\right\} \rightarrow \begin{array}{l} V = C\theta^{1/2} y^{1/2} \\ q = Vy = \alpha y^{3/2}\end{array} \quad \text{KINEMATIC WAVE}$$

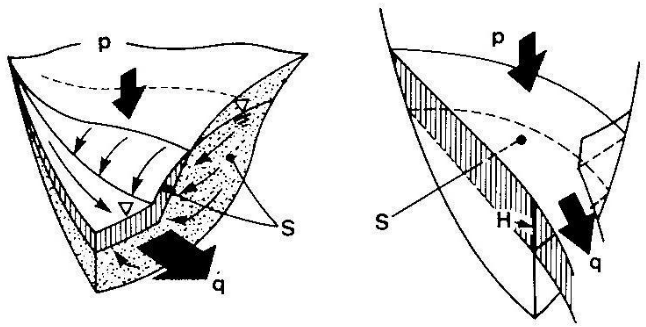
HYDROLOGY

flow rate $q = V y z$

$$\frac{q_x - q_{x+\Delta x}}{\Delta x}\,\Delta x + \frac{S_t - S_{t+\Delta t}}{\Delta t} = 0$$

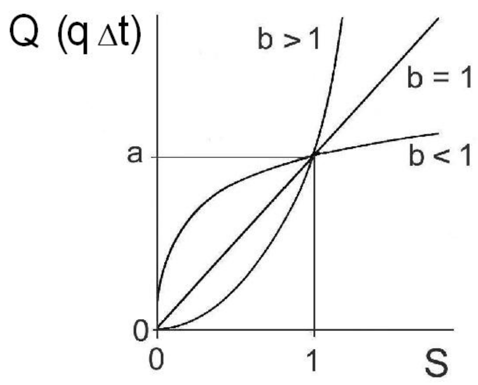
$$(q_x - q_{x+\Delta x})\Delta t = S_{t+\Delta t} - S_t$$

$$p\,\Delta t - q\,\Delta t = S_{t+\Delta t} - S_t$$



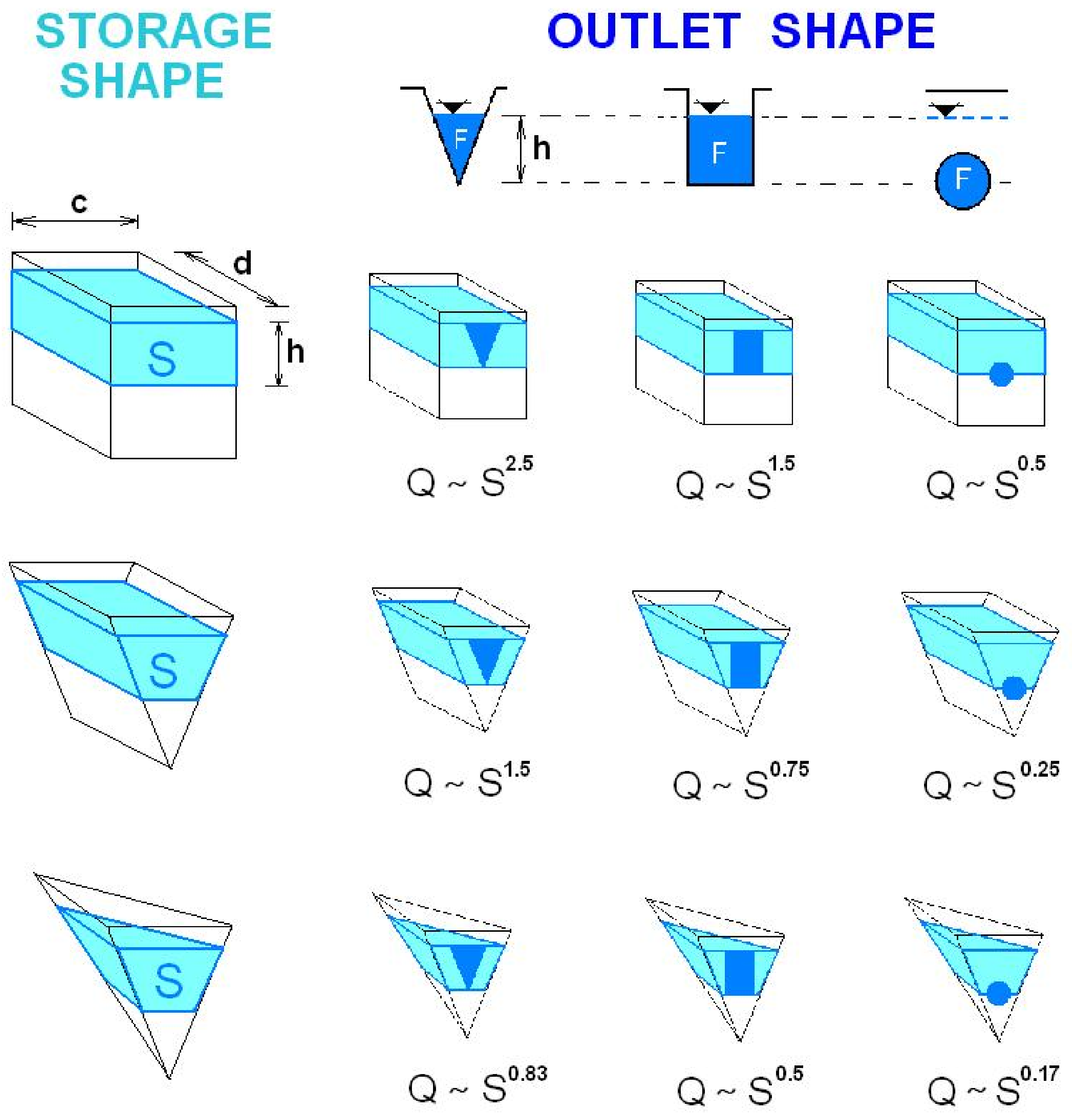
$$\left.\begin{array}{l} q = \alpha H^{\beta} \\ S = \lambda H^{\kappa}\end{array}\right\} q = aS^b$$

