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Grassed Surface Water Channels for Road Runoff (including Amendment No. 1 dated June 2015)

DN-DNG-03073

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DN Design

Standards

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For all documents that existed within the NRA DMRB or the NRA MCDRW prior to the launch of TII Publications, the NRA document reference used previously is listed above under 'historical reference'. The TII Publication Number also shown above now supersedes this historical reference. All historical references within this document are deemed to be replaced by the TII Publication Number. For the equivalent TII Publication Number for all other historical references contained within this document, please refer to the TII Publications website.

**Grassed Surface Water Channels for Road
Runoff
(including Amendment No.1)**

March 2015 (including Amendment No. 1, dated June 2015)

Summary:

This Standard provides information on the hydraulic and structural design of grassed surface water channel for road drainage. The type of system considered consists of a shallow surface water channel that is lined with grass.

**VOLUME 4 GEOTECHNICS AND
DRAINAGE**

SECTION 2 DRAINAGE

PART 9

NRA HD 119/15

**GRASSED SURFACE WATER CHANNELS
FOR ROAD RUNOFF
(INCLUDING AMENDMENT NO. 1)**

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1. INTRODUCTION

General

- 1.1 This Standard shall be used for the hydraulic and structural design of grassed surface water channels for road drainage. The type of system considered consists of a shallow surface water channel that is lined with grass. The grass sward reduces the flow velocity in the channel providing flow attenuation and facilitating deposition of suspended sediments and polluting heavy metals. Although, when compared with concrete surface water channels, the grassed surface water channels will require more maintenance in the form of mowing, they are considered a sustainable drainage system (SuDS) and offer environmental benefits: a potential habitat for local fauna coupled with a better aesthetic value. The system is particularly suited to in-situ construction techniques. However, the hydraulic design procedures provided are generally applicable and are not limited to a particular method of construction.
- 1.2 The function of the surface channel is to collect and convey surface water runoff from the road surface. At suitable points along the channel, water is discharged into a separate carrier pipe to the rear, or possibly beneath the channel.
- 1.3 This Standard should be read in conjunction with the following documents in the NRA DMRB:
 - a) NRA HD 33 Drainage Systems for National Roads;
 - b) NRA HD 45 Road Drainage and the Water Environment;
 - c) NRA HD 137 Hydraulic Design of Road-Edge Surface Water Channels;
 - d) NRA HD 78 Design of Outfalls for Surface Water Channels;
 - e) NRA HD 83 Safety Aspects of Road Edge Drainage Features;
 - f) NRA HD 103 Vegetated Drainage Systems for Road Runoff;
 - g) NRA HA 33 Drainage, Attenuation and Pollution Control Design
- 1.4 The use of surface water channels should take account of advice on safety given in NRA HD 83.
- 1.5 The selection of grassed surface water channels cannot be prescribed. Each situation must be considered individually taking into account the local landscape, geology, hydrology, climate and the practicality of provision for maintenance.
- 1.6 The 2015 revision of the NRA's drainage standards was precipitated by post-doctoral research carried out under the NRA's Research Fellowship Programme and mentored by the NRA's Environment Unit. This research looked at the impacts of national road drainage systems on both surface and ground water. The research concluded that the NRA's drainage standards needed to be expanded to promote the use of sustainable drainage systems and to maximise environmental benefits. A report entitled *Drainage Design for National Road Schemes – Sustainable Drainage Options* (NRA, 2014) documents this research and provides useful background reading to the NRA's drainage standards. This document is available at: nrastandards.nra.ie/latest/other-nra-documents.

Scope

- 1.7 The principles outlined in this Standard apply to all National Road Projects.

Implementation

- 1.8 ¹This Standard shall be used forthwith on all schemes for the construction and/or improvement of national roads except where the scheme has received, prior to publication of this Standard, its statutory approvals to allow it to proceed. If this exception applies, the standard to be used may be either this current Standard or the Standard applicable preceding the March 2015 version of the Standard. Where the previous Standard is to be used, Designers Organisations shall confirm this by e-mail to the Standards Section of the National Roads Authority at infoDMRB@tii.ie.

¹ Amended as per Amendment No. 1, item 1

2. SAFETY ASPECTS

General

- 2.1 When considering the use of a grassed surface water channel, safety aspects relating to its location should be taken into account in accordance with the guidelines given in NRA HD 83.
- 2.2 Grassed surface water channels will usually be sited adjacent to the hardstrip or hardshoulder or at the edge of the carriageway and in front of the safety barrier, where one is provided. Layout details are given in Series 100 and 500 of NRA Road Construction Details (NRA RCD) (MCDRW 4). Grassed surface water channels can be triangular or trapezoidal in cross-section. Non-symmetrical shapes can be considered provided account is taken of the following recommendations. In verges, the side slopes of the channel should not be steeper than 1:5 (vertical: horizontal) for triangular and trapezoidal channels whether symmetrical or not. In very exceptional cases, the side slope remote from the running lane may have a slope of 1:4.5 if permitted by the National Road Authority.
- 2.3 Grassed triangular channels of depth greater than 200 mm should be used only when safety barriers are provided between the channel and the carriageway. Systems of this type will normally only be justified when safety barriers are warranted by other considerations. In addition, such systems should not be located in the zone behind the safety barrier into which the barrier might reasonably be expected to deflect on vehicle impact (because of the risk of the vehicle overturning due to it being too low relative to the safety barrier). Shallower types of channel may be located in this deflection zone, or be crossed by the safety barrier (usually at a narrow angle), provided that the combined layout complies with the requirements of other relevant parts of the NRA DMRB (refer to NRA GD 02 Volume Contents and Alpha-Numeric Index to the NRA Design Manual for Roads and Bridges for contents list and index).
- 2.4 The need to minimise safety risks will inevitably mean that the layout of safety barriers and grassed surface water channels should be agreed at an early stage in design and not left to compromise at later stages. Where safety barriers are not immediately deemed necessary, sufficient space should be provided in the verge allow for their possible installation. The combined layout must comply with the requirements of NRA TD 19 Safety Barriers and NRA TD 27 Cross Sections and Headroom.
- 2.5 The constraints on channel geometry given in this document also apply to the outlet arrangements used to discharge flow from the channel to the carrier drain or watercourse. For outlets and channel terminations, slopes exceeding 1:4 should not be used on any faces, particularly those orthogonal to the direction of traffic, unless such faces are behind a safety barrier.
- 2.6 Gully gratings used in a combined system to discharge water from the surface water channel to the adjacent carrier pipe (or to an outlet) should meet the geometrical and structural requirements of I.S. EN 124 and BS 7903 and be of the appropriate load class as required by NRA HD 33.
- 2.7 When dry, a grassed surface water channel of appropriate construction, should be capable of supporting a heavy vehicle, refer to Appendix D, without incurring significant damage. Where grassed surface water channels are used in conjunction with a national road with one metre hardstrip, and non-accidental vehicle loading may be anticipated, for example a vehicle standing during routine maintenance operations, then consideration should be given to locally reinforcing the channel surface at these locations. (Refer to Chapters 11 and 12 and Appendix D.)

3. DESCRIPTION

General

- 3.1 The drainage system described in this Standard consists of a grassed triangular or trapezoidal surface water channel that is installed at the pavement edge to collect and convey rainfall runoff from the road surface. The cross-sectional geometry of a typical grassed surface water channel system is shown in Series 100 of NRA RCD, RCD/100/4. Recommendations on appropriate methods of sub-surface drainage are given in Chapter 8.

Ground Water Implications

- 3.2 Groundwater risk assessments shall be carried out in accordance with NRA HD 45. Infiltration of runoff through the grassed surface water channel can potentially impact on the receiving ground waters. Pollution protection response measures are specified in NRA HD 45. Note that the use of cohesive subsoil in the channel construction is to be avoided due to poor performance when driven over. Acceptable subsoil material for grassed surface water channel construction is specified in Series 500 of the NRA Specification for Road Works (NRA SRW) (MCDRW 1).

