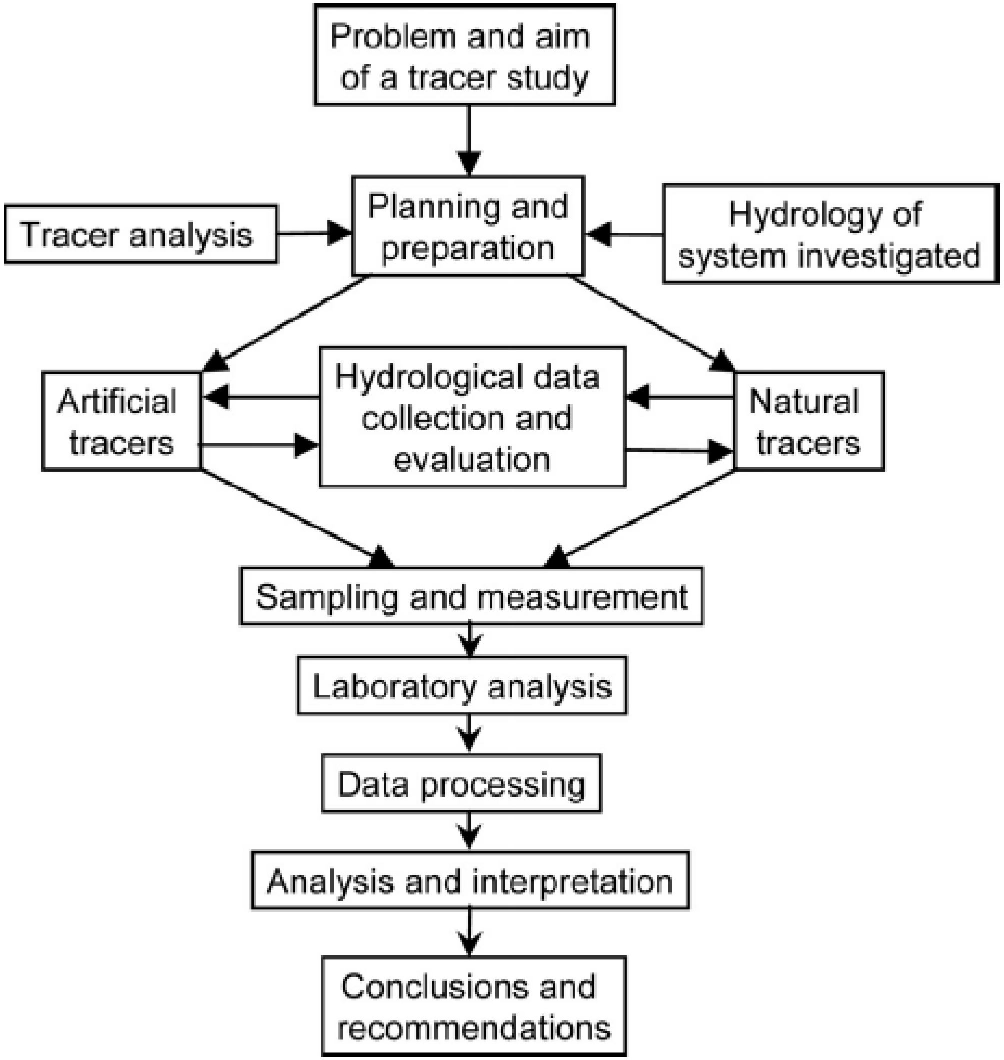
Tracers in Hydrology Exercise II: Tracer mass estimation methods

Prof. Dr. Christoph Külls

Planing a Tracer Test



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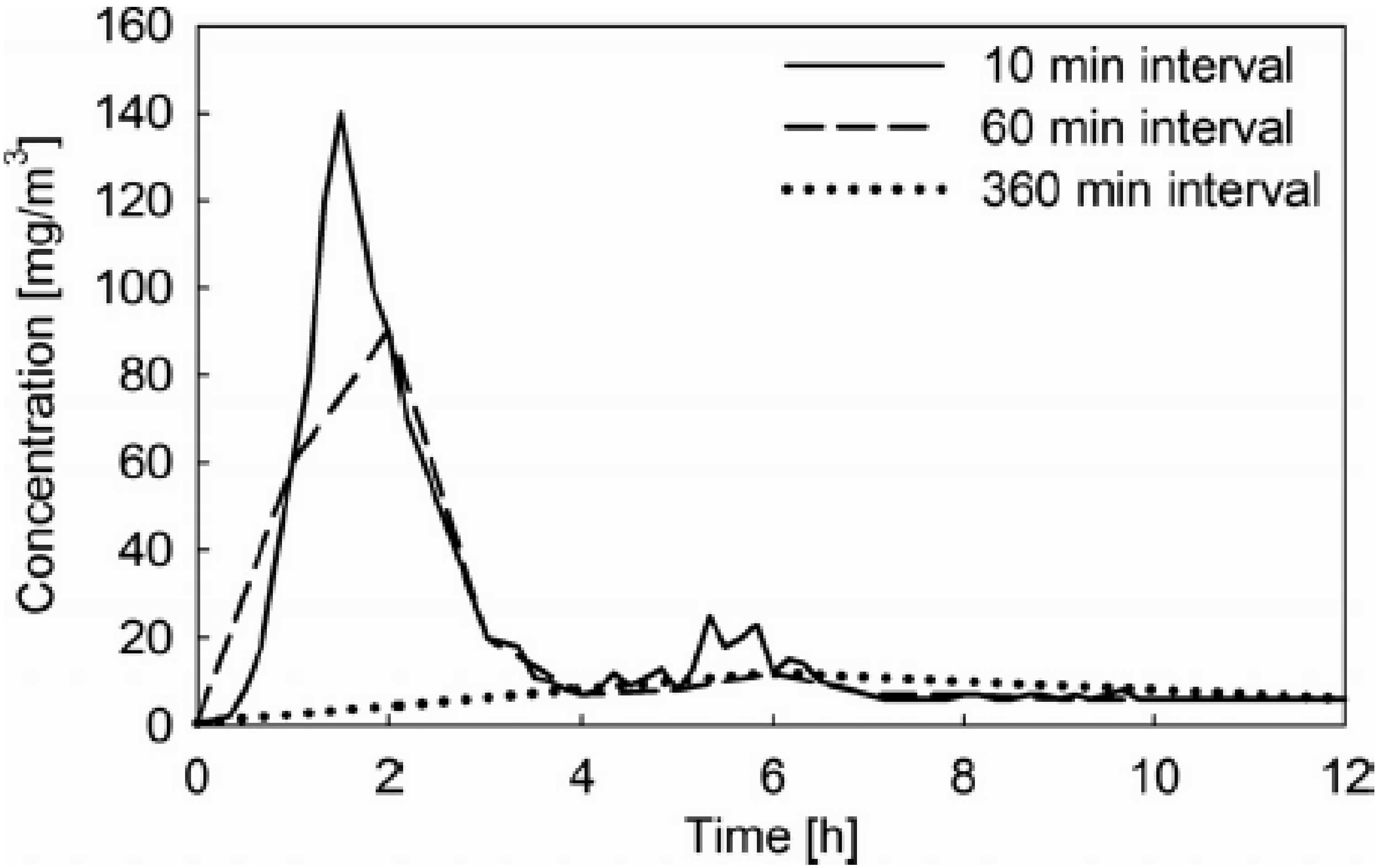

