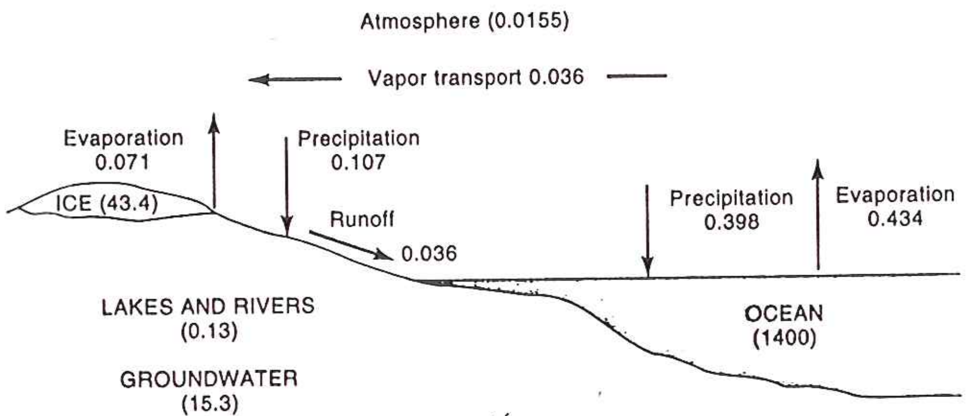
Stream Discharge:

reservoir units: $10^6\ km^3$
flux units: $10^6\ km^3/yr$



river flux
36,000 km^3/yr

Units: flux (discharge) = $\frac{\text{volume}}{\text{time}}$ = area × velocity

$$\boxed{\text{Discharge } Q = \int_{\text{cross section}} v\, dA = \bar{v} A}$$

$\bar{v}$: mean velocity
A: cross-sectional area of flow

laboratory scale model

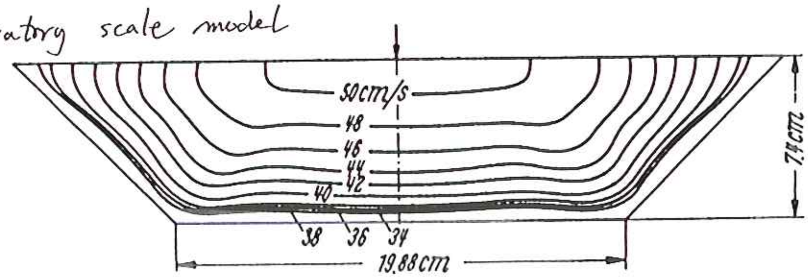


Fig. 50. Velocity distribution in a prismatic channel. (After Schmidt 1957)

width & depth
~30X
Stony Brook

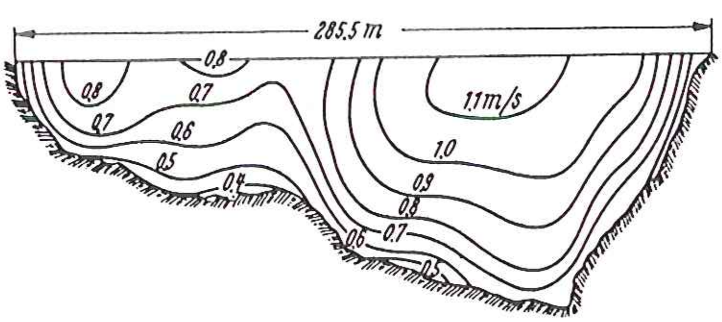


Fig. 51. Velocity distribution in a river. (After Schmidt 1957)

Common to use stream height $h(t)$ as a proxy for discharge $Q(t)$.