Recommended Configuration

- 3.3 Grassed surface water channels can be triangular (see Appendix D) or trapezoidal in cross-section; non-symmetrical triangular channels can be considered to take advantage of the verge space (see Appendix C). Details of the grassed surface water channel configuration are given in the Series 500 NRA RCD and the NRA SRW.
- 3.4 The width of the channel may be limited by the width of available verge. For safety reasons the depth should not exceed 200 mm or side slopes be steeper than 1:5 (vertical : horizontal) for triangular channels, or 1:4.5 (vertical : horizontal) for trapezoidal channels. In order to ensure effective conveyance, grassed surface water channel depth should not be less than 150 mm.

4. ENVIRONMENTAL BENEFITS

General

- 4.1 Grassed surface water channels are a vegetated drainage system (see NRA HD 103) and may also be considered to be a Sustainable Drainage System (SuDS), in that they use minimal non-replenishable materials such as quarried stone or oil based products. The system also offers potential environmental benefits not found in most conventional road drainage systems.
- 4.2 The visual environment is improved by the apparent reduction in width of the road, which for a rural Dual All Purpose carriageway could be between 10 and 15%. Replacing the concrete surface water channel by a grassed surface water channel represents a visual 'greening' of the road.

Flow Attenuation

- 4.3 The increased surface roughness of the grassed surface water channel in comparison with that of concrete will reduce the corresponding flow velocity. Comparison between average flow velocities in the two types of channel indicates velocities in grassed surface water channels around 25% of those in concrete surface water channels. A reduction in velocity will increase the time of flow within the channel and thereby increase the time of concentration. Consequently, the peak discharge flow rate to a receiving watercourse will be less from the grassed surface water channel.

Sediment Deposition

- 4.4 The lower flow velocity generates less energy thereby reducing the sediment transport ability of the channel flow. Sediment will settle in the channel bed and be trapped by the grass blades.

Pollution Containment

- 4.5 Sediment is the prime constituent in the transport of heavy metals and polluting materials, such as lead, copper, zinc, cadmium etc. Metals are mainly contained in the suspended solids carried along by the channel flow and are removed when the solids are deposited as sediment. Increased sediment deposition will result in less of these pollutants reaching the receiving watercourse.
- 4.6 While grasses may not be as effective as reed beds in absorbing heavy metals and pollutants, the grass root system may remove some of the sediment borne contaminants. NRA HD 45 ascribes the same risk reduction factor, 0.6, to grassed surface water channels as to filter drains, soakaways/infiltration basins and sediment traps.
- 4.7 Under no, or low, flow conditions, accidental spillages may be readily contained due to the very low velocity of the spillage and the ability of the grass to retain the contaminant by permitting it to soak into the topsoil. The grass and contaminated soil may be removed and the channel section reconstructed.

5. HYDRAULIC DESIGN PRINCIPLES

General

- 5.1 The methods given in Chapter 6 for determining the drainage capacities of a grassed surface water channel are based on the same principles as those used in NRA HD 137 for conventional surface water channels. An outline description of the principles is given in this Standard.
- 5.2 It is a feature of the grassed surface water channel that the longitudinal gradients of the channel normally be the same as the longitudinal gradient of the pavement being drained.
- 5.3 For a section of road at constant longitudinal gradient, the design should involve the following steps:
- Assume a suitable size and cross-sectional geometry for the grassed surface water channel and use the method given in Chapter 6 to find the length of road, L (in m), that can be drained by the channel before it reaches its design capacity. This length, L , determines the maximum allowable distance between the upstream end of the system and the first outlet and also the spacings between subsequent outlets to a carrier pipe line.
 - The carrier pipe should be designed to the principles set out in NRA HD 33.
- 5.4 The hydraulic capacity of a grassed surface water channel is a function of the following factors:
- The longitudinal gradient of the road, S (vertical fall per unit distance along the road, in m per m);
 - The effective width, W_E (in m), of the catchment drained by the channel, taking account if appropriate of any run-off from cuttings (see NRA HD 137);
 - The size, shape and cross-sectional area of the surface channel;
 - The hydraulic roughness values of the channel, which are dependent on grass type and height, as well as on flow conditions;
 - The statistical rainfall characteristics at the site, i.e. the relationship between the rainfall intensity, the duration of the design storm and its frequency of occurrence;
 - The variation of rainfall intensity with time during the design storm.
- 5.5 The effects of these various factors can be taken into account using a method based on kinematic wave theory. This method provides information about the variation of flow conditions with time during a storm and enables the duration of storm that produces the worst flow conditions to be determined. The applicability of this method to the specific case of grassed surface water channels where, in contrast with concrete surface water channels, the hydraulic resistance of the grass depends on the flow conditions in the channel, was investigated and is described in Escarameia and Todd.
- 5.6 The flow capacity of the channel can be determined from the Manning resistance equation which has the form:

$$Q = \frac{A R^{2/3} S^{1/2}}{n} \quad (1)$$

where Q is the flow rate (in m^3/s), A is the cross-sectional area of flow (in m^2), and n is the Manning roughness coefficient of the channel. The hydraulic radius, R (in m), of the flow is given by:

$$R = \frac{A}{P} \quad (2)$$

where P is the wetted perimeter of the channel (in m).

- 5.7 The Manning's roughness coefficient, n , can be calculated using the following formulae derived from laboratory tests and validated using field trial data (Ref 14.4):

$$n = 0.05 + 0.0048(1 + \alpha) \frac{H}{VR} \quad (3)$$

with $\alpha = 0$ for Perennial Ryegrass dominated grass mixtures

$\alpha = 1$ for Fescues dominated grass mixtures

where H is the grass height in metres, V is the velocity in metres/second and R is the hydraulic radius in metres.

Equation (3) is applicable for $VR > 0.002$. The great majority of design cases will be in that category; however, if any situations arise where $VR < 0.002$, n can be calculated using the following expression:

$$n = 0.05 + 2.4(1 + \alpha)H \quad (4)$$

- 5.8 Rainfall statistics for short-duration storms in Ireland can be approximated by the following equation:

$$I_o = 32.7 (N - 0.4)^{0.223} \frac{(T - 0.4)^{0.565}}{T} (2 \text{ min } M5) \quad (5)$$

where I_o is the mean rainfall intensity (mm/h), factored for climate change in accordance with the guidance contained in NRA HD 33, occurring in a storm of duration T (minutes) with a return period of N (years), such that a storm of this intensity will occur on average once every N years. The quantity $2 \text{ min } M5$ is the depth of rainfall (in mm) occurring in a storm at the specified geographical location during a period of $T = 2$ minutes with a return period of $N = 5$ years. $M5-2D$, $M5-60$ and $r\%$ values required to derive $2 \text{ min } M5$ values shall be estimated from maps included in the Flood Studies Report, (NERC, 1975). Details of the basis for Equation (5) are given in NRA HD 137.

- 5.9 The higher resistance of grass, when compared with concrete and other artificial materials, generates lower flow velocities and flow rates in the channel (see Appendix B). For channels of equivalent size and slope, mean flow velocities in grassed surface water channels can be of the order of 25% of those in concrete surface water channels. Attenuation of peak flows is therefore better achieved in grassed surface water channels and consequently the rate of discharge of runoff into the receiving watercourse is significantly slowed down.

6. DRAINAGE CAPACITY OF CHANNEL

Determination of Hydraulic Resistance

6.1 The first step in determining the capacity of grassed surface water channels is concerned with the determination of the grass resistance coefficient. The procedure for obtaining this value is as follows:

- a) Define the cross-sectional characteristics of the channel. Assume design water depth is equal to 0.200m.
- b) Determine the hydraulic radius, R , of the channel as the ratio of the cross-sectional area and the wetted perimeter for the design water depth, see Equation (2). For the determination of these quantities, consider that the boundaries of the grassed surface water channel are defined by the level of the soil from which the grass grows (as opposed to the tips of the grass blades).
- c) Decide on the grass mixture type (Fescues dominated mixture or Perennial Ryegrass dominated mixture) (see Chapter 10).
- d) For design purposes assume a grass height of $H=0.05\text{m}$ for Fescues dominated mixture and $H=0.075\text{m}$ for Perennial Ryegrass dominated mixture.
- e) Using the value of the longitudinal slope of the road, S , calculate the term $H/(R^{5/3}S^{1/2})$, where H is the grass height (in metres) and R is the hydraulic radius (in metres) and calculate the following expression:

$$n = \frac{0.05}{1 - \frac{mH}{R^{5/3}S^{1/2}}} \quad (6)$$

where $m = 0.0048$ for Perennial Rye Grass and $m = 0.0096$ for Fescues dominated mix.

