VOLUME 4 GEOTECHNICS AND DRAINAGE
SECTION 2 DRAINAGE

PART 4

HA 219/09

DETERMINATION OF PIPE ROUGHNESS AND ASSESSMENT OF SEDIMENT DEPOSITION TO AID PIPELINE DESIGN

SUMMARY

This Advice Note examines the key parameters used in the hydraulic design of pipelines and provides further guidance in determining optimum design, based on sediment transport, in terms of roughness coefficient and velocity. This Advice Note also gives guidance on how to assess the volume of sediment deposition in existing drainage to aid prioritising maintenance.

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THE HIGHWAYS AGENCY

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THE DEPARTMENT FOR REGIONAL DEVELOPMENT
NORTHERN IRELAND

Determination of Pipe Roughness and Assessment of Sediment Deposition to Aid Pipeline Design

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DETERMINATION OF PIPE ROUGHNESS AND ASSESSMENT OF SEDIMENT DEPOSITION TO AID PIPELINE DESIGN

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1. INTRODUCTION

General

1.1 This Advice Note examines the key parameters used in the hydraulic design of pipelines and provides further guidance in determining optimum design, based on sediment transport, in terms of roughness coefficient and velocity.

1.2 It gives guidance on the hydraulic design of pipelines for road drainage. In most of the UK the term 'highways' is equivalent to Scotland and Northern Ireland's 'roads'. In this document, as with the guidance provided in HA 216 (DMRB 11.3.10) (Ref 2), the term 'roads' will be used as standard terminology. Although the advice should be fully taken into account in the design of new schemes (see 1.7), this Advice Note contains no mandatory requirements.

1.3 The structural design of pipes for road drainage is described in HA 40: *Determination of pipe and bedding combinations for highway drainage* (DMRB 4.2.5) (Ref 2).

1.4 Following the introduction of HA 105 Sumpless Gullies (DMRB 4.2.3), the drainage philosophy is to reduce maintenance where practical and improve the quality of surface water run off from the carriageway. The elimination of the gully sump will lead to an improvement in water quality but will potentially increase the amount of sediment entering the drainage system. By improving the ability of the pipe line to transport sediment, there is scope to reduce the number or frequency of catchpits and to trap sediment at more centralised locations where it can be removed without recourse to the major traffic management associated with lane closures.

1.5 This document provides general design advice in relation to sediment transport, however there are a number of design procedures described herein which must be adopted as mandatory practice, for which reference is made to HD 33 as appropriate.

1.6 This Advice Note also gives guidance on how to assess the volume of sediment deposition in existing drainage to aid prioritising maintenance.

Scope

1.7 The principles outlined in this Advice Note apply to all schemes on trunk roads including motorways. They may also be applied generally to other new road schemes and by other highway authorities for use during the preparation, design and construction of their own comparable schemes.

Implementation

1.8 This Advice Note should be used forthwith for all schemes currently being prepared provided that, in the opinion of the Overseeing Organisation, this would not result in significant additional expense or delay progress *(in either case the decision must be recorded in accordance with the procedure required by the Overseeing Organisation)*. Design Organisations should confirm its application to particular schemes with the Overseeing Organisation.

1.9 Whilst the general principles of the advice and guidance contained in this document are endorsed, this Advice Note is not directly operable in Scotland and reference should be made to the Overseeing Organisation in terms of appropriate procedures.

2. PRINCIPLES OF SEDIMENT TRANSPORT

General

2.1 Even in pipes without any sediment deposits, the discharge capacity of the pipe can be reduced by up to 4% due to increased energy losses caused by the movement of sediment along the pipe invert (Construction Industry Research and Information Association (CIRIA) Report 141, Ref 3). With deposition in the pipe, the impact of the sediment is naturally more pronounced as it results from the combination of a reduced cross-sectional area and an increased bed roughness. For small deposits, i.e. a depth of deposit corresponding to a small proportion of the pipe diameter, it has been established that the main factor in loss of discharge capacity is the increased bed roughness.

2.2 The recent Sediment Loads Monitoring study (Ref 4) (the output is explained in Chapter 6), showed that land use was a significant factor affecting the amount of sediment entering the drainage system, but that there is a marked difference in the amount between rural and urban locations. The designer should not place too much reliance on existing land use as it is a changeable factor, both in terms of time and distance along a road. During the life of a road, adjacent rural areas may easily change from being grazing grounds (grassland) to forested areas, for example, and it would be unwise to base the design of the drainage system on factors that cannot be controlled by the Overseeing Organisation.