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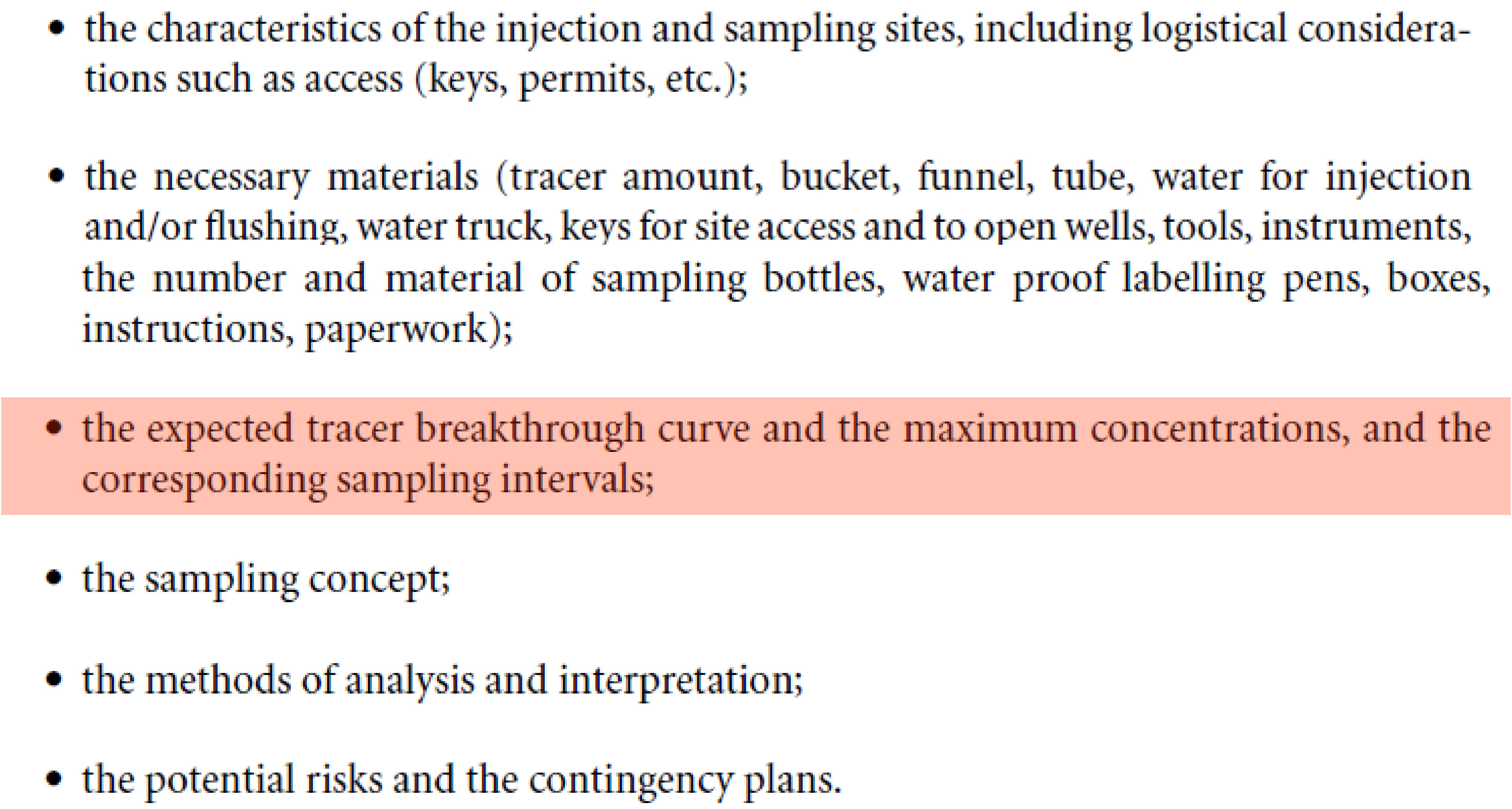

- the characteristics of the injection and sampling sites, including logistical considerations such as access (keys, permits, etc.);
- the necessary materials (tracer amount, bucket, funnel, tube, water for injection and/or flushing, water truck, keys for site access and to open wells, tools, instruments, the number and material of sampling bottles, water proof labelling pens, boxes, instructions, paperwork);
- the expected tracer breakthrough curve and the maximum concentrations, and the corresponding sampling intervals;
- the sampling concept;
- the methods of analysis and interpretation;
- the potential risks and the contingency plans.

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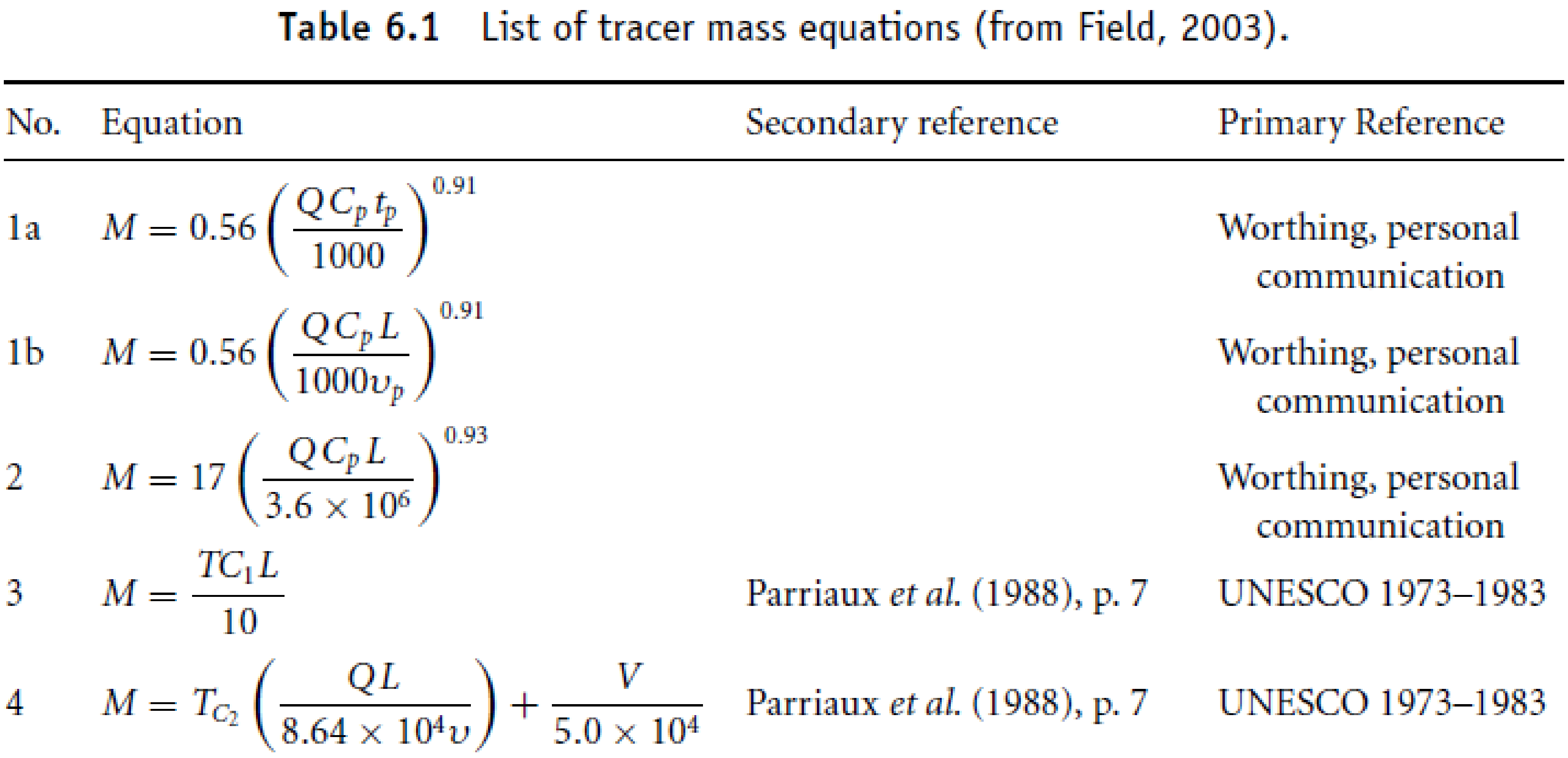