Values of n are typically within the range 0.05 to 0.1.

- f) Follow the procedure described in NRA HD 137 to find the drainage length (see below).

6.2 Factors that influence the effective value of n are the grass stem density, grass stem length, soil composition, energy losses caused by the flow entering the channel from the road, and the presence of sediment or debris deposited in the channel.

Drainage Length

6.3 The grassed surface water channel is divided into separate drainage lengths by the intermediate outlets and terminal outlet. For a given size of channel, the maximum allowable distance between adjacent outlets will vary with the longitudinal gradient of the road and the effective width of the catchment being drained. The outlets may not, therefore, be equally spaced. Alternatively, it is possible to use a standardised spacing equal to the length of road that the channel can drain in the most critical section of the carrier pipe system.

6.4 For an individual section of grassed surface water channel, the drainage length, L (in m), is defined as the maximum length of road that can be drained by the channel under design conditions without the flow exceeding the allowable water depth in the channel. At the downstream end of the drainage length, the flow needs to be discharged from the channel to either the carrier pipe via an intermediate outlet, or to a watercourse or other drainage system via a terminal outlet (see Chapter 7).

6.5 In addition to the physical properties of the road and the channel, the value of L depends upon the rainfall characteristics at the site and the selected value of return period for the design storm. Based on the hydraulic principles described in Chapter 5, the following equation can be used to determine values of drainage length for triangular surface channels of symmetrical cross-section:

$$L = 1.56 \times 10^6 \frac{(BY)^{2.29}}{(B^2 + 4Y^2)^{1/3}} \frac{S^{1/2}}{n} \frac{(N - 0.4)^{-0.362}}{[W_E (2 \min M5)]^{1.62}} \quad (7)$$

where:

- a) Y is the design depth of flow in the triangular channel (in m) – see Chapter 2 and Appendix C;
- b) B is the corresponding surface width of flow (in m);
- c) S is the longitudinal gradient of the channel (in m per m);
- d) n is the Manning roughness coefficient of the channel (obtained from Equation (6));
- e) W_E is the effective width of the catchment drained by the channel (in m);
- f) N is the return period of the design storm (in years);
- g) $2 \min M5$ is a value of rainfall depth (in mm) characteristic of the geographical location of the site.

6.6 Equivalent formulae for the drainage capacities of other cross-sectional shapes of channel (asymmetric triangular, trapezoidal, rectangular and dished) are given in NRA HD 137.

Maximum Flow Capacity

6.7 The maximum flow capacity, Q (in m³/s), of a surface channel when it is just flowing full at its design depth of flow, Y , can be determined from the Manning resistance Equation (1). For the particular case of a triangular channel of symmetrical cross-section, the equation has the form:

$$Q = 0.315 \frac{(BY)^{5/3}}{(B^2 + 4Y^2)^{1/3}} \frac{S^{1/2}}{n} \quad (8)$$

Longitudinal Gradient

6.8 If the longitudinal gradient of the road and the grassed surface water channel varies along the drainage distance, L , the value of S in Equations (7) and (8) should be replaced by the effective value of longitudinal gradient, S_E . This can be estimated approximately from:

$$S_E = \frac{\Delta Z}{L} \quad (9)$$

where ΔZ (in m) is the difference in invert level of the channel between the upstream and downstream ends of the drainage length, L . If the variation in longitudinal gradient is considerable, a more accurate estimate of S_E may be obtained from Equation (15) in NRA HD 137. In either case, an iterative procedure may be necessary to determine S_E if the longitudinal profile of the road has been determined in advance of the hydraulic design.

6.9 Appendix B provides a comparison of flow capacities of concrete and grassed surface water channels over a range of longitudinal gradients.

Storm Return Period

6.10 Recommendations on the selection of design storm return periods for road drainage systems are given in NRA HD 33.

Surcharging of the Channel

6.11 Limited surcharging of grassed surface water channels is permissible during rarer storms. Recommendations on the selection of design storm return periods for this are given in NRA HD 33.

6.12 The following simplified method may be used to calculate the length of road that a grassed surface water channel can drain to an outlet when the channel is flowing in a surcharged condition:

- a) First use Equation (7) to calculate the maximum length of road, L (in m), that can be drained by the channel when just flowing full at the design flow depth, Y . N is the design storm return period for the channel flowing full and shall be in accordance with NRA HD 33.
- b) The maximum length of road, L_s (in m), that the channel can drain to an outlet in the surcharged condition is given by:

$$L_s = \phi L \tag{10}$$

where ϕ is a factor given in Table 6.1 and is dependent on the allowable width of flow, B_s , on the adjacent hard strip or hardshoulder. N is the design storm return period for the surcharged conditions and shall be in accordance with NRA HD 33.

Table 6.1 – Values of ϕ

Road cross-fall	Values of ϕ	
	Allowable width on hard strip $B_s = 1\text{m}$	Allowable width on hardshoulder $B_s = 1.5\text{m}$
1:30	1.5	1.8
1:40	1.4	1.6
1:50	1.2	1.4

This simplified method assumes that the channel has a symmetrical triangular profile and provides estimates of L_s that will tend to err on the conservative side.

6.13 The maximum flow capacity of the channel, Q_s (in m^3/s), under surcharged conditions can be estimated from:

$$Q_s = 1.575 \phi Q \tag{11}$$

where the value of Q is the design capacity of the channel obtained from Equation (8).

Flow By-passing at Intermediate Outlets

- 6.14 Because velocities in grassed surface water channels are so low in comparison with concrete, it is expected that, even under surcharged conditions, the volume of flow by-passing the gratings would be minimal, therefore outlet gratings are designed on 100% efficiency.

7. OUTLETS AND TERMINAL OUTFALLS

General

- 7.1 The outlet from the channel should be of similar arrangement to that of concrete surface water channels, described in NRA HD 78. The grating may be either flat or V-shaped to correspond with the channel profile. To avoid dangers to vehicles or flooding, care should be taken to ensure the level of the grating is not higher than the invert level at the centre of the channel.
- 7.2 The growth of grass around the outlet may obstruct flow into the grating. To minimise the risk of this occurring, the immediate area around the grating shall be paved to form an apron. The surround (apron) to the grating acts as a transition from the grassed surface water channel and may be formed using concrete or plastic cellular block grass reinforcement, hence incorrect positioning of the apron will be expensive to rectify.
- 7.3 The terminal outlet may contain more than one grating, which may necessitate extending the apron beyond the downstream end of the channel. Refer to Figure C3 and NRA HD 78 for the terminal outlet detail.
- 7.4 The piped sub-surface drainage system, e.g. Type 6 fin drain, may be connected to intermediate chambers but should be connected to the terminal outlet chamber. Ensure that the level of the outlet from the chamber is below this sub-surface pipe so that surcharge will not result in a back flow of water into the sub-surface drain.
- 7.5 The outlets from the channel form a solid obstruction within an area of comparatively soft channel construction. Any vehicle wheel that impacts with the outlet structure could be damaged or, if travelling at a high velocity, the vehicle itself may be damaged. To minimise this risk it is recommended that a transition zone in the form of an apron, is constructed around the outlet structure. This apron should be of a cellular structure, comprising concrete or plastic blocks incorporating holes for topsoil and grass growth, inclined to slope downwards from the edge of the outlet to below the channel, see detail in Appendix C. This should absorb much of the energy and protect both the vehicle and the structure.

