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APPENDIX A

MEASUREMENT OF HYDRAULIC CONDUCTIVITY IN SOILS FOR USE IN WATER-SENSITIVE DESIGN

INTRODUCTION

One of the most basic techniques included in ‘source control’ practices is that of retaining storm runoff in “leaky” devices such as perforated wells and gravel-filled trenches or “soakaways”. Use of these systems in sandy or sandy-clay soils is well established throughout the world. Their extension into less permeable clay soils needs to be approached with caution, but successful systems constructed in such soils are known in Europe, Japan and in South Australia.

The following notes have been compiled from experience in South Australia and in Auckland (“Stormwater Soakage Design Manual” by P. Nagels) : the latter reference is acknowledged with gratitude.

Soakage Report

Details to be covered in the Report include :

- weather conditions preceding and during the field test : the full test duration may spread over two or three days;
- soil profile : bore log with apparent permeability of the strata encountered, including water table;
- apparent long-term water table (if different from above);
- pre-soaking procedure : duration of pre-soaking.
- data from ‘constant head’ test (head $\approx h_o$) and calculation of hydraulic conductivity from these data;
- graph of ‘falling head’ test (time, t vs depth, h relationship);
- calculation of hydraulic conductivity at time = 60 minutes (clay soils) or depth = $0.85\ h_o$ in sandy soils;
- plan of site showing bore positions in relation to buildings, existing soakholes, driveways, overland flow path, boundaries, contours or spot levels, any area intended for on-site retention, future site development, etc.;
- supply a dimensioned drawing showing details of the proposed “leaky” device or system;
- describe the consequences of the “leaky” device or system overflowing, i.e. effect on foundations, neighbouring properties, site stability, etc.; and,
- report signed and dated by either a civil engineer, civil engineering technician, or an engineering geologist experienced in soakage systems.

The bore hole

A minimum of two tests shall be carried out on each site. On large sites a minimum of one test should be carried out per 400 m^2 of site area. Each hole should correspond with the site position(s) of the proposed soakage devices.

Test holes of 100 mm diameter should be bored to a depth of 2.5 m in soil where rock is not encountered; otherwise, terminate drilling at the soil/rock interface. These depths correspond to the dimension, h_o. The soil profile should be recorded as excavation proceeds and presented with the soakage report.

The hole should be prepared by carefully scratching the sides with a sharp-pointed tool to remove any smeared soil surfaces and to provide a natural soil interface through which water may infiltrate.

The hole must be lined with perforated or slotted PVC pipe (at least 20 holes per metre length of pipe). In sandy soil the perforations/slots should be covered (outside) with geotextile to prevent soil collapse into the bore through the slots or perforations. Any gap between the PVC liner and the wall should be filled with clean sand.

Boreholes drilled at sites where surfaces are waterlogged, indicating the presence of free surface water, should be protected from the entry of surface water during tests. This can be accomplished by forming a low soil mound 50 – 70 mm high around the top of the hole or driving a PVC “ring”, say 300 mm diameter, into the soil at the top of the hole. The ring should be symmetrical about the hole and present a 50 – 70 mm “wall” to surface runoff local to the borehole.

It is of vital importance to record groundwater level if encountered before the 2.50 m depth is reached. In heavy clay soils it is necessary to allow the hole to ‘stand’ for one or two days after drilling to ensure that the long-term groundwater level is clearly identified.

Pre-soak

After the long-term groundwater level has been established (where a watertable is encountered), the well should be filled with water and left to stand for 24 hours (clay soils). “Pre-soaking” in sandy soils consists of filling and allowing the borehole to drain three times.

Constant head test

The ‘constant head’ test seeks the flow rate of water into the bore sufficient to maintain water depth constant at h_o. In fact, despite pre-soaking, there will be a gradual decline in the quantity of inflow required to maintain water depth **constant at h_o**.

In sandy soils, the flow rate is usually small but comfortably supplied from a one litre flask : the time taken to empty each one litre of input must be recorded.

In clay soils, the inflow rate is likely to be very small and the task of maintaining a constant water depth not easy to accomplish. An acceptable procedure for achieving a ‘constant head’ test result under these circumstances is to allow the water level to fall over a period of, say, 15 – 30 minutes and then to fill the hole to the initial level. The time (t_c) of water level fall should be noted as well as the volume of water required (V_c) to restore the level.

Tests in both sandy and clay soils should be repeated at least four times.

Falling head test

The ‘falling head’ test follows immediately completion of the ‘constant head’ test and involves, simply, allowing the borehole to drain without further addition of water.

In the case of sandy soils, the rate of fall may be quite rapid and the task of recording water depth below the top of the PVC liner (used as datum) and the corresponding time, is a two-person operation. In such circumstances an acceptable depth vs time curve may be obtained from the average of three or more ‘runs’. A light staff with scale supported by a float can be used to obtain more accurate readings of borehole water depth.

In clay soils the rate of fall may be very slow and early values hard to distinguish. This is of little consequence as the most critical time/depth conditions are those around t = 60 minutes, in particular, between t = 45 minutes and t = 75 minutes. Some ‘scatter’ of points is to be expected and a curve of best fit should be applied to the data. Again, the depth of water in the borehole can be obtained from measurements taken from the top of the PVC liner used as datum or, for greater accuracy, with a scale supported by a float. A typical t versus h curve is shown in Figure A-1.

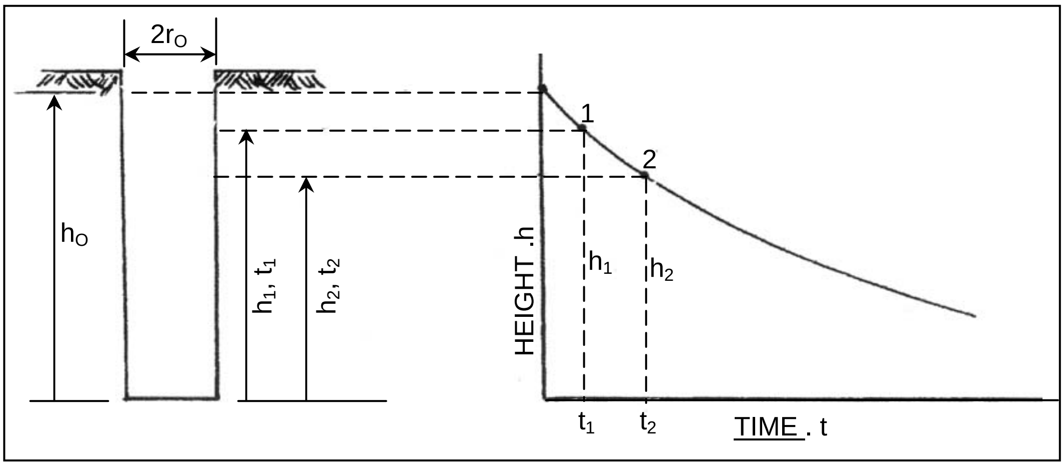

FIGURE A-1 : Inverse augerhole test – definition of terms and typical ‘h’ versus ‘t’ relationship

ANALYSIS OF RESULTS

Constant head test : The hydraulic conductivity of soil given by the constant head test comes from calculating the average flow rate, $Q = V_c / t_c$ expressed in units of m^3 per second, and substituting this into the formula :

$$k_h = \frac{Q}{\left[\pi r_o^2 + 2\pi r_o h\right]}$$

where r_o = radius of the **borehole** (not PVC liner) in metres;

h_o = initial water depth in metres.

Falling head test : In this case, data from two water depth conditions taken from the 'falling head' curve illustrated in Figure A-1 are required. In the case of clay soils :

t_1 = 45 minutes = 2,700 seconds; and, t_2 = 75 minutes = 4,500 seconds.

The corresponding depths, h_1 and h_2 are measured in metres.

The values for t_1 , t_2 , h_1 and h_2 are substituted into the following expression :

$$\text{Hydraulic conductivity } k_h = \frac{1.15 r_o}{(t_2 - t_1)} \log_{10}\left[\frac{h_1 + \frac{r_o}{2}}{h_2 + \frac{r_o}{2}}\right] \text{ m/s} \qquad \textbf{(3.13)}$$

In the case of sandy soils which show very rapid fall in water level, two positions corresponding to t_1 and t_2 should be chosen such that the average of the corresponding values of h_1 and h_2 is about 0.85 h_o. The some formula as above may be used, this time for the chosen values of t_1 and t_2 (in seconds) and corresponding values of h_1 and h_2 in metres.