Table 6.1 List of tracer mass equations (from Field, 2003).

No.	Equation	Secondary reference	Primary Reference
1a	$M = 0.56\left(\frac{QC_p t_p}{1000}\right)^{0.91}$		Worthing, personal communication
1b	$M = 0.56\left(\frac{QC_p L}{1000\upsilon_p}\right)^{0.91}$		Worthing, personal communication
2	$M = 17\left(\frac{QC_p L}{3.6 \times 10^6}\right)^{0.93}$		Worthing, personal communication
3	$M = \frac{TC_1 L}{10}$	Parriaux *et al.* (1988), p. 7	UNESCO 1973–1983
4	$M = T_{C_2}\left(\frac{QL}{8.64 \times 10^4 \upsilon}\right) + \frac{V}{5.0 \times 10^4}$	Parriaux *et al.* (1988), p. 7	UNESCO 1973–1983

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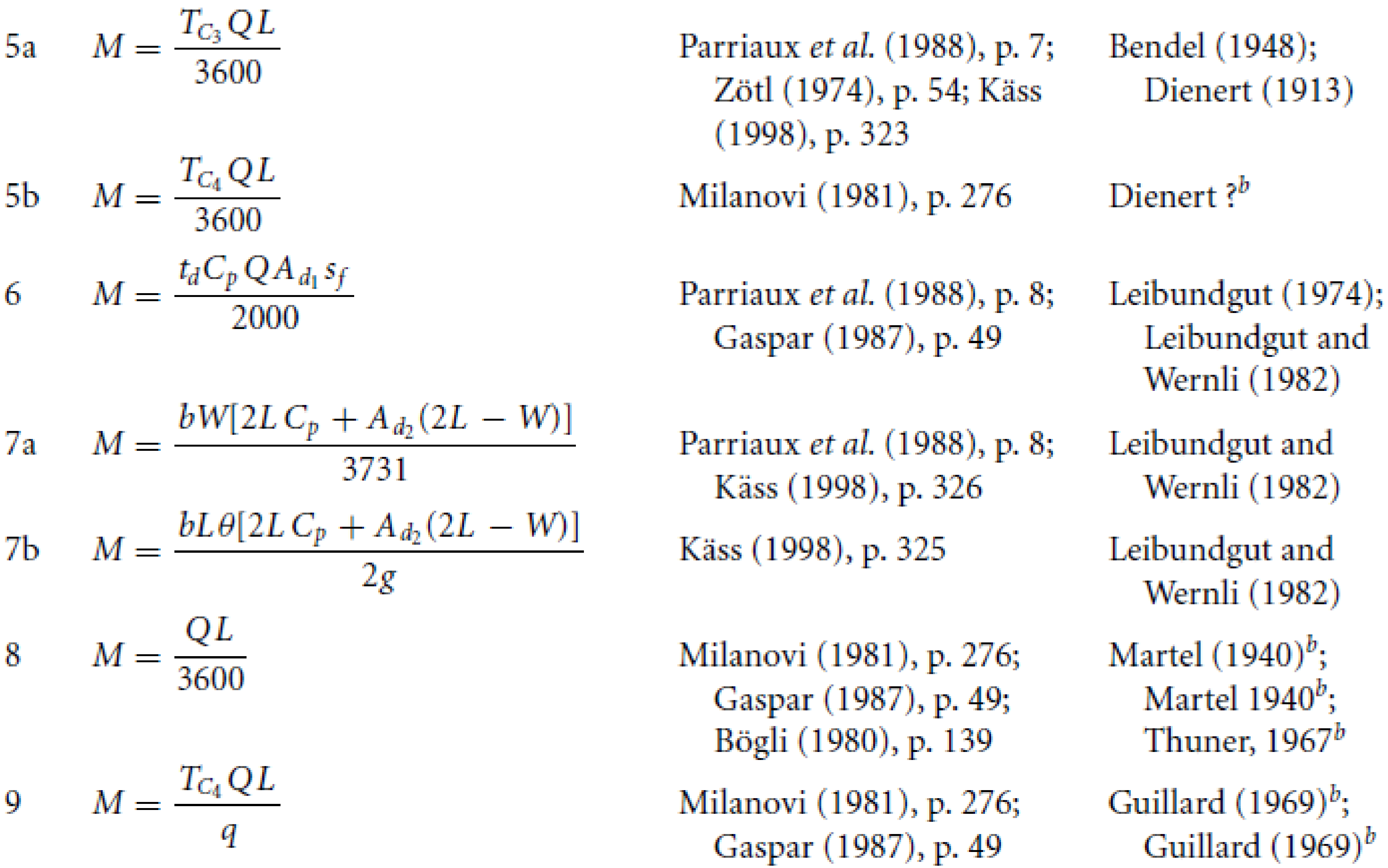

5a	$M = \frac{T_{C_3} Q L}{3600}$	Parriaux *et al.* (1988), p. 7; Zötl (1974), p. 54; Käss (1998), p. 323	Bendel (1948); Dienert (1913)
5b	$M = \frac{T_{C_4} Q L}{3600}$	Milanovi (1981), p. 276	Dienert ?^{b}
6	$M = \frac{t_d C_p Q A_{d_1} s_f}{2000}$	Parriaux *et al.* (1988), p. 8; Gaspar (1987), p. 49	Leibundgut (1974); Leibundgut and Wernli (1982)
7a	$M = \frac{bW[2L C_p + A_{d_2}(2L - W)]}{3731}$	Parriaux *et al.* (1988), p. 8; Käss (1998), p. 326	Leibundgut and Wernli (1982)
7b	$M = \frac{bL\theta[2L C_p + A_{d_2}(2L - W)]}{2g}$	Käss (1998), p. 325	Leibundgut and Wernli (1982)
8	$M = \frac{QL}{3600}$	Milanovi (1981), p. 276; Gaspar (1987), p. 49; Bögli (1980), p. 139	Martel (1940)^{b}; Martel 1940^{b}; Thuner, 1967^{b}
9	$M = \frac{T_{C_4} Q L}{q}$	Milanovi (1981), p. 276; Gaspar (1987), p. 49	Guillard (1969)^{b}; Guillard (1969)^{b}