Intermediate Outlets

- 7.6 Intermediate outlets for grassed surface water channels, see Appendix C, consist of gratings, installed in the base of the channel, that discharge the flow from the surface water channel to a carrier pipeline or, in certain circumstances, directly to a watercourse.
- 7.7 The hydraulic design of the gratings (type, spacing, number) is described in NRA HD 78. The following alternative geometries for intermediate outlets, presented in NRA HD 78, are generally suitable for grassed surface water channels:
 - a) **In-line outlet**, the preferred option, where the water is essentially collected symmetrically through the channel invert (see NRA HD 78); or
 - b) **Off-line outlet**, where the channel is widened away from the carriageway and the outlet is offset from the centreline of the channel (see NRA HD 78).

For triangular channels the in-line design is generally more efficient than the off-line design, but reasons for choosing between them will mainly depend on constructional aspects (see Chapter 11).

Other factors being equal, in-line outlets are preferable to off-line outlets because they can enable use of a narrower verge.

Terminal Outlets

- 7.8 Terminal outlets comprise chambers with catchpits that also receive flow from the grassed surface water channel and convey the flow to a suitable watercourse, ditch or continuation carrier pipe.
- 7.9 To avoid an errant vehicle losing control when a channel is not protected by a safety barrier, the upper surface of the terminal outlet should terminate with a smooth transition, without abrupt changes in level or width (following the recommendations in NRA HD 78).
- 7.10 The plan shape of the chamber will be determined by the layout of the gratings forming the terminal outlet. The invert level of the outgoing pipe from the chamber should be governed by the following two criteria:
- The invert level should be set at a minimum of 300 mm above the bottom of the chamber to provide an adequate volume for sediment retention.
 - The invert level should be such that the water level in the chamber does not rise high enough to prevent flow discharging freely from the surface channel into the chamber.
- 7.11 In order to meet criterion (2) in 7.10, it is recommended that the water level in the chamber should be at least 150 mm below the underside of the gratings when the chamber is receiving flow from the channel under surcharged conditions. The height Z (in m) of the water surface in the chamber above the invert of the outgoing pipe can be estimated from the equation:

$$Z = \frac{D}{2} + 0.23 \frac{Q^2}{D^4} \quad (12)$$

where D is the diameter of the outgoing pipe (in m) and Q is the design flow rate (in m³/s).

- 7.12 The gradient and diameter of the outgoing pipe from the chamber should be determined from a suitable resistance equation or flow tables (such as HR Wallingford and Barr) assuming that the pipe is just running full at the design flow rate, Q .
- 7.13 An example of a suitable layout for a terminal outlet chamber is given in Appendix C.

Steep Roads

- 7.14 On steep roads (typically with gradients of $S > 1/50$), the flow collection efficiency of the gratings may be insufficient due to the effect of high water velocities in the grassed surface water channel. This could also cause scouring in the channel. The designer shall check scouring velocities for the design storm return periods.

8. SUB-SURFACE DRAINAGE

General

- 8.1 Sub-surface water flow must be prevented from entering the unbound pavement foundation, where the presence of moisture can cause premature failure of the pavement.

Drainage System

- 8.2 A sub-surface drainage system shall be provided to ensure that any percolation through the channel is intercepted before reaching the unbound pavement layers. Refer to NRA HD 33 for suitable sub-surface drainage systems.
- 8.3 Sub-surface drainage systems include the installation of a fin drain, Type 5 or 6 in RCD/500/41, at the edge of the pavement construction. The fin drain should incorporate a double cusped central core, made from a suitable impermeable material such as polyethylene or polypropylene, which acts as a barrier between the two constructions. A narrow filter drain, Type 7 or 8 as per RCD/500/42 may also be a suitable drainage system.
- 8.4 The top of the fin/narrow filter drain should be located above the top of the pavement sub-base level, but care is necessary to ensure that the fin does not protrude into the grassed topsoil.
- 8.5 The extension of a capping layer to the edge of embankment as per RCD/100/5 may be appropriate as a means of sub-surface drainage. Refer to Series 600 of NRA SRW for appropriate material specification and testing requirements.

9. SOIL PROPERTIES

General

- 9.1 The channel should comprise of graded subsoil, a layer of topsoil and sub-surface drainage (see Chapter 8). The subsoil should be graded to the required cross-sectional and longitudinal profiles.
- 9.2 The channel may be either seeded or lined with turf. Where seeded directly on to the topsoil, the depth of topsoil should be minimal, around 100mm, to ensure that the grass roots penetrate the subsoil and bond the two layers together.
- 9.3 A geo-grid may be placed between the two soil layers to provide reinforcement until the grass becomes established. The use of a biodegradable material is preferable and should provide protection for some 2 to 3 years. The geo-grid is usually held in place by U-shaped steel pins or staples. The presence of the staples should be borne in mind when considering the use of grassed surface water channels, especially where an impermeable liner is required (see Chapter 3).

Subsoil Requirements

- 9.4 The grassed surface water channel subsoil requirements shall comply with details provided in Series 500 of NRA SRW.

Topsoil Requirements

- 9.5 The topsoil used should comply with Series 600 of NRA SRW general purpose topsoil, screened for stones larger than 50mm.
- 9.6 To ensure good grass growth it is recommended that, in terms of textural classification, the soil should be a sandy loam or loamy sand, with a pH greater than 5.5.
- 9.7 The depth of topsoil shall be 100mm as greater depths of topsoil will encourage the growth of weeds and other forms of vegetation.

Topsoil Preparation

- 9.8 The steps for seedbed/turfbed preparation are as follows:
 - a) Cultivation of the topsoil and rolling, under suitable ground conditions to form the seedbed;
 - b) Application of lime, dependent on pH test results. Acid soils, for example, the pH range is from 6.0 to 6.5;
 - c) Application of seedbed fertiliser e.g. 10:15:10 (N:P₂O₅:K₂O) at 30 g/m²;
 - d) Final raking or harrowing before seeding/hydroseeding or turfing.

10. GRASS TYPE SELECTION

Suitable Grass Types

- 10.1 When selecting the most appropriate grass types for surface water channels the main issues to be considered are:
- a) Suitability of grasses for different climatic areas;
 - b) Ease of establishment;
 - c) Salt tolerance;
 - d) Susceptibility to pollution from exhaust emissions and runoff from road surfaces;
 - e) Tolerance of the wetter conditions that may prevail in drainage channels;
 - f) Growth rates;
 - g) Erosion control;
 - h) Recovery rates from damage.

Regional Variation in Climate

- 10.2 A wide range of cool season grasses is potentially available within grassed surface water channels in Ireland. The climatic range is probably not great enough to justify differences in seed mixtures for different parts of the country, but grasses that predominate after establishment will be influenced by both climate and soil type.

Grass Establishment

- 10.3 The advantages and disadvantages of various techniques for establishing grass within the channel (seeding, hydro-seeding and turfing) are set out in Table 10.1.

Table 10.1 – Advantages and Disadvantages of Different Establishment Methods

Method	Advantages	Disadvantages
Seeding	Control over grass seed used. Low cost. Seed will generally remain dormant if there are hot dry spells after sowing but will establish when suitable weather conditions return.	Potential loss of seed if heavy rainfall occurs during establishment. Greater risk of erosion.
Hydroseeding	Control over grass seed used. Less risk of seed loss if heavy rain occurs during establishment. Less risk of erosion.	More expensive than conventional seeding.
Turfing	Instant grass cover. Less risk of erosion.	High initial cost. High labour requirement/cost for laying. Cost of mowing. Vulnerable to drying out if hot, dry spell occurs after laying. Unless specifically grown for grassed surface water channels, may not have the grass species required.

10.4 If grassed surface water channels are to be established from seed, it is important that the seed germinates quickly and that the grass cover develops rapidly. Roadside verges are unlikely to receive irrigation to help establishment therefore the requirement is for grass types that will develop quickly.

10.5 The speed of grass establishment varies according to the species. The establishment rates for common Ireland turf grasses (Ref 14.7) are shown in Table 10.2 below.