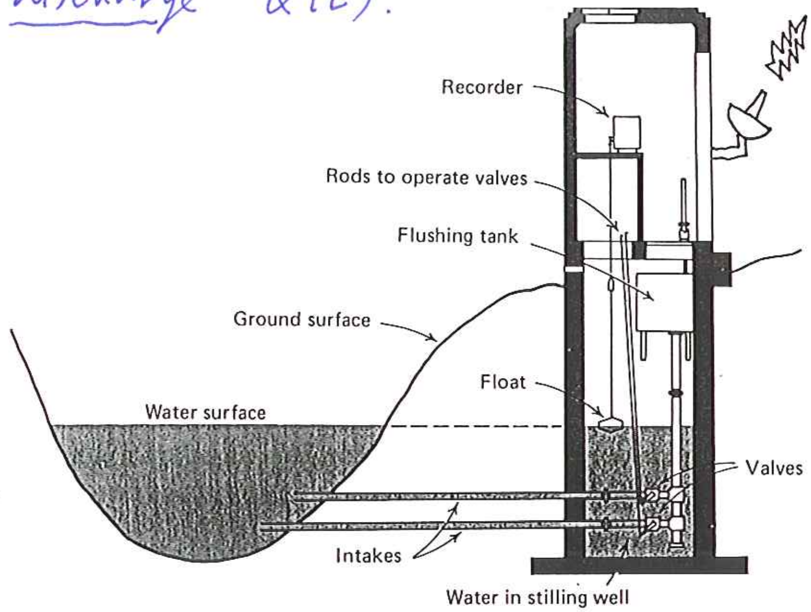
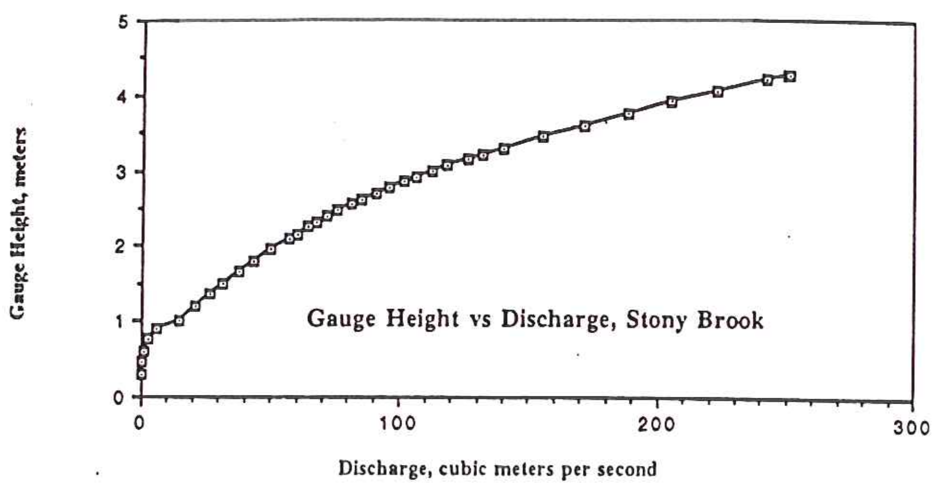
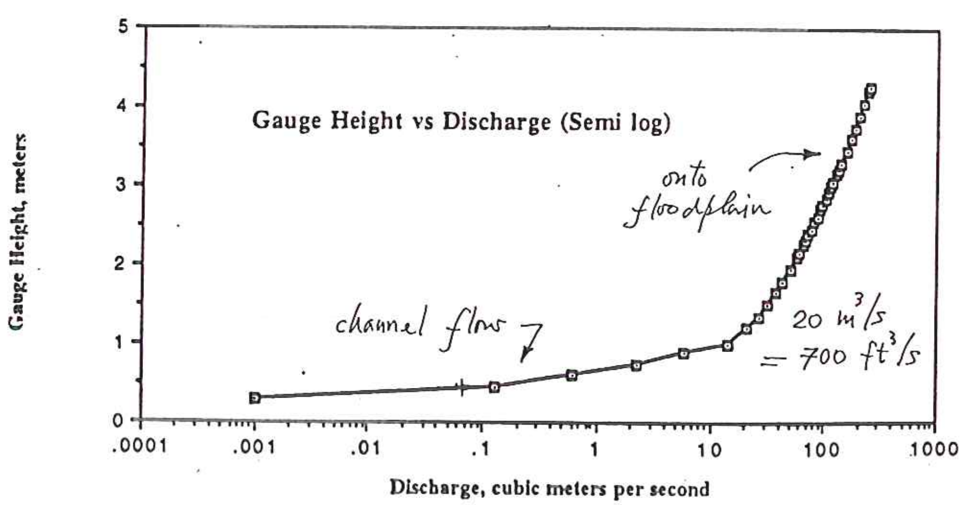


Figure 10
Diagram of a gaging station, showing relation of water in the stilling well to the river. (U.S.G.S.)