Design

Sediment Load

2.3 The results of the Sediment Loads Monitoring study showed that urban roads, which have been found to create more sediment than rural roads, generate maximum values of the order of 200 g/m^2 per annum, about 90 g/m^2 per annum of which is retained in gully pots. These values are one order of magnitude lower than those given by other studies and reported in CIRIA R141. This finding indicates that previous recommendations may err on the conservative side.

Sediment Concentrations

2.4 The value of sediment concentration obtained for rural roads corresponds approximately to the 'medium concentration' recommended in CIRIA for sewer design, i.e. 50 mg/l, whereas for urban roads it is approximately 115 mg/l, a value that is still well below the 'high concentration' value given in CIRIA (200 mg/l). This indicates that sediment concentration levels in UK road drainage are comparable with the average values associated with other surface water sewers.

Methodology to Assess Sediment Load

2.5 The methodology adopted is based on using sediment sizes as surrogate parameters for the type of location factor, i.e. urban versus rural. Measurements of sediment loads at these two types of location showed that urban roads are associated with average sizes of 0.5 mm whereas sediment coming from rural surrounds tends to be larger, with an average size of 0.9 mm.

2.6 Carrier pipes should be designed to achieve 'self-cleansing' conditions which either prevent sediment from depositing, or allow a certain amount of deposition that is not detrimental, and produce a balance between the processes of deposition and erosion during a specified period. The designer would normally decide between the above two options in order to minimise costs. Although carrying out a cost benefit analysis may be the right approach for large sewer networks, it is unlikely to be justifiable for simpler road drainage systems. For the above reasons, the simplified approach given in CIRIA R141, which assumes a bed deposit equal to 2% of pipe diameter, has been adopted.

2.7 The procedure followed to produce the Tables for both the design of pipes in average and in deteriorated condition for urban and rural roads is summarised below:

Pipe roughness coefficient k_0

1. Determination of a suitable baseline value for the pipe roughness coefficient, k_0, to be used in the design and which is representative of any pipe material likely to be used in road drainage. Although a wide range of materials is available, a value of k_0 = 0.6 mm is commonly used to represent the pipe roughness average conditions when new.

2. Determination of a suitable value for the pipe roughness coefficient, k_0, which is representative of the deteriorated pipe condition (ageing plus misalignment). The effect of ageing was taken into account by increasing the roughness coefficient to 1.5 mm and an additional increase of 0.6 mm for misalignment. This corresponds to a step of 14-18 mm at the pipe joint and raises the total value of the coefficient to 2.1 mm).

Composite pipe roughness k_c

3. Sediment load and type of location (rural versus urban) was accounted for by using a sediment size of 0.5 mm for urban roads and 0.9 mm for rural roads. The corresponding values of composite pipe roughness, k_c, due to the presence of the sediment, were calculated for the range of pipe sizes typically available for use in road drainage (150 mm to 900 mm).

Temperature value T and Specific gravity

4. A suitable temperature value for the water needed to be stated as this affects the value of viscosity and friction losses in the pipes. A value of T=15^{o}C was adopted. Also an appropriate value for the specific gravity of the sediment needed to be determined. From the Sediment Loads Monitoring report (Ref 4), the average particle density was determined as being 2,220 kg/m^3 for both rural and urban locations. A value of specific gravity of 2.22 was subsequently used in all simulations.

5. The transport equation for deposited bed. (May's equation of 1994 described in CIRIA R141 and shown as equation 1 in Chapter 3) (Ref 3) was used to obtain minimum flow velocities V and associated pipe gradients.

Sediment Transport

2.8 There is a plethora of sediment transport equations that can be applied for the design of pipes with a deposited bed of sediment. As with all sediment transport formulae there is a significant variation in the results given and a thorough evaluation of the various equations was carried out and presented in CIRIA R141. This assessment showed that the equation due to May (1994) (Ref 3), which was developed from data collected in pipes with diameters in the range 154 to 450 mm, gave prediction values that were closer to the six sets of laboratory data than most of the other equations and produced smaller standard deviations.

2.9 Calculations using this equation involve two stages:

1. the roughness of the sediment bed is first determined and then used to calculate the hydraulic resistance of the pipe;

2. the sediment concentration is calculated from the known flow conditions. The resistance of the bed (which is composed of grain resistance and of form resistance caused by the development of dunes) was found to be dependent on the grain mobility factor and on the Froude number of the flow. To calculate the sediment transport capacity of the pipe, the particle Reynolds number needs also to be determined.

