Drainage Design For National Road Schemes - **Sustainable Drainage Options**

NRA
An tÚdarás um Bóithre Náisiúnta
National Roads Authority
Environment

ACKNOWLEDGEMENTS

To support the Environmental Integration Model (EIM), the National Roads Authority has undertaken a number of post EIA evaluation research studies to monitor the *actual* impacts of national road scheme developments on the environment. Post EIA research evaluation entailed the collection, structuring, analysis and assessment of information covering the impacts of road scheme projects that has been subject to the environmental impact assessment (EIA) procedure. The results from these research studies assist in:

- facilitating better feasibility analysis of sites and projects,
- scoping EISs and supporting the prediction methodologies used in EISs,
- informing future environmental policy and best practice guidelines in relation to road infrastructure,
- building databases of actual impacts of road schemes on different ecosystems and revision of prediction methodologies, and
- assessing the effectiveness of mitigation measures at reducing significant adverse environmental impacts.

In a series of environmental research studies, the NRA focused on a range of individual issues that initially targeted the original EIA assessments which then lead to the assessment of the performance of various mitigation measures used on the national road network.

In developing national road schemes, every effort is made to ensure that the approach to drainage is appropriate for the location of the proposed development. In order to assess the appropriateness of the methodologies adopted for the determination of the drainage design, the NRA has prepared the following report outlining the findings of a two year research programme addressing post EIA evaluation studies of sustainable drainage options.

This document has been prepared by Dr. Billy O'Keeffe, Trinity College Dublin in conjunction with the NRA. The NRA would like to acknowledge and express its thanks for the contribution of a number of NRA Regional Managers, Engineering Inspectors and National Roads Regional and Project Office Engineers who contributed to the content of the document. The NRA would also like to express its thanks to several consultants and contractors who facilitated several site visits and attendance at workshops.

This work was funded through the National Roads Authority's research programme and the content of this document provides guidance on the use of Sustainable Drainage Designs for different hydrological environments for National Road Schemes in Ireland. The findings of this work will form the basis for the revision of the NRA's current drainage standards.

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1 Executive Summary

This purpose of this document is to review the current approach to the design of drainage systems and provide guidance on the use of sustainable drainage systems for national road projects in Ireland. The content and structure is based on several site visits examining drainage designs on national road projects both in construction and in operation. Consultation with design engineers and hydrologists was an essential element of the project. The key findings are outlined in relation to current design practice. Based on these findings recommendations are developed to promote a more sustainable drainage design approach to suit the requirements of specific hydrological environments. The guidance is based on road projects constructed with a Design and Build and Public Private Partnership (PPP) approach but the guidance is also suited to projects designed by the employer.

The main emphasis of the guidance is to promote the use of sustainable drainage designs both for conveyance and storage (e.g. grassed channels, wetlands) so that these systems become the preferred option rather than the current conventional systems (e.g. kerb and gully, concrete channels, detention basins). This approach represents a fundamental change in the discharge of road runoff from the current point source discharge to streams and rivers through detention basins to a more linear diffuse discharge though vegetated systems allowing for some infiltration to groundwater as well as a significantly reduced, treated, discharge to surface waters.

1.1 Key Findings

These findings are specifically related to the design of drainage systems.

Consultation with government agencies is an integral part of the road planning process. Engagement with government bodies such as Inland Fisheries Ireland (IFI), Office of Public Works (OPW) and the National Parks and Wildlife Service (NPWS) takes place in relation to the drainage design. In many cases, detailed consultation takes place after completion of the Environmental Impact Statement (EIS) where the land-take which is a crucial component for drainage systems has been fixed. This process means that if these government agencies require alterations to the drainage design to meet specific requirements then there is limited scope to adopt these changes in the design as options for additional land-take are limited.

During the planning process a conceptual preliminary drainage design is developed. There are seven phases involved in the development of national road schemes namely: 1. Scheme Concept and Feasibility Study, 2. Route Selection, 3. Design, 4. EIS/EIR and the Statutory Process, 5. Advance works and Construction Documents. Preparation Tender and Award, 6. Construction and Implementation, 5. Handover Review and Closeout. Planning refers to phases 1 to 4. The final drainage design is developed during the construction phase and can vary significantly from the conceptual preliminary design outlined in phases 3 to 4. A final design, in some instances, is only available after completion of construction of the road scheme. This means that the employer's representative on site is not in a position to fully validate the design elements and ensure compliance with environmental commitments in the EIS until the road is fully constructed.

The main reasons why sustainable drainage designs are not developed on national road projects relate to the lack of guidance on construction of these systems and the fact that designers are following the NRA design standards which do not openly promote the use of these systems.

Other findings include the lack of guidance on the types of field surveys required for adoption of sustainable drainage systems and confusion over the volumetric calculations such as attenuation requirements, surface runoff and discharge rates.

Road runoff contains pollutants such as suspended solids, heavy metals and hydrocarbons (e.g. polycyclic aromatic hydrocarbons (PAHs)). These pollutants represent a risk to both surface waters and groundwaters if the runoff does not undergo treatment. The pollutants are both in the sediment bound phase and in the soluble phase. Much of the pollutant load, including PAHs, is associated with the sediment bound phase. It is essential, therefore, than the suspended solid load is treated before allowing infiltration to groundwater or discharge to surface waters. Vegetated systems represent the most effective method of achieving the treatment objectives. The key factors that determine the concentration of pollutants in road runoff are traffic volumes and rainfall intensity.

1.2 Key recommendations

- It is important to undertake consultation with the relevant government agencies during the planning process (phases 1 to 4 of the NRA Project Management Guidelines) so that any necessary land-take to accommodate specific requirements for the drainage design can be facilitated prior to submission of the EIS and included in the compulsory purchase order (CPO). In order to undertake this consultation, a more detailed drainage design is required outlining the precise nature of the conveyance system, location of the attenuation or wetland ponds, the specific discharge rates and storm volumetric requirements from each road section. This will allow for a full risk assessment of the likely significant impacts of the road runoff.

- A risk assessment for determining the impacts of road runoff on groundwater and surface water should be undertaken when preparing drainage designs. A procedure for doing this is described in this document. This is important because the factors influencing the transport of contaminants from road runoff to groundwater are related to the nature of the pathways and include parameters such as the clay content and sorption characteristics of the soil, thickness and permeability of the sub soil and the thickness of the unsaturated zone. It is also a function of the type of drainage design.

- Current practice in treating road runoff primarily consists of conveying road runoff, without treatment, to a single point such as a detention basin. There the pollutant load is allowed to settle out prior to discharge to a river or stream. A more sustainable drainage design should incorporate treatment during conveyance and should promote infiltration of the treated runoff to groundwater. This will reduce the volumetric attenuation requirements and mimic greenfield site conditions maintaining the catchment balance of groundwater and surface water flow. Grassed channels and wetlands can replace the more conventional systems such as concrete channels and detention basins. This will improve the water quality of road runoff through treatment before discharge to the receiving environment. This approach will also reduce runoff rates and volumes reducing the impacts on stream morphology and flooding. This represents a shift in emphasis from point source discharge to a linear diffuse discharge. Groundwater sources, used as drinking water supplies, need to be identified along the proposed route and adequate protection ensured from road runoff if infiltration is to be adopted.

- The attenuation objectives will depend specifically on the nature of the receiving environment. In some cases a simple detention basin will be sufficient to meet environmental objectives. In other cases a higher level of treatment will be required such as a sedimentation pond or a wetland. In the case of a detention basin, the objective should be to attenuate the 1 in 100 year critical storm and storage systems should be sized to cater for this event, if feasible. Discharge rates should be limited to greenfield site rates. Where treatment is required then sedimentation ponds and constructed wetlands should be sized to allow a sufficient residence time to meet the objectives of the receiving environment. Guidance on these calculations is included in this research document.

- When designing a drainage system, cognisance should be taken of the nature and sensitivity of the receiving environment. The design needs to conform to the environmental quality standards and threshold values outlined in the Water Framework Directive, the Groundwater Directive and the relevant transposing regulations such as the Surface Water Regulations, Groundwater Regulations and Freshwater Pearl Mussel Regulations for the relevant traffic related pollutants. This will normally require at least two stages of treatment i.e. during conveyance and prior to discharge. A type of tertiary treatment through the use of petrol inceptors on all discharge is often adopted on national road projects. The requirements of the Habitats Directive are also taken into account specifically in relation to riverine European sites and groundwater dependent terrestrial ecosystems. Other important legislation to be taken into account is the European Communities (Drinking Water) (No.2) Regulations.

- The procedure for selecting the most appropriate drainage design is based on a risk assessment protocol outlined in this document. This examines the risk of road runoff to surface water and groundwater. Account and guidance is also given of the possibility of an accidental spill.

- Guidance on the design and use of the various sustainable drainage components such as grassed channels, swales, wetlands, attenuation ponds and combined filter drains is given in the document. The necessary field and desktop surveys required to construct an appropriate design are described. A number of case studies are outlined considering differing hydrological environments with different levels of sensitivity.

2 Section 1 Part 1 - Introduction to the Guidance Document

2.1 Objectives

The purpose of this document is to review current approaches used for the design of drainage systems and promote the adoption of sustainable drainage systems (vegetative systems) when developing road drainage designs for national road projects in Ireland. Vegetated systems such as grassed channels and wetlands have proven to be very effective at:

- Improving the water quality of road runoff through treatment before discharge to the receiving environment,
- Reducing runoff rates and volumes of road runoff and therefore reducing the impacts on stream morphology and flooding.

These designs, therefore, are better suited to meeting the environmental objectives and standards for groundwater and surface water specified in the Water Framework Directive, and its daughter the Groundwater Directive. One of the primary objectives of this document is to encourage the consultation process between the design team and the various environmental professionals (such as the hydrologists, ecologists and hydrogeologist) employed to complete the Environmental Impact Statement (EIS) at an early planning stage(phases 3 and 4 of Project Management Guidelines). This will, in turn, lead to the development of a robust drainage design taking account of the most important and relevant environmental factors. As such, the document is intended to familiarise the EIS specialists with the basic components of road drainage design, along with the various volumetric calculations associated with road runoff. The document is also intended to inform the design engineer of the benefits of having an early input from the EIS specialists and, in particular, what type of hydrological and hydrogeological information is required to protect both surface water and groundwater from road runoff.

The guidance is based on road projects constructed with a Design and Build and Public Private Partnership (PPP) approach but the guidance is also suited to projects designed by the employer.

The specific objectives of this document include:

- To outline best practice options for road drainage systems to be used on national road schemes in Ireland,
- To highlight the key environmental issues related to minimising impacts of road drainage on both surface water and groundwater,
- To provide guidance on the risk assessment process to determine the likely significant impacts, and
- To outline what Sustainable Urban Drainage Systems (SUDS) are most appropriate for the particular terrain taking account of the different hydrological environments in Ireland.

2.2 Limitations of this Guidance

The issues in this guidance document are specifically related to road projects, the different hydrogeological settings and meteorological conditions encountered in Ireland. The document is designed to conform to the stages and procedures outlined in National Roads Authority's (NRA) environmental integration model (Figure 1 http://www.nra.ie/Environment/) and the NRA's Project Management Guidelines (http://www.nra.ie/Publications/ProjectManagement/). It is not intended that this document provide a detailed overview of the specific components of road drainage design which is assessed in the NRA's Design Manual for Roads and Bridges (http://nrastandards.nra.ie). The principal goal is to focus on the environmental factors and to provide a general overview of the main components of some of the sustainable designs most suited to road projects in Ireland. In all cases the proposed drainage design is discussed and reviewed with National State agencies such as the Office of Public Works (OPW), Inland Fisheries (IFI) and the National Parks and Wildlife Service

(NPWS) as part of the planning process. Some of the designs discussed in this document will require a departure from the NRA before implementation as they do not comply with the design standards. Where there is a conflict between these designs and the standards then this must be reviewed with the NRA before implementation. The document takes into account the planning process in Ireland and the requirement for statutory consultation with the various stakeholders.

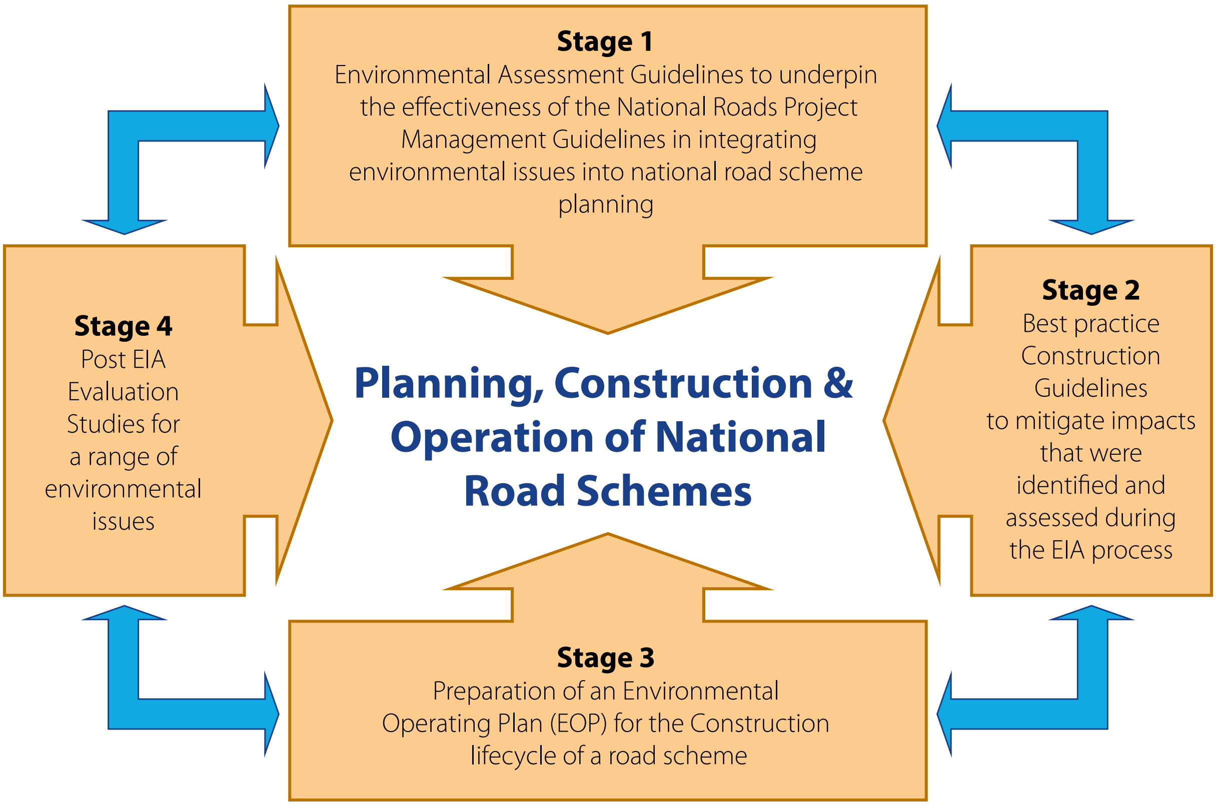


Figure 1 NRA Environmental Integration Model

2.2.1 Safety and Road Drainage Design

This document does not deal comprehensively with the safety elements associated with the design of the drainage components as these are covered in the standards.

2.3 Structure of this Guidance Document

The document is divided into 6 sections

Section 1 outlines the approach adopted to developing the guidance document. It examines road drainage and potential impacts on the environment and outlines the relevant legislation.

Section 2 deals with current practices in Ireland and factors that influence the transport of road runoff. It also encompasses an assessment of aquifer classification and vulnerability in Ireland and develops an appropriate risk assessment methodology for likely impacts.

Section 3 addresses the volumetric calculations including greenfield runoff rates, development runoff rates and runoff volumes. A brief discussion of the sizing of carrier pipes and attenuation ponds is included. The appropriate flow calculations for the design of culverts and bridges are also outlined.

Section 4 undertakes a review of the various SUDS components outlining the qualitative and quantitative control offered by such systems.

Section 5 deals with the design of various SUDS components, principally wetlands, grassed channels, swales, ponds and infiltration systems.

Section 6 is an appendix with maps of Ireland showing rainfall intensities for different return periods and storm durations and a summary of flow charts from the document.

Plate 1 Concrete channel used to convey surface runoff, part of a sealed drainage system. A separate fin drain, below the concrete channel, is used for conveying groundwater.

2.4 Sources of Information

The main sources of information related to the impacts of road runoff and the design of SUDS include:

2.4.1 UK Documents

- *The SUDS Manual.* – LONDON. CIRIA C697 – 2007 (CIRIA C697 2007),
- Defra / Environment Agency. Flood and Coastal Defence R&D programme. *Preliminary rainfall runoff management for developments*. 2005. (Defra / Environmental Agency 2005),
- UK DMRB documents related to drainage design and SUDS – Volume 4 and volume 11,
- *Designing for exceedance in urban drainage – good practice.* – LONDON. CIRIA C635. 2006. (CIRIA C635 2006),
- *SUDS for Roads.* 2009. Scottish SUDS Working party.

2.4.2 Irish Documents

- *Greater Dublin Strategic Drainage Study*. 2005. www.fingalcoco.ie/Water/WaterServicesProjects/RegionalProjects/GreaterDublinStrategicDrainageStudy/,

- GSI Website – Groundwater mapping section
    - Aquifer vulnerability, Aquifer classification, Source Protection Areas, Recharge maps,
    - Geological Survey of Ireland. *GSI Groundwater web mapping.* 2010. http://www.gsi.ie/Programmes/Groundwater/Groundwater+web+mapping.htm.
- *Impact Assessment of Highway Drainage on Surface Water Quality, 2000-MS-13-M2, Main Report.* 2006. (M. Bruen 2006).

2.5 Linked Publications

The NRA has published a series of best practice environmental impact appraisal documents related to the planning, construction and operation of national road projects as part of the overall environmental integration strategy. These documents cover a wide range of topics but the most relevant publications to this guidance document include:

- *NRA. Environmental Impact Assessment of National Road Schemes. A Practical Guide.* Revised 2008. (NRA 2008),
- *NRA. Guidelines for Assessment of Ecological Impacts of National Road Schemes*. Revised 2009. (NRA 2009),
- *NRA. Guidelines for the Crossing of Watercourses During the Construction of National Road Schemes. 2005.* (NRA 2005),
- *NRA. Guidelines on Procedures for the Assessment and Treatment of Geology, Hydrology and Hydrogeology for National Road Schemes. 2008.* (NRA 2008),
- The NRA has also published a series of documents related to road design and construction standards and project management. The most relevant publications include:
    - *NRA. The NRA Design Manual for Roads and Bridges (NRA DMRB),*
    - *NRA. NRA Project Management Guidelines. Revised 2010.*

All of the NRA documents are available on the NRA's website, http://www.nra.ie/.

2.6 Approach to Developing the Guideline Document

Figure 2 outlines the approach taken to developing this document and it lays the foundation for the document's structure.

2.6.1 Literature Review

The literature review focussed on:

- The impacts of road drainage on both surface and groundwaters,
- A review of current drainage design systems used in Ireland,
- A review of the legislation and how it might impact road runoff discharge,
- A review of the different hydrological environments and how each environment will influence the drainage design options,

- SUDS drainage designs.

2.6.2 Site Visits

Several site visits were undertaken examining the current drainage design practices on national road projects in different hydrological environments across the country. These visits included environments such as:

- Karst limestone and limestone pavement,
- Road projects crossing protected rivers and streams,
- Extreme and highly vulnerable bedrock aquifers,
- Highly vulnerable sand and gravel aquifers, and
- Areas with thick subsoil affording substantial protection to the underlying rock aquifer.

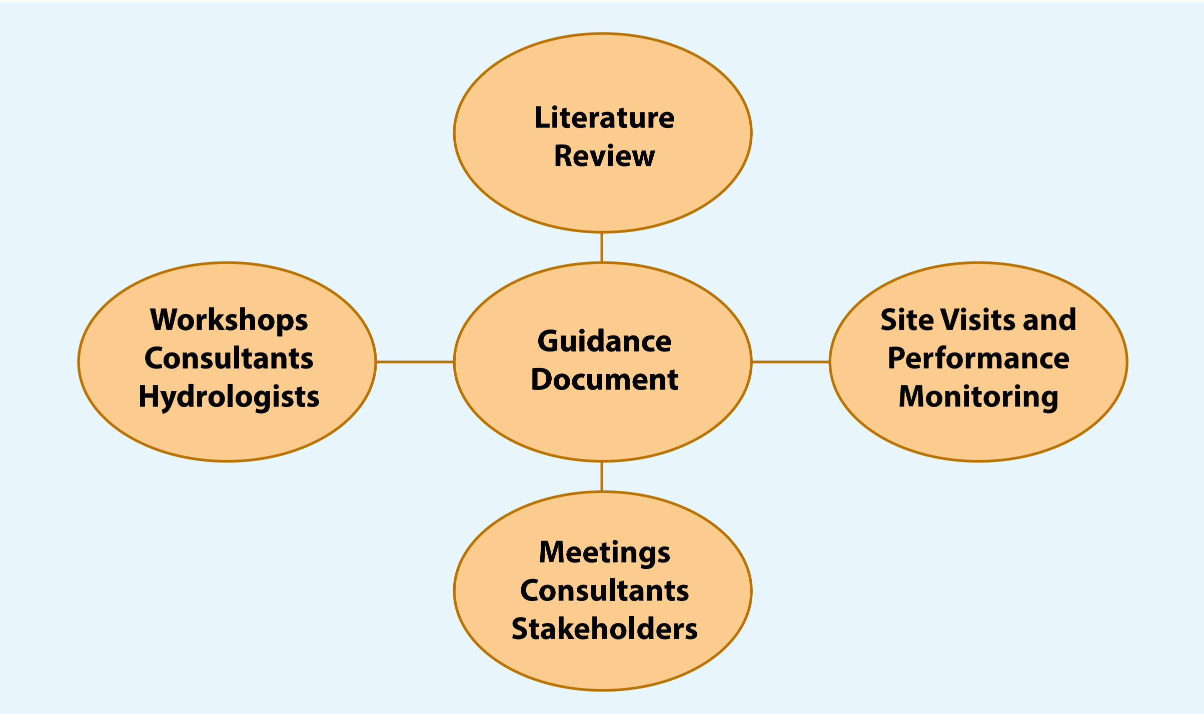


Figure 2 Stages of developing the guidance document

The site visits were an essential element of the project and formed the basis for developing the content and structure of the guidance document. Several different types of drainage design systems were examined ranging from filter drains, sealed systems with kerb and gully, concrete channels, grassed channels, over the edge drainage and various types of attenuation basins, infiltration basins and hybrid ponds. The systems were discharging both to surface waters and groundwaters. It is important to note that a number of national road schemes already have SUDS systems in place with wetlands, grassed channels and other innovative systems effectively treating road runoff in sensitive locations. The site visits did, however, highlight areas where alternative systems may have been more appropriate.

2.6.3 Consultation

Consultation with road design engineers, hydrologists, government agencies and local authorities was undertaken to establish current procedures, approaches and issues related to road drainage design. This led to the identification of key issues to be covered in the guidance document. This consultation also highlighted situations where detailed design of road drainage was required at the early design and EIS phases because of the sensitivity of the receiving environment. In relation to drainage design, the key stakeholders are OPW, Inland Fisheries Ireland and NPWS. These government bodies are consulted on the drainage design and form part of a statutory consultation procedure in the Environmental Impact Assessment process.

Plate 2 Wetland system with sediment forebay and berms.

2.6.4 Workshops

During the development of this document a number of national road projects were under construction. The construction process includes structured workshops with representatives from the NRA, the Monitoring Team (Employer's Representative) and the Contractor's Consultant. These workshops are held to discuss any issues related to aspects of the construction phase, including the drainage design. It is important to note that it is only during this construction phase that the final details of the drainage design are established. Attending these workshops was very beneficial in understanding how the final and detailed aspects of the drainage design are arrived at.

2.6.5 Feedback

The key areas identified through the consultation process and site visits are summarised in Box 1. The issues related to these topics are expanded upon in various sections of the guidance.

Planning process

- Detailed consultation with government agencies takes place too late in the road scheme development (after the EIS in some cases).

Drainage design process

- Inconsistent approach, preliminary drainage design is not sufficiently developed,
- Alterations to the detailed drainage design often take place during construction.

Technical issues

- Confusion over the approach to volumetric calculations such as greenfield runoff and attenuation requirements.
- Lack of standards for some drainage components

Design of SUDS components

- Lack of guidance on where these systems could be used.

Survey requirements

- Lack of guidance on what type of surveys are required for detailed drainage design.

Box 1 Identified areas of concern in relation to drainage design

2.6.5.1 EIA Process

During the EIA process there is a requirement to send the EIS to various prescribed government agencies and they are entitled to make submissions to An Bord Pleanala. There is also a requirement to consult with Inland Fisheries Ireland and OPW. Inland Fisheries Ireland will generally comment on both quality and quantity aspects of the design especially where there is a proposal to discharge to protected rivers or streams. The OPW will comment on issues related to flooding and in particular the size and location of culverts. The NPWS are consulted on all ecological matters related to the road scheme and have the potential to influence the drainage design. The principal area of concern relates to the timing of the consultation. A "Consult and Comply" process with Inland Fisheries and OPW takes place after consent has been granted and results in detailed consultation after the Environmental Impact Statement (EIS) has been completed. At this stage the road scheme has been approved and the "Land Take" has been completed. Therefore, if there are aspects of the drainage design that are not deemed to be suitable by these government agencies for the particular environmental setting then there is little scope to make major amendments as additional land take is often required to significantly alter the drainage design. The principal reason why the detailed consultation takes place after the EIA and the statutory process phase is that the detailed drainage design is only carried out by the contractor during this period. The EIS produces an early drainage design that, in many cases, does not have sufficient detail for the consult and comply process.

2.6.5.2 Drainage Design Procedure

During the planning process a preliminary drainage design is produced with varying amount of detail, often a function of the sensitivity of the receiving environment. In many cases, as part of the EIS, attenuation ponds are sized, locations are identified and suitable discharge points from the ponds are indicated. After consent for the road scheme has been granted, the contractor will often redesign several elements of the proposed drainage system potentially resulting in major alterations to the design e.g. the location and size of the ponds can vary considerably from the original preliminary design, discharge points can also change. The most significant problem with this process is that the monitoring team are not in a position to fully assess the new drainage design until it is actually constructed.

2.6.5.3 Technical Issues

The technical issues relate to the volumetric calculations, principally those used to calculate greenfield runoff rates and attenuation volumes. There is also a range of calculation methodologies used by different consultants in similar catchment areas. The greenfield runoff rate is the runoff that would normally occur without any development. This rate is then adopted as an acceptable discharge rate from the attenuation ponds or wetlands. Runoff is defined as that proportion of the rainfall that contributes to stream flow through base flow, interflow and overland flow. The greenfield runoff rate can vary significantly depending on what calculation method is used and what return period is adopted. The choice of attenuation volumes can also vary as there appears to be no accepted return period or time duration of storm.

Return periods can vary from 1 in 10 years to 1 in 100 years. The storm duration can also vary from a few hours to 2 days. This results in an inconsistency in attenuation volumes and discharge rates used in road projects in similar environments.

These greenfield calculations are separate to those used to calculate the sizing of pipes for the drainage design which are clearly defined in the standards.

2.6.5.4 Design of SUDS Drainage Features

Although there are many excellent publications on how to design SUDS drainage components such as wetlands, swales and grassed channels, there are very few detailing exactly where these systems should be used. There are a range of very different hydrological and hydrogeological environments across Ireland, many of which will require different treatment options and treatment trains. One of the principal objectives of this document is to develop suitable treatment options for the different hydrological setting across Ireland as a function of the sensitivity and nature of the receiving environment.

2.6.5.5 Survey Requirements

As part of the EIS, many of the basic site investigation surveys required for drainage design are completed. There are, however, some detailed aspects of the receiving environment, essential for drainage design, that are only developed at the construction phase. These mostly relate to the capacity of streams and rivers downstream and upstream of proposed discharge points. Without a complete assessment of the receiving watercourse, especially in relation to the lower volume streams, an issue with flooding can suddenly arise resulting in modifications of the drainage design.

2.6.6 Summary

A number of key areas in relation to drainage design were identified through a literature review, a detailed consultation process and several site visits.

During the planning process (phases 3 and 4 in particular) a conceptual preliminary drainage design is presented in the EIS. The final design is only developed as construction takes place and can vary significantly from the conceptual preliminary design. This means that the employer's representative on site is not in a position to fully validate the design elements and ensure compliance with environmental commitments in the EIS until the road is fully constructed. The consult and comply process needs to be completed during phases 3 and 4 (design and EIS phases).

The main reasons why sustainable designs are not developed on national road projects is due to the fact that designers are following the NRA design standards which do not openly promote the use of these systems.

Other findings include the lack of guidance on the types of field surveys required for adoption of sustainable drainage systems and confusion over the volumetric calculations such as attenuation requirements, surface runoff and discharge rates.

The remainder of this report will focus on the key environmental issues and how they can be resolved in the context of new legislation related to the protection of surface and groundwater and within the framework of the Habitats Directive.

The key recommendations will be to promote the adaptation of sustainable drainage systems rather than the conventional designs so that these become standard practice and to change the current approach of discharging runoff to streams from a point source, i.e. via an attenuation pond, to a more diffuse discharge allowing both infiltration to groundwater and discharge to surface waters of the treated runoff.

3 Section 1 Part 2 - Road Runoff and Pollutants

3.1 Introduction

The principal pollutants in road runoff are heavy metals (copper, zinc, cadmium) and Polycyclic Aromatic Hydrocarbons (PAHs) such as fluoroanthene and pyrene. Road runoff can also contain a high concentration of suspended solids (SS). There are many other minor pollutants including other types of metals and also pollutants related to de-icing salts but the pollutants mentioned above are considered to be the most important in relation to environmental impacts on surface water and groundwaters.

The concentration of pollutants in road runoff has been established by numerous studies including a detailed study in the UK funded by the Highways Agency (B. Crabtree 2008) and also a research project funded jointly by the NRA and the EPA in Ireland (M. Bruen 2006). The findings of these two studies are considered to be most relevant to road drainage design in the Irish context.

3.2 UK Study

The UK study commenced in 2002, comprised 5 stages, and was completed in 2009. Although the findings of the study are considered to be primarily applicable to the UK there are many similarities with the situation in Ireland and many of the main conclusions are directly relevant. The phases of the study consisted of:

1. The determination of pollutants in highway runoff.
2. Effects of soluble pollutants on the ecology of receiving waters.
3. Impact of highway-derived sediments on receiving water biota.
4. Development of the Highways Agency Water Risk Assessment Tool (HAWRAT).
5. Evaluation of HAWRAT tool and revision of guidance (DMRB HD 45/09 2009).

The principal difference between this study and previous investigations was the emphasis at determining the effects of both the soluble and sediment derived fractions on the ecology and biota of the receiving waters. The study resulted in the development of a very useful risk assessment tool which can be used to determine the expected concentrations of pollutants in road runoff. The tool can then be used to decide on the level of mitigation required to protect the receiving waters (Highways Agency Risk Assessment Tool - HAWRAT).

The principal findings of the study are published in a number of documents but are summarised in the UK DMRB document HD 45/09 (DMRB HD 45/09 2009). The study collected data from 280 rainfall events from 24 different sites across the UK. The sites were chosen to represent a range of different traffic bands and different climatic conditions related to rainfall and temperature. Sites with a range of different traffic bands were selected so that correlations could be made between pollutant concentrations and traffic counts. This implies that direct comparisons can be made with the situation in Ireland in relation to traffic volumes. Table 1 shows the traffic bands chosen for the study. The sites also had varying climatic conditions which were divided into 4 zones, i.e. cold wet, cold dry, warm wet, warm dry (wet = > 800mm annual rainfall, cold = <3^0C average winter temperature). Climatic conditions in the two countries are also very similar.

It is worth highlighting some of the key findings as they have a significant influence on the approach to drainage design.

Traffic Band (AADT)	Number of Locations
5000 - 14999	1
15000 - 29999	5
30000 - 49999	4
50000 - 79999	7
80000 - 119000	4
120000 - 200000	3

Table 1 Traffic Bands UK Study from Crabtree *et al* 2008

3.2.1 Key Findings

The principal findings are related to the types of pollutants, their impact on biota and the factors that influence their concentration and can be summarised as follows:

- Pollutants are routinely present in road runoff,
- The key soluble pollutants in road runoff are copper and zinc,
- Thy key sediment-bound pollutants are copper, zinc, cadmium and Polycyclic Aromatic Hydrocarbons (PAHs),
- Pollutants likely to exert a short term acute impact are in the soluble form,
- Pollutants likely to exert a longer term chronic impact are in the insoluble form (sediment-bound),
- Key factors in determining pollutant concentrations in runoff are:
    - annual average daily traffic (AADT),
    - climate region,
    - seasonality,
    - maximum rainfall intensity,
    - antecedent dry weather period.

Other interesting findings were related to the correlation between pollutant concentrations and traffic counts and the timing of the heaviest concentration in relation to the rainfall event. These can be summarised as follows:

- Little correlation between PAHs and AADT,
- Reasonable correlation between metals and AADT:
    - Big increase in correlations at high traffic bands > 80,000,
- Biggest concentration of metals NOT in first flush and in general:
    - Concentrations of total metals and suspended solids peaked at peak of hydrograph,

- Concentration of dissolved metals increase during rainfall event.

There was little correlation between PAH concentrations and traffic volumes. This is covered in Section 3.4. There was a reasonable correlation between traffic volumes and metal concentrations. The correlation improved significantly, however, at the higher traffic bands (> 80,000 AADT). For the lower traffic bands 15,000 to 80,000 the variability in concentrations e.g. dissolved copper, did not show a good correlation between median values and traffic bands.

The relationship between the intensity of the rainfall and the concentration of pollutants is one of the most significant findings in relation to drainage design. Treatment devices are often focussed on treating the first flush from a rainfall event making the assumption that it contains the highest concentration of pollutants. The findings of the study indicate that this is not always the case and the highest concentration can occur late in the rainfall event and is a function of the peak rainfall intensity during the storm rather than the initial intensity. The erosion and transport of sediment associated with road runoff is more influenced by the peak rainfall intensity and the transport capacity of the flow. There were some cases where the highest concentration may occur at the initial flush but this is more related to the availability of sediment. If there is a limited supply of sediment then it may be exhausted quickly and highest concentrations in this case can occur at the initial flush. This was a rare event in the study with only 7 out 40 events measured indicating a higher concentration in the first flush.

This implies that treatment systems such as wetlands, swales and infiltration basins will be required to treat larger volumes than that of the first flush (sometimes taken to be 12 to 15mm of rainfall). Capacity of the treatment system may have to be increased to treat more of the storm volume.

3.2.2 UK Surface Water Risk Assessment Tool

As part of the UK research, a water risk assessment tool was developed (HAWRAT). This is described in detail in HD 45/09 (DMRB HD 45/09 2009) . This allows a prediction of pollutant concentrations with some simple input parameters such as traffic counts, rainfall and climatic conditions. The model allows pollutant predictions at 3 levels (steps). The first is a worst case scenario with no dilution effects or mitigation; just traffic counts and rainfall. The second step takes into account the dilution effects of the receiving water body and finally the third step considers the proposed mitigation measures (treatment systems). In order to account for the dilution effects of flows in the receiving water body, surface water flows must be quantified.

During each step a simple *pass/ fail* is the result with corresponding concentrations of pollutants highlighted. A re-evaluation of mitigation measures will be required until a *pass* is the result. The assessment tool is very useful tool for determining the likely concentrations of pollutants in road runoff. The threshold levels required for a pass have been discussed with the Environmental Agency in the UK taking the objectives of the Water Framework Directive into account, specifically the environmental quality objectives of the receiving water bodies. In order to adopt these threshold levels in Ireland agreement should be reached with the relevant government agencies. Different threshold limits may be required for different receiving environments. If the receiving water body is protected (e.g. an SAC) then threshold limits are halved in the HAWRAT procedure.

3.3 Irish Study

A major research project funded by the EPA/NRA, completed jointly by Trinity College Dublin and University College Dublin, was aimed at investigating the impact of road runoff on the surface water quality receptors (M. Bruen 2006). The study undertook comprehensive hydrological and water quality measurements at 4 sites on the new motorway network as well as hydrobiological measurements at 14 river crossing sites across Ireland. The study also looked at the efficiency of some drainage design such as Combined Filter Drains and in particular their ability to collect road runoff. One of the key aspects of the investigation was related to the construction of a wetland on one of the major inter urban-routes (M7) in Ireland and a detailed study was undertaken on the efficiency of the wetland at treating road runoff. Many of the key findings in relation to the nature of pollutants are similar to the UK study and included:

- Road runoff does contain pollutants, mainly:
  - SS, Heavy metals, PAHs, chlorides, nitrates and phosphorous,
  - The range of concentration levels of pollutants were very similar in both the Irish and UK studies,
- There was, however, no significant impact on vegetation, macro invertebrates or fish downstream of outfalls from road discharge,
- French (Combined Filter) Drains were identified:
  - As having have low runoff coefficients;
    - A significant portion of road runoff (up to 80%) in areas of filter drains was bypassing the drainage system and entering the subsurface receiving environment,
  - To clog very quickly, contain heavy metals but can act as a filter,
- Wetlands are very effective at removing pollutants, removing up to 94% of total suspended solids, 67% of total phosphate, 91% of total zinc, 67% of total cadmium, 60% of total lead and 78% of total copper;
  - In addition Peak flow rates were reduced by 96% and the wetland now provides a habitat for many species.

Plate 3 Linear attenuation ponds can become wetlands through naturally vegetation providing a permanent water table is present.

Most of the contaminants were attributed to road traffic sources but contaminants such as nitrates and phosphorous could have upstream sources. The lack of measurable impact on the surface water ecology may be attributed to a number of factors;

- The effects of dilution and attenuation in the treatment systems in use were efficient in minimising impacts on surface water quality,
- The streams and rivers had a major dilution effect,
- The traffic volumes were low and consequently the pollutant load was low,
- The drainage systems were not collecting the bulk of the runoff volumes from the road.

One of the major negative findings of the report was in relation to the success of Combined Filter Drains (French drains) in collecting the generated volumes of road runoff. French or Filter drains are the most common form of collector system used on the national road network. In some cases this drainage system was only conveying 25% of the expected runoff as they become clogged by fine silt and clay very soon after construction. The implication was that most of the road runoff was bypassing the road drainage system and continuing into the receiving environment. This suggests that a possible receptor for this pollution load was groundwater and not surface water.

It was also noted that a significant number of the rivers, especially in the east of the country, were already polluted from upstream sources.

Table 2 shows the concentration of pollutants in road runoff from the two studies. For the UK study the median value is shown, while the range of values is presented for the Irish study. For the measured parameters the values are broadly similar.

	UK Study µg/l	Ireland Study µg/l
Parameter	Median Values	Range
Cu	43	19 - 95
Cu Dissolved	23	
Zn	140	81 - 426
Zn Dissolved	58	
Cd	0.29	nd - 8
Fluoroanthene	0.3	
Pyrene	0.31	
PAH	3.33	
TSS mg/l	139	43 - 437
Phosphorous		60 - 188
Lead		27 - 92

Table 2 Concentration of pollutants in road runoff. nd = not detected. TSS shown in mg/l.

Plate 4 Clogged Filter Drain. Combined filter drains (French Drains) can become clogged with silt resulting in surface runoff bypassing the system and entering the receiving environment. In vulnerable areas groundwater can be a potential receptor.

3.4 Source of road pollutants, Metals and Polycyclic Aromatic Hydrocarbons (PAH)

An estimated 495 billion vehicle kilometres were travelled in the UK in 2003, a figure available from the UK national Statistics Online database (Napier F. 2008). This figure was used to estimate the amount of pollutants coming from the various sources in UK traffic (Napier F. 2008). The study highlights the range of sources of the pollutants, consisting of heavy metals and PAHs from oil losses, brake wear, tyre erosion and exhaust emissions. A summary of the total amounts of pollutants is presented in Table 3.

TYRE EROSION	BRAKE WEAR	OIL LOSSES	EXHAUST EMISSIONS
PAHs 34.7 t (350mg/kg)	Lead 1.5 t (3µg /km/veh)	PAHs 320 t	PAHs 130 t
Lead 1.0 t	Copper 24 t (75µg/km/veh)	Lead 0.02 t	Lead 1.1 t
Copper 0.3 t	Zinc 44 t (89µg/km/veh)	Copper 0.038 t	Copper 0.4 t
Zinc 990 t		Zinc 2.3 t	Zinc 1.0 t
(All Metals 0.125µg/km/veh)		See text	Air emissions Inventory for values

Table 3 Derived values for estimated pollutant emissions from car components in the UK (Napier 2008)

PAHs consist of thousands of compounds but the United States Environmental Protection Agency (USEPA) have chosen 16 to represent the entire range and these have become the standard suite. The PAH values given above are for total PAH content based on the USEPA 16.

Average metal concentrations of 125mg/l Zn, 2mg/l Cu and 1.1 mg/l Pb for motor oil and a conversion factor of 1142 l of oil to 1 tonne was assumed. The total PAH content for oil is far less clear with values ranging from 43mg/kg (unused oil) to 43,000 mg/kg (used oil). A value of 20,000mg/kg was used for the study. Based on the above calculations the authors concluded that:

- Car-derived copper is now the biggest source of atmospheric copper pollution,
- Although there was a drop in lead concentrations this was not reflected in the total riverine concentration or aquatic organisms implying that further action was required,
- Traffic is also the major source of PAHs and this is likely to continue and get worse if there is a shift towards diesel cars that have a higher PAH exhaust emission.

Although there are several papers documenting the significant concentrations of PAHs in road runoff there is considerable debate as to the precise source. Among the possible sources are exhaust emissions, tyres, oil and asphalt. Since PAHs are easily biodegradable and since each PAH has different degradability then it is difficult to identify their source through marker compounds as they are not stable. More stable compounds such as Tri-terpanes, which are contained within crude oil, have been used as markers (Kose T. 2008). In order to distinguish between a petrogenic and pyrogenic source four PAHs can be used and plotted as ratios, fluoranthene (Fluo), pyrene (Pyr), phenantherene (Phen) and anthracene (Anth). The ratio of Phen/Anth versu Fluo/Pyr are plotted against each other. The results from a study in Japan (AADT 30,000 to 100,000) show a mixed signature (Kose T. 2008). In the same study the authors compared the profiles of tri-terpanes and were able to demonstrate that the composition of road dust was identical to the runoff. They also concluded that the major source of tri-terpanes in the road dust was from tyres, with a contribution from asphalt. Exhaust emissions were considered negligible.

3.4.1 Groundwater

3.4.1.1 POLMIT Study

One of the principal research projects in recent years in relation to groundwater contamination was a Transport Research Laboratory of the UK coordinated COST project, entitled 'POLMIT - Pollution of Groundwater and Soil by Road and Traffic Sources: Dispersal Mechanisms, Pathways and Mitigation Measures' (Transport Research Laboratory (ed.), 2002). This project gathered material from seven European countries (UK, Netherlands, Denmark, Sweden, Finland, France and Portugal). A very brief summary of the findings is presented below.

Concentrations of heavy metals in groundwaters were low and for the most part below Dutch intervention levels for groundwaters (Pb 75µg/l, Cu 75µg/l, Zn 800 µg/l). Soil intervention levels were only exceeded for Pb (530 mg/kg), with most of the Pb probably having been deposited when leaded fuel use was at a peak. At some sites, Cu (190mg/kg) and Zn (720 mg/kg) concentrations did approach intervention levels, but were thought to be derived from the presence of nearby crash barriers, rather than from roads or vehicles directly.

One of the principal findings of the project was that metals in runoff are strongly adsorbed to soil particle surfaces and do not easily leach downwards through the soil profile into the underlying aquifer. The metals however can go back into solution when chlorine levels are elevated in the road runoff. This occurs when de-icing salts are applied. Elevated levels of heavy metals were encountered when large amounts of salts were applied. The Dutch intervention level for chloride (0.5 mg/l) was exceeded at most sites as a result of de-icing salts. At some sites, the maximum recorded concentration was almost 5 times the intervention level. However, concentrations rapidly reduced to below the intervention level during the summer months when de-icing salts were no longer applied.

In a similar manner to soils, concentrations of total hydrocarbons in groundwater varied greatly from site to site, with the intervention level being exceeded at 5 sites. Three of these sites also had elevated concentration in soil. However, two sites had excessively high concentrations (over 30,000 µg/l) in groundwater alone, possibly indicating a non-road source.

It was suggested that the large variation in concentrations reflected the probable accidental nature of the source of this pollutant

POLMIT Study
• Metal values in groundwaters were low but did occasionally exceed Dutch intervention values.
• Metals are strongly adsorbed by the clay fraction of soils but can be dissolved back into solution if the runoff has high chlorine content from salt.
• Concentrations of hydrocarbons varied greatly and exceeded Dutch intervention values at 5 sites.

Box 2 Summary of POLMIT Study - Groundwater

3.4.1.2 UK Highways Agency (2010)

Recognising the importance of the unsaturated zone in groundwater protection, the UK Highways Agency conducted further detailed studies at four highway sites on the M25, M27, A3 and A417 (Scott Wilson, 2010). The aims of the studies were:

- To understand the transport and fate of highway derived contaminants in the unsaturated zone.
- To quantify the extent to which highway contaminants may be immobilized, degraded and leached in the unsaturated zone.
- To review the current risk assessment methodology contained in HD45 (Highways Agency, 2009).

The first phase of the project analysed surface sediment and cores from the sites. Discharge of highway runoff to ground was via soakaways or infiltration trenches for all four sites. Samples were taken within the infiltration device. A further uncontaminated core was taken to establish background values. Contaminant concentrations in the surface sediments ranged from: 98 – 410 mg/kg (Copper); 48 – 214 mg/kg (Lead); 278 – 1366 mg/kg (Zinc); and 11 – 22 mg/kg (total PAHs). There were no clear relationships between contaminant concentrations and factors such as AADT, possibly due to the small sample size and local effects. Metal and PAH concentrations reduced with soil depth for chalks, reverting to background concentrations at depth of 600 mm from ground level. No reduction with depth was observed for the limestone cores, where contaminant transport through fissures was suspected.

The second phase of the study involved artificial loading of core samples in the laboratory using synthetic runoff. The average annual infiltration rate for the UK was calculated from estimates of rainfall, runoff and evaporation. By applying this rate continuously, the 7-month laboratory trial simulated loading between 125 and 302 years, depending on soil type.

The percentage of metals leached varied by soil type, but typically 20-50%. The high experimental loading rates of metals were acknowledged to contribute to the high leaching rates; it is likely that lower rates would be observed in field conditions. The clay content, organic content and pH were key determinants of the soil's ability to retain the contaminants.

Extremely low leaching rates were measured for the PAHs (Naphthalene, Fluoranthene and Pyrene): less than 1%, and Total Petroleum Hydrocarbons (TPHs): less than 4%. Biodegradation was shown to be responsible for reducing PAHs by more than 98% and TPHs by 83%. This may explain, to some extent, the low recovery rates of PAHs observed in the POLMIT study.

Based on the sorption and retardation factors measured in the laboratory tests, a minimum breakthrough time of 60 years for highway pollutants to enter the groundwater was suggested as a conservative measure for screening purposes.

The effect of Sodium Chloride application was also investigated. It was shown to readily mobilise the available Cadmium, Copper, Lead, Zinc, Fluoranthene, Pyrene, Naphthalene and TPHs. Furthermore, long-term cumulative effects of Sodium Chloride were observed, so groundwater impacts of salt application may not be limited to the winter season.

The limitations of the laboratory tests included the small number of soil types, the difficulty in maintaining the organic compounds in solution, and the differences between the synthetic runoff (limited number of constituents) and highway runoff (complex matrix of constituents).

The study outputs were related to the current UK Highways Agency risk assessment methodology (Highways Agency (2009)). The authors considered the elements of the risk assessment under the following headings:

Traffic density

Based on the data collected in this study, there was no clear relationship between AADT and soil contaminant levels, so the authors suggested the weighting factor should be re-considered (presumably reduced). However, the limited data collected does not seem to support such a conclusion, which is contrary to the findings of WRc (2008), where a large dataset was available.

Rainfall volume and intensity

The authors suggested that rainfall intensity is linked to short-term variations in runoff concentrations, but in the long-term, the impact of contaminants to groundwater is limited by the mass available in the catchment. Therefore, the groundwater response will be relatively insensitive to variations in rainfall intensity. On the other hand, rainfall volume is the driver for contaminant flux in the unsaturated zone. This lead the authors to suggest that total rainfall should be assigned a greater weighting in the risk assessment than rainfall intensity. This view has certain merit where the unsaturated zone consists of a substantial depth of low-permeability material. However, in some environments, particularly karst, a rapid response of groundwater to highway runoff may be observed, and in these circumstances the rainfall intensity is a relevant parameter.

Soakaway geometry

Considering the finite storage for contaminants available in the unsaturated zone, the authors concluded that the ratio of drained highway area to the infiltration area would be a more realistic metric for risk assessment, rather than the current classification. This is a logical approach, and this ratio could be calculated easily at the preliminary drainage design stage.