Where the test borehole intercepts groundwater, the depths h_o, h_1 and h_2 are measured from the **long-term** level of the groundwater (see Figures A-2). Substitution t_1, t_2, h_1 and h_2, similar to the above, is then made into the following formula :

$$\text{Hydraulic conductivity, } k_h = \frac{1.15 r_o}{(t_2 - t_1)} \log_{10}\left[\frac{h_1}{h_2}\right] \qquad \textbf{(3.14)}$$

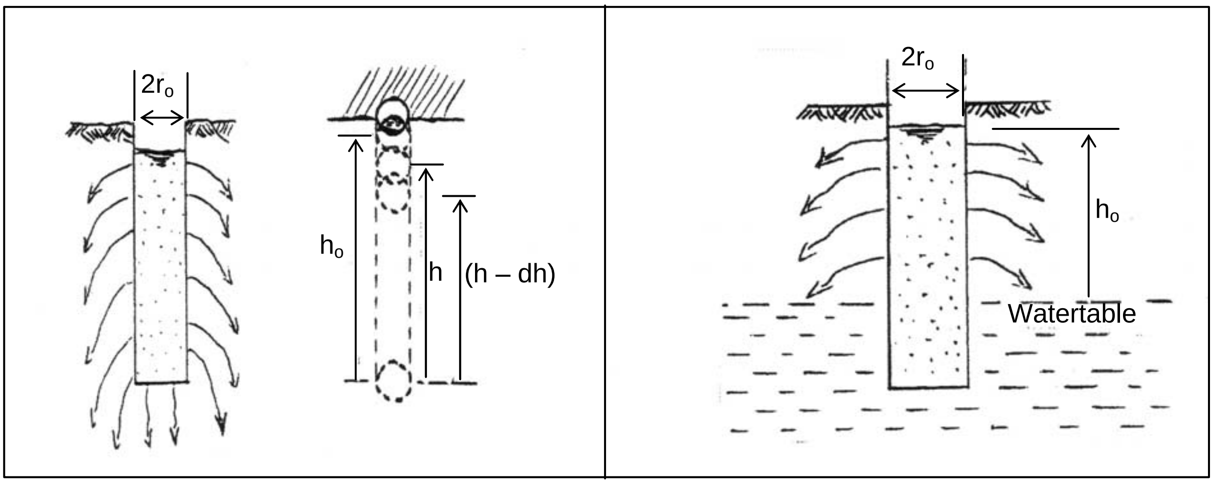

FIGURE A-2 : Boreholes with watertable intersection : definition of h_o and other water depths

HYDRAULIC CONDUCTIVITY RANGES FOR COMMON SOILS

The values of ‘k_h’ derived from the above processes should fall into the following ranges for commonly encountered soils :

Sandy soil : $k_h > 5\times10^{-5}$ m/s;

Sandy clay : k_h between 1×10^{-5} and 5×10^{-5} m/s;

Medium clay : k_h between 1×10^{-6} and 1×10^{-5} m/s;

Heavy clay : k_h between 1×10^{-8} and 1×10^{-6} m/s.

APPENDIX B

RAINFALL I-F-D CHARTS FOR TYPICAL NORTHERN, INTERMEDIATE AND SOUTHERN AUSTRALIAN LOCATIONS

The Tables of IFD data included in Appendix B are representative only of rainfall in the stated locations, and are provided for illustrative purposes only and for use in tutorial exercises included in Appendix F. **Under no circumstances should these data be used for design purposes in the Adelaide, Newcastle or Brisbane regions.** Competent design requires the use of IFD data for specific locations with a resolution of 2.5 km, available from the Bureau of Meteorology or other competent sources. (See www.bom.gov.au/hydro/has/ifd.shtml and follow the link to IFD Request Form.)

TABLE B-1

RAINFALL INTENSITY DURATION DATA

ADELAIDE, SOUTH AUSTRALIA

Geographic Location : 34.9333° South; 138.6° East AUSIFD Version 2.0

DURATION	1 YEAR ARI (mm/hour)	2 YEAR ARI (mm/hour)	5 YEAR ARI (mm/hour)	10 YEAR ARI (mm/hour)	20 YEAR ARI (mm/hour)	50 YEAR ARI (mm/hour)	100 YEAR ARI (mm/hour)
Minutes :							
5	42.9	58.0	81.0	98.0	121.0	155.0	186.0
6	40.0	54.0	75.0	91.0	112.0	144.0	172.0
7	37.6	51.0	70.0	85.0	105.0	135.0	161.0
8	35.5	47.9	67.0	80.0	99.0	127.0	151.0
9	33.8	45.5	63.0	76.0	94.0	120.0	143.0
10	32.2	43.3	60.0	72.0	89.0	114.0	136.0
11	30.8	41.5	57.0	69.0	85.0	109.0	129.0
12	29.6	39.8	55.0	66.0	81.0	104.0	124.0
13	28.5	38.3	53.0	64.0	78.0	100.0	119.0
14	27.4	36.9	51.0	61.0	75.0	96.0	114.0
15	26.5	35.6	49.1	59.0	72.0	93.0	110.0
16	25.7	34.5	47.5	57.0	70.0	89.0	106.0
17	24.9	33.4	46.0	55.0	68.0	86.0	103.0
18	24.2	32.4	44.6	53.0	66.0	84.0	99.0
19	23.5	31.5	43.3	52.0	64.0	81.0	96.0
20	22.8	30.6	42.1	50.0	62.0	79.0	94.0
25	20.2	27.1	37.1	44.4	54.0	69.0	82.0
30	18.2	24.4	33.6	39.9	48.7	62.0	73.4
35	16.7	22.3	30.6	36.3	44.3	56.3	66.6
40	15.4	20.6	28.1	33.4	40.7	52.0	61.0
45	14.4	19.2	26.1	31.0	37.8	47.9	57.0
50	13.5	18.0	24.4	29.0	35.3	44.7	53.0
55	12.7	17.0	23.0	27.3	33.2	41.9	49.5
Hours :							
1.0	12.0	16.1	21.7	25.8	31.3	39.6	46.6
1.5	9.4	12.5	16.8	19.9	24.0	30.2	35.5
2.0	7.9	10.5	14.0	16.4	19.8	24.8	29.1
3.0	6.1	8.1	10.7	12.5	15.1	18.8	21.9
4.0	5.1	6.7	8.9	10.4	12.4	15.4	17.9
5.0	4.4	5.8	7.7	8.9	10.7	13.2	15.4
6.0	4.0	5.2	6.8	7.9	9.4	11.6	13.5
7.0	3.6	4.7	6.1	7.1	8.5	10.5	12.1
8.0	3.3	4.3	5.6	6.5	7.8	9.6	11.1
9.0	3.1	4.0	5.2	6.0	7.2	8.8	10.2
10.0	2.88	3.76	4.86	5.62	6.67	8.20	9.47
11.0	2.71	3.54	4.57	5.28	6.26	7.68	8.86
12.0	2.57	3.35	4.32	4.98	5.90	7.23	8.34
14.0	2.29	3.00	3.86	4.45	5.27	6.45	7.44
16.0	2.08	2.72	3.50	4.03	4.77	5.84	6.74
18.0	1.91	2.49	3.21	3.69	4.37	5.35	6.17
20.0	1.77	2.31	2.97	3.42	4.04	4.94	5.70
24.0	1.54	2.01	2.59	2.98	3.52	4.31	4.96
36.0	1.13	1.48	1.90	2.18	2.58	3.15	3.62
48.0	0.90	1.18	1.51	1.73	2.04	2.49	2.87
60.0	0.75	0.98	1.25	1.43	1.69	2.06	2.37
72.0	0.64	0.83	1.06	1.22	1.44	1.75	2.02

The rainfall intensities shown above are calculated in accordance with Chapter 2, Australian Rainfall and Runoff – 1987 Edition.

AUS-IFD Ver.2.0, 2001 : http://www.ens.gu.edu.au/eve/research/AusIfd/AusIfdVer2.htm