2.10 This equation was adopted in the simplified guidance given in Part B of CIRIA R141 in spite of being quite complex to apply. In effect, this 'equation' requires the determination of a long set of parameters using iterative procedures which are only practical to carry out by means of a computer program. For details of the full equation and its associated parameters see CIRIA R141.

Numerical Simulations and Results

2.11 A FORTRAN program, TransDB8, previously developed by HR Wallingford, was used to determine the minimum flow velocities and pipe gradients required to ensure sediment transport without erosion or deposition of the sediment bed. For application of the program it was necessary to give an estimate of the sediment concentration and values of C_v equal to 115 mg/l and 50 mg/l were used for urban and rural roads, respectively.

Simulations were run for:

- Urban roads, design conditions
  k_0=0.6 mm; d_{50}=0.5 mm; C_v=115 mg/l

- Rural roads, design conditions
  k_0=0.6 mm; d_{50}=0.9 mm; C_v=50 mg/l

- Urban roads, deteriorated condition
  k_0=2.1 mm; d_{50}=0.5 mm; C_v=115 mg/l

- Rural roads, deteriorated condition
  k_0=2.1 mm; d_{50}=0.9 mm; C_v=50 mg/l

The results from these simulations are used in the calculation of minimum velocities tabulated in Tables 3 to 7 in Chapter 4.

3. PIPE ROUGHNESS COEFFICIENTS

General

3.1 If the hydraulic design of pipelines is based on allowing a certain (limited) depth of deposited sediment, then the effect of the bed roughness will need to be taken into account in the estimation of the overall roughness of the pipe, or its composite roughness k_c. In general, the presence of sediment will increase the roughness coefficient to a value above the one associated with the pipe material only, k_o. The roughness coefficient of the sediment bed, k_b, can be estimated using an equation developed by May 1993 (Ref 3) from laboratory tests on pipe full flows.

$$k_b = 5.62 \, R^{0.61} \, d_{50}^{\,0.39} \qquad (1)$$

where

R is the hydraulic radius (flow area divided by the wetted perimeter); and

d_{50} is the nominal sediment size (mm).

3.2 From the various methods used for calculating the composite roughness, the most reliable has been found to be that which uses the perimeter weighting of the Darcy-Weisbach friction factors for the bed and pipe walls. This takes into account the proportional weights of the two types of roughness and their hydraulic contribution to friction losses and is given as:

$$\lambda_c = \frac{\lambda_0 P_0 + \lambda_b W_b}{P_0 + W_b} \qquad (2)$$

where

λ is the friction factor, subscripts 0 and b refer to the pipe wall and sediment bed respectively,

P_0 is the length of pipe wall exposed to water, and

W_b is the deposited bed width.

3.3 Knowing the composite friction factor λ_c, the composite roughness k_c can be calculated from the following simplified formula:

$$k_c = 3.7\,D\ [10^{-\left(\frac{1}{4\lambda_c}\right)^{0.5}}] \qquad (3)$$

where D is the pipe diameter (mm).

Tables 1 and 2 summarise the values of composite roughness coefficient obtained for two different assumptions of pipe wall roughness:

- the design condition, taken here as k_0 = 0.6 mm
- deteriorated condition due to pipe ageing and misalignment, taken as k_0 = 2.1 mm.

Table 1: Values of composite roughness coefficient for design condition

k_0 = 0.6 mm

d_{50} (mm)	D (mm)	y (mm)	W_b (mm)	k_b (mm)	k_c (mm)
0.5	150	3	42	39.1	2.1
0.5	200	4	56	46.6	2.2
0.5	225	4.5	63	50.1	2.3
0.5	250	5	70	53.4	2.3
0.5	275	5.5	77	56.6	2.4
0.5	300	6	84	59.7	2.4
0.5	350	7	98	65.5	2.5
0.5	375	7.5	105	68.4	2.5
0.5	400	8	112	71.1	2.5
0.5	450	9	126	76.4	2.6
0.5	500	10	140	81.5	2.6
0.5	525	10.5	147	83.9	2.7
0.5	600	12	168	91.1	2.7
0.5	675	13.5	189	97.8	2.8
0.5	700	14	196	100	2.8
0.5	750	15	210	104.3	2.8
0.5	800	16	224	108.5	2.9
0.5	825	16.5	231	110.6	2.9
0.5	900	18	252	116.6	2.9
0.9	150	3	42	49.2	2.6
0.9	200	4	56	58.6	2.7
0.9	225	4.5	63	63	2.8
0.9	250	5	70	67.1	2.8
0.9	275	5.5	77	71.1	2.9
0.9	300	6	84	75	2.9
0.9	350	7	98	82.4	3.0
0.9	375	7.5	105	86	3.1
0.9	400	8	112	89.4	3.1
0.9	450	9	126	96.1	3.2
0.9	500	10	140	102.5	3.2
0.9	525	10.5	147	105.6	3.2
0.9	600	12	168	114.5	3.3
0.9	675	13.5	189	123	3.4
0.9	700	14	196	125.8	3.4
0.9	750	15	210	131.2	3.5
0.9	800	16	224	136.5	3.5
0.9	825	16.5	231	139.1	3.5
0.9	900	18	252	146.6	3.6