Flow type

The flow type was linked to contaminant transport rates in the laboratory tests, so its inclusion in the risk assessment is deemed appropriate.

Effective grain size

The authors suggest that the effective grain size is difficult to separate from the flow type in its application to the risk assessment, and the two factors should be amalgamated. However, HD 45/09 (Highways Agency, 2009) considers the grain size in relation to the soakaway construction material, which can be separated from the unsaturated zone, if considered as a two-layer system. The effectiveness of the soakaway in containing contaminants can only be included though if the runoff is discharged to the top of the infiltration device, as in the case with over-the-edge drainage. Therefore, effective grain size should be retained separately, but the method of discharge to the soakaway should also be considered.

Lithology

Currently, the clay content is the sole proxy considered for sorption and retardation of highway contaminants in the unsaturated zone. The laboratory studies indicated that the organic content and pH were also relevant soil parameters.

These variables could be included in the risk assessment and their measurement is relatively straightforward, but until their influence in the context of Irish soils is established, these parameters may be of limited benefit.

3.5 Summary Pollutants and Road Runoff

It is evident from current research both in Ireland and the UK that pollutants in road runoff can pose a threat to the ecology of surface waters (Box 3). Typical pollutants include heavy metals such as zinc, copper and cadmium and PAHs such as pyrene and fluoroanthene. Road runoff can also contain a high level of suspended solids. These pollutants can result in deleterious effects to the ecology of the receiving waters if untreated both in soluble form and in the sediment – bound phase. Various treatment options are available to minimise these impacts and these will be discussed in detail in this document. Very little research has been completed on the impacts of road runoff on groundwater. This leads to a perceived risk and costly mitigation measures in relation to drainage design. Groundwaters are most at risk from soluble pollutants. PAHs are mainly bound in the sediment phase. If protection of groundwater is a priority then it is imperative that the suspended solids are removed prior to discharge to groundwater aquifers.

- Road runoff contains SS, heavy metals and PAHs.
- These pollutants represent a pressure on surface waters and groundwaters.
- Extensive research has been conducted on impacts on surface waters and mitigation measures can readily be defined, little research conducted on impacts to groundwaters.
- Combined Filter drains clog quickly allowing runoff to bypass the system.
- Groundwater is less susceptible to pollution by particulates, but remains at risk from soluble contaminants.
- Biggest concentration of pollutants is in sediment bound phase.
- There is no clear correlation between PAH concentrations and traffic volumes.

Box 3 Summary of road pollutants and environmental impacts

Plate 5 Small Detention basin adjacent to salmonid river. A detention basin will allow settlement of suspended solids prior to discharge. Control of discharge rates, through a suitable control structure, is essential to allow sufficient residence time.

4 Section 1 Part 3 - Legislative Context

4.1 Introduction

In 2000 the European Parliament and Council adopted 2000/60/EC – the Water Framework Directive (WFD)[1]. This establishes the legal framework for the protection, improvement and sustainable management of, inland surface waters, transitional waters, coastal waters and groundwater. The WFD was transposed into Irish law by the European Communities Water Policy Regulations 2003 (S.I. 722 of 2003)[2]. The Directive sets out a series of steps required to reach stated objectives. An outline of the various phases is given in Box 4. In order to meet the objectives, groundwater bodies were delineated for management purposes. The objectives include:

- Prevention or limit the input of pollutants into groundwater and prevent deterioration of the status of all bodies of surface and groundwater and
- Protect, enhance and restore all bodies of surface and groundwater with the aim of achieving good status by 2015.

Water Framework Directive – Timeframe for Implementation
2000 Directive entered into force in EU
2003 Directive transposed into Irish Law. River Basin Districts (RBDs) identified
2004 Pressures and impacts on water bodies completed = Characterisation Report
2006 Monitoring programmes initiated as basis for Water Management Plan
2008 Publish Water Management Plan
2009 Establish programme of measures (objectives) • Surface water regulations • Groundwater regulations • Pearl mussel regulations
2012 Programme of measures in operation
2015 Meet good status

Box 4 Water Framework Directive. Timescale for implementation.

In 2004 the characteristics of the river basin districts in Ireland were identified and water bodies were defined. These included:

- 757 Groundwater Bodies,
- 4,468 Rivers,
- 210 Lakes,
- 196 Transitional Waters,
- 113 Coastal Waters.

All of the various milestones have been met in Ireland and the programmes of measures, due in 2009, have been published under the various regulations (Box 4).

1 Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy, in short, the **EU Water Framework Directive**
2 S.I. 722 of 2003. European Communities (Water Policy) Regulations 2003

The regulations give legal status to the criteria and standards to be used in classifying surface waters and groundwaters. Basic measures include controls on groundwater abstraction and controls on artificial recharge. Point source discharges and diffuse sources liable to cause pollution are regulated and direct discharge of pollutants into groundwater is prohibited subject to a range of provisions outlined in Art 11 of the WFD.

4.2 Surface Water Regulations (S.I. No. 272 of 2009)[3]

The purpose of the Surface Water Regulations is to give legal status to the criteria and standards to be used for classifying surface waters in accordance with the ecological objectives outlined in the Water Framework Directive. Waters classified as either high or good status must not be allowed to deteriorate and those classified as less than good must be restored. The Surface Water Regulation introduce environmental quality standards that allow authorities authorising discharges to surface waters (e.g. EPA, local authorities) to determine the allowable concentrations in discharge without causing damage to aquatic communities.

The full purpose and scope of the Regulations includes:

- The obligation to protect and restore waters,
- The requirement to prevent and reduce pollution of waters by dangerous substances,
- The need to establish environmental quality standards,
- The need to establish environmental quality ratios representing the class boundaries for the biological elements,
- Rules for the presentation and reporting of surface water monitoring results and the classification of waters,
- Programmes to achieve objectives.

Plate 6 Detention Basin. Typical storm water attenuation system used on many National Road Projects.

Regulation 7 of the Surface Water Regulations requires that point and diffuse discharges liable to cause water pollution are prohibited except where subject to a system of prior authorisation or a system of registration based on general

3 S.I. No 272 of 2009 - European Communities Environmental Objectives (Surface Waters) Regulations 2009

binding rules. A public authority that authorises discharge to waters must lay down emission limits that meet two requirements.

1. The emission limits should establish the maximum concentrations and the maximum quantity of a substance permitted and should aim to meet the environmental objectives and quality standards set out in Schedule 5 and 6 of the Regulations, and

2. Discharges should be controlled according to the combined approach whereby emission limits are established by the stricter of the requirements based on the quality standards in Schedule 5 and 6. Where appropriate, the application of limits can be based on

    a. Emission controls based on best available technique or

    b. Relevant emission limit values or

    c. In the case of diffuse impacts, controls including, as appropriate, best environmental practice.

Regulation 46 deals with mixing zones at the point of discharge. Pollutant levels will normally be higher at the point of discharge than the ambient concentrations. This Regulation allows for the use of mixing zones when carrying out an assessment for compliance with environmental quality standards provided this does not affect compliance with the rest of the water body. Mixing zones must be restricted to the proximity to the point of discharge and defined in the authorisation process. The delineation of mixing zones is undertaken in accordance with technical procedures referred to in Article 21 (2) of the WFD.

4.3 Protected Areas and the Water Framework Directive

In relation to protected areas Article 4 (1) (c) of the Water Framework Directive states that Member States are required to achieve compliance with the objectives and standards specified in the Community legislation under which individual protected areas have been developed. This is in addition to achieving compliance with the criteria related to achieving good status under the Surface Water Regulations. Protected areas include the following:

- Areas designated for the abstraction of water intended for human consumption,
- Areas designated for the protection of economically significant aquatic species, e.g. areas covered under the Shellfish Waters Directive or the Freshwater Fish Directive,
- Bodies of water designated under the Bathing Waters Directive,
- Nutrient sensitive areas including areas designated as Sensitive Areas under the Urban Waste Water Treatment Directive,
- Areas designated for the protection of habitats and species under the Habitats Directive where the maintenance or improvement of the status of water is an important factor in their protection.
    - Each SAC in Ireland will have a site synopsis outlining the important ecological features of the site and the environmental objectives which are related to maintaining the conservation status of the site.

Schedules 5 and 6 of the Surface Water Regulations specify the environmental quality standards for several substances. The standards are given either as Annual Averages (AA), Maximum Allowable Concentrations (MAC) or both. The more relevant parameters are given below Table 4.

Substance	AA-EQS Inland Surface waters	AA - EQS Other surface waters	MAC Inland Surface waters	MAC Other Surface waters
Cadmium and its compounds - Depending on water hardness	Class 1 <0.08 Class 2 0.08 Class 3 0.09 Class 4 0.15 Class 5 0.25	0.2	Class 1 < 0.45 Class 2 0.45 Class 3 0.6 Class 4 0.9 Class 5 1.5	Class 1 < 0.45 Class 2 0.45 Class 3 0.6 Class 4 0.9 Class 5 1.5
Zinc	8, 50, 100	40		
Copper	5, 30	5		
Lead and its compounds	7.2	7.2		
Benzo(a) pyrene	0.05	0.05	0.1	0.1
Benzo(b)(k)fluoranthene	0.03	0.03		

Table 4 Surface Water Environmental Quality Standards (EQS) and Maximum Allowable Concentration (MAC). Units in μg/l.

Notes on Table 4

In the case of Copper the value 5 applies where the water hardness measured in mg/l $CaCO_3$ is less than or equal to 100; the value 30 applies where the water hardness exceeds 100 mg/l $CaCO_3$.

In the case of Zinc, the standard shall be 8 μg /l for water hardness with annual average values less than or equal to 10 mg/l $CaCO_3$, 50 μg /l for water hardness greater than 10 mg/l $CaCO_3$ and less than or equal to 100 mg/l $CaCO_3$ and 100 μg /l elsewhere.

For the group of substances polyaromatic hydrocarbons (PAH) each individual EQS is applicable, i.e. the EQS for Benzo(a) pyrene, the EQS for the sum of Benzo(b)fluoranthene and Benzo(k)fluoranthene and the EQS for the sum of Benzo(g,h,i)perylene and Indeno(1,2,3-ncd) pyrene must be met.

Plate 7 Limestone Pavement – An example of a Priority Habitat.

4.4 Groundwater Regulations SI No. 9 of 2010[4]

The Groundwater Directive 2006/118/EC was developed as part of the requirements of Article 4(1)(b) of the WFD. This Directive was transposed into Irish law primarily through the European Communities Environmental Objectives (Groundwater) Regulations 2010 [SI No. 9 of 2010]. These came into operation in January 2010.

The 2010 Regulations set clear environmental objectives with groundwater quality standards and threshold values for the classification of groundwater and protection against pollution. The main objectives of the Regulations are:

- Public authorities must prevent or limit the inputs of pollutants into groundwater,
- Groundwater bodies must be protected, enhanced and restored to ensure a balance between abstraction and recharge,
- A reversal of any significant upward trend in pollutant concentrations resulting from human activity,
- Standards for groundwater dependant ecosystems must be achieved by 2015.

Groundwater body classification is based on objectives defined in Annexes I – III of the Groundwater Directive. These are:

1. No saline or other intrusions,
2. Achieving the objectives of the WFD for dependant surface waters including no deterioration in status,
3. No damage to any wetlands that depend on groundwater,
4. No impact on drinking water protected areas,
5. No significant impairment of human use of groundwater.

There are five chemical and four quantitative tests applied by the EPA to groundwater bodies. These are summarized in the following tables.

Plate 8 Lined conveyance channel linking carrier drain from motorway to a wetland. Channel is lined to protect an underlying karst aquifer of regional importance.

4 SI No 9 of 2010 - European Communities Environmental Objectives (Groundwater) Regulations 2010

4.4.1 Chemical Tests

Test	Trigger for applying test	Criteria for poor status
Saline Intrusion.	Failure of a threshold value indicative of a risk of saline intrusion or other intrusion.	Upward trend in conductivity. Upward trend in concentrations indication of saline intrusion or other.
Adverse impacts of the chemical inputs from groundwater on surface water.	Failure of a groundwater threshold value that impacts on a surface water. Surface water is not at good status because of groundwater inputs.	A standard is not met in associated surface water. Input via groundwater is greater than 50% of the surface water standard of the surface water body.
Adverse impact on groundwater dependant ecosystem	Significant damage to a wetland from groundwater pollution.	Pollution from groundwater reaching wetland
Untreated groundwater satisfies drinking water protected areas requirements.	Failure of a threshold value with a risk to human health. Failure of the drinking water protected area objective of the water body.	Threshold chemical value exceeded. Upward trend in chemical concentration.
General quality of groundwater and its ability to support human use impaired.	Failure of threshold value with potential risk to general quality.	Chemical threshold value exceeded.

Table 5 Qualitative Tests for groundwater

The groundwater regulations have also set threshold values for groundwater for a range of parameters. The parameters with most relevance to road runoff are listed in Table 7.

4.4.2 Quantitative Tests

Test	Trigger for applying test	Criteria for poor status
Saline intrusions.	Failure of a threshold value indicative of a risk of saline intrusion or other intrusion.	Upward trend in conductivity. Upward trend in concentrations indication of saline intrusion or other.
Adverse impacts of the chemical inputs from groundwater on surface water.	Failure of a groundwater threshold value that impacts on a surface water. Surface water is not at good status because of groundwater inputs.	A standard is not met in associated surface water. Input via groundwater is greater than 50% of the surface water standard of the surface water body.
Adverse impact on groundwater dependant ecosystem.	Significant damage to a wetland due to availability of insufficient groundwater	Evidence of significant damage to wetland due to human activities.
Water Balance.	All groundwater bodies where there is abstraction.	Annual average volume of water abstracted from groundwater represents more than 80% of recharge. Annual average volume of water abstracted from groundwater represents more than 20% of recharge in bedrock aquifers with evidence of a drop in water levels. GWDTE is damaged and the annual average volume abstracted represents more than 5% of the long term annual volume with evidence of a drop in groundwater levels.

Table 6 Quantitative tests for groundwater

Chemical	Threshold Value(µg/l)
Cadmium	3.75
Nickel	15
Lead	18.75
Copper	1500
Total PAH	0.075

Table 7 Selected threshold values for groundwater.

4.5 Freshwater Pearl Mussel Regulations (S.I. No. 296 of 2009)[5].

Although freshwater pearl mussel is widespread in Ireland, particularly in the South West, West, North West, only one of the 96 known populations is in favourable status (reproduction and juvenile survival does not match adult mortality). 27 of these populations are designated within 19 Special Areas of Conservation (SAC). 27 sub-basin management plans have been produced, acting alongside the wider River Basin Management Plans. These plans provide a programme of measures required to improve the habitat of the freshwater pearl mussel. Freshwater pearl mussel habitat is restricted to near natural, clean flowing waters.

The Regulations:

- Set out environmental quality objectives for freshwater pearl mussel habitat,
- Require the production of sub-basin plans with programmes of measures to achieve the quality objectives, and
- Set out the responsibilities of public authorities in respect to implementing the sub-basin plans and associated measures.

The sub-basin plans must include:

a) Specific objectives and targets in accordance with Regulation 2 and the Third and Forth Schedules and deadlines for their achievement,

b) The investigation of sources of pressure leading to the unfavourable conservation status of the pearl mussel,

c) The establishment of a programme, including a timeframe, for the reduction of pressures giving rise to unfavourable status,

d) A detailed programme of monitoring to be implemented within the sub-basin to evaluate effectiveness of measures.

4.5.1 Programme of Measures

A full national list of measures is given in a Department of Environment; Heritage and Local Government publication entitled Freshwater Pearl Mussel, Appropriate Assessment for Natura 2000 sites (DOEHLG 2010). Some aspects of the more relevant measures are presented in Table 8.

5 SI 296 of 2009 THE EUROPEAN COMMUNITIES ENVIRONMENTAL OBJECTIVES (FRESHWATER PEARL MUSSEL) REGULATIONS 2009.

Measure	Discussion
All plans, programmes and projects with the potential to impact on the pearl mussel population, or any other Natura 2000 sites and their qualifying features, must be screened for Appropriate Assessment in accordance with Article 6 of the Habitats Directive and where judged necessary an Appropriate Assessment must be conducted.	Required to maintain integrity of the sites.
All planned future roads or bridges of any size shall be assessed for potential negative impacts on mussel populations during construction and operation. Future roads and bridges of any size should be subject to morphological controls.	Assessment of impacts not complete
Remediate hydromorphological damage caused by temporary or permanent roads and bridges, where such work has been judged necessary and through Appropriate Assessment and/or EIA, unlikely to significantly impact on the environment	Not assessed
Remediate hardcore or surfacing that includes substantial limestone content, where such work has been judged necessary and through Appropriate Assessment and/or EIA, unlikely to significantly impact on the environment	Benefit is reduced loading of suspended solids and nutrients to assist protection of key environmental conditions to support site integrity.

Table 8 Freshwater Pearl Mussel, Programme of measures

4.6 Habitats Directive

The Habitats Directive (Council Directive 92/43/EEC), is transposed into national law by various measures including the European Communities (Birds and Natural Habitats) Regulations[6], 2011., and the Planning and Development (Amendment) Act, 2010. The Directive requires Member States to designate sites based on species and habitats that are listed in a series of annexes. These sites then become Natura 2000 sites once agreed. Member States are then required to take measures to maintain or restore these sites to a favourable conservation status based on the habitats and species they are supporting.

In situations where a European site needs to be considered then additional investigations may need to be undertaken to assess the likely impacts. The procedures involved in complying with the Directive are covered under Article 6(3) and 6(4) of the Habitats Directive. These procedures are described in detail in *Appropriate Assessment of Plans and Projects in Ireland Guidance for Planning Authorities* Department of Environment, Heritage and Local Government, 2009. The NRA has also published information on Article 6 (3) and 6(4) and how to the procedures relate specifically to road schemes in *Guidelines for Assessment of Ecological Impacts of National Road Schemes, NRA Revised 2009.* Many of the European sites are dependent on both surface water and/or groundwater. Maintaining surface water supply and groundwater levels is often an important conservation objective and will often form part of the management plans for the site.

The first stage of the Appropriate Assessment process is referred to as "*Screening*". This involves a thorough review of all existing and planned developments that might act in combination with the proposed road development to produce a likelihood of significant impact on the European sites. This phase is essentially a risk assessment and should deal with the following issues.

6 European Communities (Birds and Natural Habitats) Regulations., 2001 (S.I. No. 477 of 2011)

- Is there a potential impact related to surface water flow or groundwater flow (including abstraction) that might be connected to the conservation objectives of the site directly or indirectly?
- Are the conservation objectives of the site sensitive to these impacts?
- Is the impact likely to undermine any of the conservation objectives?
- What is the significance of the likely impact?
- Likely impacts on such ecosystems could include:
- Changes in groundwater levels in groundwater dependent ecosystems
- Changes in wetland water levels and flooding regime
- Changes in river morphology due to alteration of flow regime
- Modifications of groundwater divide
- Alterations to surface water catchment area due to paving
- Changes in surface water and groundwater chemistry
- Loss of habitat (including Annex I and priority and non-priority habitat)
- Reduction in the dilution capacity of surface water and groundwater due to abstraction or loss of baseflow.

Further discussion is contained in: "*Hydrological impact appraisal for dewatering abstraction,.*" EA. Science report – SC040020/SR1.

Guidance of quantifying the impacts of abstractions in Ireland is presented in: "*GUIDANCE ON THE ASSESSMENT OF THE IMPACT OF GROUNDWATER ABSTRACTIONS",* Paper by the Working Group on Groundwater. Guidance document no. GW5. 2004.

If it cannot be demonstrated that there is no likelihood of significant effects then appropriate assessment should be carried out. Appropriate assessment is dealt with under Article 6(3) of the Habitats Directive and in the case of proposed road development, Regulation 30 of the Habitats Regulations, 1997.

The objective of the Appropriate Assessment is to establish that the development will or will not adversely affect the integrity of the Natura 2000 site. This will involve an understanding of the water balance for the site and the development of a conceptual model. The impacts associated with alterations in the surface and groundwater regime will often be inextricably linked to impacts on the ecology of the site. The degree of site investigation will depend on the individual sites but details of groundwater levels, permeability tests and occasionally groundwater modelling may be necessary.

It should be noted that it is generally An Bord Pleanála who carry out the appropriate assessment, not the project developers. However, the developer should provide the information necessary to enable the board complete the appropriate assessment. The competent authority (normally An Bord Pleanala) will then make a determination on the appropriate assessment based on the information supplied.

Plate 9 Filter Drain on low embankment. Newly constructed combined filter drain.

4.7 Dangerous Substances Directive 2006/11/EC

This Directive seeks to ensure effective protection of the aquatic environment of the Community. Two lists of substances are established in the Directive. List I contains substances that are considered harmful based on their toxicity, persistence and ability to bioaccumulate. Pollution through the discharge of these of substances must be eliminated. List II contains substances that are considered to have a deleterious effect on the aquatic environment but can be confined to a given area depending on the sensitivity of the receiving waters. There is a requirement to reduce water pollution caused by List II substances and Member States are required to set environmental quality standards for the substances concerned.

4.7.1 List I

List I contains:

1. organohalogen compounds and substances which may form such compounds in the aquatic environment;
2. organophosphorus compounds;
3. organotin compounds;
4. substances which have been proved to possess carcinogenic properties in or via the aquatic environment;
5. mercury and its compounds;
6. cadmium and its compounds;
7. persistent mineral oils and hydrocarbons of petroleum origin;

   and for the purposes of implementing Articles 3, 7, 8 and 12:

8. persistent synthetic substances which may float, remain in suspension or sink and which may interfere with any

use of the waters.

4.7.2 List II

List II contains:

— substances belonging to the families and groups of substances in List I for which the emission limit values laid down by the Directives referred to in Annex IX to Directive 2000/60/EC have not been determined by those Directives,

— certain individual substances and categories of substances belonging to the families and groups of substances listed in annex I (see Table 9), and which have a deleterious effect on the aquatic environment, which can, however, be confined to a given area and which depends on the characteristics and location of the water into which such substances are discharged.

The following metalloids and metals and their compounds:

zinc	selenium	tin	vanadium
copper	arsenic	barium	cobalt
nickel	antimony	beryllium	thalium
chromium	molybdenum	boron	tellurium
lead	titanium	uranium	Silver

Table 9Partial list of List II metals

The complete list of List II substances is given in the 2006/11/EC Directive.

4.8 European Communities (Drinking Water Regulations) 2007

European Communities (Drinking Water) (No.2) Regulations 2007 came into force in 2007 (S.I. No. 278 of 2007). Under these regulations the Environmental Protection Agency (EPA), is the supervisory authority for public water supplies. These Regulations provide the EPA with powers of direction to direct a local authority to improve the management or quality of a public water supply while the local authorities have a similar supervisory role in relation to group water schemes and private supplies. The Regulations prescribe standards for 48 individual microbiological, chemical and indicator parameters. Details on monitoring and compliance with these regulations are contained in *Guidelines on Procedures for the Assessment and Treatment of Geology, Hydrology and Hydrogeology for National Road Schemes. 2008.*

4.9 Implications for Road Drainage Design.

In Scotland major roads require a discharge licence which is required if there is considered to be a high risk of contamination, while in England major roads do not require consent and the responsibility is on highway authorities to determine pollution control. This is done in consultation with Environmental Agency and threshold limits are now imposed using the HAWRAT procedure.

In Ireland road discharge is not regulated and does not require a discharge licence to either discharge to surface water or groundwater. Consultation does take place with local authorities, IFI, OPW and the NPWS in relation to road drainage design and discharge. Although there are no requirements under the new Surface Water and Groundwater Regulations to seek discharge consent there is a requirement to comply with the various environmental quality objectives listed in the legislation.

The most current surface and groundwater legislation sets threshold values for groundwater and environmental quality standards for surface waters. The values are shown in Table 10 and compared with measured values in road runoff from the UK and Ireland.

4.9.1 Groundwater

4.9.1.1 Metals

The groundwater threshold values for copper are very high compared with those measured in road runoff. Lead values show a large range but median values are on average lower than the groundwater threshold values. Some lead values measured in the Irish study are higher than groundwater threshold values. The cadmium median values measured in the UK study are low in road runoff. Some higher values were measured in the Irish study.

In Ireland the biggest threat to groundwater from metals contained in road runoff, in relation to groundwater threshold values, is lead and to a lesser extent cadmium.

4.9.1.2 PAHs

The prescribed threshold values for individual PAHs pyrene and total PAH are very low compared with typical values found in road runoff. In relation to groundwater the biggest threat is related to PAH concentration rather than metal values based on the Groundwater Regulations.

4.9.2 Surface Water

4.9.2.1 Metals

The annual average environmental quality standards vary depending on water hardness. The standards are lower than the groundwater thresholds. The metal values are all broadly higher in road runoff compared with the surface water standards. The maximum allowable concentrations set for Cadmium is 0.45 µg/l. The range measured in Ireland was up to 8 µg/l.

4.9.2.2 PAHs

Surface water standards are higher for PAHs than groundwater thresholds and are set for pyrene and fluoroanthene. Again the typical values for runoff are higher than the set standards.

In light of the differing standards and thresholds for surface and groundwater there may be a requirement to adopt different strategies for the treatment of runoff depending on whether the intended receptor is surface water of groundwater especially in relation to PAH values. As the Surface Water and Groundwater Regulations currently apply, the onus is on designers of road drainage systems to ensure compliance with these standards and/or thresholds. In order to do so the concentrations of pollutants in road runoff for the particular road scheme must be established. The most effective way of establishing these concentrations is to use the Highways Agency Water Risk Assessment Tool. This tool is available on the Highways Agency website. The nature of the receiving environment will dictate the types of treatment systems that are then required to meet the objectives of the Regulations.

Parameter	Median	Range	GW Thresholds	SW Regulations Annual Averages	SW Regulations MAC
Cu	43	19 - 95	1500	5 or 30	
Cu Dis	23				
Zn	140	81 - 426		8, 50, 100	
Zn dis	58				
Cd	0.29	nd - 8	3.75	0.08	0.45
Lead	9.5	27 - 92	18.75	7.2	
Fluoroanthene	0.3			0.03	
Pyrene	0.31		0.00075	0.05	0.01
PAH	3.33		0.075		
TSS mg/l	139	43 - 437			
Phosphorous		60 - 188	35		

Table 10 Threshold values and environmental quality standards for groundwaters and surface waters compared with measured concentrations in road runoff. Units µg/l except where stated.

Regulation 8 of the Groundwater Regulations deals with permitted discharges and below is a section from the Regulations.

The following discharges may be permitted subject to a requirement for prior authorisation provided such discharges, and the conditions imposed, do not compromise the achievement of the environmental objectives established for the body of groundwater into which the discharge is made;

(v) discharges resulting from construction, civil engineering and building works and similar activities on, or in the ground which come into contact with groundwater. Such activities may be treated as having been authorised provided that they are conducted in accordance with general binding rules which are applicable to such activities,

Regulation 18 deals with categories of exempted pollutant inputs and below is a section from this regulation.

14. The Agency may, where it considers it appropriate or necessary, establish detailed technical rules under which the following categories of pollutant inputs may be exempted from the provisions of this Part:

(a) inputs that are the result of direct discharges authorised in accordance with Regulation 8;

(b) inputs considered to be of a quantity and concentration so small as to obviate any present or future danger of deterioration in the quality of the receiving groundwater;

* Agency means Environmental Protection Agency.

Under Regulation 8 permission from the EPA is also required to discharge from civil engineering works.

Regulation 7 of the Surface Water Regulations also requires authorisation of point and/or diffuse discharge if they are likely to cause pollution of surface waters. It is important, therefore, for the developer to demonstrate compliance with the various legislative requirements as currently authorisation is not required. It must be demonstrated that road runoff is not likely to cause a pollution threat by adopting pollution control mitigation measures that are effective in ensuring compliance with surface water and groundwater quality requirements.

One mechanism of demonstrating compliance is to adopt the same approach as the Highways Agency and impose threshold limits on runoff concentrations. This will require agreement with the Environmental Protection Agency on threshold values for pollutant levels.

4.10 Conclusions

In order to meet the terms of the Surface and Groundwater Regulations it is likely that road runoff from national road projects will have to be treated to reduce its pollutant concentration. The type of treatment will depend on the sensitivity of the receiving environment. Authorisation for discharge to both surface waters and groundwaters is not required but consultation with the local authority is necessary.

Most of this review section has focussed on the water quality aspect of road runoff. There are several other impacts related to water quantity such as flooding, stream morphology and impacts on groundwater dependent ecosystems. Such impacts can also have a profound effect on ecology particularly in fresh water pearl mussel streams where morphology plays a key role. These impacts are associated with permitted discharge rates, attenuation volumes and dewatering and will be dealt with in later chapters.

5 Section 2 Part 1 - Current Drainage Design Practices in Ireland and Risk assessment Procedure

5.1 Introduction

The purpose of this section is to give a more detailed account of the current approach to drainage design on Irish national road projects and define the key areas to be addressed in the guideline document based on current practice. The information was gathered through a number of site visits to national road projects that were under construction or completed and through several meetings and workshops with various consultants, engineering inspectors, NRA Employer's Representatives and design engineers.

5.2 Planning Process

The phases for the project management of National Road Schemes (http://nra.ie/Publications/ProjectManagement/) are presented in Table 11. On completion of the route corridor selection process, a preferred route is chosen and a design for this route is developed. Phases 3 and 4 generally take place in tandem as a design cannot be completed without knowledge of the site investigation carried out as part of the EIS and the required mitigation measures identified during this process. The drainage aspect of the design is developed taking into account the likely significant impacts identified during the site investigation and various EIS surveys. The surveys and procedures required to identify the hydrology and hydrologeology related impacts are outlined in the National Roads Authority document '*Guidelines on Procedures for Assessment and Treatment of Geology, Hydrology and Hydrogeology for National Road Schemes*' ((NRA 2008)). The results of these surveys are then used to decide on the components of the drainage design based on the required mitigation measures.

The level of detail in phase 3 in relation to the drainage design can vary significantly depending on the location of the scheme. If the scheme is located in a particularly sensitive location then the design will identify all the components of the drainage system, discharge points, attenuation ponds, nature of the conveyance system, etc in some detail. This level of drainage detail is developed because the drainage from the road scheme is considered to be a significant threat to the receiving environment. In other situations, where the receiving environment is not as sensitive to development, a conceptual design is presented as part of the EIS with very little information on the nature of the drainage components and often with a very general commitment to adopt SUDS principles.

Once consent for the road scheme has been granted and the contract has been awarded, the contractor then takes on the task of redesigning the drainage (Phase 6) based on a new assessment of the route but taking account of the required mitigation measures. In most instances this process results in significant changes to the planned drainage design irrespective of the level of detail in the EIS and phase 3 design. Some of the reasons for these changes are both related to costs (contractor will often tend towards a more cost effective design than that outlined in phase 3) and the fact that additional more detailed site investigation is carried out during this construction phase. It is evident that in most cases the required level of information for a detailed drainage system is only established during the construction phase.

PHASE 1	Scheme Concept and Feasibility Study
PHASE 2	Route Selection
PHASE 3	Design
PHASE 4	EIA/EIR and The Statutory Processes
PHASE 5	Advance Works and Construction Documents. Preparation Tender and Award
PHASE 7	Construction and Implementation
PHASE 8	Handover Review and Closeout

Table 11 7 Phases of NRA Project Management

This process has the potential to lead to a number of discrepancies between the commitments outlined in the EIS and the objectives achieved by the final design. In many cases pond sizes and locations are altered, discharge points are changed and alternative conveyance systems are adopted.

5.3 Consultation Process

After consent has been granted the contractor presents the detailed drainage design elements to the various government bodies and statutory consultees. The most prominent government bodies involved in this process are the IFI and OPW. Generally Inland Fisheries Ireland will comment on issues related to water quality especially in protected rivers and streams. Often there is a requirement to alter the drainage design to accommodate requests from fisheries to construct features such as wetlands or bigger attenuation ponds with longer residence times. OPW will generally comment on issues related to flooding and culvert sizing. Consent from the Commissioners of Public Works for construction works to bridges and similar structures must be secured. This consent process is referred to as Section 50 of the Arterial Drainage Act, 1945 (See also NRA, Guidelines for the Crossing of Watercourses During the Construction of National Road Schemes 2005). Section 50 is now secured during phase 4.

Section 50 of the Arterial Drainage Act, 1945 requires that:

> *No local authority, no railway company, canal company or other similar body, and no industrial concern shall construct any new bridge or alter, reconstruct, or restore any existing bridge over any watercourse without the consent of the Commissioners or otherwise than in accordance with plans previously approved of by the Commissioners.*

The OPW is the main agency responsible for the implementation of the regulations in the Arterial Drainage Act, 1945, including Section 50.

The main issue with this consult and comply process is that it takes place after the land take has been completed and often there is little scope to make significant alterations to the drainage design if these alterations require additional land take e.g. a wetland. This consultation process would be better conducted during phase 3 and 4 and having establish the requirements of these government bodies, incorporate these required elements into the drainage design. If, however, there were significant alterations required during construction as a result of additional survey information, these amendments would have to be reviewed again through the consultation process.

5.4 Drainage Systems

The various options for drainage designs for national road projects are outlined in the National Roads Authority Design Manual for Roads and Bridges (NRA, DMRB 2009) and associated documents (NRA MCDRW Vol 4 2007) (NRA MCDRW Vol 1 2007). Standard HD 33/06 – Surface and Sub-surface Drainage Systems for Highways (DMRB HA 103/06 Vol. 4 2006) – is applicable in Ireland with some minor amendments. The main types of drainage design components used on national road projects include:

- Combined Filter (French) Drain,
- Kerbs and Gullies,
- Combined Surface Water Channel and Pipe Systems,
- Over-the-edge Drainage,
- Fin or Narrow Filter (NF) Drains,
- SUDS systems, Grassed Channels, Swales.

The choice of drainage design is dependent on a number of factors such as:

- urban or rural setting
- cutting or on embankment
- vulnerability of underlying aquifer

In some situations, such as an urban setting there is little choice but to adopt a sealed kerb and gully system. There may also be a requirement to use a sealed system such as kerb and gully in rural situations where the underlying aquifer is considered to be highly vulnerable. For other options the main factors are related to whether the road is in cutting or on embankment. Series 500 in Volume 4 of the NRA's Manual of Contract Documents for Road Works gives road construction details for road edge drainage design. Drawings RCD/500/25 to RCD/500/29 give details of the five relevant standards (Table 12). The procedure for deciding the drainage design is shown in Figure 3.

Option	RCD	Comment
1	Figure 4 RCD/500/25	Kerb and gully system is required and road is in cutting.
2	Figure 5 RCD/500/26	Road is on a high embankment > 6m.
3	Figure 6 RCD/500/27	Road is in cutting and there is no specific requirement for a sealed system.
4	Figure 7 RCD/500/28	Road is in cutting or in a low embankment < 1.5m.
5	Figure 8 RCD/500/29	Road is on an embankment 1.5 to 6m and there is no specific requirement for a sealed system

Table 12 Drainage Design Options for national road projects

It is important to note that groundwater problems in this drawing refer to drainage of the sub base of the road and not groundwater vulnerability.

5.4.1 Alternatives

There are options for the use of SUDS systems in the drainage design such as swales, grassed channels and wetlands.

These are appearing more frequently on national road projects on a site specific basis. SUDS systems are generally considered in areas where the receiving environment is particularly sensitive and additional treatment of road runoff is considered more appropriate.

Other conditions relate to the nature of the underlying aquifer. Where the underlying aquifer is considered to be high or extremely vulnerable a sealed system is adopted. A sealed system may be:

a) Raised kerbs and gullies,

b) Combined kerb and drainage blocks,

c) Linear concrete drainage channels, and

d) Lined Swales.

Regional scale aquifer vulnerability maps are available on the Geology Survey of Ireland (GSI) Website. These maps are then used to decide on the nature of the drainage design.

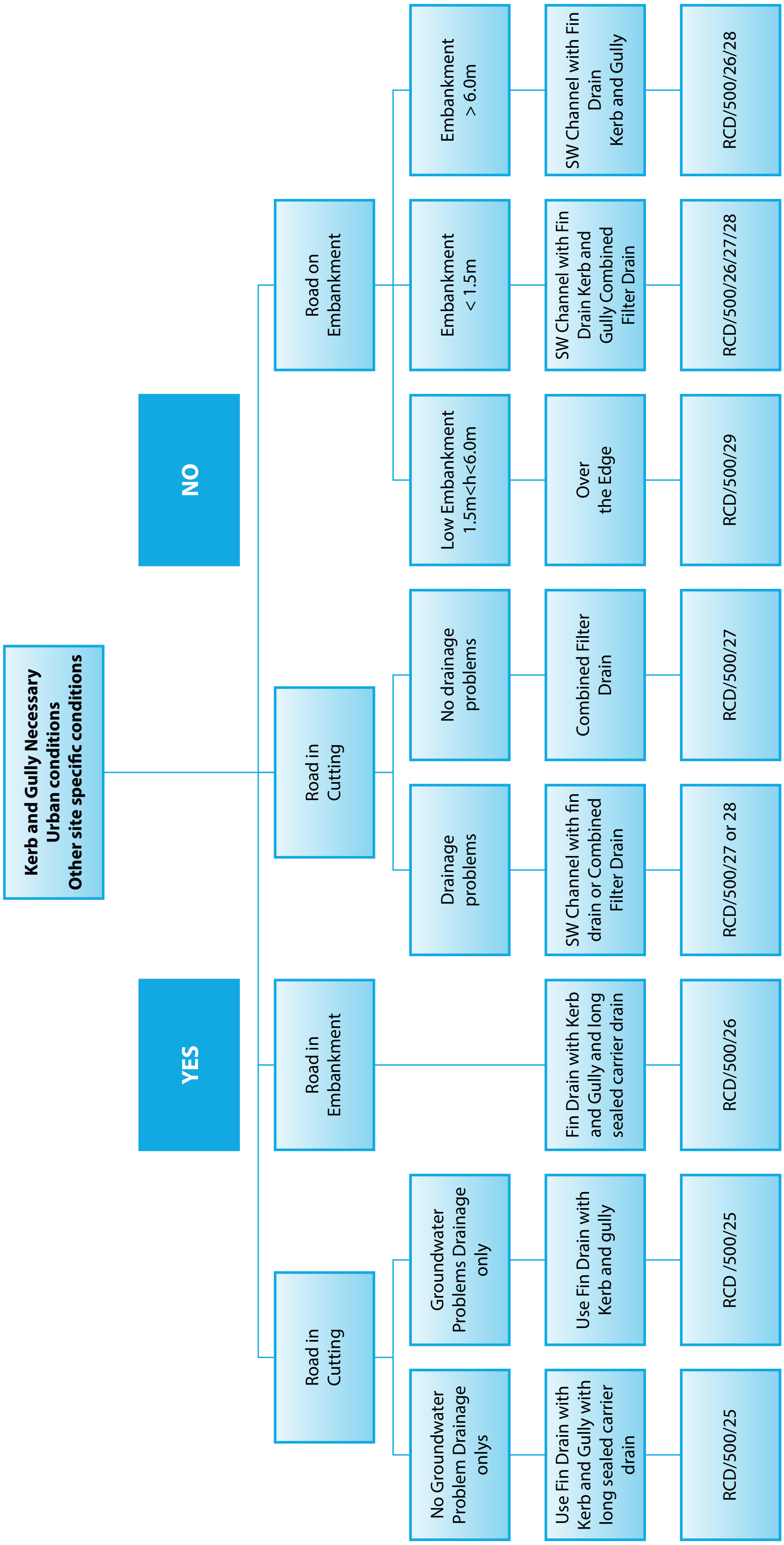


Figure 3 Drainage Design Options and Standards as specified in NRA standards

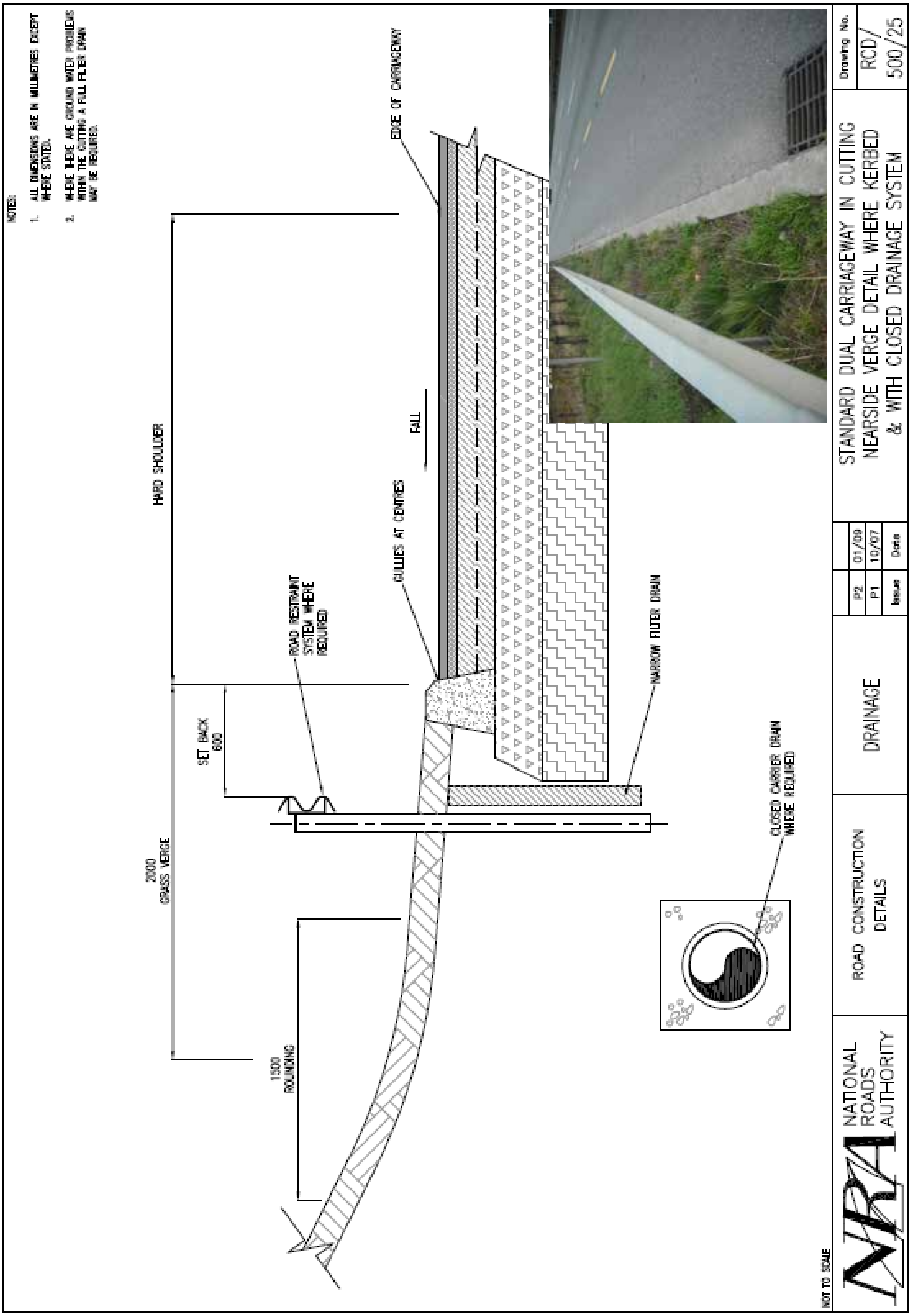


Figure 4 RCD/500/25. Kerb and gully system is required and road is in cutting. The drainage system consists of a fin drain for draining the sub grade and a kerb and gully system for collecting the road runoff.

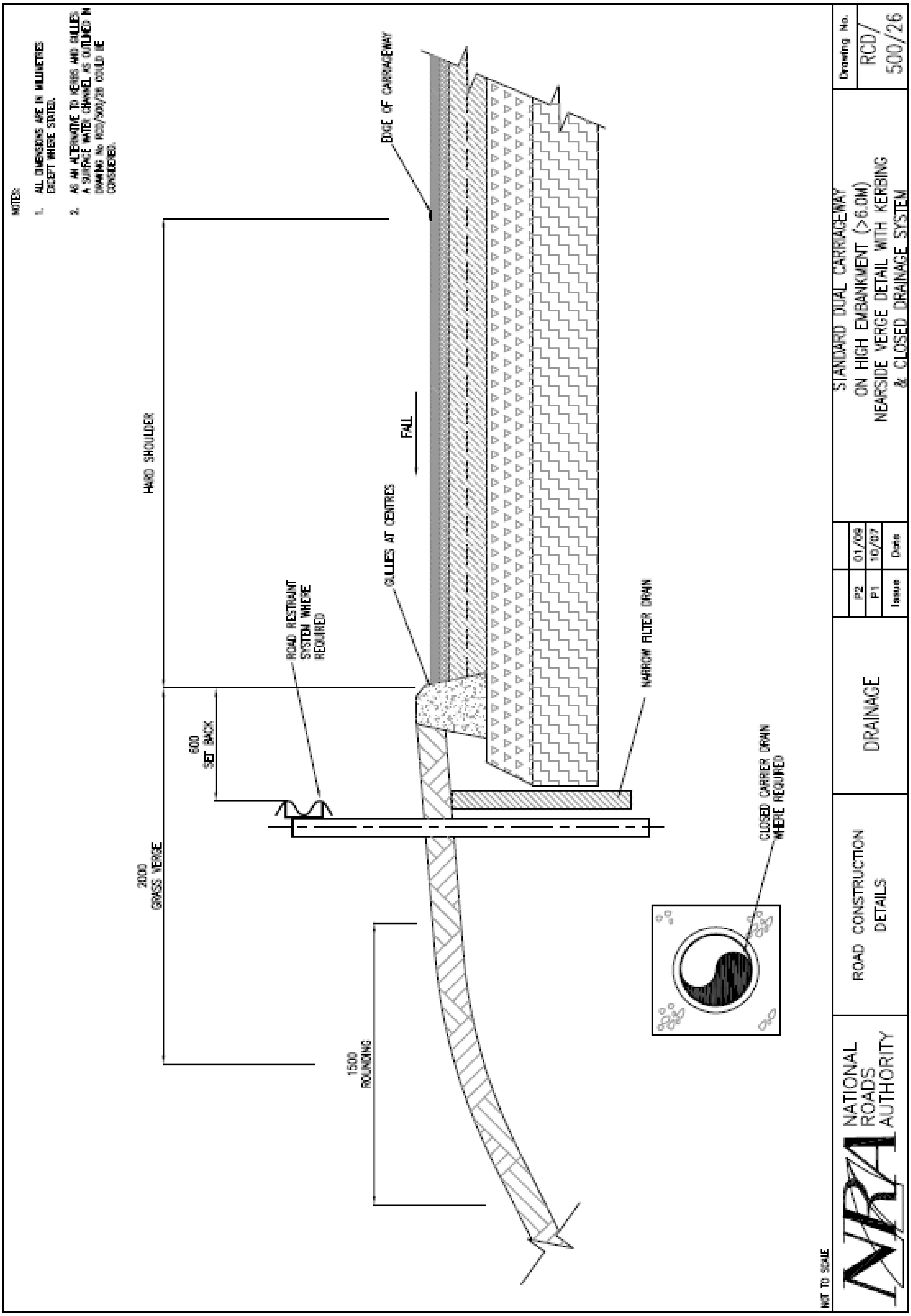


Figure 5 RCD/500/26. Road is on a high embankment > 6m. The design is the same as above with a fin drain and a kerb and gully system.

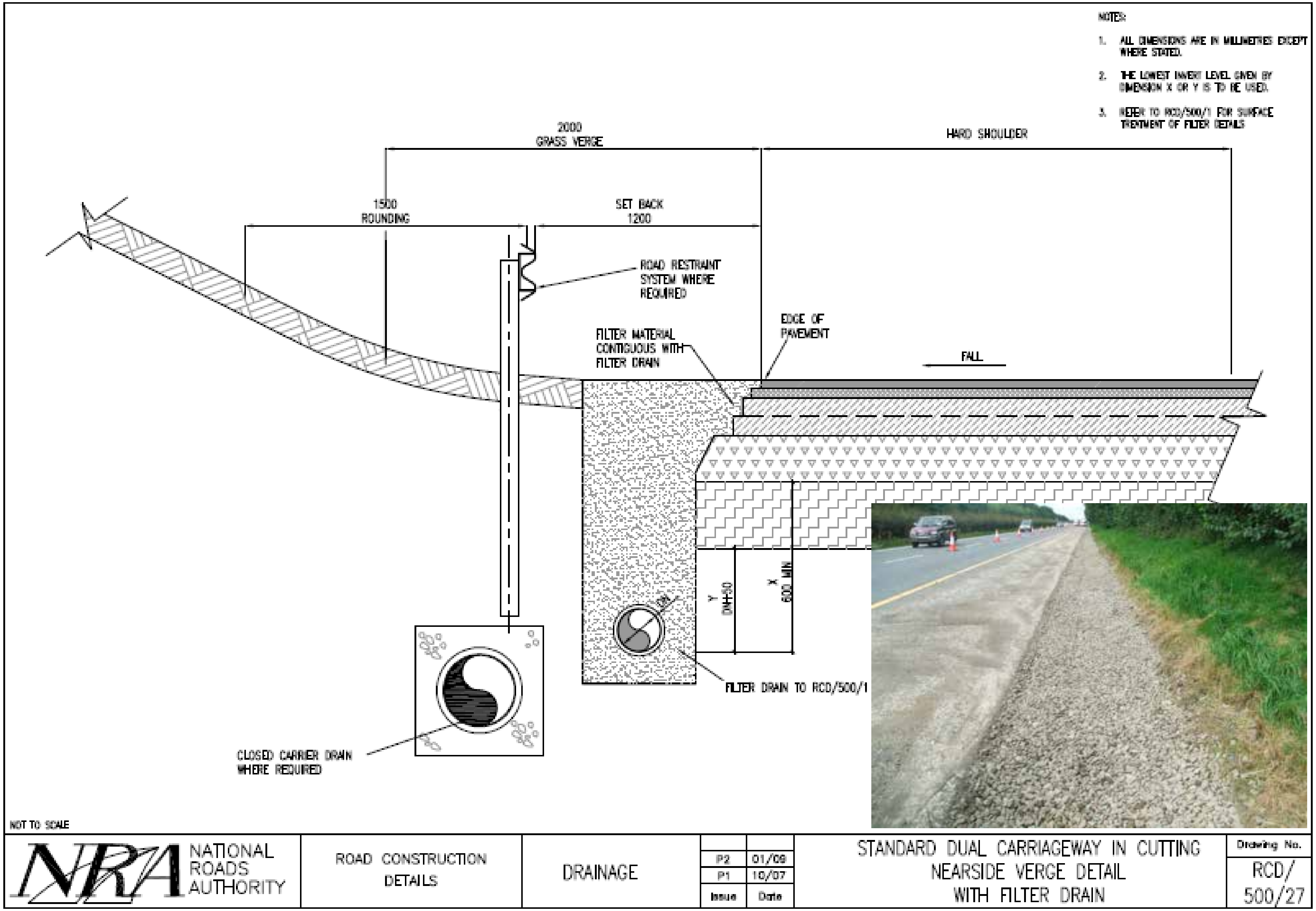


Figure 6 RCD/500/27. Road is in cutting and there is no specific requirement for a sealed system. In this case a French (Combined Filter) drain may be used draining both the sub grade and the road surface. Both waters are mixed and conveyed in a carrier pipe.

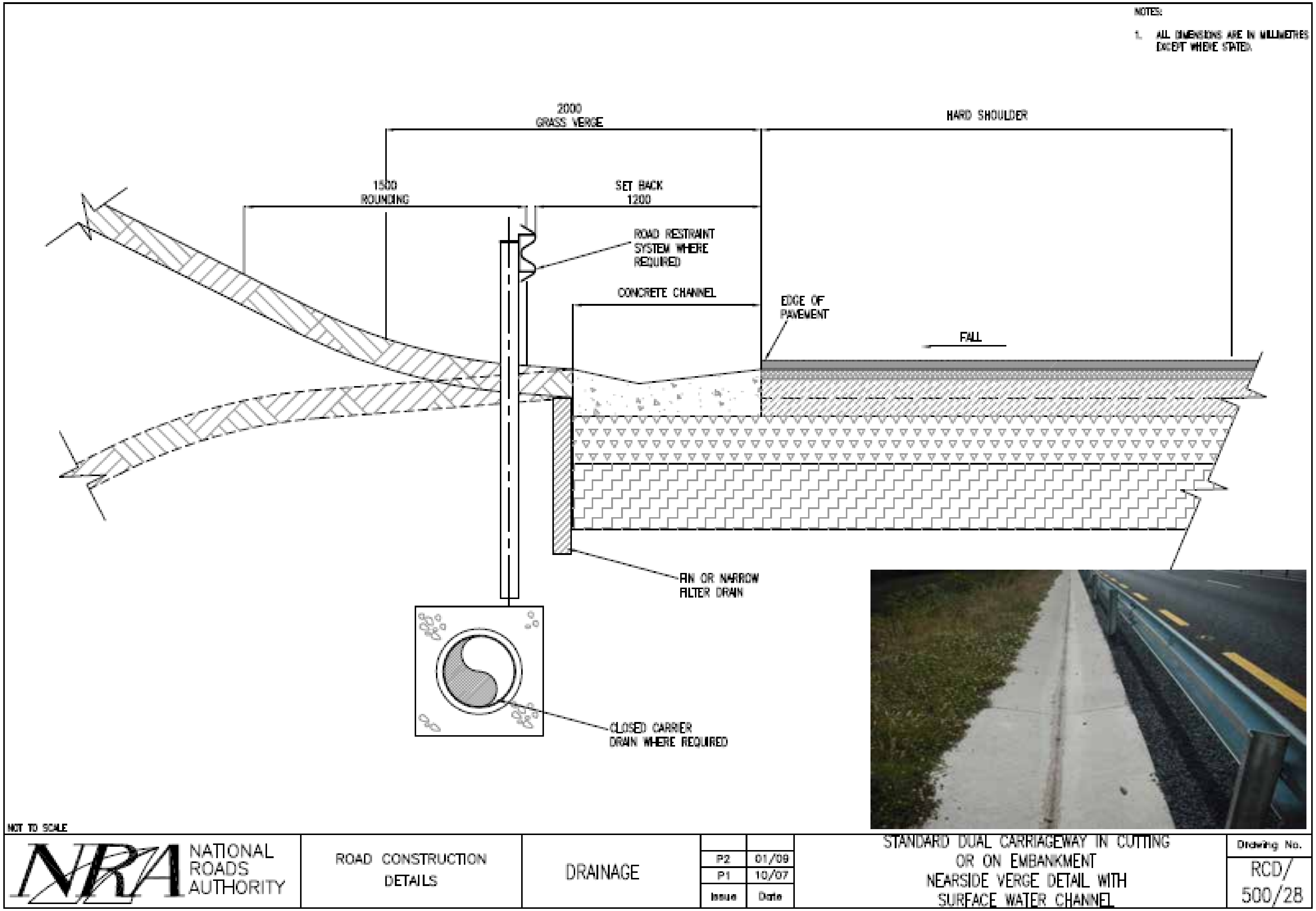


Figure 7 RCD/500/28. Road is in cutting or in a low embankment < 1.5m. In this situation there is a combined system of fin drains and surface water concrete channels.

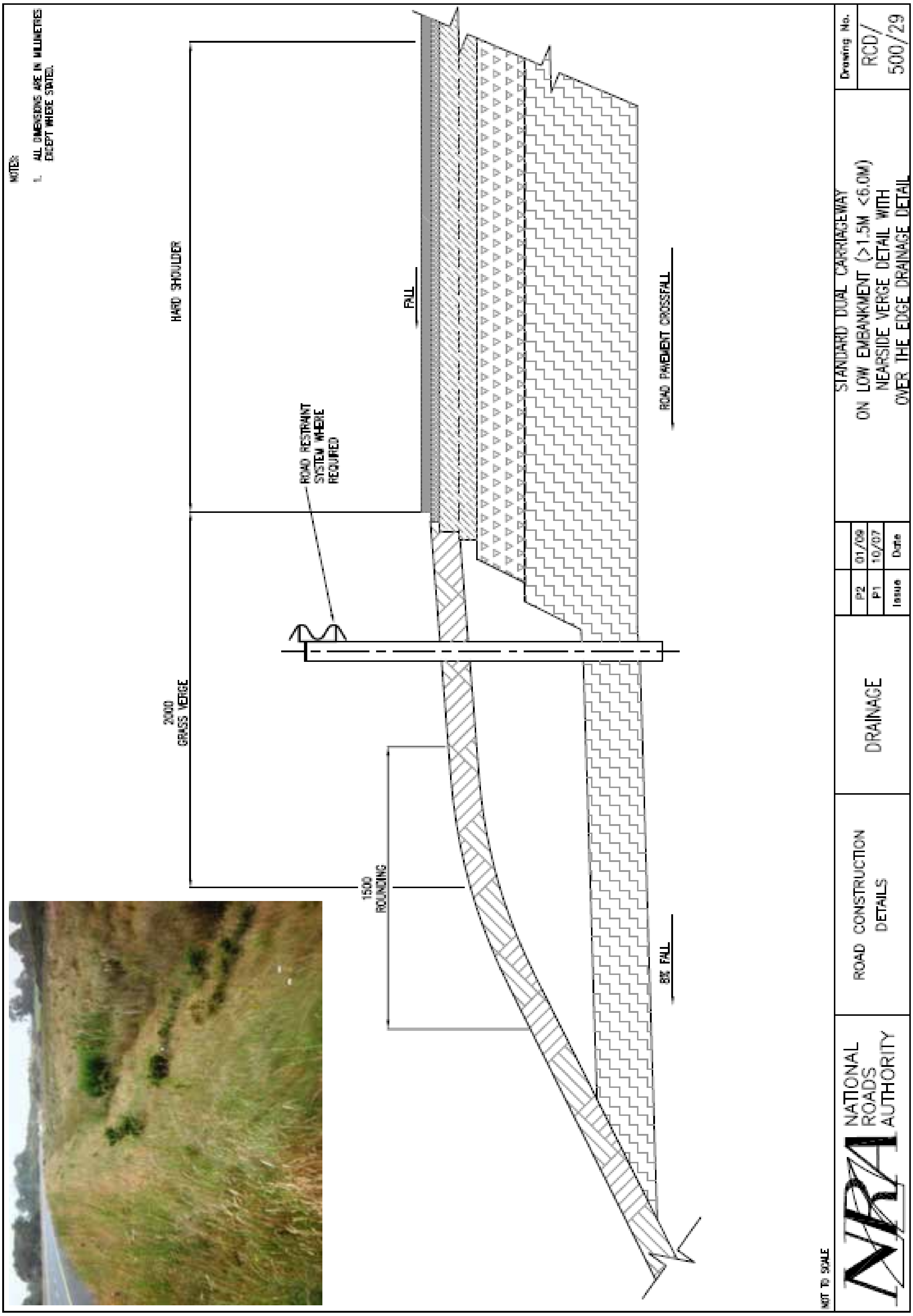


Figure 8 RCD/500/29. Road is on an embankment 1.5 to 6m and there is no specific requirement for a sealed system. In this case over the edge draining is permitted.

5.4.2 Discussion

The current procedure for choosing a drainage system is very much reliant on the standards specified by the NRA and most contractors find it easiest to follow this process rather than invest time in alternatives such as grassed channels, swales or wetlands. These systems will only appear if there is a specific request from inland fisheries or national parks and wildlife. The main reason for not developing more SUDS systems relates to the fact that contractors are not sure in what hydrological setting such systems should be used and how they should be designed. At present there is no clear guidance for contractors on where these systems should be used and it is simpler to follow the standards.

Plate 10 Linear wetland constructed adjacent to motoway. Runoff enters the linear wetland as sheet flow across a grass filter strip resulting in primary and secondary treatment prior to discharge.

5.5 Aquifer Vulnerability and Classification

5.5.1 Introduction

One of the most important elements of drainage design is an assessment of the vulnerability of the underlying aquifer. This assessment forms the basis for the decision process on the types of drainage systems used on national road projects. If the aquifer vulnerability maps (Geological Survey of Ireland 2010) show a high or extreme vulnerability then a sealed system is adopted.

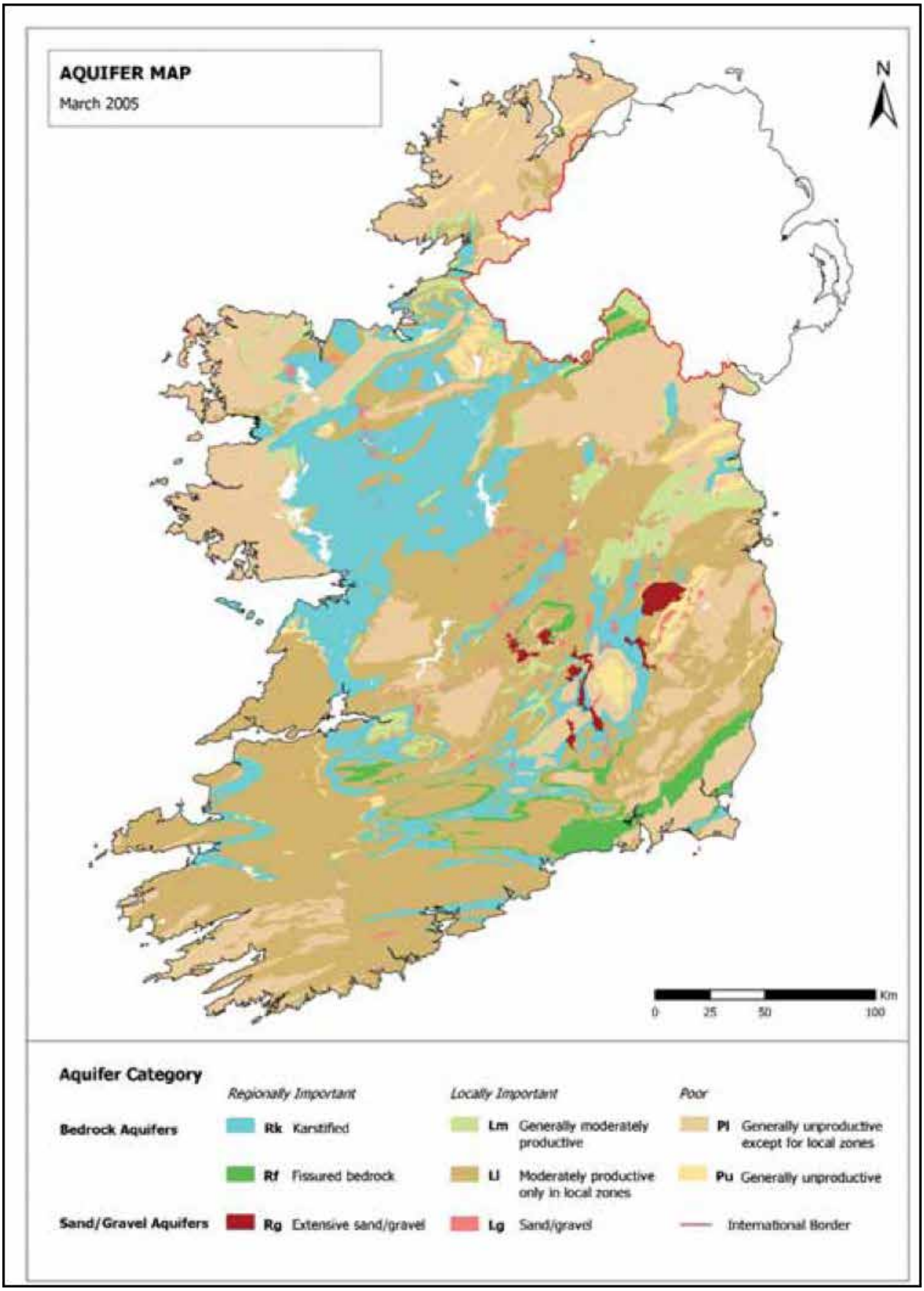


Figure 9 Aquifer Map of Ireland

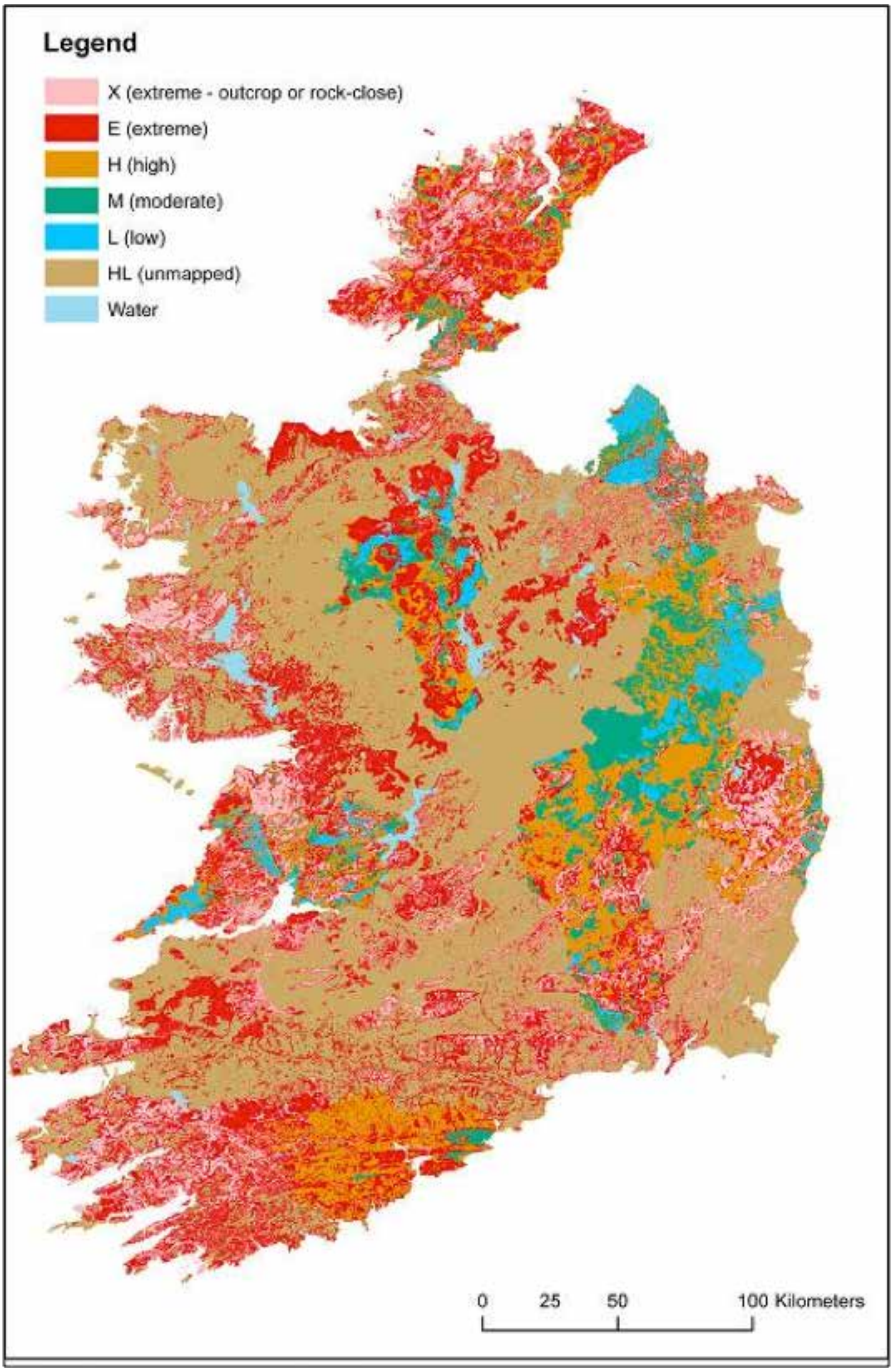


Figure 10 Aquifer Vulnerability Map of Ireland

The aquifer classification system is based on yield and areal extent (Box 5).

The regionally important aquifers consist of: • Karstified Aquifers with conduit flow • Fractured bedrock • Extensive sands and gravels
These have well yields of >400m^3/d and areal extent > 25km^2.
The locally important aquifers consist of: • Sands and gravels with lower yields • Fractured bedrock with well yields 100 – 400m^3/d
Areal extent is > 25km^2.
The poor producers consist of: • Fractured bedrock with low yields
Areal extent is not relevant.

Box 5 Aquifer Classification systems in Ireland

Where the bedrock forms the aquifer the vulnerability rating is simply based on the thickness and permeability of the subsoil (Misstear 2000) and it is this assessment process that influences the type of drainage design. The aquifer vulnerability map for Ireland is shown in Figure 10. As this vulnerability element plays such an important role in the drainage design then it is important to assess how and why this classification system was developed and in particular how it is suited to assess the risk posed by road runoff.

5.5.2 *Aquifer vulnerability assessment*

The methodology for assigning a vulnerability classification is outlined Table 13.

Vulnerability Rating	**Hydrogeological Conditions**				
	Subsoil Type, Permeability and Thickness			Unsaturated Zone	Karst Features
	High Permeability	Moderate Permeability	Low Permeability	Sand and gravel aquifers	< 30m radius
Extreme	0 – 3.0m	0 – 3.0m	0 - 3.0m	0 - 3m	-
High	> 3m	3.0 – 10m	3.0 – 5.0m	> 3.0m	N/A
Moderate	N/A	> 10.0m	5.0 – 10.0m	N/A	N/A
Low	N/A	N/A	> 10.0m	N/A	N/A
Notes **Precise permeability values not given** **Release point of contaminants is 1-2m below ground surface.**					

Table 13 Vulnerability classification system

Areas of high or extreme vulnerability occur where:

- Extreme

   - Bedrock is outcropping,
   - Where there is less than 3.0 m of subsoil,

- High
   - Where there is 3 – 10m of moderate permeability subsoil,
   - Where there is 3 – 5 m of low permeability subsoil.

This system differs significantly from that used in the Britain and Northern Ireland. In Britain the topsoil is taken into account in the vulnerability assessment and is considered to be the main source of protection for the underlying aquifer. The subsoil in Britain is considered only a secondary feature whereas it forms the main feature in Ireland. The different approaches are related to the difference in the main source of pollutants. The main concern in Britain was diffuse pollution from agricultural fertilizers. In this case the leaching potential of the topsoil is the most important parameter. In Ireland the principal concern is related to point source pollution such as septic tanks where the pollutants are entering the ground from below the top soil. This explains the note in Table 13 where the release point of contaminants is taken to be 1 to 2 m below the groundwater table. It is important to point out that for sand and gravel aquifers there is a different assessment methodology that takes the unsaturated zone into account. If there is less than 3m of unsaturated material between the source of pollutants and the groundwater table then it falls into the extreme vulnerability category.

Another important aspect of the vulnerability classification is that it takes the nature of the recharge into account (that portion of the rainfall that recharges the groundwater aquifer). In karst areas the recharge tends to be indirect through discrete points such as swallow holes and sink holes rather than diffuse through the soil. In areas such as this the important aspect is the actual points of recharge and likely contamination through these recharge areas. An interim groundwater recharge map for Ireland is shown in

Figure 11. In areas of karst along the west coast the recharge is very high with up to 1400mm/yr going to recharge. In these areas the soil type is often a peat or low permeability till. The important aspect for the assessment of runoff and vulnerability in these areas is the karst nature rather than the permeability of the soils.

It is clear from the differing approaches that the nature of the pollution i.e. whether it is point source or diffuse and how it enters the environment i.e. is it above the top soil or below form a critical part of any vulnerability classification system. The nature of the recharge also plays an important role specifically in karst areas. The next section will examine the nature of road runoff pollution and assess how to adopt the vulnerability classification system used in Ireland for determining the risk to groundwater resources from road runoff. It is also important to note that the groundwater aquifers in Ireland are considered to be mainly in the bedrock aquifers and not simply the saturated zone in the soil.

5.5.3 Sealed Drainage Systems

The current approach requires a sealed drainage design in areas of high or extreme vulnerable aquifers. In many cases the adoption of a sealed system ignores the productive nature of the underlying aquifer i.e. whether it is a regionally important, locally important or a poor producer (Figure 9). The yield of the aquifer should play an important role in the design process. Important aquifers in Ireland are considered to be dominantly in the bedrock rather than the soil (Figure 9). There are a few exceptions with sands and gravel aquifers in the midlands.

A sealed drainage design results in a point source discharge from an attenuation basin. The runoff and its associated pollutants are gathered to one location and allowed to discharge to a stream or river or to groundwater through an infiltration system. In many karst areas the underlying aquifer has a high or extreme vulnerability rating resulting in the use of sealed drainage system. The design generally requires that the attenuation pond is also lined to prevent infiltration.

The problem with discharging to a stream in such a location is that the river or stream becomes part of the groundwater system by flowing through such features as sinkholes or estavelles. The river is therefore part of the groundwater system and the runoff is discharging directly to the groundwater body. In such terrains an alternative approach to drainage design should be considered. A preferred option would be to allow a more diffuse input into the groundwater body of treated runoff rather than a point source. This could be achieved through the use of vegetated systems such as grassed channels provided there is sufficient subsoil thickness above the aquifer to allow for adequate treatment of the infiltrating runoff. This is discussed further in the next chapter.

A similar argument can be made for the use of sealed drainage in areas other than karst. A preferred option would be to use a drainage design that allows a diffuse source of treated runoff rather than a point source.

5.5.4 Petrol Interceptors

Petrol interceptors are normally recommended at every discharge location on major road schemes. Their design is covered in the NRA DMRB.

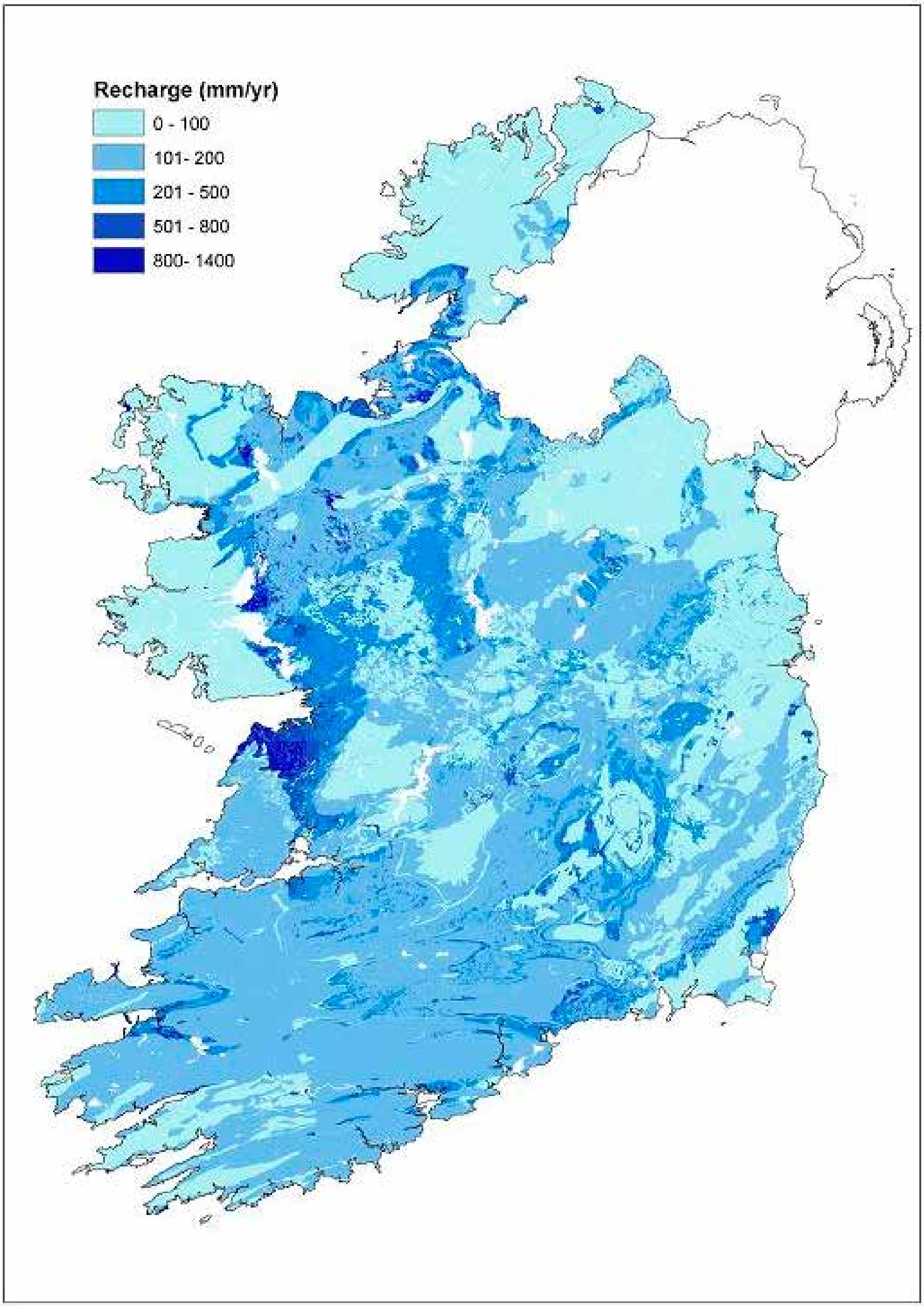


Figure 11 Interim Groundwater Recharge Map (GSI)

6 Section 2 Part 2 - Factors Influencing Transport of Contaminants from Road Runoff

The main factors that influence the transport of contaminants in relation to the pathways include:

1. Groundwater flow process i.e. translatory or preferential flow,
2. Water content and suction characteristics of the unsaturated zone,
3. Sorption characteristics and contaminant properties of heavy metals and PAHs,
4. Permeability and sub soil thickness,
5. Karst features (swallow holes, estevalles etc.).

6.1 Groundwater flow - Translatory versus Preferential Flow Processes

Preferential flow is of major concern to hydrogeologist assessing groundwater contamination. If contaminated water quickly infiltrates the soil medium and bypasses the soil matrix through preferential flow then it represents a major threat to both groundwater quality and also river water as baseflow will ultimately end up as river flow.

There are a number of definitions of preferential flow in the literature. Preferential flow may be ascribed to groundwater transport in pore spaces that exceed a certain diameter, but different authors use different threshold values. Preferential flow can be defined as that fraction of the groundwater that occurs decoupled from the soil matrix (non Darcian flow). In this case the flow is related to the chosen observed parameters and the scale of observation. Many investigations use tracers to distinguish between event water and pre event water. Event water is that portion of rainfall that reaches groundwater during a rainfall event. This portion is often described as preferential flow.

Translatory flow describes piston-flow displacement or pre-event water as a result of the increasing pressure of rain infiltration. If the effective porosity of the soil is low then the rate of the pressure wave associated with the infiltration can be similar to surface runoff giving a rapid hydrograph response.

Observed preferential flow may not just be attributed to the inherent properties of the soil matrix but are dependent on the scale of observation and the kinetics of equilibration of the parameters used for the tracer studies. Some parameters react very slowly with the soil matrix e.g. ^{2}H and ^{18}O isotopes and Si, whereas some ions are quickly exchanged with the soil matrix e.g. SO^{4}, Al.

A detailed study of groundwater flow in the Lehstenbach watershed in Germany (Lischeid 2002) concluded that the extent to which groundwater flow can be described as translatory or preferential was related to the scale of observation and the parameters used in the study. By measuring soil suction (tensiometers) and water content (Time domain reflectometry TDR probes) in the unsaturated zone the authors were able to demonstrate that movement of groundwater was a rapid progradation of a wetting front to the groundwater table by translatory flow. Parallel readings of water content and soil suction across the watershed indicate translatory rather than preferential flow. The saturated conductivity of the top soil exceeded the maximum rainfall intensity by two orders of magnitude so no overland flow was observed.

Another important conclusion was in relation to lag times between rainfall intensity and discharge peak. This was in the range of 2 to 5hrs in line with many other catchments (Lischeid 2002). This suggests that the speed of the vertical pressure wave in the transient saturated zone determines the rapid response in stream discharge.

Solute concentrations may be used as natural tracers depending on the kinetics of the interaction with the soil matrix and with the pre event groundwater pool. During heavy rainfall events solute concentrations in the groundwater recharge and discharge showed a shift towards pre-event concentrations rather than throughfall. This again suggests translatory flow rather than preferential flow.

Translatory flow reduces the risk of contamination of groundwaters.

6.2 Sorption Characteristics

The transport of contaminants in road runoff is primarily dependent on the permeability of the soil since advection (flow with groundwater or Darcian flow) is usually the principal mechanism of transport. As discussed earlier the presence of an unsaturated zone between the runoff and the water table (or between the base course and the groundwater table) is important as this zone has a strong sorptive capacity (defined as Kd, the partition coefficient) which can vary for the different metals (mainly Cu, Zn, Cd) found in road runoff. The permeability of this zone is very different from the saturated zone and this permeability can be assessed from the relationship between soil suction and water content. There are many factors that influence the sorptive capacity and partitioning coefficient including specific surface area, chemical composition of the soil particles, ionic nature of the contaminants, presence of dissolved organic matter, ion complexes (organic, inorganic) etc. The solubility and mobility of heavy metals are often controlled by complexation with dissolved organic matter (DOM). (Davis 1994) showed that a high level of DOM enhanced the solubility of Cr. (Jensen 1999) investigated the speciation of heavy metals in landfill leachates and showed that dissolved Cu, Cd and Pb were mainly associated with DOM whereas Ni and Zn were present in the form of carbonate complexes, organic complexes and free ions. Studies have revealed the presence of organic complexes in road runoff (Dijkstra 2004) (Wust 1994). In a further study (Murakami 2008) concluded that copper existed predominantly as organic complexes and carbonates while Mn, Zn and Cd were found to exist in the form of free ions and carbonate complexes. They also found that stable organic complexes of Cu in road dust were adsorbed by soakaway sediments even though there was limited adsorption of dissolved organic carbon (DOC). In the case of Mn, Zn and Cd there was desorption indicating that these ions represent the biggest threat to groundwater.

The impacts of runoff on groundwater was examined by conducting a two dimensional numerical simulation of groundwater contamination from road runoff (Dawson 2009). Contamination of the groundwater was again principally influenced by the sorption characteristics of the soils. For sands with low sorption water quality, standards were exceeded after two years in the model. For other soils contamination is very limited. The pattern of rainfall infiltration had little effect but the total volumes of infiltration did. The lateral drain carrying the water away from the pavement could act as a concentrating source of contaminants to the groundwater table. Sorption capacity was the biggest factor in contaminant spread. The partitioning coefficient Kd of cadmium is the lowest. The concentration relative to drinking water standards is the highest.

Plate 11 Box culvert with mammal ledge and flow control structures.

Sorption of heavy metals

The presence of an unsaturated zone between the base of the road drainage systems and the groundwater table can have a major role on the transport of contaminants. If this zone has high clay content then there is a strong capacity to adsorb metals protecting the underlying aquifer. If the underlying unsaturated zone is dominantly sands then there is a much lower sorption capacity. The transport of metals is further complicated by complexation with dissolved organic matter which can enhance the solubility of some of the metals.

Box 6 Sorption Process

6.3 Permeability and subsoil in Ireland

The main aquifers in Ireland are found in the Palaeozoic bedrocks (Carboniferous Limestones and Sandstones, Old Red Sandstones and the Ordovician Volcanics). The Irish groundwater protection scheme was initially developed by the Geological Survey of Ireland (GSI) and then by the GSI in conjunction with the Department of the Environment and Local Government (DoELG) and the EPA. The two main components of the scheme are land surface zoning and response matrix for polluting activities. Land surface zoning comprises:

1. Mapping the groundwater vulnerability,
2. Defining protection areas around major wells and springs,
3. Classifying the value of the groundwater resource.

The GSI have published a series of maps showing aquifer vulnerability, aquifer classification and protection zones. The vulnerability maps are developed as a response to the nature of the pollutants which, in Ireland, is considered to be mainly to be from septic tanks and farmyards. These are point sources. These maps are extremely useful and are generally included in the hydrogeology section of every EIS. The vulnerability classification system was discussed earlier.

Plate 12 Glacial Sub soils with a variety of permeabilities. The nature and thickness of the subsoil determines the vulnerable rating of the underlying aquifer. Glacial subsoils can have a large variety of permeabilities indicating the importance of local site investigation.

6.4 Karst Environments

Road projects crossing karst terrains are of primary concern in Ireland because of the impacts of stormwater runoff on water quality, flooding and also concerns of sinkhole collapse. In addition many designated wetland features such as turloughs are associated with these terrains and are protected under the Habitats Directive. This often leads to the requirement for extensive hydrogeological surveys in these areas.

Sinkholes are characteristic landforms of karst terrains in Ireland and direct stormwater runoff into karst aquifers. Sinkholes are sometimes used for the disposal of runoff from highways in some countries (Zhou 2005) and by farmers to drain lands. Soil sedimentation in sinkholes will reduce their capacity to transmit water resulting in flooding while the removal of soil can increase the contaminant risk to groundwater. An EIS for a road scheme in a karst terrain will have to address issues of land stability, flooding and groundwater quality. Groundwater is particularly vulnerable in karst terrains where soil cover is thin or non-existent. Sinkholes often occur in clusters.

As groundwater flow, in karst terrains, can be highly variable, velocity and permeabilities can vary considerably within individual aquifers, there can be a large spatial and temporal variation in hydrochemistry. In order to assess the impacts of road runoff on an aquifer long term site specific monitoring of water quality during and after storm events is required.

Karst aquifers are normally classified as having diffuse or conduit flow. If the flow is purely diffuse then recharge can be completely mixed with the groundwater in the aquifer and the resulting spring will show little variation in hydrochemistry. If the flow is conduit then there may be large variations in chemistry as there is little mixing. The variance of the chemograph of a spring can be used to establish the degree of mixing provided the pathways are established. Other sources of contaminants, such as agriculture, are also likely and must be taken into account. By examining the recession constant in turloughs, (Tynan 2007) showed that there may be conduit flow; diffuse flow or a mixture of both to turlough systems in the West of Ireland. The recession constant is higher for conduit- fed turlough systems (turlough empties quicker). This is been used as a part of a classification system along with the ecology and in particular wetness indices.

The most effective pollution treatment systems in karst terrains include vegetative controls (swales, drainage ditches, grassed channels), infiltrations basins, wet detention basins and wetlands. These may be used individually or in combination.

Vegetated systems reduce runoff velocity, promote sedimentation, filter suspended solids and increase infiltration. If drainage ditches have a gradient of 3% or more they are generally lined with some form of geomembrane. If untreated in karst areas, the runoff accumulates and results in continuous percolation into the underlying aquifer. This can lead to sinkhole development. It is important not to allow runoff to accumulate (W. Zhou. 2005). Although vegetative controls may be used in karst areas, it is likely that some form of lining may also have to be used.

The use of infiltration systems will require a subsoil thickness of 3m or more below the bottom of the infiltration point and sufficient storage for the design runoff event (Zhou 2005).

Wetlands are considered to be the most effective runoff management systems. Wetlands differ from detention basins in that they are shallower, use vegetation as a pollutant removal mechanism and emphasise slow moving sheet flow across the wetland (Wanielista 1992).


Plate 13 Turloughs are seasonal Lakes with a unique mixed wetland flora – An example of a Priority Habitat.

6.5 Groundwater Monitoring on the N7

6.5.1 Introduction and objectives

This study was carried out as part of the TCD/NRA research project to investigate the risk of groundwater pollution from highway runoff. Groundwater sampling on the N7 at Rathcoole was conducted between November 2011 and February 2012, forming the basis of a BAI Thesis (Kennedy, 2012). Further groundwater sampling was conducted between May and September 2013. The following summary aims to:

- Synthesise the N7 monitoring results.
- Relate the monitoring results to recent research in this area.
- Recommend, if necessary, further groundwater monitoring at sites on the Irish national road network.

6.5.2 Groundwater Monitoring Sites

The N7 at Rathcoole was chosen for the groundwater monitoring due to its high traffic density, aquifer vulnerability classification (high/extreme), and the use of filter drains at the monitored locations. Furthermore, rehabilitation works on the existing filter drain in the area facilitated traffic management during the drilling operations. Single boreholes (RC1 and RC2) were installed at two locations and double boreholes were installed at one other location (RC3), one at 1.5 m depth (RC3A) and the other at 6m depth (RC3B). The boreholes were drilled at an offset of 2m from the filter drain in the case of RC1 and RC2, but RC3A and RC3B were drilled through the filter drain. In addition, a nearby wetland was sampled at the inlet basin, and in the treatment basin, as an indication of the road runoff quality from a filter drain system.

6.5.2.1 Ground conditions

Borehole locations and logs for each drilling location can be found in (Kennedy, 2012). The response zone (i.e., depth of piezometer tip) was generally between 4 m and 7.5 m. Apart from RC3A, a clay layer of at least 3 m was present in the unsaturated zone.

6.5.2.2 Contributing areas

The road areas contributing to the filter drain at each location were calculated from the as-built drawings. Contributing areas of 4100 m^2, 320 m^2 and 300m^2 were determined for boreholes RC1, RC2 and RC3, respectively. However, these values should be used as a guide only, since preferential flow paths on the road surface, and infiltration along the filter drain will impact on the runoff quantity flowing along or infiltrating, at any single point on the filter drain.

6.5.2.3 Traffic density

Traffic data for the site was obtained from the traffic counter in close proximity to Johnstown which is available on the National Roads Authority's website. Recent data, available from March 2013 to October 2013, indicate an average AADT of 74,371.

6.5.2.4 Sample collection and storage

Samples were obtained from the boreholes by means of a baler. Samples were preserved with 1% hydrochloric acid, stored in brown glass bottle to prevent UV degradation, and refrigerated prior to analysis, which was performed within 6 months of sample collection.

6.5.3 Sample analysis

6.5.3.1 Electrical conductivity

A calibrated electrical conductivity (EC) meter (WTW ProfiLine) was used for the determination of conductivity (in $\mu S\ cm^{-1}$ at 25 °C). EC was recorded on site immediately after sampling.

6.5.3.2 Heavy metals

Heavy metals analysis was performed in the TCD Environmental Engineering Laboratory. Concentrations of heavy metals (Copper, Chromium, Lead and Zinc) were determined in the dissolved phase by ICPAES, in accordance with Method 200.7 (USEPA, 1994).

6.5.3.3 PAHs

Sample analysis was conducted for the 16 U.S. EPA PAH constituents by Complete Laboratory Solutions (Galway). The laboratory is fully accredited to ISO and the Irish National Accreditation Board.

6.5.4 Results

6.5.4.1 PAHs

PAH concentrations are shown for the groundwater and wetland samples in Table 14. In boreholes RC1 and RC2, PAHs were detected in just 7% of the samples. Of the 7 PAHs identified, Fluorene, Fluoranthene and Phenanthrene were the most frequently detected. The most commonly detected PAHs in UK Highway runoff were Fluoranthene and Pyrene (WRc, 2008); and from Irish motorways: Fluoranthene, Naphthalene, Phenanthrene and Pyrene (Higgins, 2007). Therefore, it is likely that the PAHs detected in RC1 and RC2 were motorway-derived. Total PAH thresholds were exceeded in 2 out of 6 samples (RC1), and 1 out of 7 samples (RC2). Similar PAH levels were recorded at the wetland inlet basin.

PAH	Pyrene	Benzo(a)pyrene (SW)	Benzo(b)fluoranthene	Acenaphthylene	Benzo(k)fluoranthene	Indeno(1,2,3-cd)pyrene	Naphtalene	Acenaphthene	Fluorene	Phenanthrene	Anthracene	Fluoranthene	Benzo(a)anthracene	Chrysene	Dibenzo(a,h)anthracene	Benzo(g,h,i)perylene	Total PAHs
	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l
Detec Limit	0.05	0.01	0.01	0.05	0.01	0.01	0.05	0.05	0.01	0.05	0.01	0.01	0.01	0.01	0.01	0.01	
Threshold (1)																	0.075
Sample																	
RC1 16/11/11	nd	nd	nd	nd	nd	nd	nd	nd	0.03	nd	nd	0.03	nd	nd	nd	nd	0.06
RC1 21/12/11	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.00
RC1 25/01/12	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.00
RC1 13/02/12	nd	nd	nd	nd	nd	nd	nd	nd	0.01	0.06	0.02	0.04	nd	nd	nd	nd	**0.12**
RC1 07/06/13	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.00
RC1 24/09/13	nd	nd	nd	nd	nd	nd	nd	nd	0.02	0.05	nd	0.07	nd	nd	nd	nd	**0.14**
RC2 16/11/11	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.03	0.07	nd	nd	nd	**0.10**
RC2 21/12/11	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.00
RC2 25/01/12	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.05	0.05
RC2 13/02/12	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.05	nd	nd	nd	nd	0.05
RC2 24/05/13	nd	nd	0.01	nd	nd	nd	nd	nd	nd	nd	nd	0.02	nd	nd	nd	nd	0.03
RC2 07/06/13	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.00
RC2 24/09/13	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.00
RC3A 16/11/11	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.01	nd	nd	nd	nd	0.01
RC3A 21/12/11	0.36	0.10	nd	nd	0.07	0.03	nd	nd	0.02	0.22	0.02	0.38	0.06	0.10	0.18	0.05	**1.58**
RC3A 25/01/12	0.51	0.16	0.20	nd	0.11	0.11	nd	nd	0.07	0.32	0.04	0.62	0.16	0.20	nd	0.07	**2.57**
RC3A 13/02/12	0.06	0.01	nd	nd	nd	nd	nd	nd	0.02	nd	nd	0.04	nd	nd	nd	nd	**0.13**
RC3A 24/05/13	nd	nd	0.01	nd	nd	nd	nd	nd	nd	nd	nd	0.03	nd	0.02	0.02	0.05	**0.13**
RC3A 07/06/13	0.09	0.04	0.06	nd	nd	nd	nd	nd	nd	0.06	nd	0.08	0.04	0.02	0.07	0.06	**0.52**
RC3B 16/11/11	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.03	nd	nd	nd	nd	0.03
RC3B 21/12/11	0.19	0.03	0.04	nd	0.02	0.02	nd	nd	nd	0.07	nd	0.13	0.04	0.05	nd	0.01	**0.59**
RC3B 25/01/12	nd	0.01	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.05	0.01	0.02	nd	nd	**0.09**
RC3B 13/02/12	0.14	0.01	0.02	nd	0.02	nd	nd	nd	0.03	0.09	0.01	0.11	0.03	nd	nd	nd	**0.46**
RC3B 24/05/13	nd	nd	nd	nd	nd	nd	1.79	0.08	nd	nd	nd	0.03	0.01	0.01	0.02	0.03	**1.97**
RC3B 07/06/13	0.23	0.06	0.10	nd	0.05	0.11	1.76	nd	nd	0.16	nd	0.24	0.07	0.10	0.12	0.08	**3.08**
RC5 25/01/12	nd	0.01	0.02	nd	nd	nd	nd	nd	nd	nd	nd	0.03	0.02	nd	nd	nd	**0.08**
RC5 13/02/12	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.01	0.02	nd	nd	nd	nd	0.03
RC5 24/05/13	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	0.02	nd	nd	nd	nd	0.02
RC5 07/06/13	nd	nd	nd	nd	0.01	nd	0.05	0.14	nd	0.06	nd	0.08	0.01	0.03	0.04	0.15	**0.57**
RC6 25/01/12	nd	nd	nd	nd	nd	nd	0.06	0.05	0.04	nd	nd	nd	nd	nd	nd	nd	**0.15**

(1) Groundwater Regulations (2010); nd = not detectable

Table 14. PAH concentrations in groundwater and wetland

In contrast, concentrations of total PAHs exceeded threshold values by up to 40 times in RC3A and RC3B, and a broad range of PAHs were present. This indicates a non-road source, or possibly a preferential pathway for runoff to reach groundwater, since the boreholes were drilled on the filter drain. To investigate the latter scenario, the results for RC3A/B were compared to runoff concentrations measured on the N7 at the Kildare Town Bypass (Higgins, 2007). At this location, the road was drained by a pipe and gully system, so the runoff was not subject to any treatment prior to sampling. Two event mean concentrations (EMCs) of PAHs were reported for this site; these have been averaged, and compared to the mean PAH concentration of all RC3A and RC3B samples or each constituent (Figure 12). The chemical signatures of the runoff and groundwater samples are similar, which suggests that the PAHs observed in RC3A and RC3B originated on the motorway. The high concentrations relative to RC1 and RC2 could be due to the boreholes providing a preferential pathway, thus circumventing treatment in the unsaturated zone.

Naphthalene concentrations in RC3B were omitted from Figure 12. In two samples, high concentrations (1.76 and 1.79 µg/l) were observed in May and June 2013, the reason for which is unclear. However, Naphthalene, due to its lower molecular weight, may be more mobile than other PAHs (Scott Wilson, 2009).

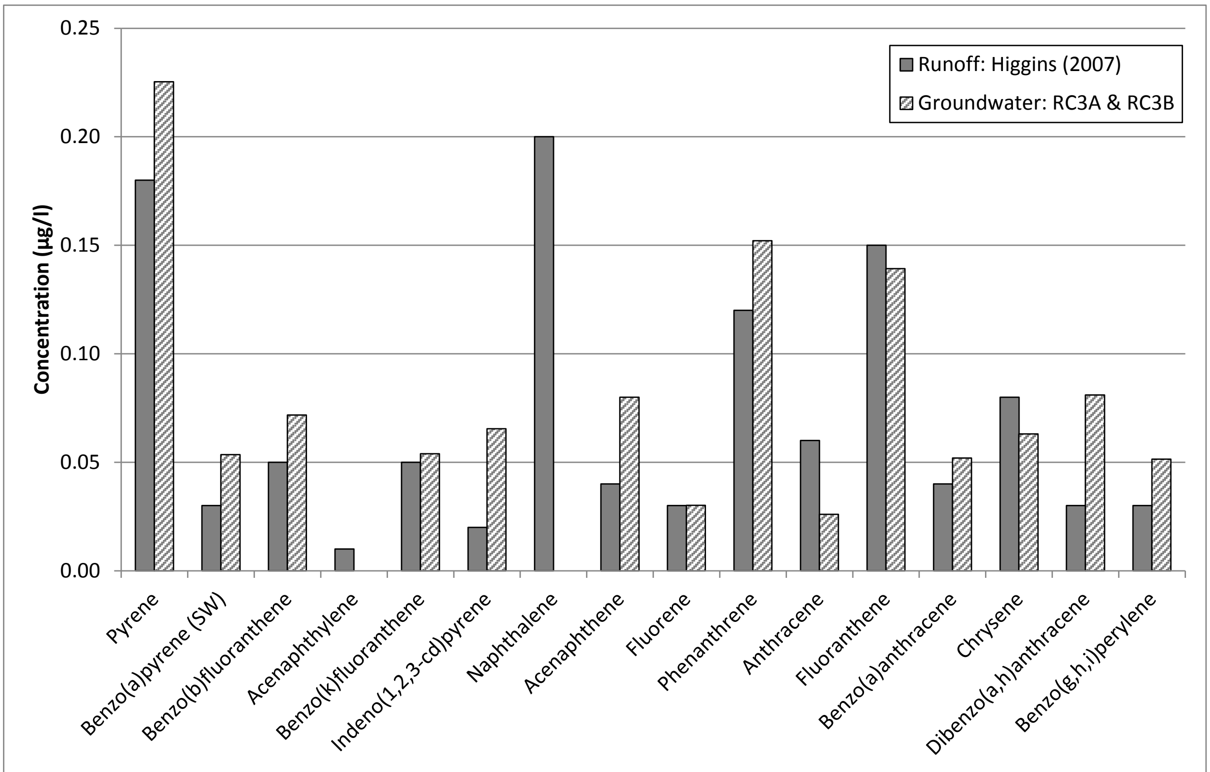


Figure 12. PAH concentrations in RC3A/B and runoff (Higgins, 2009)

6.5.4.2 Heavy Metals

Heavy metals were analysed in groundwater on four occasions: November and December 2011, January and February 2012. Heavy metals were above detection limits in all samples, but were particularly high in January and February, where RC1 and RC2 levels exceeded those of RC3A/B. This is contrary to the trend identified for the PAH concentrations, but may be explained by the presence of road salt. Sodium chloride has been linked with dissolution of heavy metals in the unsaturated zone. The presence of sodium chloride may have coincided with the elevated conductivity observed in RC3A (January and February), and in RC3B (February). Since flow through the unsaturated zone to RC1 and RC2 was slower than RC3A/B (previous section), it is reasonable to assume a higher attenuation of contaminants, and therefore a higher flux of contaminants on application of road salt. Threshold levels were exceeded for Chromium in 5 samples; Lead in 3 samples;

and Zinc in 2 samples, all occurring in January and February 2012.

Location	Date	Constituent	Conductivity	Cr	Cu	Pb	Zn
		Units	µS/s	mg/l	mg/l	mg/l	mg/l
		Detection Limit		*0.002*	*0.005*	*0.005*	*0.005*
		Threshold		*0.037*(1)	*1.5*(1)	*0.018*(1)	*0.8*(2)
RC1	16-Nov-11		709	nd	0.006	0.005	0.215
	21-Dec-11		-	0.009	0.007	nd	0.099
	25-Jan-12		640	**0.171**	0.010	0.005	0.413
	13-Feb-12		663	**0.062**	0.737	**0.040**	**0.848**
	07-Jun-13		-	-	-	-	-
	24-Sep-13		-	-	-	-	-
RC2	16-Nov-11		680	nd	0.007	0.005	0.208
	21-Dec-11		-	nd	0.006	0.005	0.202
	25-Jan-12		666	**0.121**	0.008	0.006	0.375
	13-Feb-12		663	**0.128**	0.033	0.008	**0.843**
	24-May-13		-	-	-	-	-
	07-Jun-13		-	-	-	-	-
	24-Sep-13		-	-	-	-	-
RC3A	16-Nov-11		692	nd	0.006	nd	0.149
	21-Dec-11		-	**0.286**	0.023	0.009	0.404
	25-Jan-12		1137	0.006	0.030	**0.024**	0.158
	13-Feb-12		1495	0.019	0.042	0.014	0.501
	24-May-13		-	-	-	-	-
	07-Jun-13		-	-	-	-	-
RC3B	16-Nov-11		568	-	0.008	0.005	0.158
	21-Dec-11		-	-	-	-	0.125
	25-Jan-12		616	-	0.070	0.006	0.116
	13-Feb-12		995	0.009	0.019	**0.028**	0.505
Wetland	25-Jan-12		-	nd	0.019	0.011	0.797
(inlet)	13-Feb-12		-	0.007	0.018	0.009	0.641
	24-May-13		-	-	-	-	-
	07-Jun-13		-	-	-	-	-
Wetland	25-Jan-12		-	nd	0.014	0.009	0.654
(basin)							
(1) Groundwater Regulations (2010); (2) Dutch Intervention Level (2010)							
nd = not detectable; - not analysed							

Table 15 Heavy metal concentrations in groundwater and wetland

6.5.5 Conclusions

Recent research has highlighted the importance of the unsaturated zone for the biodegradation of PAHs. However, heavy metals retained in the unsaturated zone may be released under certain conditions.

These findings were largely confirmed through monitoring of groundwater on the N7 highway. PAH levels were generally low, and where thresholds were exceeded, the borehole construction may have been responsible for the rapid transport of contaminants to the groundwater. The PAH chemical signature of the groundwater samples from these boreholes was very similar to road runoff sampled at a nearby location on the N7. Elevated heavy metal concentrations coincided with the road salting season and elevated conductivity in the groundwater samples.

6.5.6 Recommendations

The ability of the unsaturated zone to treat PAHs from road runoff needs to be established for a range of Irish soils. This could be achieved simply through analysis of PAHs in subsoils below or adjacent to filter drains, at a range of depths.

The attenuation of heavy metals in the unsaturated zone, and their interaction with road salt application warrants further attention. This should include characterisation of the runoff where necessary and span at least 12 months, with groundwater sampling occurring monthly, and more frequently in the winter season. Furthermore, boreholes should not be drilled directly on the filter drain to avoid providing a preferential pathway for contaminants.

6.6 Risk of Impact of Pollution to Groundwater from Routine Runoff – DMRB

HD 45/09 of the UK DMRB examines road drainage and the water environment. Incorporated into the guidance is a methodology for assessing the risk of road runoff to groundwater (Table 16). The scoring system is discussed later.The method takes the source and various pathways into account. The source considers 3 main parameters, traffic density, average annual rainfall and rainfall intensity. The pathway has several components including:

- Nature of the drainage system (soakaway geometry),
- The unsaturated zone,
- Nature of the flow in the aquifer,
- Grain size,
- Lithology.

The risk assessment takes a number of factors into account that are not included as part of the vulnerability classification system used in Ireland. The most important differences are:

The unsaturated zone is taken into consideration.

The nature of the drainage system plays a key role.

The importance of the unsaturated zone has been discussed in relation to sorption characteristics (Box 6).

Pathway	Parameter	Low Risk	Medium Risk	High Risk
	Soakaway Geometry	Continuous linear	Single point shallow	Single point deep
	Unsaturated Zone	Depth to water table > 15m	<15 > 5	< 5m
	Flow type	Non fractured	Consolidated mixed fracture and intergranular	Fracture dominant
	Effective grain size	Fine sand and below	Coarse sand	Very coarse and above
	Lithology	>15% clay minerals	<5 - >1% clay	< 1% clay
Source	Traffic	<15,000	15,000 - 50,000	>50,000
	Rainfall Volume	<740mm	740 - 1060mm	>1060mm
	Rainfall Intensity	<35mm FEH 1Hr	35-47	>47

Table 16 Matrix for the risk assessment of runoff on groundwater (HD 45/09)

The rainfall intensity is based on the 1 hour storm with a return period of 100 years. The relevance of the actual drainage system can often be overlooked when assessing the risk to the groundwater aquifer. A continuous linear soakaway that allows infiltration represents the least risk. This type of system would be represented by over the edge drainage or a combined filter drain (without a carrier pipe). These types of systems can only be used if there is adequate protection to the aquifer either through a thick unsaturated zone or the presence low permeability soils. However, there must be a balance with the permeability as a very low permeability will not allow infiltration.

A single deep point source represents the highest risk. These systems are represented by deep infiltration basins or attenuation basins with their base within or below the groundwater table. This is the most common form of drainage design on national road projects. In areas of high or extreme vulnerability the common approach is to use a sealed drainage system discharging to an attenuation pond. This type of situation is typical of karst terrains. The problem now lies with the discharge from the attenuation pond. In karst areas there is often a lack of surface streams as most of the flow is in underground conduit often feeding features such as Turloughs. Any surface streams will often only flow along the surface for a short distance before disappearing again underground. If these streams are used for discharge outlets then it is effectively the same as discharging to groundwater. A sealed system such as kerb and gully offers little treatment for road runoff and this type of approach, gathering runoff in an attenuation basin, is compounding the pollution impacts on groundwater. A different drainage design is required in this situation where the runoff is conveyed in systems that offer attenuation and treatment such as grassed channels, linear wetlands or swales. These devices will allow infiltration but only after treatment, through a soil base. If the road is on an embankment then it is likely that the base of these systems will be above the groundwater table and also have an unsaturated zone for additional treatment through the sorption processes.

6.6.1 Discussion

The vulnerability classification process used in Ireland (developed for point source pollution entering the soil 1-2m below surface) is a conceptual model and site investigation should be used, if available, to further develop this model. This conceptual approach has been applied for different human activities including septic tanks, land spreading of organic fertilizers, landfills and constructed wetlands. The vulnerability system is suited to assessing various individual elements of the drainage systems such as infiltration basins and attenuation basins where the source of pollution is now below the top soil and in many cases 4 to 5m into the subsoil. The vulnerability in this situation, however, must take into account the depth of the base of these systems and the thickness of subsoil between the base of the attenuation system and the bedrock. This can often result in going from moderate vulnerability to a high or extreme vulnerability classification.

Where infiltration systems are used and road runoff enters the environment above the top soil, the role of the unsaturated zone must be taken into account. Based on the DMRB risk assessment matrix, there is a higher risk if the depth to the water table is < 5m.

In summary there is a requirement to re-evaluate the vulnerability classification system and how it should be applied to road projects in Ireland. The current approach is resulting in the use of sealed systems in areas that would be better suited to the use of linear infiltration systems. In areas where the road scheme is at grade or on embankment the unsaturated zone can play a major role in the transport of contaminants and should be taken into consideration.

The Environmental Protection Agency (EPA) has published a document that outlines detailed technical assessments required to authorise discharge to groundwater – Guidance on the Authorisation of Discharges to Groundwater (2011) (EPA 2011). This document adopts the Source-Pathway-Receptor (SPR) model and develops a framework for the process that includes guidance on:

- Risk screening for potential impact to groundwater based on pollutant load;
- Levels of technical assessment for different types of discharge;
- Predicting impact, and
- Appropriate monitoring.

The approach outlined in this document should be considered for road drainage systems. The recent research undertaken by the NRA looking at the impact of road runoff on groundwater has clearly highlighted the importance of the unsaturated zone for the biodegradation of PAHs (see section 6.5). However, additional research is necessary in order to establish the ability of the unsaturated zone to treat PAHs from road runoff for a range of Irish soils. In addition the attenuation of heavy metals in the unsaturated zone, and their interaction with road salt application warrants further attention.

6.6.2 Groundwater Risk Assessment and Scoring Matrix.

The first phase of assessing the drainage options is based on the requirement for a sealed drainage (kerb and gully, concrete channels) as described in HD33/06 (Figure 3). In some situations a sealed drainage option is a requirement. The focus of the risk assessment will then relate to the location of the attenuation system (attenuation pond or wetland). This risk assessment should then follow the assessment outlined in Table 17 for the particular location of the pond.

The scoring procedure combines elements of the UK HD 45/09 with the GSI vulnerability and aquifer classification systems. An overall score is obtained by multiplying the risk score with the weighting factor as described in the DMRB. The risk score (1 to 3) is multiplied by the weighting factors (10, 15, 20, 25, 30) to give an overall score. For example if the traffic band is in the 50 – 100,000 range then the risk score is 2. The weighting factor is 15 so the overall score for the traffic volume is 30. The final overall score is the sum of each of the individual component scores. The methodology takes into account the nature and source of road runoff, the pathways and the receptors. Many of the parameters are readily available from various maps available online. However some parameters will require some site investigation.

The risk assessment procedure, as outlined in Table 17, will give an overall score of low, moderate or high risk which in turn forms the basis for deciding on the type of drainage design or mitigation measures. The scoring matrix, Table 15, should only be used for situations where the GSI aquifer mapping indicates a bedrock aquifer as the receptor. In situations where the GSI mapping indicates gravel or sand aquifers, the pathway is related to the nature of the unsaturated zone and Table 18 should be used. In these situations the groundwater aquifer will usually require protection either through a sealed drainage design or lined vegetated systems. In some situations, where the groundwater table is sufficiently below the invert of the drainage components (a function of permeability and depth), it may be possible to protect the aquifer through the use of SUDS systems.

6.6.2.1 Source

The source parameters are the same as those adopted in the DMRB guidance, namely traffic volumes and rainfall. The traffic volumes are the annual average daily counts (AADT) and should be those for the design year of the proposed road scheme. The rainfall has two components and the highest score should be used for the overall assessment. SAAR (seasonal annual average rainfall) relates to the average annual rainfall in Ireland and rainfall intensity is the intensity of the 1 hr storm with a 100 year return period. Both of these parameters are available from Met Eireann (Appendix II). The rainfall intensity may also be assessed using the flood studies report method (i.e. applying a factor to the M5-2D rainfall, this will be explained in a later section).

6.6.2.2 Pathway

The pathway has two components, the vulnerability classification from the GSI and the unsaturated zone. The unsaturated zone is considered to play an important role in the removal of pollutants from road runoff. The depth to the water table will be investigated during site investigation. The depth to bedrock should also be established during site investigation allowing a complete review of the GSI vulnerability classification. The unsaturated zone has two important components, the depth to the water table and the clay content. The clay content may be assessed during site investigation or reference can be made to the soil maps produced by Teagasc.

	Component		Weighting	Risk scoring Multiply weighting by Value		
				Low Value 1	Medium Value 2	High Value 3
Source	Traffic Volume AADT		15	<50,000	50 - 100,000	>100,000
	Rainfall (Take highest component)	SAAR	15	<740	740 - 1060	>1060
		Intensity mm/hr		<35	35-47	>47
Pathway	Vulnerability		30	Low	Moderate	High or extreme
	Unsaturated Zone	Depth	10	>10	3 to 10	<3
		Clay Content	10	>13%	10 - 13%	<10%
Receptor	Aquifer Production yield		20	Poor	Local	Regional

Table 17 Risk assessment scoring Matrix for Bedrock Aquifers

6.6.2.3 Receptor

The scoring in the receptor is based on the production yield of the aquifer. The GSI has produced an aquifer classification map based on yield with poor, local and regionally important aquifers for both bedrock and gravels aquifers.

	Component		Weighting	Risk scoring Multiply weighting by Value		
				Low Value 1	Medium Value 2	High Value 3
Source	Traffic Volume AADT		15	50,000	50 - 100,000	>100,000
	Rainfall	SAAR	15	<740	740 - 1060	>1060
		Intensity mm/hr		<35	35-47	>47
Pathway						
	Unsaturated Zone	Depth	25	>10	3 to 10	<3
		Clay Content	25	>13%	10 - 13%	<10%
Receptor	Aquifer Production yield		20	Poor	Local	Regional

Table 18 Risk assessment scoring matrix for gravel and sand aquifers

6.6.2.4 Scoring Implications

The following table gives guideline values of the overall risk of impact. In all cases the drainage systems can only be adopted when due consideration has been given to flooding issues. The scoring is slightly different to that of the UK guidance after a number of test cases were reviewed.

Overall Score	Risk of Impact
< 150	Low
150 to 230	Moderate
>230	High

6.6.2.4.1 Low Risk category

In the low risk category, consideration should be given to over the edge systems allowing groundwater infiltration through such systems as interceptor ditches, filter drains or grassed channels. In areas of low permeability infiltration will not be feasible and conveyance will be required with discharge through attenuation system, e.g. ponds or wetlands. The conveyance system should allow for as much infiltration as possible through the use of structures such as check dams.

6.6.2.4.2 Moderate Risk Category

In this situation, the groundwater may require some protection through the use of geosynthetic liners or various treatment systems such as swales, grassed channels, linear wetlands or wetland ponds. Infiltration may be feasible in certain sections that have adequate subsoil cover. Detailed site investigation will be required to identify these sections. The objective is to provide additional protection for the underlying aquifer either though the use of liners or through SUDS systems that will lower the risk to the low risk category by providing an additional treatment zone above the aquifer. Conveyance through the use of perforated carrier pipes incorporated into the base of grassed channels will reduce the amount of infiltration and reduce the risk to the underlying aquifer.

Surface Waters - Discharge	Objectives	Site Control
Protected or Salmonid Rivers	Limit Discharge Rates to minimise SS and treat to reduce soluble fraction in pollutants	Wetlands.
Hybrid Ponds		
Non-salmonid Rivers	Limit Discharge Rates	Attenuation Ponds
Karst areas	Maximum treatment required to protect surface water as it likely to be part of groundwater system	Wetlands

Table 19 Site Control for Surface Water Discharge

6.6.2.4.3 High Risk Category

These situations will generally require a lined conveyance and attenuation system with no infiltration. It is recommended that detailed site investigation be carried out with specific emphasis on the unsaturated zone and the vulnerability. The site investigation may well provide additional information that will allow infiltration in certain sections of the alignment. It is important to note that the vulnerability mapping is based on regional considerations with limited information and the site investigation should be used to reassess the vulnerability classification.

Tables 19 and 20 outline drainage design options for different hydrological situations based on the risk assessment procedure.

Risk category	Typical Hydrological Environments	Objectives	Problems	Source Control.	Site Control
Low Risk (<150)	Areas with thick sub-soil > 10m of moderate permeability or 5 – 10m of low permeability	Allow for infiltration to groundwater.	Some conveyance will be required as systems are unlikely to allow full infiltration due to permeability of subsoils and large landtake required for infiltration areas.	Over the edge (Ditches). Grass Filter strips. Combined Filter Drains. Grassed Channels. Swales. Linear Wetlands. Combined filter drain and GSWC	Ponds Infiltration Systems
Moderate Risk (150 – 230)	Areas with 3 – 10m of moderate permeability and 3 – 5m of low permeability	Allow for some infiltration but greater emphasis on conveyance	Likely to be sections requiring lining or additional treatment using vegetative systems prior to discharge to groundwater.	Grassed Channels (GSWC). Swales. Linear Wetlands. Combined Filter Drains. Combined filter drain and GSWC	Wetlands. Attenuation Ponds. Combined Wetland and attenuation Pond
High Risk (>230)	Areas with <3m subsoil. Karst Areas and Limestone Pavement	Protect Groundwater Aquifer. Avoid point source discharge of untreated runoff.	Lining required unless in low permeability soils. Lining not required if 1.5m of low permeability subsoil.	Lined Grass Channels or Swales. Lined linear wetlands. Combined filter drain and GSWC	Wetlands. Hybrid Ponds. Wetland and Attenuation Pond.

Table 20 Drainage options based on groundwater risk assessment

6.6.3 Accidental Spill

The method for assessing the risk associated with accidental spillage, as outlined in DMRB Volume 11 Section 3 Part 10 HD 45/09, should be adopted for national road projects. A brief description of the approach is given here but the reader should refer to the DMRB document for further details.

There are two parts to the calculation:

1. Calculate the probability of a spillage occurring
2. Calculate the probability of the spillage causing a serious pollution event.

The result from part 1 is used to calculate part 2.

An acceptable risk for part 2 (the risk of a serious pollution event occurring) is <1% generally or < 0.5% if a protected area, such as an SAC, is at risk.

6.6.3.1 Part 1

The formula for part 1 is as follows.

$P_{SPL} = RL \times SS \times (AADT \times 365 \times 10^{-9}) \times (\%HGV/100)$

Where:

- P_{SPL} = annual probability of a spillage with the potential to cause a serious pollution incident,
- RL = road length in kilometres,
- SS = spillage rates from Table 19 (taken from DMRB),
- AADT = annual average daily traffic (use design year for new road),
- %HGV = percentage of heavy goods vehicles.

	Motorways	Rural Trunk Roads	Urban Trunk Roads
No Junction	0.36	0.29	0.31
Slip Road	0.43	0.83	0.36
Roundabout	3.09	3.09	5.35
Crossroad		0.88	1.46
Side Road		0.93	1.81
Total	0.37	0.45	0.85

Table 21 Serious Spillages in Billion HGV km/year

The probability of an event occurring is calculated for each length of road section category outlined in Table 21.

6.6.3.2 Part 2

The approach for part 2 is as follows.

$P_{INC} = P_{SPL} \times P_{POL}$

Where:

- P_{INC} = the probability of a spillage with an associated risk of a serious pollution incident occurring,
- P_{POL} = the probability, given a spillage, that a serious pollution incident will result. An appropriate value for this is to be selected from Table 22 (taken from DMRB). This will depend on the location of the water course and how soon it can be reached by the emergency services.

Receiving water body	Urban (response time to site < 20 minutes)	Rural (response time to site < 1 hour)	Remote (response time to site > 1 hour)
Surface watercourse	0.45	0.6	0.75
Groundwater	0.3	0.3	0.5

Table 22 Probability of a serious pollution incident occurring as a result of a serious spillage

The annual probabilities for each section of road draining into to an outfall are added to give the overall score. A worked example is given in HD45/09 and this should be reviewed before applying the formula.

6.6.3.3 Discussion

There are very close similarities in accident rates, Table 21, and response times, Table 22, for the situation in Ireland. The differences in accident rates are not considered to be significant enough to affect the overall outcome of the approach. If there is doubt about the response time, a factor of 1 should be applied i.e. PINC = PSPL.

6.6.4 Surface Water Impact assessment - The HAWRAT tool.

The Highways Agency Water Risk Assessment Tool (HAWRAT) is used in the UK to assess whether road runoff is likely to have an impact on receiving water courses. The tool is available as an excel spreadsheet but is specific to the UK and its climatic conditions. The method was approved by the UK Environmental Agency and has taken the environmental quality objectives of the Water Framework Directive into account. The tool was developed after a detailed study was undertaken by the Highways Agency and several third level institutions into the effects of road runoff on surface water ecology. The study was very much focussed on the impact of soluble and sediment bound pollutants on the biota of the surface water and developed threshold values for both short term and long term impacts. The results of the procedure are a pass or fail. Pass implies that discharge is not likely to impact on the receiving watercourse, while a fail indicates that mitigation measures are required. Although the tool is specific to the UK, the differences in climatic conditions between the UK and Ireland are not considered to be significant enough to merit a total revalidation of the tool and it is recommended that it is adopted in Ireland. In all cases consultation with the various statutory consultees will be required before discharging to a watercourse. It is worth noting that the tool does take into account sensitive or protected sites by halving the permitted discharge concentrations. The biggest climatic differences are related to rainfall amounts. Higher rainfall amounts in Ireland will result in a bigger dilution and the tool is therefore conservative.

In the application of step 1 of the assessment tool begins by predicting pollutant concentrations of road runoff based on traffic counts (note it is two way AADT) and annual rainfall only. The first step, therefore, disregards any dilution effects from river flow volumes. The tool will predict annual average concentrations of the runoff and will in all cases result in a fail as there are no dilution effects or mitigation measures taken into account. The results therefore give the worst case scenario.

Step 2 involves inputting data about the receiving water course and the information on the areas of paved and unpaved surfaces in two tiers (steps). Tier 1 involves inputting the 95%ile river flow or the flow that is exceeded 95% of the time, the area of paved and unpaved surfaces, the base flow index and identifying whether the road scheme is close to a protected site. This will then take into account the effects of dilution. The base flow index is unlikely to be known and a value of 0.5 is recommended in this situation. For a tier 2 assessment a site visit is required to obtain the information relating to the watercourse such as bed width, slope and the manning coefficient. Detailed information on all of these parameters is outlined in HD45/09.

Step 3 deals with mitigation measures. If the results from the first two steps indicate a fail, step 3 allows input of the proposed mitigation measures, specifically the control related to discharge rates and, secondly, the percentage of settlement that the drainage design allows for through either attenuation by pond (wetlands) or removal of suspended solids during conveyance (e.g. grassed channels or swales).

The HAWRAT tool is a very powerful method for assessing the impacts of road runoff based on detailed measured pollutant concentrations and measured impacts on biota. It is very easy to use and should form part of the EIA process. However, there will be situations where a more detailed impact assessment is required e.g. when sensitive habitats such as freshwater pearl mussels or oligotrophic lakes form part of the receiving environment. When the tool is used with the low traffic counts on the rural network the result is often a pass with little or no treatment required. This may not be acceptable in light of the nature of the receiving environment. In such cases additional treatment may be required despite the implications from the HAWRAT results.

If the discharge from these attenuation ponds is low (<5 l/s) and the receiving water has a reasonable flow, it is likely that, in most instances the tool will result in a pass even for sensitive watercourses as a low discharge rate will result in a high residence time allowing settlement of suspended solids. The key to maintaining water quality is to control discharge rates. The use of grassed channels and wetlands will add additional treatment including the removal of the soluble load.

6.6.5 Risk Assessment Groundwater and Surface Water Procedure.

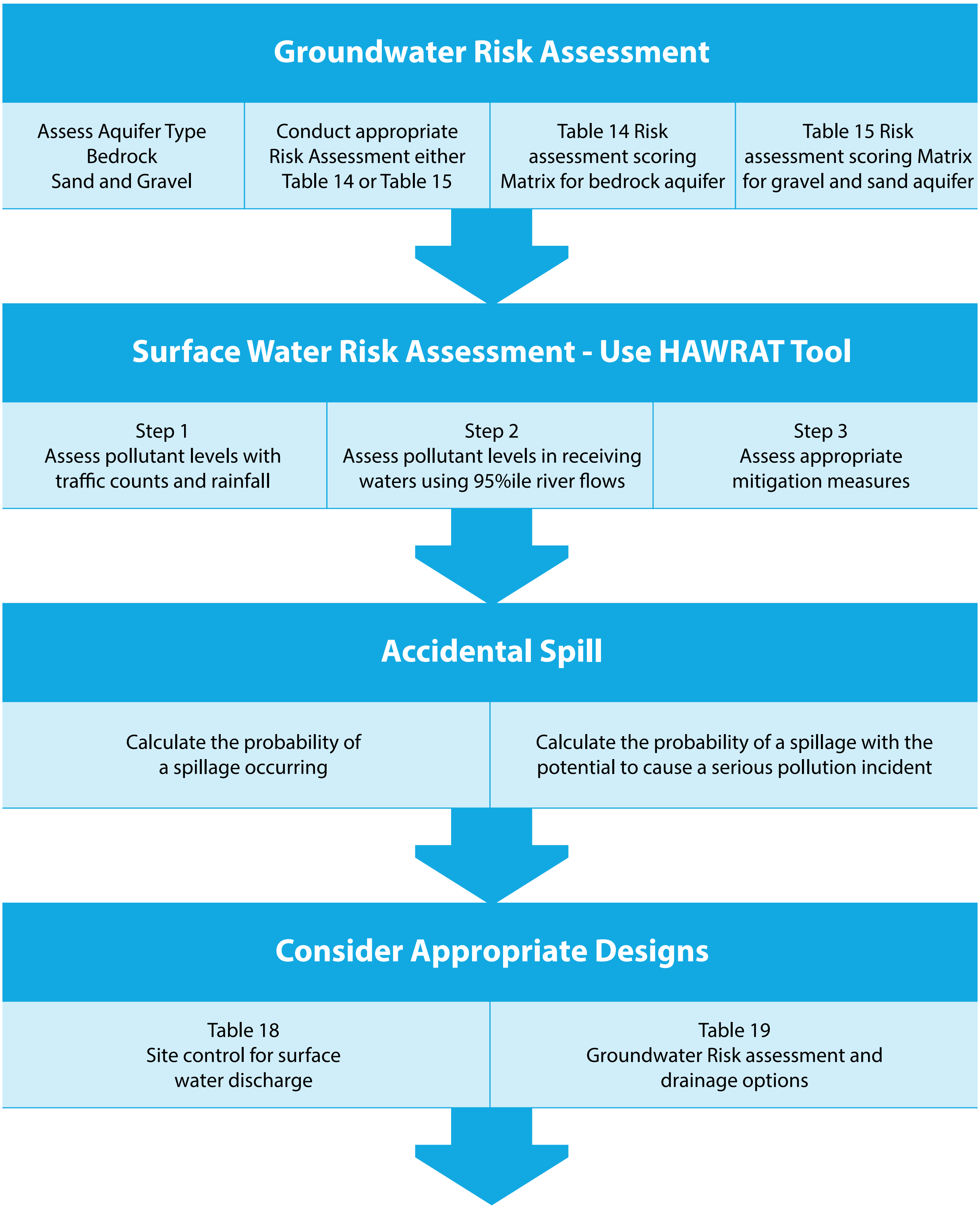


Chart 1 Risk Assessment procedure for groundwater and surface water

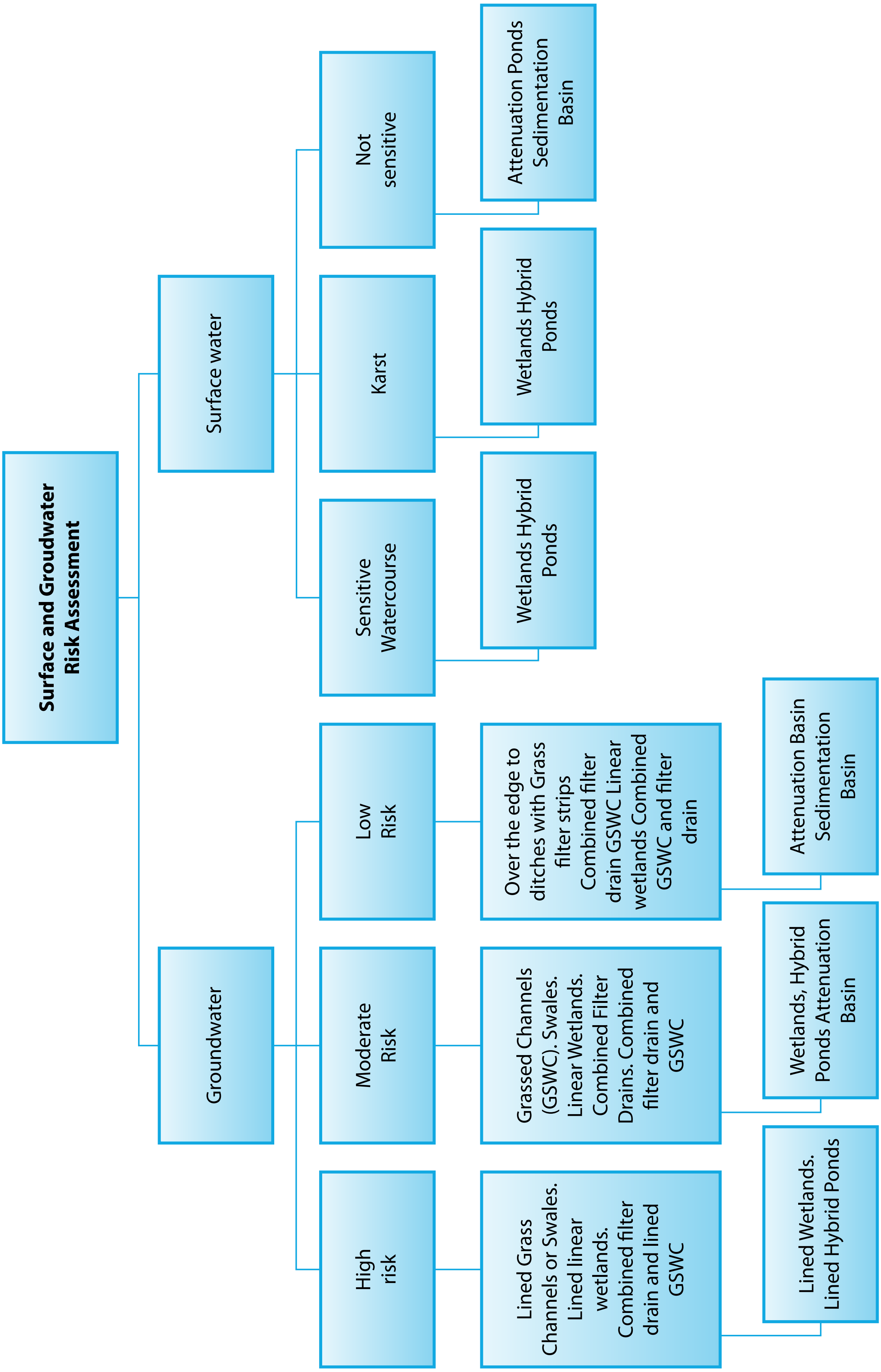


Chart 2 Drainage Design based on risk assessment

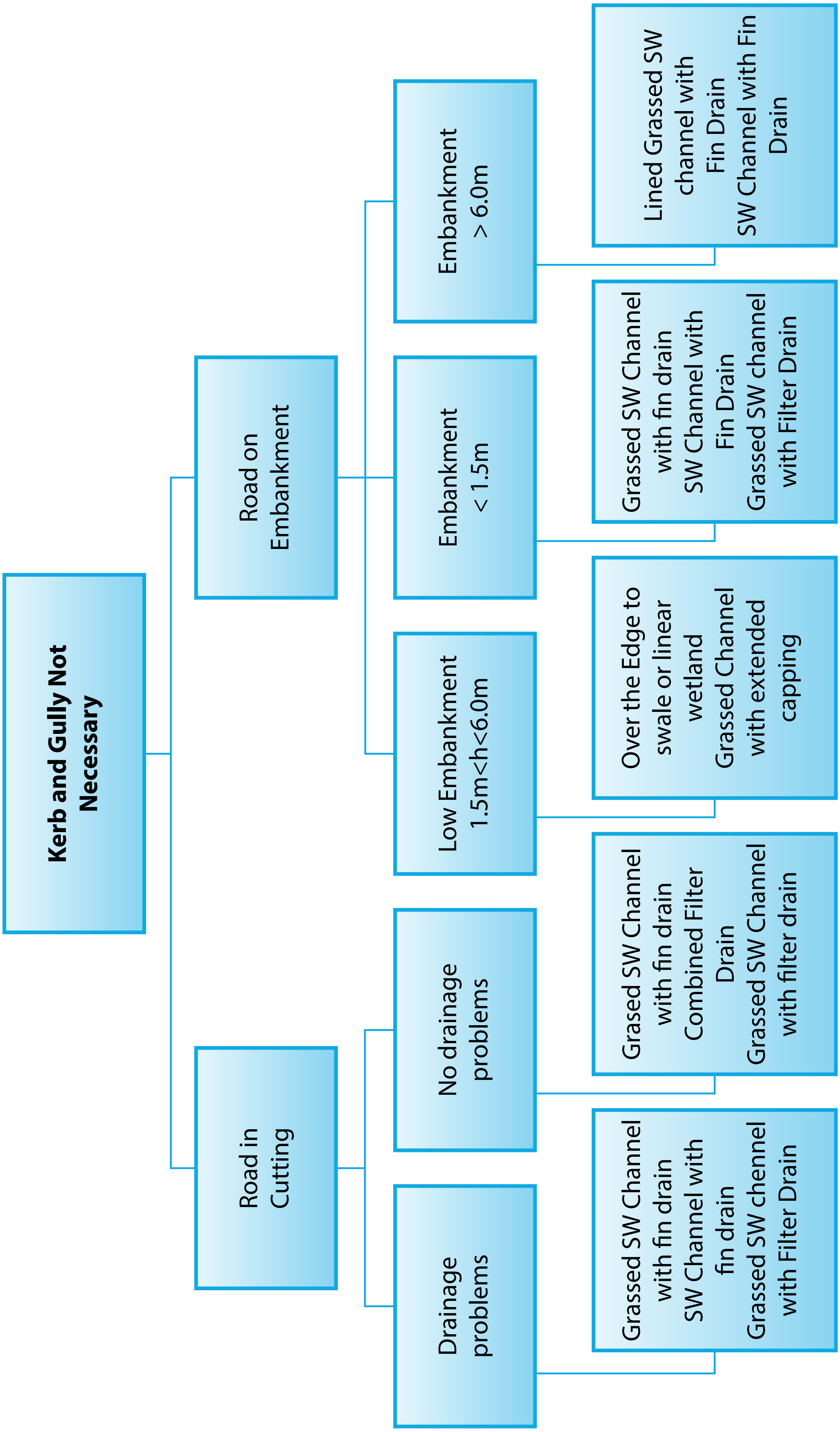


Chart 3 Drainage design based on vertical alignment

7 Section 3 Part 1 - Hydrology and hydrogeology, volumetric calculations

7.1 Introduction

Hydrology and hydrogeology refers to the presence and movement of water in the hydrosphere which accounts for movement above, below and on the earth's surface. The hydrological cycle is driven by energy from solar radiation. One of the most important aspects of understanding the hydrological cycle is quantifying the amounts of water associated with different phases of the cycle and the rate and volumes of transfer from one phase to the next. Water balance calculations play a key role accounting for all water entering, leaving and stored in a catchment area. These catchment areas may be on very different scales ranging from individual wetland areas to large regional scale river basins. An example of a water balance is shown in Figure 12.

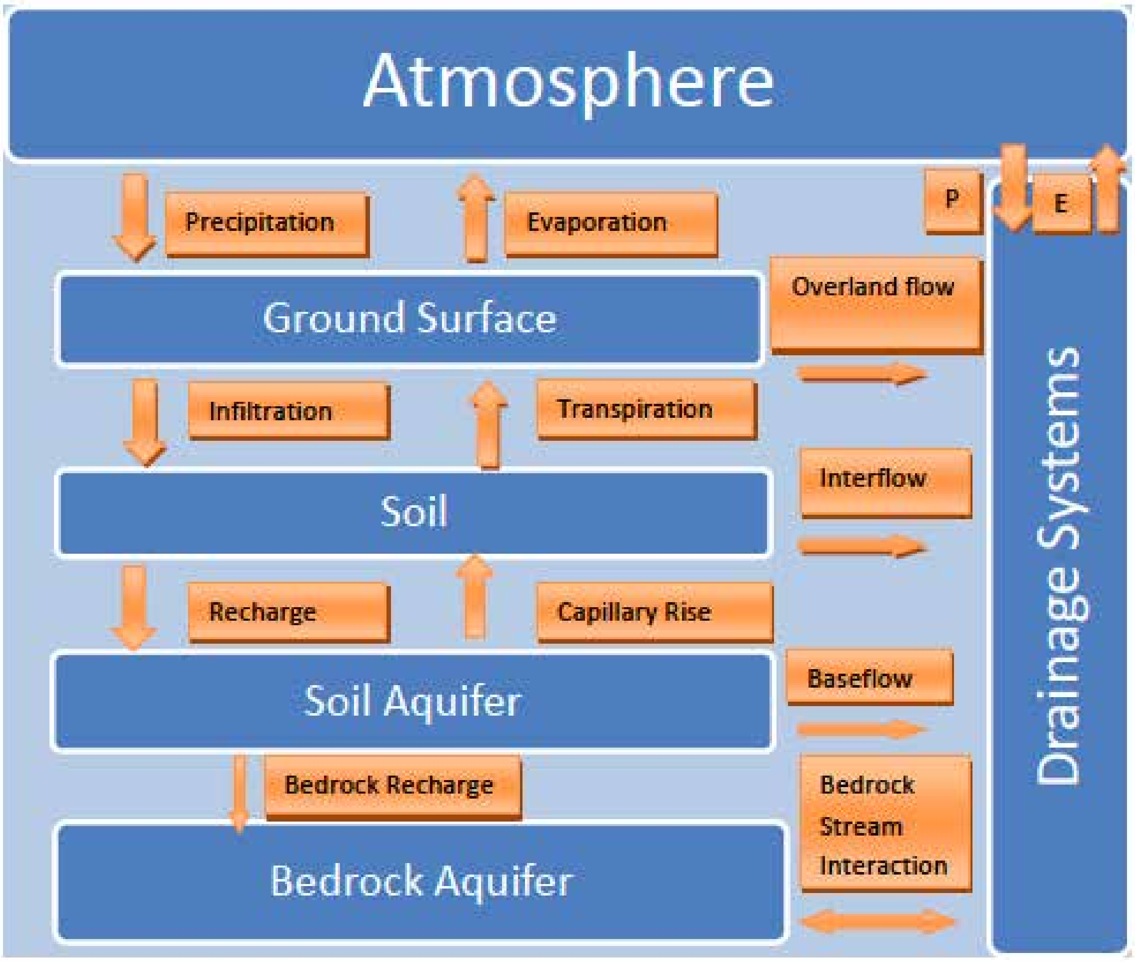


Figure 13 Water Balance for a catchment

The diagram is useful for highlighting some of the key parameters involved in water balance calculations. In a typical catchment, where the land surface is sloping towards a discharge point, the precipitation and runoff is generally measured through rain gauges and flow measurements and the evapotranspiration (evaporation + transpiration) is either measured or estimated (often through soil moisture budget calculations). This type of approach refers to gauged catchments. Runoff during a storm event refers to all waters that end up in the watershed or discharge point of the catchment. There are many concepts dealing with how rainfall becomes runoff. Runoff can include overland flow, interflow above the saturated zone in the soil and additional interflow through the saturated zone into the river system. This concept is referred to as subsurface streamflow. Effective rainfall is generally taken as the total rainfall less evapotranspiration. Effective rainfall will therefore contribute to overland flow, interflow, additional baseflow and groundwater recharge. The groundwater recharge will involve recharging the saturated zone and also deeper recharge to the bedrock aquifer.

Some of the most important elements in the calculations are involved with separating the transfer volumes related to recharge and runoff. This can be further complicated in areas where the sub surface catchment area is not coincident with the surface catchment and is therefore not defined by the same catchment divides. This can occur where the groundwater flow is dominated by fracture flow in rock types such as limestone or volcanic rocks.

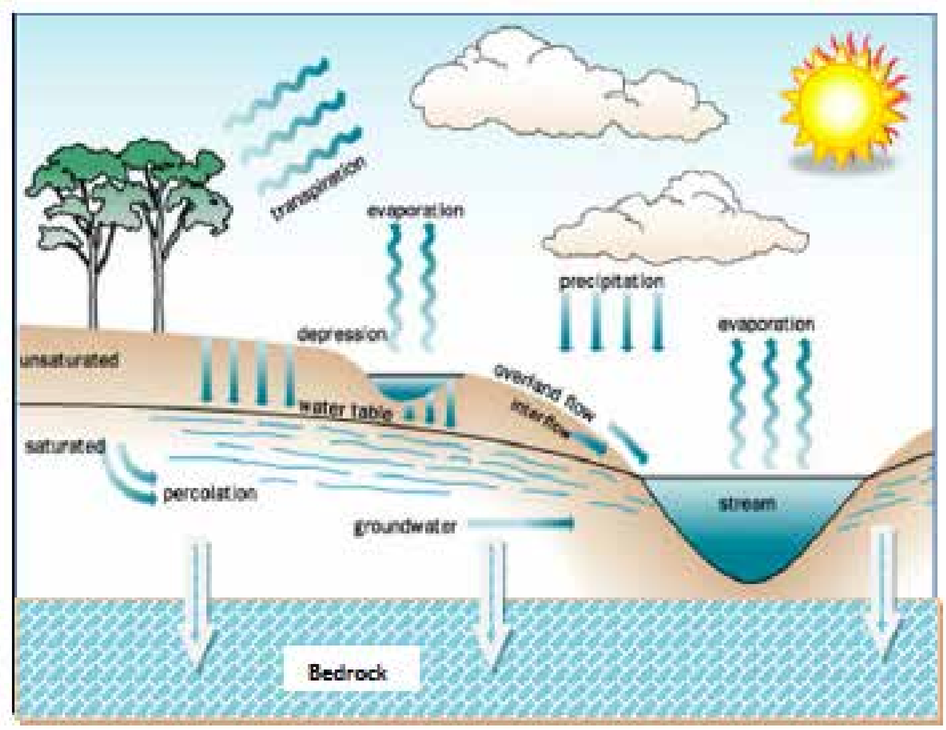


Figure 14 Conceptual Model for Hydrogeological Cycle

Figure 14 shows the essential elements of the hydrological cycle. Effective rainfall makes its way through the unsaturated zone where it can travel as interflow or baseflow to the drainage system. Recharge is taken to be that proportion of rainfall that recharges the saturated zone. Runoff is taken to have two components, rainfall that cannot penetrate the soil surface becomes overland flow and subsurface water that rises to the surface becoming runoff.

As a consequence of development or paving a portion of the land surface there are a number of specific calculations that are most relevant. Runoff from the greenfield site is calculated and used to limit discharge from the development. The volume and rate of runoff generated from the paved surface is calculated to size the attenuation requirements and conveyance systems. The impact of paving concerning the reduction of recharge and increase in surface water runoff is also required to assess the likely environmental impacts related to hydrologically and hydrgeologically sensitive sites.

7.2 Hydrometric Calculations

7.21 Receiving Environment

Before beginning any of the of the hydrometric calculations it is essential to define what the objectives are for the receiving environment as these objectives will define the nature of the attenuating system and consequently the types of volumetric and discharge requirements. There are three different approaches outlined in Chart 4. These include:

- A simple detention basin,
- A sedimentation pond and
- A wetland system.

Each of these systems has different environmental objectives and discharge requirements. The detention basin simply provides storage for a particular storm event. The focus is on attenuation capacity rather that treatment. The sedimentation basin and the wetland are focussed on treatment with a lesser focus on storm capacity. The critical difference between the two approaches i.e. capacity versus treatment is that the discharge rates are based on different criteria. For any treatment system the discharge rate is based on a certain residence time. For sedimentation ponds this is often taken 24 hours to allow for suspended solids to settle. For a wetland system the residence time will be less than 24 hours as the planting within the wetland provides additional treatment. Further guidance on residence time for wetland systems is discussed later. These two approaches will result in very different pond sizing. This is now explained in more detail.

Historically the approach on national road projects has been to use a detention basin. The approach is generally to provide a capacity for a certain storm return period (e.g. 1: 100) and discharge at greenfield rates. The actual volume of the pond is determined by the storm return period, the critical storm event and the factored greenfield rate. The critical storm is the storm duration for the chosen return period that produces the largest volume taking account of the permitted discharge rate. This approach is used where the primary objective is to protect the morphology of the receiving waters. This approach will also mitigate against any flooding associated impacts with the development. The pond will provide a certain basic level of treatment as by default there will be a certain residence time for the smaller storm events and there will be provision for long term storage as part of the design.

If the runoff is discharging to a sensitive environment, a certain level of treatment will generally be required. In this case the discharge rate and hence the pond volumes are based on a residence time. For a sedimentation pond a 24 hour residence time is often take as best practice. The residence time is calculated using the formula:

$Rt=V/D$ where:

R_t = Residence time

V = volume of the pond

D = discharge Rate

The discharge rate in this case can often be less than that calculated for greenfield runoff to give the required residence time resulting in large pond volumes for the larger return periods. A balance between treatment and capacity must be realised.

For a wetland system the approach is also based on residence time but in this case the residence time will be less than 24 hours because of the treatment capabilities of the plant species and the design of the wetland. The approach is to treat a certain volume of the rainfall event – the first flush and control the discharge rate for this volume. The runoff from the larger return period storms must be allowed to bypass the system.

In summary the approach to sizing the attenuation systems is completely reliant on the receiving environment and the quality objectives required meeting these objectives.

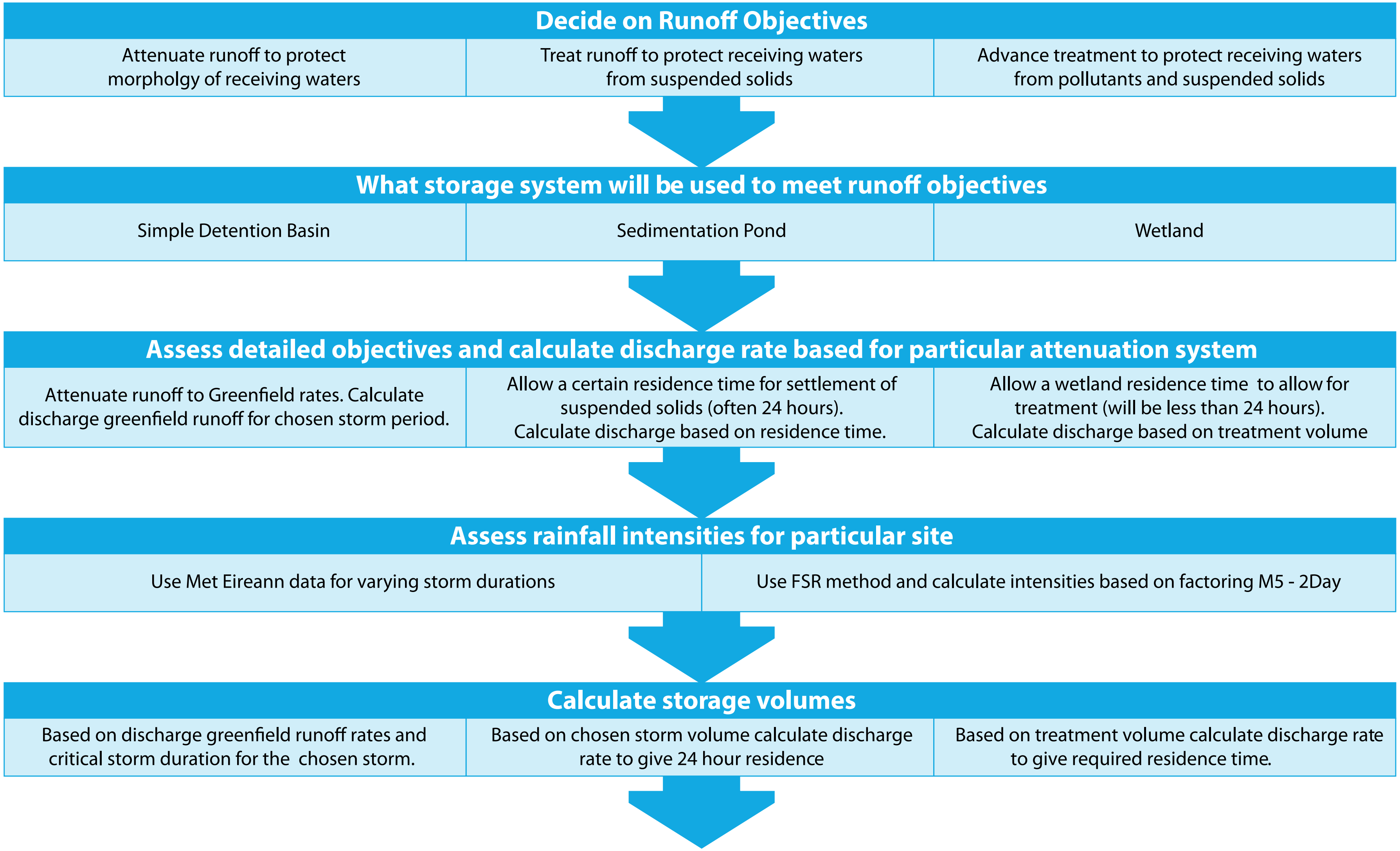


Chart 4 Attenuation systems and hydrometric calculation.

7.2.2 Volumetric Calculations

Below is a listing of the types of calculations involved with road scheme development:

1. Greenfield runoff

   These calculations are carried out to assess the permitted discharge rates from the development to streams and rivers. The objective is to limit the discharge rates to that of the greenfield site prior to development. This is done for detention basins.

2. Volumetric calculations related to peak runoff rates from the paved surface and sizing of carrier pipes. Pipe sizes will be a function of chosen storm return period with allowances for a certain amount of surcharge and will also vary depending on location relative to the paved surface i.e. carrier pipes conveying runoff transversely under the roadway will be designed for larger return storms. Further guidance on the sizing of pipes is given in (NRA 2009). The formula used is generally the rational formula. These are often done with specifically designed software packages.

3. Volumetric calculations related to runoff and peak runoff rates from the paved surface and sizing of surface water channels, ditches and attenuation ponds such as detention basins, sedimentation ponds and wetlands.

   There is often a requirement to take account of additional runoff from outside the paved surface in the case of development in cuttings. There may also be a component from the Greenfield site although this is generally intercepted through the use of interceptor ditches.

4. Residence time calculations for sedimentation ponds and wetland systems to provide sufficient treatment for the runoff in sensitive environments.

5. Calculations related to design of culverts and bridges

   Finally, detailed calculations of runoff from steam and river catchments are required to assess the appropriate sizes of culverts and flooding impacts. In Ireland, approval under Section 50 (1) of the Arterial Drainage Act, 1945, as amended, is required from the Office of Public Works (OPW) for such crossings. Guidance on these types of calculations is given on the OPW website. The types of runoff calculations include empirical formulae such as the QBAR (annual mean flood) or QMED (median flood) and the use of actual data from gauged catchments. Clearly gauged sites with records are the preferred option but in many cases there are inadequate data to allow for sizing with the required return period of 1 in 100 years and empirical formulae must be used. The types of empirical formulae are the same as those used for the greenfield runoff calculations and include:

- IH 124,
- FSR 6 variable method,
- FSR 3 variable method,
- FEH 1999,
- Unit hydrograph.

These will be discussed in more detail later.

7.2.3 Climate Change

The main impacts related to climate change vary across the country but include: heavier and more intense rainfall events, flooding and increase in runoff and erosion. An increase in intensity could lead to an increase in pollutant concentrations especially during the summer months after a prolonged dry period.

Advice on the how to take account of climate change is given in a report by Defra 2005 EA/Defra Flood and Coastal Defence R&D Programme (Defra / Environmental Agency 2005).

Climate change is taken into account by adding 10% to the rainfall depths for calculating storage volumes and 20% is added to river flows (10% increase in rainfall will result in a 20% increase in river flow). No factor is applied to the calculated greenfield peak rates as changes in short duration events are considered to be very low.

Advice on climate change is also given in the SUDS manual for conveyance and flood routing.

Category	Climate Change factors			
	1990-2025	2025-2055	2055-2085	2085-2115
Rainfall %	5	10	20	30
River Flows %	10	20	20	20

Table 23 Climate change factors for conveyance and routing.

Runoff factors are not yet related to climate change but a factor of 10% is recommended.

In the design of pavement edge drainage, the UK DMRB HD 33/06 states that a sensitivity test should be carried out to allow for climate change by adding 20% to the design storm rainfall intensity. This is in the context of designing channels that should accommodate the 1:1 year storm without surcharging. The allowable surcharge widths are then checked for the 1:5 year storm

OPW have published a document on flood risk management and future climatic scenarios (OPW 2009). The approach adopted by the OPW is the recommended approach to be applied in all Flood Risk Management related work in Ireland. The two minimum scenarios are referred to as the Mid-Range Future Scenario (MRFS) and the High-End Future Scenario (HEFS). The Mid-Range Scenario recommends a 20% increase in extreme rainfall intensities and 20% increase in flood flows. There may be situations where the drainage design for a national road scheme can be considered as part of flood risk management and therefore fall into this category of management.

The climate change factor should relate to the significance of flooding and the requirement for mitigation at the particular site. This should be discussed with OPW.

In this document, a factor of 10% is added to rainfall intensities for storage calculations in line with the Defra document.

7.2.4 Greenfield Runoff rates

7.2.4.1 Impacts of paving

The effects of paving on runoff rates on a greenfield site are shown in Figure 15 . The necessary volumetric calculations relate to flow rates and stormwater attenuation. Paving in a rural area will result in a larger volume of runoff and a higher discharge peak rate. There is also a lesser volume of base flow to rivers and streams thereby reducing flow rates in surface streams and potentially impacting on groundwater fed ecosystems. Road runoff will have higher concentrations of suspended solids, heavy metals and hydrocarbons.

7.2.4.2 Flow Rates

Development runoff from road projects through pipe networks will discharge to the environment orders of magnitude faster than the greenfield site. This results in flashy flow in streams and rivers causing erosion and scour. Attenuation storage is required to limit the rate of runoff. The objective is to:

- Limit the runoff rates for rainfall events to the same frequency of occurrence and the same peak rate as that taking place in the greenfield site (CIRIA C697 2007).

The first phase of hydrometric calculations relates to the greenfield runoff rate, often referred to as QBAR or the annual mean flood. This calculation is conducted in order to estimate the acceptable discharge rate to the receiving environment. It is based on what discharge rate would occur in the absence of any development or any paving. A number of different methods are outlined in the literature and the most common procedures are shown in Table 24.

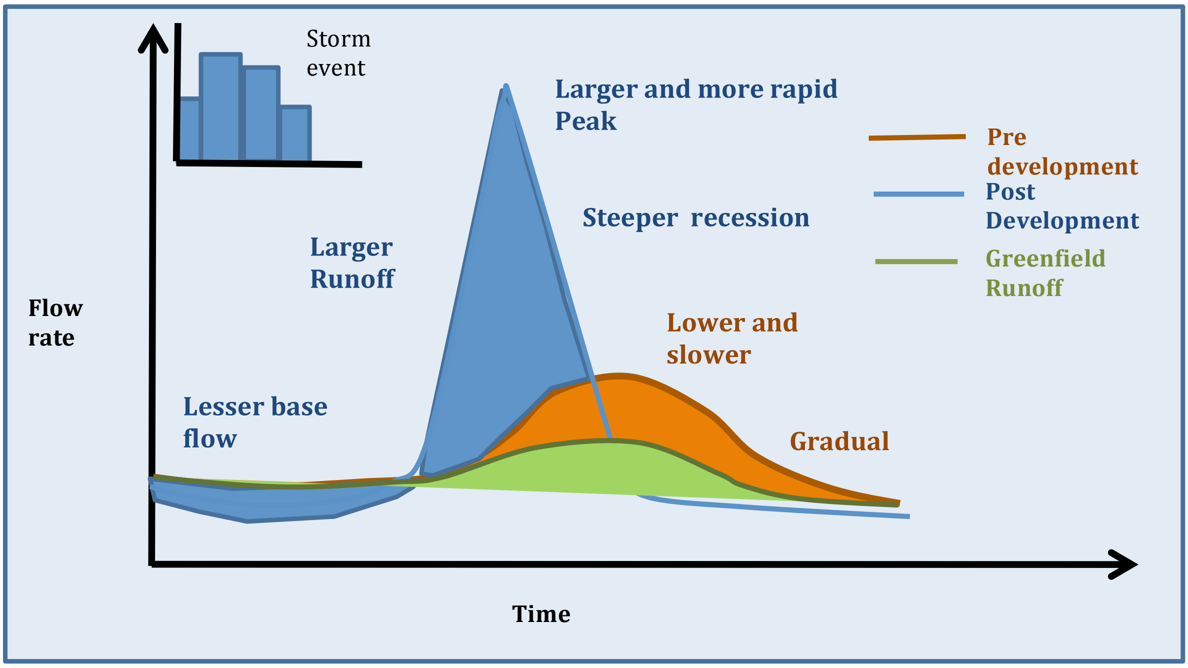


Figure 15 Impacts of paving on greenfield runoff rates

Area	Method
0 - 50 ha	Inst. of hydrology handbook report 124 Flood estimation for small catchments to determine QBAR. FSSR regional growth curves use to calculate Greenfield peak flow rates for 1, 30 and 100 year returns.
50 – 200 ha	IH report 124
Above 200 ha	IH 124 or FEH (IH, 1999)

Table 24 Methodologies for calculating Greenfield Runoff

These methods are known as flood frequency methods and use catchment descriptors to determine an index flood magnitude such as the annual max flood QBAR (IH 124) or the median flood (FEH method). These calculated runoff rates are then multiplied by an appropriate regional flood frequency growth factor to give the appropriate discharge rates for various return period e.g. Q100. Requirements for attenuation may vary but in general best practice is to attenuate the 1 in 100 year storm with a 6 hour duration (CIRIA C697 2007). In practice the critical storm duration for simple detention ponds is often less than 6 hours due to high discharge rates in areas of high runoff. The permitted discharge rate during this event is therefore the QBAR factored for the 1 in 100 year return. The growth factors used for Ireland are shown in Table 25. The formula for calculating the growth curve factor is given below.

T	1	2	5	10	25	50	100	200
Xt	0.87	0.96	1.20	1.37	1.60	1.77	1.96	2.14

Table 25 Growth Curve Factors for index flood (NERC 1975) to be applied to QBAR calculation.

$$Q_t = Q_{BAR}\, x_t$$

$$x_t = \frac{Q_t}{Q_{BAR}} = -3.33 + 4.20e^{0.05Y_t}$$

Where : $Y_t = -\ln(-\ln(T - \frac{1}{T})$

The most common formula used for greenfield runoff calculations is the IH 124 method. This requires 3 simple parameters i.e. area, annual average rainfall and the soil type which are used to assess the runoff coefficient or the WRAP value (winter rainfall acceptance potential). This is the most common procedure but it is not always suited to Irish catchments (Cawley 2003). Two other methods of assessing greenfield runoff rates are discussed below, the ADAS method and a type of rational method. The purpose of examining these methods is to highlight the differences in the resulting runoff rates depending on the methodology. Both the ADAS and the rational method tend to give lower discharge rates for the higher soil classes (higher runoff coefficient). This will result in the requirement for larger attenuation ponds. The designer is encouraged to investigate the various methodologies described below and decide on the most appropriate method for the particular catchment in consultation with the hydrologist.

7.2.4.2.1 IH124

In most cases the catchment area for road projects will be below 50 hectares and the most common formulae used is the IH 124 method. The formula is given below. It is important to note that this method is most suited to catchments of 50 hectares or more. To use this method for smaller catchments the recommended procedure is to adopt a catchment area of 50 ha and then apply a factorial correction for catchment sizes e.g. if the catchment size is 10 ha then the QBAR is then divided by 5. In order to calculate the permitted discharge rate from a particular pond or catchment area, the QBAR is calculated and then factored for the appropriate storm return period e.g. if there is a requirement to attenuate the 1 in 100 year storm a factor of 1.96 is applied to the QBAR. This discharge rate is the required discharge from the storm attenuation system *during that storm event.* During smaller storm events with lesser return periods the system should also be discharging at the lower greenfield runoff rates equivalent to the smaller storm event. This is achieved through the use of a flow control device. The factored discharge rate is then used to calculate the size of the attenuation system using the discharge rate, rainfall intensity of required storm event and the area involved.

Small catchments IH 124 eqn.

QBAR = 0.00108 $\text{Area}^{0.89}\ \text{Saar}^{1.17}\ \text{Soil}^{2.17}$

QBAR = mean annual flood m^3/s

Area = Catchment area km^2

SAAR = standard average annual rainfall in mm

SOIL = Soil Index based on WRAP values (winter rainfall acceptance potential) calculated as follows:

$SOIL = (0.10S1 + 0.30S_2 + 0.37S_3 + 0.47S_4 + 0.53S_5)/ (S1 + S2 + S3 + S4 + S5)$

S1 to S5 = proportion of the catchment covered by each of the soil classes

Soils are classified based on runoff potential. S1 has a low runoff value of 0.1 while S5 has a very high runoff potential of 0.53.

Note: Standard percentage runoff values (SPR) were assigned to each soil class and are as follows: 15, 30, 40, 45 and 50 for each of the 5 soil classes – these values are sometimes used for other formulae but should not be used for the above.

The value of QBAR can then be factored to take account of a particular return period according to the Flood Studies Report regional growth curves or the modified factors for Ireland.

Typical runoff rates for the different soil classes with a 1000mm annual rainfall are shown on Table 26. These values will then be factored for the appropriate design storm (Table 25) e.g. the allowable discharge rate for a 1 in 100 year return event in area with a soil type 4 is 7.32 * 1.96 = 14.3 l/s/ha.

7.2.4.2.1.1 Soil Classes

The soil classes are normally based on the FSR 1975 soil maps. This is the soil index which is an index found from the Flood Studies Report soil maps of the WRAP (Winter Rainfall Acceptance Procedure) map of the Wallingford procedure.

Alternatively the soil class can be determined based on site investigation or the Teagasc soil maps for Ireland and matched with the WRAP classes.

Soil Types	1	2	3	4	5
Soil Index	0.1	0.3	0.37	0.47	0.53
Area	**Runoff l/s/ha**				
1Ha	0.25	2.77	4.36	7.32	9.5

Table 26 Runoff rates for 1ha site IH 124.

Cawley and Cunnane 2003 examined the data set used for the IH 124 formula for Irish catchments. They noted that of the catchment areas less than 5km², (17 catchments), soil classes 1 and 2 are not represented at all, soil classes 3 and 4 have 4 catchments each and soil class 5 has 9 catchments. Three catchments with SOIL classes 1, 2 and 3 had been excluded from the IH 124 formula because they had high urban cover. When these are included for regression, the formula changes considerably. The authors concluded that '*due to the poor representation of lower soil classes in the sample and the sensitivity of the regression equation when either three additional catchments of the lower soil types or an alternate minimisation function are included seriously questions of the validity of the IH 124 equation to small catchments and also for soil classes 1 to 3. SOIL Classes 1,2 and 3 are the most common categories for Ireland and particularly in the low-lying urban centres'.*

It is important to note that the use of this formula in the context of road runoff is merely to decide on an average discharge limit so in this context the formula may be considered useful and applicable.

7.2.4.3 Alternative Models

7.2.4.3.1 ADAS

The ADAS (Ministry of Agriculture and Food) method was developed for very small scale catchments and the design of field drainage pipe systems and as such could be suitable for road scale. There are many variations of the formula but the most suitable method is the ADAS 1982 publication (MAAF Ref 345 1982). The procedure is described in detail in the publication. The information required for the calculation includes:

- Area of the catchment in hectares
- Maximum length of catchment in metres
- Average slope
- Average annual rainfall
- Crop type
- Soil type factor

The following parameters were used to calculate some typical greenfield discharge values.

- Area 1 = hectare.
- Length = 1km (typical catchment for road scheme)
- Slope = Used 1:100 (flat) and 5 :100 average.
- Annual rainfall = 1000mm
- Crop type = grass
- Soil factor = Used range of soil types based on permeability.

The equation is in the form of:

$$Q = S_T FA$$

Where

- Q is the 1 year peak flow in l/s
- St is a soil factor and has values between 0.1 and 1.3. (Not the same as WRAP)
- F is function of catchment characteristics such as slope, drainage length, rainfall. The value is got from a nomograph in the ADAS report
- A Area in hectares

A second slope coefficient C is also derived. C=0.0001L/S where

- S = slope
- L= catchment length

For a flat slope the values ranged from 0.6 to 6 l/s/ha for the various soil types. For an average slope of 5:100, the values ranged from 0.9 to 9 l/s/ha for the range of soil. These are broadly similar to the IH 124 values. Similar modified growth curve factors to take account of the fact that this is considered to be an annual flow (return period 1 year) may then be applied to get the required return storm (Table 25).

7.2.4.3.2 Rational Method

An alternative approach to estimate peak flow rates is to adopt the rational type formulae or modified rational method. This is often used for paved or developed sites but the principles can be applied to greenfield sites.

The basic formula is where:

- Q = peak runoff rate m^3/s
- C = runoff coefficient
- i = rainfall intensity for the design return period (mm/hr) based on time of concentration of the catchment
- A = catchment area

The time of concentration in this case (greenfield site) is the lag interval between the rainfall event and the peak flow in the river. This parameter can vary significantly for different catchments and is dependent on many parameters (Lischeid 2002). As an example a time of concentration of 2 to 3 hours was chosen to check the validity of the approach. This is clearly an over simplification as catchment times of concentration do vary considerably. The equivalent rainfall intensity for the 2 to 3 hour storm with a 2 year return period can be got from Met Eireann for the particular catchment (approximately 8mm/h). This will be approximately equivalent to QBAR (Return 2.2 years).

Typical values for the runoff coefficient will depend on the soil type. Again clay soils will have a higher runoff coefficient than sands. Typical values for rural setting are shown in Table 27 (Iowa State University, Institute for Transportation 2009).

Catchment Slope	Soil A	Soil B	Soil C	Soil D
Flat 0 – 1%	.04 -.09	.07 - .12	.11 - .16	.15 - .20
Average 2 – 6%	.09 - .14	.12 - .17	.16 - .21	.20 - .25
Steep	.13 - .18	.18 - .24	.23 - .31	.28 - .38

Table 27 Runoff coefficients for rural catchments ((Iowa State University, Institute for Transportation 2009).

Group A. Soils having low runoff potential and a high infiltration rate, even when thoroughly wetted, consisting chiefly of deep, well to excessively well-drained sands or gravels.

Group B. Soils having a moderate infiltration rate when thoroughly wetted, consisting chiefly of moderately-deep to deep, moderately-well to well-drained soils, with moderately fine to moderately-coarse texture.

Group C. Soils having a slow infiltration rate when thoroughly wetted, consisting chiefly of soils with a layer that impedes downward movement of water or soils with moderately-fine to fine texture.

Group D. Soils having high runoff potential and a very slow infiltration rate when thoroughly wetted, consisting chiefly of clay soils with a high swelling potential.

The runoff coefficients may also be assessed based on the recommendations of the Irish Working Group on Groundwater (METHODOLOGY FOR RISK CHARACTERISATION OF IRELAND'S GROUNDWATER, Guidance Document no. GW8). In that guidance document the Working Group recommends various recharge coefficients (percentages of effective rainfall) for different soil conditions. The runoff coefficient can be taken as the percentage difference left from the recharge, e.g. 90% recharge in sandstone aquifers equates to a 0.1 runoff coefficient.

The runoff rates for an average slope are given in Table 28. The runoff rates are similar to previous formula for the permeable soils but significantly lower for low permeability soils.

7.2.4.3.3 ADAS Report No. 5 method (MAFF 1980)

This is a rational type approach and takes into account parameters such as the winter rainfall acceptance (SOIL) and land drainage parameters such as catchment slope and the saturated nature of the catchments. The formula is:

$$Q_t = 2.78\, M_F^{2.0}\; F_A\, A\, I_{\,tc,T}$$

Where

- F_A is the annual rainfall factor = 0.00127SAAR – 0.321 (dimensionless) and SAAR the annual average rainfall is in mm.
- L_c the characteristic length = 0.0001(L_2/Z)
- L the catchment length measured as the distance from the outlet to the watershed passing through the middle of the catchment (m)
- Z is the average elevation of the catchment above the outlet (m)
- Design Rainfall intensity of Duration t_c and return period T obtained from the rainfall intensity-duration-frequency relationship
- t_c the time of concentration = 6.09(Lc)0.39 (hrs)
- M_F is Soil permeability modifying factor = 4.938 $S^{2.0}{}_m$
- Sm is the soil index = $(0.15S_1 + 0.3S_2 + 0.4S_3 + 0.45\,S_4 + 0.50\,S_5)/(1 - S_u)$

7.2.4.4 Summary Flow Rates

The objective of determining the greenfield runoff rate is to decide on what is the maximum permitted discharge rate from the development during a storm event for a detention basin. The most commonly used method is the IH 124 method in the absence of gauged information. There are many issues with adopting this formula for Irish catchments (Cawley 2003). In the context of limiting discharge rates from road scheme development, the issues will relate to the sizing of attenuation ponds. Clearly a higher discharge rate will result in a smaller attenuation system. Additional important criteria related to the sizing of the ponds, include the choice of return period and storm duration. A minimum discharge of 2 l/s/ha is often adopted for highly permeable soils as the calculated low discharge rates can result in large attenuation systems. The ADAS method is probably most suited to small catchments such as road projects but significant engineering judgement is required for the various parameters. The rational method referred to above results in conservative discharge rates for the less permeable soils. This may be suited to situations where flooding impacts are to be minimised (e.g. karst areas). In most other cases the IH 124 method should be used.

Soil Type	1	2	3	4
Runoff Coefficient	0.115	.155	0.185	0.225
Q l/s/ha	2.5	3.5	4.1	5.0

Table 28 Runoff Rates based on adapted rational formula

7.1.1 Runoff Volumes

There are three types of storage volumes that need to be considered for stormwater control. These are referred to as:

- Attenuation storage,
- Long term storage and
- Treatment storage.

Attenuation storage is the volume of water required to be attenuated in order to limit the discharge to the greenfield runoff rate. In traditional drainage designs, this was achieved through the construction of attenuation basins or ponds. More recently, there is a shift in drainage design to SUDs systems that are far more efficient at attenuating runoff.

Long term storage relates to the extra volume of water created by the development. It is desirable that this extra volume is allowed to infiltrate the groundwater aquifer and compensate for the reduction in recharge or if this is not possible then this volume of water is discharged to the receiving watercourse, at low runoff rates (<2 l/s/ha) after the storm has passed.

If there is an issue with lands available for treatment then the focus often shifts to treatment volume of the first flush which is assumed to contain most of the pollutants. The objective is to provide adequate treatment volumes for the first 15mm of rainfall. The problem with the first flush phenomenon has already been discussed and detailed studies have shown that for road runoff the contaminants are not always contained in the first flush. In most cases, as a matter of caution, a factor is often applied to this calculation, of up to 4 times the volume, to establish the treatment volume.

7.2.5.1.1.1 Attenuation storage

Having determined the permitted design discharge rate the next step is to assess the required attenuation volumes. The essential parameters for assessing storage requirements are the storm duration and rainfall intensities.

7.2.5.1.1.2 Storm return period and duration

The storm event is used to calculate peak discharge rates and detention volume. For the design of drainage conveyance systems, the critical storm is that which produces the highest discharge rates, based on the time of concentration. For road projects, the time of concentration is variable but often in the region of 15 to 30 minutes. For the volumetric component, the critical storm is that which produces the largest detention volume taking the permitted discharge rates into account. This must also take into account the design return period. The objective should be to attenuate the 1 in 100 year storm. HD 103/06 states that *'The capacity of the pond should normally be such as to attenuate an event with an annual probability of 1% for that catchment and discharge the water into the downstream watercourse at a rate that would occur in those rainfall conditions if no road were present'*. Generally the critical storm duration for a 1 in 100 year event is determined by calculating the volume from several different storm durations. To determine the volumetric requirements, the rainfall intensities are needed for the different durations and the percentage runoff. An example of the assessment of the critical storm duration for a 1 in 100 year storm is shown in Figure 15. In this case, a discharge rate of 9 l/s/ha was chosen. The critical storm has a duration of 4 hours with a volumetric requirement in excess of 600m3/ha. The rainfall intensity was based on the FSR method described in the next section. As the permitted discharge rate increases, the critical storm duration is lowered. For national road projects the objective should be:

- To attenuate the 1 in 100 year storm with duration of 6 hours if discharge rates are low and the critical storm is longer than 6 hours.
- Or, in most cases, attenuate the 1:100 critical storm if the critical storm duration is less than 6 hours.

Typical rainfall amounts for a 6 hour storm with a return period of 100 years range from 40 to 130 mm in Ireland based on Met Eireann data with an average value of 62mm.

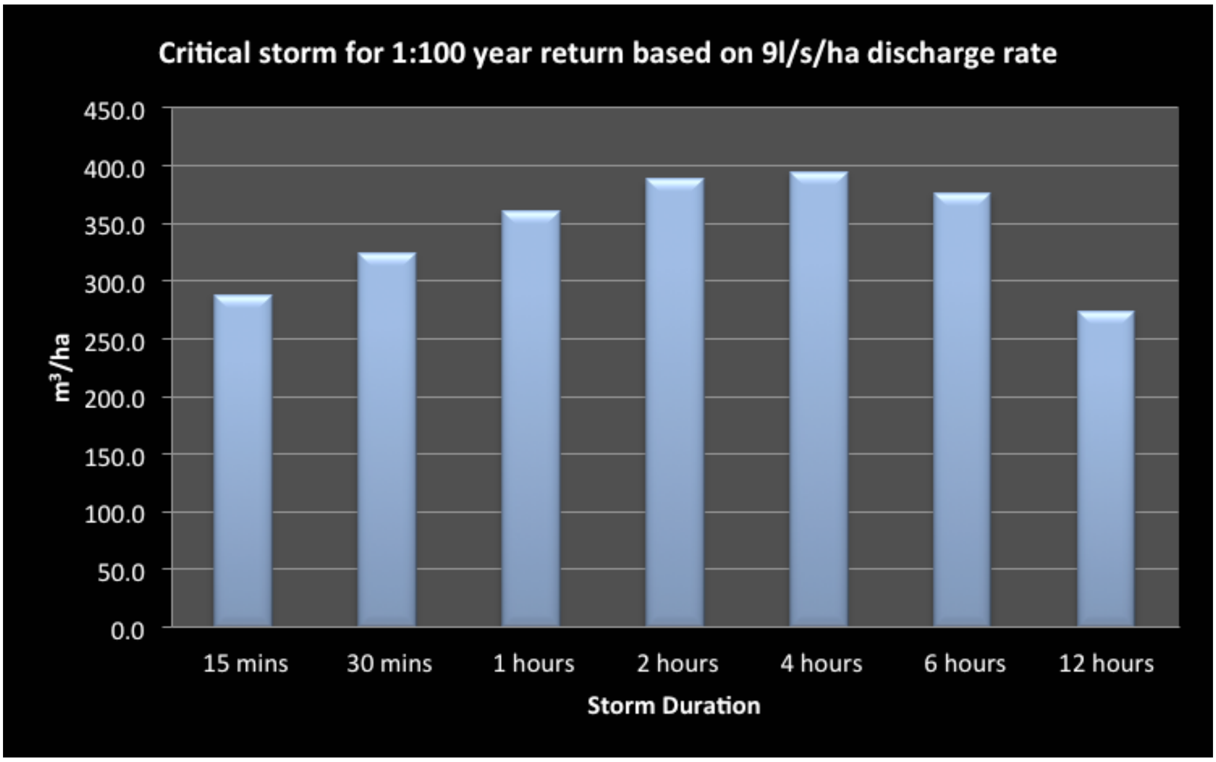


Figure 16 Critical storm duration - 9/s/ha discharge rate

7.2.5.1.1.3 Rainfall intensities

The most common way of determining the rainfall intensities is to use the method described in the FSR. For storm duration less than 48 hours the procedure is as follows:

1. Estimate the M5 2D rainfall intensity from Flood studies map. This is the 2 day rainfall intensity with a 5 year return period.
2. Estimate the ratio r = M5 60 min/M5 2D given as a map in Flood studies. The ratio of the 60 minute storm with a return period of 5 years to the M5 2D.
3. These two values are then used to calculate the rainfall for the 1 : 5 year return for any duration by applying a series of growth factors to the M5 2D depending of the value of r.
4. A further series of growth factors are then applied to 1:5 year event to get the required return period e.g. 1:100.

Alternatively, the data from Met Eireann can be used (see Appendix II Section 6).

An example of storage calculations based on Met Eireann data and the FSR method is given in Appendix III.

7.2.6 Percentage Runoff – Long term storage and accounting for cuttings

In the case of developed sites, the percentage of runoff will depend on many variables related to the percentage of pervious and impervious area, soil types, slopes, how saturated the soil is, rainfall intensity, stream density and area. In general there will be little contribution from the pervious areas that allow infiltration. In most cases the runoff from the greenfield area is intercepted with purpose built interceptor ditches and does not enter the drainage system for the road development. There are certain situations, however, where there may be additional volumes of water that must be accounted for in the drainage design coming from areas other than the road surface. This will occur when the road scheme is in deep cutting, resulting in a groundwater flow from dewatering into the drainage design systems. There may also be additional surface runoff in rock cuttings and soil cuttings with steep slopes and low permeability.

The objectives are to mimic greenfield site conditions and therefore to:

1. Have no runoff for small rainfall events.
2. Reduce runoff for large events.
3. Limit the rate of runoff to greenfield conditions.

The percentage runoff for developed sites is often estimated by using the fixed UK percentage runoff model or the variable UK runoff model. For road projects where only the paved surface is contributing to the drainage systems i.e. on embankments, a simple model of 100% runoff volumes for the chosen storm design is generally used. Where there is an additional component, e.g. from cuttings, then the fixed or variable UK method may be used.

7.2.6.1 Reduction in runoff volumes and long term storage

To reduce the runoff from a storm event to the greenfield volumes, the differences in volumes of runoff generated between the paved site and the unpaved site must be calculated. This is generally assessed using the following formula (assuming only the paved surface is draining to the network).

$$Vol_{xs} = RD.A.10\,((0.8\,PIMP/100) - SPR)$$

Where:

Vol_{xs} = the extra runoff volume (m_3) of development runoff over Greenfield runoff

RD = the rainfall depth for the 100 year, 6 hour event (mm)

PIMP = the impermeable area as a percentage of the total area

A = the area of the site (ha)

SPR = the "SPR" index for the FSR SOIL type

This volume is stored in long term storage and released after the storm event at a slow rate of 2 l/s/ha. The rest is released at the factored greenfield rate.

7.2.6.2 Runoff from cutting slopes

Where the road is in cutting, there will be a contribution from the cutting slope to the road drainage system. The method for taking this additional component into account is based on the fixed UK runoff method and involves assessing a runoff coefficient for the cutting slope based on the permeability and is described below.

7.2.6.2.1 Fixed UK runoff model

This model assumes that the percentage of runoff stays constant and does not increase as the catchment gets wetter. The percentage runoff is given as:

PR = 0.829 PIMP + 25.0 SOIL + 0.078 UCWI – 20.7 where:

PR = percentage runoff

PIMP = percentage impermeable

SOIL = Soil index SPR (0.15 to 0.5)

Urban Catchment Wetness Index, which is a composite of two antecedent wetness parameters and is given by:

UCWI = 125 + 8API5 - SMD

Where API5 = 5-day antecedent precipitation index (mm)

SMD = soil moisture deficit (mm)

A modified (earlier) version of this formula is recommended by the DMRB for use in road cuttings DMRB Vol. 4 Section 2 HA 37/97) and has the form of:

PR = 0.662 + 0.00219 (100 – PIMP). SOIL. UCWI.

An effective width of the catchment which is given as:

$W_e = W + \alpha C$ where:

W = width of the paved area.

α = runoff coefficient for the catchment = SOIL.UCWI/300 based on PR eqn. above.

C = average width of the cutting

The effective width of the catchment is equal to the width of the carriageway, the width of any surface channel plus an allowance made for runoff from the cutting. As the slopes of the road cuttings are generally steeper than most natural catchments, it is reasonable to assume that there will be a higher runoff coefficient. For this reason, the values used for the SOIL index (SPR) are slightly higher than the normal SPR values 0.3 to 0.6.

Soil Type	UCWI	α
High Permeability	Medium	0.11
	High	0.13
Medium Permeability	Medium	0.16
	High	0.20
Low Permeability	Medium	0.21
	High	0.26

Table 29 Runoff Coefficients for cuttings from DMRM HA 37/97

Typical values for runoff coefficients are shown in Table 29.

7.2.7 Runoff from natural catchment

Guidance on the approaches to dealing with runoff from natural catchments is given in the DMRB Volume 4 Section 2 HA 106/04. The runoff from the natural catchment is intercepted and kept separate from the road drainage. Slopes without a well defined water course are discharged using interceptor ditches. The ditches are located at the top of cuttings and the toe of embankments. A slope that is intercepted by a road development that contains a well defined water course will involve the construction of a culvert to convey the runoff away from the road construction.

7.2.7.1 Return Period

In dealing with runoff from the natural catchment without a well defined water course, the DMRB recommends that the flow rates are assessed for a design return of 75 years. The design standard (HD 33/06) requires that the edge of pavement drainage systems be able to convey flows produced by storms with a return period of 1 year without any surcharging or surface flooding. Limited surcharging onto the hard shoulder is acceptable for storms with a return period up to 5 years. As the critical storm duration and time of concentration for natural catchments will be considerably longer (3 to 5 hours instead on minutes), it follows that the excess volume of runoff generated from a natural catchment can be very large, leading to possible flooding on the road. Based on an assessment of the impact on road uses, taking account of the magnitude of the flooding, the time for which flooding lasts and how frequently the flooding occurs, a return period of 75 years was adopted (DMRB HA 106/04 2004) for interceptor ditches.

Plate 14 Interceptor ditch intercepting runoff from the natural catchment before it enters the road drainage system.

The methods for assessing the flow rates from natural catchments are the same as those used to calculate greenfield runoff. The two approaches recommended by the DMRB HA 106/04 are:

1. IH 124 method for catchments greater than $0.5 km^2$
    - $QBAR = 0.00108\ AREA^{0.89}\ SAAR^{1.17}\ SOIL^{2.17}\ \ m^3/s$

- Parameters as before
- This is then factored for the required return period of 75 years

2. ADAS method for catchments less than $0.5km^2$

- For the required return period of 75 years the recommended formula is
- Q = AREA (0.0443 SAAR – 11.19) SOIL $^{2.0}$ * ($18.79T^{0.28}$-1/10T) where T is the time of concentration and given by
  - $T = 0.1677\ W^{0.78}/Z^{0.39}$
    - W is the maximum catchment width in metres
    - Z is the average height of the catchment divide above the discharge level.
    - More detailed definitions can be got in HA 106/04

The required sizes of the ditches can then be assessed using the manning equation:

- $A = n\ Q/S^{1/2}\ R^{2/3}$ where
  - A = cross sectional area of flow m^2
  - Q = flow rate m3/s
  - n = manning roughness coefficient (typically 0.05 for a grassed channel)
  - S = longitudinal gradient m/m
  - R = A/P where
    - P is the wetted perimeter
- It is also recommended that the ditches should be trapezoidal in shape for stability. For a ditch of base width B, side slopes 1:b (vertical: horizontal) and flow depth y R can be calculated using:
  - $R = (yB+y^2b)/B+2(y^2b^2+y^2)^{0.5}$

7.2.7.2 Additional volumes from Dewatering of cuttings

Significant long term flow volumes of groundwater can be added to the drainage systems through dewatering in cuttings and this is often difficult to assess especially in rock cuttings where the flow is through conduits. Guidance on assessment methods for calculating dewatering volumes is given in (CIRIA 2000). The document deals with partially penetration and fully penetrating slots for confined and unconfined conditions. The most common situation encountered in national road projects is likely to be unconfined conditions in partially penetrating slots. The formula for calculating discharge in this situation (trench with flow 2 sides) is:

$Q = [0.73 + 0.27\ p/H]\ kx(H^2 – h_w^2)/L_0$

Where :

- $Q = m^3/s$
- P = drawdown $(H – h_w)$

- H = height of original piezometric surface
- hw = drawdown piezometric height
- K = conductivity m^3/s
- X = length of slot (cutting)
- L_0 = Distance of influence

Many of these types of formula are developed for dewatering of quarries and use adopted formula for flow to wells. The formula is then altered to suit different types of situations. The above formula is very sensitive to L_0 or the zone of influence.

L_0 is sometimes calculated using

$L_0 = C(H-h_w)\sqrt{k}$

Where;

- C is an empirical calibration factor (1500 to 2000)
- $H-h_w$ is drawdown
- k is conductivity m/s

Note this L_0 is for a narrow slot so L_0 must be considerably larger for a road cutting.

L_0 may also be calculated from (Niccoli W 1998). In this equation R_0 represents the radius of influence.

$$\boxed{H = \sqrt{h_s^2 + \frac{P}{K_{h1}}\left[R_0^2 \ln\left(\frac{R_0}{r_w}\right) - \frac{R_0^2 - r_w^2}{2}\right]}}$$

- This is again based on well geometry and the effective radius must be calculated to determine L_0.
- H = height of water table at radius of influence m
- h_s = saturated thickness to seepage face m
- K is conductivity m/d
- r_w = radius of quarry
- P = recharge m/d

Further guidance on the use of this approach is given in Hydrogeological impact appraisal for dewatering abstractions Science Report – SC040020/SR1.EA 2007. (Boak 2007). The solution is solved by iteration.

Alternative approach – Dupuit Forchheimer

Flow in an unconfined aquifer

$Q = Kx\,(H^2 - h^2)/2L$

- H is the height of the water table at radius of influence
- h is height of water at drawdown
- L is the distance between H and h.
- x is length of trench or cutting which flow occurs
- K is conductivity

With recharge this becomes:

$Q = K\,(H_0^{\,2} - H_w^{\,2})/2L - (w((L/2)\text{-}x))$

- w is the recharge rate
- Q is discharge per unit width.

For detailed analysis of flows from cuttings it is advisable to get expert advice from a hydrogeologist. Continuous flows from cuttings can lead to constant inundation of any drainage system and constant discharge. More detailed advice is beyond the scope of this text. For worked examples refer to (Boak 2007).

An example is given in Appendix III.

7.2.8 Development Runoff Rates

The development runoff rates, used for pipe sizing, are generally assessed using the rational method. For road projects a conservative rainfall intensity of 50mm/hr or 35mm/hr is often assumed. If open channel systems, such as grassed channels or swales, are used then design will generally not be a function of conveyance capacity.

Plate 15 Box culvert with natural base to allow fish passage.

7.2.9 Culvert and Bridge Design

Catchment scale runoff rates are required in order to design culverts and bridge structures across streams and rivers. In Ireland, certain bodies must get the consent of the Commissioners of Public Works for construction works to bridges and similar structures. This consent process is referred to as Section 50 consent (NRA, Guidelines for the Crossing of Watercourses During the Construction of National Road Schemes 2005). Guidance on how to obtain a section 50 and how to calculate runoff rates including worked examples are given in the OPW website www.opw.ie/en/FloodRiskManagement/StatutoryandRegulatoryFunctions/Section50/.

Recommended methods for calculating greenfield runoff rates for ungauged catchments include:

- IH 124
- FSR 6 variable method
- FSR 3 variable method
- FEH 1999
- Unit hydrograph

7.2.9.1 Statistical Methods

Method	Formula	Variations	Comment
1975 FSR	$QBAR = C\ AREA^{0.95} F_S^{0.22} SOIL^{1.18} SAAR^{1.05} S1085^{0.16} (1+LAKE)^{-0.93}$	$QBAR = 4.53 \times 10^{-7} AREA^{0.84} F_S^{0.51} SAAR^{1.34}$ $QBAR = 2.242 \times 10^{-7} AREA^{0.84} SAAR^{2.09}$ $QBAR = 0.667 AREA^{0.77}$	C = 0.00042 for Ireland
1978 FSSR No. 6	$QBAR = 0.0288\ AREA^{0.90} RSMD^{1.23} SOIL^{1.77} Fs^{0.23}$	$QBAR = 0.00066 AREA^{0.92} SAAR^{1.22} SOIL^{2.0}$	
IH 124	$QBAR = 0.00108 AREA^{0.89} SAAR^{1.17} SOIL^{2.17}$	$QBAR = 3.6 \times 10^{-5} AREA^{0.94} SAAR^{1.58} SOIL^{1.85}$	Little account for Soil type 1,2,3, Not suited to small catchments
FEH 1999	$QMED_{rural} = 1.172\ AREA^{AE} (SAAR/1000)^{1.560} FARL^{2.642} (SPR\ HOST/100)^{1.211}\ 0.098^{REHOST}$		Specific to UK

Parameters

RSMD = net 1 day 5 year rainfall – soil moisture deficit. This is obtained from on the 2 day R5 rainfall value and r value. Soil moisture deficit is determined from maps in the FSR.

Fs = n/A = stream frequency average number of stream junctions per k² on 1:25:000 scale. If other scales are used then *a correction factor must be used with a formula given in FSR.*

AREA = catchment area km²

SAAR = standard average annual rainfall mm.

QMED = median annual maximum flood

FARL = flood attenuation by reservoirs and lakes factor

SPRHOST = standard percentage runoff based on hydrology of soil types map

AE = area exponent (which varies with area)

RESHOST = a factor based on baseflow index (BFIHOST) and SPRHOST which reflects relative flashiness or sluggishness of the catchment.

SOIL = soil index

Lake = index of lake area as proportion of total area.

S1085 = slope of the main channel between 10% and 85% of its length measured from the catchment outlet (m/km)

The FEH recommend that for un-gauged sites the index flood may be improved by the use of flood values calculated from river flow data from donor or analogue catchments. A donor catchment is typically on the same river as the site in question whereas an analogue site is a catchment site with similar hydrogeological characteristics.

7.2.9.2 Unit Hydrograph

The unit hydrograph is widely used in Ireland for un-gauged catchments using the design flood hydrograph to describe the magnitude of the flood peaks and flood volume. The method requires several steps and requires data on the following parameters:

- Time to peak (tp) based on catchment characteristics.
- Design rainstorm characteristics
  - Return period
  - Storm duration
  - Rainfall depth and profile
  - Runoff based on SOIL type, catchment wetness and rainfall intensity

7.2.9.3 Gauged Sites

Where gauged data is available, flows can be calculated using statistical distributions from the annual maximum series or peaks over threshold series. The FSR recommends distributions such as Gumbel Extreme Value 1 (EV1) and the Generalised Extreme Value (GEV). The Weibull distribution is also used.

If the gauged data covers a period that is less than the required return period, the FEH recommends a pooling analysis. This involves using data from hydrologically similar catchments based on three catchment descriptors i.e. area, rainfall and soil properties.

Chart 5 Flow chart for volumetric calculations

8 Section 4 - Sustainable Drainage Systems SUDS

8.1 Objectives

Sustainable drainage is a broad term that is centred on clear objectives related to both volumetric and quality control on storm runoff and the promotion of habitat diversity. The objectives are:

- Volumetric
  - Reduce runoff rate and reduce risk of flooding
  - Reduce additional runoff volumes and frequencies resulting from paved surface
  - Promote natural groundwater recharge minimising impacts on surface water bodies
- Quality
  - Minimise impact on groundwater aquifers through treatment and filtration
  - Reduce pollutant concentration in discharge
  - Control and containment of accidental spills
- Promote habitat diversity

Paving in a rural area will result in a larger volume of runoff and a higher discharge peak rate (Figure 14). There is also a lesser volume of base flow to rivers and streams, thereby reducing flow rates in such water bodies. By adopting the above SUDS objectives, these effects are minimised through mimicking the greenfield site conditions, i.e. conditions prior to development.

The volumetric and qualitative effects of paving (CIRIA C697 2007) can be summarised as follows:

- Changes to stream flow
  - Increase in runoff volumes
  - Increase in peak runoff rates
  - Flooding
- Changes to stream morphology
  - Stream widening
  - Erosion
  - Loss of riparian habitat
  - Channel bed profile
- Water Quality impacts
  - Loss of pool riffle structure
  - Impacts on aquatic diversity (dissolved and particulate phase)

- Siltation
- Temperature
- Reduce O2
- Base metals (lead, zinc, copper, nickel, chromium, cadmium) and PAHs
- De-icing salt – normally rock salt and grit but also cyanide, phosphates as anti-caking and corrosion inhibitors, heavy metals, urea and ethylene glycol.

Current drainage systems are designed to carry water quickly away from the road surface, in most cases without treatment, to an attenuation system and then discharge to a receiving water body. The main goals of using a more sustainable approach are to treat and attenuate the runoff during conveyance and to allow for infiltration to recharge the groundwater aquifer. This quality control process during conveyance is the main difference between the current approach and the use of SUDS.

8.2 Quality Control Using SUDS

There are several different types of treatment systems that can be used for road runoff that offer a range of quality control on pollutants. The processes involved (CIRIA C697 2007) include:

- Sedimentation and settlement
    - Pollution in runoff is attached to sediment particles. Settlement, through the reduction of flow velocity through a SUDS component, can remove a substantial pollutant load.
- Filtration
    - Trapping within the soil matrix, grass filter strips or geotextile grid.
- Adsorption
    - Pollutants attached to soil or aggregates
        - Adsorption – binds to surface,
        - Cation exchange – exchange of cations in clay minerals,
        - Chemisorption – Solute is incorporated in the structure of a soil,
        - Absorption – solute diffuses into soil.
- Biodegradion
    - Biological treatment – bacteria break down organic pollutants.
- Uptake by plants
    - Wetlands plants uptake metals.
- Nitrification, photoloysis.

The main pollutants in road runoff consist of heavy metals, suspended solids and PAHs. The most suitable processes required to treat road runoff containing these pollutants are summarised in Table 28:

Pollutant	Quality Control Process
Heavy Metals	Sedimentation, Adsorption, Filtration, Plant uptake
Hydrocarbons	Biodegradation, Photolysis, Filtration, Adsorption
Suspended Solids	Sedimentation, Filtration

Table 30 Quality Control Process for Road Runoff

The most suitable SUDS systems for road runoff must, therefore, include the quality control processes outlined in Table 30.

8.3 SUDS Components for Roads

It is likely that road runoff will require at least two levels of treatment and for major national roads three treatment levels may be required (Working Party suds 2010) (Box 7).

Treatment types for runoff may be divided into three categories (Table 31).

- Pre Treatment
- Source Control
- Site Control

8.3.1 Pre-Treatment

Pre-treatment generally refers to the removal of debris and silt before the runoff enters the main conveyance system. These systems consist of:

- Gullies
    - Gullies are used to trap sediment and silt.
- Silt traps (catchpits)
    - Catchpits and silt traps are bigger chambers used to collect sediment and silt. There are often used in areas of drainage pipe junctions or where a change is required in the direction of flow.

Plate 16 Catchpit with main carrier drain in black and slotted pipe from fin drain in blue. Surface water from road runoff and groundwater are mixed in the above catchpit.

Pre Treatment	Source Control	Site Control
Gullies	Grass Filter Strips	Attenuation Basin
Silt Traps	Swales	Infiltration Basins
	Grasses Channels	Wetlands
	Combined Filter Drain	Hybrid Ponds
	Over the Edge	

Table 31 SUDS Components

SUDS Components for Major Roads,

The number of SUDs components will depend on the sensitivity of the receiving environment – may be up to 4 but minimum 2 (Working Party suds 2010).

•Conveyance system

- Settlement
- Tertiary Treatment
    - E.g. Filter Drain, Attenuation Basin, Wetland.

Box 7 SUDS Components for Major Roads

8.3.2 Source Control

Source control refers to the main conveyance system which is often the focus of the drainage design for SUDS systems as it will offers both attenuation and treatment prior to discharge. The main SUDS components of source control include:

- Filter Strips (Grass filter strips),
- Grassed channels,
- Swales,
- Combined Filter Drains,
- Over the edge drainage – Interception ditches.

8.3.2.1 Grass Filter Strips

These are gently sloping strips of land, over which road runoff flows at low velocities and as sheet flow, removing a high percentage of the suspended solid load. They can also be classified as pre-treatment devices. They are best used at road edges for pre-treatment prior to the runoff entering a second SUDS component such as a combined filer drain or a swale. By ensuring that a high proportion of the suspended solid load is removed, the combined filter drain will have a significantly longer effective conveyance period without becoming clogged.

Currently, on national road projects, grassed channels are rarely used as a pre- treatment for combined filter drains but grassed embankments (not true filter strips) are used when over the edge drainage is adopted.

8.3.2.2 Swales

Swales are vegetated linear features used to convey and store road runoff but can also be used to allow infiltration. They are generally vegetated with grass and this promotes the treatment of suspended solids in particular. They are very efficient at pollutant control. Residence time and low flow velocities are important to ensure efficient pollutant removal. There are three types of swale:

- Standard swale,
- Dry swale,
- Wet swale.

8.3.2.2.1 Standard swale

A shallow grassed channel that is generally used to convey runoff to the next treatment phase. They are used for vegetative treatment and storage, if required (often through the use of check dams). They can be designed to allow for infiltration if the underlying soils are suitably permeable and if the underlying aquifer does not require additional protection or they may be designed to be impermeable through the use of a lining if the aquifer is vulnerable.

8.3.2.2.2 Dry Swale

The surface design is similar to the standard swale but in this case the underlying layers consist of a filter bed (permeable soil material) that provides additional treatment and storage capacity. These may also be lined, if required.

8.3.2.2.3 Wet Swale

This has the same design as the standard conveyance swale but promotes wet conditions to allow for additional treatment through the use of wetland plants. These are suited to areas where the underlying soils are impermeable. If the soils are not impermeable, these conditions can be created through the use of liners.

8.3.2.3 Grassed Channels

These are very similar to the standard conveyance swale. The principal differences are related to channel dimensions and flow mechanisms. Grassed channels are used in situations where sheet flow dominates, whereas swales require a number of point source inlets to allow for sufficient residence time. The differences are minor, however, and grassed channels are often referred to as a type of swale.

8.3.2.4 Combined filter drains

Combined filter drains are also known as French Drains and are very common on national road projects in Ireland. These are drains that are filled with a filter material allowing road runoff to enter the drain, from the road edge, where it is filtered and conveyed. The drains often have a perforated pipe at the base to convey the runoff to a secondary treatment component. They also have a significant storage capacity.

8.3.2.5 Over the edge drainage

In certain situations where the road scheme is on a low embankment and on granular material over the edge drainage is the preferred option. In this situation the road runoff flows as sheet flow down the road embankment into an interceptor ditch. The ditch will convey and also allow infiltration.

8.3.3 Site Control

Site control refers to the final phase of treatment prior to discharge to either a surface water system or to groundwater through an infiltration basin. The principal components of the site control consist of:

- Attenuation Ponds,
- Infiltration Basins,
- Wetlands,
- Hybrid Ponds.

8.3.3.1 Attenuation Ponds

Attenuation ponds refer to basins that normally have a permanent pool of water providing additional treatment through settlement and also providing for storm attenuation. They often support aquatic vegetation, both emergent and submerged, along the edges and shallow sections of the pond. These plants often provide for additional treatment through biological uptake of pollutants, such as metals. Attenuation ponds are a very common feature on national road projects in Ireland and often form the final treatment prior to stream discharge. They are also called detention basins They are designed to provide flood attenuation for varying return periods up to 1 in 200 years.

8.3.3.2 Infiltration Basin

Infiltration basins are generally only used on national road projects where there is a lack of surface features such as streams and rivers for discharge. They are often used to discharge excess water for storm events with low return periods such as a 1 in 10 or 1 in 30 year event. Runoff is directed to the infiltration basin where it is retained and then infiltrates the groundwater aquifer. Pre treatment is essential for effective use of infiltration basins as even a small suspended solid load will clog the system very quickly.

8.3.3.3 Wetlands

Wetlands are shallow ponds, often with varying water depths that provide different aquatic conditions for various plant species. Wetlands are not normally suited for attenuation of large storm events but can provide significant temporary storage for smaller storms. Wetlands require a continuous base flow through the system to maintain the aquatic plants and micro-organisms. If properly constructed, wetlands are the most efficient SUDS component for treating road runoff. Wetlands can also offer important wildlife benefits by promoting habitat diversity. The most important aspect of wetland design is to ensure sufficient residence time to allow for sediment particles to settle and the removal of pollutants through adhesion to vegetation. If attenuation is required then an attenuation pond should form part of the treatment system. An alternative is to allow for additional attenuation in the source components, e.g. swales will offer significant additional attenuation and storage.

8.3.3.4 Hybrid Ponds

Hybrid ponds are a combination of attenuation basin and a wetland. The ponds can provide significantly more storage than a constructed wetland but also have an area that contains aquatic species for treatment. These types of systems are becoming increasingly popular as they can provide additional storage.

8.4 Quality Control and Removal Efficiencies of SUDS Components.

The quality control processes are outlined in previous sections and this section deals briefly with the efficiencies of the various SUDS components and why they are specifically suited to the treatment of road runoff.

The following tables, (Mudge 2001) (DMRB HD 45/09 2009) (Higgins n.d.), outline the efficiencies of various drainage design components used on road projects in UK and Ireland. The main emphasis is on heavy metals, hydrocarbons and suspended solids. The tables show a variety of removal efficiencies and some conflicting results.

8.4.1 Wetlands

Wetlands show a consistent trend in all the studies and are very efficient at removing all of the pollutants associated with runoff both in the sediment bound phase and the soluble phases. The range of removal efficiencies does vary, however, and this may reflect construction practices. If the wetland is not constructed to achieve a minimum residence time of 24 hours, it will not operate to its full pollutant control potential. It is evident from the tables that of all the SUDS components, wetlands are the most effective treatment control.

Treatment System	TSS	Hydrocarbons	Metals Total	Metals Dissolved
	% Reduction			
Gully/Pipe System	10 – 30	5 – 10	10 -20	0
French Drain	60 – 90	70 – 90	70 – 90	10 – 20
Infiltration Trench	60 – 90	70 – 90	70 – 90	20 – 35
Swale	10 – 40	60 – 75	70 – 90	15 – 25
Oil Separator	30 - 70	40 – 80	30 – 60	0 – 5
Detention Basin	30 – 60	30 – 50	20 – 50	0 – 5
Retention Basin	40 - 80	30 – 60	30 – 60	5 – 10
Wetland	70 - 95	50 - 85	40 - 75	15 - 40

Table 32 Treatment Efficiencies of Road Drainage Components (Mudge and Ellis 2001)

Drainage Components		% Reduction		
		Primary Treatment	Secondary Treatment	Total Reduction
Oil separator/Wetland/Wet balancing Pond	Metals	15	11	24
	PAHs	-1	99	99
	TSS	37	73	83
Filter Drain	Metals	7		7
	PAHs	52		52
	TSS	38		38
Oil Trap/sedimentation Tank	Metals	-7	41	30
	PAHs	-30	-26	
	TSS	-19	43	33
Oil Separator/wet balancing pond	Metals	19	35	48
	PAHs	13	50	57
	TSS	-9	62	58
Oil Separator/dry balancing pond	Metals	27	39	56
	PAHs	4	16	22
	TSS	56	-37	40

Table 33 Indicative treatment efficiencies (DMRB 2006)

Parameter	Inlet mg/l	Outlet mg/l	% Reduction
TSS	43 - 437	10 - 32	88
TOC	2.23 - 47.04	2.74 - 13.4	14
TCu	0.019 - 0.095	0.008 - 0.039	68
TPb	0.027 - 0.092	0.016 - 0.045	62
TZn	0.081 - 0.426	0.012 - 0.045	85
TCd	nd - 0 .008	nd - 0.002	62
TP	0.06 - 0.188	0.008 - 0.039	68

Table 34 Treatment efficiencies of Wetland on M7 (Higgings n.d.)

8.4.2 Combined Filter Drains (French Drains)

Although combined filter drains were principally designed as a conveyance component they do show significant treatment capacities, up to 90% for metals and PAHs. This is probably due to the fact that these systems get clogged with clay particles that in turn treat the runoff through filtration and adsorption processes. The negative aspect is that they will then only treat a small fraction of the runoff as it will bypass the system once clogged.

8.4.3 Wet Ponds, wet balancing ponds, detention basins (Attenuation Ponds)

Wet ponds again show a consistency through the efficiency tables above and are efficient at the removal of suspended solids and, therefore, also the sediment bound phase of the heavy metals but not the soluble phase.

8.4.4 Oil Separators (traps).

Oil separators tend to show a very inconsistent set of results with in some cases negative results indicating that the concentration of pollutants in the outlet is actually higher than the input concentration. The oil separators are generally not efficient at removing PAHs as they are again bound to sediment particles. The negative results are probably due to turbulent flow through the oil traps resulting in a higher sediment load at the outlet and consequently a higher concentration of both metals and PAHs. This is not always the case, however, and various design criteria controlling flow through the separator must be an important factor.

8.4.5 Swales

Based on Table 30 swales are efficient at the removal of both heavy metals and PAHs and will also treat the dissolved fraction of the metals.

8.4.6 Summary

Most of the SUDS components are efficient at removing pollutants from road runoff. As the highest concentration of pollutants is associated with the sediment fraction, simple attenuation (settlement) ponds still have a major role to play. Where additional treatment is necessary due to the sensitivity of the receiving environment, further treatment systems will be required. The most efficient treatment system is a constructed wetland. Swales also offer good treatment for runoff and have a major additional benefit of providing significant additional storage capacity. A combination of swales with attenuation ponds and wetlands would suit the most sensitive environmental constraints. The attenuation pond is required as it offers additional attenuation for storm events that may not be catered for by the wetland. If, however, there is sufficient capacity within the swale, a hybrid pond may be a viable alternative.

Plate 17 Simple detention basin with flow control structure.

9 Section 5 Part 1 - Design Criteria and Site Surveys

9.1 Site Investigation and Drainage Design

This section reviews the site investigation requirements for drainage design and the approach to be adopted during the planning and design of national road scheme development. Table 35 outlines the site investigation that takes place as part of the EIS requirements and the geotechnical investigations during the EIS phase (phase 4) of a national road scheme. Many of the site investigation surveys required for drainage design are carried out as a routine part of the road scheme EIS phase (phase 4) which is primarily focussed on assessing and mitigating environmental impacts. It is vital that any additional information required for the drainage design is incorporated into this phase and that these additional requirements are discussed between the design team, the hydrologist and hydrogeologist. This will avoid unnecessary survey duplication and result in a more comprehensive robust drainage design at the design and EIS phase (phases 3 and 4). The following sections outline the approach to drainage design, survey requirements and design practice.

9.1.1 Drainage Design – Good Practice

The realisation of the primary goal of achieving a sustainable drainage design will require liaison between the design team, the hydrologists or hydrogeologist and the ecologist. The key environmental objectives and site investigation surveys should be focussed on the likely significant impacts and a robust drainage design developed in response to the key environmental objectives.

During the EIS phase (phase 4), the following items should be covered:

- Outline details on consultations,
- Method statement on how runoff will be dealt with during construction,
- Details on how drainage design will meet SUDS objectives both volumetrically and qualitatively
  - Agree hydraulic, water quality, amenity and ecological objectives for site,
- Land take required,
- Maintenance responsibilities,
- Risk assessment to groundwater and surface water,
- Take account of existing and future development,
- Safety measures for ponds and conveyance systems.

9.1.2 Drainage Design – Survey Requirements

The following are required for a detailed design of the drainage systems to be adopted. The level of detail will vary depending on the sensitivity of the receiving environment. In areas where protected areas are at risk or where the groundwater resources are vulnerable, the following should be addressed at the planning stage. In other situations a lesser detailed approach may be adopted. In all cases the drainage design will be reviewed by the statutory consultees at the EIS phase and prior to construction.

9.1.2.1 Catchment Characteristics

- Drainage patterns, flow directions and flow volumes,
- Catchment areas for road and river crossings,
- Soils – permeability, recharge coefficients, type,
- Groundwater levels,
- Bedrock – type, recharge mechanisms,
- Vulnerability of bedrock aquifer,
- Rainfall patterns for design storms either
    - Met Eireann
    - NERC FSR 1975 approach,
- Receiving watercourse water quality and capacity,
- Methodology for culvert sizing,
- Flooding information to include impacts on overland flow,
- Account for Climate change.

9.1.2.2 Drainage Details

- Identify outfall locations,
- Proposed discharge rate for each outfall,
- Outline drainage components, pre treatment, source control and site control ,
- Infiltration tests,
- Volumetric calculations
    - Pre and post peak runoff rates,
    - Attenuation for storm events,
    - Short term and long term storage,
    - Drain down time,
    - Treatment volumes,
- Downstream analysis of discharge locations – risk assessment,
- Erosion control
    - Streambank stabilisation,

- Erosion prevention,
- Velocity control.

9.1.2.3 Summary

It is evident that many of the site survey details required for the drainage design are established during the EIA and geotechnical investigation. Additional surveys on the downstream capacity of receiving waters and issues related to erosion control are relatively minor and should be included as part of the EIS phase. Is it essential that assessments are based on the site investigation results and not simply on desk top studies, e.g. aquifer vulnerability. The site investigation surveys will be considerably more detailed than the information available from desk top sources.

Geological Parameter	Method of Determination
Depth of subsoil / depth to bedrock	Trial pits Cable percussion boreholes Percussive drillholes
Rock type, weathering, structure	Rotary core drillholes
Soil re-usability	Soil compaction, MCV and CBR tests
Soil contamination	Soil quality tests (as per CLEA Soil Guideline Values) Soil leachate tests (as per Council Decision 2003/33 criteria)
Buried cavities (in karst)	Geophysical surveys (microgravity, ground penetrating radar)
Soil strength / stability	Standard penetration tests (SPT) Undrained shear strength tests Effective stress strength tests
Aggregate resource	PSD analysis (of granular soil) Petrographic analysis (of rock) Rock aggregate testing
Rock excavatability	Rock strength tests Geophysical surveys (seismic refraction)
Soil compressibility (settlement)	Oedometer tests
Hydrogeological Parameter	**Method of Determination**
Soil profile / depth of subsoil / depth to bedrock	Trial pits Cable percussion boreholes Percussive drillholes
Rock type, weathering, structure	Rotary core drillholes
Rock fracturing	Downhole acoustic or optical televiewer

Permeability	PSD analysis (of all subsoils) In-situ permeability tests Packer tests (rock) Pumping tests Laboratory tests (ideally on 'undisturbed' samples)
Buried cavities (in karst)	Geophysical surveys (microgravity, ground penetrating radar)
Flow paths in karst	Dye tracing
Groundwater level, hydraulic gradient, groundwater flow direction	Standpipes and/or piezometers in completed boreholes or drillholes (consider continuous monitoring with dataloggers at particularly sensitive sites)
Groundwater quality	Various laboratory techniques
Hydrological Parameter	**Method of Determination**
Flow Records Gauged Rivers	Records OPW
Flooding Records	Records OPW
Flow measurements Ungauged Rivers	Field studies
Water Quality Monitoring	Field Studies
Abstractions	Local Authorities, GSI

Table 35 Site investigations EIS Phase(phase 4)

Planning Drainage Design

- Outline details on consultations
- Method statement on how runoff will be dealt with during construction
- Details on how drainage design will meet SUDS objectives both volumetrically and qualitatively
  - Agree hydraulic, water quality, amenity and ecological objectives for site
- Land Take required
- Maintenance responsibilities
- Risk assessment to groundwater and surface water.
- Take account of existing and future development
- Safety Measure for ponds and conveyance systems

Chart 6 Requirements for planning drainage design

Catchment Characteristics

• Drainage Patterns, flow directions and flow volumes
• Catchment areas for road and river crossings
• Soils – permeability, recharge coefficients, type
• Groundwater levels
• Bedrock – type, recharge mechanisms
• Vulnerability of bedrock aquifer
• Rainfall patterns for design storms either
    - Met Eireann
    - NERC FSR 1975 approach
• Receiving watercourse water quality and capacity
• Methodology for culvert sizing
• Flooding information to include impacts on overland flow
• Account for Climate change

Chart 7 Catchment characteristics for drainage design

Drainage Details

• Identify outfall locations
• Proposed discharge rate for each outfall
• Outline drainage components, pre treatment, source control and site control
• Infiltration tests
• Volumetric calculations
    - Pre and post peak runoff rates
    - Attenuation for storm events
    - Short term and long term storage
    - Drain down time
    - Treatment volumes
• Downstream analysis of discharge locations – risk assessment
• Erosion control
    - Streambank stabilisation
    - Erosion prevention
    - Velocity control

Chart 8 Drainage design details

9.2 Design Criteria

The following section contains key aspects of the design criteria for the SUDS components based on the SUDS Manual (CIRIA C697 2007) and the DMRB (several HA documents).

9.3 Pre Treatment

The design of silt traps, catch pits and gullies is addressed in the NRA MANUAL OF CONTRACT DOCUMENTS FOR ROAD WORKS. VOLUME 4. ROAD CONSTRUCTION DETAILS.

9.4 Source Control

9.4.1 Filter Strips

Purpose built grass filter strips are rarely used on national road projects but are common on rural roads. For national road projects, when the road alignment is on low embankment, an over the edge drainage system is sometimes adopted (following the HD33/06 guidance) with interceptor ditches or grassed channels at the base of the embankment conveying the runoff. In most cases these systems will also allow infiltration to groundwater as they are rarely required to be lined, unless the aquifer is highly vulnerable. In this situation the runoff is conveyed by sheet flow into the drainage ditches across the grassed embankment. The slopes of these embankments are generally steeper than the recommended slopes for filter strips but these grassed slopes will offer some treatment. Steep slopes can result in flow concentration resulting in erosion and impacts on the integrity of the embankment.

Purpose built filter strips consist of gently sloping strips of grass designed to treat road runoff through the removal of suspended solids by filtering and infiltration. They can be used as a pre treatment before systems such as filter drains. They will also offer attenuation reducing the time of concentration for the drainage design by encouraging evaporation and infiltration. The velocity of the flow needs to be low (0.3 m/s) to allow for efficient treatment.

Filter strips should only be used as a pre-treatment system on national road projects as a large land take is required to function independently.

9.4.1.1 Key Design Criteria

- Slopes not exceeding 1:20. Minimum of 1:50,
- Width 1m for every 6m length of paved surface,
- Water lower than height of vegetation generally <50mm,
- Flow velocity of 0.3m/s to ensure treatment and <1.5m/s to avoid erosion,
- Use Manning's equation to design strip
    - $V = d^{2/3} S^{1/2}/n$
        - V = mean cross-sectional flow velocity (m/s)
        - d = depth of flow (m)
        - S = longitudinal slope of filter strip (i.e. in the direction of flow) (m/m)

- n = Manning's n roughness coefficient ($m^{-1/3}s$),

- Longitudinal slope of 1:50 and max 1:20,
- Detail design – The SUDS Manual.

9.4.2 Note

To avoid sediment build up and resulting flooding, the grass filter strip should be 50mm below the road surface (see SUDS for Roads - Scottish SUDS Working party).

9.4.2.1 Maintenance

- Regular mowing to ensure efficiency
- Removal of litter and debris
- Check and remove any invasive species
- Check for any preferential flow path development and remove any silt.
- Check for pollutant load in soil.

9.4.3 Trenches – Combined Filter Drains

Combined filter drains or trenches are shallow linear excavations filled with stone and are very common on national road projects especially in cuttings. These systems offer temporary storage of runoff prior to infiltration to groundwater or conveyance via a perforated pipe to an attenuation system. If these systems are to be used for infiltration, the base of the drain must be above the groundwater table. These filter drains are not designed to function as sediment traps and some pre-treatment should be part of the design, e.g. grass filter strip. If pre-treatment cannot be provided, the top layer will have to be regularly removed as the drains will become clogged soon after construction (time span depending on sediment load but can be as little as 1 year). This can be achieved using a geotextile separator as shown in Figure 17. This enables the top layer to be removed for cleaning or replacement. The design standard is given in detail in the NRA DMRB MANUAL OF CONTRACT DOCUMENTS FOR ROAD WORKS. VOLUME 4. RCD 500/1.

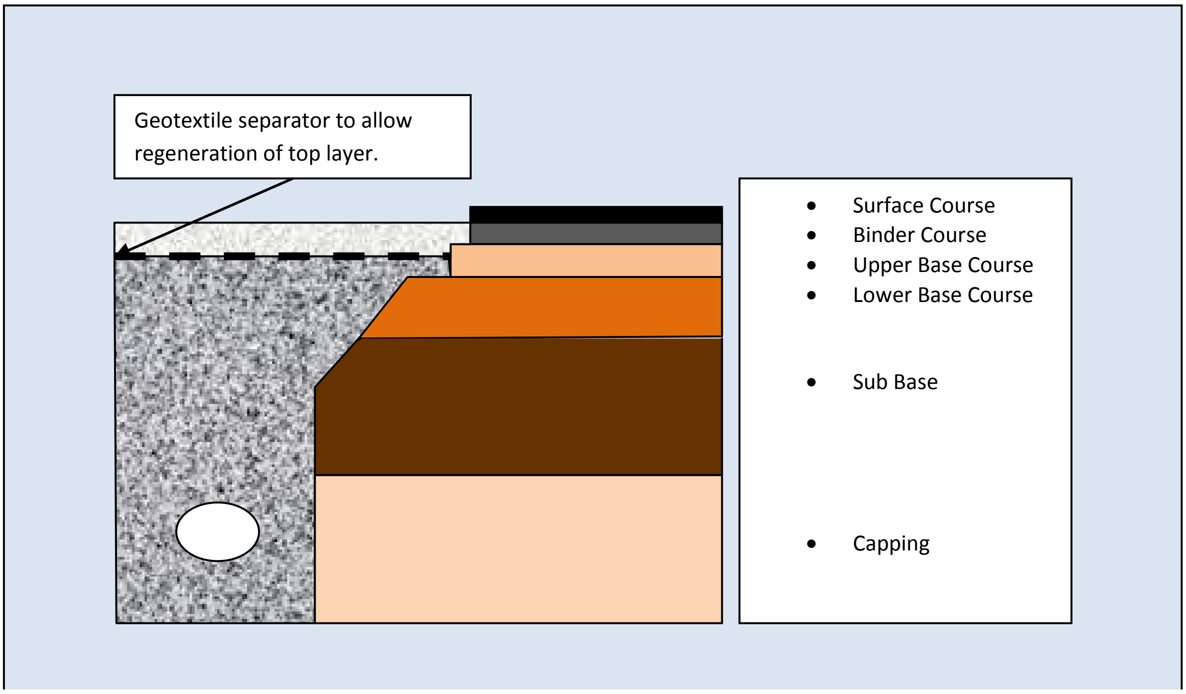


Figure 17 Combined filter drain with geotextile grid and carrier pipe

Combined filter drains are most suited to areas where there is low risk to the underlying bedrock aquifers, i.e. areas with low or moderate vulnerability. They are not suited to areas of high vulnerability or areas with sand or gravel aquifers. In areas of low risk they can be used as infiltration systems. Infiltration rate is generally assessed using Darcy's Law. However, as low risk areas generally mean low or moderate permeability, it is unlikely that there will be a sufficient infiltration rate and a perforated carrier pipe is generally required conveying to an attenuation pond. Combined filter drains can offer significant storage when functioning properly, reducing the required size of attenuation ponds.

Plate 18 Regenerated French Drain. After clogging the combined filter drain can be cleaned.

9.4.3.1 Key Design Criteria

- Pre-treatment or the use of geotextile separator to allow regeneration,
- Will require observation points for maintenance,
- No infiltration in high or extreme vulnerable aquifers,
- Will need to establish permeability on underlying subsoil to establish if infiltration is feasible otherwise use perforated carrier pipe and convey to attenuation system.

9.4.3.2 Maintenance

- Regular inspections to remove weed and grass,
- Remove any silt build up by regeneration,
- Check inspection points (catchpits) for clogging,
- Check all outlets from carrier pipes for clogging.

9.4.4 Grassed Surface Water Channels

Grassed channels offer significant environmental benefits in a cost effective manner and are used in many instances as a replacement for concrete channels. Details of surface water channels and their design are given in DMRB Volume 4 Section 2 Part 9 HA 119/06. A grassed channel will attenuate the flow rates of road runoff due to the increased surface roughness and will therefore increase the time of concentration. This will, in turn, reduce the peak runoff rates to the receiving watercourse or secondary treatment system (wetland, attenuation pond, infiltration system). An example of a hydrograph from a lined grassed channel system used in a karst area in the west of Ireland is shown (Figure 18). The grassed channel is discharging to a wetland system and the outlet from the grassed channel to the wetland was monitored. The peak discharge rates from the grassed channels for this particular rainfall event to the wetland are < 20 l/s. The lag interval is in the region of 1 hour.

The expected discharge rates from a typical concrete channel system or a kerb and gully system would be in excess of 70 l/s with a lag interval of < 15 minutes. As well as attenuating the flow, the grassed channel system will remove much of the suspended solid load. Since many of the road runoff pollutants are associated with the sediment bound phase, the system will, therefore, significantly reduce the pollutant concentration reaching the receiving watercourse or the attenuation system.

Data from these grassed channel and wetland systems **is** still being assessed and further research is required before any runoff coefficients can be adopted for these systems and applied to road drainage design.

In the event of an accidental spill, the grass channel will contain the hydrocarbons due to the low flow velocity by retaining the pollutants in the top soil which can then be removed and reconstructed.

Details of construction and worked examples are given in HA 119/06 and should be referred to. Brief outlines of the key elements are given here.

9.4.5 Design Criteria

In most instances a symmetrical triangular shape can be adopted with side slope of 1:5 maximum (Figure 19) (see HA

119/06 for worked examples).

Plate 19 Grassed surface water channel used to treat and convey surface runoff. Contains a mix of grass types to attenuate flow.

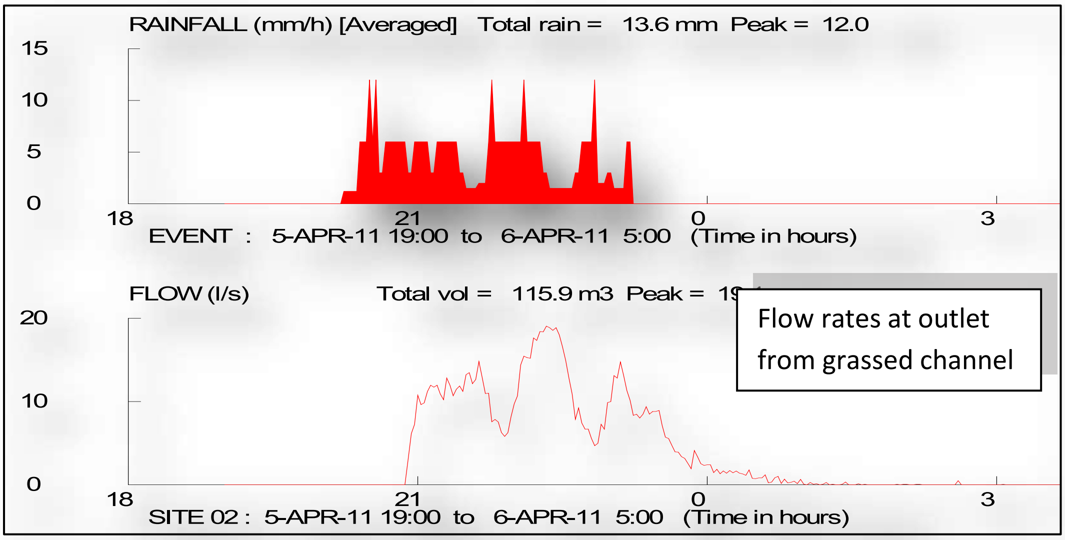


Figure 18 Hydrograph for grassed channel system

The flow capacity of the channel is assessed using the Manning resistance equation and for the above triangular cross section the equation has the form:

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

Where:

- Q is the maximum discharge rate (m^3/s)
  - B is surface flow width

- Y is flow depth

- n is Mannings roughness coefficient.

Typical values of n (generally from 0.05 to 0.1) will vary depending on the grass type, the hydraulic radius of the channel and the slope of the road and is calculated using the following:

$$n = 0.5/ (1-(mH/R^{5/3}\ S^{1/2})$$

where:

- H = 0.05m for Fescues dominated mixtures and 0.075 for perennial grass
- m = 0.0096 for Fescues dominated mix and 0.0048 for perennial grass
- S = slope of road m per m
- R = hydraulic radius = A/P (cross sectional area / wetted perimeter for design flow)

Typical maximum flow rates for a 2 meter surface width (B) and a 0.2m flow height with perennial grass, road gradient of 1 in 100m (S = .01) are approximately .07 m^3/s or 70 l/s.

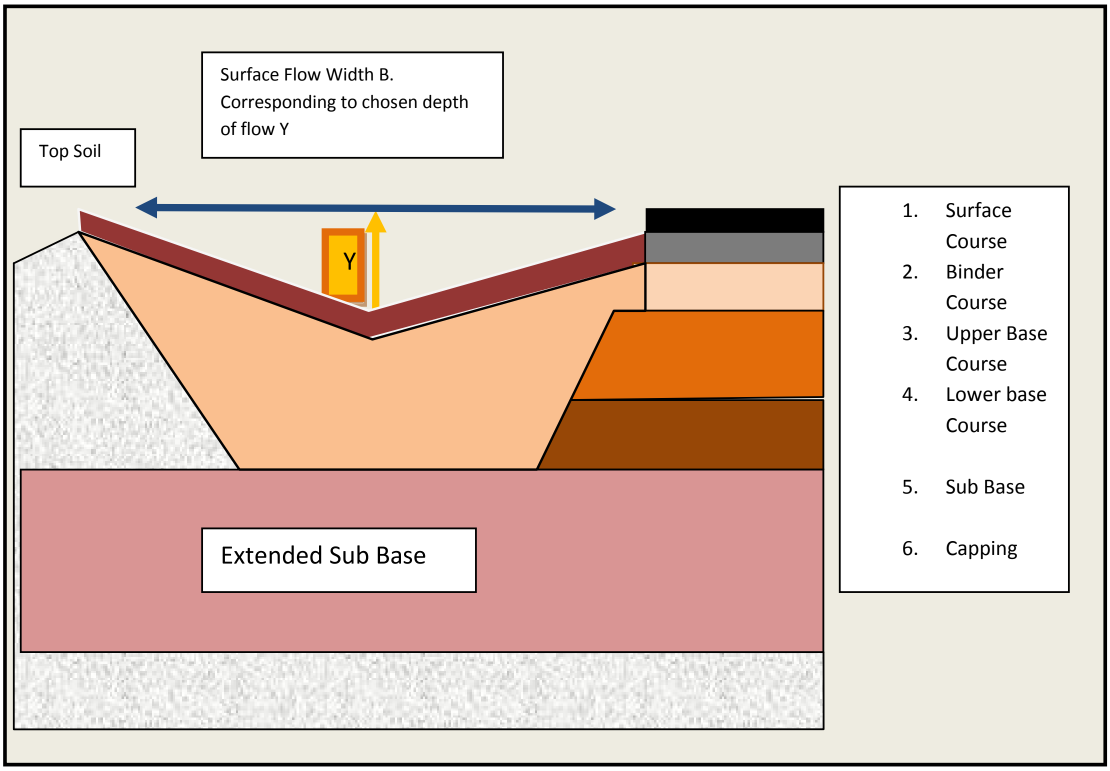


Figure 19 Grassed Surface Water Channel

9.4.5.1 Additional Design Features

Some additional design features may be required depending on the sensitivity of the receiving environment and the hydrogeological conditions.

9.4.5.1.1 Liner

A liner may be required in areas of high or extreme vulnerability (Figure 20). Guidelines on the appropriate liners are given in the NRA DMRB.

9.4.5.1.2 Sub Soil

The grassed channel, founded on prepared ground can supply additional treatment capabilities above the natural sub soil. This can have the effect of reducing the risk to groundwater in an otherwise high risk area.

9.4.5.1.3 Fin Drains / Carrier pipes

In areas of cutting, a fin drain will be required to convey groundwater. In areas of moderate vulnerability and where there is a medium risk to groundwater, consideration should be given to using a carrier pipe within the grassed channel as shown (Figure 20).

9.4.5.1.4 Separation of groundwater and surface water

Every effort should be made to keep groundwater and surface water separate especially in sensitive environments. This will allow for recharge of the groundwater aquifer with the groundwater conveyed through the fin drains and a separate treatment system for the road runoff.

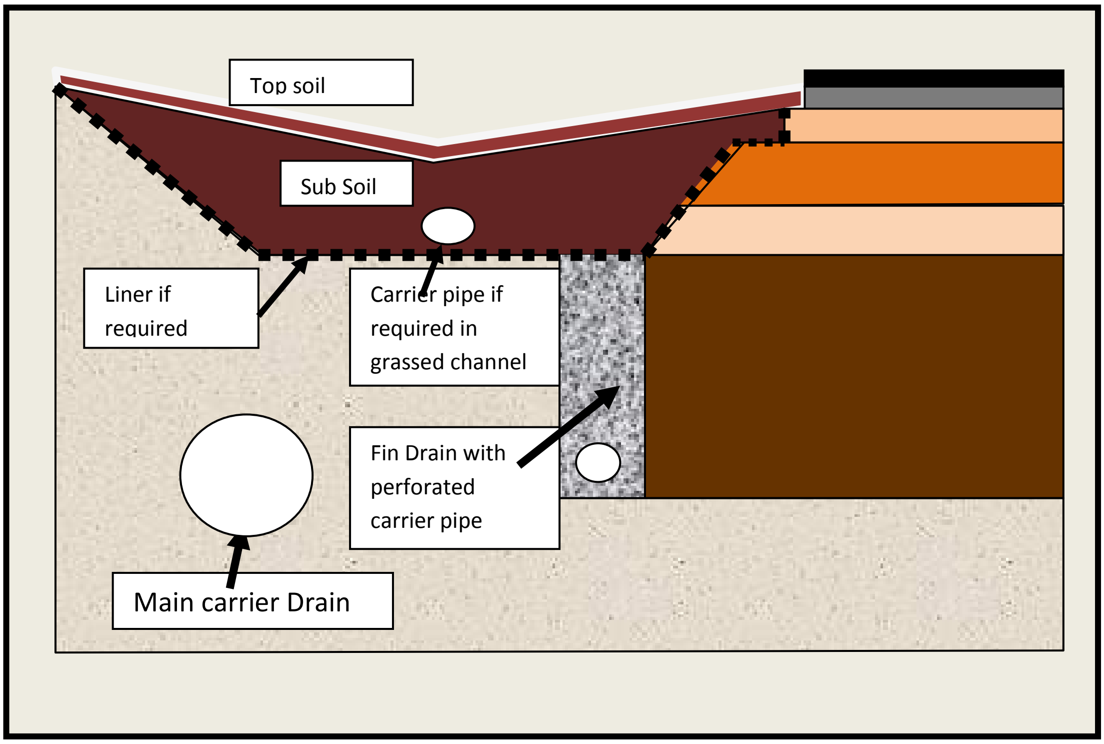


Figure 20 Additional Design Features for Grassed Channels

9.4.5.2 Maintenance

- Regular inspections to remove litter and debris
- Regular mowing
- Ensure sheet flow into channels is maintained and inspect for preferential flow paths
- Remove any silting at road edge.
- Check for pollutant levels in soils
- Check for pollutant levels at outlets.

9.4.5.3 Planting

Suitable grass types are a Perennial Ryegrass and Fescues dominated mixtures. HA 119/06 gives further advice on the types of grasses and a typical example would consist of :

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

A further example of a seed mix is given in a paper on the A120 in the UK (Macer-Wright 2003)

9.4.6 Combined Filter Drain and grassed channel

HA 119/06 refers to a design detail that consists of a combined filter drain and grassed channel. This may be used to prevent stone scatter. A geotextile may be required to be placed above the filter drain material to prevent fines clogging the drain. A schematic representation of the design is presented in Figure 21. The detailed design is given in drawings B15 of the B series (MCHW Vol 3 2008)and in F2 of the F series of the HCD – MCHW3 (MCHW 2008). These systems may be adopted for cuttings and where retrofitting is required due to the clogging of the filter drain.

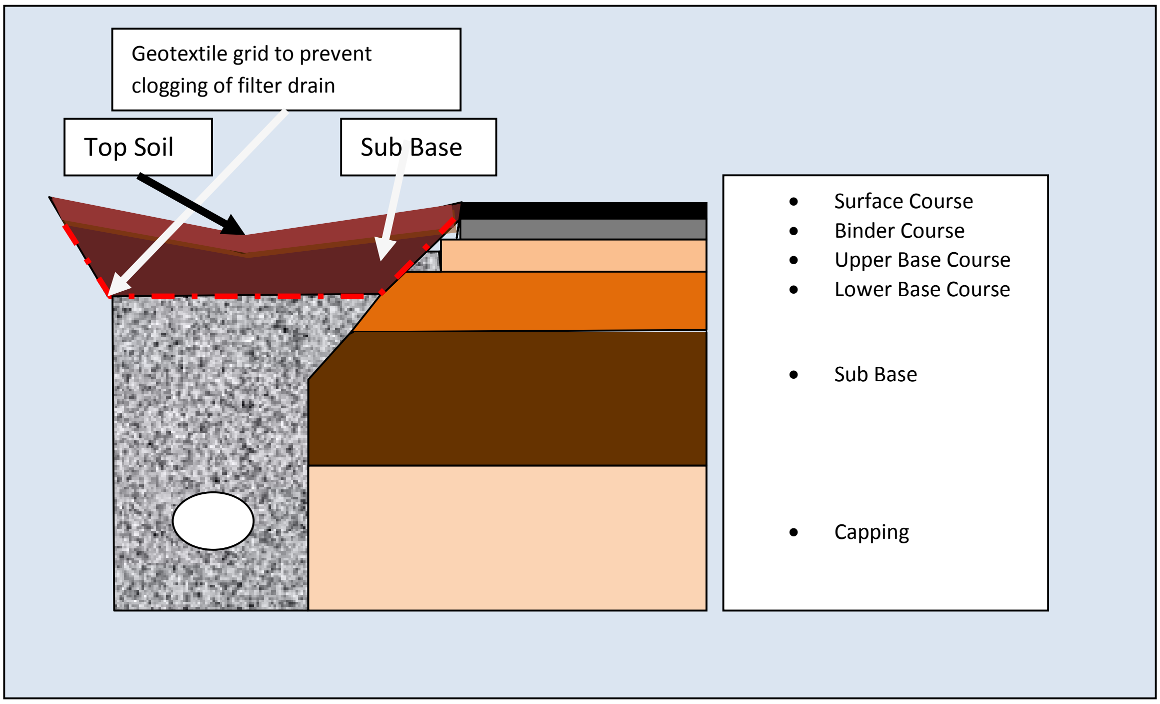


Figure 21 Combined filter drain and grassed channel

9.4.7 Swales

Swales are shallow channels designed to store and convey water and remove pollutants and are very similar to grassed channels. The principal differences are related to dimensions. True swales will require a larger land take based on the design criteria described in the SUDS manual. They can also be designed to promote infiltration and can have check dams to trap particulate pollutants. The three types of swales are the standard conveyance swale, the dry swale and the wet swale. The standard conveyance swale conveys the runoff to the next treatment system treating the runoff by detention and filtration. A dry swale consists of filter layer of prepared soil overlying the existing stratum providing additional protection and additional storage capacity. The wet swale will also convey but will at all times remains marshy and wet either through the use of liners or because of their location on poorly drained soil. Wet swales can become linear wetlands offering ideal treatment for both sediment bound and soluble pollutants.

9.4.7.1 Swale types (Based on The SUDS Manual)

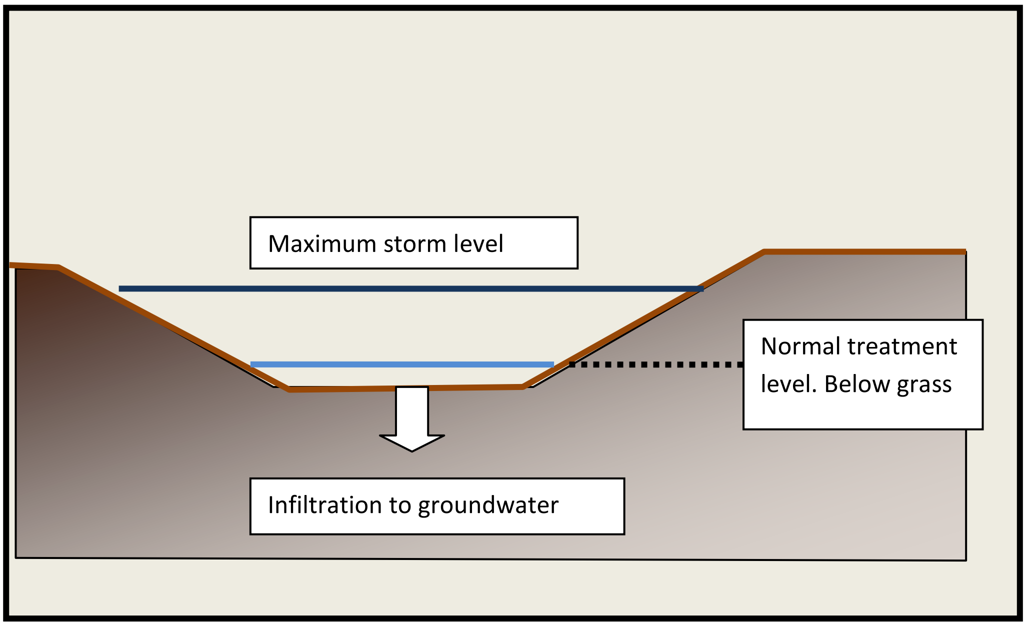


Figure 22 Typical standard conveyance swale

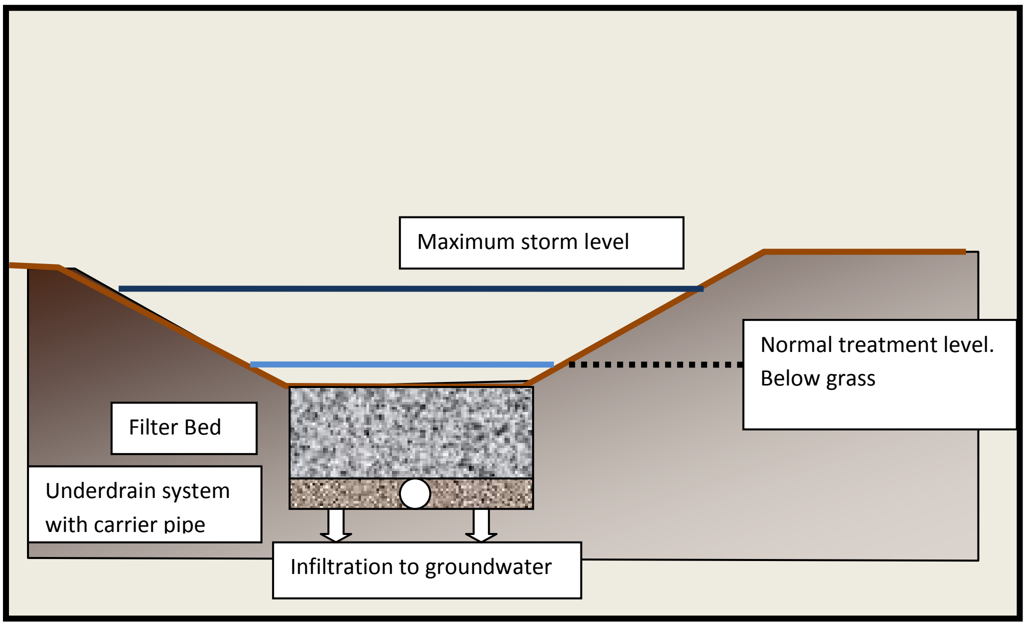


Figure 23 Dry Swale

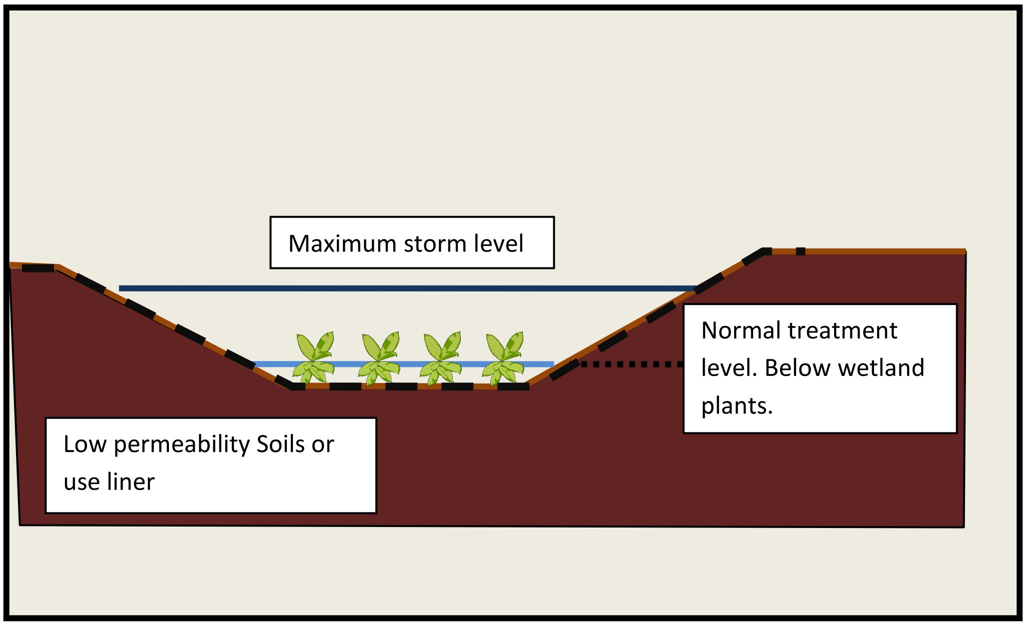


Figure 24 Wet Swale

Conveyance or standard swales can be used for conveyance and detention through the use of check dams. They may be lined in situations where the groundwater aquifer requires protection. Dry swales can have a filter bed and an underdrain system for additional conveyance capacity. The filter bed adds another layer of treatment to the component of runoff reaching groundwater. If infiltration is to be adopted, the base of the conveyance swale or the dry swale must be 1 m above the winter groundwater level. A wet swale is suited to situations where the subsoil has low permeability and wetland conditions are likely to develop. If the permeability of the subsoil is high, a liner could be used to promote marshy conditions. Linear wetland systems, such as a wet swale, are considered to be one of the best treatment options for road runoff. These systems could be suited to karst areas with low permeability subsoils.

Swales are generally promoted as treatment systems in urban situations where kerb and gully drainage designs collect runoff which is then conveyed to the swale by means of paving slabs or other systems that facilitate sheet flow. Because of the large land take required they are not often adopted on national road projects. The previous section on grassed channels shares many of the principal concepts. Swales can also be used as the principal conveyance system in the same manner as grassed channels.

9.4.7.2 Design Criteria

- Flow velocities are calculated using the Manning resistance equation. Typical values for n are 0.25 for a water level below the vegetation and 0.1 for a water level above the vegetation,
- Flow velocities for extreme events should be 1.0 – 2.0 m/s to avoid erosion,
- Shapes should be trapezoidal or parabolic in cross section,
- Side slopes should be no greater than 1:4 but can be 1:3 if safety designs allow,
- A free board of 150mm should be provided over the design depth of flow,
- Longitudinal slopes.
    - Conveyance swale minimum 1:300 but not less than 1:100

    - Dry or wet swale. No minimum but do not exceed 1:40 or 1:25 if safety consideration allow,
- Base of swale should be between 0.5 and 2m,
- Maintain flow level to below vegetation height for treatment events.

9.4.7.3 Maintenance

- Regular inspections to remove litter and debris,
- Regular mowing,
- Ensure sheet flow into channels is maintained and inspect for preferential flow paths,
- Remove any silting at road edge,
- Check for pollutant levels in soils.

9.4.8 Linear wetlands

Linear wetlands and wet swales are considered in many countries to be best practice for the treatment of road runoff (e.g. (Virginia Water Resource Research Centre 2011)). These types of systems would be suited to many areas in Ireland where there is a requirement to maintain the hydrological regime and wetland systems. They could also be adopted for use in karst areas where is important to avoid point source discharge and instead, allow treated runoff to infiltrate in a diffuse manner. These systems will attenuate and store runoff keeping the runoff in the same catchment and have been shown to treat road runoff to a high standard.

9.4.8.1 Design Criteria

The design criteria for linear wetlands are very similar to wet swales (Figure 24). Side slopes can, however, be steeper (1:3) providing safety considerations have been taken into account. Flow into linear wetlands may be from sheet flow or from a point source. The principal objective is to ensure adequate residence time allowing suspended solids to settle out. Flow, therefore, can be directed from e.g. a kerb and gully system into a linear wetland and then discharged to a receiving watercourse or can be gathered from over the edge systems. If the required attenuation is not sufficient to avoid flooding impacts, the flow can be directed into an attenuation pond or a conventional wetland prior to discharge.

When adopting over the edge drainage design, the flow will be directed into a linear channel or ditch at the toe of the embankment. These ditches often end up as linear wetlands where the soil has low permeability.

Plate 20 Linear wetland with wetland plants, constructed adjacent to the motorway, is used to convey and treat road runoff prior to discharging to either surface water or groundwater.

9.5 Site Control

9.5.1 Wetlands

Wetlands have proven to be the most effective attenuation system for treating road runoff. Detailed and prolonged monitoring of a wetland system used on a motorway in Ireland has indicated significant treatment efficiencies with a 88% reduction of suspended solids and 60 to 80% reduction in metal concentrations. The wetland was collecting runoff from a kerb and gully system and discharging to a major river (M. Bruen 2006). These types of treatment efficiencies are common throughout countries that have adopted these systems. As well as offering efficient treatment, the wetlands will also significantly reduce the discharge rates. The treatment is based on establishing a sufficient residence time which is often taken as 24 hours R = V/D where R is residence time, V is volume of water in the pond and D is the discharge rate. Residence time is further discussed below. Wetland systems are suited to most hydrological areas provided they can be kept wet to maintain plant life. In extreme or high vulnerable areas (e.g. karst) the wetland system will require lining. Detail on wetland design is given in The SUDS Manual ((CIRIA C697 2007) in The DMRB guidance HA 103/06 (DMRB HA 103/06 Vol. 4 2006) and in (Shutes 1999). Some of the principal design elements are discussed here. There are a number of different types of wetlands used to treat road runoff, namely surface flow and sub-surface flow systems. Surface flow wetlands are normally used for the treatment of road runoff.

9.5.1.1 Principal Components of a wetland

A wetland (Figure 25) will generally contain the following elements:

- oil separator and silt trap
- area for spillage containment
- settlement pond or forebay or both

- constructed wetland and associated berm flow control structures
- outfall into receiving watercourse with a flow control
- access track for vehicles for essential maintenance

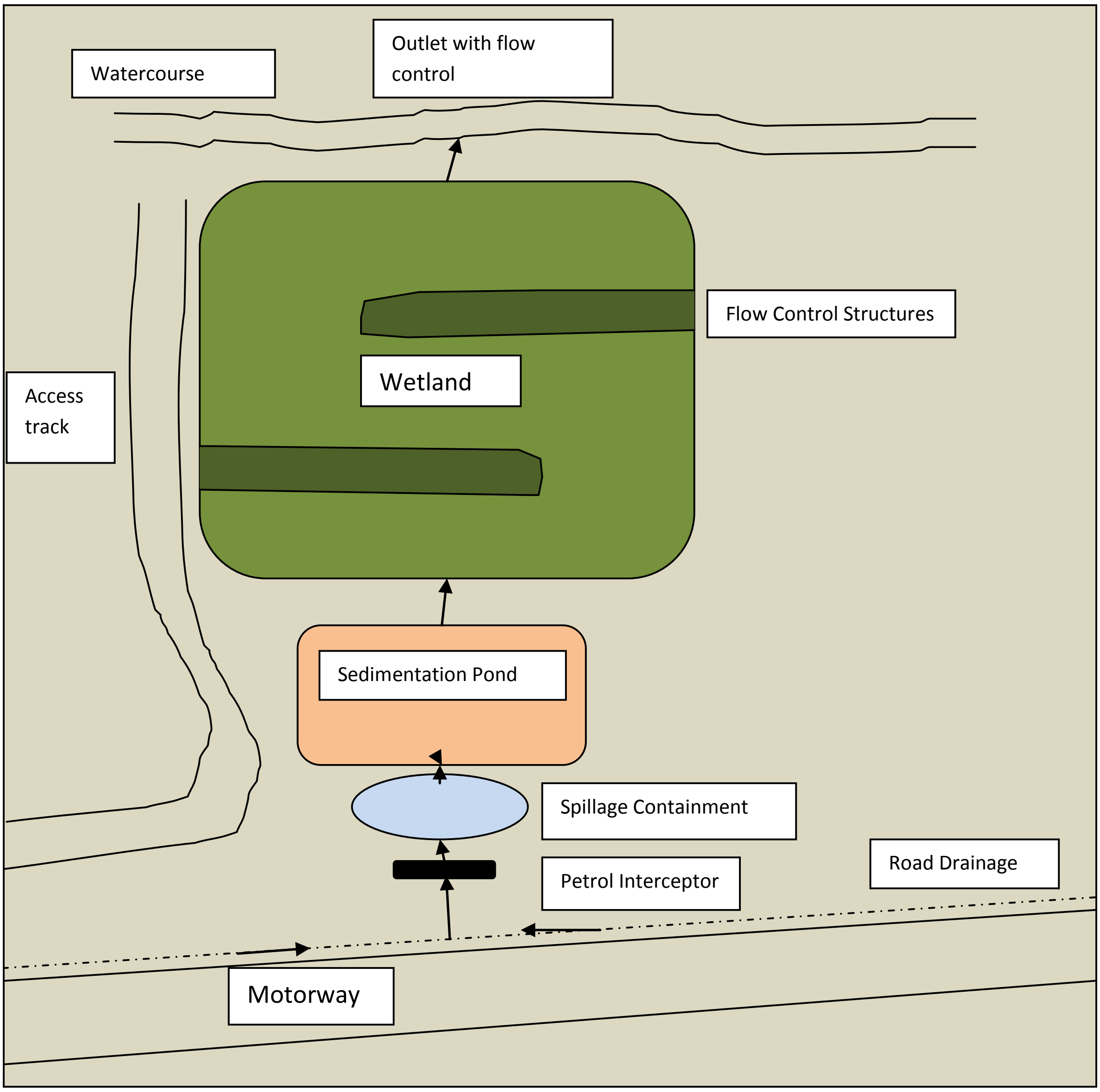


Figure 25 Idealised Wetland components

In many instances the sedimentation pond is incorporated into the wetland as a sediment forebay forming a hybrid pond (Figure 26). These combine the features of balancing ponds and wetlands and are most suited to treating road runoff especially where land take is an issue.

Plate 21 Hybrid Wetland with sediment forebay, berms and a range of water depths to promote different aquatic habitats.

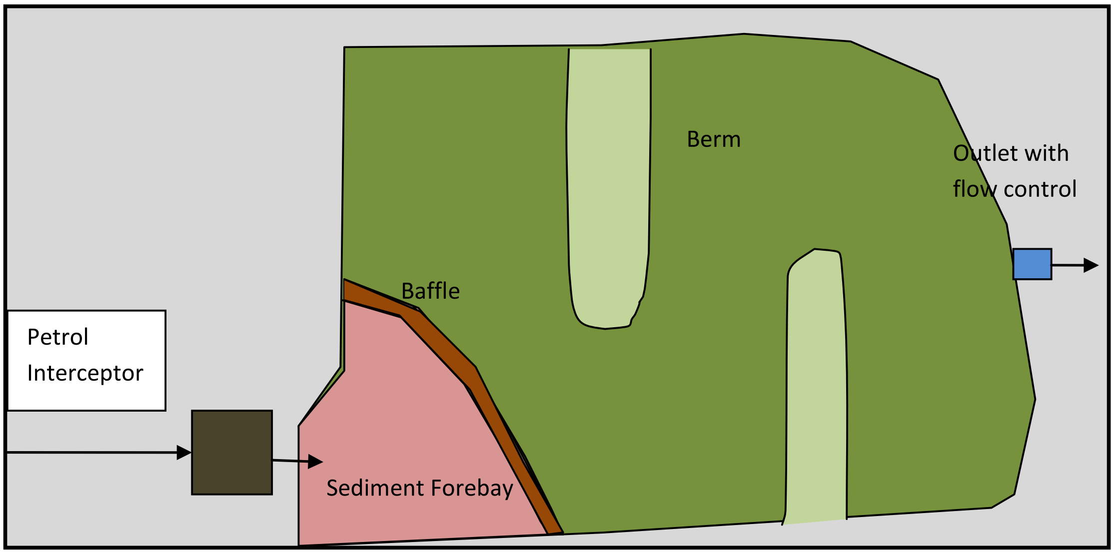


Figure 26 Hybrid Wetland

If wetlands are used in conjunction with a vegetated conveyance system, such as grassed channels or swales, the system is far more likely to be able to cope with the design storm due to the capacity and attenuation properties of the grass channel in conjunction with the wetland (e.g. Figure 27). Figure 27 shows measured flow from a wetland. The wetland is discharging at a peak rate of 3.4 l/s compared with a peak inlet flow 19.1 l/s. If, however, a wetland is used with a kerb and gully or concrete channels then it is likely that the sizing of the pond will be an issue when it comes to the design storm. In this situation the wetland will treat a portion of the storm event (treatment volume) and overflow systems will have to be included in the wetland design. The wetland will, however, treat most of the lesser storm events. Treatment volume is calculated using the following formula:

Vt (m³/ha) = 9.D. (SOIL/2 + (1-SOIL/2).I) where:

D = M5-60, I =Fraction impermeable

Wetlands can be designed with various water levels to incorporate different types of planting and enhance biodiversity (Figure 28).

The ponds should have low flow velocities (<0.1m/s) and should be drought resistant for 30 days. Continuous baseflow is important to ensure the wetland does not dry out. The length to width ratio should be between 1.5: 1 and 4 : 1.

9.5.1.2 Flow Control

It is essential to control the discharge rate to ensure sufficient residence time. Guidance on the design of outflow systems is given in HA 103/06 (DMRB HA 103/06 Vol. 4 2006). Outflow systems control flows using weirs, outflow pipes and an orifice control. For storm events with an annual probability of >10% the discharge rate is controlled by the orifice. For storm events between 1 and 10% the flow is controlled by the outflow pipe. For the <1% storm flow of the surplus water is via a spillway or overflow system. A typical flow control structure may be designed to control the outflow rates for a 10-year storm return event to 1 year greenfield rates (Macer-Wright 2003).

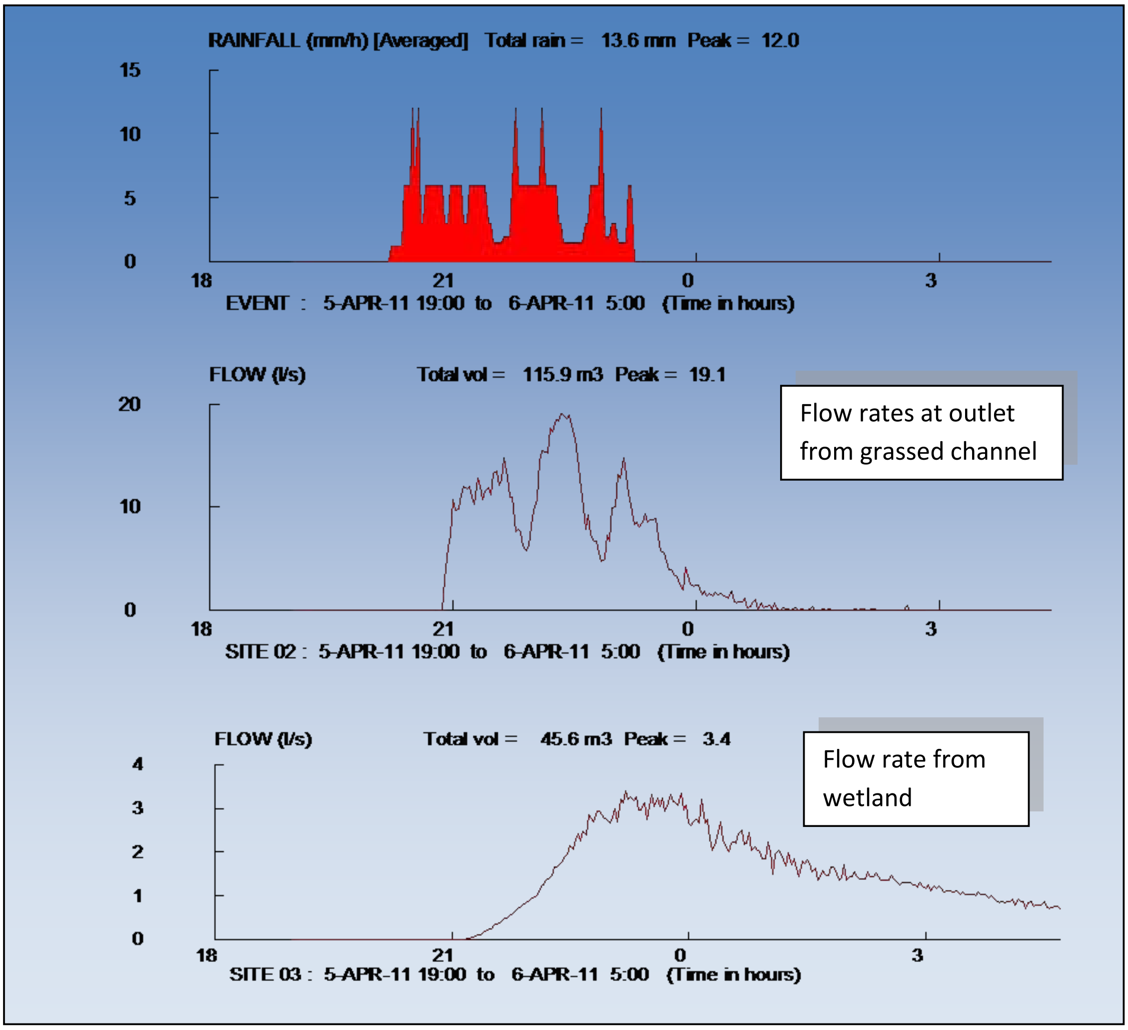


Figure 27 effects of wetland on peak discharge rates

9.5.1.3 Residence Time

HA 103/06 recommends a minimum residence time for a wetland system of 24 hours for the design storm. The objective of a wetland system is to capture and treat runoff from frequent events and to capture and treat a proportion of first flush from larger storm events.

The residence time is given as $R_t = V/D$ where V is the volume of the wetland and D is the discharge rate. The flow rate into the pond is taken from the inlet into the sediment forebay or the inlet from a sedimentation pond. The flow rate, therefore, takes into account the conveyance system. If this is a vegetated system, it will significantly reduce the peak flow rates compared with a concrete channel. It may not be feasible in certain situations to achieve the required residence time due to land availability. In these situations, a compromise solution between conventional drainage design systems such as balancing ponds and vegetated systems, should be adopted to achieve the required attenuation for the design storm.

An alternative approach to residence time is outlined in a paper focussed on the design of vegetative constructed wetlands for the treatment of highway runoff (Shutes 1999). Here the author suggests a minimum residence time of 30 minutes for the design storm. The ideal design should retain the annual average storm volume for a minimum of 3 to 5 hours and preferably for 10 to 15 hours for efficient removal of pollutants (Shutes 1999).

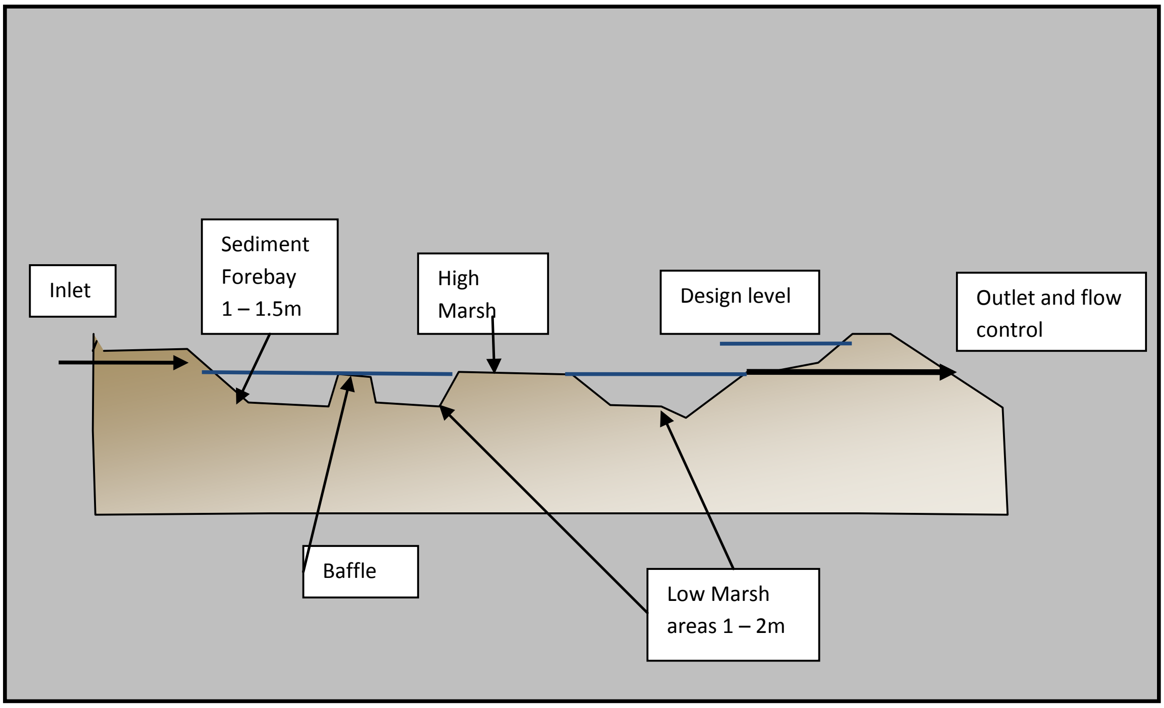


Figure 28 Schematic cross section through a hybrid wetland

9.5.1.4 Planting

Wetland plants should include *Phragmites australis* and *Typha latifolia* for pollution control and other species as directed by the ecologist to enhance biodiversity. Planting density of the pollution control species should be 4 per square metre. Plants should be established with a height of 70 to 90 mm.

9.5.1.5 Maintenance

- Removal of sediment and regeneration of the wetland is expected to take place every 25 years,

- Monitor inlets and outlets for blockages,
- Repair landscaping and planting as required.

9.5.2 Attenuation Ponds

Attenuation ponds are very common on national road projects and advice on their design is given in HA 33/06. The attenuation requirements often vary depending on the nature of the receiving environment but the objective should be to attenuate the 1:100 year storm with 6 hour duration. The principal components of a pond can include:

- Sediment forebay,
- Permanent Pool,
- A temporary storage volume providing storage for the required storm event,
- Shallow aquatic area.

Plate 22 Attenuation pond showing natural vegetation with wetland plants.

9.5.2.1 Design Criteria

- Side slopes 1:3 minimum,
- Length Width ratio of between 3:1 and 5:1,
- Minimum depth of open water 1.2m and Maximum depth of permanent pool 2,
- Control inlet velocities to < 0.5 m/s to avoid resuspension of solids,
- Outlet flow control structure to limit discharge rate to greenfield rate,
- Erosion control on inlet and outlet,

- In areas of high vulnerability a liner is required if soil is not sufficiently impermeable and >1.5m in thickness,
- Winter groundwater level should below the base of the pond.

9.5.2.2 Maintenance

- Sediment removal when required,
- Manage and repair landscaping as required,
- Check inlets and outlets for blockages.

9.5.3 Detention Basins

Detention basin are similar to attenuation ponds but will generally be dry and only fill during the storm event. They may include a small permanent pool to prevent resuspension. The discharge is controlled by constrained flow that allows the basin to fill. The basins will require lining in vulnerable areas but if the base of the basin is below groundwater level than the liner may float. In small catchment areas (<3ha) the permitted discharge rate may require a small outlet pipe to constrain the flow although such pipes may be prone to clogging.

9.5.3.1 Design Criteria

- Length: Width 2:1 maximum,
- Side slopes 1:4,
- Max depth of water <3m,
- 1:100 slope towards outlet.

9.5.3.2 Maintenance

- Sediment removal when required,
- Manage and repair landscaping as required,
- Check inlets and outlets for blockages.

9.5.4 Infiltration Basins

Infiltration basins consist of vegetated depressions storing road runoff and allow infiltration to groundwater. These systems will require pre-treatment, which is essential, to remove the sediment load prior to infiltration, otherwise they will become clogged very quickly. They are generally not suitable in areas of highly vulnerable aquifers or karst areas. In these areas at least two treatment systems should be used prior to discharge to an infiltration basin, e.g. grassed channels and a wetland. They will also require considerable land take to cope with the design storm. A preferred option would be long linear infiltration systems for road runoff rather than discrete basins. Infiltration basins are only suitable for treatment of small storms and the SUDS manual recommends that they be designed offline.

Infiltration tests should be undertaken as described in BRE Digest 365, at the proposed invert level of all infiltration areas. If the infiltration tests do not establishthe required drain down time, an alternative design must be considered.

9.5.4.1 Design Criteria

- Side slopes 1:4 maximum
- Flat basin floor
- Controlled outfall required
- Half drain down time in 24 hours and full drain down in 72 hours

9.5.4.2 Maintenance

- Sediment removal when required
- Manage and repair landscaping as required.
- Check inlets and outlets for blockages.

10 Section 6 – Appendix I Flow Charts and Checklist for Drainage Design

Groundwater Risk Assessment

Assess Aquifer Type Bedrock Sand and Gravel	Conduct appropriate Risk Assessment either Table 14 or Table 15	Table 14 Risk assessment scoring Matrix for bedrock aquifer	Table 15 Risk assessment scoring Matrix for gravel and sand aquifer

Surface Water Risk Assessment - Use HAWRAT Tool

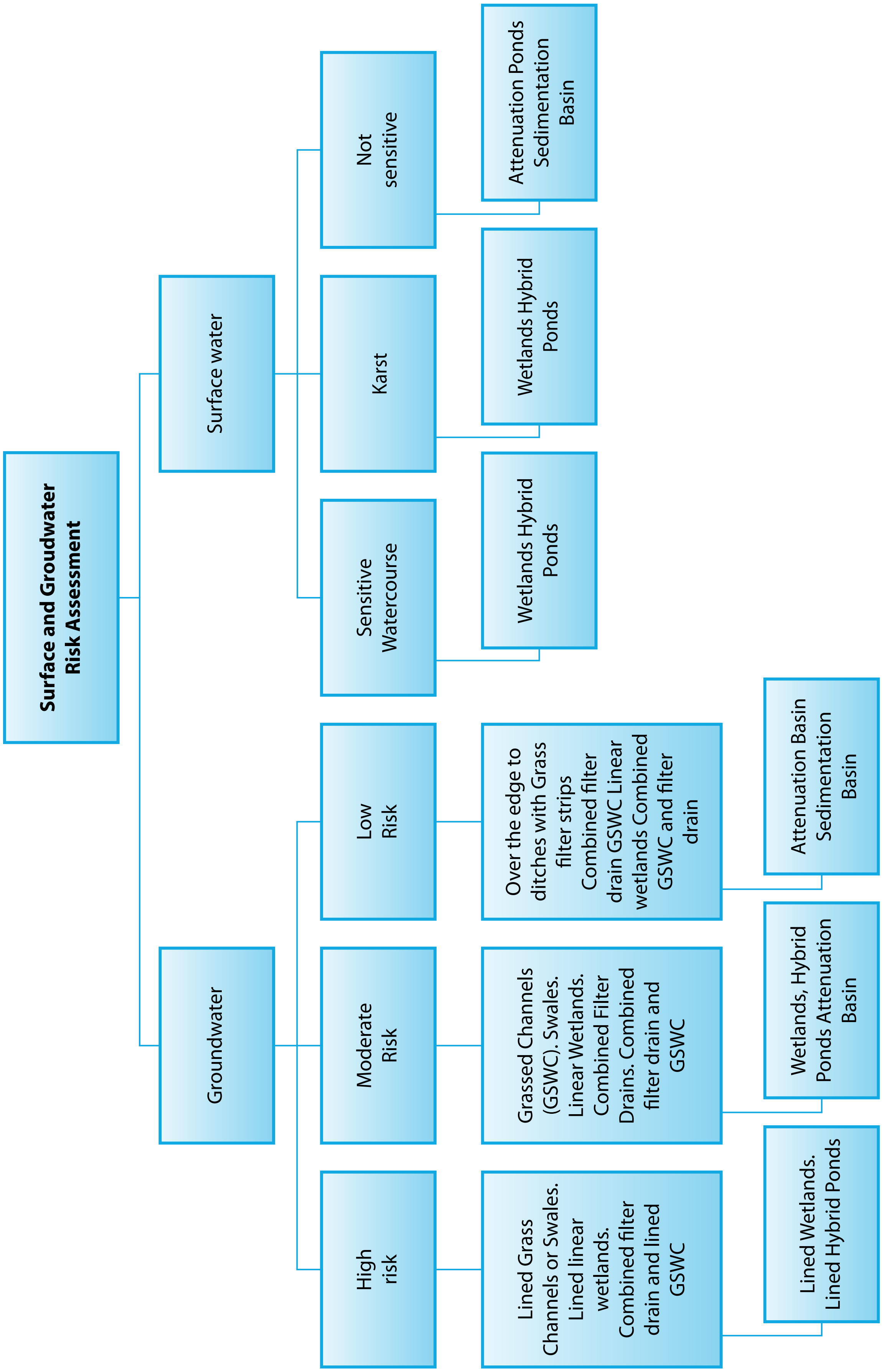
Step 1 Assess pollutant levels with traffic counts and rainfall	Step 2 Assess pollutant levels in receiving waters using 95%ile river flows	Step 3 Assess appropriate mitigation measures

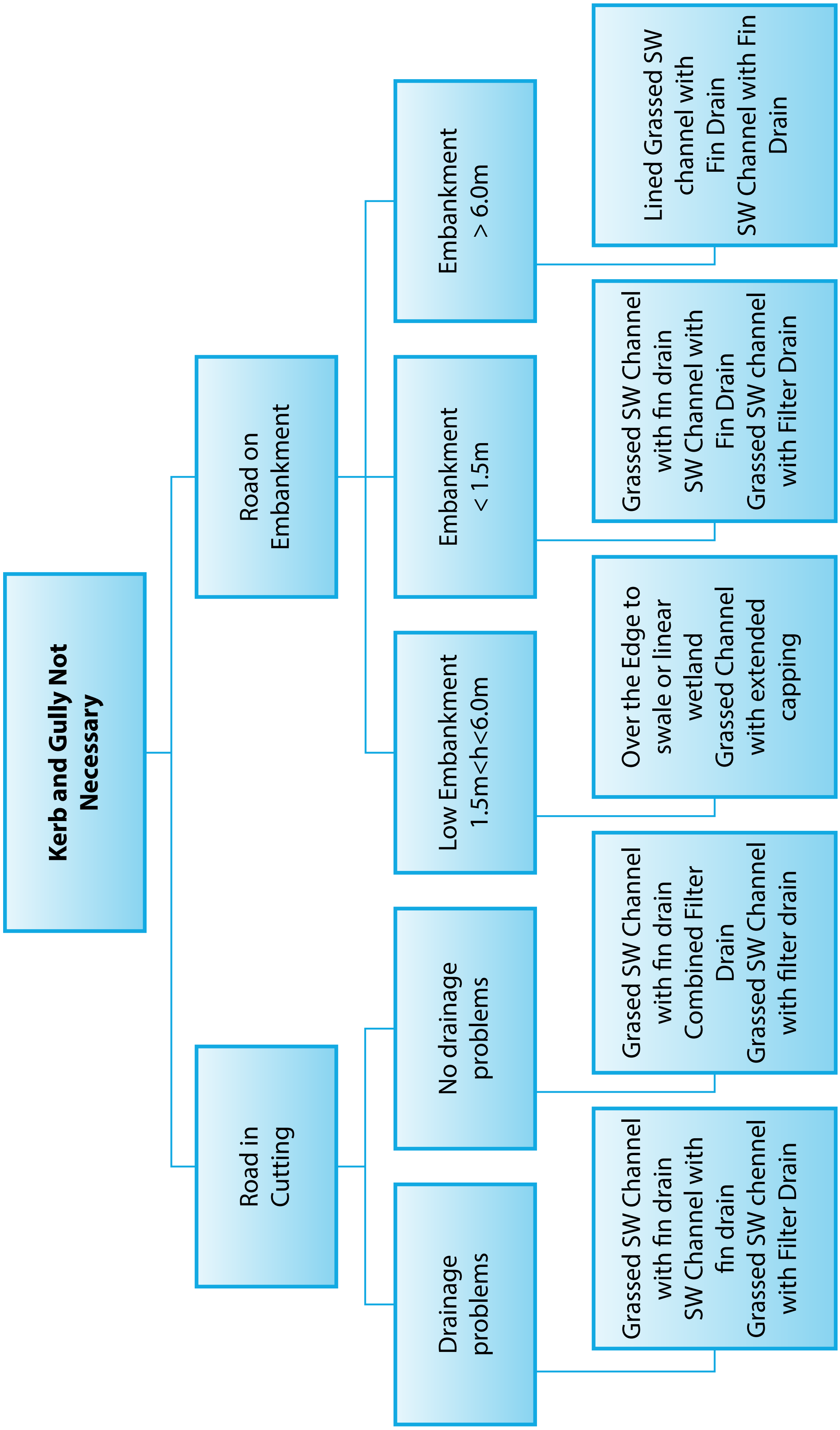
Accidental Spill

Calculate the probability of a spillage occurring	Calculate the probability of a spillage with the potential to cause a serious pollution incident

Consider Appropriate Designs

Table 18 Site control for surface water discharge	Table 19 Groundwater Risk assessment and drainage options


Surface and Groudwater Risk Assessment
Surface water
Groundwater
Sensitive Watercourse
Karst
Not sensitive
Low Risk
Moderate Risk
High risk
Wetlands Hybrid Ponds
Wetlands Hybrid Ponds
Attenuation Ponds Sedimentation Basin
Over the edge to ditches with Grass filter strips Combined filter drain GSWC Linear wetlands Combined GSWC and filter drain
Grassed Channels (GSWC). Swales. Linear Wetlands. Combined Filter Drains. Combined filter drain and GSWC
Lined Grass Channels or Swales. Lined linear wetlands. Combined filter drain and lined GSWC
Attenuation Basin Sedimentation Basin
Wetlands, Hybrid Ponds Attenuation Basin
Lined Wetlands. Lined Hybrid Ponds



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National Roads Authority
Environment

Step 1 Greenfield Runoff

Calculate Greenfield runoff rate per ha for soil class and average annual rinfal

Step 2 Storm Event

Decide on storm return period to be attenuated

Step 3 Factor Greenfield Runoff Rate

Factor Greenfield Runoff rate for storm return period = pemitted discharge rate

Step 4 Rainfall Intensity (Met Eireann or FSR)

Calculate rainfall intensity for the storm return period and various durations
(e.g. 5 mins to 2 days)

Critical Storm

Use rainfall intensities and discharge rates to calculate critical storm duration

Step 5 Groundwater and Natural Catchment

Consider volumes of groudwater from cuttings	Consider any input from natural catchment

Step 6 Discharge Rates and volume requirements

Based on the permitted discharge rate calculate the required volume for attenuation

Planning Drainage Design
• Outline details on consultations
• Method statement on how runoff will be dealt with during construction
• Details on how drainage design will meet SUDS objectives both volumetrically and qualitatively
- Agree hydraulic, water quality, amenity and ecological objectives for site
• Land Take required
• Maintenance responsibilities
• Risk assessment to groundwater and surface water.
• Take account of existing and future development
• Safety Measure for ponds and conveyance systems

Catchment Characteristics
• Drainage Patterns, flow directions and flow volumes
• Catchment areas for road and river crossings
• Soils – permeability, recharge coefficients, type
• Groundwater levels
• Bedrock – type, recharge mechanisms
• Vulnerability of bedrock aquifer
• Rainfall patterns for design storms either
- Met Eireann
- NERC FSR 1975 approach
• Receiving watercourse water quality and capacity
• Methodology for culvert sizing
• Flooding information to include impacts on overland flow
• Account for Climate change

Drainage Details

• Identify outfall locations
• Proposed discharge rate for each outfall
• Outline drainage components, pre treatment, source control and site control
• Infiltration tests
• Volumetric calculations
  - Pre and post peak runoff rates
  - Attenuation for storm events
  - Short term and long term storage
  - Drain down time
  - Treatment volumes
• Downstream analysis of discharge locations – risk assessment
• Erosion control
  - Streambank stabilisation
  - Erosion prevention
  - Velocity control

11 Section 6 - Appendix II Rainfall Intensities for different return periods

The following presents a series of maps (Figures 29-35) for different return periods and varying durations. The data are based on a study conducted for Flood Studies Update (FSU) Programme. Met Éireann, using funding provided by the Office of Public Works (OPW), developed a depth duration frequency model, allowing the estimation of point rainfall frequencies for a range of durations for any location in Ireland (Met Eireann, Technical Note 61 available on Met Eireann website). The following is an abstract from the Met Eireann technical note.

A depth duration frequency model is developed which allows for the estimation of point rainfall frequencies for a range of durations for any location in Ireland. The model consists of an index (median) rainfall and a log-logistic growth curve which provides a multiplier of the index rainfall. Rainfall station data were analysed and an index rainfall extracted, interpolated and mapped on a 2km grid. The model was fitted to series of annual maxima and the growth curve parameters were determined; these were also interpolated and mapped on a 2km grid. Computer applications were written to apply the model and produce gridded outputs of the return period rainfalls which can easily be mapped; an application for deriving rarity estimates was also developed. An account is also given of the reliability and probable accuracy of the model and the probable effects of Climate Change on extreme rainfalls.

Data from 1941-2004 was used in the study.

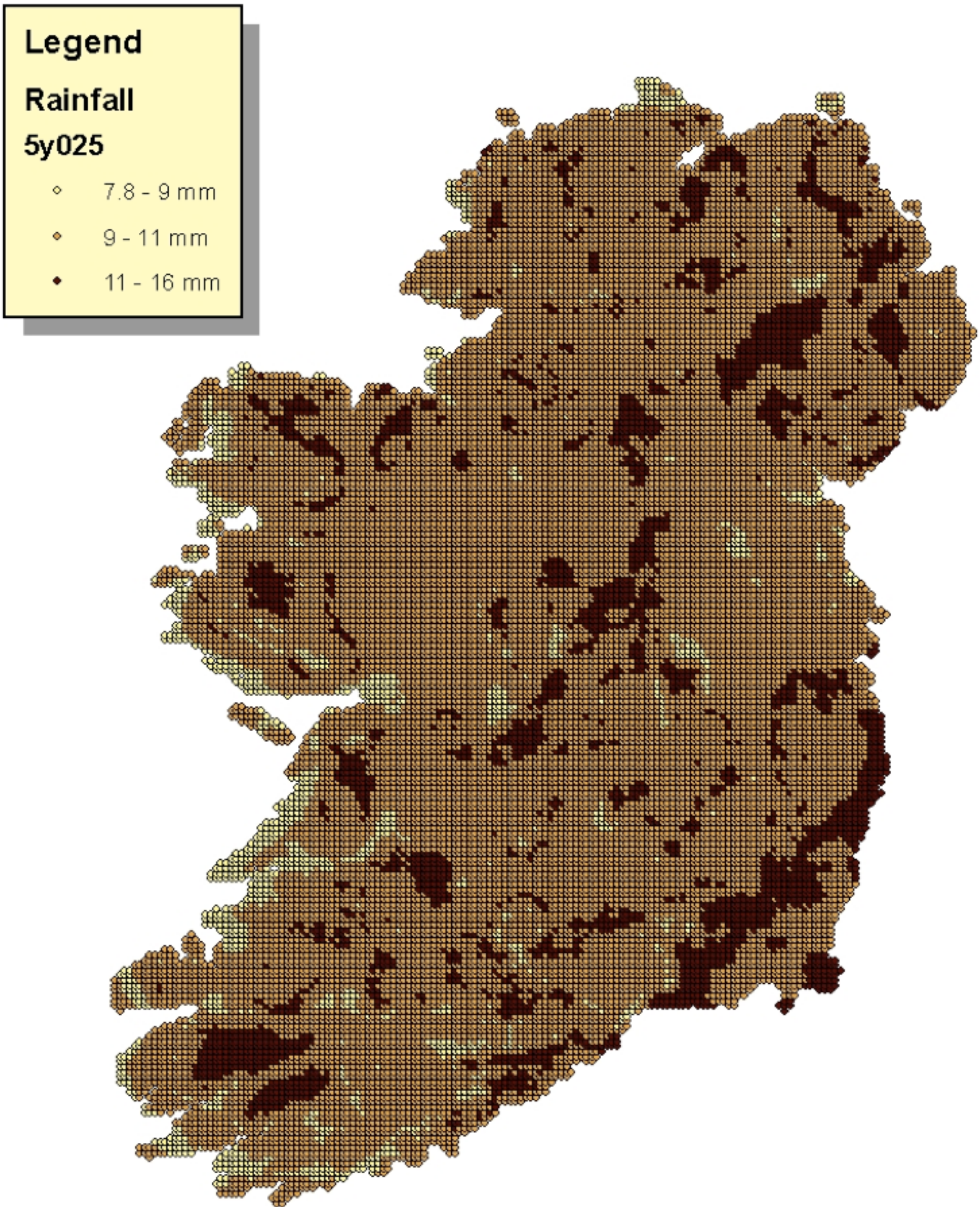


Figure 29 5 year return period 15 minutes duration

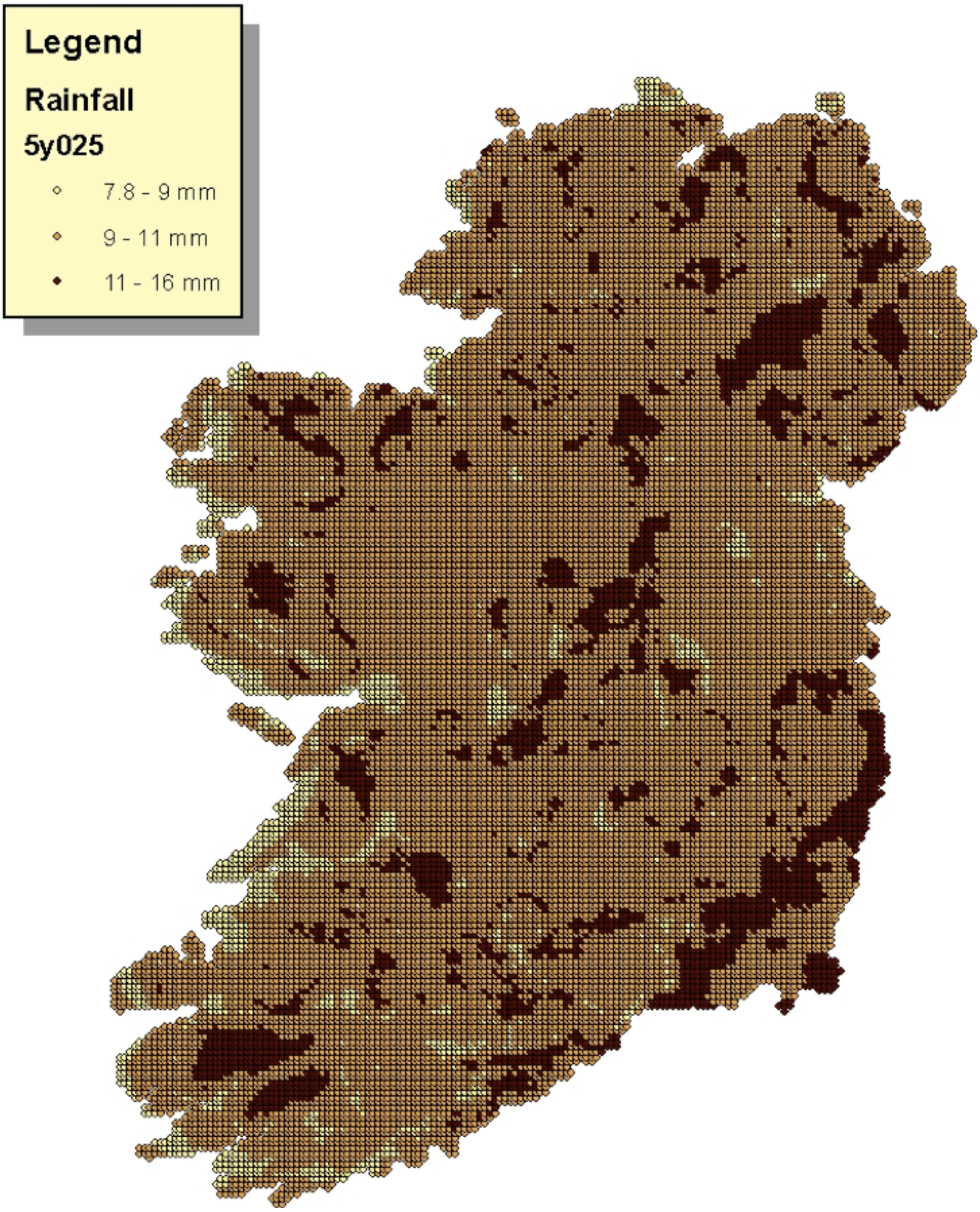


Figure 30 5 year return period 1 hour duration

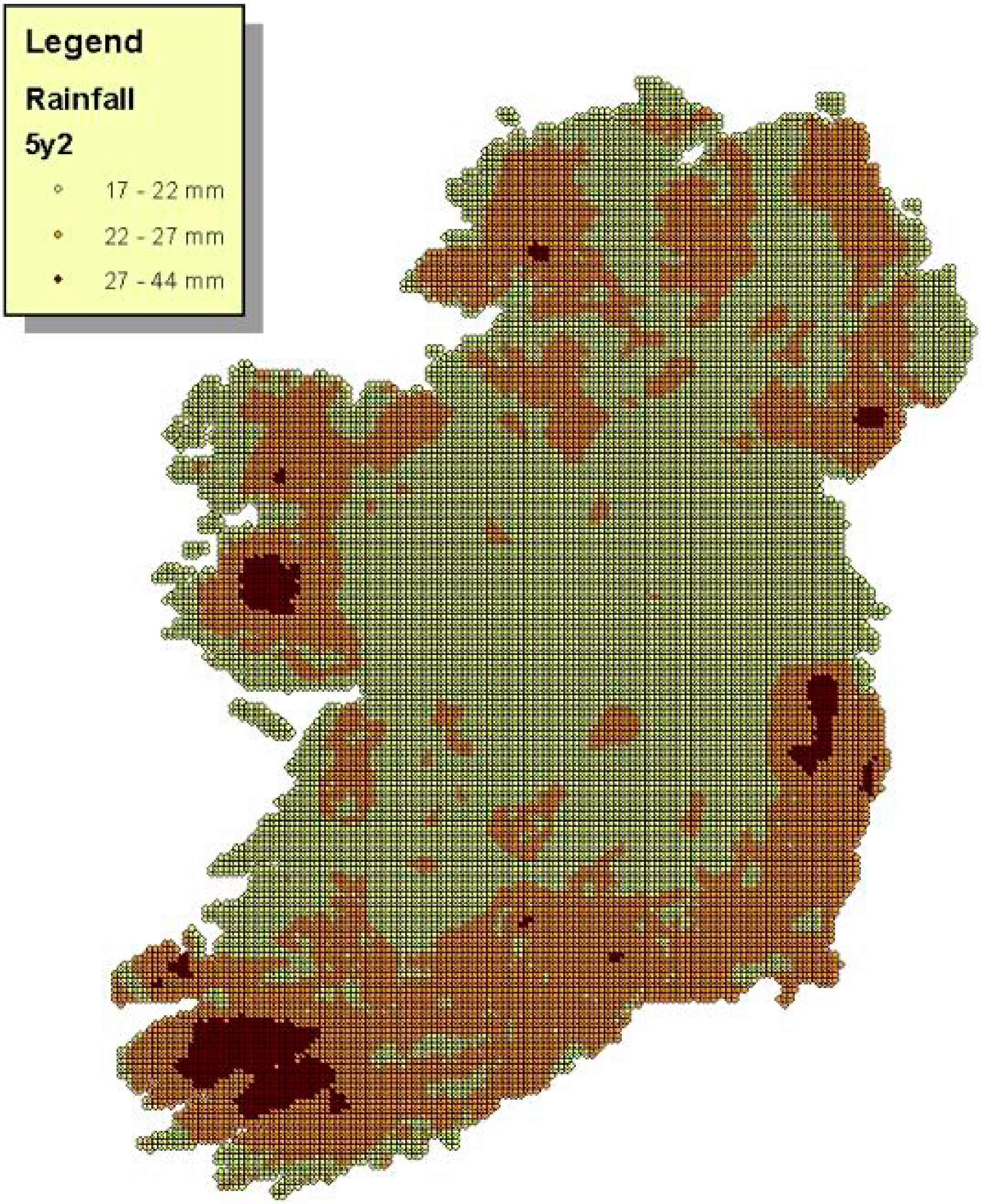


Figure 31 5 year return period 2 hour duration

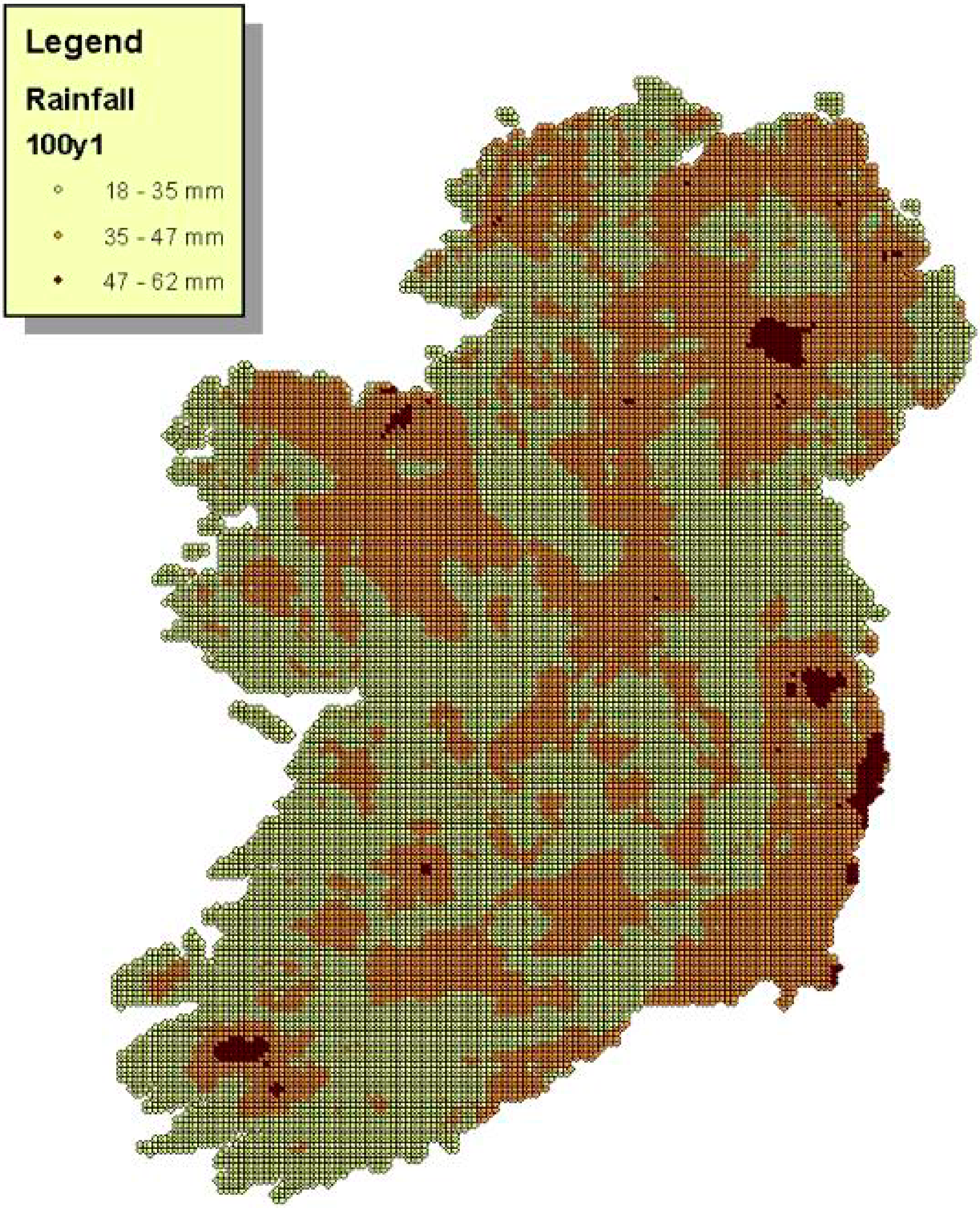


Figure 32 100 year return 1 hour duration

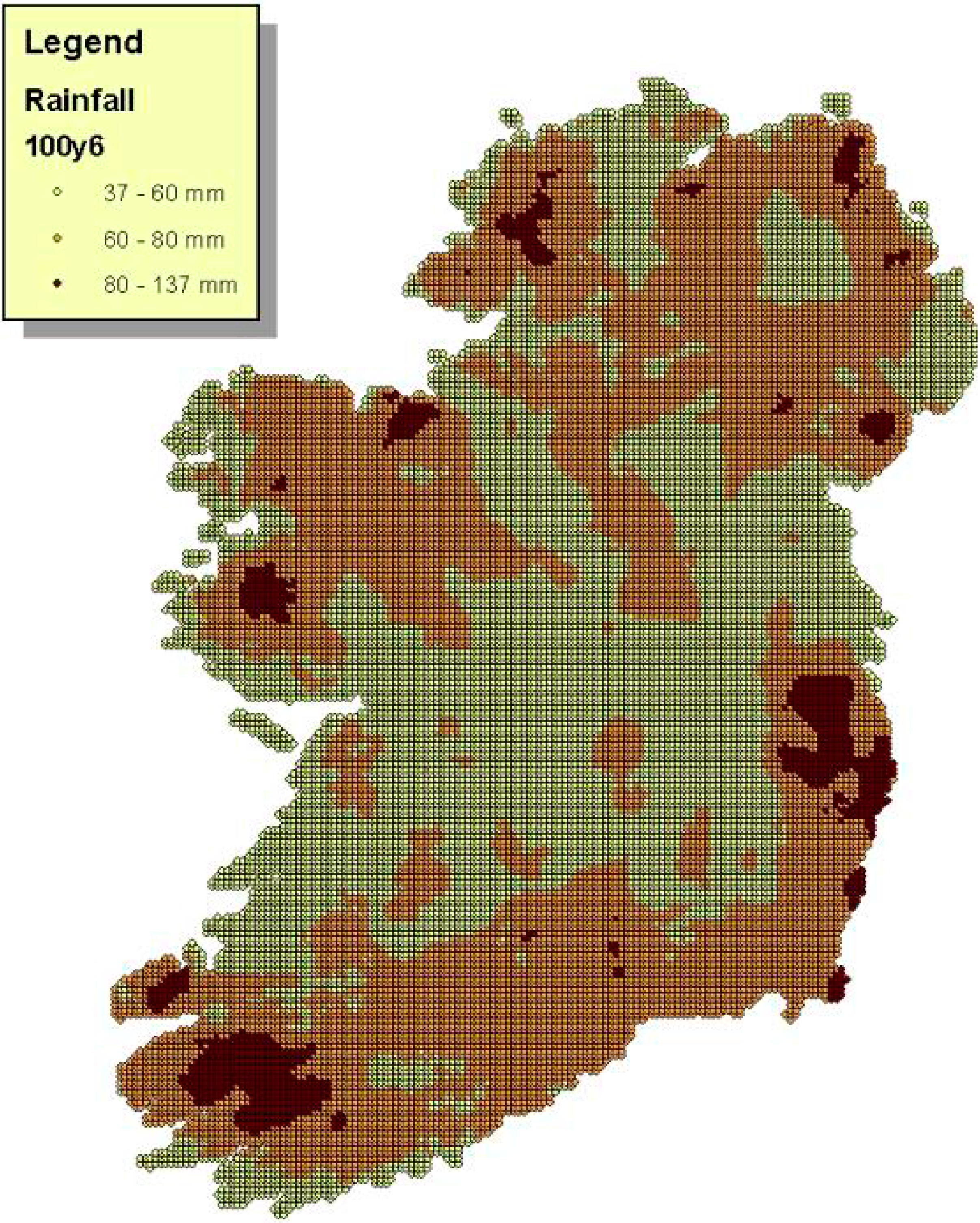


Figure 33 100 year return period 6 hour duration

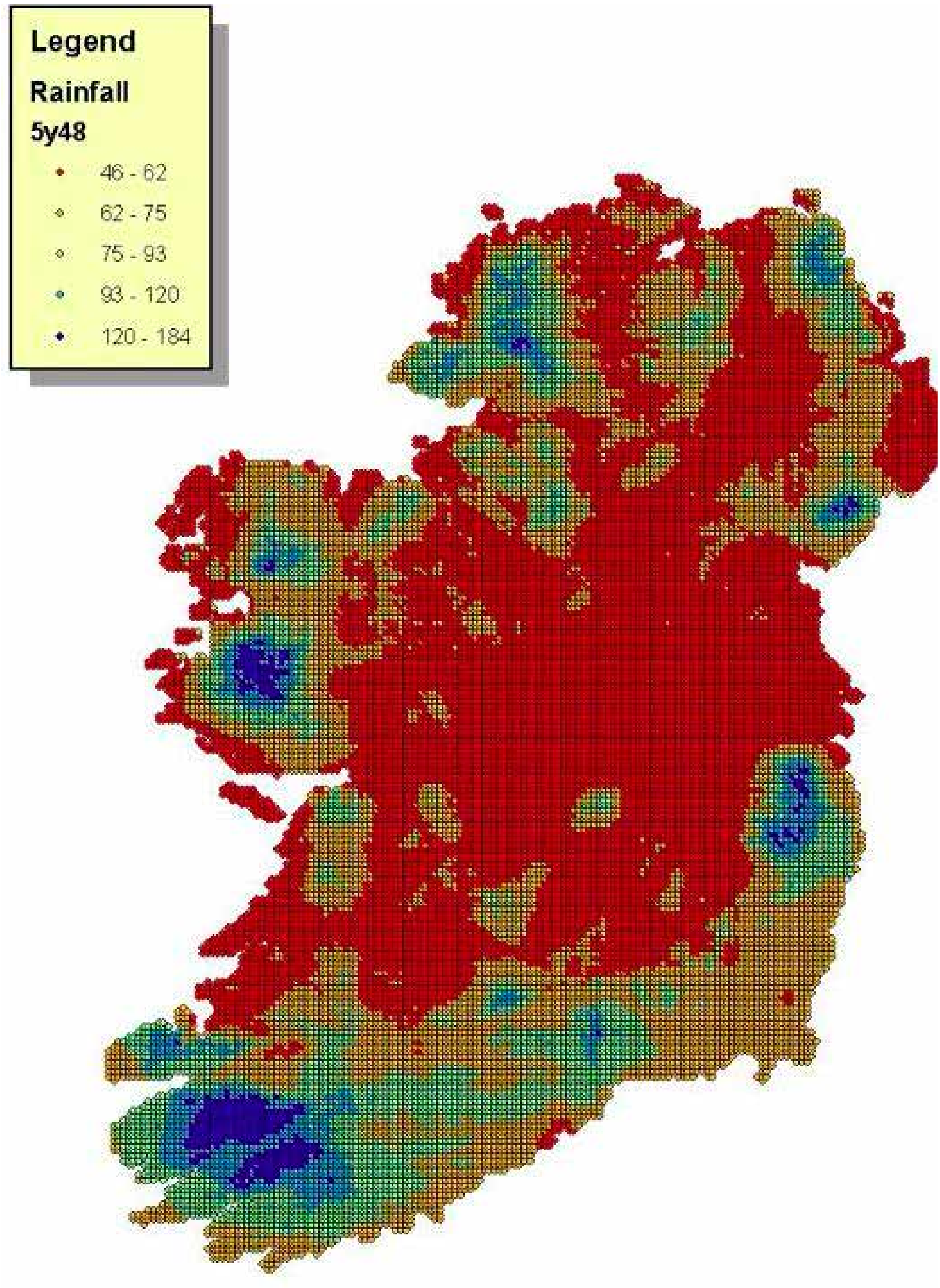


Figure 34 5 year return period 2 day duration M5 - 2D

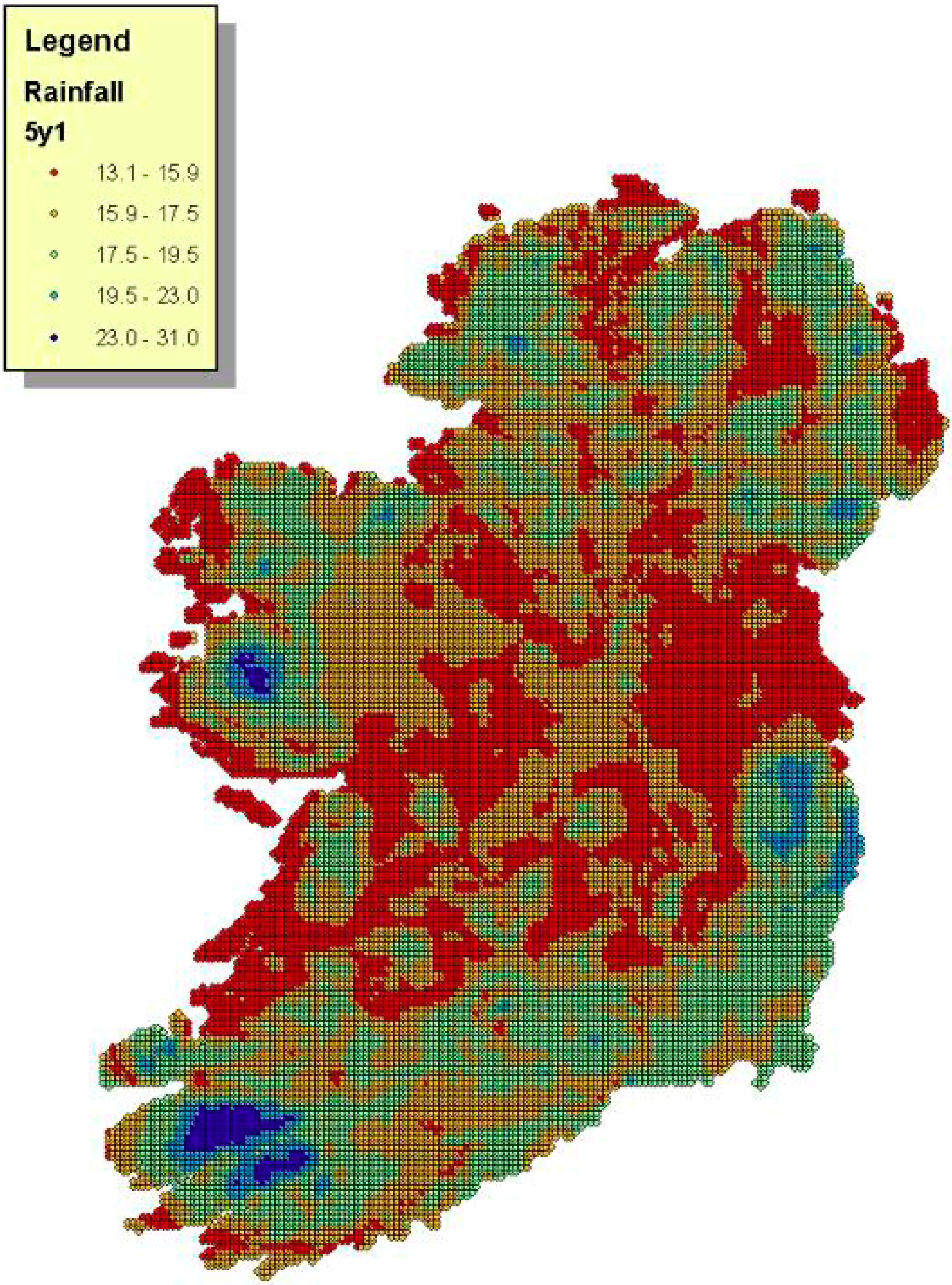
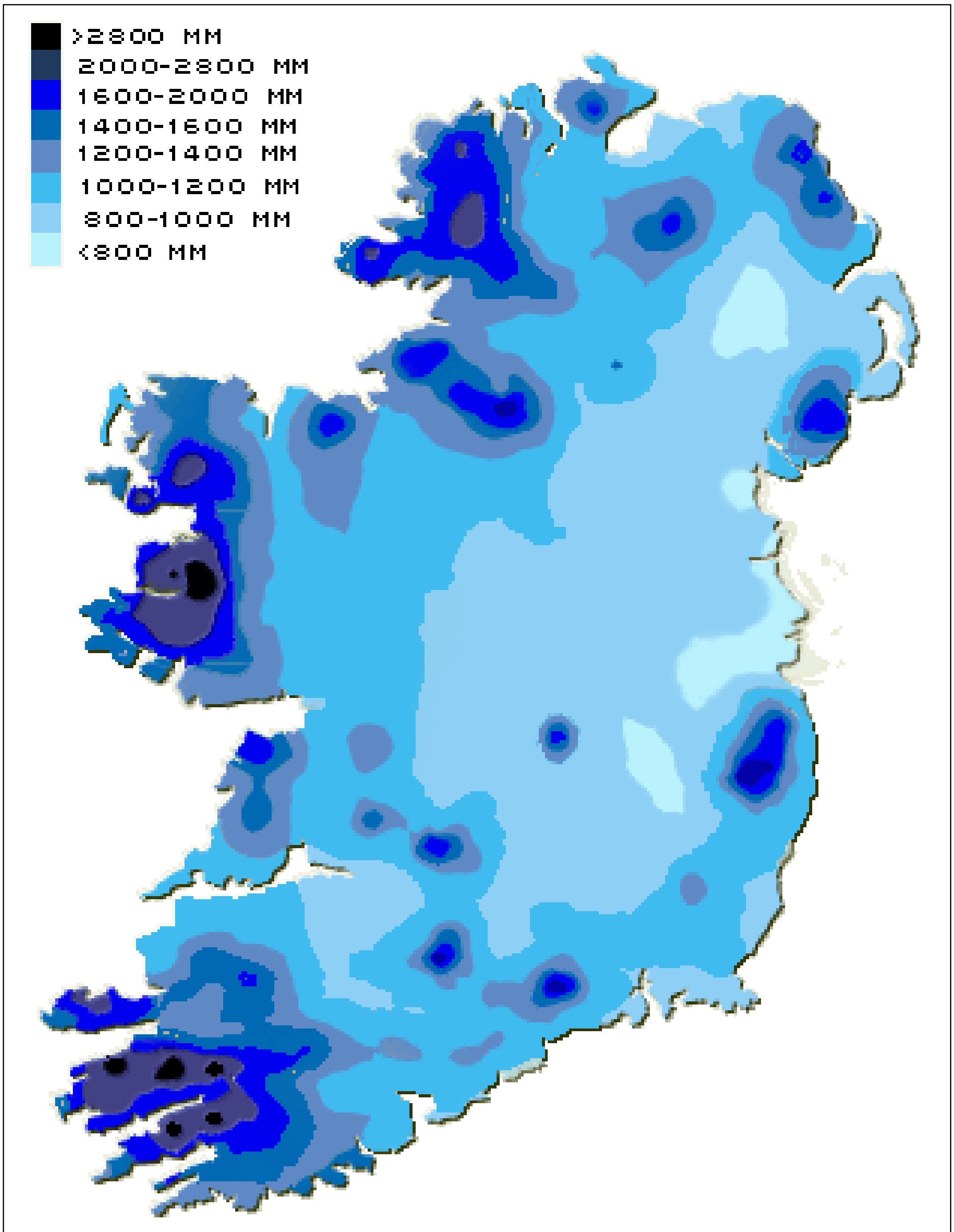


Figure 35 Detailed 5 year return period 1 hour duration M5 - 60



1961-90 Mean Annual Rainfall (mm)

12 Section 6 - Appendix III Examples of Volumetric Calculations and Worked Examples

The following is an example of a storage pond calculations using rainfall intensities from Met Eireann and using the FSR approach. The rainfall intensities are factored for the 1:100 year return storm.

- The permitted discharge rate is calculated using the IH 124 method.
- The critic storm event (the storm that produces the largest volume of storage) is then calculated based on the permitted discharge rate and the rainfall intensities for different durations.

In this case the rainfall intensities have not been factored for climate change in the tables but a 10% increase should be factored in for climate change. This results in a 15% increase (approx) in pond storage (Section 12.1.3).

12.1 Example FSR Rainfall intensity and Met Eireann.

The following is an example of calculating volumes for attenuation ponds using the FSR method for rainfall intensities and the Met Eireann data. The example is from an area in the west of Ireland.

M5 2D from FSR Map	65.000
R from FSR map	0.270
AAR from Met Eireann	1405.000

Greenfield runoff	**SOIL Type 3**	**SOIL = 0.37**
IH 124 method	**Rainfall**	**1405**
	QBAR	**6.5 litres/s/ha**
	Q100	**12.7 litres/s/ha**

12.1.1 Met Eireann Data.

Met Eireann data can be acquired for any given duration for any given return period. This example looks at the 1:100 year return period and a range of durations between 10 minutes and 1 day. The table below gives the storage requirements for the different durations. The critical storm is based on the rainfall intensities and the permitted discharge rate which is calculated using the IH 124 method. In this case the critical storm has a duration of 4 hours and a the storage requirements are 318 m³ per hectare of road catchment.

Met eireann	***10 mins***	***15 mins***	***30 mins***	***1 hours***	***2 hours***	***4 hours***	***6 hours***	***12 hours***	***24 hours***
M100 rainfall	15.70	18.40	23.70	30.40	39.00	50.10	58.00	74.50	95.70
M100 mm/hr	94.20	73.60	47.40	30.40	19.50	12.53	9.67	6.21	3.99
M100 m^3/ha	157.00	184.00	237.00	304.00	390.00	501.00	580.00	745.00	957.00
Inflow l/s/ha	261.67	204.44	131.67	84.44	54.17	34.79	26.85	17.25	11.08
Greenfield l/s/ha discharge	12.70	12.70	12.70	12.70	12.70	12.70	12.70	12.70	12.70
Inflow - Greenfield l/s	248.97	191.74	118.97	71.74	41.47	22.09	14.15	4.55	-1.62
m^3 storage	149.38	172.57	214.14	258.28	298.56	318.12	305.68	196.36	-140.28

Calculations Explained

Met eireann	10 mins	15 mins	30 mins	1 hours	2 hours	4 hours	6 hours	12 hours	24 hours
M100 rainfall	Data Acquired from Met Eireann								
M100 mm/hr	1:100 year Rainfall converted to mm/hr								
M100 m^3	Amount of rainfall in m^3/hectare								
Inflow l/s/ha	Amount of rainfall in litres/second/hectare								
Greenfield l/s/ha	Permitted Discharge rate (outflow) for 1:100 year event								
Inflow - Greenfield l/s	Storage = Inflow – permitted discharge (greenfield)								
m^3 storage	m^3 per hectare storage requirements = inflow – outflow for duration								

12.1.2 FSR Approach

The FSR approach is based on a series of maps and tables. Below is an example taking the parameters from the same area as the met Eireann data.

1) Calculate 1:5 year intensities based on M5 2D and r ratio.

Factors to be applied to M5 2D for r = 0.27

Duration mins	10.00	15.00	30.00	60.00	120.00	240.00	360.00	720.00	1440.00
Factor of M5 2D	0.13	0.16	0.21	0.27	0.35	0.44	0.51	0.65	0.83

Resulting 1:5 year rainfall

M 1:5 year	8.39	10.08	13.46	17.55	22.75	28.60	33.15	42.25	53.95
1:5 mm/hr	50.31	40.30	26.91	17.55	11.38	7.15	5.53	3.52	2.25

2) 1:100 year Rainfall for same durations

Factors to be applied to 1:5 year rainfall to give 1:100 year intensities.

M100 Factors	1.86	1.97	1.97	1.98	1.93	1.89	1.85	1.77	1.72

Resulting 1:100 year rainfall

M100 mm/hr	93.58	79.39	53.01	34.75	21.95	13.51	10.22	6.23	3.87

Storage requirements

	10 mins	15 mins	30 mins	1 hours	2 hours	4 hours	6 hours	12 hours	24 hours
M100 amount of rainfall	15.60	19.85	26.51	34.75	43.91	54.05	61.33	74.78	92.79
M100 m^3	155.96	198.48	265.06	347.49	439.08	540.54	613.28	747.83	927.94
Inflow l/s/ha	259.94	220.53	147.26	96.53	60.98	37.54	28.39	17.31	10.74
Greenfield l/s/ha	12.70	12.70	12.70	12.70	12.70	12.70	12.70	12.70	12.70
Inflow - Greenfield l/s	247.24	207.83	134.56	83.83	48.28	24.84	15.69	4.61	N/A
m^3 storage	148.34	187.05	242.20	301.77	347.64	357.66	338.96	199.19	N/A

Using the FSR approach the critical storm is 4 hours with a storage requirement of 357m^3 per hectare of road catchment. The rainfall intensities for the FSR approach are slightly higher but show a very good correlation. A slightly greater pond size is required with the FSR approach. There is a certain degree of judgement required in choosing the correct r value and M5 2D. The differences could be attributed to such judgement. Either method can be used for assessing rainfall intensities.

12.1.3 Climate change factor

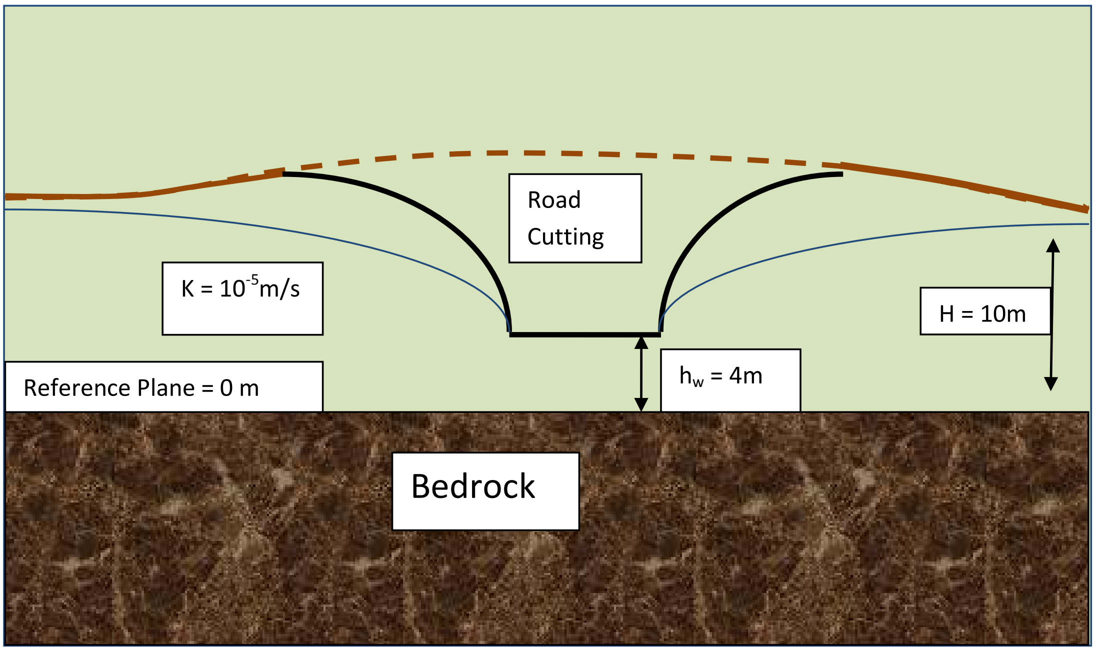
By applying a 10% increase in the rainfall intensities, the pond size will increase to 412m^3 from 357m^3 i.e. a 15% increase in pond size. The appropriate climate change factor should be discussed with OPW. This factor may vary due to site specific requirements and whether the drainage design is important for a flood defence strategy at the particular location.

12.2 Worked Example for Cutting Dewatering

Below is a worked example of a cutting in a moderate permeability aquifer. There are several methods for calculating volumes from cuttings and in some cases detailed groundwater modelling may be required. The following is a simple model and is presented here purely to highlight the fact that long term groundwater flows from areas of cutting should be taken into account. The models are based on several assumptions depending on the method used including:

- The slot is infinite in length
- R_0/H greater than or equal to 3 for method 1
- The aquifer is unconfined
- The aquifer is homogeneous, isotropic and of uniform thickness
- The Dupuit Forchheimer assumption is valid
- The aquifer has reached steady state conditions
- The initial water table is horizontal

These assumptions are important especially if flow is from bedrock and groundwater flow is through fissures. In this case the volumes of groundwater from the cutting will be very difficult to predict and will rely on conceptual groundwater modelling. The example below highlights the importance of taking cutting groundwater volumes into account both during construction and operation.



Road cutting in glacial sand aquifer.

Cutting dimensions and groundwater table

- 300m long
- 40 m wide
- H = 10m
- h_w = 4m
- p = 6m drawdown

Rainfall

- 1000mm/year Recharge

Aquifer Conductivity

- K = 10^{-5}m/s (0.864m^3/d)

Method 1 Unconfined aquifer Trench with flow 2 sides

$$Q = [0.73 + 0.27\ p/H]\ kx(H^2 - h_w^2)/L_0$$

- Step 1 Calculate effective radius

  Re= √ab/π

  - A = width of excavation

- B = length of excavation.
- Re = 62m

- Step 2 Calculate radius of influence (L_0) (Niccoli 1998)

$$\boxed{H = \sqrt{h_s^{\,2} + \frac{P}{K_{h1}}\left[R_0^{\,2}\ln\left(\frac{R_0}{r_w}\right) - \frac{R_0^{\,2} - r_w^{\,2}}{2}\right]}}$$

- R_0 = 196 (Use as L_0) – Solved by iteration.

- Step 3 calculate discharge rate

  $Q = [0.73 + 0.27(p/H)]\ kx(H^2 – h_w^{\,2})/L_0$

- x= length of trench = 300m
- Q = 100m3/d or 1.15 litre/s

Method 2 Steady flow in an unconfined aquifer per unit face Dupuit Forchheimer

$Q = Kx\ (H^2 – h^2)/2L$

- Taking radius of influence as above = 195 = L
- x = 600 (flow both sides)

  Q = 111m3/d = 1.28 litres/s

With recharge this becomes:

$Q = K\ (H_0^{\,2} – H_w^{\,2})/2L – (w((L/2)\text{-}x))$

- w is the recharge rate (0.0027m/d)
- L = x = radius of influence = 196m.
- Q is discharge per unit width
- Q = 0.448 per unit width * 600m for cutting

  Q = 269m³/d = 3.1 litres/s

12.3 Worked Examples

12.3.1 Greenfield Runoff

- Area is dominated by SOIL type 3(WRAP = 0.37)
- Seasonal Rainfall (annual average rainfall) is 1000mm.

IH 124 $QBAR = 0.00108AREA^{0.89}\ SAAR^{1.17}\ SOIL^{2.17}$

- QBAR = mean annual flood m^3/s
- Area = Catchment area km^2
- SAAR = standard average annual rainfall in mm
- SOIL = Soil Index based on WRAP values (winter rainfall acceptance potential) calculated as follows:
  - SOIL = $(0.10S1 + 0.30S_2 + 0.37S_3 + 0.47S_4 + 0.53S_5)/S1 + S2 + S3 + S4 + S5$
    - In this case with just one soil type SOIL = 0.37

- As area is less than 50 ha – calculate for 50 and Divide QBAR by 50.

QBAR = 4.4 l/s/ha (Annual flood Return of 2.2 year)

ADAS Q=StFA

- Q is the 1 year peak flow in l/s
- St is a soil factor and has values between 0.1 and 1.3. (Not the same as WRAP)
- F is function of catchment characteristics such as slope, drainage length, and rainfall. The value is got from a nomograph in the ADAS report
- A Area in hectares

A second slope coefficient C is also derived. C=0.0001L/S where

- S = slope
- L= catchment length

Slope of catchment is average 5:100

Crop type is grass

Soil type 3 = moderate soil type factor St = 0.5

Length of catchment 1km

F = 9

Q (1 year) = 4.5 l/s/ha

1. Rational Method Q = 0.278 CiA

- Q = m^3/s
- i = intensity of rainfall mm/hr for the specific duration related to the time of concentration of the event.
- A = Area of catchment in km^2

- C = runoff coefficient

i = 8mm/h (taking time of concentration between 2 to 3 hours and 2 year return)

C = .0.185 for average catchment slope

A = 0.01km^2

Q = 4.1 l/s/ha (2 year return)

Factor for Storm period

Using IH 124 result

Factor (NERC 1975) for Ireland for 1: 100 year storm is 1.96

Permitted discharge rate during storm event:

4.4 x 1.96 = **8.8 l/s/ha**

12.3.2 Runoff Volumes

Planned storm attenuation is for 1:100 year storm.

Rainfall intensity

a. Use Met Eireann data or

b. Use FSR approach

Storage requirements Met Eireann data.

Discharge rate of 8.8l/s.

Met eireann	15 mins	30 mins	1 hours	2 hours	4 hours	6 hours	12 hours	24 hours
Rainfall	26.9	30.9	35.7	41.1	47.4	51.5	59.5	68.0
M100 mm/hr	107.6	61.8	35.7	20.6	11.9	8.6	5.0	2.8
Climate Factor 1.1	118.4	68.0	39.3	22.6	13.0	9.4	5.5	3.1
M100 amount of rainfall	29.6	34.0	39.3	45.2	52.1	56.7	65.5	74.8
M100 m3/ha	295.9	339.9	392.7	452.1	521.4	566.5	654.5	748.0
Inflow l/s/ha	328.8	188.8	109.1	62.8	36.2	26.2	15.2	8.7
Greenfield l/s/ha	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8
Inflow - Greenfield l/s	320.0	180.0	100.3	54.0	27.4	17.4	6.4	N/A
m3 storage	288.0	324.1	361.0	388.7	394.7	376.4	274.3	N/A

Storage requirements = 395 m^3 / ha including climate change factor. Critical storm is 4 hours duration.

12.3.3 Long term storage

Storage to be stormed long term and released after storm event at a slow discharge rate (2 l/s/ha)

Vol_{xs} = RD.A.10 (0.8 PIMP/100 – SPR)

Where:

Vol_{xs} = the extra runoff volume (m^3) of development runoff over Greenfield runoff

RD = the rainfall depth for the 100 year, 6 hour event (mm)

PIMP = the impermeable area as a percentage of the total area

A = the area of the site (ha)

SPR = the "SPR" index for the FSR SOIL type

RD = 56.7mm

PIMP = Percentage of catchment, road and additional areas including slope areas of cutting e.g. 100%

SPR = Soil type 3 = 0.3

Volume to be stored long term = 283 m^3/ha

12.3.4 Treatment Volume

To be used for infiltration or in some cases wetlands.

Vt (m^3/ha) = 9.D. (SOIL/2 + (1-SOIL/2).I)

D = M5-60, I = Fraction impermeable

D = M5 – 60 = 16.9

SOIL = 0.3

I = 0.8

Vt = 124m^3/ha

12.3.5 Percentage runoff, catchment area and additional component from cuttings

The area contributing to the storage ponds or wetlands may include additional components from cutting slopes or areas from outside the road paving that are also contributing to the road drainage design. There are two options but the simplest method for taking account of this additional component is option 2 below. Option 1 modifies the percentage runoff figure to account for the additional components whereas option 2 modifies the area.

12.3.5.1 Option 1 Use fixed UK method

PR = 0.829 PIMP + 25.0 SOIL + 0.078 UCWI – 20.7 where:

PR = percentage runoff

PIMP = percentage impermeable

SOIL = Soil index SPR (0.15 to 0.5)

UCWI = Urban catchment wetness index. Varies with annual rainfall. Typical values 110 to 125 but can be considerable higher during winter months for1:100 year storm event.

PIMP = 80%

SOIL= 0.3

UCWI = 120

PR = 62%

This calculation will increase substantially for a 1:100 years storm when the catchment is at field capacity. The above calculation assumed a low API (antecedent precipitation index)

12.3.5.2 Option 2 Use DMRB Approach to calculate effective area.

- Assume 100% runoff for storm event for paved area.

An effective width of the catchment which is given as:

$W_e = W + \alpha C$ where:

W = width of the paved area.

α = runoff coefficient for the catchment = SOIL.UCWI/300 based on PR eqn.

C = average width of the cutting

This calculation involves a detailed assessment of the catchment size for each pond area taking account of the areas in cutting and applying a runoff coefficient for these areas based on slope and permeability. There are worked examples in the DMRB along with a table to work out the values of α (DMRB HA 37/97 1997).

12.3.6 Development Runoff Rates

Rational Method Q = 0.278 CiA

C = 0.8 to 0.9

i= 35mm/hr (approximate value for rainfall intensity with 15 minute time of concentration).

A = 0.01 km^2

Peak discharge rates = 78 to 88 l/s/ha of development.

13 Section 6 Appendix IV - Case Studies

13.1 Case Study 1

13.1.1 Hydrological and Hydogeological Environment

Road scheme is planned in an area in the midlands overlying a thick sequence of subsoils with moderate to low vulnerability. Road discharge will be to a number of rivers and streams that are not salmonid and are not part of an SAC complex.

13.1.2 HD 33/06

A review of the standards for such an area shows that a sealed system is not required. The drainage design elements are required to follow HD 33/06 and various options to be considered relate to the height of the road embankment and whether the road is in cutting.

13.1.3 Risk Assessment

13.1.3.1 Groundwater Risk assessment

Source elements

- Traffic volumes are less than 50,000 AADT,
- Rainfall is 1000mm/year and rainfall intensities are in the range of 35 – 47 (100 year return 1 hour's duration) see Section 6 Appendix II.

Pathway

- Vulnerability is moderate to low,
- Unsaturated zone varies but generally in the range of 3 to 10m below ground level,
- Clay content is 10 to 13%.

Receptor

- Receptor is a regionally important limestone aquifer.

13.1.3.1.1 Groundwater Scoring

Parameter	Weighting X Risk score	Score
Traffic Volumes	15 X1	15
Rainfall	15X2	30
Vulnerability	30x2	60
Unsaturated Zone Depth	10X2	20
Unsaturated Zone Clay %	10X2	20
Receptor	20X3	60
Total		205

E.G. Score for each category is calculated by multiplying the weighting by the risk score (Vulnerability = moderate so weighting is 30 and risk score is 2 = 60).

Total Score is in Moderate Risk Category. Objectives are to promote infiltration through the use of linear vegetated conveyance systems. Some sections may require additional protection through the use of liners depending on the detailed site investigation.

13.1.3.2 Surface Water Risk Assessment

Use HAWRAT for individual outfalls.

Example

AADT = <50,000.

Rainfall = 1000mm.

Impermeable area is 5 hectares.

River flow 95% ile flow is .03 m^3/s.

Establish

- Stream width e.g. 3m,
- Mannings n e.g. 0.08,
- Side slope e.g. 0.7m/m,
- Long slope e.g. 0.0007,
- Water Hardness e.g. 50 – 200 $CaCO_3$/l.

Use default settings for others

Surface water impact

Results for step 1 and step 2 indicate that the discharge will pass for pollutant concentration but fails for sediment impact. The table indicates that 27% settlement is required through mitigation.

This can be achieved through the use of treatment systems either in conveyance or through the use of an attenuation pond limiting discharge and allowing settlement of suspended solids.

13.1.3.3 Accidental Spill

See section 5.5.3 and refer to HD 45/09 for details on how to carry out calculations with a worked example.

The section of motorway is 2.5 km long draining to a watercourse. There is a junction within this section with two slip roads.

%HGV = 12%

AADT = 25,000 for motorway

AADT = 4000 for slip road

13.1.3.3.1 Part 1

The total probability of a spill involves calculating the probability for 3 lengths of road with different spillage probability rates.

PSPL = RL x SS x (AADT x 365 x 10^{-9}) x (%HGV/100)

1. Motorway excluding junction area (2.5 – 0.2 km = 1.3km)
2. Junction area of motorway (0.1 km either side = 0.2km)
3. Slip road section (take 0.4km for each slip road = 0.8km)

Motorway section excluding junction area.

Spillage rate for motorway Table 19 is 0.36.

PPSL = 2.3 x 0.36 x (25,000 x 365 x 10^{-9}) x (12/100)

= 9.07 X 10^{-4}

Junction area of motorway

Spillage rate = 0.43

PSPL = 0.2 x 0.43 x (25,000 x 365 x10^{-9}) x (12/100)

= 9.42 X 10^{-5}

Slip road sections

Spillages rate = 0.43

PSPL = 0.8 x 0.43 x (5000 x 365 x 10^{-9}) x (12/100)

= 7.5 x 10^{-5}

Total annual probability of a spill = 9.07 X 10^{-4} + 9.42 X 10^{-5}+ 7.5 x 10^{-5}

= 1.08 X 10^{-3}

13.1.3.3.2 Part 2

Probability of a serious pollution incident arising as a result of the spillage.

Take surface water and remote site (Table 20), PPOL = 0.75

PINC = PSPL x PPOL

PINC = 1.08 X 10^{-3} x 0.75

= 0.08%

This is less than 1%.

13.1.4 Volumetric Calculations

13.1.4.1 Greenfield runoff

Using IH 124 formula.

- SOIL is type 3 (SOIL = 0.37)
- 5 hectares
- 1000mm rainfall

Q = 4.4 l/s/ha (calculate for 50 hectares ($0.5km^2$) and divide by 10 for 5 hectares.

Factor for 1 in 100 year storm (1.96) = 8.6 l/s/ha.

43 l/s for impermeable area.

Permitted discharge during 1:100 year storm is 43 l/s from attenuation pond.

13.1.4.2 Attenuation Requirements

Objective is to attenuate 1:100 storm.

13.1.4.2.1 Storage requirements

Pond is required to attenuate 395 m^3 /ha = 1975m^3 storage required taking discharge rate into account. See 12.3.2 for detailed calculations.

13.1.4.2.2 Long term storage

Vol_{xs} = RD.A.10 ((0.8 PIMP/100) – SPR)

RD = 60mm

PIMP = 100%

SPR = Soil type 3 = 0.3

Long term storage is 1500m^3

13.1.5 Drainage Options

The final drainage design elements will rely on the vertical alignment and detailed site investigation particularly in relation to lining of attenuation ponds and the conveyance system. Where there at least 1.5m of low permeability soil, between the base of the conveyance system and the top of the groundwater table (soil aquifer), lining should not be required. In areas of moderate permeability the details will be agreed with the government agencies involved but 3m of an unsaturated zone should provide adequate protection without liners in areas of moderate vulnerability.

See Table 18 for drainage options.

13.1.5.1 Conveyance system may consist of the following.

13.1.5.1.1 Low embankment.

Over the edge drainage into a grassed channel or ditch allowing infiltration. Consider the use of a linear wetland if soil has low permeability.

13.1.5.1.2 High embankment

Kerb and gully required or concrete channels. This could in turn supply a linear ditch, grassed channel or linear wetland at the toe of the embankment.

13.1.5.1.3 Areas of cutting

Detail will depend on groundwater table. If winter groundwater table is >1m below base of conveyance system, a combined filter drain may be adopted or a combination of a grassed channel and a fin drain. If groundwater table is higher than 1m below system, fin drain may be carrying large volumes of groundwater and a sealed grass channel or a concrete channel may be require to avoid infiltration and potential flooding.

13.2 Case Study 2

13.2.1 Hydrological and Hydrogeological Environment

Road scheme is planned for an area in the west that is dominated by karst and areas of high and extreme vulnerability. Road discharge will be to rivers that are in turn part of the groundwater system (i.e. discharge is to groundwater). Some sections are covered in peat deposits. Recharge is indirect through fissures and swallow holes. There are a number of karst features noted along the route such as turloughs. The karst nature of the area is defined by these features even though there were few karst features intersected in the initial site investigation. The major groundwater flow is through conduits with some diffuse flow through the epikarst zone at the bedrock interface.

13.2.2 Risk Assessment

13.2.2.1 Groundwater Risk assessment

Source elements

- Traffic volumes are less than 50,000 AADT.
- Rainfall is 1200mm/year and rainfall intensities are in the range of 35 – 47 (100 year return 1 hour duration) see Section 6.

Pathway

- Vulnerability is high to extreme,
- Unsaturated zone varies but generally in the range of 1 to 3m below ground level,

- Clay content is high and some areas are covered in peat.

Receptor

- Receptor is a regionally important limestone karstified aquifer.

13.2.2.1.1 Groundwater Scoring

Traffic Volume	15 X1	15
Rainfall	15X3	45
Vulnerability	30x3	90
Unsaturated Zone Depth	10X3	20
Unsaturated Zone Clay %	10X2	20
Receptor	20X3	60
Total		250

Total score is in the high risk category. Objective is to design a drainage system that will protect the underlying aquifer. Lining of both the conveyance and attenuation systems will be required in some sections. However, it is important to limit the point source drainage options, if possible, as this is likely to result in a higher risk. Infiltration in selected areas giving a diffuse discharge is an objective if the hydrogeological investigation indicates a reduced risk. Runoff is discharging to groundwater in karst area so maximum treatment is required during conveyance and during attenuation. Discharge rate should be kept to a minimum and maximum settlement of suspended solids is required.

13.2.2.2 Surface water Risk assessment

As the outfall is discharging to a river in a karst area HAWRAT is not a suitable tool as it is based on surface water objectives. The river outlet has to be considered as groundwater.

- AADT = <50,000
- Rainfall = 1200mm
- Impermeable area is 5 hectares

13.2.2.3 Accidental Spill

See previous example.

13.2.3 Volumetric Calculations

13.2.3.1 Greenfield runoff

Using IH 124 formula.

- SOIL is type 5 (0.53)
- 5 hectares
- 1200 mm rainfall

Q = 11.8 l/s/ha

Factor for 1 in 100 year storm (1.96) = 23.1 l/s/ha.

115 l/s for impermeable area (5 ha).

13.2.3.2 Attenuation Requirements

Objective is to attenuate 1:100 storm.

13.2.3.2.1 Storage requirements

Pond is required to attenuate 263 m^3 /ha = 1315 m^3 storage (5 ha) required taking discharge rate into account. Smaller pond as discharge rate is higher for soil type 5.

Met eireann	15 mins	30 mins	1 hours	2 hours	4 hours	6 hours	12 hours
Rainfall	18.4	23.7	30.4	39.0	50.1	58.0	74.5
M100 mm/hr	73.6	47.4	30.4	19.5	12.5	9.7	6.2
Climate Factor 1.1	81.0	52.1	33.4	21.5	13.8	10.6	6.8
M100 amount of rainfall	20.2	26.1	33.4	42.9	55.1	63.8	82.0
M100 m3/ha	202.4	260.7	334.4	429.0	551.1	638.0	819.5
Inflow l/s/ha	224.9	144.8	92.9	59.6	38.3	29.5	19.0
Greenfield l/s/ha	23.1	23.1	23.1	23.1	23.1	23.1	23.1
Inflow - Greenfield l/s	201.8	121.7	69.8	36.5	15.2	6.4	N/A
m3 storage	181.6	219.1	251.2	262.7	218.5	139.0	N/A

13.2.3.2.2 Long term storage

$$Vol_{xs} = RD.A.10\,((0.8\ PIMP/100) – SPR)$$

RD = 60mm

PIMP = 100%

SPR = Soil type 5 = 0.5

Long term storage is 900m^3

13.2.4 Drainage Options

Detailed site investigation will be required to establish the drainage components and in particular whether a liner is required or not. It is imperative to establish the thickness and permeability of the sub soil for each drainage section as well as the thickness of the unsaturated zone. As there is a requirement for maximum treatment, grassed channels or swales could be a suitable conveyance system. A further alternative is to consider the use of linear wetlands. These are considered to be the most effective drainage design in karst areas as they offer the best treatment and attenuation. These are often suited to this type of terrain as low permeability soils are often a feature of karst areas and these wetlands can be constructed without the use of liners. A system consisting of a grass filter strip feeding into a linear wetland would represent a viable option. In areas of moderate or high permeability, these wetlands will require lining. Where grassed channels or swales are adopted, lining will be required if these are located on the verge and peat deposits have been removed for construction or there is inadequate sub soil cover below the base of the channel.

A constructed wetland is the preferred option for attenuation.

13.2.4.1 Sizing of wetland

For a 24 hour residence time.

R = V/D

- R = Residence time
- V = Volume of pond
- D = Discharge rate
- D = 115 l/s for 100 year storm.

This gives a required volume of 9,936 m^3.

This is clearly unrealistic as this would require a huge land take.

An alternative calculation approach is adopting a treatment volume.

Vt (m^3/ha) = 9.D. (SOIL/2 + (1-SOIL/2).I) where:

D = M5-60, I =Fraction impermeable

M5 – 60 = 18mm/hr (based on Met Eireann data)

Vt = 162 m^3 / ha

= 810 m^3 (for 5ha)

Apply a factor of safety of 4 (CIRIA C521 1999) = 3,240m^3. The Greater Dublin Strategic Drainage Study (Dublin City Council 2005) (see www.dublincity.ie for a copy of the documents) recommends that for the Dublin areas a figure of 15mm should be used to determine the size of the permanent pool. This will give a low volume (675m^3) for the permanent pool.

The above treatment volume has not taken into account the treatment or capacity of the conveyance system. The use of a grassed channel should reduce the requirement for 24 hour residence in the wetland as a sizeable percentage of the suspended solids will be removed.

In general wetlands are not designed to attenuate a 1:100 year storm event due to the large land take required. The objective is to:

1. Capture and treat runoff from frequent events
2. Capture and treat a proportion of first flush from larger storm events

An alternative is to attenuate the average annual storm (take discharge rate as QBAR i.e. 11.8 l/s/ha and to ensure a residence time of 15 hours (Shutes 1999) and, accordingly, the volume of the wetland required is 3186 m^3. This is very much in line with the treatment volume calculated above with the factor of 4 applied and represents a reasonable compromise.

Clearly there are a number of options for the sizing of the wetland. The final design will depend on the sensitivity of the receiving environment and should also be discussed with the relevant government agencies.

13.2.4.2 Wetland and Attenuation Pond.

If flooding and quality issues are a major concern, a dual attenuation pond system and wetland could be constructed. The attenuation pond will control the discharge rate into the wetland maintaining a wet environment, and attenuate the required storm.

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Glossary of Terms

Aquifer	A rock that stores and transmits water in significant quantities.
Attenuation Pond	Pond designed to attenuate and control flow rates from surface runoff.
Balancing Pond	Pond designed to attenuate flow and release water at a controlled rate**.**
Berm	A structural mound formed to control flow.
Catchment	The area contributing surface runoff to a river system.
Constructed wetlands	A constructed system designed to treat stormwaters using the natural processes of wetlands.
Control Structure	Structure controlling the rate of flow.
Design and Build	A form of contract for procuring national road schemes that transfers greater risk from the road authority to the contractor. The contractor undertakes some of the detailed design of the scheme after approval has been obtained from An Bord Pleanála. This allows the contractor to introduce innovative methods to aspects of the scheme design, including in relation to environmental mitigation measures and asregards methods of construction.
Detention Pond	A pond constructed to store and attenuate flow.
Diffuse pollution	Pollution arising from land use activities that are dispersed across the catchment area.
Doline	A small to medium sized closed depression. Dolines function as funnels, allowing point recharge of the karstic aquifer.
Employers Representative	The Project Manager in conjunction with the NRA appoint an Employers Representative together with a site supervisory team to monitor the works on behalf of the Employer.
Environmental Impact Assessment – EIA	The process of examining the environmental effects of the proposed road scheme development – from consideration of environmental aspects at design stage through to preparation of an Environmental Impact Statement, evaluation of the EIS by the competent authority and the subsequent decision as to whether the development should be permitted to proceed, also encompassing public response to that decision.
Environmental Impact Statement – EIS	A statement of the effects, if any, which the proposed development, if carried out, is likely to have on the environment.
Estavelle	A karst feature that can function as a spring or as a swallow hole depending on underground water levels.
Filter Drain	A linear drain consisting of permeable fill generally with a conveyance pipe at the base.
First Flush	Initial flow from a catchment area.
Grassed Channel	A grass lined channel, trapezoidal or parabolic in shape used to convey stormwater.
Greenfield runoff rate	The surface runoff from the site prior to development.

Hydrogeology	The study of water below the earth's surface and its interaction with surface waters.
Hydrograph	A graph of flow rate with time.
Hydrology	The study involving the behaviour of water in the atmosphere, on surface and underground.
Infiltration Basin	A constructed basin promoting infiltration of surface water to groundwater.
Karst	An area of limestone or other highly soluble rock, in which the landforms are of dominantly solutional origin, and in which the drainage is usually underground in solutionally enlarged fissures and conduits.
Limestone Pavement	Bare limestone surface from which soil and loose rocks have been stripped – usually by relatively recent ice erosion during a glacial period.
Morphology	The characteristic features of a river, its form and structure.
Point source pollution	Pollution arising from a single identifiable source, often a discharge pipe.
Porosity	The percentage of the bulk volume of rock or soil that is occupied by voids.
Public Private Partnership	A Public Private Partnership (PPP) is a partnership between the public and private sector for the purpose of delivering a project or service traditionally provided by the public sector.
Q_{BAR}	Median annual peak flow.
Q_{MED}	Mean annual peak flow.
Retention Pond	A pond where water runoff is detained for a period of time to allow treatment.
Return Period	How regularly an event occurs. A 100 year storm event occurs on average once every 100 years and has an annual probability of 0.01.
Runoff	That part of a rainfall event that appears in surface streams.
Soakaway	A structure promoting infiltration to groundwater.
Statutory Consultees	Organisations and authorities stipulated by legislation (in Acts and Regulations) that are to be sent a copy of the road scheme environmental impact statement, together with a notice in the prescribed form stating that the road authority has made an application to ABP for approval of the proposed road development.
Swale	A shallow vegetated channel that conveys water but may also allow infiltration.
Swallow hole, Pothole	The point at which a surface stream sinks underground.
Threshold Effects Level	The concentration below which toxic effects in aquatic fauna are extremely rare.
Turlough	Seasonal lakes found in the lowland karsts of western Ireland. They often fill and empty via estavelles

Waulsortian Limestones A group of limestones of Carboniferous age which were laid down as massive calcareous mud mounds. Found in many parts of the country.