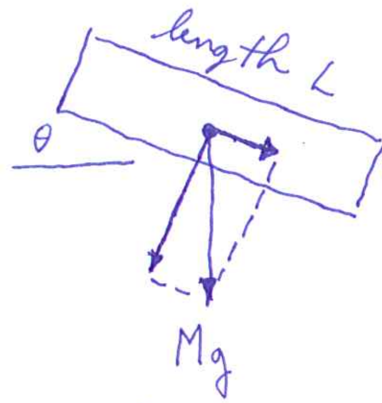


Chézy (1769) — extremely simple mechanical analysis

Consider a plug of water in the channel.

↕ wetted perimeter P

Balance the driving & resisting forces



θ: slope of streambed

ρ: density of H_2O

$M = AL\rho$: mass of plug

The gravitational driving force is

$$F_{grav} = Mg \sin\theta = AL\rho g \sin\theta$$

The traction (force/unit area) due to turbulent drag is assumed to be described by a standard quasi-empirical relation:

$$\text{traction } \tau_{resist} = \frac{1}{2} C_{drag} \rho \bar{v}^2, \quad C_{drag} = \text{drag coefficient}$$

(dimensionless, of order 1)

The net resistive force on the wetted area PL is

$$F_{resist} = \tau_{resist} PL = \frac{1}{2} C_{drag} PL \bar{v}^2$$

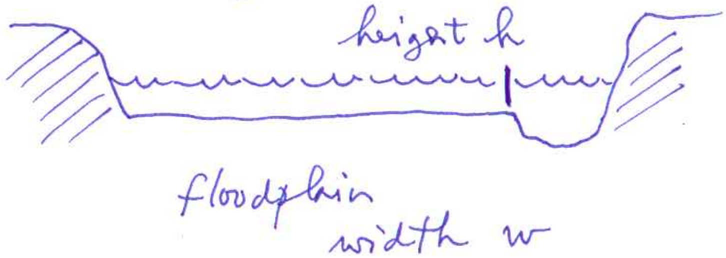
Equating: $F_{drag} = F_{resist}$

$$\bar{v} = \sqrt{\frac{2gA \sin\theta}{C_{drag} P}} = \text{const} \sqrt{\frac{A}{P} \sin\theta}$$

Hydraulic radius $R = \frac{A}{P}$

$$\boxed{\bar{v} = \text{const} \sqrt{R \sin\theta}}$$ — Chézy equation

Example: Stony Brook in flood stage

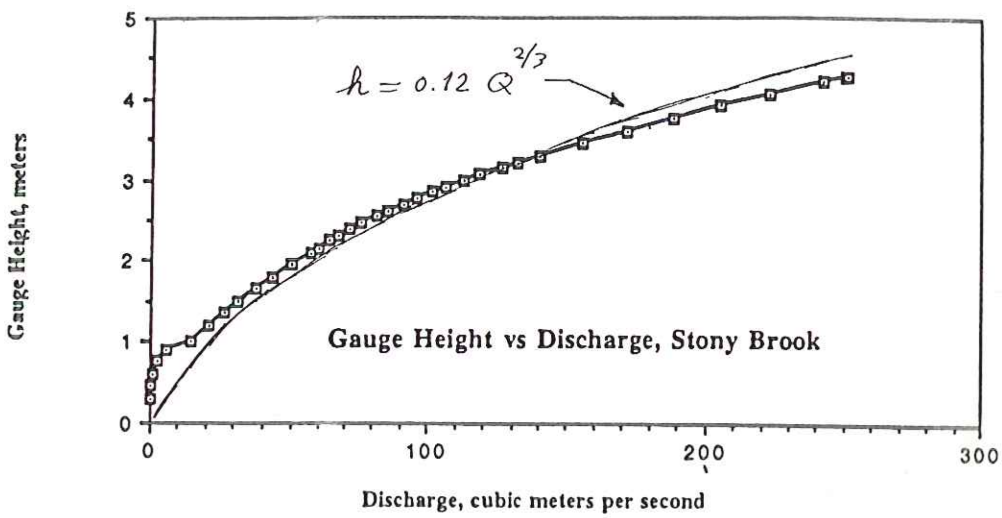


$A = wh$, $P \approx w$ $\Longrightarrow$ $R \approx h$

Flux or discharge $Q = \bar{v} A$

$$= \text{const} \sqrt{h \sin\theta}\, wh$$

i.e., $Q \sim h^{3/2}$, or $\boxed{h = \text{const}\, Q^{2/3}}$



Gauge Height vs Discharge, Stony Brook

Manning empirical formula:

$$\bar{v} = \frac{1.486}{n} R^{1/6} \sqrt{R \sin\theta}$$

mean velocity

Manning roughness coefficient

Chézy term

extra weak dependence on R

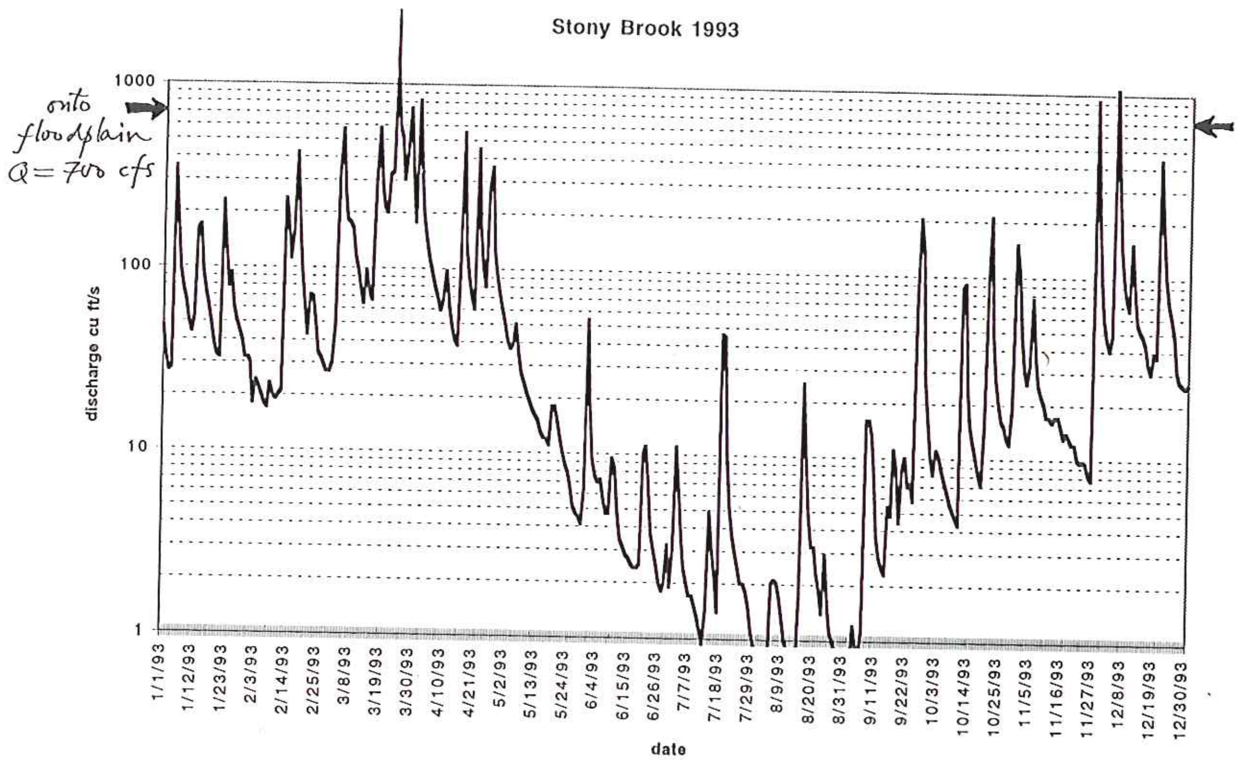
$\bar{v}$ in ft/sec
R in ft
n in $\sqrt[6]{ft}$

TABLE 6.1 Manning roughness coefficients (n) for different boundary types.