Notes:

k_0 – roughness coefficient of pipe walls (mm)
d_{50} – nominal sediment size (mm)
D – pipe diameter (mm)
y – depth of deposited bed (2% of pipe diameter) (mm)
W_b – width of deposited bed (mm)
k_b – roughness coefficient of deposited bed (mm)
k_c – composite roughness coefficient (mm)

Table 2: Values of composite roughness coefficient for deteriorating condition (ageing and misalignment)

k_0 = 2.1 mm

d_{50} (mm)	D (mm)	y (mm)	W_b (mm)	k_b (mm)	k_c (mm)
0.5	150	3	42	39.1	4.2
0.5	200	4	56	46.6	4.4
0.5	225	4.5	63	50.1	4.5
0.5	250	5	70	53.4	4.6
0.5	275	5.5	77	56.6	4.7
0.5	300	6	84	59.7	4.7
0.5	350	7	98	65.5	4.9
0.5	375	7.5	105	68.4	4.9
0.5	400	8	112	71.1	5.0
0.5	450	9	126	76.4	5.1
0.5	500	10	140	81.5	5.2
0.5	525	10.5	147	83.9	5.2
0.5	600	12	168	91.1	5.4
0.5	675	13.5	189	97.8	5.5
0.5	700	14	196	100	5.5
0.5	750	15	210	104.3	5.6
0.5	800	16	224	108.5	5.6
0.5	825	16.5	231	110.6	5.7
0.5	900	18	252	116.6	5.8
0.9	150	3	42	49.2	4.8
0.9	200	4	56	58.6	5.1
0.9	225	4.5	63	63.0	5.2
0.9	250	5	70	67.1	5.3
0.9	275	5.5	77	71.1	5.4
0.9	300	6	84	75	5.5
0.9	350	7	98	82.4	5.6
0.9	375	7.5	105	86	5.7
0.9	400	8	112	89.4	5.8
0.9	450	9	126	96.1	5.9
0.9	500	10	140	102.5	6.0
0.9	525	10.5	147	105.6	6.1
0.9	600	12	168	114.5	6.2
0.9	675	13.5	189	123	6.3
0.9	700	14	196	125.8	6.4
0.9	750	15	210	131.2	6.5
0.9	800	16	224	136.5	6.5
0.9	825	16.5	231	139.1	6.6
0.9	900	18	252	146.6	6.7

Notes:

k_0 – roughness coefficient of pipe walls (mm)
d_{50} – nominal sediment size (mm)
D – pipe diameter (mm)
y – depth of deposited bed (2% of pipe diameter) (mm)
W_b – width of deposited bed (mm)
k_b – roughness coefficient of deposited bed (mm)
k_c – composite roughness coefficient (mm)

4. HEAD LOSS IN HYDRAULIC DESIGN

General

4.1 The velocities necessary to maintain sediment transport and minimise deposition are a function of pipe gradient and can be expressed either as a minimum velocity or a minimum gradient. The minimum velocities are determined on the assumption of continuous straight pipelines, however, as part of the design, changes in direction are necessary and these result in a reduction in flow velocity or Head Loss.

Head Loss

4.2 Loss of energy or head loss occurs wherever there is an impact on the flow within the pipe or channel. These may be from a lateral connection, bend in a manhole or change in pipe size.

4.3 Local losses that occur in highway drainage systems will typically be associated with the presence of bends and junctions in pipes, entry to and exit from manholes/chambers/gully pots and exit at outfalls. These losses are approximately proportional to the square of the flow velocity, V, and it is common practice to assign to them a non-dimensional loss coefficient K, which results from the division of the head loss by the velocity parameter $V^2/2g$ (kinematic head).

