Impact Assessment of Highway Drainage on Surface Water Quality
2000-MS-13-M2
Main Report

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Introduction

1.1 Background

It has long been known that the road density in Ireland is high for the size of the population and thus, for many years, the vehicle density per kilometre of road was also small. Moreover, in spite of relatively high rainfall in many parts of the country and ad hoc methods of road drainage, the environmental impacts of road runoff were usually small and/or temporary. In the last 20 years, however, the road building programme has increased in intensity and the length of dual carriageway/motorway has also dramatically increased. Vehicle ownership and traffic densities have correspondingly climbed. In response, new transport infrastructure, such as TRANSPORT 21, have a significant new roads component and an environmental remit. Apart from the requirements of environmental EU directives, there is a clear intrinsic need to determine if the changing quantity and quality of road runoff will pose a problem for the receiving environment. In Ireland, there is, a wide diversity of road types, ranging from the boreen to the motorway and there is an equal diversity in receiving environments, ranging from peatlands to limestone hills with little or no soil cover. However, from considerations of traffic densities and carriageway areas, it is likely that dual carriageways will pose the most immediate problems. It is also important to consider the diversity of potential receiving environments.

Previous research has shown that highway runoff can contain a cocktail of potential pollutants, with more than 30 substances found in highway discharges in a study undertaken by CIRIA (1994) and reiterated in a report by Hird (1999). The impact of the pollutants on adjacent watercourses, including groundwater, can be very site specific, and is a function of the nature of the road and the traffic it carries, management systems, drainage systems and hydrological conditions amongst others. Some sites may be more sensitive than others. For example, sensitivity is increased if a water course is a spawning site for salmon such as occurs near Gory, Co. Wexford or a water supply such as Lough Mourne in Donegal. More difficult to assess is groundwater which frequently occurs near the ground surface in Ireland although overlying subsoils, where they exist, may afford some protection.

Some criteria for assessing impacts on such receiving environments have been available for some time, such as the Drinking Water Regulations or permissible contaminant levels in salmonid rivers, but within the EU, the emphasis on the approach to criteria selection has been changing. The Water Framework Directive (WFD), aims at establishing concentration levels in the aquatic environment mainly in so far as they affect the prevailing ecology. Thus, in any proposed road drainage site, it is necessary to first establish a baseline ecology from which acceptable levels of drainage discharge and quality can be determined. Moreover, the approach will be catchment based, so that a potential drainage site will have to be set in the context of local catchment ecology and hydrology. It is important to identify pragmatic and cost-effective measures for mitigation of runoff rates and quality in this context.

The ongoing development of the national road network in Ireland, and in particular highly trafficked dual carriageways and motorways will require careful planning and knowledge of impacts and how they can be minimised. The principal drainage systems used in Ireland are filter drains, positive drains (closed pipe - with/without gullies), lined and unlined interceptor drains, shaped concrete channels and soakaways (with or without outfall pipes). Grit collection systems and petrol/oil interceptors are sometimes used where surface water may be discharged to sensitive streams/rivers. Pollution can occur directly from discharge of polluted water and sediment during rainfall and even indirectly during gully cleaning operations. A study completed by WS Atkins staff (Atkins, 1998) has identified gully cleaning operations and the subsequent disposal of arisings as a major threat to watercourses adjacent to highways.

Under these considerations, the development of sustainable drainage systems has been the subject of research and implementation for some time in Europe and North America. This development includes the use of swales, reedbeds/wetlands and permeable surfaces, in addition to the commonly used filter drains and detention ponds. Atkins McCarthy, WS Atkins, and the Transport Research Laboratory (TRL) in the UK are at the forefront of designing and implementing sustainable urban drainage systems (SUDS) for both highway drainage and residential surface water systems, and are therefore strongly placed to comment on the use of such systems in Ireland.

There is an increased awareness among engineers, planners and decision makers of the importance of flood estimation in the light of a recent flood prone decade (climate change?), increasing population, incursion of developments into marginal lands, expanding infrastructure and public awareness of climate change issues. Runoff prediction from roadways has been studied for over 30 years (Swinnerton et al. (1973),Overton and Meadows (1976)) to the extent of providing practical methodologies (in which one of the present partners, TCD, was involved) for use in drainage design. However, the rainfall-runoff design flood methodology needs to be re-examined and possibly re-calibrated for Irish conditions, particularly in the light of the forthcoming reworking of design flood and rainfall estimation in the current Flood Studies Update programme, managed by the Office of Public Works.

In summary, the problem of quantity and quality of road drainage is a complex issue in any context and Ireland has its own hydrological and transport related characteristics which need to be taken into account in order to define a set of pragmatic design guidelines. The choice and design of a particular drainage system will depend on the quality of the runoff water, the rate of rainfall and runoff (site hydrology), the traffic regime, the type of receiving environment and the applicable criteria for the receiving water course.

1.2 Objectives

The project objectives are:

1. Review existing practice with respect to road drainage design and maintenance (quantity and quality) for rural dual carriageways and motorways in Ireland and the assessment of any environmental impacts of such runoff. Set this practice in the context of current practice elsewhere in Europe.

2. Identify suitable candidate sites (maximum 15) for monitoring flow and quality of road drainage waters. Specify appropriate equipment for automated measurement of flows and sample collection at these sites as a prelude to selecting at least two for detailed monitoring.

