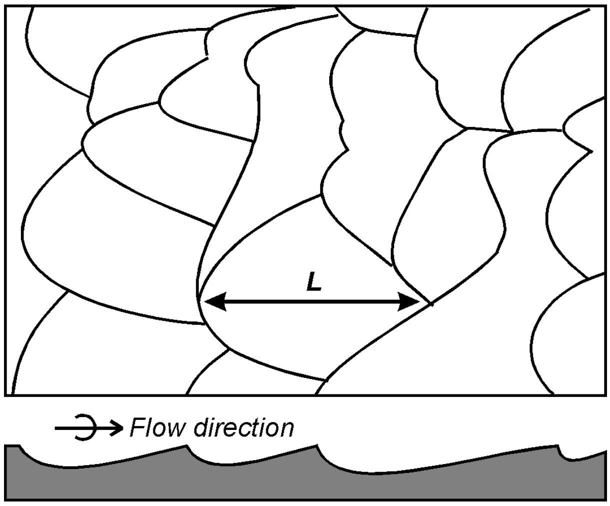
Estimating OLD Flow-rates: Scallops

For quick comparisons of different passages, the relative stream velocities are inversely proportional to the scallop length (L). Multiplying in the passage cross-section area allows us to compare discharges in a relative sense. The direction of flow is given by the scallop shape - the upstream edge is steeper than the downstream end (see fig.).



Scallops: in plan & section

Getting absolute numbers is a bit more complicated

For a detailed (but maths-rich) discussion see: Curl, R., 1974: Deducing flow velocity in cave conduits from scallops. *NSS Bull.*, 36(2) 1-5, and errata in 36(3), p 22. Or see the summary in White (1988, pp 96-100)

Note Curl's comments about assumptions and factors that will effect the accuracy.

- The conduit must have a regular cross-section over a long enough straight segment to allow a regular flow.
- The flow must have had a constant velocity and temperature during the formation of the scallops. This is unlikely - but one can assume that the scallops represent the higher velocities (flood events) rather than the average; once small high-velocity scallops have formed it is difficult to replace them with larger (slow) scallops.
- The method is relatively independent of the conditions in different caves, as long as the limestone is fine grained and competent. (so the formulae might need re-calibration for porous, soft-rock limestones ?)
- Many factors can obscure or modify scallops: e.g. close jointing, heavy bed-load, deposition of clay, numerous inclusions in the limestone.

Note that, for discharge estimates, we are interested in the average flow in the **whole** conduit, rather than the actual velocity at the rock surface. The measurement of conduit diameter (D) or fissure width allows for the frictional effect of the walls. Slightly different constants are used for circular tubes and parallel-walled fissures.

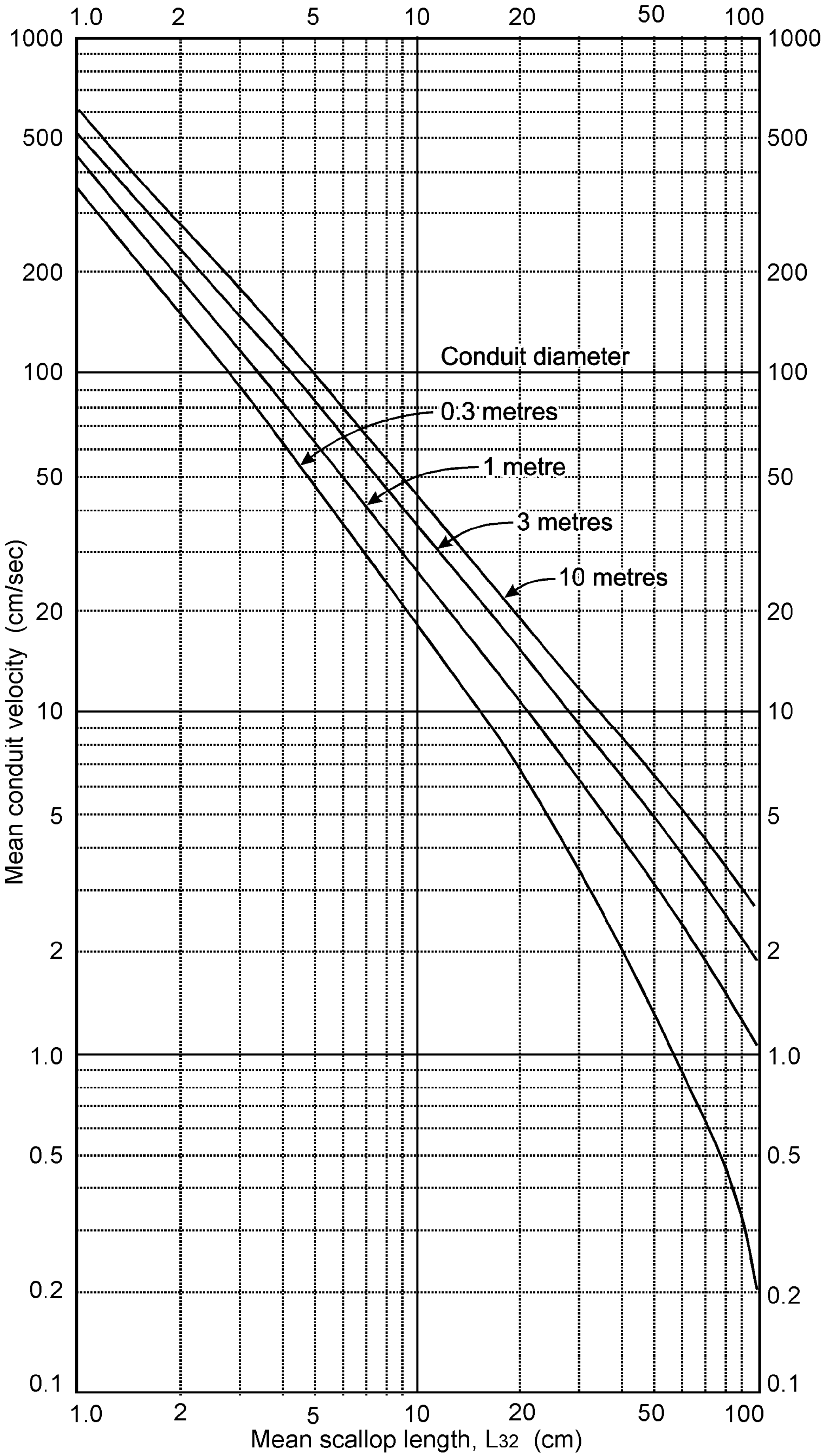
Doing it by Charts.