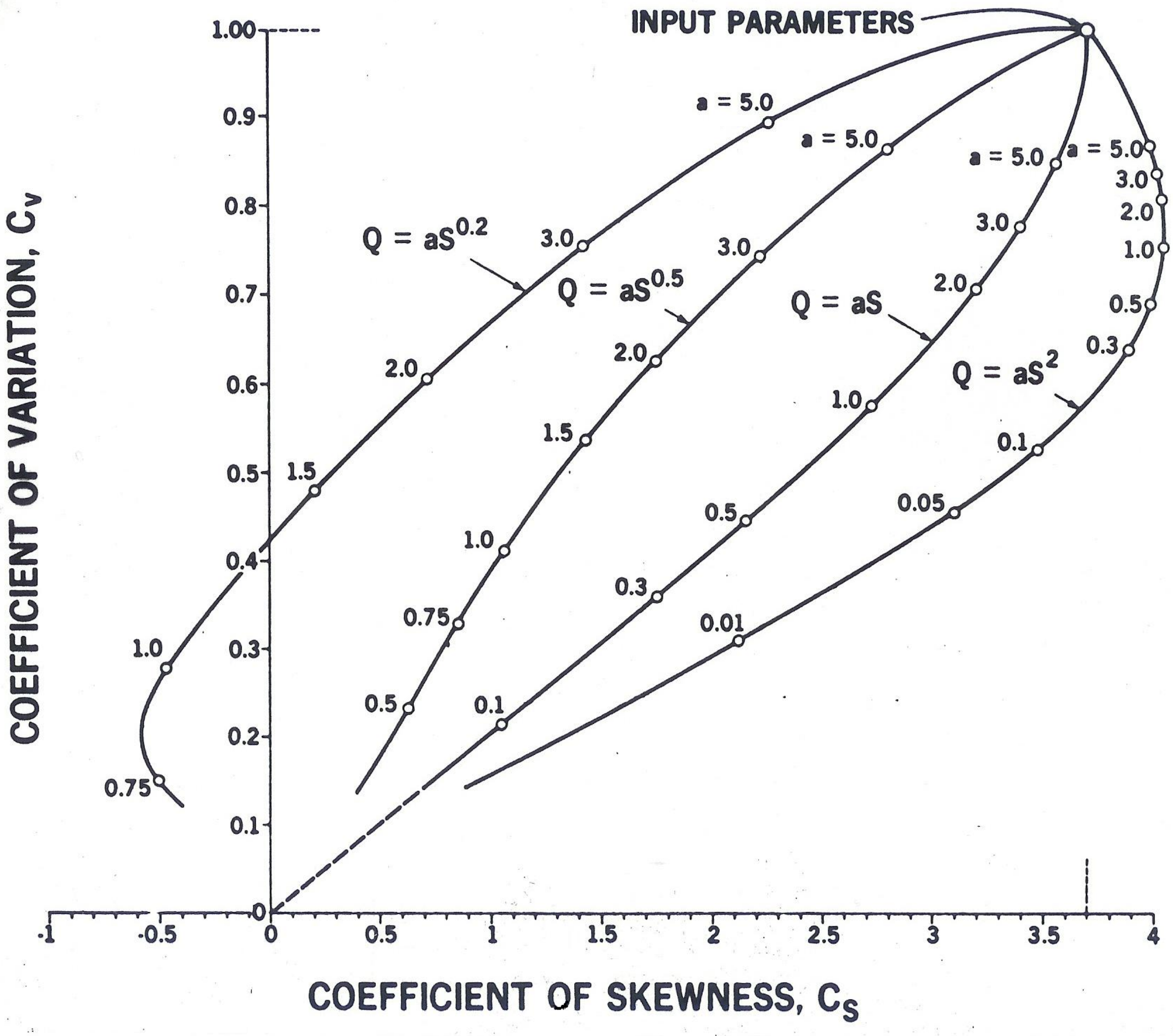
NONLINEAR RESERVOIR



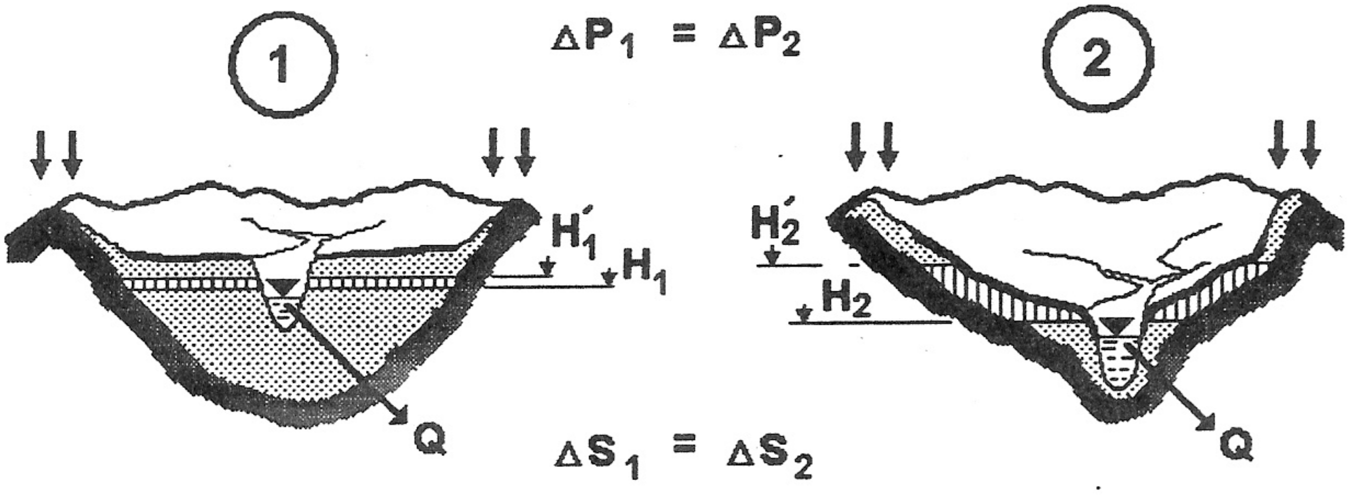
NONLINEAR RESERVOIR

$$Q \sim F\sqrt{2gh} \rightarrow \ \sim Fh^{1/2} \rightarrow \ \sim S^{b}$$

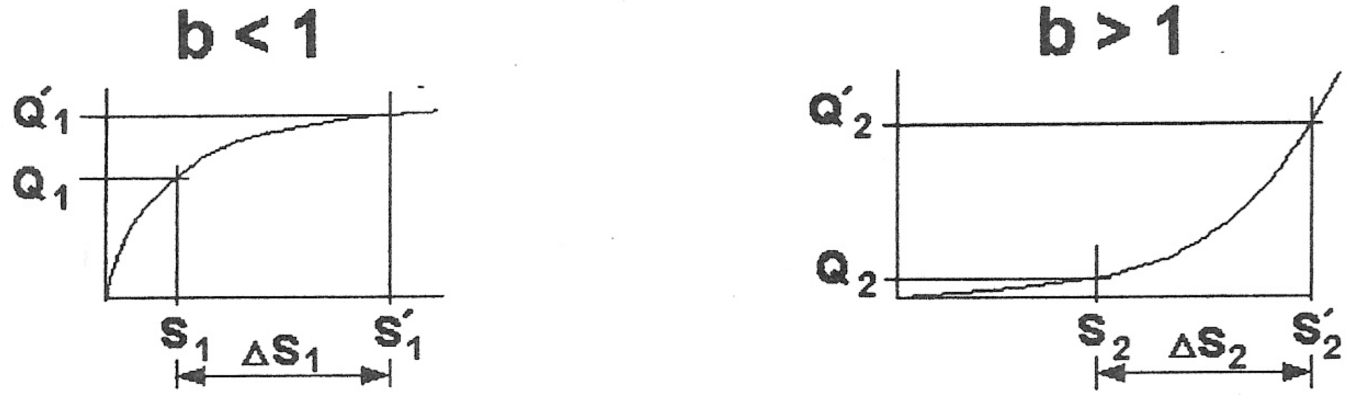


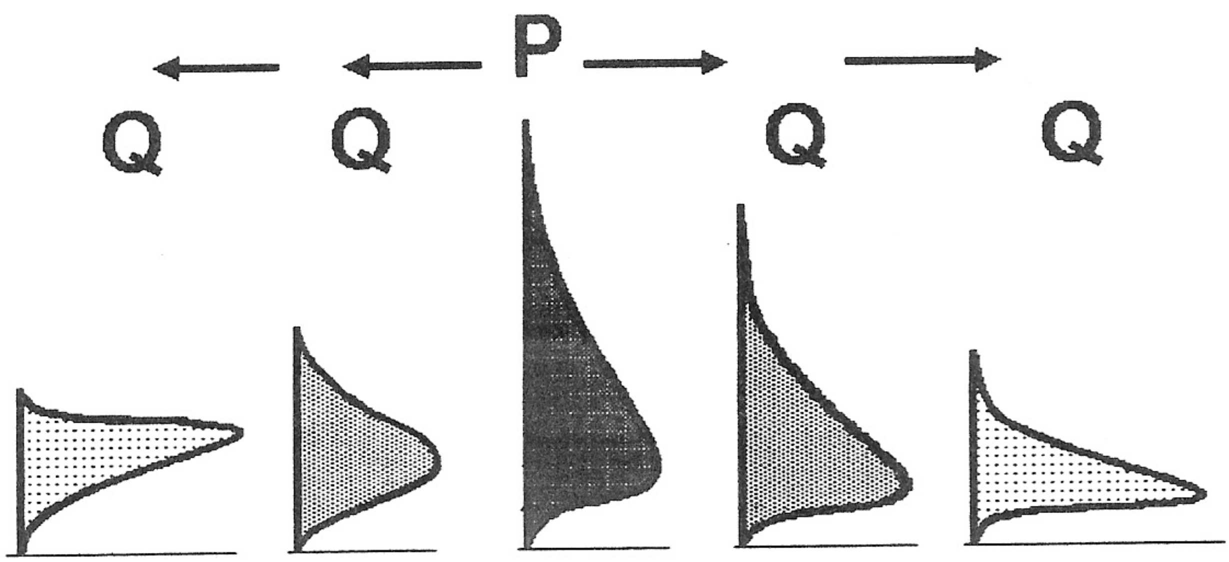


INPUT PARAMETERS
COEFFICIENT OF VARIATION, C_V
COEFFICIENT OF SKEWNESS, C_S
$Q = aS^{0.2}$
$Q = aS^{0.5}$
$Q = aS$
$Q = aS^2$
a = 5.0
a = 5.0
a = 5.0
a = 5.0
3.0
2.0
1.5
1.0
0.75
0.5
0.3
0.1
0.05
0.01
1.00
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-1
-0.5
0
0.5
1
1.5
2
2.5
3
3.5
4



$$Q = a\,S^{b}$$





Effect of nonlinear transformation of input P on distribution shape of output Q

Outflow **Q** from a reservoir with storage **S** and random inflow **P**

(After V. Klemeš, "Watershed as Semiinfinite Storage Reservoir", Proc. ASCE, Vol. 99, IR4, 1973)