Table 10.2 – Establishment Rates for Common Turf Grasses

Species	Speed of Establishment (5=best)
Perennial ryegrass	5
Timothy	4
Crested dogstail	4
Strong creeping red fescue	4
Rough stalked meadow grass	4
Slender creeping red fescue	3-4
Chewings fescue	3
Annual meadow grass	3
Sheep's hard fescue	2

Bents	2
Smooth stalked meadow grass	1

Salt Tolerance

10.6 The use of salt for de-icing requires the consideration of salt tolerance. Table 10.3 below gives an indication of salt tolerance of the main turf grasses. None of the grasses has a high salt tolerance, in contrast to some warm-season species, but the most tolerant are slender creeping fescue, tall fescue and perennial ryegrass (Ref 14.8).

Table 10.3 – Salt Tolerance of Turf Grasses

<p>Moderately Tolerant</p> <p>Slender creeping red fescue cv Dawson Tall fescue Perennial ryegrass</p>
<p>Moderately Susceptible</p> <p>Annual ryegrass Chewings fescue Creeping bent Strong creeping red fescue Hard fescue Rough stalked meadow grass</p>
<p>Susceptible</p> <p>Annual meadow grass Browntop bent Smooth stalked meadow grass</p>

Pollution Susceptibility

- 10.7 Grass is more resistant to phytotoxic effects of lead and other heavy metals than most other plants although very high concentrations can affect growth.
- 10.8 Some species such as strong creeping red fescue are known to have a greater resistance to heavy metals.
- 10.9 Raising the soil pH by liming improves plant health but has a detrimental effect on the plants absorption of toxic micronutrients and heavy metals.
- 10.10 Care should be taken to prevent nutrients being washed into adjacent watercourses. A buffer zone could be created around the area when seeding or hand seeding could be carried out in the immediate proximity of watercourses.

Tolerance to Wetter Conditions of Drainage Channels

10.11 Grassed surface water channels will probably be wetter than grass verges on comparable soil types. This may cause changes in the balance of grass species over time, favouring grasses such as timothy, perennial ryegrass and annual meadow grass that are more tolerant of wet conditions. It is quite probable that these grasses may eventually become more dominant in the lower lying central section of the grassed surface water channel, whereas the drier upper slope may retain grasses better adapted to the drier conditions, such as fescues.

Growth Rate

10.12 Road side verges are low maintenance areas and consequently it is desirable that any grasses used are slow growing so that mowing frequency is minimised and the volume of cuttings reduced.

Table 10.4 – Growth Rates for Turf Grasses

Species	Low Growth Rate (5=lowest rate)
Perennial ryegrass	1-2
Strong creeping red fescue	1-2
Timothy	1-2
Slender creeping red fescue	2-3
Smooth stalked meadow grass	2-4
Crested dogstail	3
Chewings fescue	3
Sheep's hard fescue	3
Rough stalked meadow grass	3
Bents	3-4
Annual meadow grass	3-5

10.13 Growth rates will be modified by fertility and soil moisture content, guidance on growth rates (Ref 14.7) is shown in Table 10.4.

Damage Recovery

10.14 The most likely cause of physical damage to the grassed surface water channel is from vehicle over-run. The amount of damage that occurs will be dependent on the weight of the vehicle and the interaction between the soil moisture content and soil strength.

10.15 In severe cases extra topsoil and re-levelling may be required to repair deeper ruts.

10.16 The inclusion of a biodegradable matting should assist in the reinforcement of the grassed surface water channel as the sward becomes established.

10.17 Recovery rates for different grasses (Ref 14.7) are given in Table 10.5.

Table 10.5 – Recovery Rates for Turf Grasses

Species	Recuperation (5=best)
Perennial ryegrass	5
Annual meadow grass	5
Timothy	3-4
Smooth stalked meadow grass	3-4
Slender creeping red fescue	3
Chewings fescue	3
Strong creeping red fescue	2-3
Bents	2-3
Sheep’s hard fescue	2
Crested dogstail	1
Rough stalked meadow grass	1

Indicative Grass Seed Mix

10.18 Both Perennial Ryegrass dominated mixtures and Fescues dominated mixtures are particularly suitable for grassed surface water channels. The following is an example of a resilient and slow growing mix, but is by no means the only mix suitable:

- 20% Perennial Ryegrass
- 10% Highland Bent
- 20% Chewings Fescue
- 40% Slender Creeping Red Fescue
- 10% Smooth stalked Meadow Grass

11. CONSTRUCTION ASPECTS

Verge Ancillaries

- 11.1 A large number of ancillary structures can be positioned adjacent to the carriageway and will require accommodation within, or close to, the grassed surface water channel and to which access will be required. These structures can include fixed sign and variable message sign structures, gantries, lighting and CCTV columns, motorway communications cabinets and roadside emergency telephones.

Ducted Cables

- 11.2 Ducts for motorway communications cables are located in the verge. The location for the ducts is shown on the Series 500 of NRA RCD.
- 11.3 Ducts run both parallel to and perpendicular to the carriageway and require the construction of chambers at changes in direction. It is essential that chambers are remote from the grassed surface water channel as ducts are a means of introducing surface water into the pavement construction. It is also essential that the grassed surface water channels do not run off surface water on to the chamber tops allowing the introduction of surface water into the duct network. Details for ducts are shown on RCD/500/60 to RCD/500/67.

Detector Loops

- 11.4 Detector loops in the carriageway surface and loop joint chambers in the verge result in very shallow cables being present at the carriageway edge. The designer should be aware of the potential conflict between these cables and the grassed surface water channel. Detector loops are generally installed at 500m intervals. NRA HD 20 Loop Detectors for Motorways provides information.

Signage

- 11.5 Signs are generally remote from the pavement edge and are protected by safety barriers. The designer should ensure that no signs encroach into the channel.

Lighting Columns

- 11.6 Lighting columns should be remote from the pavement edge, however where lighting columns are proposed, the designer should ensure that the columns themselves are protected from channel flows.

Safety Barriers

- 11.7 The presence of barriers may adversely affect the maintenance (mowing) of the grass and hence the suitability of grassed surface water channels where long sections of barriers are proposed.

Grassed Surface Water Channel Construction

- 11.8 It is recommended that a narrow filter drain or fin drain is installed at the edge of pavement to intercept infiltration through the grassed surface water channel before it reaches the pavement construction (see Chapter 8) and similarly intercept flows from beneath the pavement. The

recommended fin drain is either a Type 5 or Type 6 of RCD/500/41 with a double cusped core. The extension of a capping layer to the edge of embankment as per RCD/100/5 may be appropriate as a means of sub-surface drainage.

- 11.9 During construction of the channels, temporary measures may be necessary to prevent surface runoff from the pavement, or verge, washing away the topsoil or surcharging the fin drain.
- 11.10 To reduce the risk of topsoil becoming saturated due to heavy rain, subsoil (where imported) and topsoil placement should commence at the highest point of the channel and work downstream.
- 11.11 The subsoil shall comply with details provided in Series 500 of NRA SRW.
- 11.12 Where turf is used, this should be placed immediately after compaction of the topsoil to minimise the risk of soil fines being washed away by surface runoff. Turfing offers advantages over hydro-seeding in that it will give a much greater level of initial protection to the topsoil and hydro-seeding is very dependent on the quality of the seed mixture and the fibre reinforcement.
- 11.13 The grassed surface water channel should be operational at the end of the road construction stage. To avoid long establishment times in winter months as well as the inclement weather of the hotter and colder months, grassed surface water channel construction should preferably be undertaken in early Spring or early Autumn.

Vehicle Pull Off Location

- 11.14 Access to communications apparatus and similar equipment may necessitate vehicles being deliberately driven on to the grassed surface water channel, particularly where there is only a one metre hardstrip. In these circumstances it may be appropriate to locally reinforce the grassed surface water channel to minimise damage should the channel surface be softened by water flowing in the channel. Appropriate grass reinforcement systems include installing a reinforcing mat within the topsoil and grass roots, (see Plate D.3), or proprietary grass surface reinforcement products.

Field Access

- 11.15 Where grassed surface water channels are proposed for use on All Purpose Roads, the presence of field access crossings should be considered. In these instances, the grassed surface water channel should terminate at the crossing and recommence on the downstream side. A terminal outlet chamber and carrier drain will be required. The ends of the grassed surface water channel should be sufficiently remote from the crossing that there is no risk of over-running by farm vehicles as they turn.