The chart overleaf is a simplified one from White (1988) which ignores temperature effects (it seems to be for 5°C), and assumes a cylindrical conduit.

$\mathbf{L_{32}}$ is the "Sauter mean" length of the scallops. This is better than a simple mean as it reduces the influence of occasional short scallops. The Sauter Mean (L_{32}) is calculated by summing L^3 and dividing that by the sum of L^2.

ie: $L_{32} = \sum l_i^3 \ / \ \sum l_i^2$ (where l_i is the length of each measured scallop)

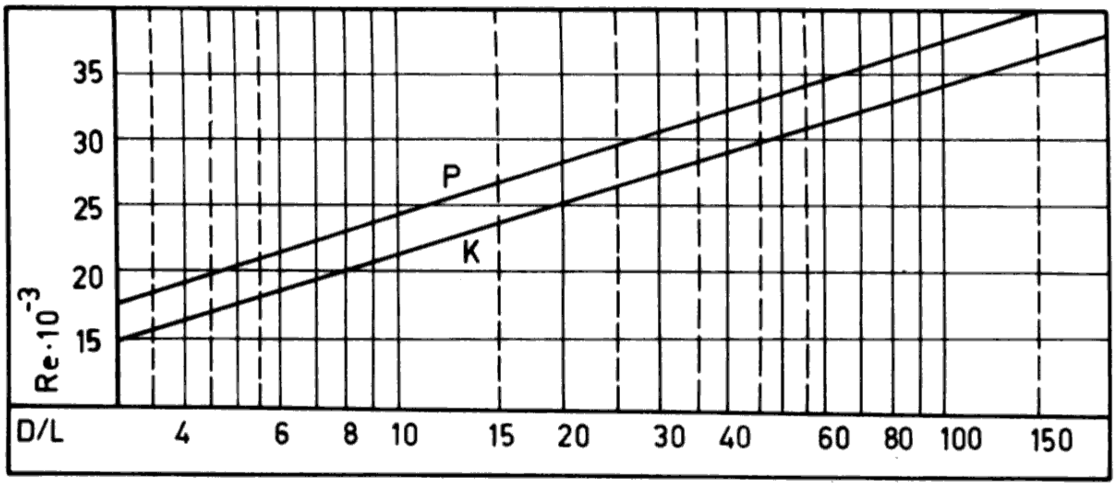
A more accurate approach (which allows for temperature, and caters for fissures also) appears on the following page.



Relationship between the mean channel velocity and mean scallop length.
After W.B. White (1988)
Geomorphology and Hydrology of Limestone Terrains, p 100.

Scallops, continued...

An alternative set of charts comes from Bogli (1980).



Relationship between Re_L and D/L according to Curl (1974). ***P*** passage with rectangular cross-section; ***K*** passage with circular cross-section (after Bogli, 1980)

First one gets the Scallop Reynolds number (Re) from the chart.
D is the diameter of a cylindrical passage (use line K), or the width of a fissure (use line P).
L is the Sauter mean (as per the previous page).

The **Mean velocity** for the conduit (in cm/s) = (Re . v) / L_{32}

Where ***v*** is viscosity from the table of temperatures below.

Kinematic viscosity v for water at different temperatures.

temp	0˚C	5˚C	10˚C	15˚C	20˚C	25˚C	30˚C
v	0.0179	0.0152	0.0131	0.0114	0.0100	0.0090	0.0080

Example (from Bogli, 1980).
For a rectangular passage of width 3m, having an average scallop length of 15cm.
The Re from the chart will be 28,000 (using line 'P')
For an assumed paleo-temperature of 5° C, we get a Mean Velocity of 28.4 cm/s.