Linear reservoir

$$Q = a\,S$$

$$S = 1/a\,Q$$

$$Q_i = \boxed{r}\,Q_{i-1} + \boxed{(1-r)}\,P_i$$

$$r = \frac{1}{a+1}$$

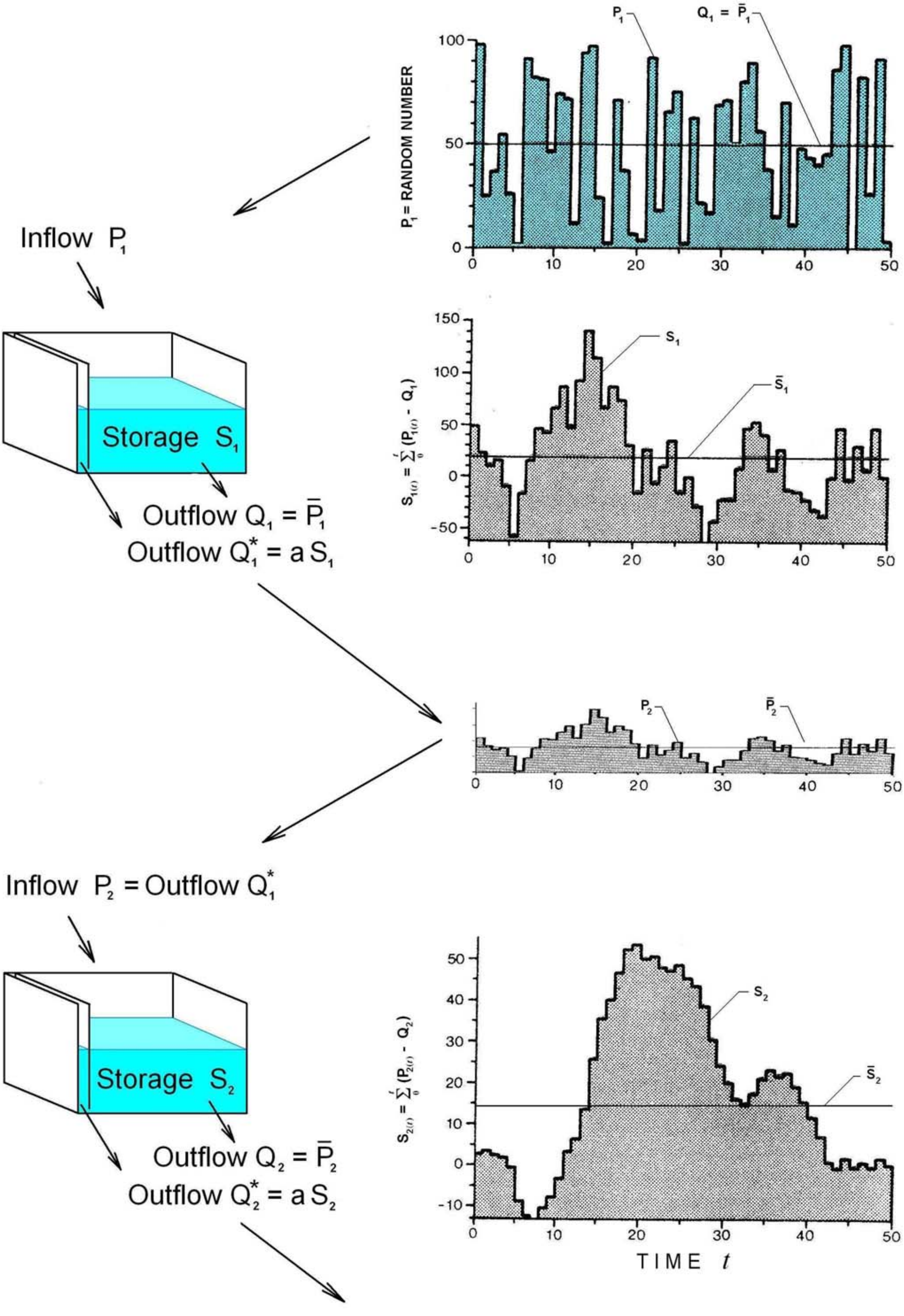
Nonlinear reservoir

$$Q = a\,S^b$$

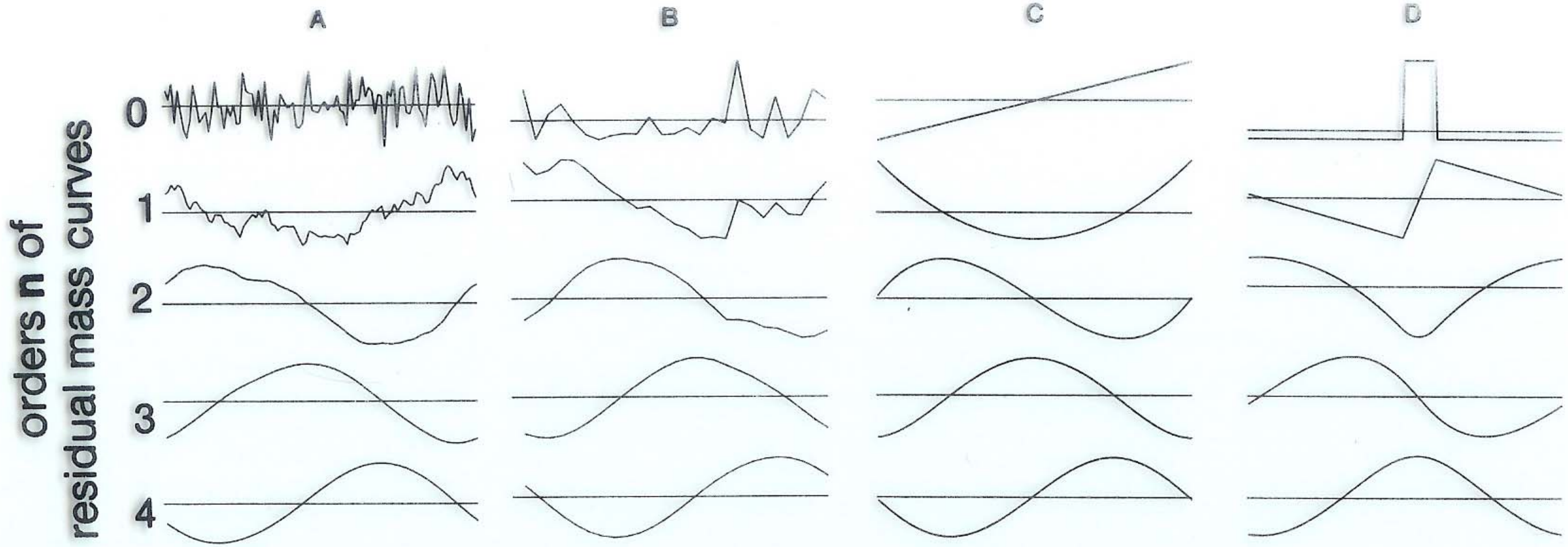
$$S = a^{-1/b}\,Q^{1/b} = \alpha Q^{\beta} = g(Q)$$

$$Q_i = \frac{g'(Q_{i-1})}{g'(Q_{i-1})+\beta}\,Q_{i-1} + \frac{\beta}{g'(Q_{i-1})+\beta}\,P_i$$