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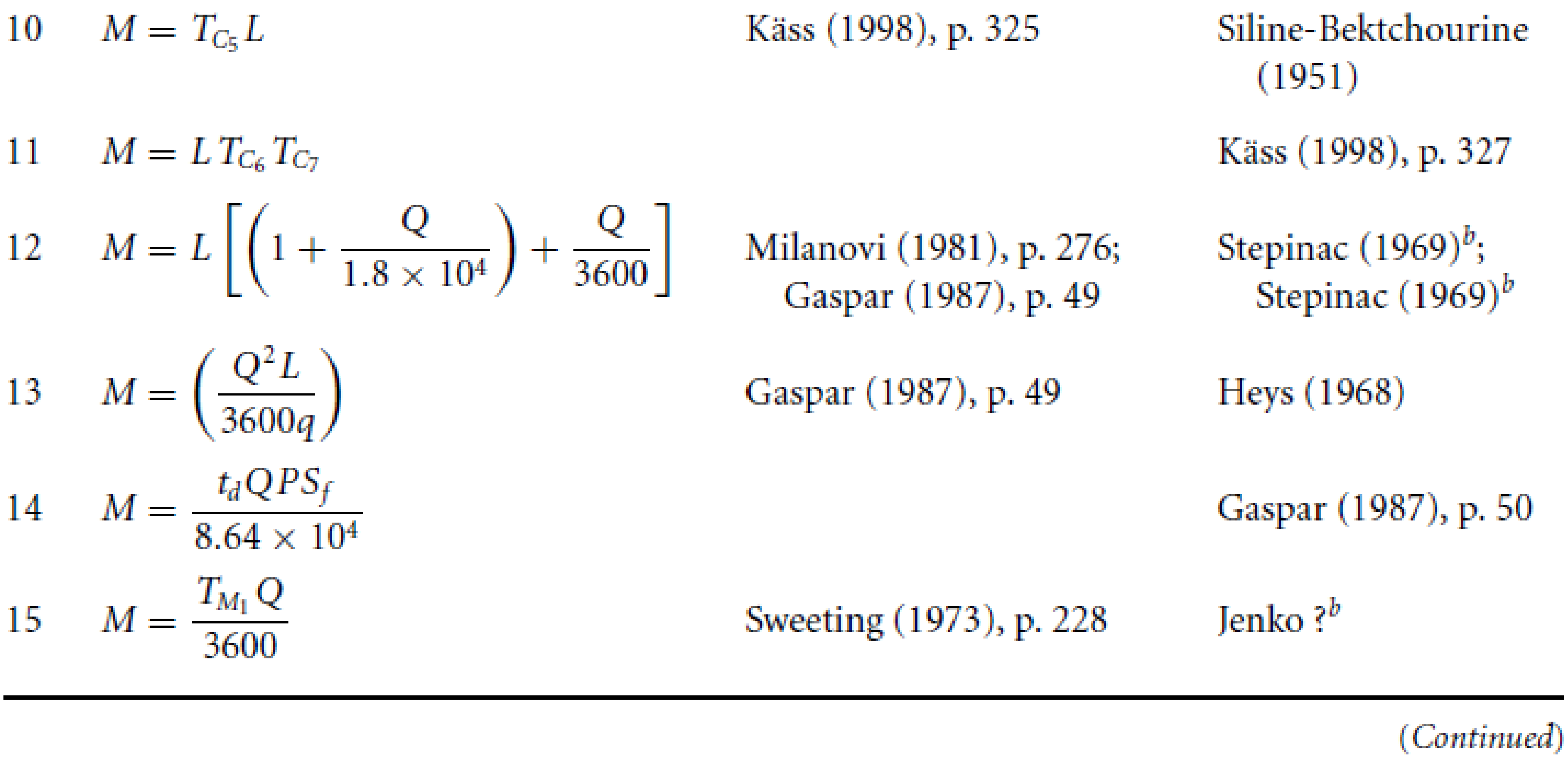
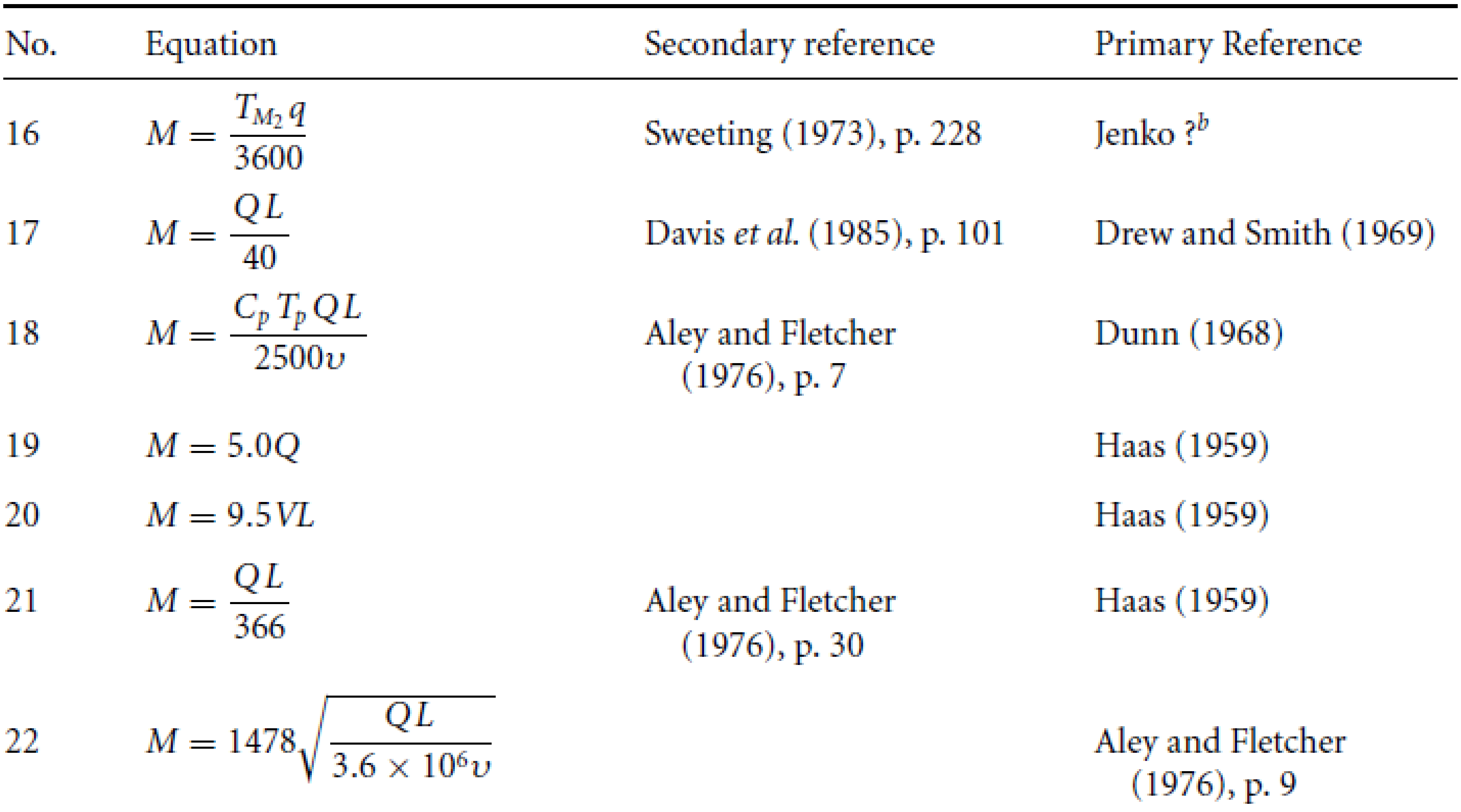