Values of K

Inlet		
	straight run	0.50
	angled 90^o	1.50
	angled 60^o	1.25
	angled 45^o	1.10
	angled 22.5^o	0.70
Manhole		
	straight run	0.15
	angled 90^o	1.00
	angled 60^o	1.85
	angled 45^o	0.75
	angled 22.5^o	0.45

Minimum Velocities

4.4 Tables 3 to 6 present the minimum velocities and associated pipe gradients for the various cases/conditions of straight pipe runs.

Table 3: Urban – Design conditions

k_0 = 0.6 mm

Pipe diameter mm	Min V m/s	Slope
150	0.47	1/304
200	0.52	1/362
225	0.54	1/387
250	0.56	1/411
275	0.58	1/433
300	0.6	1/455
350	0.63	1/496
375	0.65	1/515
400	0.66	1/534
450	0.69	1/570
500	0.72	1/603
525	0.73	1/619
600	0.78	1/640
675	0.84	1/641
700	0.86	1/640
750	0.9	1/638
800	0.94	1/635
825	0.96	1/633
900	1.02	1/625

Table 4: Rural – Design conditions

k_0=0.6 mm

Pipe diameter mm	Min V m/s	Slope
150	0.41	1/363
200	0.44	1/463
225	0.45	1/511
250	0.46	1/558
275	0.47	1/603
300	0.48	1/646
350	0.5	1/730
375	0.51	1/771
400	0.52	1/810
450	0.53	1/887
500	0.55	1/961
525	0.56	1/997
600	0.58	1/1100
675	0.6	1/1190
700	0.6	1/1212
750	0.62	1/1256
800	0.63	1/1298
825	0.64	1/1319
900	0.66	1/1379

Table 5: Urban – Deteriorated conditions

k_0 = 2.1 mm

Pipe diameter mm	Min V m/s	Slope
150	0.45	1/256
200	0.5	1/306
225	0.52	1/328
250	0.54	1/349
275	0.56	1/369
300	0.58	1/388
350	0.61	1/424
375	0.63	1/441
400	0.64	1/457
450	0.67	1/488
500	0.7	1/518
525	0.71	1/532
600	0.76	1/550
675	0.82	1/551
700	0.84	1/551
750	0.88	1/549
800	0.92	1/546
825	0.94	1/544
900	1	1/537

Table 6: Rural – Deteriorated conditions

k_0=2.1 mm

Pipe diameter mm	Min V m/s	Slope
150	0.4	1/304
200	0.43	1/391
225	0.44	1/433
250	0.45	1/473
275	0.46	1/512
300	0.47	1/550
350	0.49	1/623
375	0.5	1/659
400	0.51	1/694
450	0.52	1/760
500	0.54	1/825
525	0.54	1/856
600	0.56	1/947
675	0.59	1/1025
700	0.59	1/1045
750	0.61	1/1083
800	0.62	1/1120
825	0.63	1/1138
900	0.65	1/1190

4.5 Data collected during the Sediment Loads Monitoring Study (Ref 4) revealed that within the various rural locations there was a wide range of average sediment sizes depending on the land use of the surrounding areas. The maximum average sediment size measured corresponded to adjacent grassland and had d50=2.15mm. Additional computer simulations were carried out to assess the effect of the larger sediment size on minimum velocities and pipe gradients and these are summarised in Table 7. As expected, when compared with similar conditions but smaller sediment size (Table 4), larger minimum flow velocities and steeper pipe gradients are required.

Table 7: Rural – design conditions; d_{50}=2.15 mm

k_0=0.6 mm

Pipe diameter mm	Min V m/s	Slope
150	0.41	1/316
200	0.46	1/363
225	0.49	1/383
250	0.51	1/402
275	0.53	1/429
300	0.54	1/461
350	0.56	1/524
375	0.57	1/554
400	0.58	1/584
450	0.59	1/641
500	0.61	1/696
525	0.62	1/723
600	0.64	1/802
675	0.66	1/876
700	0.66	1/900
750	0.68	1/947
800	0.69	1/993
825	0.69	1/1016
900	0.71	1/1081

5. APPLICATION OF DESIGN SOFTWARE

General

5.1 There is software available specifically for the estimation of sediment deposition within drainage (sewer) systems that has been developed primarily for use by the Water Industry.

5.2 The proprietary software predominantly used for the design of pipes for road drainage systems handles sediment transport by means of minimum flow velocities and roughness coefficients input as design parameters.