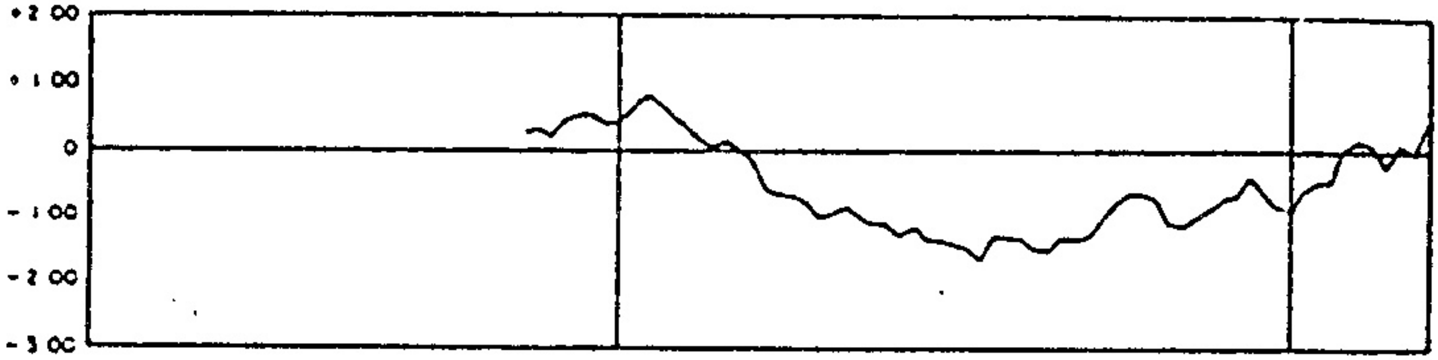
$$Q_i = \boxed{f(Q_{i-1})}\,Q_{i-1} + \boxed{(1-f(Q_{i-1}))}\,P_i$$



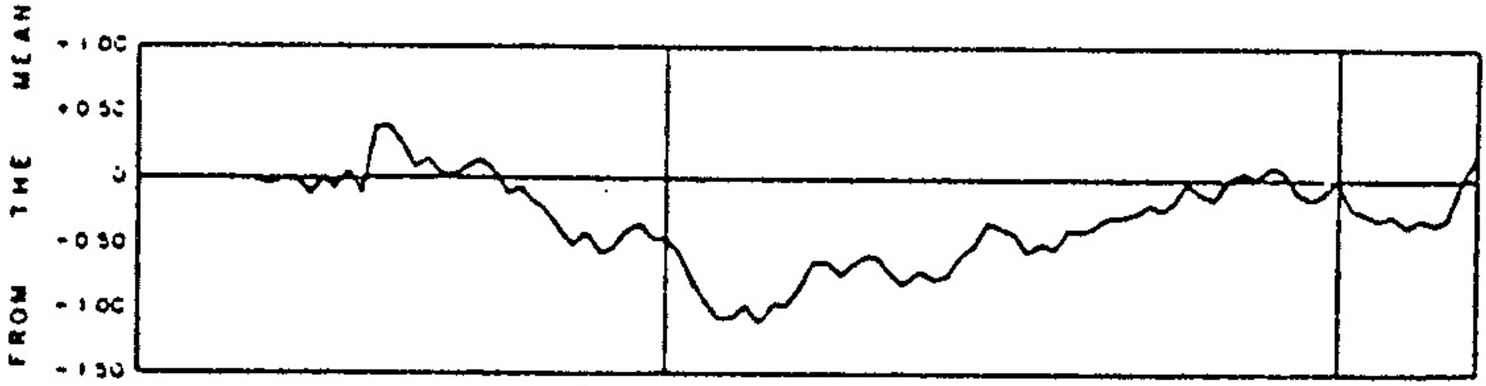
Inflow P_1
Storage S_1
Outflow $Q_1 = \bar{P}_1$
Outflow $Q_1^* = a\,S_1$
Inflow P_2 = Outflow Q_1^*
Storage S_2
Outflow $Q_2 = \bar{P}_2$
Outflow $Q_2^* = a\,S_2$
P_1 = RANDOM NUMBER
P_1
$Q_1 = \bar{P}_1$
$S_{1(t)} = \sum_0^t (P_{1(t)} - Q_1)$
S_1
$\bar{S}_1$
P_2
$\bar{P}_2$
$S_{2(t)} = \sum_0^t (P_{2(t)} - Q_2)$
S_2
$\bar{S}_2$
TIME t



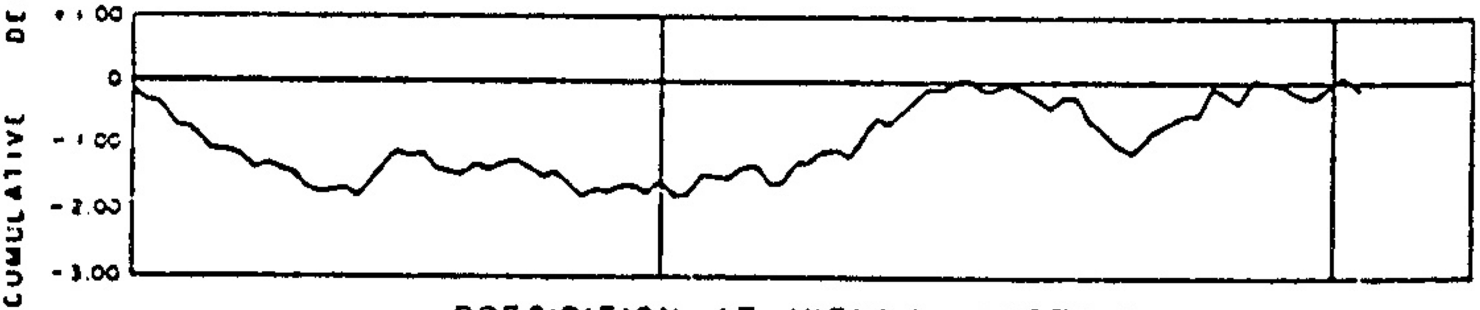
A
B
C
D
0
1
2
3
4
orders n of
residual mass curves