Boundary	Manning n ($ft^{1/6}$)
Very smooth surfaces such as glass, plastic, or brass	0.010
Very smooth concrete and planed timber	0.011
Smooth concrete	0.012
Ordinary concrete lining	0.013
Good wood	0.014
Vitrified clay	0.015
Shot concrete, untroweled, and earth channels in best condition	0.017
Straight unlined earth canals in good condition	0.020
Rivers and earth canals in fair condition; some growth	0.025
Winding natural streams and canals in poor condition; considerable moss growth	0.035
Mountain streams with rocky beds and rivers with variable sections and some vegetation along banks	0.041–0.050

Source: *Handbook of Applied Hydrology,* ed. by Ven T. Chow, copyright 1964 McGraw-Hill Publishing Co., Inc.

Bigger $n \Rightarrow$ rougher bottom — slows the flow rate $\bar{v}$ down



River	Average runoff (km^3y^{-1})	Area of basin (10^3km^2)	Length (km)	Continent
Amazon	6930	6915	6280	South America
Congo	1460	3820	4370	Africa
Ganges (with Brahmaputra)	1400	1730	3000	Asia
Yangzijiang	995	1800	5520	Asia
Orinoco	914	1000	2740	South America
Paraná	725	2970	4700	South America
Yenisei	610	2580	3490	Asia
Mississippi	580	3220	5985	North America
Lena	532	2490	4400	Asia
Mekong	510	810	4500	Asia
Irrawaddy	486	410	2300	Asia
St Lawrence	439	1290	3060	North America
Ob	395	2990	3650	Asia
Chutsyan	363	437	2130	Asia
Amur	355	1855	2820	Asia
Mackenzie	350	1800	4240	North America
Niger	320	2090	4160	Africa
Columbia	267	669	1950	North America
Magdalena	260	260	1530	South America
Volga	254	1360	3350	Europe
Indus	220	960	3180	Asia
Danube	214	817	2860	Europe
Salween	211	325	2820	Asia
Yukon	207	852	3000	North America
Nile	202	2870	6670	Africa

Table 1.4 Mean annual runoff of the world's largest rivers. From Shiklomanov (1993) [21].

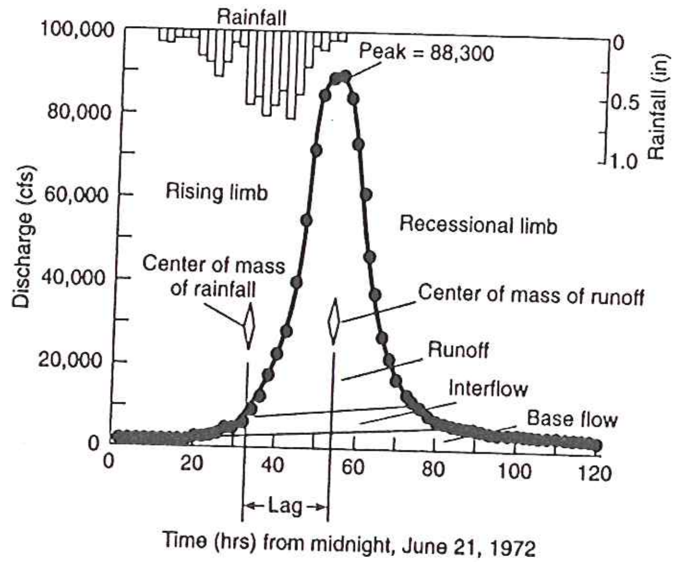


FIGURE 5.8

Flood hydrograph of the Hurricane Agnes flood of June 1972 on the Conestoga River at Lancaster, Pa. Although the curve is rather symmetrical, most hydrographs show significant skewness with a broader recessional limb reflecting interflow and groundwater inputs after a storm.