Sediment Modelling

InfoWorks CS

5.3 The simulation engine uses a numerical method to solve the St Venant equations at each computational node and each timestep to simulate time-varying flow in a network, which can be looped and contain branches, pumps, weirs, etc., and both closed pipes and open channels. Its main strength is in simulating the behaviour of existing systems and evaluating proposed improvements/alterations, including Sustainable Drainage System (SUDS) measures. It can also be used for completely new systems, but does not have specific features to help a designer to, for example, lay out a drainage network or optimise sizes and gradients or produce drawings for construction. It can, however, import and export data from and to CAD and GIS packages.

5.4 InfoWorks CS features explicit modelling of sediment and pollutants, needed mainly to simulate the impact of overflows into rivers, subject to purchase of an add-on licence. As pollutants can be attached to sediments on the contributing surfaces, in gully pots and in sewers, an accumulation of sediment often causes a concentrated 'first flush' of pollution in a spill from an overflow, so it is important to be able to model both the deposition and erosion of sediment. Two sediment fractions can be modelled, and parameters can be varied to suit circumstances.

Surface Washoff

5.5 The model is based on either the default Desbordes Model (the single linear reservoir runoff routing model) or the native runoff model chosen for the hydraulic calculations. The mass of each pollutant attached to the sediment washed into the system is calculated using potency factors, which depend on the rainfall intensity.

Gully Pot Flushing

5.6 A separate Gully Pot model represents the amount of dissolved pollutant washed into the system from the gully pots by runoff from the road surface. The underlying assumption is even mixing of the pollutant mass in the gully-pot and that resulting from surface washoff. The resulting pollutant flow depends on the inflow from the runoff module.

Deposition/Erosion in Pipes

5.7 Three erosion/deposition models are available: the Ackers White, Velikanof and Katholieke Universiteit Leuven (KUL) models. Modellers can choose the model to use depending on availability of relevant data.

5.8 A strength of the software is the option to make sediment deposition and erosion affect the hydraulic simulation, at the expense of extended run times. This is of particular value in situations where sediment is readily deposited and rarely scoured away due to very slack gradients, and builds up to a significant depth over time so that it restricts the capacity of the pipework.

MicroDrainage (WinDes and WinDAP)

5.9 Minimum velocities are used in WinDes to prevent settlement, and reports in WinDAP can be used to identify areas where, for example, velocities do not exceed a definable self-cleansing value in a one-year time series of storms. There is no specific modelling of sediment.

Mike Urban/Mouse

5.10 This software has similar functionality to InfoWorks. It uses different algorithms and a different interface, and is more commonly used in continental Europe than in the UK. It includes, also subject to purchase of the appropriate licence, explicit modelling of pollutants and sediment. It uses the MU CS Pollution Transport module to model transport of pollutants from surface water and through the pipe network.

6. AN ASSESSMENT OF THE SEDIMENT DEPOSITION IN EXISTING DRAINAGE TO PRIORITISE MAINTENANCE

General

6.1 The parameters below have been derived from site trials in England. The derived Geographical Factors are based on rainfall, soil type and general topography and hence only apply to England. These may be extrapolated for Wales, Scotland and Northern Ireland with guidance from the Overseeing Organisation.

Sediment Deposition in Pipes

6.2 The volume of sediment deposited in the pipeline, the Primary Bed Load (B_p), is the volume of sediment annually generated by an area of road and is taken to be 0.05 kg/m^2 per annum (Ref 4).

6.3 To determine the predicted sediment load for a section of road, the Specific Bed Load (B_s), the Primary Bed Load is multiplied by the sum of four weighted factors.

These Factors are:

- Land Use (F_l);
- Geographical Location (F_g);
- Road Size (F_r); and
- Profile (F_p).

A coefficient, or weighting, is then applied in the formula to represent the influence these factors have on sediment deposition

The figures are then inserted into the following equation

$B_s = B_p (F_l + F_g + F_r + F_p)$ kg/m^2

Land uses and Factors (F_l) are:

- Rural General (adjacent land has a mixture of uses): 1.0
- Rural Grassland (adjacent land is predominantly covered with grassland): 0.9
- Rural Arable (adjacent land is used for arable farming): 0.1
- Rural Forested (adjacent land has a very high number of trees): 0.35

A weighting of 50% is applied to the land-use factors.

Geographical Location and Factors (F_g) are:

- South West: 1.0
- London, South and SE: 0.1
- East Anglia: 17.0
- Midlands: 4.2
- NW and Yorkshire: 6.2
- Lancs, Cumbria and NE: 1.5

A weighting of 35% is applied to the Geographical Location Factors.