10	$M = T_{C_5} L$	Käss (1998), p. 325	Siline-Bektchourine (1951)
11	$M = L T_{C_6} T_{C_7}$		Käss (1998), p. 327
12	$M = L\left[\left(1 + \frac{Q}{1.8 \times 10^4}\right) + \frac{Q}{3600}\right]$	Milanovi (1981), p. 276; Gaspar (1987), p. 49	Stepinac (1969)[b]; Stepinac (1969)[b]
13	$M = \left(\frac{Q^2 L}{3600q}\right)$	Gaspar (1987), p. 49	Heys (1968)
14	$M = \frac{t_d Q P S_f}{8.64 \times 10^4}$		Gaspar (1987), p. 50
15	$M = \frac{T_{M_1} Q}{3600}$	Sweeting (1973), p. 228	Jenko ?[b]

(*Continued*)

Planing a Tracer Test



No.	Equation	Secondary reference	Primary Reference
16	$M = \frac{T_{M_2} q}{3600}$	Sweeting (1973), p. 228	Jenko ?[b]
17	$M = \frac{QL}{40}$	Davis *et al.* (1985), p. 101	Drew and Smith (1969)
18	$M = \frac{C_p T_p QL}{2500\upsilon}$	Aley and Fletcher (1976), p. 7	Dunn (1968)
19	$M = 5.0Q$		Haas (1959)
20	$M = 9.5VL$		Haas (1959)
21	$M = \frac{QL}{366}$	Aley and Fletcher (1976), p. 30	Haas (1959)
22	$M = 1478\sqrt{\frac{QL}{3.6 \times 10^6 \upsilon}}$		Aley and Fletcher (1976), p. 9

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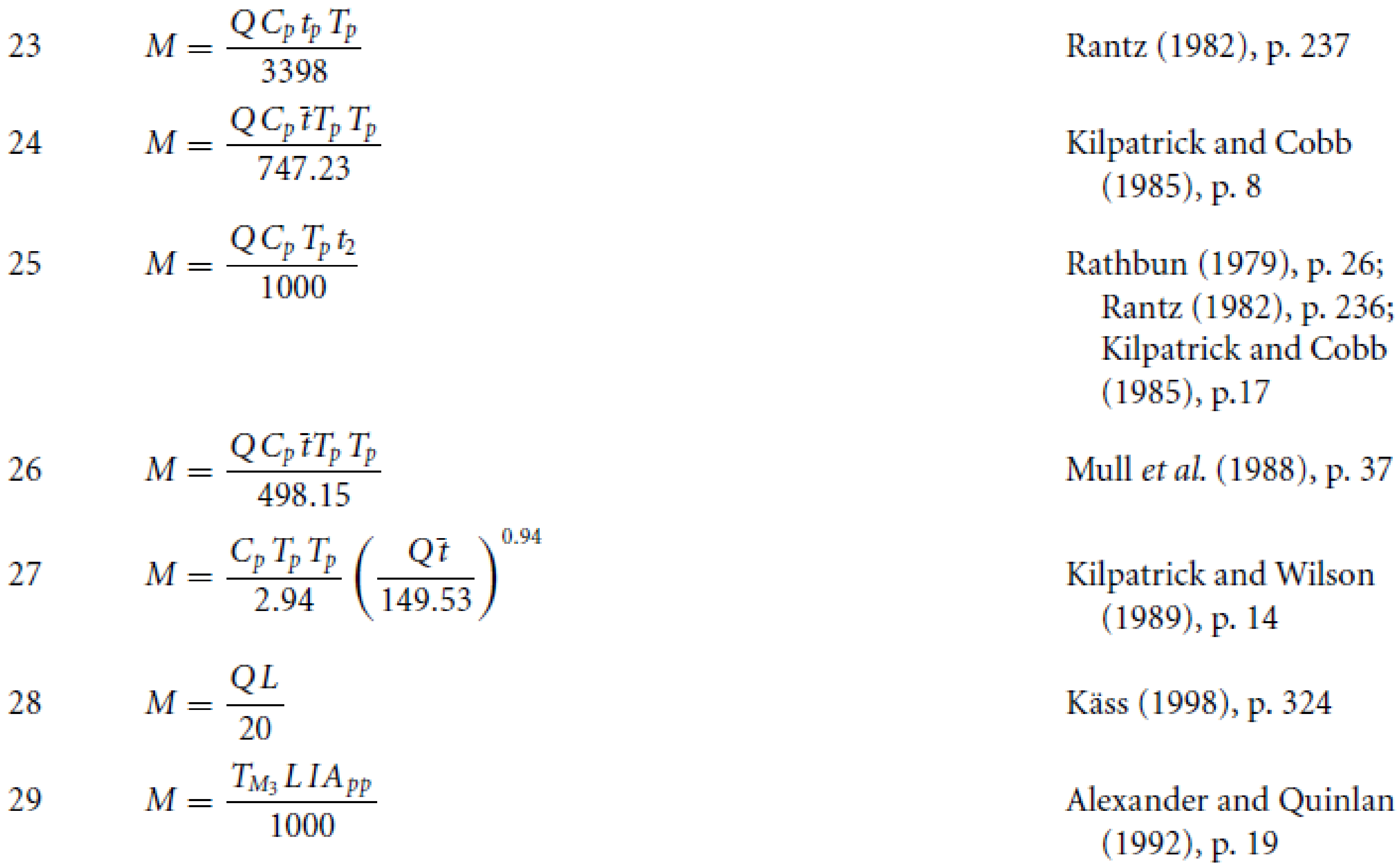

23	$M = \frac{Q C_p t_p T_p}{3398}$	Rantz (1982), p. 237
24	$M = \frac{Q C_p \bar{t} T_p T_p}{747.23}$	Kilpatrick and Cobb (1985), p. 8
25	$M = \frac{Q C_p T_p t_2}{1000}$	Rathbun (1979), p. 26; Rantz (1982), p. 236; Kilpatrick and Cobb (1985), p.17
26	$M = \frac{Q C_p \bar{t} T_p T_p}{498.15}$	Mull *et al.* (1988), p. 37
27	$M = \frac{C_p T_p T_p}{2.94} \left(\frac{Q \bar{t}}{149.53} \right)^{0.94}$	Kilpatrick and Wilson (1989), p. 14
28	$M = \frac{Q L}{20}$	Käss (1998), p. 324
29	$M = \frac{T_{M_3} L I A_{pp}}{1000}$	Alexander and Quinlan (1992), p. 19