TABLE B-2

RAINFALL INTENSITY DURATION DATA

NEWCASTLE, NEW SOUTH WALES

Geographic Location : 32.917° South; 151.8° East AUSIFD Version 2.0

DURATION	**1 YEAR ARI** (mm/hour)	**2 YEAR ARI** (mm/hour)	**5 YEAR ARI** (mm/hour)	**10 YEAR ARI** (mm/hour)	**20 YEAR ARI** (mm/hour)	**50 YEAR ARI** (mm/hour)	**100 YEAR ARI** (mm/hour)
Minutes :							
5	88.0	113.0	142.0	159.0	181.0	210.0	232.0
6	83.0	106.0	133.0	149.0	170.0	197.0	218.0
7	78.0	100.0	126.0	141.0	160.0	186.0	206.0
8	74.0	95.0	119.0	133.0	152.0	177.0	195.0
9	71.0	90.0	114.0	127.0	145.0	169.0	186.0
10	68.0	87.0	109.0	122.0	139.0	162.0	178.0
11	65.0	83.0	105.0	117.0	134.0	155.0	171.0
12	63.0	80.0	101.0	113.0	129.0	149.0	165.0
13	60.0	77.0	97.0	109.0	124.0	144.0	159.0
14	58.0	75.0	94.0	105.0	120.0	140.0	154.0
15	57.0	72.0	91.0	102.0	117.0	135.0	149.0
16	55.0	70.0	89.0	99.0	113.0	131.0	145.0
17	53.0	68.0	86.0	96.0	110.0	128.0	141.0
18	52.0	66.0	84.0	94.0	107.0	124.0	137.0
19	51.0	65.0	82.0	91.0	104.0	121.0	134.0
20	49.3	63.0	80.0	89.0	102.0	118.0	130.0
25	44.1	56.0	71.0	80.0	91.0	106.0	117.0
30	40.1	51.0	65.0	72.0	83.0	96.0	106.0
35	37.0	47.3	60.0	67.0	76.0	88.5	97.5
40	34.3	43.9	56.0	62.0	71.0	82.0	91.0
45	32.2	41.2	52.0	58.0	66.0	77.0	85.0
50	30.3	38.8	49.0	55.0	63.0	73.0	81.0
55	28.7	36.8	46.5	52.0	59.0	69.0	76.0
Hours :							
1.0	27.3	35.0	44.2	49.5	57.0	66.0	73.0
1.5	21.1	27.1	34.3	38.4	43.9	51.0	57.0
2.0	17.6	22.5	28.5	32.0	36.6	42.6	47.2
3.0	13.5	17.3	21.9	24.6	28.2	32.9	36.4
4.0	11.1	14.3	18.2	20.4	23.4	27.3	30.3
5.0	9.62	12.4	15.7	17.7	20.3	23.7	26.3
6.0	8.54	11.0	14.0	15.7	18.0	21.1	23.4
7.0	7.72	9.91	12.7	14.2	16.3	19.1	21.2
8.0	7.07	9.08	11.6	13.1	15.0	17.5	19.4
9.0	6.55	8.41	10.8	12.1	13.9	16.3	18.0
10.0	6.11	7.86	10.1	11.3	13.0	15.2	16.9
11.0	5.74	7.38	9.45	10.6	12.2	14.3	15.9
12.0	5.43	6.98	8.93	10.1	11.6	13.5	15.0
14.0	4.96	6.39	8.19	9.24	10.6	12.4	13.8
16.0	4.59	5.91	7.6	8.58	9.88	11.6	12.9
18.0	4.29	5.52	7.11	8.04	9.26	10.9	12.1
20.0	4.03	5.2	6.7	7.58	8.74	10.3	11.4
24.0	3.62	4.67	6.04	6.84	7.89	9.27	10.3
36.0	2.83	3.66	4.76	5.41	6.26	7.37	8.23
48.0	2.36	3.06	3.99	4.55	5.27	6.22	6.95
60.0	2.04	2.64	3.46	3.95	4.58	5.42	6.06
72.0	1.79	2.33	3.06	3.5	4.06	4.81	5.39

The rainfall intensities shown above are calculated in accordance with Chapter 2, Australian Rainfall and Runoff – 1987 Edition.

AUS-IFD Ver.2.0, 2001 : http://www.ens.gu.edu.au/eve/research/AusIfd/AusIfdVer2.htm

TABLE B-3

RAINFALL INTENSITY DURATION DATA

BRISBANE, QUEENSLAND

Geographic Location : 27.4667° South; 153.0167° East AUSIFD Version 2.0

DURATION	**1 YEAR ARI** (mm/hour)	**2 YEAR ARI** (mm/hour)	**5 YEAR ARI** (mm/hour)	**10 YEAR ARI** (mm/hour)	**20 YEAR ARI** (mm/hour)	**50 YEAR ARI** (mm/hour)	**100 YEAR ARI** (mm/hour)
Minutes :							
5	117.0	151.0	191.0	215.0	247.0	290.0	324.0
6	110.0	141.0	180.0	202.0	233.0	274.0	305.0
7	104.0	134.0	170.0	192.0	221.0	260.0	290.0
8	99.0	127.0	162.0	183.0	210.0	248.0	277.0
9	94.0	121.0	155.0	175.0	201.0	237.0	265.0
10	90.0	116.0	148.0	168.0	193.0	228.0	255.0
11	86.0	111.0	143.0	161.0	186.0	220.0	246.0
12	83.0	107.0	138.0	156.0	180.0	212.0	237.0
13	80.0	104.0	133.0	151.0	174.0	206.0	230.0
14	78.0	100.0	129.0	146.0	169.0	199.0	223.0
15	75.0	97.0	125.0	142.0	164.0	194.0	217.0
16	73.0	94.0	121.0	138.0	159.0	188.0	211.0
17	71.0	92.0	118.0	134.0	155.0	184.0	206.0
18	69.0	89.0	115.0	131.0	151.0	179.0	201.0
19	67.0	87.0	112.0	127.0	148.0	175.0	196.0
20	66.0	85.0	110.0	124.0	144.0	171.0	192.0
25	59.0	76.0	98.0	112.0	130.0	154.0	173.0
30	53.0	69.0	90.0	102.0	119.0	141.0	159.0
35	49.2	64.0	83.0	94.5	110.5	131.0	148.0
40	45.7	59.0	77.0	88.0	103.0	123.0	138.0
45	42.8	56.0	73.0	83.0	97.0	116.0	130.0
50	40.4	53.0	69.0	79.0	92.0	110.0	124.0
55	38.2	49.8	65.0	75.0	87.0	104.0	118.0
Hours :							
1.0	36.4	47.4	62.0	71.0	83.0	100.0	113.0
1.5	27.4	35.7	47.1	54.0	63.0	76.0	86.0
2.0	22.3	29.1	38.5	44.4	52.0	62.0	71.0
3.0	16.6	21.8	28.9	33.4	39.2	47.2	53.0
4.0	13.5	17.7	23.6	27.2	32.1	38.6	43.8
5.0	11.5	15.1	20.1	23.3	27.4	33.1	37.5
6.0	10.1	13.2	17.7	20.5	24.1	29.1	33.1
7.0	9.0	11.8	15.8	18.4	21.7	26.2	29.7
8.0	8.18	10.7	14.4	16.7	19.7	23.9	27.1
9.0	7.51	9.86	13.3	15.4	18.2	22.0	25.0
10.0	6.96	9.15	12.3	14.3	16.9	20.5	23.3
11.0	6.5	8.54	11.5	13.4	15.8	19.2	21.8
12.0	6.1	8.02	10.8	12.6	14.9	18.0	20.5
14.0	5.58	7.33	9.86	11.5	13.5	16.4	18.7
16.0	5.16	6.77	9.1	10.6	12.5	15.1	17.2
18.0	4.81	6.32	8.48	9.84	11.6	14.0	16.0
20.0	4.52	5.93	7.95	9.22	10.9	13.1	14.9
24.0	4.06	5.32	7.12	8.24	9.71	11.7	13.3
36.0	3.17	4.15	5.52	6.38	7.5	9.02	10.2
48.0	2.64	3.45	4.57	5.27	6.19	7.43	8.41
60.0	2.27	2.97	3.92	4.51	5.29	6.35	7.18
72.0	2.0	2.61	3.44	3.95	4.63	5.54	6.26

The rainfall intensities shown above are calculated in accordance with Chapter 2, Australian Rainfall and Runoff – 1987 Edition.

AUS-IFD Ver.2.0, 2001 : http://www.ens.gu.edu.au/eve/research/AusIfd/AusIfdVer2.htm

TABLE B-4

RAINFALL INTENSITY DURATION DATA

PERTH, WESTERN AUSTRALIA

Geographic Location : 31.95° South; 115.85° East

DURATION	1 YEAR ARI (mm/hour)	2 YEAR ARI (mm/hour)	5 YEAR ARI (mm/hour)	10 YEAR ARI (mm/hour)	20 YEAR ARI (mm/hour)	50 YEAR ARI (mm/hour)	100 YEAR ARI (mm/hour)
Minutes : 5	59.0	78.0	103.0	120.0	145.0	181.0	213.0
6	55.0	73.0	95.0	111.0	134.0	167.0	196.0
7	52.0	68.0	89.0	104.0	124.0	155.0	181.0
8	48.7	64.0	84.0	97.0	117.0	145.0	170.0
9	46.2	61.0	79.0	92.0	110.0	137.0	159.0
10	44.0	58.0	75.0	87.0	104.0	129.0	151.0
11	42.0	55.0	71.0	83.0	99.0	123.0	143.0
12	40.3	53.0	68.0	79.0	94.0	117.0	136.0
13	38.7	51.0	65.0	76.0	90.0	112.0	130.0
14	37.2	48.8	63.0	73.0	87.0	107.0	124.0
15	35.9	47.1	61.0	70.0	83.0	103.0	119.0
16	34.8	45.5	58.0	67.0	80.0	99.0	115.0
17	33.6	44.0	56.0	65.0	77.0	95.0	111.0
18	32.6	42.6	55.0	63.0	75.0	92.0	107.0
19	31.7	41.4	53.0	61.0	72.0	89.0	103.0
20	30.8	40.2	51.0	59.0	70.0	86.0	100.0
25	27.2	35.4	44.9	52.0	61.0	75.0	86.0
30	24.4	31.7	40.1	46.0	54.0	66.0	76.0
35	22.3	28.9	36.4	41.6	48.9	59.5	68.5
40	20.5	26.6	33.4	38.0	44.6	54.0	62.0
45	19.1	24.7	30.9	35.1	41.1	49.9	57.0
50	17.8	23.0	28.8	32.7	38.2	46.2	53.0
55	16.8	21.7	27.0	30.6	35.7	43.2	49.3
Hours : 1.0	15.9	20.5	25.4	28.8	33.6	40.5	46.2
1.5	12.3	15.8	19.5	22.1	25.7	30.9	35.2
2.0	10.2	13.1	16.2	18.2	21.2	25.0	28.9
3.0	7.83	10.1	12.3	13.9	16.1	19.2	21.9
4.0	6.49	8.31	10.2	11.4	13.2	15.8	17.9
5.0	5.61	7.18	8.75	9.81	11.3	13.5	15.3
6.0	4.98	6.36	7.75	8.67	10.0	11.9	13.5
7.0	4.5	5.75	6.99	7.81	9.02	10.7	12.1
8.0	4.12	5.27	6.39	7.14	8.23	9.78	11.1
9.0	3.82	4.88	5.91	6.6	7.6	9.02	10.2
10.0	3.57	4.55	5.51	6.14	7.08	8.39	9.48
11.0	3.35	4.28	5.17	5.76	6.63	7.86	8.97
12.0	3.17	4.04	4.88	5.43	6.25	7.41	8.36
14.0	2.87	3.66	4.43	4.95	5.7	6.77	7.64
16.0	2.63	3.36	4.08	4.56	5.26	6.25	7.07
18.0	2.44	3.12	3.79	4.24	4.9	5.83	6.6
20.0	2.28	2.91	3.55	3.98	4.6	5.48	6.2
24.0	2.02	2.59	3.17	3.55	4.11	4.91	5.57
36.0	1.54	1.98	2.43	2.74	3.19	3.83	4.35
48.0	1.26	1.62	2.0	2.27	2.64	3.18	3.63
60.0	1.07	1.38	1.71	1.94	2.26	2.73	3.13
72.0	0.93	1.2	1.49	1.7	1.99	2.4	2.75