Road Size and Factors (F_r)are:

- 2 lane carriageway: 0.4
- 3 lane carriageway: 1.0
- 4 lane carriageway: 12

A weighting of 10% is applied to the Road Size factors.

Profile and Factors (F_p) are:

- Level: 56.0
- Cutting: 1.0
- Embankment: 1.2

A weighting of 5% is applied to Profile factors.

To calculate the Total Site Specific Bed Load, insert the weighted factors into the following equation:

$B_s = B_p (F_l + F_g + F_r + F_p)$ kg/m^2

$B_s = B_p$ x[(0.5xF_l)+(0.35xF_g)+(0.1xF_r)+(0.05xF_p)] kg/m^2

The proportion of the generated sediment that enters the gully (B_{sg}) has been measured as being 40% of the total sediment load, hence

B_{sg} = 0.4xB_s kg/m^2

Sediment removal

Refer to Clause 521 (MCHW 1) (Ref 1)

6.4 This procedure will provide an indication of the volume of sediment that may enter a section of pipeline. Refer to the **sediment predictor spreadsheet** and input the particular pipe line characteristics to determine whether or not sediment deposition is likely to occur. This will suggest the cleaning frequency for the pipeline. Note this will not indicate that the pipeline needs replacing.

7. SEDIMENT PREDICTOR SPREADSHEET

General

7.1 This spreadsheet contained in the Drainage Data Management System (HADDMS or WADDMS) offers a simple way to determine the likelihood of sedimentation in a piped network. It is based on a simple shear stress calculation, as bed shear stress has been found to be linked to the erosion and deposition of solids in pipes, each of which are initiated at critical shear stresses, which depend on the characteristics of the solids concerned.

7.2 Note that this method is only applicable to circular pipes. It does not predict sedimentation in gullies.

7.3 Bed shear stress is linked to velocity of flow. Erosion of existing sediment is initiated when the velocity rises and the bed shear stress exceeds the critical stress for erosion, $\tau_{erosion}$. Similarly, sediment is deposited when the shear stress falls below the critical stress for deposition, $\tau_{deposition}$, at lower flows. In between the two, sediment remains in suspension (Bouteligier *et al.*). The spreadsheet compares bed shear at various depths of flow with the critical values to indicate susceptibility to erosion or deposition.

7.4 This view is simplified, largely because it ignores whether there is sediment available to be deposited or eroded, and the capacity of the flow to transport solids. This, however, is the province of a detailed time-stepping model and is beyond a simple spreadsheet solution.

The inputs needed are simple:

- pipe reference (text);
- pipe diameter (in mm);
- pipe roughness (equivalent sand roughness ks in mm);
- pipe gradient (decimal);
- sediment particle size (d_{50} in mm);
- sediment specific gravity (dimensionless).

7.5 These can be input manually or copied from another source such as the output of a design model. Two other pieces of data are needed:

- Deposition and erosion factors (dimensionless, defaults provided)

7.6 These factors:

$\gamma_{deposition} = 0.08$;

$\gamma_{erosion} = 0.28$

are used to calculate the critical shear stresses, and can be varied to calibrate the spreadsheet in particular cases where the critical values are known from laboratory tests or other sources such as published literature for similar solids.

7.7 The results are presented in ‘traffic light’ form. Detailed instructions are included in the spreadsheet.

The spreadsheet should be used as part of a risk assessment. The first stage of this would be to identify whether the catchment is at risk of causing significant washoff of solids. If so, the representative particle size and specific gravity need to be determined, preferably using samples collected on site. If site-specific data is not available, a range of values should be used.

7.8 The spreadsheet will then identify any pipe lengths that are susceptible to deposition. If possible, these should be redesigned to eliminate the risk, generally by steepening the gradient. If this is impractical or excessively expensive, it may be worth commissioning a more detailed model to identify the risk and any improvements needed in greater detail. For example, InfoWorks CS has a Water Quality option that can model sediment transport, which has been used to calibrate the spreadsheet, as described in Chapter 5.

7.9 Should the potential for sediment deposition remain following redesign, then alternative methods of preventing or reducing the volume of sediment entering the pipeline, need to be investigated. It may be that, in these circumstances, a pipeline is not the most appropriate drainage system.

8. WORKED EXAMPLES

General

8.1 Removal of sediment from the drainage system is a routine maintenance activity that needs to be programmed. Being able to assess the volume of sediment that may enter the drain at certain locations should assist in this programming. The volume of sediment entering the piped system can be estimated from the formula in Chapter 6.