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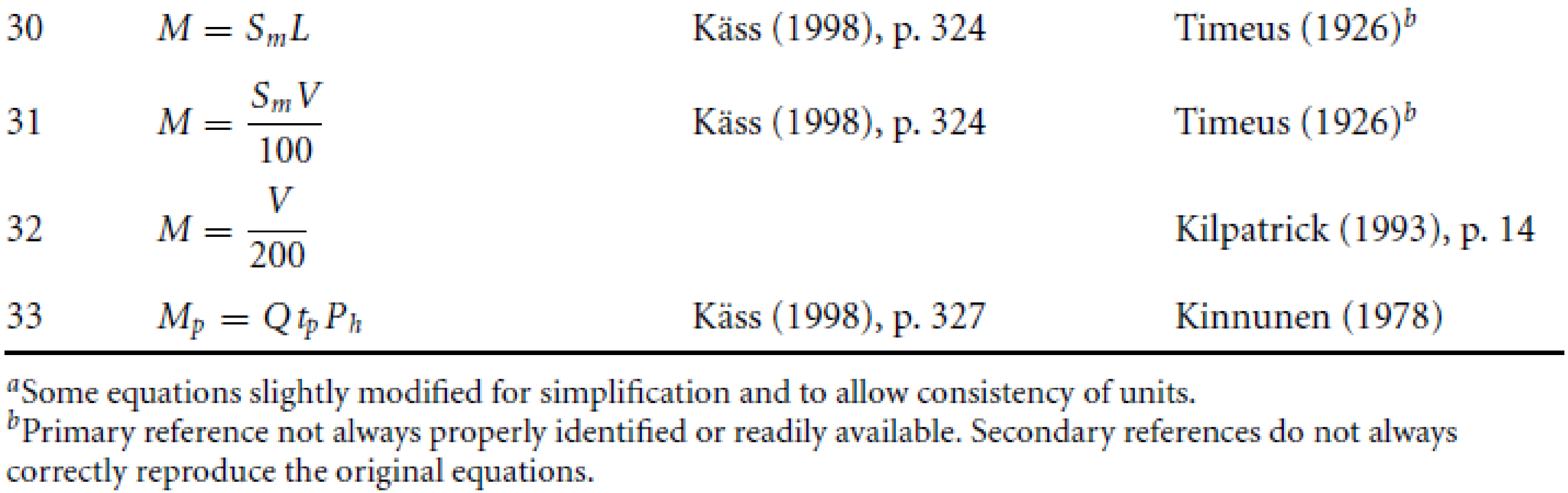
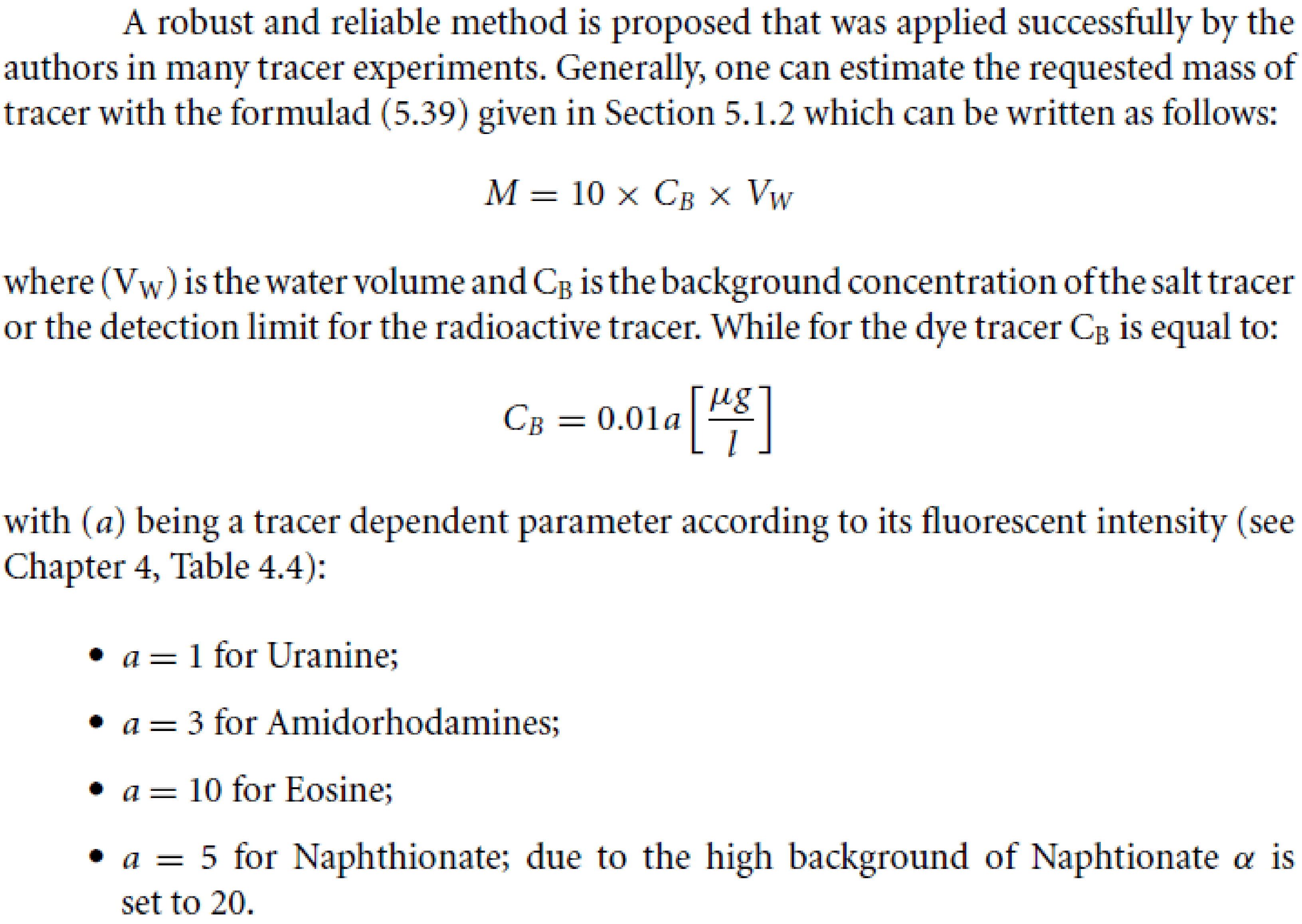


30	$M = S_m L$	Käss (1998), p. 324	Timeus (1926)[b]
31	$M = \frac{S_m V}{100}$	Käss (1998), p. 324	Timeus (1926)[b]
32	$M = \frac{V}{200}$		Kilpatrick (1993), p. 14
33	$M_p = Q t_p P_h$	Käss (1998), p. 327	Kinnunen (1978)

[a] Some equations slightly modified for simplification and to allow consistency of units.

[b] Primary reference not always properly identified or readily available. Secondary references do not always correctly reproduce the original equations.