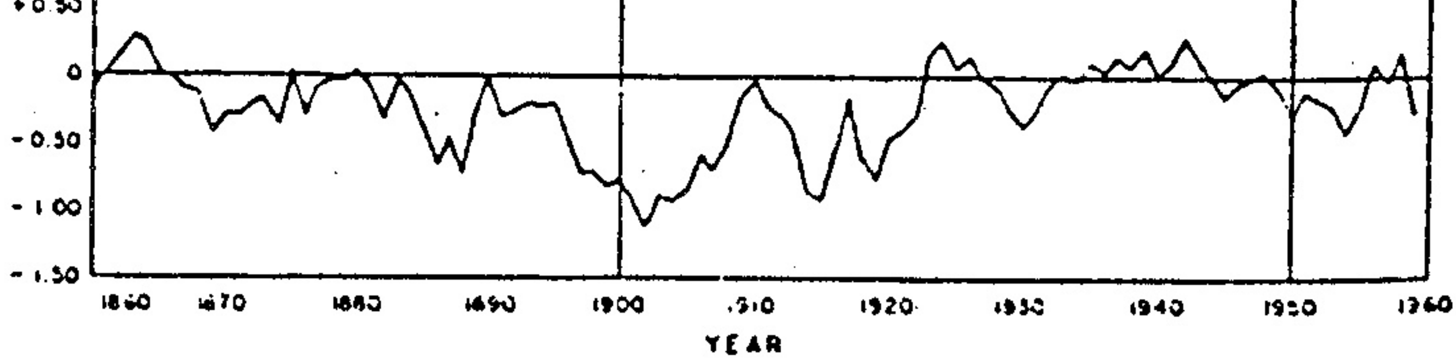
ANDROSCOGGIN RIVER AT RUMFORD, MAINE



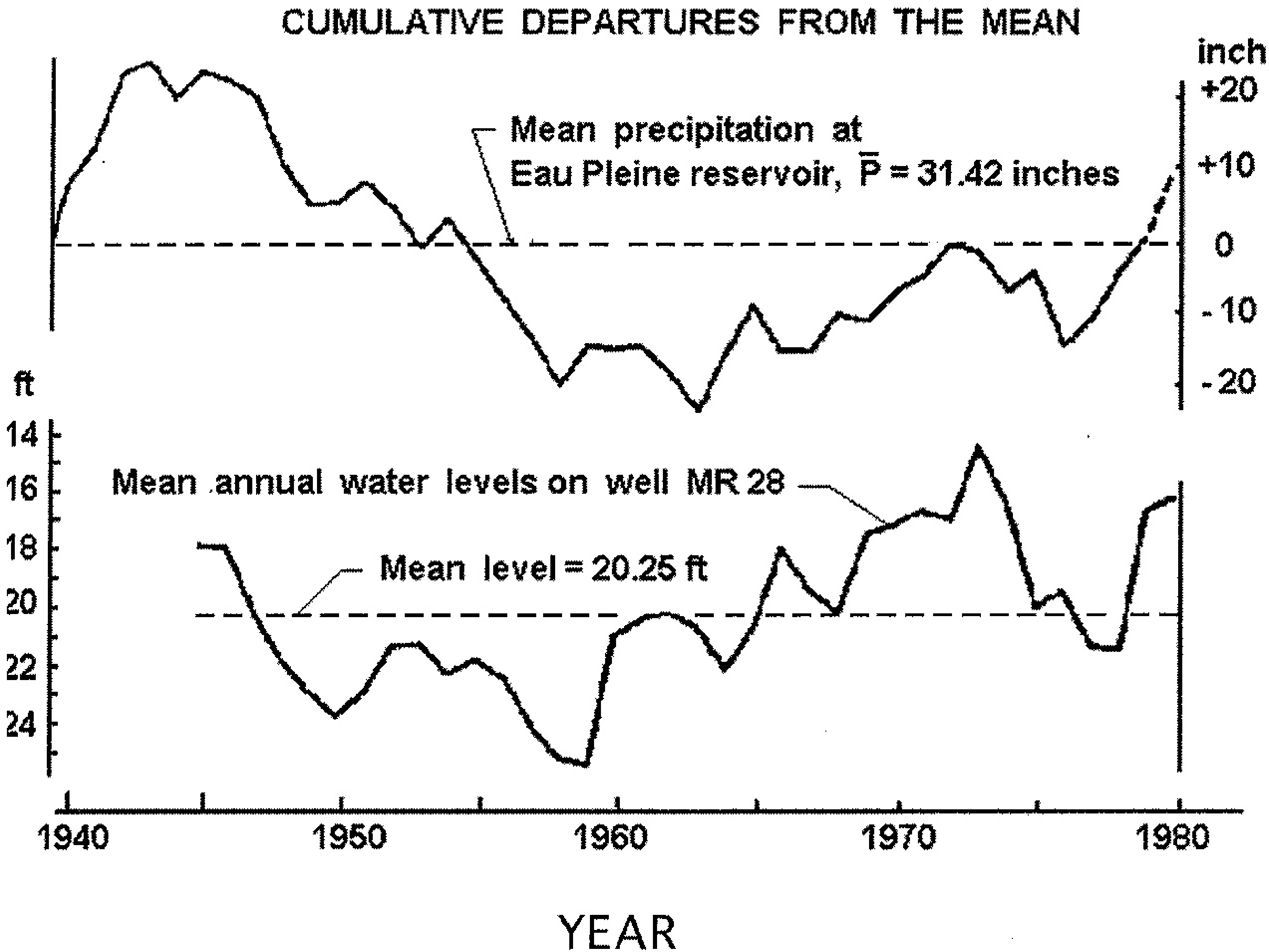
INDUS RIVER AT ATTOCK, WEST PAKISTAN



PRECIPITION AT VIENNA, AUSTRIA



PRECIPITION AT ADELAIDE, SOUTH AUSTRALIA

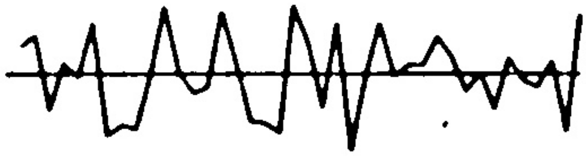


CUMULATIVE DEPARTURES FROM THE MEAN
inch
+20
+10
0
-10
-20
Mean precipitation at
Eau Pleine reservoir, $\bar{P}$ = 31.42 inches
ft
14
16
18
20
22
24
Mean annual water levels on well MR 28
Mean level = 20.25 ft
1940
1950
1960
1970
1980
YEAR