8.2 **Example 1** (an extreme case)

To estimate the volume for a 2.5 km section of 3 lane motorway constructed at grade through a rural arable site in Essex.

The land use factor for rural arable is 0.1

The geographical location factor for East Anglia is 17.0, the road size factor for a 3 lane carriageway is 1.0 and the profile factor for a road at grade is 56.0.

The appropriate weightings are applied to the factors and inserted into the equation.

The Total Site Specific Bed Load is calculated from:

$B_s = B_p (F_l + F_g + F_r + F_p)$ kg/m^2

B_s = 0.05 x([0.1x50%] + [17x35%] + [1x10%] + [56x5%])

B_s = 0.445 kg/m2 per annum

Paved area = 30.3m (29+paved c/r) x 2,500 m

Sediment load = 0.445 x 30.3 x 2,500 kg/m^2

Sediment load = 3,3931.25 kg

Or

33.9 Tonnes per annum

Or

13.6 kg/m run or 13.6 Tonnes/km

Proportion entering the gullies is 40%

B_{sg} = 0.4 x B_s

B_{sg} = 0.4 x 33.9 Tonnes

B_{sg} = 13.56 Tonnes

8.3 **Example 2**

To estimate the volume of sediment generated for a 1.8km section of 2 lane motorway on embankment through grassland in Shropshire

The land use factor for rural grassland is 0.9

The geographical location factor for Shropshire is 4.2, the road size factor for a 2 lane motorway is 0.4 and the profile factor for a road on embankment is 1.2.

The appropriate weightings are applied to the factors and inserted into the equation.

The Total Site Specific Bed Load is calculated from:

$B_s = B_p (F_l + F_g + F_r + F_p)$ kg/m^2

B_s = 0.05 x([0.9x50%] + [4.2x35%] + [0.4x10%] + [1.2x5%])

B_s = 0.101 kg/m^2 per annum

Paved area = 22.8m (21.5 + paved c/r) x 1,800m

Sediment load = .101 x 22.8 x 1,800kg/m^2

Sediment load = 4,145.04 kg

Or

4.14 Tonnes per annum

Or

2.3 kg/m run or 2.3 Tonnes per km

The percentage entering the gullies is

B_{sg} = 0.4 x 4.14 Tonnes i.e. 1.66 Tonnes

8.4 This volume of sediment will either be deposited in the pipe system, refer to Chapter 2, or, if not intercepted by a vegetative treatment system (Ref HA 103), enter the receiving water course.

9. REFERENCES AND BIBLIOGRAPHY

1. Manual of Contract Documents for Highway Works (MCHW) (The Stationery Office)

Specification for Highway Works (SHW) (MCHW 1)

Notes for Guidance on the Specification for Highway Works (NG SHW) (MCHW 2)

Highway Construction Details (HCD) (MCHW 3)

2. Design Manual for Roads and Bridges (DMRB) (The Stationery Office)

HD 33 Surface and Sub-surface Drainage Systems for Highways (DMRB 4.2.3)

HD 35 Conservation and the use of Secondary and Recycled Materials (DMRB 7.1.2)

HA 40 Determination of pipe bedding combinations for highways drainage (DMRB 4.2.5)

HA 56 The Good Roads Guide: New Roads Planting, Vegetation and Soils (DMRB 10.1.2)

HA 83 Safety Aspects of Road-edge Drainage Features (DMRB 4.2.4)

HA 98 Nature Conservation Management Advice in Relation to Amphibians (DMRB 10.4.6)

HA 103 Vegetative Treatment Systems for Highway Runoff (DMRB 4.2.1)

HA 105 Sumpless Gullies (DMRB 4.2.3)

HA 119 Grassed Surface Water Channels for Highway Runoff (DMRB 4.2.9)

HA 216 Road Drainage and the Water Environment (DMRB 11.3.10)

3. Design of Sewers to Control Sediment CIRIA Report 141 (1996): CIRIA 6 Storey's Gate Westminster, London.

4. Monitoring of Sediment Loads from High Speed Roads, Atkins Ltd Report (2006).

5. Solids in Sewers (2004). Characteristics, effects and control of sewer solids and associated pollutants, Edited by R.M. Ashley, J.-L. Bertrand-Krajewski. T. Hvitved-Jacobsen and M Verbanck. Scientific and Technical Report No. 14, IWA Publishing, London, ISBN 1 900222 91 4.

10. ENQUIRIES

All technical enquiries or comments on this Advice Note should be sent in writing as appropriate to:

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