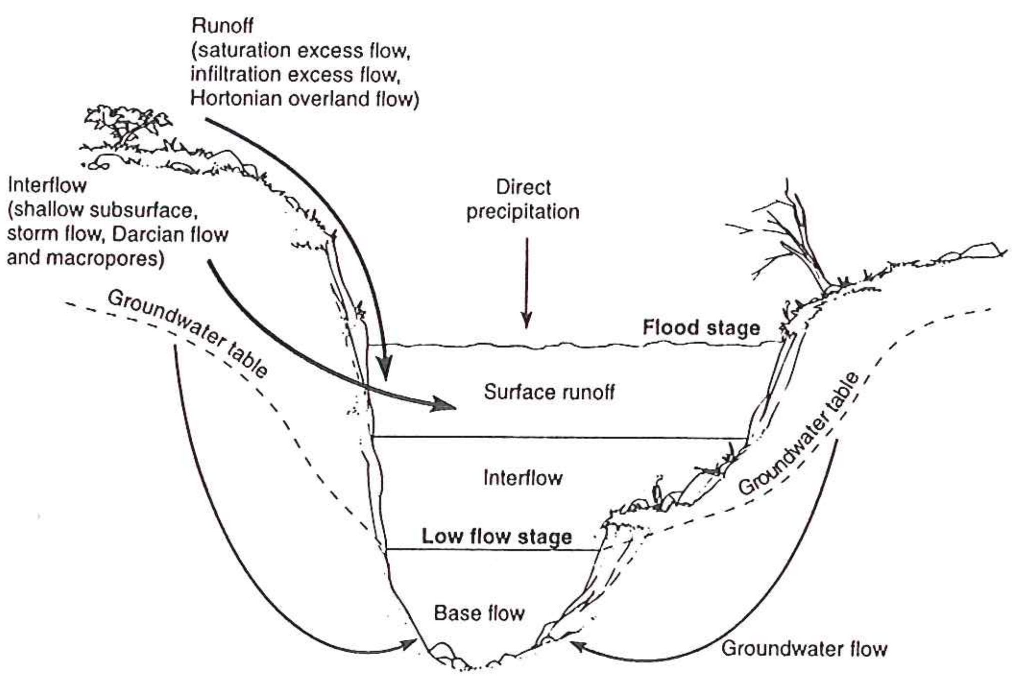
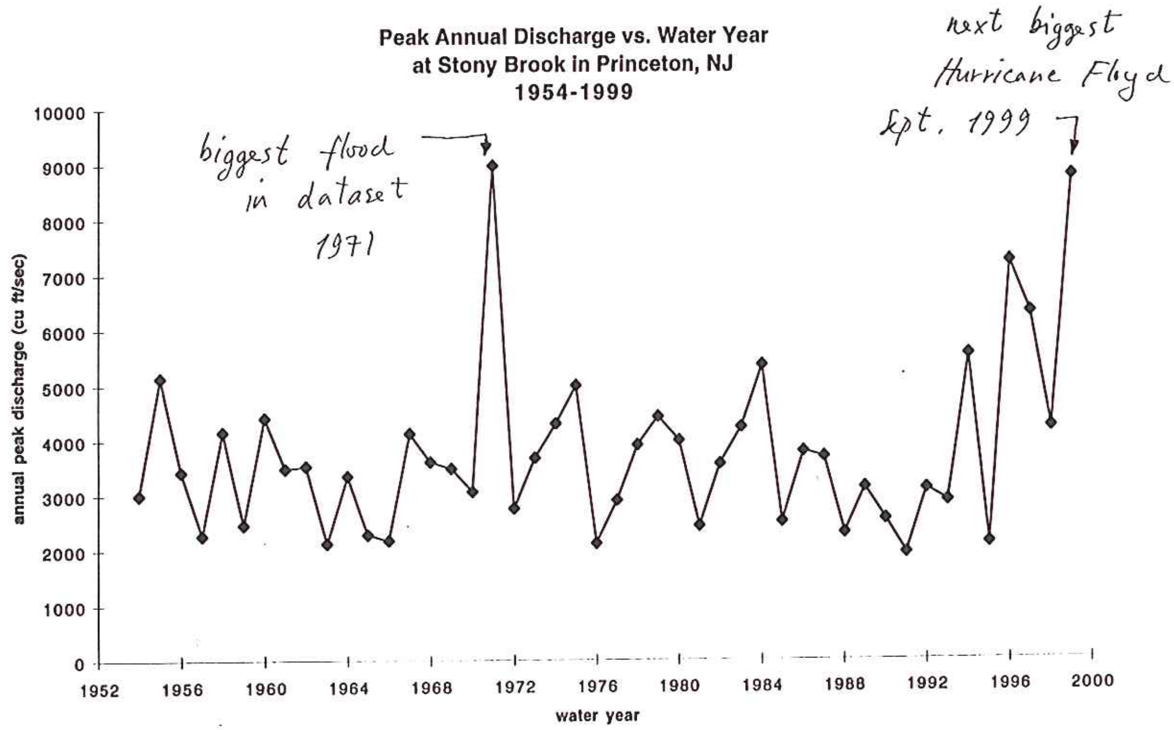


FIGURE 5.7

Schematic of stream channel showing major kinds of water contributions. Arrival of water from any given precipitation event is progressively delayed from runoff to interflow to groundwater flow.