Planing a Tracer Test



A robust and reliable method is proposed that was applied successfully by the authors in many tracer experiments. Generally, one can estimate the requested mass of tracer with the formulad (5.39) given in Section 5.1.2 which can be written as follows:

$$M = 10 \times C_B \times V_W$$

where (V_W) is the water volume and C_B is the background concentration of the salt tracer or the detection limit for the radioactive tracer. While for the dye tracer C_B is equal to:

$$C_B = 0.01a\left[\frac{\mu g}{l}\right]$$

with (a) being a tracer dependent parameter according to its fluorescent intensity (see Chapter 4, Table 4.4):

- $a = 1$ for Uranine;
- $a = 3$ for Amidorhodamines;
- $a = 10$ for Eosine;
- $a = 5$ for Naphthionate; due to the high background of Naphtionate α is set to 20.

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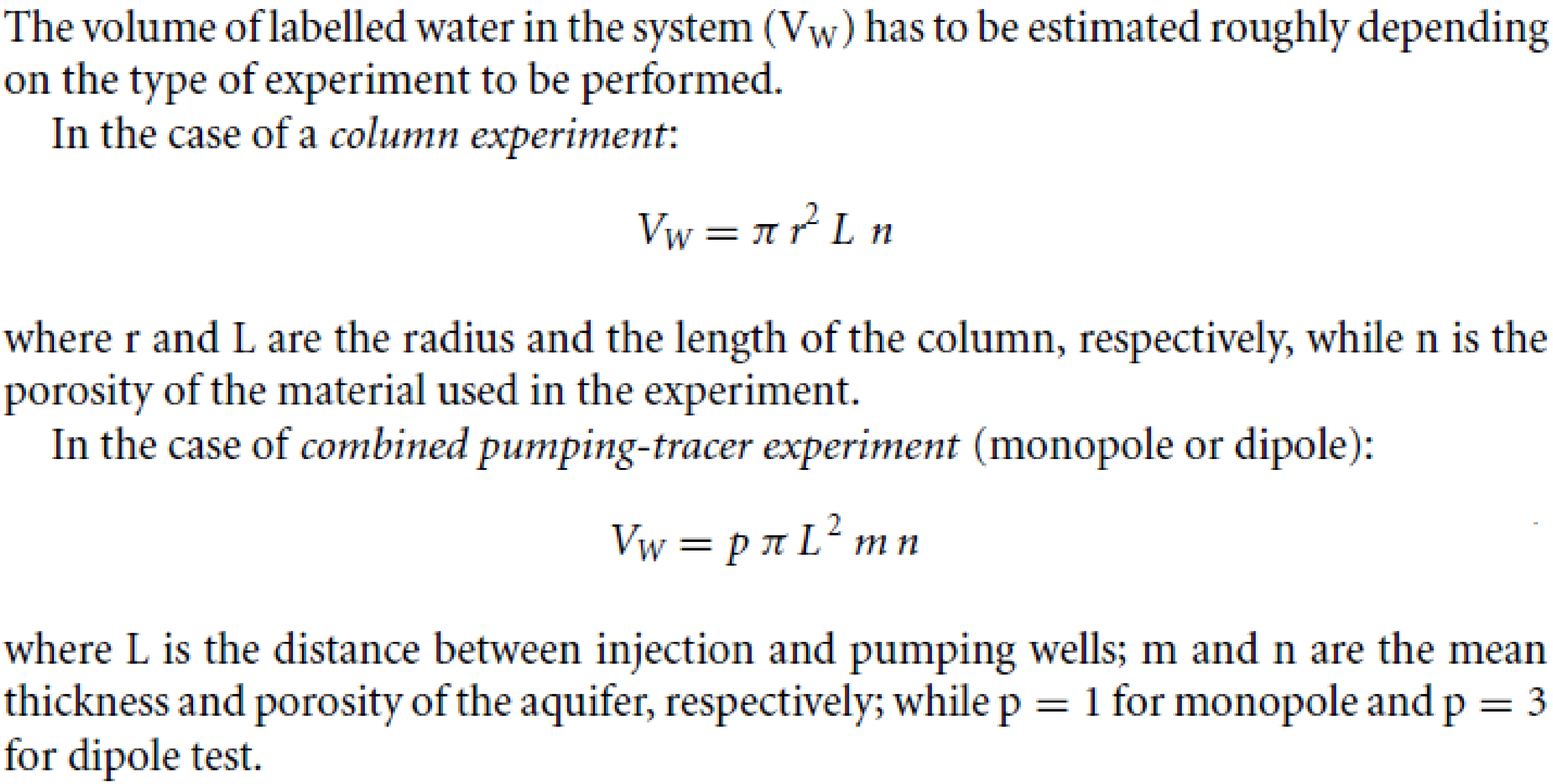

The volume of labelled water in the system (V_W) has to be estimated roughly depending on the type of experiment to be performed.

In the case of a *column experiment*:

$$V_W = \pi r^2 L n$$

where r and L are the radius and the length of the column, respectively, while n is the porosity of the material used in the experiment.

In the case of *combined pumping-tracer experiment* (monopole or dipole):

$$V_W = p \pi L^2 m n$$

where L is the distance between injection and pumping wells; m and n are the mean thickness and porosity of the aquifer, respectively; while $p = 1$ for monopole and $p = 3$ for dipole test.

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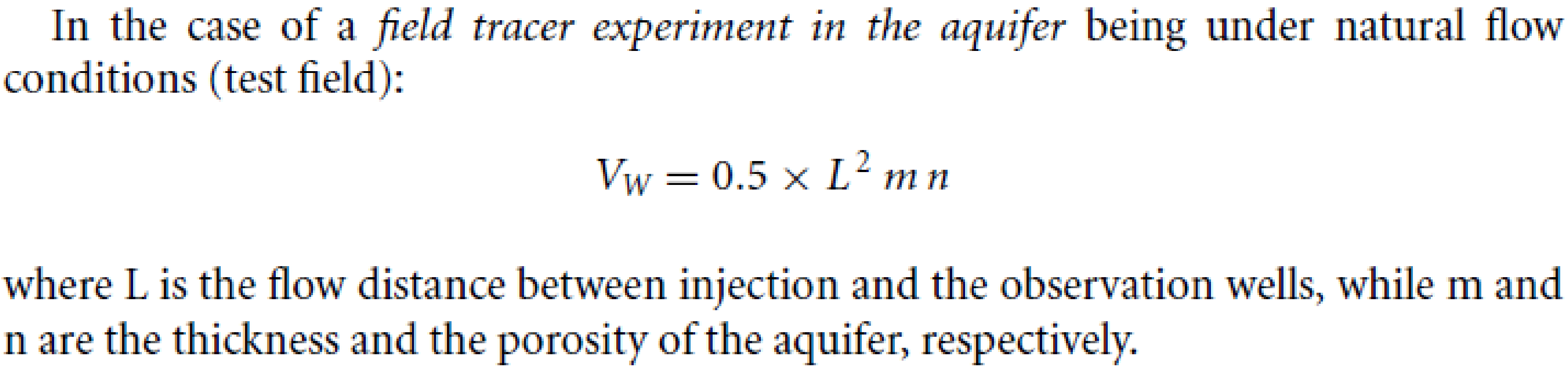

In the case of a *field tracer experiment in the aquifer* being under natural flow conditions (test field):

$$V_W = 0.5 \times L^2 m n$$

where L is the flow distance between injection and the observation wells, while m and n are the thickness and the porosity of the aquifer, respectively.

