VOLUME 4 GEOTECHNICS AND DRAINAGE
SECTION 2 DRAINAGE

PART 1

HA 106/04

DRAINAGE OF RUNOFF FROM NATURAL CATCHMENTS

SUMMARY

This Advice Note gives guidance on how to deal with surface water runoff from natural catchments draining towards trunk roads (including motorways), in order to limit the frequency and severity of flooding incidents caused by runoff from beyond the highway boundary.

INSTRUCTIONS FOR USE

This is a new Advice Note to be incorporated into the Manual.

1. Remove existing Contents pages for Volume 4.

2. Insert new Contents pages for Volume 4, dated February 2004.

3. Insert HA 106/04 into Volume 4, Section 2, Part 1.

4. Please archive this sheet as appropriate.

Note: A quarterly index with a full set of Volume Contents Pages is available separately from The Stationery Office Ltd.

THE HIGHWAYS AGENCY

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THE DEPARTMENT FOR REGIONAL DEVELOPMENT
NORTHERN IRELAND

Drainage of Runoff from Natural Catchments

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Contents

1. INTRODUCTION

General

1.1 This Advice Note gives guidance on how to deal with surface water runoff from natural catchments draining towards trunk roads (including motorways), in order to limit the frequency and severity of flooding incidents caused by runoff from beyond the highway boundary.

1.2 Surface water runoff to highway drainage systems is conventionally assumed to derive from the road cross-section. This includes the road surface, verges and adjacent cuttings or embankments (termed Interior Catchment). Additional surface flow may also be produced by runoff draining to the road from land outside the highway corridor (termed Exterior Catchment). Exterior catchments can be rural, urban or a combination of both. This Advice Note deals solely with rural (natural) catchments since exterior urban catchments have their own specific drainage systems. Its recommendations may be applied to other roads with rural (natural) catchments and traffic conditions, as appropriate.

1.3 Following the Autumn 2000 floods, a review of road flooding incidents showed that approximately two-thirds were associated with the lack of capacity of the drainage systems. Existing HA guidance on how to deal with runoff from road surfaces was found to be adequate. However, highway drainage systems were, in some cases, overloaded by additional water draining to the roads from the surrounding natural catchment. Others were unable to convey the flows because of submergence of the outfalls or blockage within the system. This document is aimed at minimising the flooding problem associated with runoff from road adjacent catchments.

1.4 General recommendations on earthworks drainage, both surface water and sub-surface water, are given in HD 33, Surface and Sub-Surface Drainage Systems for Highways (DMRB 4.2, Ref. 1). HD 33 recommends that cut-off drains are constructed at the tops of cuttings and at toes of embankments where water from adjoining land may flow towards the road. HD 33 states that intercepting drains or ditches should be sufficiently deep to collect these flows, including those from any severed agricultural drainage systems but no quantitative guidelines are given. HD 33 also highlights the importance of ensuring a coordinated analysis of the horizontal and vertical road profiles before the final alignment is chosen.

Scope

1.5 The guidance given in this Advice Note is applicable to new road projects as well as to existing road schemes where reduction of the flood risk is considered necessary to ensure resilience of the road network to extreme weather conditions.

1.6 Natural catchments adjacent to roads vary significantly in size, shape, type of soil and vegetation cover, and the amount of runoff contributed to road drainage systems can range from negligible to significant. In defining the areas of natural catchment to consider, the contribution of smaller catchments (in general terms less than 0.01 km^2, or 1ha) can be neglected. Smaller sites with a history of frequent flooding may need to be considered on a one to one basis. Catchments with surface areas greater than 25 km^2 are outside the scope of this document.

1.7 The design of culverts and outfalls to prevent flooding of roads due to high water levels at the point of discharge is given in HA 107, Design of Outfall and Culvert Details (DMRB 4.2).

1.8 Design guidance concerning prevention of flooding of roads constructed in the flood plain by high water levels in adjacent rivers or streams, is given in HA 71, The Effects of Highway Construction on Flood Plains (DMRB 4.2, Ref. 1).

1.9 In certain areas of the UK and in periods of high groundwater levels, springs may appear at the surface in catchments adjacent to roads. These springs can generate significant flows and potentially cause or increase the risk of road flooding. Since natural springs are dependent on local geological conditions and groundwater levels, they will require specific assessments to determine their likely location, flow rate and impact on road performance. This is not covered in the present document but information can be obtained from the Environment Agency and the British Geological Survey, among other sources.

Implementation

1.10 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. Design Organisations should confirm its application to particular schemes with the Overseeing Organisation.

2. METHODOLOGY

2.1 The overall procedure for dealing with runoff from natural catchments is summarised in the flowchart of Figure 1 (in Appendix A). The most important stages, which are described in detail in the next chapters, are:

i) identification of flood-prone areas and characterisation of natural catchment;

ii) estimation of runoff;

iii) hydraulic design of ditches/culverts and/or upgrade of existing road drainage system;

iv) formulation of maintenance programme.

3. NATURAL CATCHMENT IDENTIFICATION

3.1 The size, shape and other characteristics of natural catchments, such as gradients, are likely to vary considerably along the highway alignment. Their contributions in terms of runoff are also likely to vary from negligible amounts from catchments of small dimensions to large flow rates. The latter should be discharged into ditches or through culverts, or dealt with by modifications to the highway drainage system.

3.2 There are essentially two types of natural catchment that may be encountered alongside roads (see Figure 2, in Appendix A):

Valley Catchments
Catchments formed by a well-defined valley, either dry or drained by a watercourse (including ephemeral streams).

Strip Catchments
Catchments with no defined valley, forming a strip of fairly uniform width along the highway boundary.

3.3 To determine the natural catchment dimensions the following definitions apply.

Catchment width:

a) For valley catchments – the distance between the top end of the catchment and the top of the cutting, or the pavement edge, measured along the valley, perpendicular to the ground contours (distance A-B in Figure 2 of Appendix A).

b) For strip catchments – the distance between the highest point of the catchment and the top of the cutting, or the pavement edge (distance C-D in Figure 2 of Appendix A).

Catchment length:
This is defined as the distance of natural catchment adjacent to the highway boundary, measured parallel to the road.

3.4 In flat areas definition of the natural catchment boundary is not always obvious, and engineering judgement should be applied. The maximum catchment width should not exceed 10km.

3.5 When defining the extent of natural catchments adjacent to roads, Ordnance Survey maps at 1:25 000 scale should be consulted. Site inspections are also recommended as they can provide useful information on local features. Due to the linear nature of roads, the discharge points for the natural catchment flows will in most cases be the same as those used for the discharge of road runoff. However, the criteria that need to be met in terms of pollution loads may be less stringent for runoff from natural catchments and therefore more points of discharge may be considered suitable. Areas where the amount of silt in the runoff is expected to be very high can still be associated with a significant pollution risk. Catchment widths smaller than 50m can be neglected, unless there is information specific to the site indicating the need to take the local runoff into account (e.g. history of frequent local flooding).

3.6 A checklist to aid the identification of flood-prone areas is given below:

- Road configuration:
  - low points/areas (sag);
  - inner areas of bends in road alignment where accumulation of flow can occur due to adjacent catchment;
  - connection with other roadways (e.g. slip roads) that can act as a drainage pathway;
- Catchment features (see Figure 3 in Appendix A):
  - large fields adjacent to the road (Examples A.1, B.1 and C.1);
  - slopes intercepted by the road (Examples A.2 and A.3);
  - areas of well defined stream catchment (even if stream is ephemeral) producing concentrated flows;
  - presence of natural springs.

For existing schemes:

- poor condition of existing cut-off ditches, land drainage and culverts (i.e. overgrown vegetation in ditches, blockages in culverts and ditches, collapsed drains);
- level of outfalls that do not allow free discharge (see guidance in HA 107, DMRB 4.2);

- poor condition of road drainage system (blockages, siltation);

- signs of erosion (gullies) in cutting slopes; poor establishment of vegetative protection in steep cuttings; in cultivated land, furrows running in the direction of the slope (rather than transversely).

3.7 Examples of catchments that can produce significant runoff are given in Figure 3 of Appendix A. They refer to two situations (roads in cutting and in shallow embankments) and need to be considered in conjunction with the checklist given in 3.6 for the identification of flood-prone areas.

4. APPROACHES TO THE COLLECTION OF RUNOFF

4.1 Slopes containing a well defined watercourse that are intercepted by roads will usually require the provision of a culvert to ensure that the runoff is adequately conveyed away from the road construction. The design of culverts is covered by HA 107, DMRB 4.2).

4.2 Slopes intercepted by roads but without a well-defined watercourse path can also produce significant amounts of runoff, which need to be discharged by means of ditches (or pipes). Where possible, these should be located at the top of cuttings or at the toe of embankments, see HA 44, Earthworks: Design and Preparation of Contract Documents (DMRB 4.1.1, Ref. 1). If a large ditch is used at the top of a cutting, a geotechnical assessment of the cutting should be carried out (as specified in the DMRB HA 43, 44, 48 and 68 and in SH4), taking into account possible groundwater seepage from the cutting. If necessary to avoid stability problems, locating the ditch at road level should be considered.

4.3 In some locations of the road network, particularly in older schemes, there may be no space available for the construction of ditches, either at the top of cuttings, bottom of embankments or at road level. In these cases ad-hoc solutions need to be considered. Among possible measures are:

- upgrading of the road drainage system to receive runoff flows from the natural catchment;

- changes in the land-use patterns adjacent to the road to minimise gradients and potential for soil erosion (through negotiations with the land owners);

- protection of slopes against soil erosion by means of mats, for example (also through negotiations with the land owners).

4.4 When designing and constructing ditches, care should be taken not to affect the long-term drainage characteristics of environmentally sensitive soils, such as peat bogs.

5. ESTIMATION OF RUNOFF

Background

5.1 The published methods for estimating runoff have been reviewed. The criteria used for the selection of the recommended method(s) were based on technical as well as practical considerations. The recommended method should:

i) be applicable to small catchments (compared with river catchments, the linear dimension of natural catchments draining to roads can be orders of magnitude smaller);

ii) be applicable to catchments with no well-defined watercourse;

iii) not require hydraulics modelling software;

iv) be simple to use by non-river engineers.

5.2 Of the range of methods available for the prediction of runoff from pervious surfaces, most are not suited to the case of catchments alongside roads which, see Chapter 3, have specific characteristics. Some of the most recent and sophisticated methods, such as those described in the Flood Estimation Handbook, FEH (Ref. 2), were developed for pre-defined river catchments of a certain dimension and cannot deal with smaller catchments. The FEH approach also requires the use of a software package and considerable knowledge of hydraulics. Other methods assume the presence of watercourses, which is not always the case in highway applications.

Design return period

5.3 Highway drainage systems are designed to intercept and remove rainfall from short duration, high intensity events with return periods of 1 year (for no surcharge of piped systems or road-edge channels) or 5 years for no flooding of the carriageway. Flood flows from natural catchments can have durations of several hours so the potential for traffic disruption is greater than that produced by runoff from paved surfaces lasting only a few minutes. For this reason, it is recommended that flow rates from natural catchments without defined watercourses should be assessed for design storms with a return period of 75 years (see Appendix B for background on the choice of this return period). For culverts that convey permanent watercourses beneath roads, the flow rates should be assessed for return periods that can vary between 25 and 100 years depending on the implications of flooding (see HA 107, DMRB 4.2).

Recommended methods

5.4 For rural catchments larger than 0.5km^2 (or 50ha) flood flows should be estimated using a method developed by the Centre for Ecology & Hydrology, CEH, (then Institute of Hydrology) and described in report IH 124 (Ref. 3). This was based on a study of 71 small rural catchments and was derived from catchments drained by a well-defined watercourse.

The mean annual flood Q_a (in m^3/s) is calculated by:

$$Q_a = 0.00108\ AREA^{0.89}\ SAAR^{1.17}\ SOIL^{2.17} \qquad (1)$$

where

AREA (in km^2) is the catchment plan area
SAAR (in mm) is the standard average annual rainfall for the particular location (see Figure 4 of Appendix A)
SOIL is the soil index, defined as:

$$SOIL = \frac{(0.15S_1 + 0.30S_2 + 0.40S_3 + 0.45S_4 + 0.5S_5)}{(S_1 + S_2 + S_3 + S_4 + S_5)} \qquad (2)$$

$S_{1, 2....}$ denote the proportions of catchment covered by each of the soil classes 1 to 5. Soil class 1 has a low runoff potential and soil class 5 has a high runoff potential. The parameter SOIL for a natural catchment can vary between 0.15 (very low runoff) and 0.5 (very high runoff). This parameter can be estimated from soil maps reproduced in HA 71/95 (DMRB, Ref. 1) or, for a simplified approach, through consultation of Table 5/1 (adapted from the Agricultural Development and Advisory Service, ADAS, Ref. 4):

Table 5/1 Runoff potential and soil classes

General soil description	Runoff potential	Soil class
Well drained sandy, loamy or earthy peat soils Less permeable loamy soils over clayey soils on plateaux adjacent to very permeable soils in valleys	Very low	S_1
Very permeable soils (e.g. gravel, sand) with shallow groundwater Permeable soils over rocks Moderately permeable soils some with slowly permeable subsoils	Low	S_2
Very fine sands, silts and sedimentary clays Permeable soils (e.g. gravel, sand) with shallow groundwater in low lying areas Mixed areas of permeable and impermeable soils in similar proportions	Moderate	S_3
Clayey or loamy soils	High	S_4
Soils of the wet uplands: Bare rocks or cliffs Shallow, permeable rocky soils on steep slopes Peats with impermeable layers at shallow depth	Very high	S_5

Note: Chalky soils can have a wide range of permeabilities, and runoff potentials that vary between those of clay loams and those of coarse sands.

The parameter SAAR for the site under consideration can be obtained from a map of the annual average rainfall in the UK (see Figure 4 in Appendix A).

The mean annual flow can be scaled to the required return period of 75 years, by applying a scaling factor, F, based on the regional growth curves suggested by the Flood Studies Report (Ref. 5) for the area under consideration (see Figure 5 in Appendix A):

$$Q = F\,Q_a \qquad (3)$$

where

Q is the design flow (in m^3/s)
F is the scaling factor, dependent on the region
Q_a is the mean annual flow.

5.5 The Agricultural Development and Advisory Service, ADAS (Ref. 4) developed a method primarily for the sizing of field drainage pipes, which was based on the Transport and Road Research Laboratory, TRRL, method (Ref. 6). The ADAS method is applicable to very small catchments, having been developed for catchment areas up to $0.3 km^2$ (or 30ha). This method takes into account the design storm rainfall and time of concentration for the required return period by using the Bilham formula. For the required 75 year return period the design flow, Q (in m^3/s) can be determined from:

$$Q = AREA\,(0.0443\,SAAR - 11.19)\,SOIL^{2.0} * \left(\frac{18.79T^{0.28} - 1}{10T}\right) \qquad (4)$$

where

AREA (in km^2) is the catchment plan area
SAAR (in mm) is the standard average annual rainfall for the particular location (see Figure 4 in Appendix A)
SOIL is the soil index, defined as:

$$SOIL = \frac{(0.15S_1 + 0.30S_2 + 0.40S_3 + 0.45S_4 + 0.5S_5)}{(1 - S_u)} \qquad (5)$$

$S_{1,2....}$ denote the proportions of catchment covered by each of the soil classes 1 to 5 and S_u is the unclassified area of the catchment covered by water or pavement. Soil class 1 has a low runoff potential and soil class 5 has a high runoff potential. The parameter SOIL for a natural catchment can vary between 0.15 (very low runoff) to 0.5 (very high runoff). This parameter can be estimated from soil maps reproduced in HA 71/95 (DMRB, Ref. 1) or, for a simplified approach, through consultation of Table 5/1 (adapted from the Agricultural Development and Advisory Service, ADAS, Ref. 4):

T is the time of concentration (in hrs) and is given by:

$$T = 0.1677\,\frac{W^{0.78}}{Z^{0.39}} \qquad (6)$$

where

W is the maximum catchment width in metres (see definition of width in 3.3)
Z is the average height of the catchment divide in metres (see Figure 2 in Appendix A) above the discharge level (ditch level).

Application of methods

5.6 It is recommended to use:

- the IH 124 Method (described in 5.4) for catchments > 0.4km^2
- the ADAS Method (described in 5.5) for catchments ≤ 0.4km^2.

5.7 The design flows estimated with the recommended runoff methods are surface runoff flows that take into account saturation of the soil.

5.8 Worked examples are presented in Chapter 7.

6. HYDRAULIC DESIGN OF DITCHES

Location and type

6.1 Ditches should be located where they can fully intercept the flow from the natural catchments adjacent to the road. The location of ditches is mainly dependent on the space available. Possible locations are: i) along the edge of the road; (ii) along the top of cuttings or iii) at the toe of embankments. In cuttings, ditches should preferably be positioned at the top of the cuttings to avoid potential erosion of the slope by surface water. Large sized ditches may create stability problems in the cutting slope and, therefore, appropriate measures should be taken (see 4.2).

6.2 Where ditches are located alongside the road, they may be designed to convey the runoff from the carriageway as well as that of the natural catchment. HA37 (DMRB, Ref.1) can be used to determine the runoff rate from the road (including the contribution of the plan area of the cutting), which would be added to that of the natural catchment.

6.3 Ditches should preferably consist of earth channels lined with a native grass species (or combination of species), in order to provide adequate resistance to flow erosion.

Sizing

6.4 The size of ditches can be calculated using Manning's resistance equation:

$$A = \frac{n\,Q}{S^{1/2} R^{2/3}} \qquad (7)$$

where

A is the cross-sectional area of the flow (m^2)
Q is the flow rate (m^3/s)
n is the Manning roughness coefficient - values of Manning's n are given in Appendix C
and
S is the longitudinal gradient of the ditch (m/m).

The hydraulic radius R is defined by:

$$R = \frac{A}{P} \qquad (8)$$

where P is the wetted perimeter, i.e. the perimeter of the channel in contact with the water flow.

6.5 Ditches should be sized for conditions at their downstream end, where flow rates are highest. It is also recommended to carry out checks at intermediate location(s), where flow rates are smaller but gradients may be flatter. This may lead to the required size of ditch varying along its length.

6.6 The appropriate gradient, S, for use in the design should be determined from the conditions at the downstream end and, if intermediate conditions are checked, the gradients should be adjusted accordingly. The minimum design gradient for ditches should be 1/500 to ensure flow conveyance in flat areas.

6.7 To achieve stability and high flow capacity, the cross-sectional shape of ditches should be approximately trapezoidal. For a trapezoidal shape with equal side slopes, base width B, side slopes 1:b (vertical: horizontal) and flow depth y, the hydraulic radius R is given by:

$$R = \frac{y\,B + y^2 b}{B + 2\left(y^2 b^2 + y^2\right)^{0.5}} \qquad (9)$$

6.8 In some cases the design flow rate will be such that the required size for the ditch may be too large to be accommodated within the available space on the verge or the top of cuttings. The designer may then consider discharging part of the flow into the road drainage system to keep the ditch size within certain limits. In this case the road drainage system must be checked to determine its ability (or otherwise) to convey the additional flow. To check this it is recommended to estimate the runoff from the road cross-section (including areas in cutting) using the guidance in HA 37 (DMRB, Ref.1) but with a rainfall intensity of 30mm/hr. This lower rainfall intensity will reflect the low probability of simultaneous occurrence of the design storm for the natural catchment and for the road cross-section.

7. WORKED EXAMPLES

7.1 Example 1

Determine the runoff from a natural roadside catchment in Dorset, near Lyme Regis having the following characteristics:

Catchment area: $1km^2$
Catchment slope: S = 1/12.5 = 0.08
Soil type: Clay

The IH 124 method will be applied to this catchment, as the catchment area is greater than $0.4km^2$.

The value of SOIL index for the catchment can be calculated from Equation (2). It can be assumed that the catchment is uniform in terms of soil characteristics and from the soil maps in HA 71 the soil class can be taken as S_4 (alternatively, from consultation of Table 5/1, the soil class for clay soils is given as S_4). The proportions of the catchment with soil classes S_1 to S_3 and S_5 are nil, so:

SOIL = 0.4

The average annual rainfall (SAAR) for the location is obtained from Figure 4 (in Appendix A) and it can be taken as:

SAAR = 900 mm

The mean annual flood is then calculated from Equation (1) to be:

$$Q_a = 0.00108 \text{ x } (1.0)^{0.89} \text{ x } (900)^{1.17} \text{ x } (0.4)^{2.17} = 0.423m^3/s$$

For the design return period (75 years) the mean annual flow is scaled up using Figure 5. The site lies in Region 7 and therefore for a 75 year return period the scaling factor F is 2.91. The design flow can then be calculated as:

$$Q_{75} = 2.91 \text{ x } 0.423 = 1.23m^3/s$$

7.2 Example 2

Determine the runoff from a natural roadside catchment in Yorkshire, between Manchester and Huddersfield having the following characteristics:

Catchment area:	$0.14km^2$
Maximum drainage width:	250m
Average height of catchment above discharge level:	38m
Soil type:	Upland peat

The ADAS Method will be applied to this catchment, as the catchment area is smaller than $0.4km^2$.

The value of SOIL index for the catchment can be calculated from Equation (2). It can be assumed that the catchment is uniform in terms of soil characteristics and from the soil maps in HA71 the soil class can be taken as S_5 (alternatively, from consultation of Table 5/1, the soil class for upland peats soils is given as S_5). The proportions of the catchment with soil classes S_1 to S_5 are nil, so:

SOIL = 0.5

The average annual rainfall (SAAR) for the location is obtained from Figure 4 and can be taken as:

SAAR = 1400 mm

The time of concentration for the catchment, T, is calculated from Equation (6) as:

$$T = 0.1677 \times \frac{250^{0.78}}{38^{0.39}} = 3.01\text{hr}$$

Using the information above, the design flow for 75 years return period is determined from Equation (4):

$$Q = 0.14 \times (0.0443 \times 1400 - 11.19) \times 0.5^2 \times \left(\frac{18.79 \times 3.01^{0.28} - 1}{10 \times 3.01}\right) = 1.45\,\text{m}^3/\text{s}$$

As can be seen from this example, a small catchment can generate higher rates of runoff than larger catchments such as that of Example 1.

8. REFERENCES AND BIBLIOGRAPHY

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HD 33 Surface and Sub-surface Drainage Systems for Highways (DMRB 4.2)

HA 37 Hydraulic Design of Road Edge Surface Water Channels (DMRB 4.2)

HA 43 Geotechnical considerations and techniques for widening highway earthworks (DMRB 4.1)

HA 44 Earthworks: Design and preparation of contract documents (DMRB 4.1.1)

HA 48 Maintenance of highway earthworks and drainage (DMRB 4.1.3)

HA 68 Design methods for the reinforcement of highway slopes by reinforced soil and soil nailing techniques (DMRB 4.1.4)

HA 71 The Effects of Highway Construction on Flood Plains (DMRB 4.2)

HA 107 Design of Outfall and Culverts Details (DMRB 4.2)

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9. ENQUIRIES

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

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APPENDIX A FIGURES

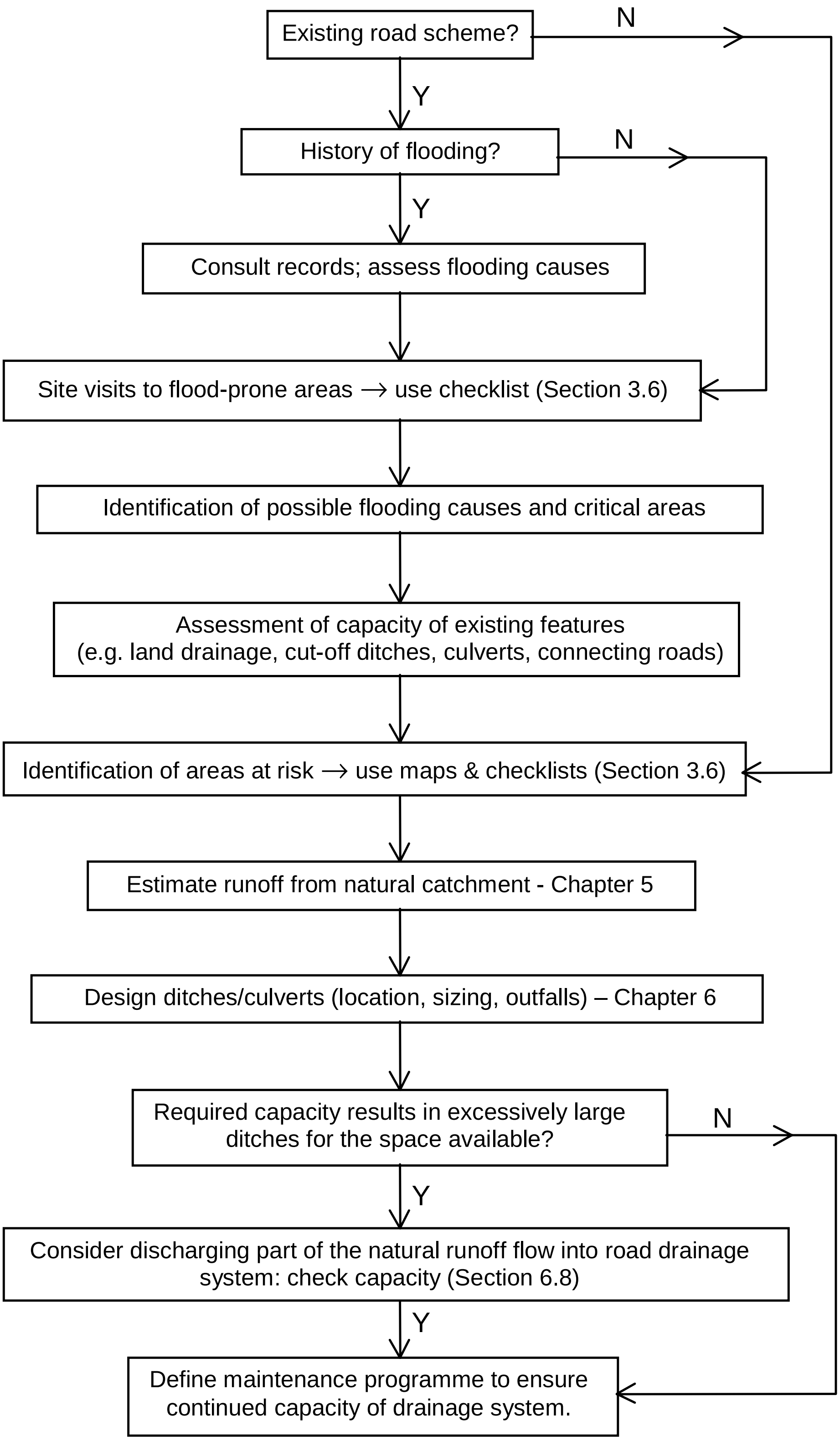
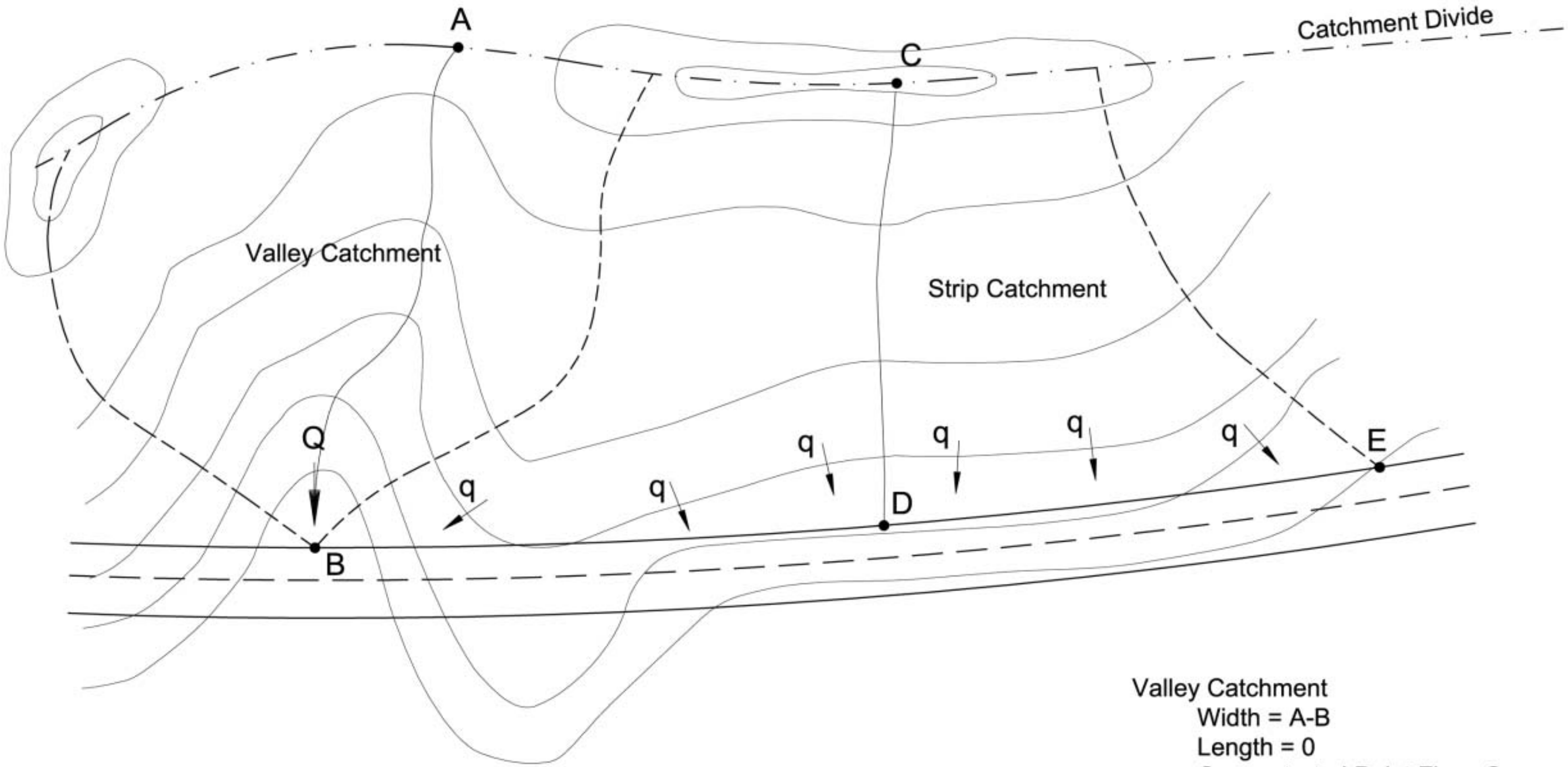


Figure 1 - Methodology Flowchart



Valley Catchment
- Width = A-B
- Length = 0
- Concentrated Point Flow, Q

Strip Catchment
- Width = C-D
- Length = B-E
- Distributed Flow, q

Figure 2 - Types of Natural Catchment

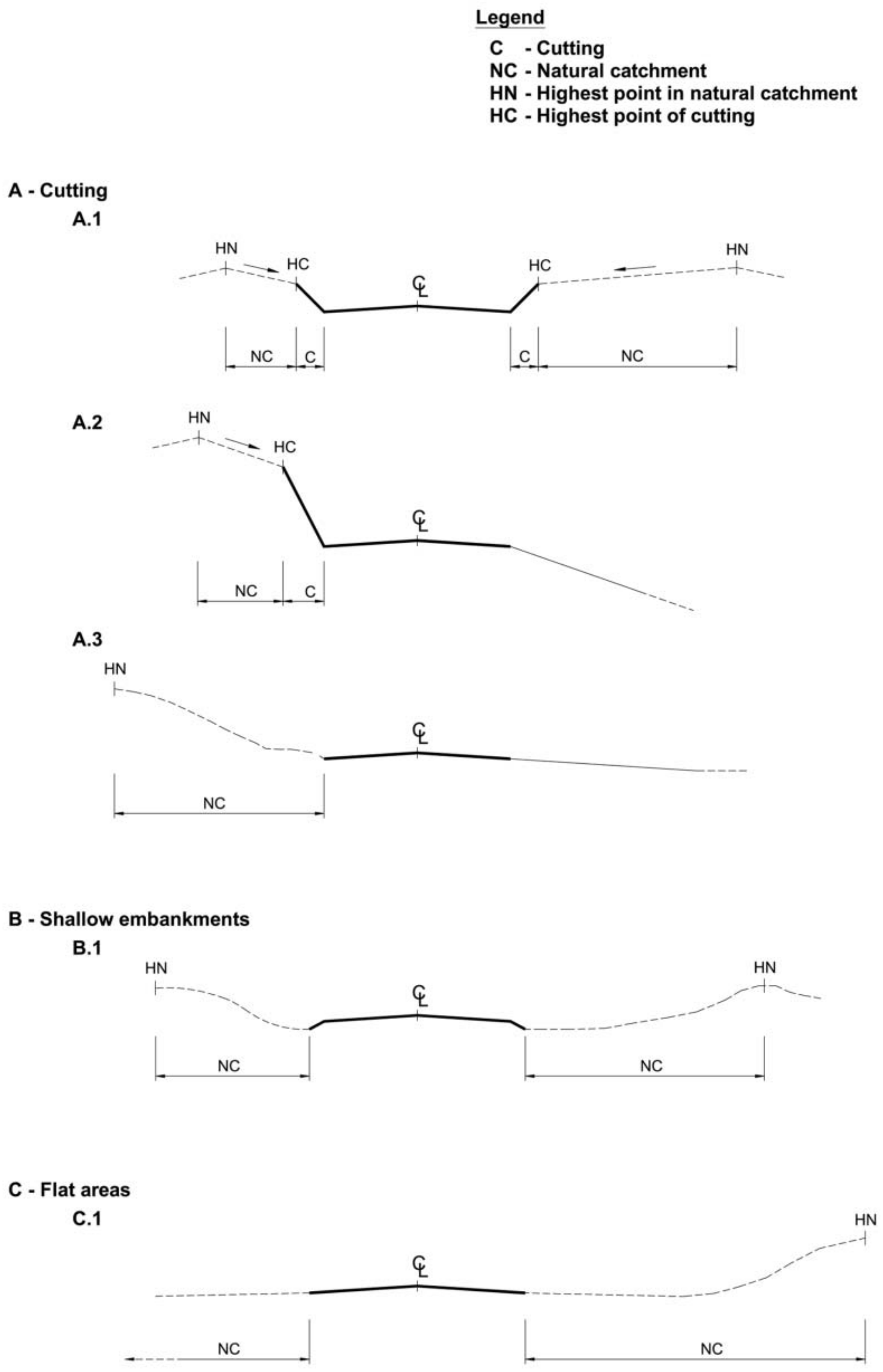


Figure 3 - Typical road catchment profiles that can generate significant runoff

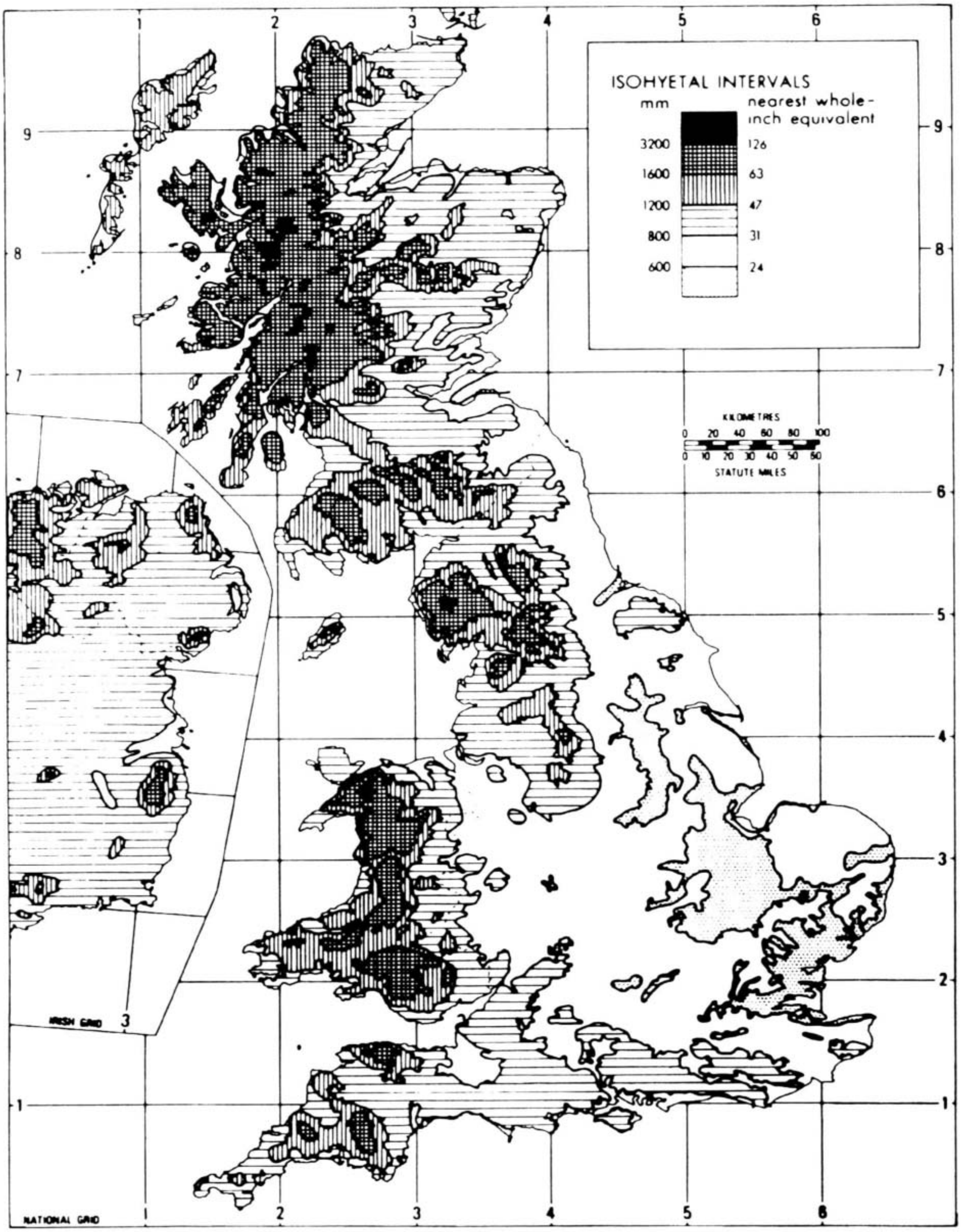
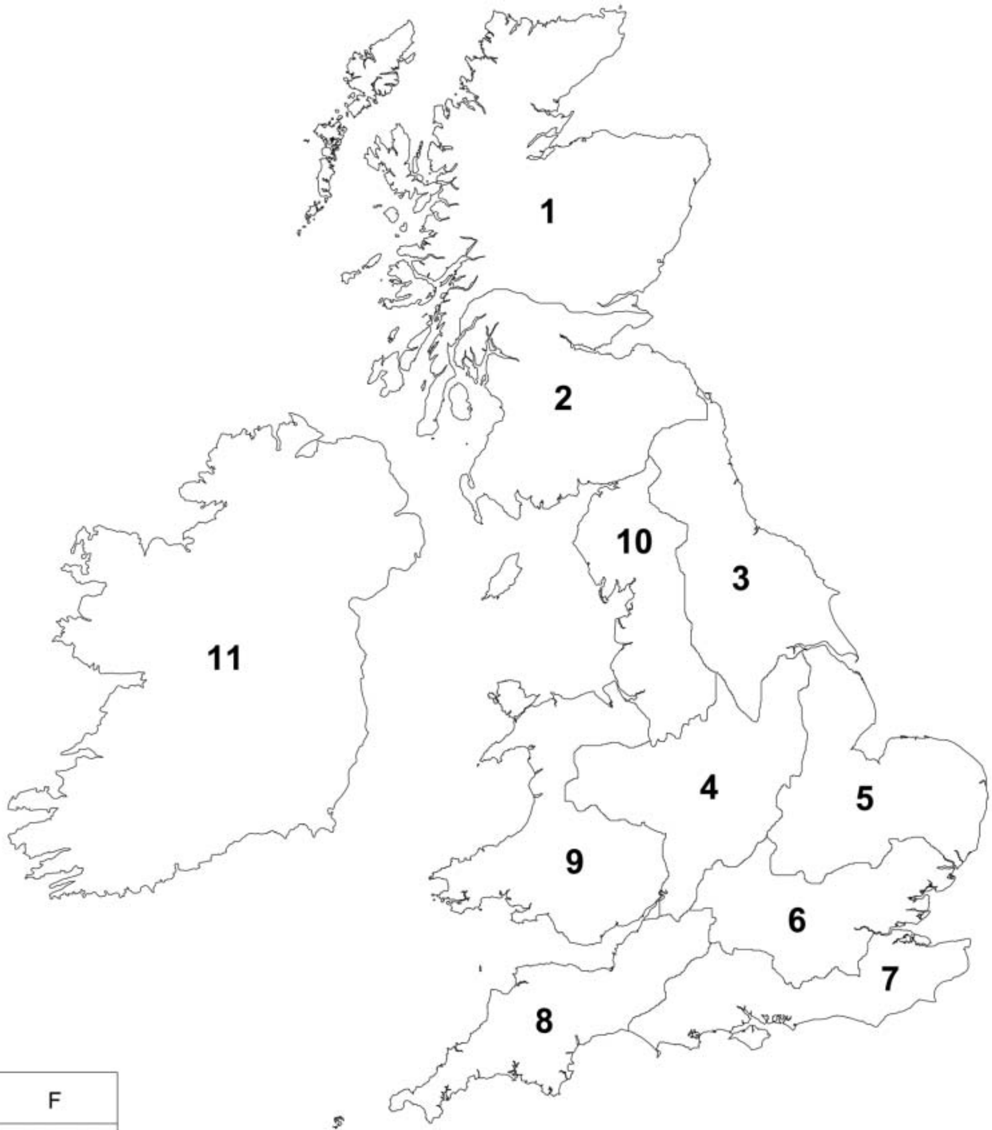


Figure 4 - Annual Average Rainfall in the UK (Originally from the Met Office; Available from Ref 7, The Wallingford Procedure)



Region	F
1	2.31
2	2.38
3	2.00
4	2.38
5	3.22
6	2.91
7	2.91
8	2.26
9	2.06
10	2.00
11	1.88

Figure 5 - Values of the Scaling Factor F for UK Regions (Derived from the Flood Studies Report, Ref. 5)

APPENDIX B DETERMINATION OF RETURN PERIOD

Introduction

B.1 The primary purposes of road drainage systems are to minimise water depths occurring on road surfaces during heavy storms and to prevent seepage causing damage to the pavement construction. Since runoff occurs rapidly from roads, the most critical storm conditions for the design of surface water drainage systems are normally associated with heavy rainfall events typically lasting between 2 and 15 minutes.

B.2 Design Standards (HD 33, DMRB 4.2, Ref. 1) require that edge-of-pavement drainage systems should be able to convey flows produced by storms with a return period of N = 1 year without any surcharging or surface flooding. Limited surcharging onto hardstrips or hardshoulders is permitted for storms with return periods between N = 1 year and N = 5 years provided that the water does not encroach onto the carriageway. It follows that in rarer storms having return periods exceeding N = 5 years there is likely to be some flooding of carriageways on roads designed in accordance with Design standards. However, such flooding will last only a few minutes and cause relatively little delay or inconvenience to road users (particularly since, in very heavy rain, drivers are likely to slow down due to poor visibility).

B.3 Flooding from natural catchments is very different in character from flooding caused by high rates of runoff from road surfaces. The most critical storm duration for design is usually equal to the time of concentration of the catchment (i.e. the time needed for the whole catchment to contribute runoff); for natural catchments draining to roads this time can typically be of the order of 5 to 50 hours. The excess volume of flow from a natural catchment can be very large and lead to widespread inundation of a road. The flooding is also likely to last several hours. As a result, the delays and inconvenience caused to road users can be very considerable, even though the rainfall intensity during the long-period storm would not itself cause a significant problem to drivers.

B.4 These considerations indicate that drainage systems dealing with runoff onto roads from natural catchments should be designed so that flooding occurs very infrequently (since closure of a section of motorway or trunk road approximately once every five years would not be a satisfactory level of service). However, the current Design Standards in HD 33 are considered to provide a satisfactory degree of protection against flooding for the case of systems dealing with runoff from the road surface. The following sections describe an analysis that was carried out to develop a quantitative measure of the performance provided by the HD 33 guidelines. This performance measure was then used to estimate a suitable design return period for the case of drainage systems dealing with runoff from natural catchments.

Flooding Index (FI)

B.5 The description in B.2 and B.3 of the different flooding characteristics produced by runoff from road surfaces and from natural characteristics indicates that the degree of inconvenience caused to road users depends on the following factors:

- the magnitude of the flooding
- the time for which the flooding lasts
- how frequently the flooding occurs.

B.6 These factors can be described quantitatively by the Flooding Index (FI) which is defined as:

$$FI = \int_{N_O}^{1000} (Q_N - Q_O)T \frac{dN}{N^2} \qquad (B.1)$$

where

N_O = return period (in years) of the storm that is used to determine the flow capacity of the drainage system (such that no flooding of the carriageway occurs for storms with return periods up to and including N_O years).

Q_N = average flow rate from a catchment per m length of road (in m^2/s) produced by a storm having a return period of N years.

Q_O = value of Q_N for the design return period of N_O (and proportional to the flow capacity of the drainage system).

T = duration (in s) of the design storm (proportional to the time for which any flooding persists).

$\frac{dN}{N^2}$ = probability of occurrence of a storm having a return period between N years and N + dN years.

The value of FI takes account of the magnitude of the flood and the period for which it lasts. The Index, therefore, provides a measure of the cumulative volume of flooding per m length of road caused by all possible storms having return periods between N_O years (below which no flooding will occur) and an assumed upper limit of 1000 years.

Comparisons

B.7 The value of FI was first calculated for a typical surface water channel receiving only runoff from the adjacent road surface (longitudinal gradient of 1/100, transverse gradient of the carriageway of 1/40). It was assumed that the duration of the design storm was T = 300s (5 minutes) and that the channel was designed to cater for storm return periods up to N_O = 5 years without any flooding of the adjacent carriageway.

B.8 The analysis was then repeated for two representative cases of natural catchments draining to roads. The two catchments were located in the south-east and the north-west of England. Values of flow rate, Q_N, and design storm duration, T, were determined using the method described in 5.4. The values obtained for T were 8 hours and 13.5 hours respectively.

B.9 The objective of the analysis was to determine appropriate values of the design return period for the systems receiving runoff from natural catchments such that they would have the same numerical value of FI as the surface water channel considered in B.7. By means of a trial-and-error procedure, it was found that the drainage systems for the two catchments needed to be sized for storm return periods of N_O = 60 years and 140 years.

B.10 Based on this method of analysis, it was decided to adopt a return period of N_O = 75 years for the design of drainage systems dealing with flow from natural catchments. It should be noted that the Flooding Index is a measure of the cumulative effect of flooding that is likely to occur on a road over a long period. The value of FI does not have a direct physical meaning but is a means of comparing the long-term performance of different types of drainage system on a common basis.

APPENDIX C ROUGHNESS VALUES FOR THE HYDRAULIC DESIGN OF DITCHES

The flow capacity of a channel is dependent to a significant extent on the surface texture. Grass can get established easily in the UK and offers good protection against flow (and wind) erosion. For these reasons it is recommended that flow from natural catchments be drained by grassed ditches whenever possible. The grass height and the presence of weeds should be controlled to maintain the capacity of the ditch and therefore regular maintenance will be necessary.

The table below gives values of the Manning's roughness coefficient for use in the hydraulic design of ditches. For the design of new ditches it is recommended to use n=0.050 in schemes where a maintenance programme will be put in place; where maintenance is doubtful or irregular, higher values must be used.

Type of channel	**Condition of the ditch**	**Manning's n**
Grassed channel, regularly maintained	Average, good	0.050
Grassed channel, not maintained, with dense weeds	Good	0.050
	Average	0.080
	Poor	0.120