12. MAINTENANCE

- 12.1 The frequencies for inspections and maintenance activities should be stated in the relevant maintenance management contract documentation. The maintenance activities are detailed below:

Frequency of Grass Cutting

- 12.2 Ideally, for optimum hydraulic performance, the grass blades should be no longer than 75mm. The mowing regime should be developed accordingly. It is anticipated that the grass should be mown three times during the late spring and summer.
- 12.3 The grassed surface water channel profile should be capable of being mowed using the same equipment that is used to maintain the verge.

Weed Control

- 12.4 Invasion of the grassed surface water channel by weeds and native grass species is inevitable since mowing alone will not prevent this. Low broad leaved weeds will cause the local grass to die back, however due to the relatively short drainage path to the watercourse, the use of herbicides should be carefully considered.

Removal of Litter and Detritus

- 12.5 The presence of litter and debris will cause the underlying grass to die with the consequential result of bare patches that may become prone to erosion. The use of grassed surface water channels may not be appropriate on sections of road subject to very high traffic densities and the consequent frequent periods of slow moving and stationary traffic.

Repair of Vehicular Damage

- 12.6 Vehicle over-run can result in rutting of the grass surface, especially if the channel is wet, or recently constructed.
- 12.7 While damp, ridges in the grass sward can be readily tamped down; wheel ruts may necessitate lifting the turf and placing an additional fine tilth of topsoil before recompacting the turf.

Patching

- 12.8 Where the grass has died or is severely damaged, the affected area should be removed, the topsoil level reinstated and a section of appropriate turf inserted. The replacement turf should be watered regularly until it becomes established in the channel.

Grassed Surface Reinforcement

- 12.9 Where a grass reinforcement system has been incorporated into the grassed surface water channel construction, these areas should be identified in the appropriate Health and Safety File and, especially during immediate post construction grass cutting operations where a reinforcement mat has been installed, care should be taken to ensure mechanical grass cutting does not result in damage to the mat.

13. WORKED EXAMPLE

13.1 It is necessary to determine the spacing between the intermediate outlets and the terminal outlet for a grassed surface water channel that will drain a section of dual two-lane carriageway. The pavement is black top with a cross fall of 1:40 on non-superelevated sections. The width of the carriageway is 9.3m (including two 1.0m wide hardstrips. The longitudinal gradient of the road is 1 in 125, $S=0.8\%$, and is at grade so will not receive runoff from the adjacent pervious area.

13.2 The principal features of the system are as follows:

- a) Surface water channel:
 - i) Symmetrical triangular channel with crossfalls of 1:5 (vertical : horizontal).
 - ii) Design flow depth: $Y = 0.2\text{m}$.
 - iii) Corresponding flow width: $B = 2.00\text{m}$.
- b) Roughness coefficient n :
 - i) Grass type: Perennial Ryegrass.
 - ii) Average grass height: $H = 0.075\text{m}$ for PRG.

c) Overall cross-sectional shape:

The grassed surface water channel is to be designed to allow a maximum width of surcharging of 1.0m on the adjacent hardstrip. For a straight section of road, with a crossfall of 1:40, this can be achieved by setting the outer edge of the channel 25mm above the level at the edge of the hardstrip. Also there is to be an upstand at the edge of the channel, nominally equal to 40mm. Given that the sides of the channel have crossfalls of 1:5, it follows that the overall width of the channel will be equal to $B+(0.065 \times 5) = 2.325\text{m}$. (applies only to the side of the channel remote from the carriageway).

13.3 Determine the roughness coefficient (Manning's n) using Equation (6).

- a) Assuming Perennial Ryegrass mix (PRG), then $m=0.0048$ and H assumed at 0.075m .
- b) Flow width $B = 2.0\text{m}$, Depth $Y = 0.2\text{m}$, Slope $S=0.008$ (1 in 125m).
- c) Substitute in Equation (6) and $n = 0.062$.

13.4 The effective catchment width, W_E , draining to the grassed surface water channel is equal to the width of the carriageway plus the width of the grassed surface water channel, including the additional width due to surcharge).

$$W_E = 9.30 + 2.325 = 11.625\text{m}$$

13.5 The rainfall depth for this example.

$$2\text{min } M5 = 4.0\text{mm}$$

Note: The allowance for the effects of Climate Change contained in NRA HD 33 should be adopted for all new designs

13.6 The first step in the hydraulic design is to determine the required spacing between intermediate outlets along the grassed surface water channel. Flows produced by storms with a return period of $N = 1$ years must be contained within the surface water channel with the flow depth not exceeding $Y = 0.20\text{m}$. Substituting the values in Equation (7), it is found that the maximum drainage length is:

$$L = 411\text{m}$$

13.7 The maximum length of road, L_s (m) that the channel can drain to an outlet in the surcharged condition for storms of return period $N=5$ years, is determined from Equation (10) where the value Φ can be obtained from Table 6.1:

$$\text{where } \Phi = 1.4 \quad L_s = 575\text{m}$$

13.8 The maximum flow capacity, Q (in m^3/s), of the grassed surface water channel when just flowing full at design depth of flow, $Y = 0.2\text{m}$, can be determined from Equation (8).

$$Q = 0.061\text{m}^3/\text{s}$$

13.9 The maximum flow capacity of the channel, Q_s (in m^3/s), under surcharged conditions can be estimated from Equation (11), where the value of Φ can be obtained from Table 6.1:

$$\text{where } \Phi = 1.4, \quad Q_s = 0.135\text{m}^3/\text{s}$$

13.10 The maximum depth of water in the outlet chamber should not rise to within 150mm of the underside of the grating under design flow conditions, see 7.11. Assume outgoing pipe diameter = 300mm and insert in Equation (12).

$$Q = 0.061\text{m}^3/\text{s} \quad Z = 256\text{mm}$$

There is no surcharge at design flow, so 300mm diameter is adequate.

Under surcharged flow conditions, Q_s

$$Q_s = 0.135\text{m}^3/\text{s} \quad Z = 668\text{mm}$$

Therefore, the outgoing pipe invert must be at least 0.818m (i.e. $0.668 + 0.150$) below underside of grating.

14. REFERENCES

14.1 Manual of Contract Documents for Road Works (NRA MCDRW)

- a) NRA Specification for Road Works (NRA SRW) (MCDRW 1)
- b) Notes for Guidance on the Specification for Road Works (NRA NGSRW) (MCDRW 2)
- c) Road Construction Details (NRA RCD) (MCDRW 4)

14.2 Design Manual for Roads and Bridges (NRA DMRB)

- a) NRA HD 33 Drainage Systems for National Roads
- b) NRA HD 45 Road Drainage and the Water Environment
- c) NRA HD 137 Hydraulic Design of Road-Edge Surface Water Channels
- d) NRA HD 139 Edge of Pavement Details
- e) NRA HD 78 Design of Outlets for Surface Water Channels
- f) NRA HD 83 Safety Aspects of Road-edge Drainage Features
- g) NRA HD 103 Vegetated Drainage Systems for Road Run-off
- h) NRA TD 19 Safety Barriers
- i) NRA TD 27 Cross Sections and Headroom
- j) NRA HD 20 Loop Detectors for Motorways

14.3 Walker CD. Safety aspects of road edge drainage features. Report 422, TRL Limited.

14.4 ESCARAMEIA M and TODD AJ, Grassed surface water channels for road drainage, Project Report, Report SR 662, HR Wallingford, 2006.

14.5 FAULKNER D, Flood Estimation Handbook, Volume 2: 'Rainfall frequency estimation' Institute of Hydrology, Wallingford.

14.6 HR WALLINGFORD and BARR DIH, Tables for the hydraulic design of pipes, sewers and channels, 7th Edition. Thomas Telford, London, 1998.

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14.11 NERC, 1975. Flood Studies Report, Natural Environment Research Council.