Supply of these rainfall Intensity-Frequency-Duration data by Western Australia EPA is greatly appreciated.

APPENDIX C

POLLUTION CONTROL/RETENTION DEVICES (“soakaways”) FOR FIVE AUSTRALIAN CLIMATE ZONES

[Climate zones are based on $i_{10,1}$ rainfall intensities*]

See Figure 3.8

*** $i_{10,1}$ rainfall intensity is that given by I.E.Aust. (1987) for**
ARI, Y = 10-years, duration 1-hour.

Graph for Southern Australia is found in Figure 7.1 in Section 7.2.

$i_{10.1}$ is less than or equal to 25 mm per hour

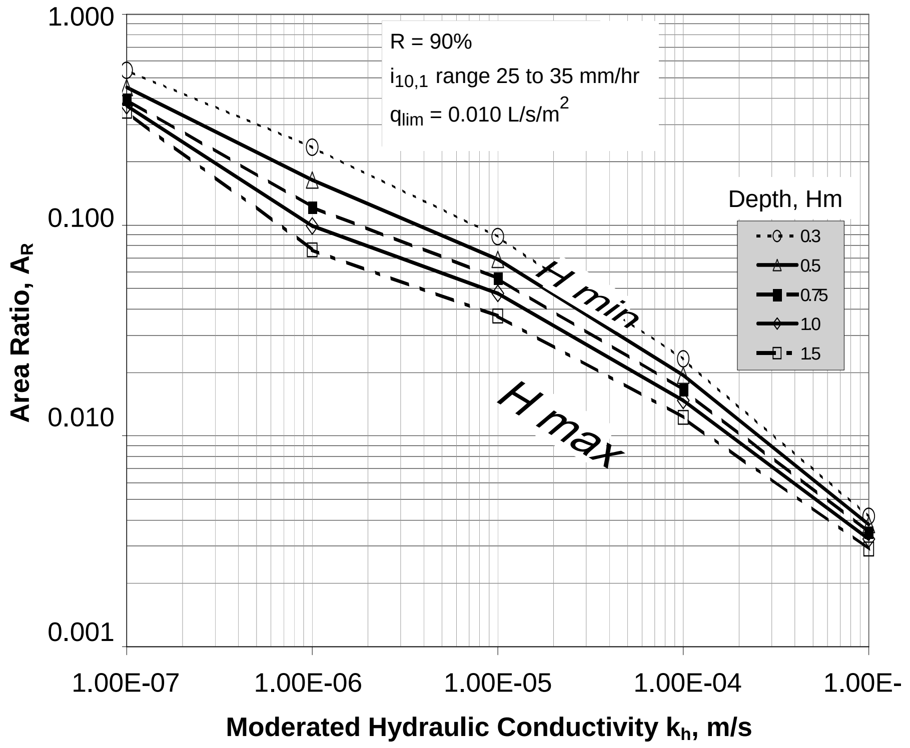

FIGURE C-1 : $i_{10,1}$ range, 25 mm/h to 35 mm/h – Lower-Intermediate Zone
Soils with moderated $k_h > 1.0 \times 10^{-4}$ m/s are, typically, unsuitable for treating *dissolved pollutants* in catchment runoff (see Mikkelsen et al, 1997; Fischer et al, 2003)

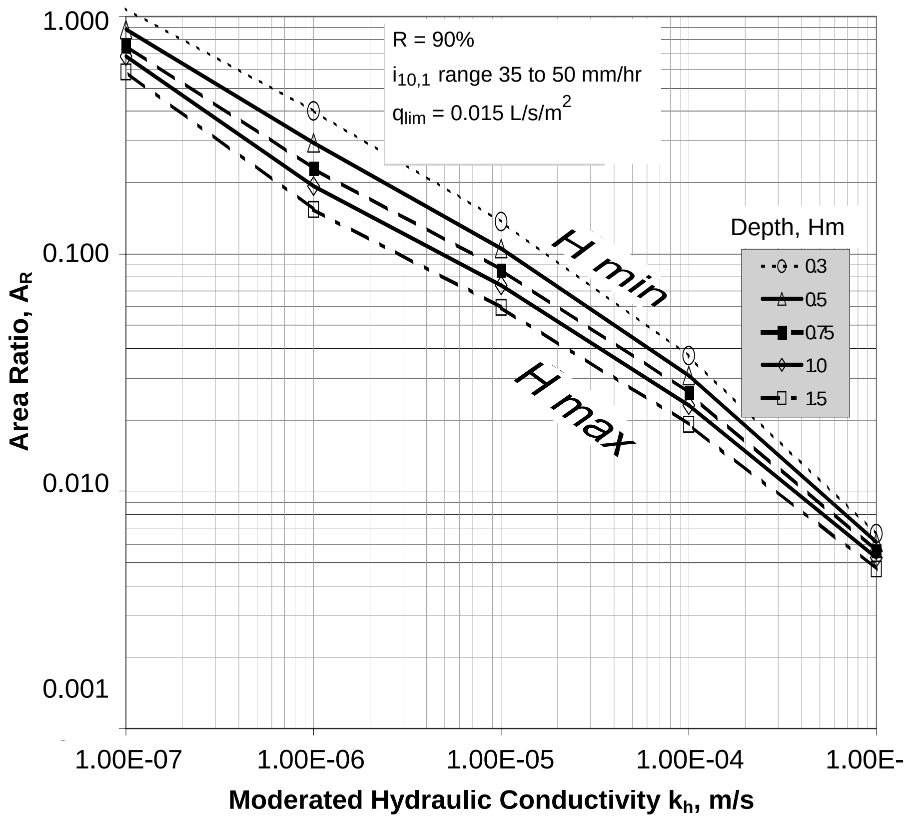

FIGURE C-2 : $i_{10,1}$ range, 35 mm/h to 50 mm/h – Mid-Intermediate Zone
Soils with moderated $k_h > 1.0 \times 10^{-4}$ m/s are, typically, unsuitable for treating *dissolved pollutants* in catchment runoff (see Mikkelsen et al, 1997; Fischer et al, 2003)

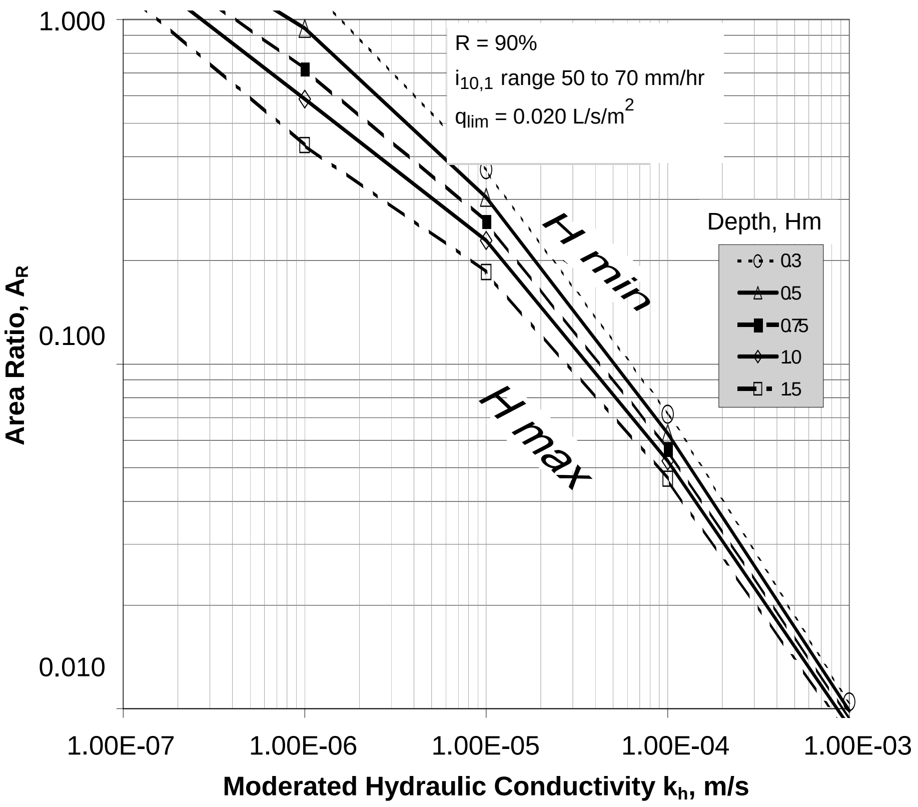

FIGURE C-3 : $i_{10,1}$ range, 50 mm/h to 70 mm/h – Upper-Intermediate Zone
Soils with moderated k_h > 1.0 × 10^{-4} m/s are, typically, unsuitable for treating *dissolved pollutants* in catchment runoff (see Mikkelsen et al, 1997; Fischer et al, 2003)

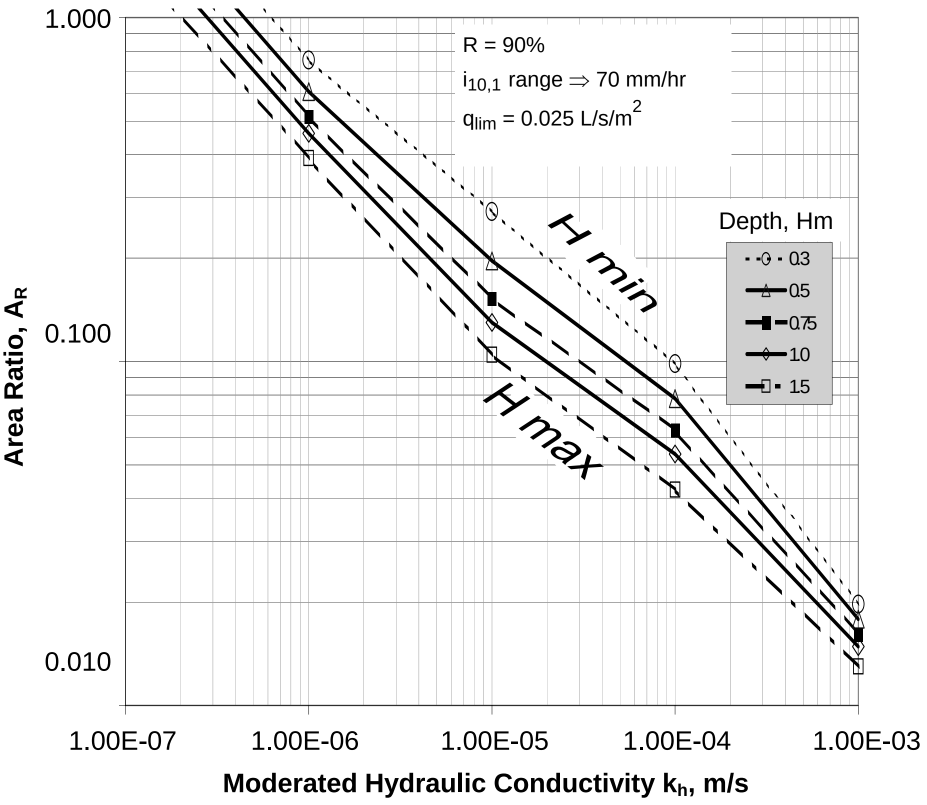

FIGURE C-4 : $i_{10,1}$ range, 70 mm/h and above – Northern Australia Zone
Soils with moderated k_h > 1.0 × 10^{-4} m/s are, typically, unsuitable for treating *dissolved pollutants* in catchment runoff (see Mikkelsen et al, 1997; Fischer et al, 2003)

APPENDIX D

DESIGN GRAPHS FOR ‘FILTER STRIP’ SWALES FOR FIVE AUSTRALIAN CLIMATE ZONES

[Climate zones are based on $i_{10,1}$ rainfall intensities*]
See Figure 3.8

*** $i_{10,1}$ rainfall intensity is that given by I.E.Aust. (1987) for ARI, Y = 10-years, duration 1-hour.**

Graph for Southern Australia is found in Figure 7.7 in Section 7.8.

$i_{10.1}$ is less than or equal to 25 mm per hour

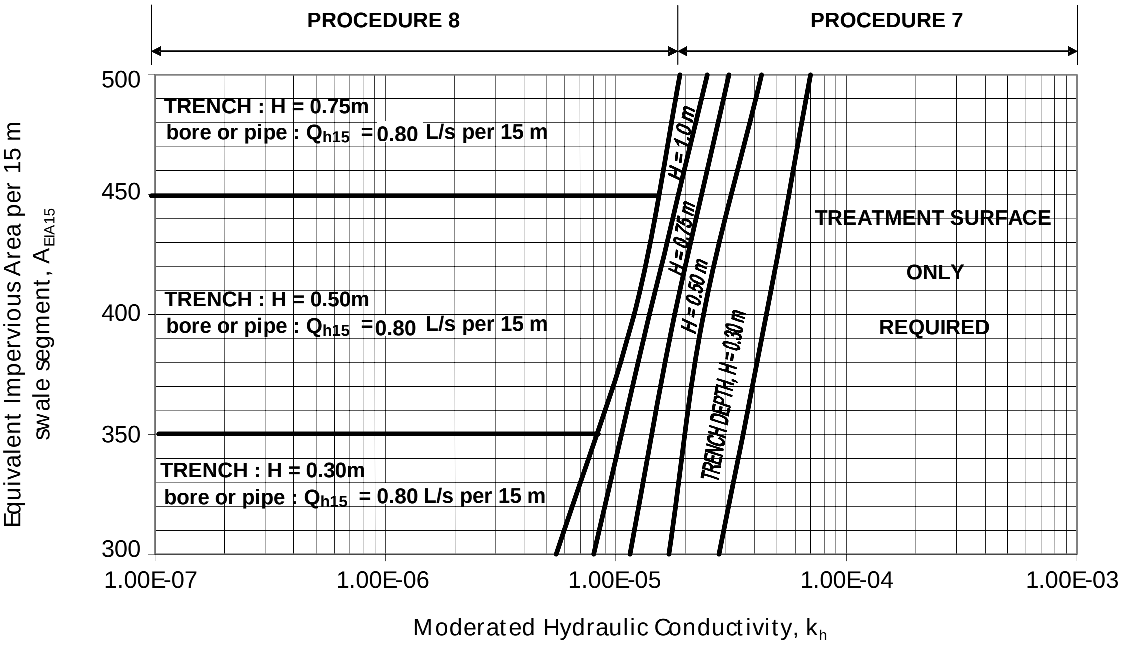

FIGURE D-1 : $i_{10,1}$ range, 25 mm/h to 35 mm/h – Lower-Intermediate Zone

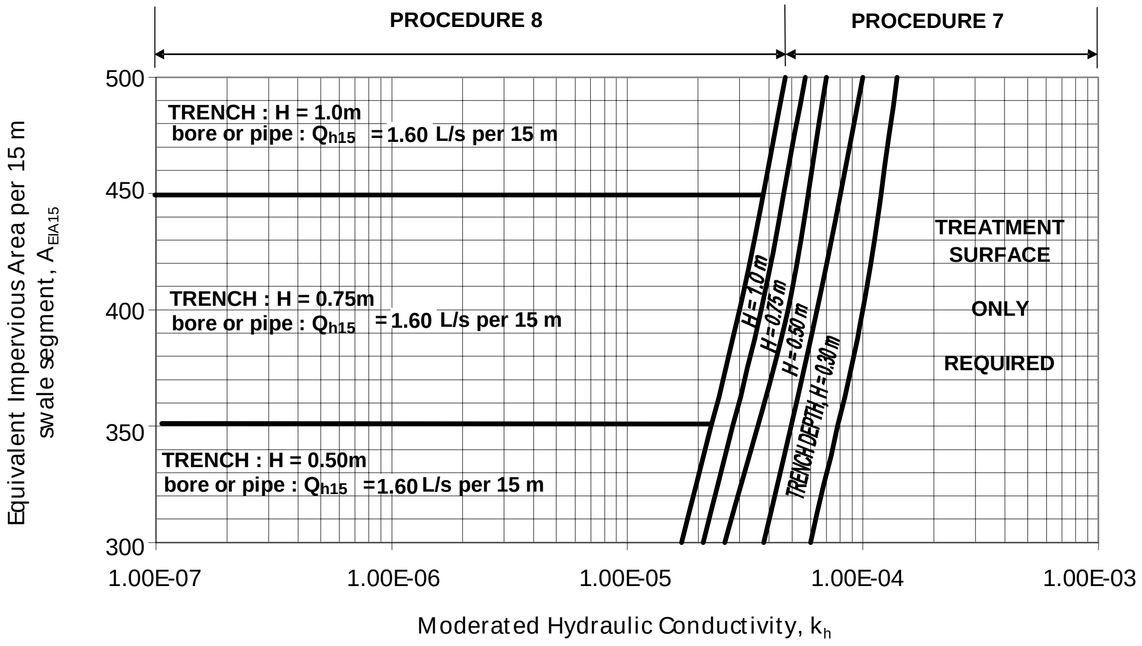

FIGURE D-2 : $i_{10,1}$ range, 35 mm/h to 50 mm/h – Mid-Intermediate Zone

Important Note: Soils with moderated $k_h > 1.0 \times 10^{-4}$ m/s are, typically, unsuitable for treating *dissolved pollutants* in catchment runoff (see Mikkelsen et al, 1997; Fischer et al, 2003)

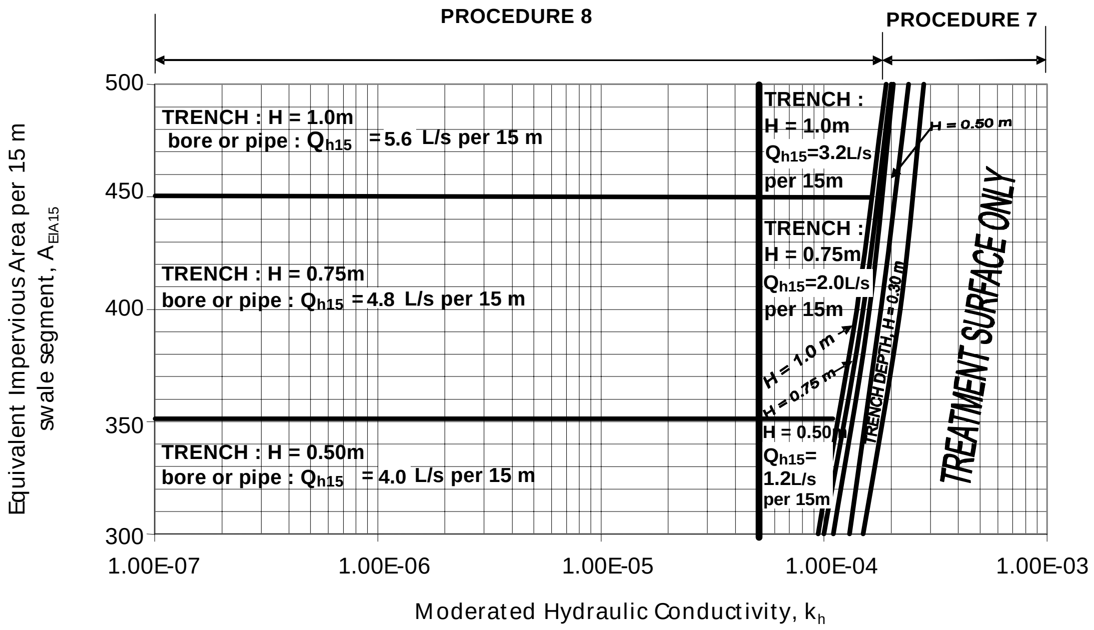

FIGURE D-3 : $i_{10,1}$ range, 50 mm/h to 70 mm/h – Upper-Intermediate Zone

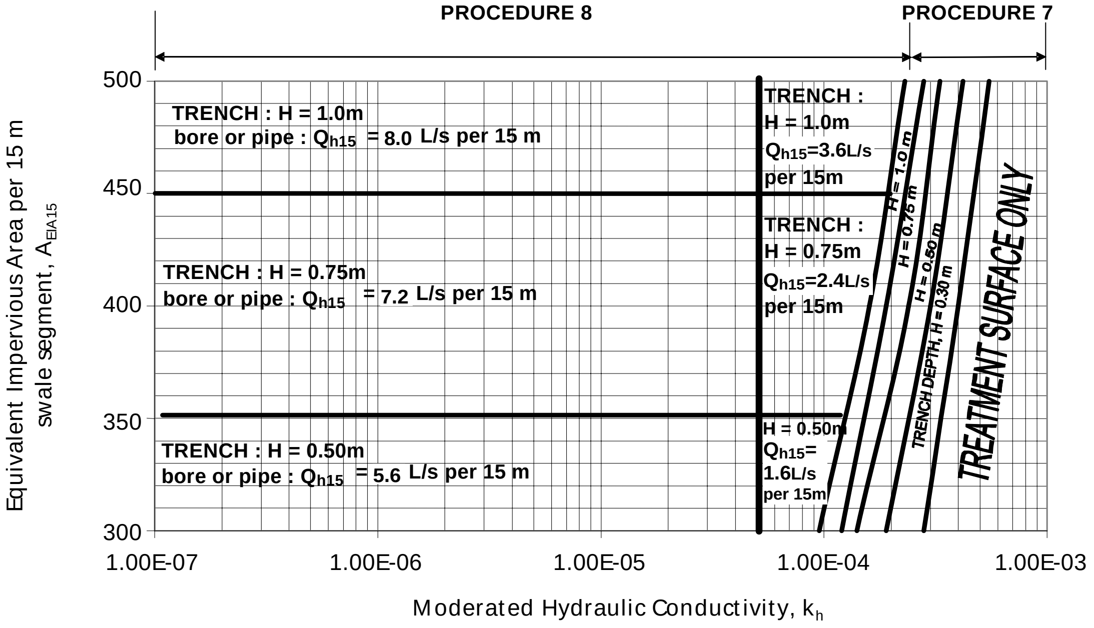

FIGURE D-4 : $i_{10,1}$ range, 70 mm/h and above – Northern Australia Zone

<u>Important Note</u>: Soils with moderated k_h > 1.0 × 10^{-4} m/s are, typically, unsuitable for treating *dissolved pollutants* in catchment runoff (see Mikkelsen et al, 1997; Fischer et al, 2003)

APPENDIX E

GRAPHS FOR A REGIONAL STORMWATER HARVESTING MODEL FOR FIVE AUSTRALIAN CLIMATE ZONES

[Climate zones are based on $i_{10,1}$ rainfall intensities*]

See Figure 3.8

*** $i_{10,1}$ rainfall intensity is that given by I.E.Aust. (1987) for ARI, Y = 10-years, duration 1-hour.**

Graph for Southern Australia is found in Figure 8.5 in Section 8.6.

$i_{10.1}$ is less than or equal to 25 mm per hour

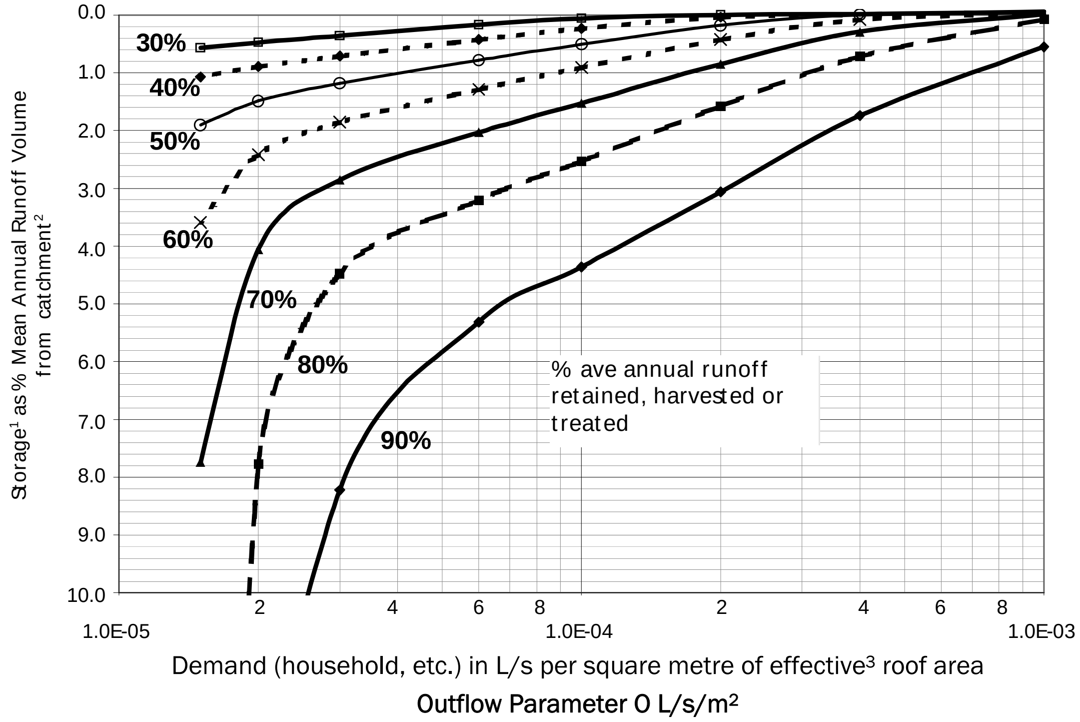

FIGURE E-1 : $i_{10,1}$ range, 25 mm/h to 35 mm/h – Lower-Intermediate Zone

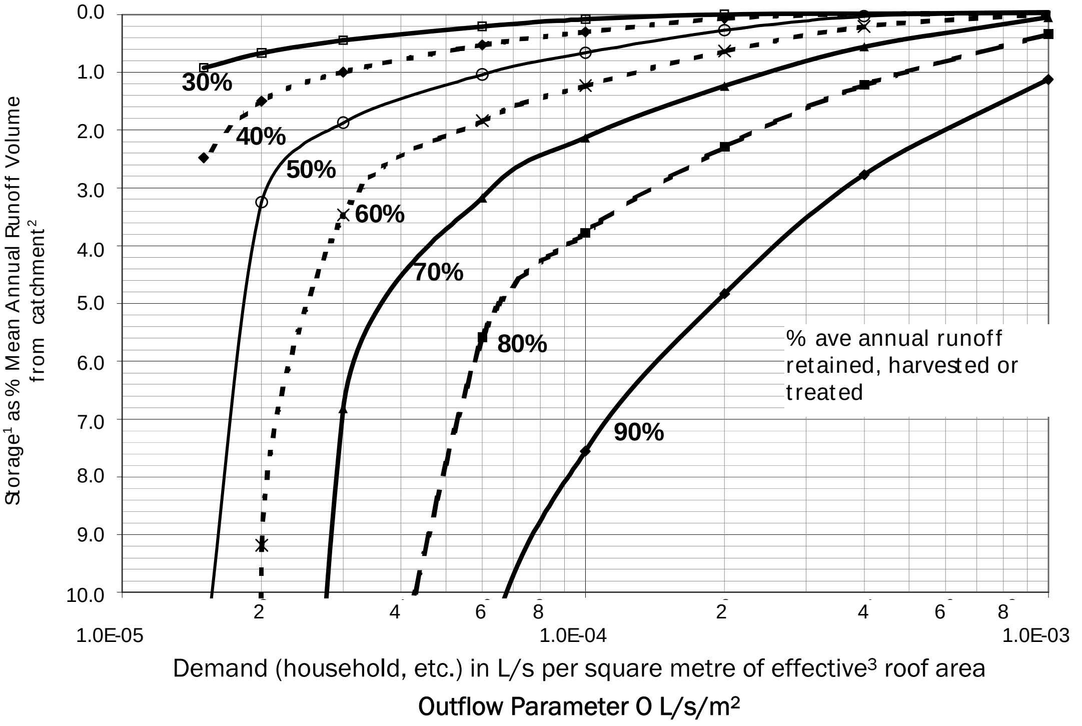

FIGURE E-2 : $i_{10,1}$ range, 35 mm/h to 50 mm/h – Mid-Intermediate Zone

NOTES : 1 : **Device** may be a pond or a rainwater tank.
2 : **Catchment** may be a ground-level paved area or a roof.
3 : Effective roof area for rainwater tanks may be as low as 80% of nominal roof area (see Section 8.3.3).

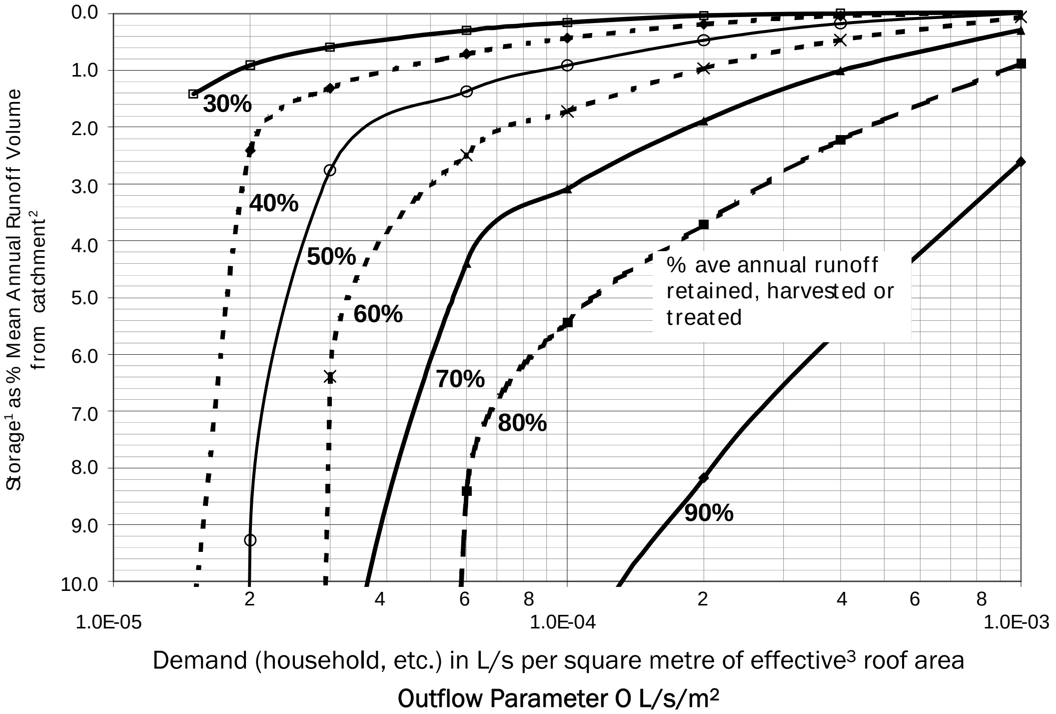

FIGURE E-3 : $i_{10,1}$ range, 50 mm/h to 70mm/h – Upper-Intermediate Zone

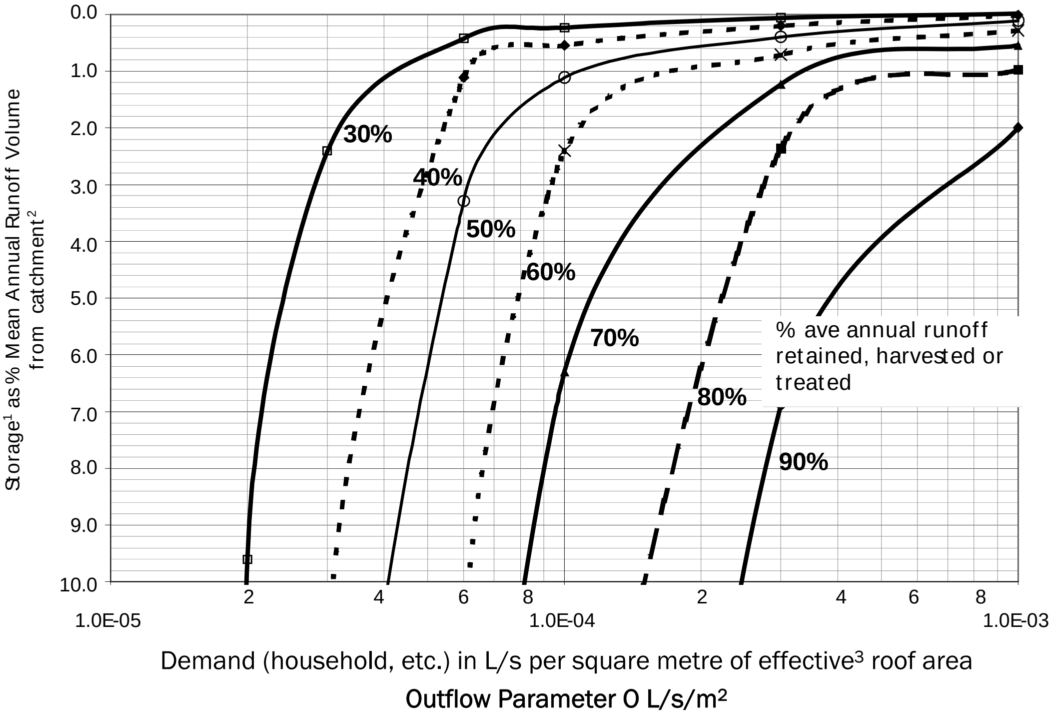

FIGURE E-4 : $i_{10,1}$ range, 70 mm/h and above – Northern Australia Zone

NOTES : 1 : **Device** may be a pond or a rainwater tank.
2 : **Catchment** may be a ground-level paved area or a roof.
3 : Effective roof area for rainwater tanks may be as low as 80% of nominal roof area (see Section 8.3.3).

APPENDIX F

TUTORIAL EXERCISES

TUTORIAL EXERCISES

EXAMPLE 1 :

The derivation of Equations 3.13 and 3.14, Section 3.2.1, includes one typographical error. Find and correct it.

EXAMPLE 2 :

Study the derivations of Equations 3.30, 3.31 and 3.32 in Section 3.5.2. Are there any typographical errors? If so find and correct them.

CHAPTER 5 : Procedures 1 – 4

One of the gravest errors which occurs in the design of storage-related flood control installations in Australia and, one suspects, overseas, arises from misunderstanding about the critical storm duration which should be used in each design context. This matter is addressed in the Handbook in Section 4.2. For this reason, the following exercises provide, typically, three 'alternative' critical storm durations : it is part of the design task to select which of these is (are) relevant to the exercise and which is (are) not.

EXAMPLE 3 :

Determine the area, A_S of a "Grasspave" vegetated porous treatment surface required for a car park with total area A = 2,500 m^2, located in Newcastle; the treatment surface must be part of (included within) the car park area. The car park is to be designed for ARI, Y = 5-years flood conditions. Also determine the expected 'lifespan' of the surface : the car park is located in an "average suburb – site with some trees" (see Table 3.1).

The alternative critical storm durations, in accordance with Section 4.2 of the Handbook are :

$$t_C = 10 \text{ minutes}; \ (T_C)_{local} = 60 \text{ mins}; \ (T_C)_{total} = 2 \text{ hours}; \ ARI = 5 \text{ years.}$$

The sand/gravel base for the "Grasspave" surface has "as constructed" hydraulic conductivity :

$$k_h = 2.5 \times 10^{-4} \text{ m/s.}$$

The blockage factor for "Grasspave" is $\Psi = 0.1$. [Ans: 1,440 m^2; 65 years]

EXAMPLE 4 :

Design an on-site stormwater retention system for runoff from a roof, A = 400 m^2, located, firstly in Perth and secondly in Brisbane : the **yield-minimum** strategy is to be applied (see Section 4.2.1 and Example 5.6 in Section 5.2). "Leaky" wells or a gravel-filled "soakaway" (e_S = 0.35) or "Atlantis" boxes (e_S = 0.95) may be used in soil of hydraulic conductivity $k_h = 1.6 \times 10^{-4}$ m/s (Perth, sandy loam) and 1.0×10^{-6}m/s (Brisbane, clay). **Local** sub-area flooding is the main design consideration :

$$\text{site } t_C = 15 \text{ minutes}, \ (T_C)_{local} = 30 \text{ minutes}; \ (T_C)_{total} = 60 \text{ minutes}; \ ARI = 2 \text{ years.}$$

Use the following to start your design :

- the well effective height, H = 2.30 m;
- "soakaway" depth, H = 0.40 m;
- "Atlantis" boxes have alternative dimensions of 0.60 m or 0.40 m.

[Ans: Perth: D = 1.50 m; a = 13.6 m^2; a = 8.14 m^2; Brisbane: 12 wells…; a = 224 m^2….; a = 216 m^2…..;]

HELPFUL HINT! The main purpose of this exercise (for Brisbane) is to show that 'source control' solutions using wells and trenches, only, sometimes lead to very impractical solutions. When you consider you have learned this lesson stop and go on to Example 5.

EXAMPLE 5 :

Repeat Example 4 (Brisbane), this time using the wells and trenches **with 'slow-drainage'** to a local waterway to solve the problem (for guidance, see Section 5.1.5 and Example 5.7, Section 5.2). [Ans: 2 wells, D = 1.70 m, q_r = 0.060 L/s; a = 71 m^2, Q_r = 0.12 L/s; a = 27 m^2, Q_r = 0.12 L/s]

EXAMPLE 6 :

Determine the plan area, $\mathbf{A_p}$, of infiltration or "dry" pond required to accept, without overflow, storm runoff from a newly developed urban area, previously a 10.0 ha "greenfields" site, near the bottom of a minor catchment in Adelaide. The **regime-in-balance** strategy is to be applied (see Section 4.2.1 and Example 5.3 in Section 5.2). When fully developed, the 10 ha site will have 5.0 ha equivalent paved area and 5.0 ha open space. ARI, Y = 100 years is to be used. Downstream flooding of local and total catchment drainage paths is considered unlikely. Relevant critical storm durations are :

site t_C = 30 minutes; $(T_C)_{local}$ = 30 minutes and $(T_C)_{total}$ = 60 minutes.

The soil at the pond site has long-term hydraulic conductivity, k_h = 5.0×10^{-5} m/s. Maximum pond depth, under design condition, d = 0.50 m.

EXAMPLE 7 :

The "Grasspave" treatment surface considered in Example 3 (Newcastle) is underlain by a gravel-filled "soakaway" (e_S = 0.35) which receives the flow, provides temporary storage and transfers the cleansed stormwater to an aquifer. Its plan area is the same as that of the treatment surface. The "soakaway" is to be designed for **yield-minimum** conditions (see Section 4.2.1 and Example 5.5 in Section 5.2). Flooding of the "soakaway" is required to be once, **only**, in every five years, on average.

- The site soil is clay for which $k_h = 1.0 \times 10^{-7}$ m/s.
- The recharge rate for the bore is estimated at q = 0.5 L/s.
- Determine a suitable depth, H, for the "soakaway".
- Alternative design storm conditions are : t_C = 30 minutes; $(T_C)_{local}$ = 60 minutes; $(T_C)_{total}$ = 2 hours; ARI = 5 years.

HINT! You will find the Equation which you need to solve this exercise in Section 5.1.5.

EXAMPLE 8 :

Determine the area, A_S of a "Hydrapave" permeable paving treatment surface required for a Council car park with **total** area A = 2,000 m^2, located in Brisbane; the treatment surface must be part of (included in) the car park area. Average recurrence interval for the facility is ARI, Y = 5-years. The following special circumstances must be taken into account in determining the area :

- The car park will be in service for a maximum of 10 years (after which time the area will become the site of a library building).
- The proposed (temporary) car park will also receive roof runoff from a Council building, area 1,000 m^2.
- "As constructed" hydraulic conductivity of "Hydrapave" permeable paving is 1.0×10^{-3} m/s.

The alternative critical storm durations are :

t_C = 10 minutes; $(T_C)_{local}$ = 60 mins; $(T_C)_{total}$ = 2 hours.

CHAPTER 7 : Procedures 5 and 6

EXAMPLE 9 : Given the following data :

Location :	Adelaide, Southern Australia zone
Soil :	medium clay, $k_h = 3 \times 10^{-6}$ m/s; Moderation factor, U = 2.0
Catchment :	paved area, $A_{EIA} = 4{,}000\ m^2$
Space available :	$A_{avail} = 600\ m^2$
Retention device :	gravel-filled "soakaway", $e_S = 0.35$.

Determine, for R = 90% and Strategy A compliance :

- treatment system capacity flow (bypass flow);
- recommended plan area of "soakaway";
- "soakaway" depth, H.

EXAMPLE 10 : Given the following data :

Location :	Newcastle, Mid-Intermediate zone
Soil :	medium clay, $k_h = 3 \times 10^{-6}$ m/s; Moderation factor, U = 2.0
Catchment :	paved area, $A_{EIA} = 4{,}000\ m^2$
Space available :	$A_{avail} = 200\ m^2$
Retention device :	gravel-filled "soakaway", $e_S = 0.35$.

Determine, for R = 90% and Strategy A compliance :

- treatment system capacity flow (bypass flow);
- recommended plan area of "soakaway";
- "soakaway" depth, H.

EXAMPLE 11 : Given the following data :

Location :	Brisbane, Northern Australia zone
Soil :	medium clay, $k_h = 3 \times 10^{-6}$ m/s; Moderation factor, U = 2.0
Catchment :	paved area, $A_{EIA} = 4{,}000\ m^2$
Space available :	$A_{avail} = 80\ m^2$
Retention device :	gravel-filled "soakaway", $e_S = 0.35$.

Determine, for R = 90% and Strategy A compliance :

- treatment system capacity flow (bypass flow);
- recommended plan area of "soakaway";
- "soakaway" depth, H.

Provision for 'slow-drainage' may be made if the space available is too small for satisfactory emptying by 'natural' drainage. In this event, determine the magnitude of 'slow-drainage' which must be provided.

EXAMPLE 12 :

Stormwater runoff from an Adelaide residential sub-division, plan area 3.0 ha, for which equivalent impervious area, A_{EIA} = 1.50 ha, is required to be treated to Strategy B standard, that is, 'first flush' treatment, only (Council specification). Local soil is sandy-clay, so a 'dry' pond appropriate to the pollution control/retention requirements of Council is to be designed (ARI, Y = 0.25-years). Given the following data :

Location : Adelaide, SA

Soil : sandy-clay, $k_h = \times 10^{-5}$ m/s; Moderation factor, U = 1.0

Catchment : paved area, $A_{EIA} = 15{,}000\ m^2$

Time of concentration : t_C = 20 minutes

Rainfall intensity : $i_{0.25} = 0.5 \times i_1$ **(3.38)**

Space available : $A_{avail} = 150\ m^2$.

Determine :

- recommended plan area of 'dry' pond;
- recommended depth of 'dry' pond;
- emptying time for 'dry' pond – compare with interim criterion (Table 3.3).