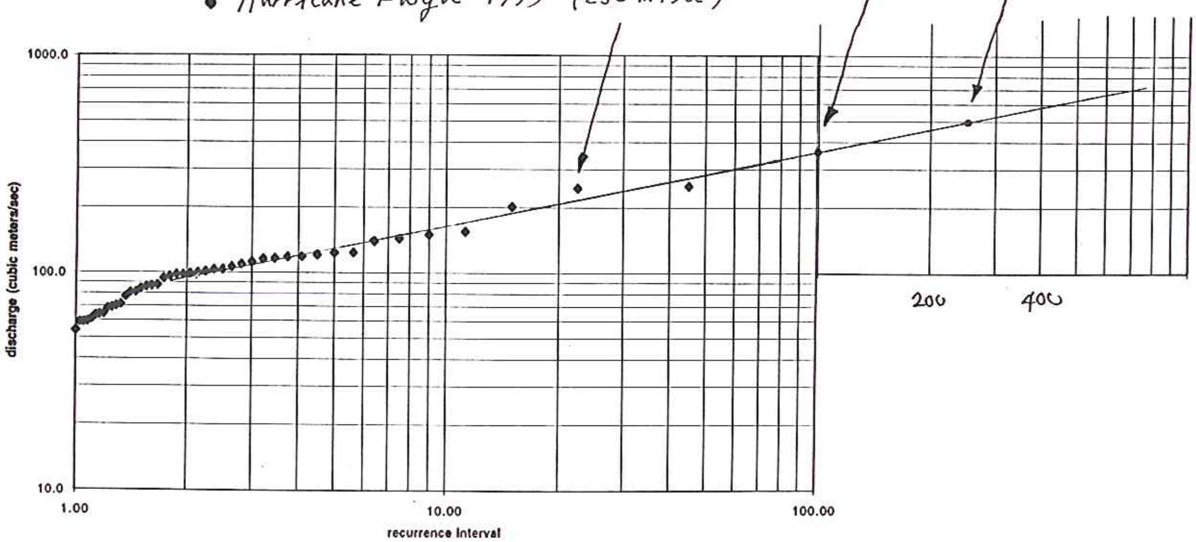
(Based on Kochel 1992)



1954 – 1999 – 46 years of data

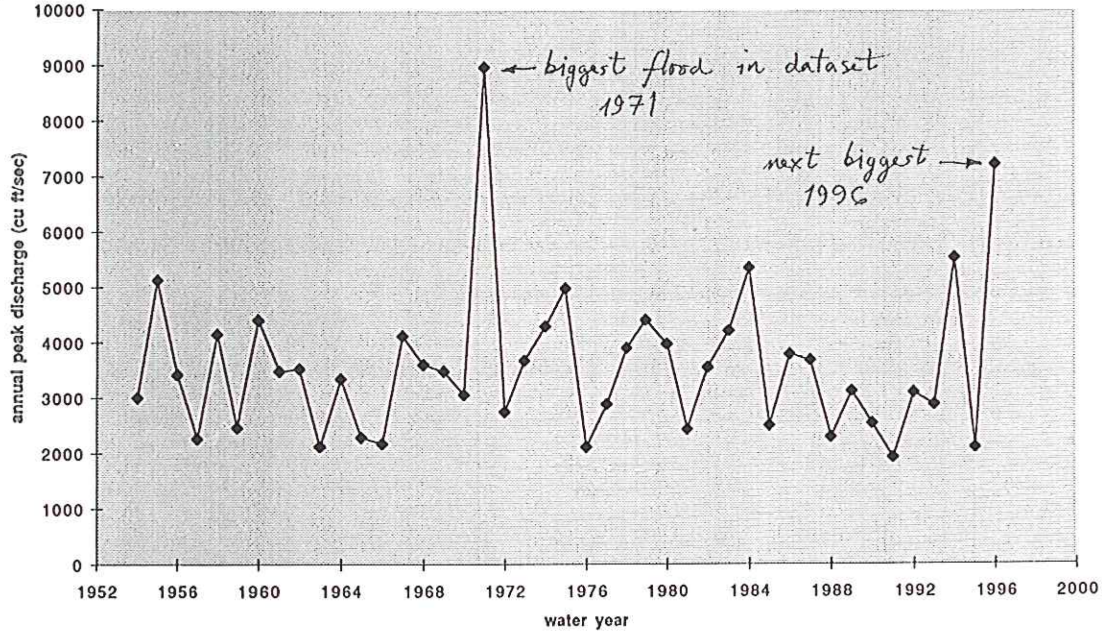
Flood forecasting – by extrapolation

- flood twice as big as largest ever recorded (i.e., 500 m^3/sec) about every 250 years
- 100-year flood (about 360 m^3/sec)
- Hurricane Floyd 1999 (250 m^3/sec)



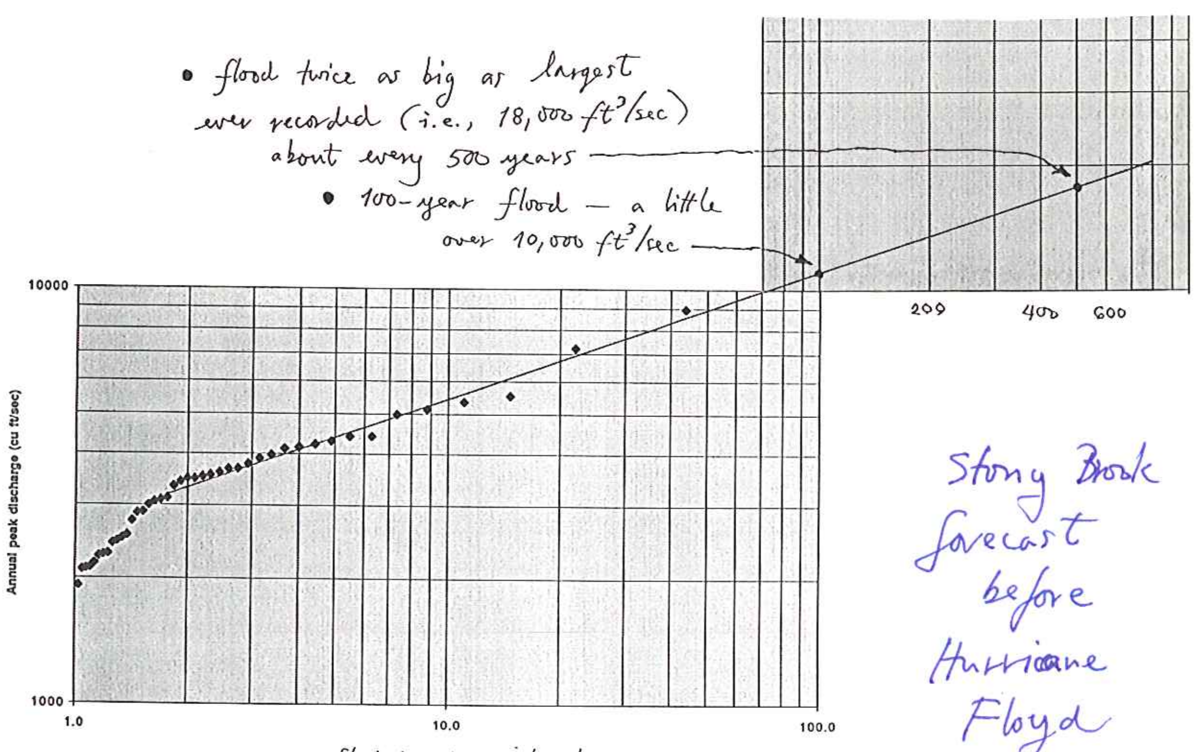
flood recurrence interval = $\frac{46}{\text{rank}}$ (years)

Peak Annual Discharge vs. Water Year
at Stony Brook in Princeton, NJ



1954 to 1996 — 43 years of data

Flood forecasting — by extrapolation



flood recurrence interval $= \frac{44}{\text{rank}}$ (years)

Stony Brook forecast before Hurricane Floyd