14.12 National Roads Authority. 2014. Drainage Design for National Road Schemes – Sustainable Drainage Options.

15. ENQUIRIES

- 15.1 All technical enquiries or comments on this document, or any of the documents listed as forming part of the NRA DMRB, should be sent by e-mail to infoDMRB@nra.ie, addressed to the following:

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National Roads Authority

Design Manual for Roads and Bridges

(NRA DMRB)

Amendment No. 1 (June 2015) to NRA Design Manual for Roads and
Bridges Volume 4, Section 2, Part 9

NRA HD 119 - Grassed Surface Water Channels for Road Runoff

Dated March 2015

The NRA Design Manual for Roads and Bridges (NRA DMRB) NRA HD 119, dated March 2015 is amended as follows:-

1. Page 2, Clause 1.8
Clause 1.8 Implementation is amended.

1. List of Symbols

		Units
A	Cross-sectional area of flow in channel	m^2
B	Surface width of flow in channel	m
B_s	Allowable width of flow on hard strip or hardshoulder adjacent to channel during surcharged conditions	m
D	Diameter	m
H	Grass height	m
I_o	Mean rainfall intensity	mm/h
L	Drainage length of channel, i.e. maximum length of road that can be drained by a section of surface channel at design depth of flow	m
L_s	Maximum length of road that can be drained by a section of surface channel under surcharged conditions	m
N	Return period of storm	years
n	Manning roughness coefficient of channel	-
P	Wetted perimeter of channel	m
Q	Flow rate in channel	m^3/s
Q_s	Flow capacity of channel in surcharged condition	m^3/s
R	Hydraulic radius of flow ($= A/P$)	m
S	Longitudinal gradient of road or channel (vertical fall per unit distance along road or channel)	m/m
S_E	Effective value of S for road or channel of non-uniform gradient	m/m
T	Duration of storm	minutes
V	Velocity of flow	m/s
W_E	Effective width of catchment drained by surface channel	m
Y	Design depth of flow in surface channel (from invert)	m
Z	Height of water surface in outlet chamber above invert level of outgoing pipe	m
ΔZ	Difference in invert level of channel between upstream and downstream ends of drainage length	m
ϕ	Surcharge factor (ratio between drainage length for surcharged channel and drainage length for channel just flowing full)	-
$2minM5$	Rainfall depth occurring in 2 minutes with return period of 5 years	mm

APPENDIX A: TABLES

Table B.1 – Comparison of Flow Capacities of Concrete and Grassed Surface Water Channels Over a Range of Longitudinal Gradients

Channel					Concrete channel		Perennial Rye Grass 40mm		Fescues 40mm	
Side slopes	Longitudinal Slope	Flow Depth m	R (m)	A (m ²)	n	Q (m ³ /s)	n	Q (m ³ /s)	n	Q (m ³ /s)
1 in 5	0.067	0.10	0.050	0.050	0.013	0.135	0.056	0.031	0.064	0.027
	0.067	0.15	0.075	0.113	0.013	0.400	0.053	0.098	0.056	0.092
	0.033	0.10	0.050	0.050	0.013	0.095	0.059	0.051	0.073	0.017
	0.033	0.15	0.075	0.116	0.013	0.281	0.054	0.067	0.059	0.061
	0.010	0.10	0.050	0.050	0.013	0.052	0.070	0.009	0.120	0.006
	0.010	0.15	0.075	0.113	0.013	0.154	0.058	0.034	0.070	0.029

APPENDIX B: FIGURES

Figure C.1: Schematic channel profiles

Figure C.2: Typical outlet detail

Figure C.3: Typical outlet detail (plan)

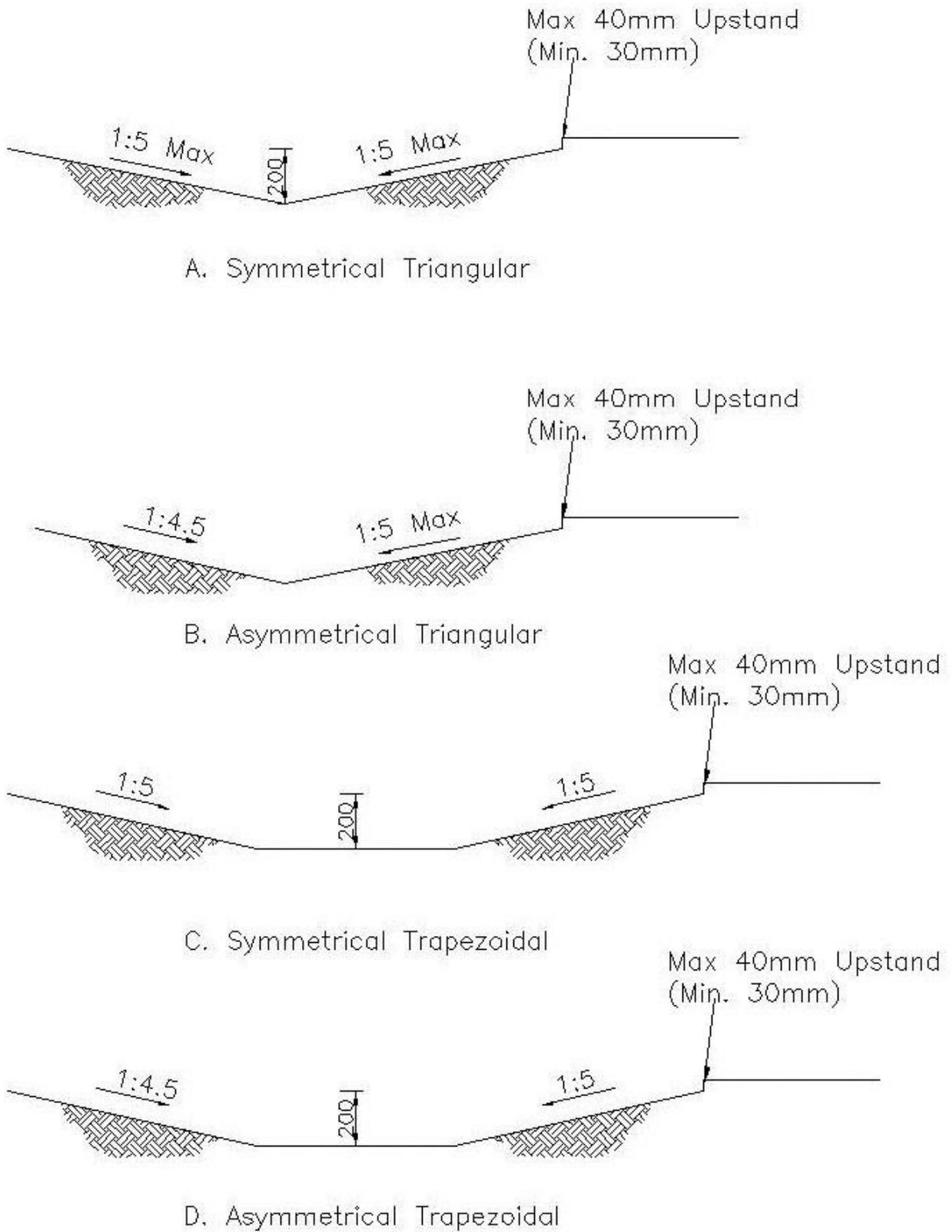
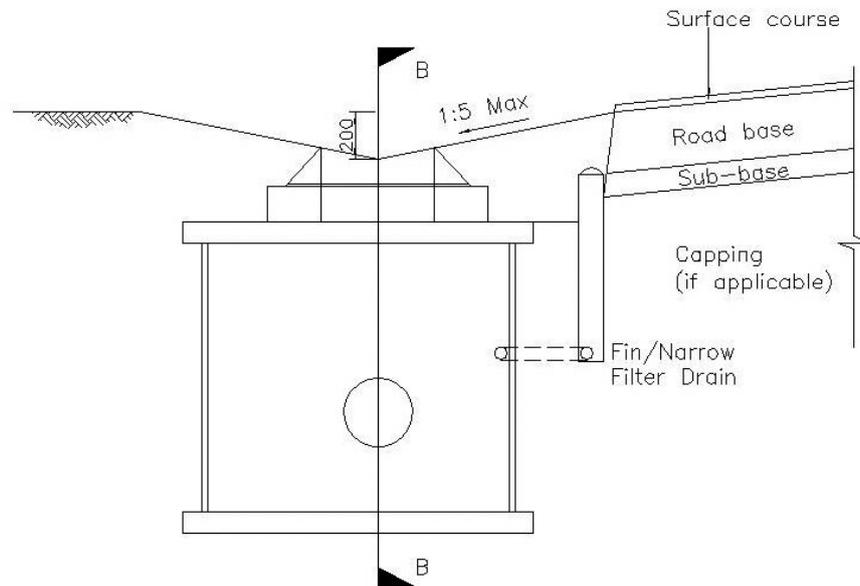
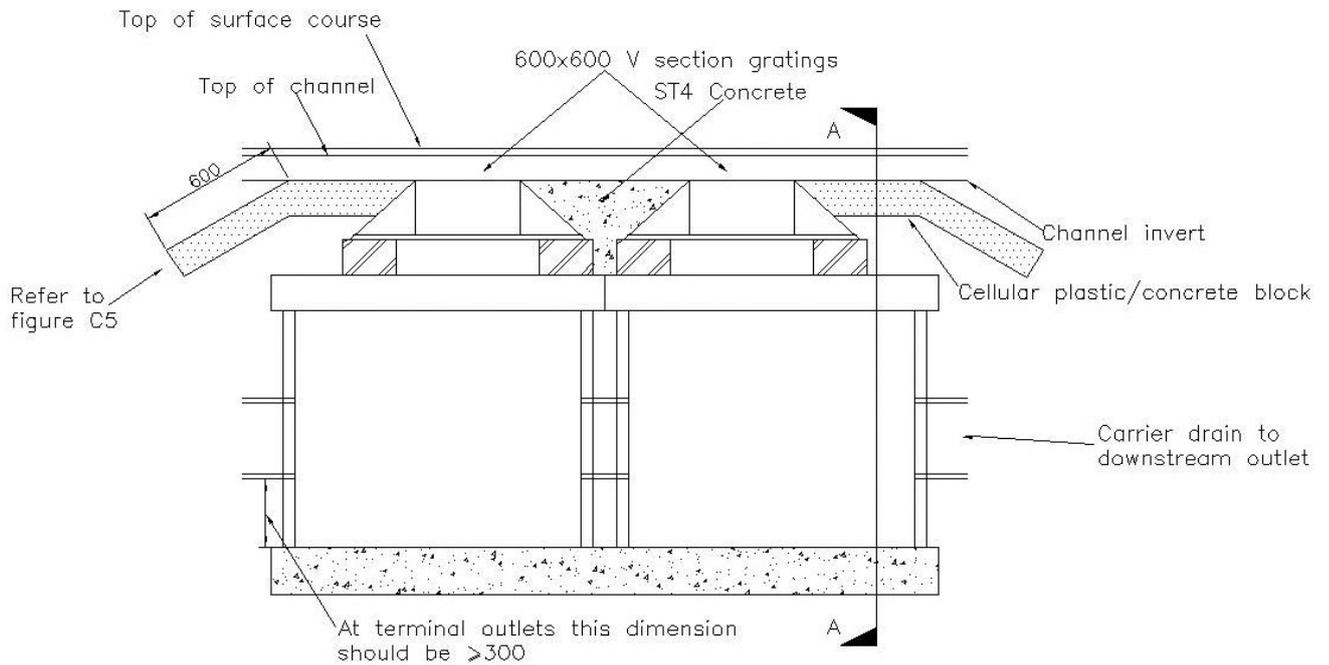