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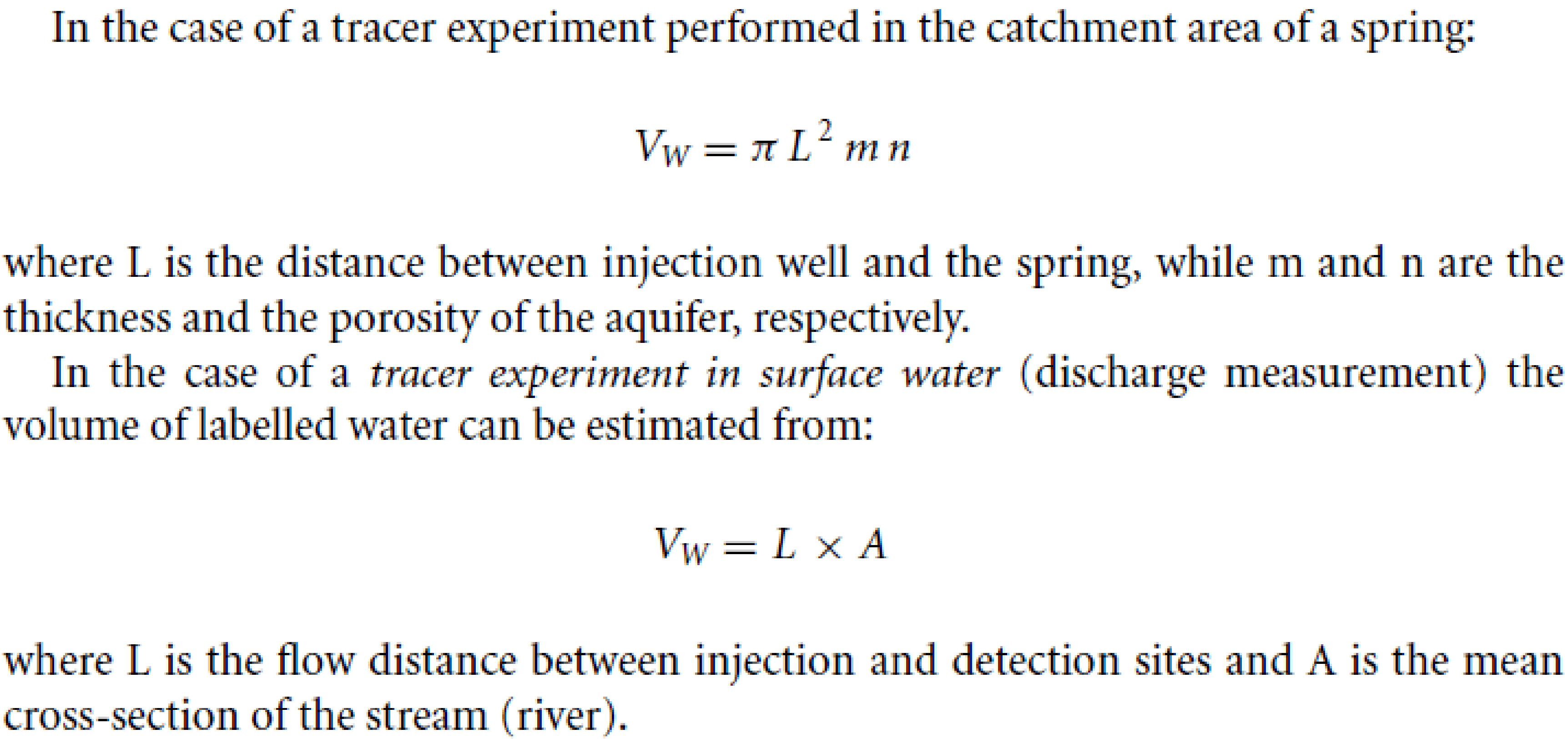

In the case of a tracer experiment performed in the catchment area of a spring:

$$V_W = \pi L^2 m n$$

where L is the distance between injection well and the spring, while m and n are the thickness and the porosity of the aquifer, respectively.

In the case of a *tracer experiment in surface water* (discharge measurement) the volume of labelled water can be estimated from:

$$V_W = L \times A$$

where L is the flow distance between injection and detection sites and A is the mean cross-section of the stream (river).

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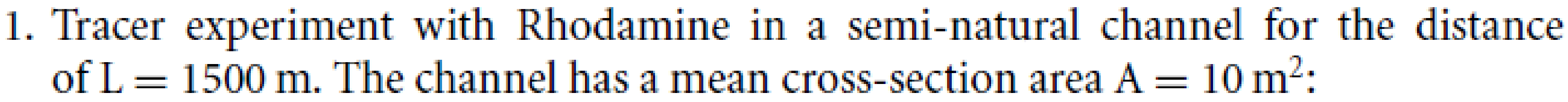
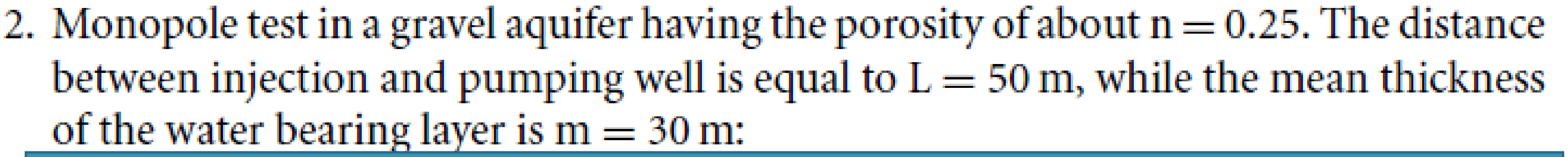
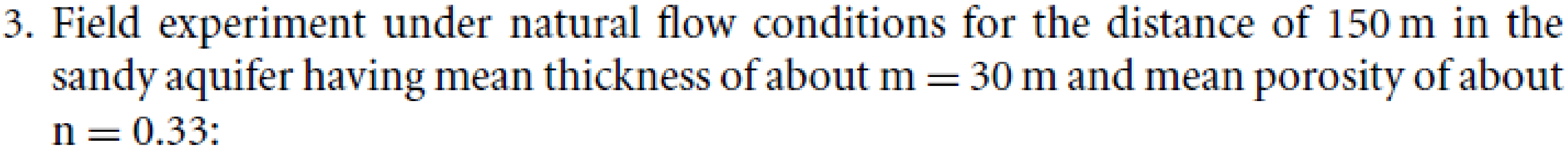


1. Tracer experiment with Rhodamine in a semi-natural channel for the distance of L = 1500 m. The channel has a mean cross-section area $A = 10\,m^2$:



2. Monopole test in a gravel aquifer having the porosity of about n = 0.25. The distance between injection and pumping well is equal to L = 50 m, while the mean thickness of the water bearing layer is m = 30 m:



3. Field experiment under natural flow conditions for the distance of 150 m in the sandy aquifer having mean thickness of about m = 30 m and mean porosity of about n = 0.33: