Tables and formulae for the management of surface water

Sustainable Forest Management Series

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Our environment, our future

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(Taken by Tony Smith)

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Disclaimer

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Preface

This Field Guide has been produced to assist Department of Environment and Conservation staff and Forest Products Commission personnel and contractors undertaking surface water management work within the forested areas of south-western Australia.

The Field Guide contains tables and formulae commonly used in the planning and construction of surface water management structures and conservation earthworks. Also contained are tables of spacings for drainage structures associated with forest track and firebreak construction.

The formulae and tables are based on best practice and are the basis of good planning. Basic planning principles include assessing landscapes and using designs to minimise erosion risk; reducing flow depth and hence velocity; and using stable outlets. Choosing appropriate structure locations, accurately setting out works and using appropriate construction techniques positively affects the longevity of installed works and ensures they achieve their stated aim.

This Field Guide provides a useful quick reference for surface water management planning in the field. This pocket book should be read in conjunction with the DEC publication *Manual for the Management of Surface Water* (Sustainable Forest Management Series, SFM Manual No. 3).

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Field texture grades – percentage of clay in soils

Field texture grades are used as an indication of the behaviour of a soil in surface water management and earthmoving operations

Table 1 Field texture grades

Field texture grade	Behaviour of moist bolus	Approximate clay content (per cent)
Sand	Coherence nil to very slight, cannot be moulded; sand grains of medium size; single sand grains adhere to fingers.	Commonly less than 5
Loamy sand	Slight coherence; sand grains of medium size; can be sheared between thumb and forefinger to give minimal ribbon of about 5 mm.	About 5
Clayey sand	Slight coherence; sand grains of medium size; sticky when wet, many sand grains stick to fingers; will form minimal ribbon of 5 – 15 mm; discolours fingers with clay stain.	5 to 10
Sandy loam	Bolus coherent but very sandy to touch; will form ribbon of 15 – 25 mm; dominant sand grains are of medium size and are readily visible.	10 to 20.
Loam	Bolus coherent and rather spongy; smooth feel when manipulated but with no obvious sandiness or 'silkiness'; may be somewhat greasy to the touch if much organic matter present; will form ribbon of about 25 mm.	About 25

Table 1 Field texture grades (continued)

Field texture grade	**Behaviour of moist bolus**	**Approximate clay content (per cent)**
Silty loam	Coherent bolus; very smooth to often silky when manipulated; will form ribbon of about 25 mm.	About 25 and with silt 25 or more
Sandy clay loam	Strongly coherent bolus, sandy to touch; medium size sand grains visible in finer matrix; will form ribbon of 25 – 40 mm.	20 to 30
Clay loam	Coherent plastic bolus, smooth to manipulate; will form ribbon of 40 - 50 mm.	30 to 35
Clay loam sandy	Coherent plastic bolus, medium size sand grains visible in finer matrix; will form ribbon of 40 – 50 mm.	30 to 35
Silty clay loam	Coherent smooth bolus, plastic and often silky to the touch; will form ribbon of 40 – 50 mm.	30 to 35 and with silt 25 or more
Light clay	Plastic bolus; smooth to touch; slight to moderate resistance to ribboning shear; will form ribbon of 75 mm.	35 to 40
Light medium clay	Plastic bolus; smooth to touch; slight resistance to ribboning shear; will form ribbon of 75 mm.	40 to 45
Medium clay	Smooth plastic bolus; smooth to touch; slightly greater resistance to ribboning shear than light clay; will form ribbon of about 75 mm.	45 to 55

Table 1 Field texture grades (continued)

Field texture grade	**Behaviour of moist bolus**	**Approximate clay content (per cent)**
Medium heavy clay	Smooth plastic bolus; handles like plasticine; can be moulded into rods without fracture; has moderate to firm resistance to ribboning shear; will form ribbon of 75 mm or more.	50 or more
Heavy clay	Smooth plastic bolus; handles like stiff plasticine; can be moulded into rods without fracture; has firm resistance to ribboning shear; will form ribbon of 75 mm or more.	50 or more

Source of data: McDonald, R. C. 1990, *Australian soil and land survey field handbook / R.C. McDonald ... [et al.]* Inkata Press, Melbourne :

Table 2 Suggested placement and maximum spacing for spreaders.

Placement (key positions)
Above river and stream crossings to slow and spread flow.
At bends where water would pond on the uphill side of a road or track.
Immediately prior to a soil or landform change where the down-slope soil represents an erosion risk. The outlet must be stable.

Grade of road or track (%)	Suggested maximum spacing (m)	
	Lateritic gravel soil	All other soils
0.5 - 1	180 - 130	120 - 90
1 - 2	130 - 100	90 - 60
2 - 3	100 - 80	60 - 50
3 - 4	80 - 70	50 - 40
4 - 5	70 - 60	40 - 36
5 - 6	60 - 55	36 - 32
6 - 10	55 - 45	32 - 25
10 - 20	45 - 30	25 - 15

Note:

Maximum spacing can be reduced where soils are identified as less stable.

Spreaders should be constructed on a grade of 0.3 – 0.5 per cent.

Table 3 Specification for size of spreaders

Size		Grade (%)	Water Dispersal
Height (cm)	**Width (cm)**		
40	120 - 320	0.3 – 0.5	Water directed from track into nearby vegetation or trash that can slow the movement of water.

Note:

Width depends on construction technique, source of material and level of compaction.

Table 4 Suggested placement and maximum spacing for rolling dips on tracks and firebreaks.

Placement (key positions)
Above river and stream crossings to slow and spread flow.
At bends where water would pond on the uphill side of a road or track.
Immediately prior to a soil or landform change where the down-slope soil represents an erosion risk. The outlet must be stable.

Grade of road or track (%)	**Suggested maximum spacing (m)**	
	Lateritic gravel soil	**All other soils**
0.5 - 1	180 - 130	170 - 120
1 - 2	130 - 100	120 - 90
2 - 3	100 - 80	90 - 70
3 - 4	80 - 70	70 - 60
4 - 5	70 - 60	60 - 55
5 - 6	60 - 55	55 - 50
6 - 10	55 - 45	50 - 40

Note:

Maximum spacing should be reduced where soils are identified as less stable.

Rolling dips should be constructed on a grade of 0.3 – 0.5 per cent.

Rolling dips are not suitable where the grade is greater than 10 per cent. Where the grade is greater than 10 per cent, consider using trafficable spreaders.

Table 5 Suggested maximum spacing for mitre drains.

Grade of road or track (%)	Maximum spacing of mitre drains (m)	
	Low erosion risk	High erosion risk
< 4	250 - 150	150 - 120
4 - 5	150 - 120	120 - 90
5 - 10	120 - 95	90 - 70
10 - 15	95 - 65	70 - 35
15 - 20	65 - 50	< 35

Note:

Mitre drains should be constructed on a grade of 0.3 – 0.5 per cent.

Mitre drains should intersect the road level with the edge of the running surface.

Mitre drain outlets should be located in stable, undisturbed areas and up-slope of river and stream reserves.

Suggested placement, capacity and maximum spacings for culverts.

Table 6 Relief culverts

Placement (key positions)
Above river and stream crossings to slow and spread flow.
At bends where water would pond on the uphill side of a road or track.
Immediately prior to a soil or landform change where the down-slope soil represents an erosion risk. The outlet must be stable.

Grade of road or track (%)	Suggested maximum spacing (m)	
	Low erosion risk	High erosion risk
< 4	250 - 150	150 -120
4 - 5	150 - 120	120 - 90
5 -10	120 - 95	90 - 70
10 -15	95 - 65	70 -35
15 - 20	65 - 50	< 35

Note:

Where used to empty a table drain, minimum diameter for a relief culvert is 30 cm.

Table 7 Culverts at river and stream crossings

Minimum return intervals to be used for estimating peak flow according to river or stream order		
River or stream order	**Minimum return interval (years)**	
	Temporary roads	**Permanent roads**
First and second	5	10
Third	10	20
Fourth	20	50
Fifth	50	>50

Note:

Use *Tools for the Management of Surface Water* (DEC SFM form No. 017) to estimate peak flow at the appropriate return interval.

Use a culvert, combination of culverts or bridge design with sufficient capacity to accommodate the estimated peak flow.

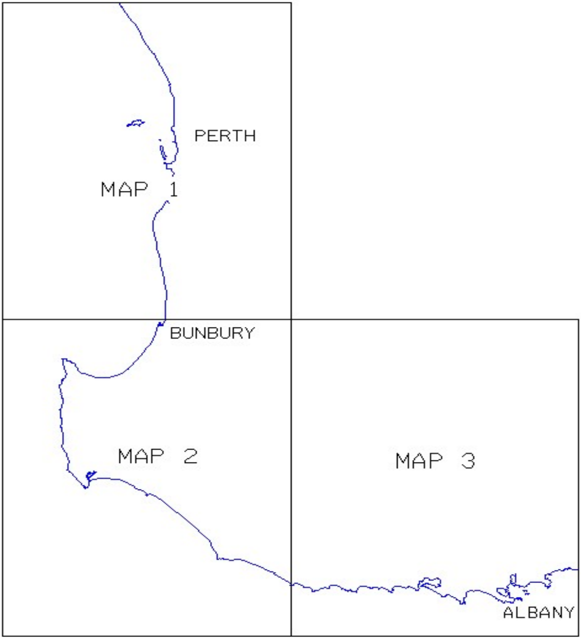
In circumstances where the recommended return interval is not used, the proponent must provide a clear justification for this, including an analysis of the flow, the values at risk and the cost-benefit of the proposed alternative.

This table will be adapted once the DEC Road Management Manual and designated road categories are developed.

Average annual rainfall

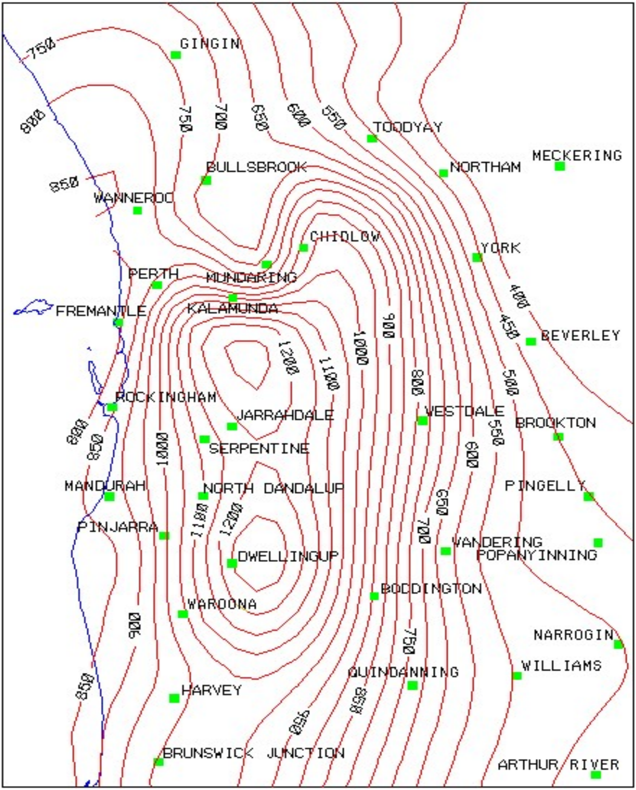
Average annual rainfall as used in the prediction of runoff using the Flood Index Method.

Index to maps on following pages



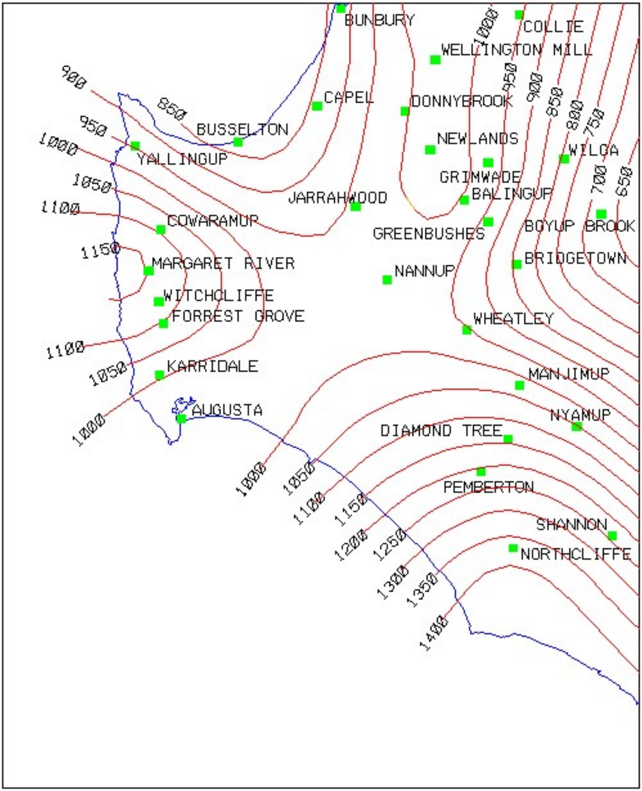
Source: BOM rainfall data to 2008. Only long term average rainfall has been used to produce the maps. Any stations that did not record continuously from 1946 to 2008 are not included.

Map 1 Average annual rainfall (north)



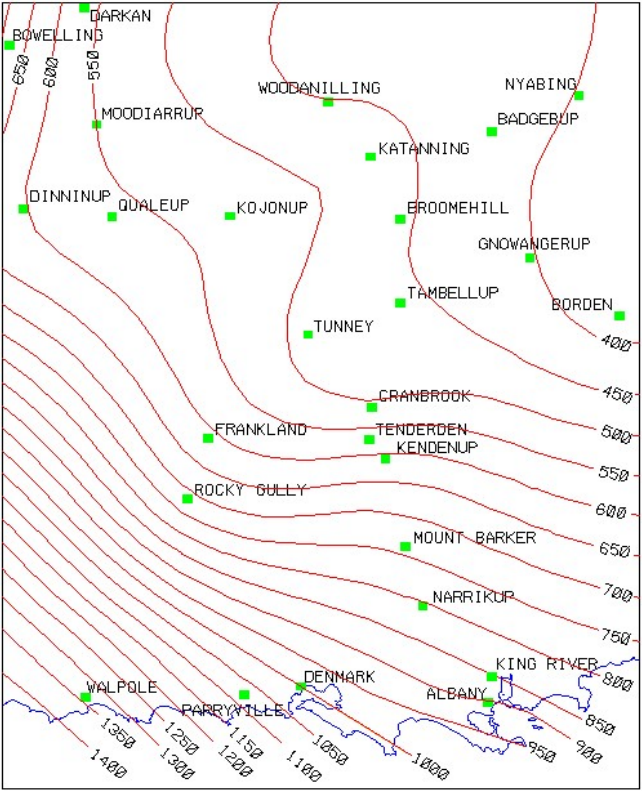
Source: BOM rainfall data to 2008. Only long term average rainfall has been used to produce this map. Any stations that did not record continuously from 1946 to 2008 are not included.

Map 2 Average annual rainfall (south west)



Source: BOM rainfall data to 2008. Only long term average rainfall has been used to produce this map. Any stations that did not record continuously from 1946 to 2008 are not included.

Map 3 Average annual rainfall (south east)



Source: BOM rainfall data to 2008. Only long term average rainfall has been used to produce this map. Any stations that did not record continuously from 1946 to 2008 are not included.

Runoff formulae

Runoff volume prediction for determination of earthwork capacity

1. Flood Index Method

(i) ***Loamy soil catchments 75-100% cleared***

$$Q_5 = 2.77 \times 10^{-6} A^{0.52} P^{2.12}$$

Frequency factors Q_Y/Q_5 are:

ARI (years)	2_y	5_y	10_y	20_y	50_y
	0.48	1.00	1.84	3.23	6.10

(ii) ***Loamy and lateritic soil catchments***

$$Q_5 = 3.04 \times 10^{-1} A^{0.60} 10^{0.0052C_L}$$

Frequency factors Q_Y/Q_5 are:

ARI (years)	2_y	5_y	10_y	20_y	50_y
	0.50	1.00	1.76	3.05	5.65

(iii) ***Jarrah forest with lateritic soils***

$$Q_2 = 8.22 \times 10^{-9} A^{0.73} P^{2.22} (LS_e)^{0.28} 10^{0.0064C_L}$$

Frequency Factors (Q_Y/Q_2)

ARI (years)	2_y	5_y	10_y	20_y	50_y
0% cleared	1.00	1.60	2.20	3.00	4.25
50% cleared	1.00	1.45	1.85	2.30	3.00
100% cleared	1.00	1.28	1.50	1.75	2.05

(iv) ***Jarrah forest with loamy soils***

$$Q_2 = 3.68 \times 10^{-8} A^{0.68} P^{2.29} 10^{0.0081 C_L}$$

Frequency Factors (Q_Y/Q_2)

ARI (years)	2_y	5_y	10_y	20_y	50_y
0-100% cleared	1.00	1.75	2.55	3.50	5.10

(v) ***Karri forest with loamy soils (less than 15% cleared)***

$$Q_2 = 6.01 \times 10^{-9} A^{0.87} P^{2.41}$$

Frequency Factors (Q_Y/Q_2)

ARI (years)	2_y	5_y	10_y	20_y	50_y
	1.00	1.51	1.94	2.40	3.05

where:

Q_2 = peak flow for 2 year return
Q_5 = peak flow for 5 year return
Q_Y = peak flow (m^3s^{-1}) for y years
A = area of catchment (km^2)
C_L = area of catchment cleared as a percentage (%)
P = average annual rainfall (mm)
L = main stream length (km)
S_e = equal area slope (m/km)

2. Rational Method

(i) ***Loamy soil catchments 75-100% cleared***

$t_c = 0.76\ A^{0.38}$

$C_{10} = 3.46 \times 10^{-1}\ L^{-0.42}$

and $Q_Y = 0.278 \times C_{10} \frac{C_Y}{C_{10}}\ It_{c,Y}\ A$

Frequency Factors (C_Y/C_{10})

ARI (years)	2*y*	5*y*	10*y*	20*y*	50*y*
	0.41	0.65	1.00	1.54	2.20

(ii) ***Loamy and lateritic soil catchments***

$t_c = 0.76\ A^{0.38}$

$C_{10} = 1.06 \times 10^{-1}\ L^{-0.32}\ 10^{0.0042C_L}$

Frequency factors C_Y/C_{10} are:

ARI (years)	2_y	5_y	10_y	20_y	50_y
	0.43	0.67	1.00	1.45	1.98

and $Q_Y = 0.278 \times C_{10} \frac{C_Y}{C_{10}}\ It_{c,Y}\ A$

(iii) ***Jarrah forest with lateritic soils***

$$t_c = 2.31\,A^{0.54}$$

$$C_{10} = 3.12 \times 10^{-2}\,10^{0.0043 C_L}\,(LS_e)^{0.24}$$

Frequency factors C_y/C_{10} are:

ARI (years)	2_y	5_y	10_y	20_y	50_y
0% cleared	0.70	0.86	1.00	1.15	1.33
50% cleared	0.75	0.88	1.00	1.13	1.27
100% cleared	0.81	0.91	1.00	1.10	1.21

and $Q_Y = 0.278 \times C_{10}\,\frac{C_Y}{C_{10}}\,It_{c,Y}\,A$

(iv) ***Jarrah forest with loamy soils***

$$t_c = 2.31\,A^{0.54}$$

$$C_{10} = 2.15 \times 10^{-1}\,10^{0.0073 C_L}$$

Frequency factors C_y/C_{10} are:

ARI (years)	2_y	5_y	10_y	20_y	50_y
0-100% cleared	0.57	0.80	1.00	1.20	1.42

and $Q_Y = 0.278 \times C_{10}\,\frac{C_Y}{C_{10}}\,It_{c,Y}\,A$

(v) ***Karri forest with loamy soils***

$$t_c = 2.31\,A^{0.54}$$

$$C_{10} = 6.56 \times 10^{-2} A^{0.22}$$

Frequency factors C_Y/C_{10} are:

ARI (years)	2_y	5_y	10_y	20_y	50_y
	0.79	0.91	1.00	1.08	1.16

and $$Q_Y = 0.278 \times C_{10} \frac{C_Y}{C_{10}} It_{c,Y}\, A$$

where:

C_{10} = 10 year return period coefficient
C_Y = return period coefficient for y years
Q_Y = peak flow (m^3s^{-1}) for y years
A = area of catchment (km^2)
L = mainstream length (km)
S_e = equal area slope (m/km)
C_L = area of catchment cleared as a percentage (%)
It_{cY} = design average rainfall intensity (mm) for return interval of Y years and duration t_c (h)
t_c = time of concentration (h)

Table 8 Box culverts (small size range to 1200 mm x 1200 mm) - approximate capacities in cubic metres/second (m^3s^{-1})

Inlet head (m) (height of water over top of culvert)	Nominal culvert height x width (mm)				
	300x1200	450x1200	600x1200	900x1200	1200x1200
0.1	0.34	0.6	1.04	1.80	2.68
0.2	0.48	0.79	1.26	2.05	2.94
0.3	0.57	0.92	1.41	2.32	3.28
0.4	0.65	1.04	1.54	2.51	3.57
0.5	0.72	1.14	1.67	2.68	3.79
0.6	0.79	1.23	1.78	2.84	3.99
0.7		1.32	1.89	2.99	4.19
0.8			1.99	3.14	4.37
0.9				3.28	4.55
1.0					4.72

Note: Estimates are based on average capacities for culverts installed on sloping landscapes, laid on a 1 per cent grade and functioning under inlet control.

Table 9 Box culverts (size range above 1200 mm x 1200 mm) - approximate capacities in cubic metres/second (m^3s^{-1})

Inlet head (m) (height of water over top of culvert)	Nominal culvert height x width (mm)				
	1500x1500	1800x1800	2400x2400	3000x3000	3600x3600
0.1	4.59	7.15	14.40	24.99	39.21
0.2	4.96	7.62	15.18	26.02	40.56
0.3	5.32	8.10	15.92	27.05	41.91
0.4	5.85	8.69	16.66	28.08	43.27
0.5	6.24	9.36	17.48	29.11	44.62
0.7	6.68	10.26	19.52	31.71	47.33
1.0	7.66	11.37	21.45	35.34	53.03
1.2		12.06	22.59	37.03	55.72
1.5			24.21	38.89	59.03
1.75			25.51	41.42	61.78
2.0				43.24	64.31
2.1					65.29

Note: Estimates are based on average capacities for culverts installed on sloping landscapes, laid on a 1 per cent grade and functioning under inlet control. Seek advice from a qualified engineer where single or a series of box culverts, greater than 1200 x 1200 mm, are used to replace bridges.

Table 10 Pipe culverts (less than 1 metre in diameter) - approximate capacities in cubic metres/second (m^3s^{-1})

Inlet head (m) (height of water over top of pipe)	Pipe diameter (mm)								
	300	375	450	525	600	675	750	825	900
0.1	0.08	0.15	0.25	0.36	0.49	0.55	0.78	0.91	1.17
0.2	0.09	0.16	0.27	0.41	0.56	0.61	0.92	1.01	1.39
0.3	0.10	0.18	0.29	0.44	0.62	0.67	1.00	1.09	1.52
0.4	0.11	0.19	0.31	0.49	0.68	0.72	1.11	1.17	1.65
0.5	0.11	0.20	0.33	0.52	0.73	0.78	1.19	1.25	1.75
0.6	0.12	0.21	0.35	0.54	0.78	0.82	1.27	1.32	1.87
0.7		0.23	0.36	0.57	0.82	0.86	1.34	1.39	1.96
0.8			0.38	0.59	0.85	0.89	1.40	1.45	2.07
0.9				0.62	0.89	0.92	1.47	1.51	2.16
1.0							1.53	1.57	2.25

Note: Estimates are based on average capacities for culverts installed on sloping landscapes, laid on a 1 per cent grade and functioning under inlet control. Concrete; corrugated metal with helical corrugations; spiral rib metal; and Polyvinyl Chloride pipes all perform similarly. Pipes manufactured from corrugated High Density Polyethylene (HDPE) generate slightly less capacity.

Table 11 Pipe culverts (more than 1 metre in diameter) - approximate capacities in cubic metres/second (m^3s^{-1})

Inlet head (m) (height of water over top of pipe)	Pipe diameter (mm)							
	1050	1200	1350	1500	1650	1800	1950	2100
0.1	1.69	2.32	3.08	3.98	5.01	6.22	7.55	9.06
0.2	2.00	2.71	3.51	4.42	5.46	6.68	8.02	9.59
0.3	2.16	2.93	3.84	4.90	6.13	7.53	8.97	10.59
0.4	2.32	3.12	4.08	5.19	6.46	7.92	9.53	11.34
0.5	2.45	3.29	4.30	5.45	6.78	8.29	9.95	11.82
0.7	2.70	3.65	4.72	5.94	7.35	8.98	10.74	12.73
1.0	3.11	4.13	5.32	6.66	8.21	9.90	11.80	13.96
1.2		4.42	5.67	7.12	8.73	10.54	12.53	14.70
1.5				7.78	9.47	11.4	13.52	15.82
1.75					10.16	12.00	14.31	16.72
2.0							14.97	17.57
2.1								18.87

Note: Estimates are based on average capacities for culverts installed on sloping landscapes, laid on a 1 per cent grade and functioning under inlet control. Concrete; corrugated metal with helical corrugations; spiral rib metal; and Polyvinyl Chloride pipes perform similarly. High Density Polyethylene (HDPE) pipes generate slightly less capacity. Seek advice from a qualified engineer where single or a series of culverts, greater than 1.05 m diameter, are used to replace bridges.

Manning’s formula

Manning’s formula is used in the calculation of channel velocity and hence the determination of channel flow volume.

1. Manning’s formula is:

$$v = \frac{1}{n} R^{2/3} s^{1/2}$$

2. Volume is:

$$Q = v \times A$$

where in both formulae:

v = average velocity of flow (ms^{-1})
R = hydraulic radius = $\frac{\text{cross sectional area } (m^2)}{\text{wetted perimeter } (m)}$
s = slope of channel bed in metres per metre
n = Manning's roughness coefficient
Q = volume of flow (m^3s^{-1})
A = cross sectional area (m^2).

Note:

(i) Calculated velocity should not exceed Average Maximum Permissible Velocity of Flow - table on page 25.
(ii) Hydraulic radius as derived from appropriate formula for channel shape pages 27 – 29.
(iii) ‘n’ from table of Manning’s ‘n’ Typical Values page 30 - 32.
(iv) Slope of channel bed in metres per metre is the difference in elevation in metres over a given length of channel divided by that length of channel in metres.

Table 12 Suggested maximum permissible velocities of temporary flow over soils by type and vegetative cover.

Material	Suggested Maximum Permissible Velocity (ms^{-1}) [a]		
	Bare	**Medium grass cover**	**Very good grass cover**
Sand	0.4	0.7	1.2
Loamy sand	0.4	0.7	1.2
Sandy loam	0.6	1.2	1.5
Loam	0.7	1.25	1.7
Sandy clay loam	0.7	1.25	1.7
Clay loam	0.75	1.3	1.8
Clay loam sandy	0.75	1.3	1.8
Medium to heavy clay	1.2	1.4	2.0
Coarse gravels[b]	1.2	1.4	NA [c]
Loose rocks/boulders	2.5		

Note:

[a] Only use velocities exceeding 1.5 ms^{-1} where grass cover is good and can be maintained. Reduce velocities for flows over easily eroded soils by 20 per cent (i.e. multiply suggested velocity by 0.80), whether bare or vegetated. For flows on slopes greater than 5% reduce velocities by 15 per cent (i.e. multiply suggested velocity by 0.85).

[b] Coarse gravel < 60 mm in diameter.

[c] Unlikely to form very good grass cover.

Table 13 Suggested Maximum Permissible Velocities of flow for channels lined with Reno Mattresses or Gabions

Material	Suggested Maximum Permissible Velocity (ms^{-1})[a]				
	Stone ranging in size (mm)[b]				
	70 – 100	**70 - 120**	**70 – 150**	**100 – 150**	**100 – 200**
Reno mattresses - thickness					
0.17 m	3.5				
0.23 m	3.6		4.5		
0.30 m		4.2		5.0	
Gabions - thickness					
0.50 m					5.8

Note:

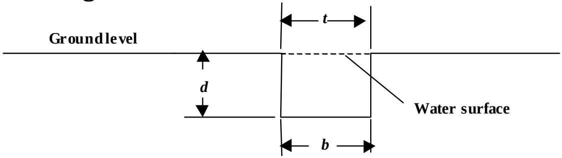
[a] At velocities, greater than Maximum Permissible Velocity, the structure will deform.
[b] Stone size is not uniform. Size range is an assortment of sizes within the given range. Stones are sorted and placed in the structure with a slight overfilling to allow for settlement.

Where stone is machine placed in structure, stone of a more uniform size is used. The chosen size is based on stacked height, related to minimising voids and relevant to the thickness of the mattress or gabion.

Hydraulic radius, cross-sectional area and wetted perimeter

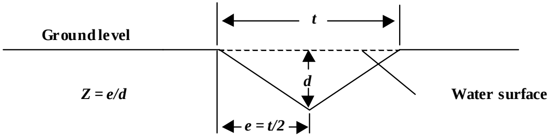
Hydraulic relationships derived from channel dimensions and used with Manning's formula to predict channel capacity. Different shaped channels have different hydraulic radius, cross-sectional area and wetted perimeter and consequently have different flow characteristics.

1. Rectangular cross-section



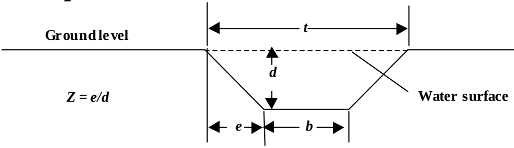
Cross-sectional area (A)	Wetted perimeter	Hydraulic radius (R)
bd	$b + 2d$	$\frac{bd}{b + 2d}$

2. Triangular cross-section



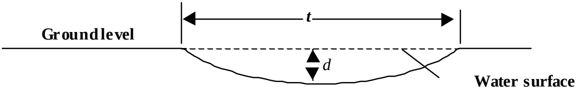
Cross-sectional area (A)	Wetted perimeter	Hydraulic radius (R)
Zd^2	$2d\sqrt{Z^2 + 1}$	$\frac{Zd^2}{2d\sqrt{Z^2 + 1}}$

3. Trapezoidal cross-section



Cross-sectional area (A)	Wetted perimeter	Hydraulic radius (R)
$bd + Zd^2$	$b + 2d\sqrt{Z^2 + 1}$	$\frac{bd + Zd^2}{b + 2d\sqrt{Z^2 + 1}}$

4. Parabolic cross-section



Cross-sectional area (A)	Wetted perimeter	Hydraulic radius (R)
$\frac{2}{3}td$	$t + \frac{8d^2}{3t}$	$\frac{t^2d}{1.5t^2 + 4d^2}$

where in all the formula:

t = top width of flow

b = base width of channel

Z = slope of channel side (Z:1) or *e/d* or horizontal over vertical

d = depth of flow.

Table 14 Coefficients of roughness 'n' for various channel surfaces as used in Manning's formula.

Surface	Manning's 'n'		
	Min	**Design**	**Max**
Bare soil			
Fine sand colloidal		0.020	
Sandy loam non-colloidal		0.020	
Loam and plastic clay		0.020	
Fine gravel > 2 mm		0.020	
Coarse gravel < 60 mm		0.025	
Low plasticity (stiff) clay		0.025	
Soils with stony surface			
- rounded		0.035	
- angular		0.040	
Grassed, constructed waterway, in sand to fine gravel soils			
Average depth of flow is 2 or more times grass height	0.025		0.030
Average depth of flow is 1 to 2 times grass height	0.030		0.040
Average depth of flow is similar to grass height	0.045		0.070
Average depth of flow is less than one half grass height	0.070		0.120

Table 14 Coefficients of roughness 'n' for various channel surfaces as used in Manning's formula (continued).

Surface	Manning's 'n'		
	Min	Design	Max
Grassed, constructed waterway, in stiff (low plasticity) clay and course gravel soils			
Average depth of flow is 2 or more times grass height	0.030		0.035
Average depth of flow is 1 to 2 times grass height	0.035		0.045
Average depth of flow is similar to grass height	0.050		0.075
Average depth of flow is less than one half grass height	0.075		0.125
Minor natural streams < 30 m wide			
Straight bank, full stage, no rifts (shallow stony sections) or deep pools	0.025	0.030	0.033
Straight bank, full stage, no deep pools, some weeds and stones	0.030	0.035	0.040
Winding bank, some pools and shoals	0.033	0.040	0.045
Winding bank, some pools, shoals, weeds and stones	0.035	0.045	0.050
Scattered shrubs, grasses and weeds - degraded natural vegetation	0.035	0.050	0.070
Light shrubs and trees - natural vegetation	0.040	0.060	0.080
Medium to dense shrubs and trees - natural vegetation	0.070	0.100	0.160

Table 14 Coefficients of roughness 'n' for various channel surfaces as used in Manning's formula (continued).

Surface	Manning's 'n'		
	Min	Design	Max
Major natural streams > 30 m wide			
Regular cross-section with no boulders or shrubs	0.025		0.060
Irregular and rough cross-section	0.035		0.100
Floodplain			
Cultivated areas, no crop	0.020	0.030	0.040
Cultivated areas, mature row crop	0.025	0.035	0.045
Pasture with short grass, no brush	0.025	0.030	0.035
Pasture with long grass, no brush	0.030	0.035	0.050
Scattered brush with grasses and weeds	0.035	0.050	0.070
Light brush and trees, heavy foliage – natural vegetation	0.040	0.060	0.080
Medium to dense brush and trees, heavy foliage – natural vegetation	0.070	0.100	0.160
Artificial channels			
Concrete culvert, straight and free of debris	0.010	0.011	0.013
Reno mattresses and gabions stone accurately placed and of uniform size	0.022		0.027
Masonry rubble, cemented	0.018	0.025	0.030
Masonry rubble, dry	0.023	0.032	0.035
Timber/logs	0.011	0.013	0.015

Waterways (constructed) – calculations of depth and width

For a given peak flow and determined maximum permissible velocity, Manning’s formula is used to calculate waterway depth and hence width.

1. Depth

   Manning’s formula is used with the hydraulic radius substituted by the average depth of flow (d_{av}). The formula is transposed so that the average depth is the unknown portion of the equation.

$$d_{av} = v^{1.5}\, n^{1.5}\, s^{-0.75}$$

2. Width

   Knowing the average depth, the width (w) can be calculated for the given peak flow at that depth.

$$w = \frac{Q}{d_{av}.v}$$

where, in both formulae:

d_{av} = average depth
v = maximum permissible velocity
s = slope of channel bed in metres/metre
n = Manning's roughness coefficient
Q = design peak flow
w = width
A = cross sectional area of flow

Side slopes for open channels

Side slopes ratios determined by soil texture and stability to alleviate sloughing.

Table 15 Suggested maximum side slope ratios for open channels

Soil type	**Side slope (Horizontal : Vertical)**	
	Shallow channels up to 1.2 m deep	**Deep channels 1.2 m and deeper**
Sand – clayey sand	2 : 1	3 : 1
Sandy loam – silt loam	1.5 : 1	2 : 1
Sandy clay loam – light clay	1 : 1	1.5 : 1
Light medium clay - heavy clay	0.5 : 1	1 : 1

Note:

(i) Side slope may also be described as vertical:horizontal. Either way the vertical component is always 1.

(ii) The word batter is sometimes used to describe side slope. Batter can also be the inclination from the vertical. In which case, 1 will be the horizontal component (ie. a batter of 3 : 1 is 1 metre inclination for every 3 metres rise).

Volumes (V) of circular dams in m^3 (batters 3:1)

Formula for determining constructed dam storage capacity and table of dimensions per volume for dam site pegging.

$$V = \pi (R^2 + Rr + r^2) \frac{d}{3}$$

where:

R = radius of water surface (m)
r = radius of floor (m)
d = depth (m)
π = *Pi* or 22÷7 or 3.14159

Table 16 Top radii for volumes of circular dams in m^3 at given depths.

Volume (m^3)	Depth (m) 4.0	5.0	6.0	7.0	8.0	9.0
4000	23.5	22.85	22.6			
4500	24.6	23.85	23.55			
5000	25.65	24.8	24.45			
5500	26.65	25.7	25.25	25.1		
6000	27.55	26.55	26.05	25.85		
6500	28.45	27.35	26.8	26.6		
7000	29.35	28.15	27.55	27.3		
7500	30.22	28.9	28.25	27.95		
8000	31.0	29.65	28.95	28.6	28.45	
8500	31.75	30.35	29.6	29.2	29.05	
9000	32.55	31.05	30.24	29.8	29.6	
9500	33.25	31.7	30.85	30.4	30.15	
10000	34.0	32.35	31.45	30.95	30.7	
10500	34.7	33.0	32.0	31.5	31.2	31.1
11000	35.4	33.6	32.6	32.0	31.75	31.6
11500	36.05	34.2	33.15	32.55	32.25	32.1
12000	36.7	34.8	33.7	33.05	32.7	32.55

(these volumes and depths produce floor sizes too small to accommodate bulldozer)

Volumes (V) of rectangular dams in m³ (batters 3:1) and side ratio of 3:2

Formula for determining constructed dam storage capacity and table of dimensions per volume for dam site pegging.

$$V = \left[(L \times W) + (l \times w) + [(L + l) \times (W + w)]\right] \frac{d}{6}$$

where:

- L = length of water surface (m)
- W = width of water surface (m)
- l = length of floor (m)
- w = width of floor (m)
- d = depth of water from surface to floor (m)

Table 17 Top sizes for volumes of rectangular dams in m³ at given depths.

Volume (m³)	Depth (m) 4.0	5.0	6.0	7.0
4000	52.9 x 35.3	51.9 x 34.6	(these volumes and depths produce floor sizes too small to accommodate bulldozer)	
4500	55.3 x 36.9	54.1 x 36.1		
5000	57.6 x 38.4	56.2 x 37.5		
5500	59.7 x 39.8	58.1 x 38.8		
6000	61.8 x 41.2	60.0 x 40.0		
6500	63.7 x 42.5	61.8 x 41.2	61.0 x 40.7	
7000	65.6 x 43.7	63.5 x 42.3	62.6 x 41.7	
7500	67.4 x 45.0	65.1 x 43.4	64.1 x 42.8	
8000	69.2 x 46.1	66.7 x 44.5	65.6 x 43.7	
8500	70.9 x 47.3	68.3 x 45.5	67.0 x 44.7	
9000	72.5 x 48.4	69.8 x 46.5	68.4 x 45.6	
9500	74.2 x 49.4	71.2 x 47.5	69.8 x 46.5	69.2 x 46.1
10000	75.7 x 50.5	72.6 x 48.4	71.1 x 47.4	70.4 x 46.9
10500	77.2 x 51.5	74.0 x 49.3	72.3 x 48.2	71.6 x 47.7
11000	78.7 x 52.5	75.3 x 50.2	73.6 x 49.0	72.8 x 48.5
11500	80.2 x 53.5	76.6 x 51.1	74.8 x 49.9	73.9 x 49.3
12000	81.6 x 54.4	77.9 x 51.9	76.0 x 50.6	75.0 x 50.0

Volumes (V) of square dams in m^3 (batters 3:1)

Formula for determining constructed dam storage capacity and table of dimensions per volume for dam site pegging.

$$V = [L^2 + (L \times l) + l^2] \frac{d}{3}$$

where:

L = top length of water surface (m)
l = floor length (m)
d = depth of water from surface to floor (m)

Table 18 Top lengths for volumes of square dams in m^3 at given depths.

Volume (m^3)	Depth (m) 4.0	5.0	6.0	7.0	8.0	9.0
4000	42.9	41.9	41.6			
4500	44.8	43.7	43.3			
5000	46.7	45.4	44.9			
5500	48.4	47.0	46.4	46.3		
6000	50.1	48.6	47.9	47.6		
6500	51.7	50.0	49.2	48.9		
7000	53.3	51.4	50.5	50.2		
7500	54.7	52.7	51.8	51.4		
8000	56.2	54.1	53.0	52.5	52.4	
8500	57.6	55.3	54.2	53.7	53.5	
9000	58.9	56.5	55.3	54.7	54.5	
9500	60.2	57.7	56.4	55.8	55.6	
10000	61.5	58.9	57.5	56.8	56.5	
10500	62.8	60.0	58.5	57.8	57.5	
11000	64.0	61.1	59.5	58.7	58.4	58.3
11500	65.2	62.2	60.5	59.7	59.3	59.2
12000	66.3	63.2	61.5	60.6	60.2	60.0

(these volumes and depths produce floor sizes too small to accommodate bulldozer)

Volumes of storage above ground (wedge) in m^3

Above ground volume of dam are not excavated during construction. However, these are calculated to determine the volume of material available for wall construction or the volume of above ground storage, preconstruction or post construction.

1. Square and Rectangular Dams

$$V = A\left(\frac{a + b + c}{3}\right)$$

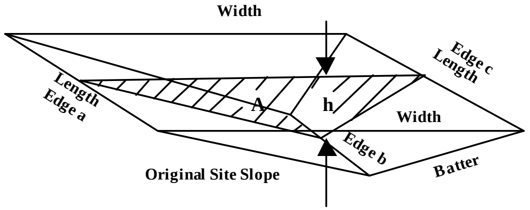
where:

A = cross sectional area (width x $\frac{h}{2}$)

a = edge a (water level length)

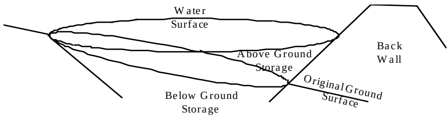
b = edge b at back wall (reset from slope of site)

c = edge c (water level length)

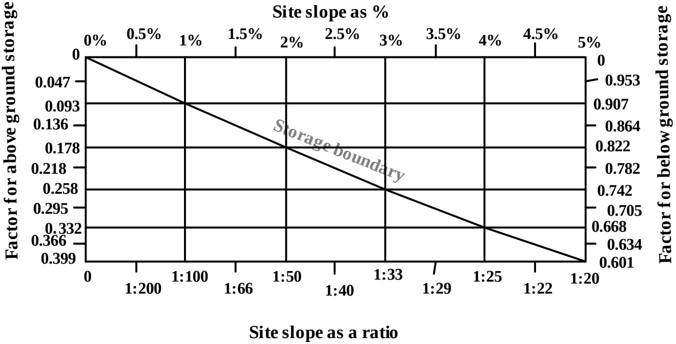


2. Circular Dams

Graphical and mathematical methods were used to develop factors to solve for above ground storage of circular dams, as defined in the diagram below. The factors are approximations, assuming batters are 3:1 and measured surfaces are regular shapes.

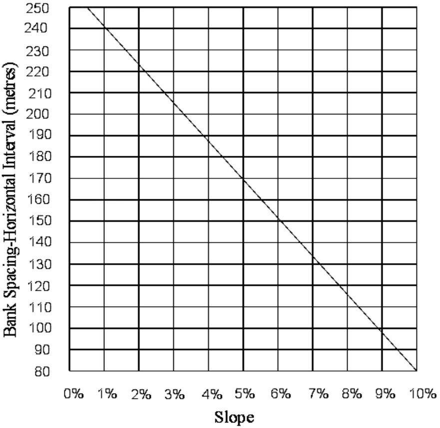


Use the graph below, to determine factors for above and below storage for dam volumes on various slopes. Multiply dam volume by factor.



Grade bank spacings (recommended maximum)

Recommended maximum grade bank spacing, for all regions, for land sloping up to 10 per cent



Note:

The recommended maximum bank spacing must be adjusted to allow for land that:

(i) has existing erosion - reduce spacings by 10 per cent;

(ii) is easily eroded - reduce spacings by 10 per cent; or

(iii) produces excessive runoff - reduce spacings by 10 per cent.

Table 19 suggested safe cut slopes for road construction

Soil type	Degrees from horizontal	Slope ratio H:V
Granular soils: sand	14^{o} 02’	4:1
Cut earth: silt, silty loam, sandy loam, clay, silty clay, sandy clay	18^{o} 26’	3:1
Weathered rock with seepage	21^{o} 48’	2.5:1
Weathered rock without seepage	33^{o} 41’	1.5:1
Solid rock	63^{o} 26’	0.5:1

Table 20 suggested safe fill slopes for road construction

Soil type	Degrees from horizontal	Slope ratio H:V
Recommended for safety, all types of compacted material: to allow errant vehicle a chance to recover	14^{o} 02’	4:1
Sand: uncompacted	9^{o} 28’	6:1
Rock: dumped	18^{o} 26’	3:1
Earth: angle of repose – before weathering/slumping occurs	33^{o} 41’	1.5:1

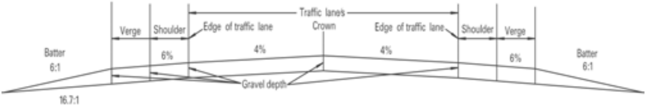
Table 21 Approximate weights and load factors for common materials excavated and moved by earthmoving machinery.

Material	Bank (B) kg/m^3	Loose (L) kg/m^3	Load Factor (LF)
Sand			
- dry	1600	1420	0.89
- wet	2080	1840	0.88
Clay			
– dry	1840	1480	0.80
– wet	2080	1660	0.80
Gravel (6-50 mm diameter)			
- dry	1900	1690	0.89
- wet	2260	2020	0.89
Sand and gravel			
- dry	1930	1720	0.89
- wet	2230	2020	0.91
Clay and gravel			
– dry	1660	1420	0.86
– wet	1840	1540	0.84
Limestone – shattered	2610	1540	0.59
Granite – shattered	2730	1660	0.61
Decomposed rock and soil mixtures			
- 75% rock	2790	1960	0.70
- 50% rock	2280	1720	0.75
- 25% rock	1960	1570	0.80

where: $$\text{Load factor (LF)} = \frac{kg/m^3 \text{ Loose}}{kg/m^3 \text{ Bank}}$$

Gravel spreading rates – access tracks

Formulae used for determining the cross-sectional area of a crowned access track. The cross-sectional area can then be divided into the capacity of the truck to give the length of the spread for that truck and/or trailer.



$$B = \frac{d \times \sin 93.4335^{o}}{\sin 6.0288^{o}}$$

$$A = 2 \times C \times d \times \left[\frac{(\sin 80.5337^{o} \times B)}{2} + (R + S + V)\right]$$

where

A = cross sectional area (m^2)
B = slope distance along batter at 6:1
C = allowance for material compaction, which includes the Load Factor. Gravel compacts approximately 20 per cent from loose material therefore, use 1.2 in the formula
d = depth of gravel (m)
R = distance from the crown to the outer edge of the traffic lane (m)
S = width of shoulder (m). Supports edge of traffic lane and provide an area for vehicles to stop and pass. Width varies, but may be zero if not required
V = width of verge (m). Width varies; supports shoulder and provide an area for vehicles to stop

Gravel spreading rates – access tracks (continued)

The length (m) of spread of a truck can be calculated by dividing truck capacity (m^3) by access track cross sectional area. Examples below are for access tracks with a 4 per cent slope from crown to the edge of traffic lane; a slope of 6 per cent for the shoulder and verge; and a 6:1 slope ratio for the batters. The sub-grade would be natural material shaped parallel to the finished surface of the access track, except for the outer batters which will slope at 6 per cent (16.7:1) instead of 6:1 as on the finished access track.

Table 22 Indicative length of spread in metres according to depth of gravel and truck and/or trailer capacity for a single lane access track.

Depth of gravel (m)	Truck and/or trailer capacity (m^3)					
	8	**10**	**12**	**15**	**20**	**25**
0.1	8.96	11.20	13.45	16.81	22.41	28.01
0.15	5.62	7.03	8.43	10.54	14.05	17.57
0.2	3.98	4.98	5.97	7.46	9.95	12.44
0.25	3.02	3.77	4.52	5.65	7.54	9.42

Note:

In this example the access track is single lane (no vehicles passing), with 1.75 metres centreline to edge of traffic lane, 1.5 metres verge and no shoulder.

Table 23 Indicative length of spread in metres according to depth of gravel and truck and/or trailer capacity for a two lane access track.

Depth of gravel (m)	Truck and/or trailer capacity (m^3)					
	8	**10**	**12**	**15**	**20**	**25**
0.1	6.09	7.62	9.14	11.4	15.31	19.05
0.15	3.90	4.87	5.84	7.31	9.74	12.18
0.2	2.85	3.51	4.21	5.26	7.02	8.77
0.25	2.16	2.70	3.24	4.5	5.40	6.75

Note:

In this example the access track is two lanes (vehicles passing), with 3.5 metres centreline to edge of traffic lane, 1.5 metres verge and no shoulder.

Table 24 Suggested compaction requirements for various road formation materials

Soil type	USCS Soil Group	Construction equipment	Maximum lift thickness (mm)	Passes (at 8 km/hr rolling, 6 km/hr vibrating)
Well graded gravels-sand mixtures, little fines	GW	Rubber tyred roller	150	10
		Smooth steel drum roller	500	8 (vibrating)
Poorly graded gravels-sand mixtures, little fines	GP	Rubber tyred roller	150	10
		Smooth steel drum roller	500	8 (vibrating)
Silty gravels, or gravel-sand-silt mixtures	GM	Rubber tyred roller	150	10
		Smooth steel drum roller	300	6 (vibrating)
Clayey gravels, gravel-sand-clay mixtures	GC	Rubber tyred roller	150	10
		Smooth steel drum roller	300	6 (vibrating)

Note:

(i) To achieve good compaction soils need to be at optimum soil moisture content.

(ii) Rubber tyred rollers are suitable for wet soils because of kneading action that expels moisture.

Metric Tables

Length

1,000 micrometres (1,000 μm)	= 1 millimetre (1 mm)
10 millimetres (10 mm)	= 1 centimetre (1 cm)
1,000 millimetres (1,000 mm)	= 1 metre (1 m)
100 centimetres (100 cm)	= 1 metre (1 m)

Area

100 sq millimetres (100 mm^2)	= 1 sq centimetre (1 cm^2)
100 sq centimetres (100 cm^2)	= 1 sq decimetre (1 dm^2)
100 sq decimetres (100 dm^2)	= 1 sq metre (1 m^2)
10,000 sq metres (10,000m^2)	= 1 hectare (1 ha)
100 hectares (100 ha)	= 1 sq kilometre (1 km^2)

Volume

1,000 cu millimetres (1,000 mm^3)	= 1 cu centimetre (1 cm^3)
1,000 cu centimetres (1,000 cm^3)	= 1 cu decimetre (1 dm^3)
1,000 cu decimetres (1,000 dm^3)	= 1 cu metre (1 m^3)
1,000 litres (1,000 L)	= 1 cu metre (1 m^3) or 1 kilolitre (1 kL)
1,000 kilolitres (1,000 kL)	= 1 mega litre (1 ML)
1,000 mega litres (1,000 ML)	= 1 giga litre (1 GL)

Mass

1,000 milligrams (1,000 mg)	= 1 gram (1 g)
1,000 grams (1,000 g)	= 1 kilogram (1 kg)
1,000 kilograms (1,000 kg)	= 1 tonne (1 t)

Rainfall

1 mm rainfall	= 1 litre per 1 sq metre

Slope ratios/gradients as percentages and ratios

Slopes or grades as ratios and percentages for the planning of earthworks

1. Percentage slope (%) = $\frac{v}{h} \times \frac{100}{1}$

where:

v = vertical fall

h = horizontal distance

100 % = 1 : 1 (ie. +/- 45 degrees from the horizontal).

2. Percentage to slope/grade ratio, 100 ÷ % = slope ratio

Table 25 Comparative table of slope expressed as ratio, per cent and degrees.

Slope Ratio	Slope in per cent	Slope in Degrees
1 : 20	5.00	2^{o} 51’
1 : 25	4.00	2^{o} 17’
1 : 50	2.00	1^{o} 09’
1 : 75	1.33	0^{o} 46’
1 : 100	1.00	0^{o} 35’
1 : 150	0.67	0^{o} 23’
1 : 200	0.50	0^{o} 17’
1 : 250	0.40	0^{o} 14’
1 : 300	0.33	0^{o} 11’
1 : 400	0.25	0^{o} 09’
1 : 500	0.20	0^{o} 07’
1 : 750	0.13	0^{o} 05’
1 : 1000	0.10	0^{o} 03’

Note: degrees expressed to nearest minute.

Slope stakes setting

To calculate the offset distance from the centre line to the position of a slope stake use:

$$d = \Delta E z + w/2$$

where:

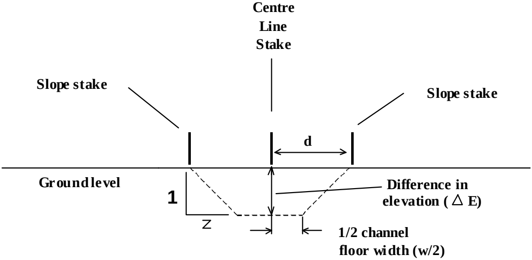
d = offset distance from centre line to edge of excavation or fill

ΔE = difference in elevation from ground level at centre line stake to floor of excavation or fill

z = side slope ratio (? : 1)

w/2 = half-base width of drain.

1. Slope stakes setting on level or near level ground – by calculating ‘d’ from difference in elevation.



2. Slope stakes setting on ground with cross fall - by comparing measured distance ‘d’ with distance ‘d’ calculated from trial difference in elevation. This method is also used to correctly position down slope corners of excavation for dams on sloping sites.

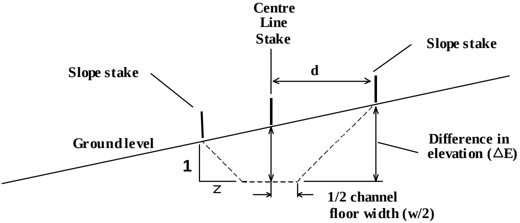


Table 26 Comparative table of side slope expressed as ratio, per cent and degrees.

Slope Ratio	Slope in per cent	Slope in Degrees
10 : 1	10	5° 43’
8 : 1	12.5	7° 08’
6 : 1	16.7	9° 33’
5 : 1	20	11° 19’
4 : 1	25	14° 02’
3 : 1	33.3	18° 26’
2 : 1	50	26° 34’
1.5 : 1	66.7	33° 41’
1 : 1	100	45 °

Glossary

Term	Definition
Catch drain	See spreader
Conservation earthworks	A range of structures used to control surface and subsurface water flows that can cause erosion, flooding, waterlogging and salinity.
Grade bank	An earth embankment with uphill channel surveyed and constructed on a grade to control surface water flow.
Level sill	A level outlet section of a soil conservation structure (in the form of a reversed bank), which spreads water flowing from the structure thereby preventing erosion.
Mitre drain	A drain to conduct surface water from table drains to a disposal area away from a road.
Relief culvert	A relatively short section of drainage pipe installed on a grade under a road or track to safely transmit water from the up-slope table drain to the down-slope side.
Rolling dip	A trafficable dip excavated on a grade and with gentle side slopes to divert water off a track or road. Spoil is moved downhill from the dip on gentler slopes or incorporated into side slopes of downhill bund.

Glossary (continued)

Term	Definition
Spreader (sometimes called a catch drain)	A short section of bank constructed on a grade and diverting channelled flow off closed tracks or shallow gullies. Structures are used to divert water to a safe disposal area. Often used with level sills at the discharge end.
Surface water management	The process of managing the overland flow of water in such a way as to protect resources and environmental values.
Table drain	A side drain of a road constructed adjacent and parallel to the road's shoulders.
Transverse culvert	See 'Relief culvert'
Unified Soil Classification System (USCS)	A system classifying soil on the basis of the texture and liquid limit. The system comprises 15 soil groups, each identified by a two letter symbol. The first symbol represents the type of soil.