Figure C.1 – Schematic Channel Profiles



Transverse Section A-A



Longitudinal Section

Figure C.2 – Typical Outlet Detail

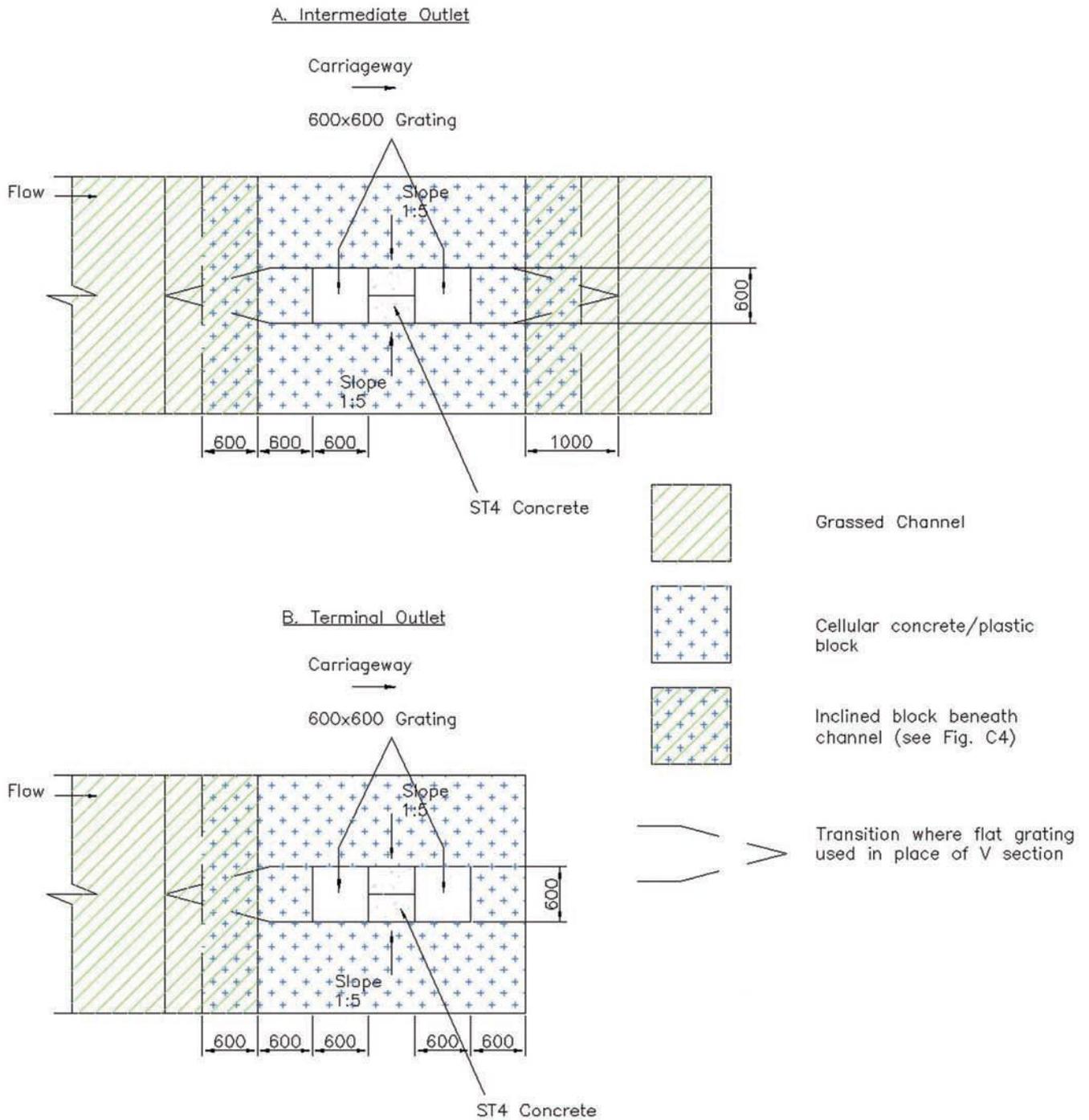


Figure C.3 – Typical Outlet Detail (plan)

APPENDIX C: PLATES



Plate D.1: General View of Grassed Surface Water Channel



Plate D.2: Outlet Arrangement Showing Cellular Blockwork



Plate D.3: Reinforcing Mat Showing Securing Pin (NB mat should be below topsoil)



Plate D.4: Vehicle Loaded to 38 Tonnes Used in Full Scale Trial



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