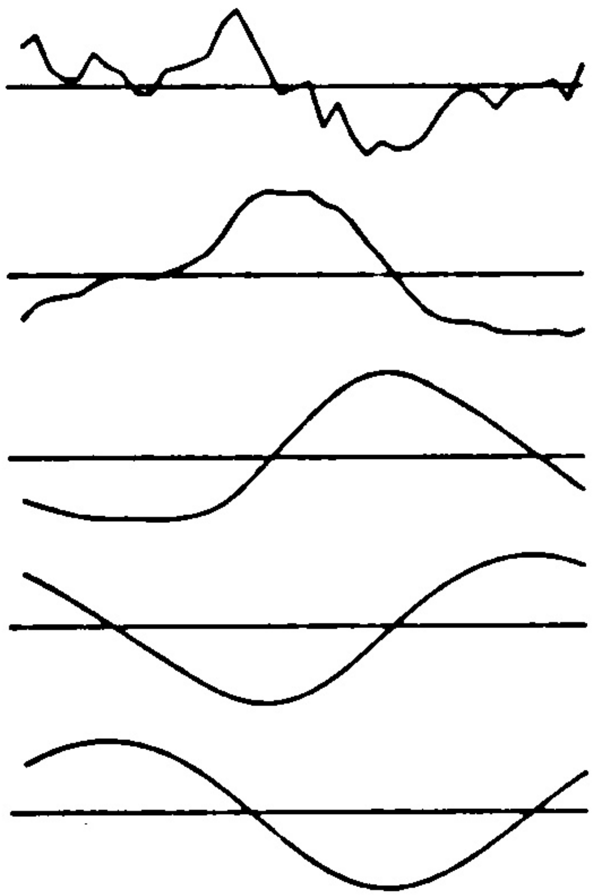
ALETSCH GLACIER

PRECIPITATION

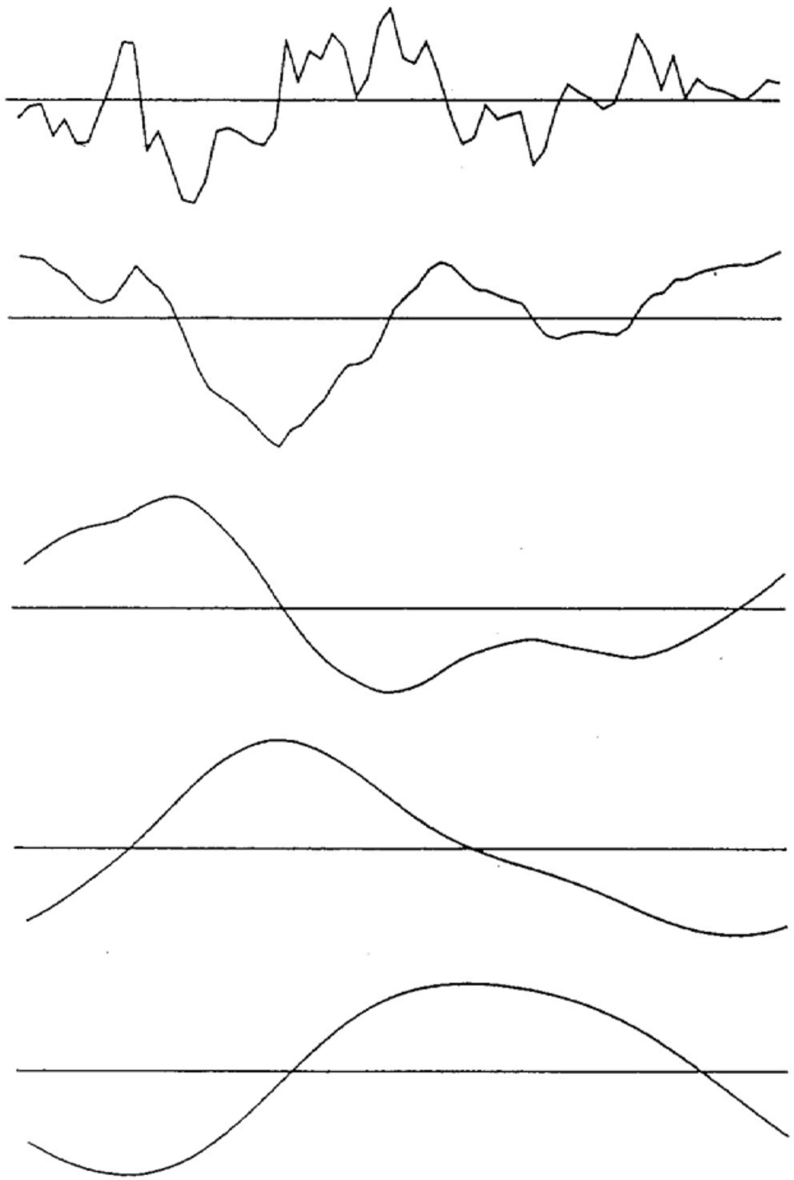
ABLATION



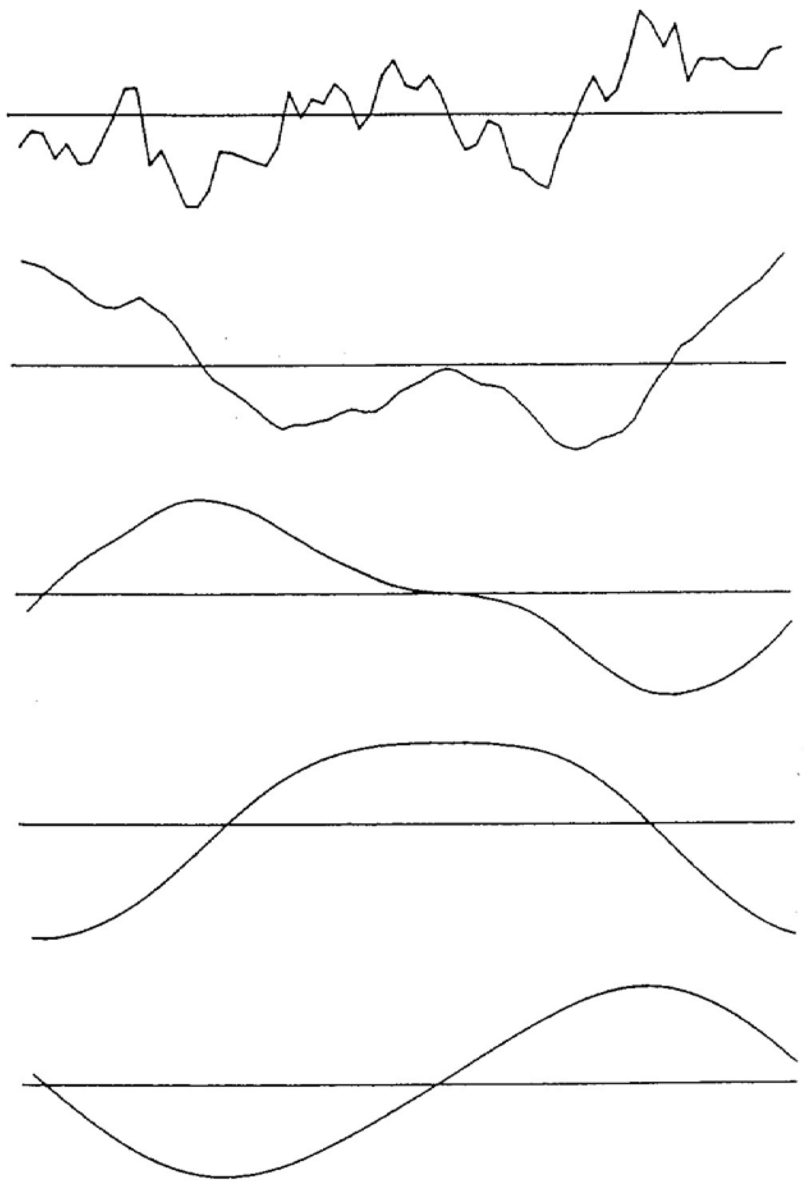
VOLUME

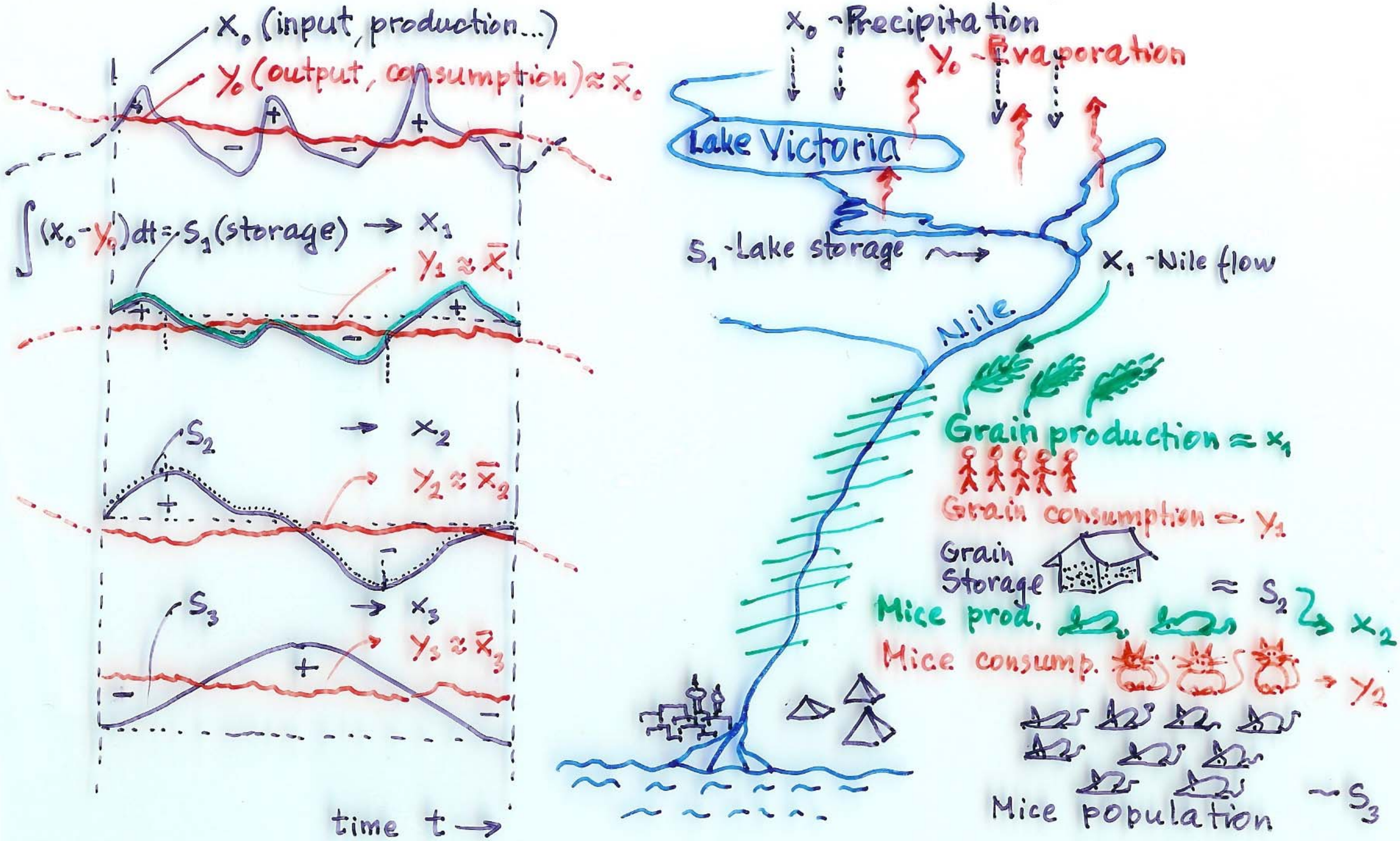


LAKE ONTARIO LEVELS
1920 - 1986



ST. LAWRENCE FLOWS
(Lake Ontario outflows)
1920 - 1986





x0 (input, production...)
Y0 (output, consumption) ≈ x̄0
+
-
∫(x0-Y0)dt = S1 (storage) → x1
Y1 ≈ x̄1
S2
→ x2
Y2 ≈ x̄2
S3
→ x3
Y3 ≈ x̄3
time t →
x0 - Precipitation
Y0 - Evaporation
Lake Victoria
S1 - Lake storage
X1 - Nile flow
Nile
Grain production ≈ x1
Grain consumption ≈ Y1
Grain Storage ≈ S2
Mice prod. ≈ x2
Mice consump. → Y2
Mice population ~ S3