3. Set up and operate at least two representative road drainage sub-catchments with instrumentation for monitoring rates of runoff and corresponding quality for a range of indicative parameters.

4. Analyse flow, rainfall and quality data, through the use of modelling, so as to be able to predict likely runoff peaks, volumes and quality from predetermined design rainstorms.

1.3 Hydrobiological Survey

The quality and quantity of road run-off ultimately affects the composition and distribution of aquatic biota in the receiving waters. The EU Water Framework Directive demands that three biological elements, macroinvertebrates, fish and aquatic flora, be used in the establishment of the ecological health of water-bodies. Macroinvertebrates have long been used as indicators of water quality and a number of water quality scoring systems are in common use throughout Europe (Rosenberg and Resh, 1993). Most of these are based on well defined responses to point discharges of organic effluents. Responses to short

Table 1.1: Activity 1.1 :Review of experience and practice in Ireland and Europe

Partners	TCD, UCD, WSA, TRL
Description	The project surveyed existing practice in Ireland with respect to road drainage design and maintenance (quantity and quality) for rural dual carriageways and motorways in Ireland and identified potential environmental impacts of such runoff. Current practice elsewhere in Europe was reviewed and best available technologies identified
Methodology	Extensive Literature review. Questionnaires with follow-up meetings/consultations with concerned authorities, local and national.Utilisation of in-house expertise.
Deliverables	Report-1 : Review of current road drainage design in Ireland and associated environmental impacts Report -2 : Review of road drainage design in Europe.

term changes in chemical composition or hydrological character may play a critical role in determining the ecological status of any particular system. The establishment of instrumented catchments with intensive sampling regimes provides the opportunity to examine the links between water chemistry, hydrology and aquatic ecology and evaluate the indicator potential of various biological taxa. Once the sites for detailed analysis were chosen a baseline hydrobiological/ecological survey of receiving water courses was undertaken to establish basic ecological states, this included macroinvertebrates, fish and aquatic flora.

Representative stream-bed sediment samples, were taken as part of the baseline survey and analysed for same range of water quality parameters, including hydrocarbons, as the regular water samples. This was to investigate the potential build-up of long-term "reservoirs" of contaminants in stream to be flushed during extreme events. Suspended sediment load were estimated from water samples taken during flood events.

1.4 The chemical characteristics of rainfall

Samples of rain were collected and analysed for the same parameters as the stream water quality samples. A number of samples typical of rainfall events in the study area were sought as a baseline for differences in chemical or hydrocarbon composition. The results are reported in Table 6.3 of Chapter 5.

1.5 Quality Control

In Phase 1 of the project, specific protocols, in conformity with internationally accepted standards, for water sampling and analysis established, Appendix E. Standard methods of chemical analysis were used for the parameters specified. Spiked samples were used for checks on analyses.

Laboratory analyses for MTBE and for PAHs were carried out at an accredited commercial laboratory, Alcontrol Geochem. Analyses for all other parameters were done by the trained research students, under expert supervision, within the water quality laboratory at UCD.

The project team established contact with a research group in UCC which also measured contaminants in road runoff. That team sampled at three sites which included a filter drain and a kerb and gully and analysed for suspended solids and some PAHs.

1.6 Organisation of the work

The project work was divided into a number of tasks, each of which was assigned to a project partner or group of partners, Tables 1.1 to 1.8.

Table 1.2: Activity 1.2 Identification of suitable monitoring sites

Partners	TCD, UCD, WSA
Description	A list of sites for monitoring road runoff quantity and quality was prepared, including a full specification of constructions and equipment for monitoring. Methodology A list of candidate sites was prepared. Suitable monitoring methods and required equipment were identified for each site. A final list of 3 sites was selected for detailed monitoring. Such identification was done in conjunction with the workshop meetings and ultimately in connection with the project steering group. A detailed list of necessary construction works and equipment was prepared for each selected site.
Deliverables	Report-3 : Monitoring Specification.This report contains a brief description of the candidate sites, the selection criteria. For each of the 3 selected sites a detailed monitoring specification is given.

Table 1.3: Activity 1.3 Protocols for laboratory analyses

Partners	UCD, TCD
Description	Much of the chemical analyses was carried out within the water and effluents laboratory, UCD. MTBE and PAH analyses was carried out in an external laboratory.In this activity, protocols for collection, storage, transportation and analysis were established and agreed. Procedures for timing the collection of samples were agreed as these depend on significant rainfall events. Methodology: In-house expertise, coupled with literature review.
Deliverables	Report -4 : Protocols for collection, storage, transportation and chemical analysis of water samples.

Table 1.4: Activity 1.4 Coordination of Phase 1

Partners	UCD, TCD
Description	The activities of Phase 1 were coordinated. Methodology Arrange project start-up meeting.Prepare and agree work schedules and detailed responsibilities for phase 1; Final editing of reports.
Deliverables	Report-5 : Phase-1 completion report

Table 1.5: Activity 2.1 Hydrobiological study

Partners	UCD
Description	Baseline hydrobiological study of selected sub-catchments. Methodology Hydrobiological surveys of the chosen sites were done at the beginning and end of the project sampling period in order to establish baseline ecological data and to record any evidence of change in response to the drainage system employed. The precise strategy depended on whether the sites chosen were already operating drainage sites or whether they were new drainage systems, about to be commissioned. (UCD/WSA/TRL)Paired catchments – A number of ”control” sites were identified near the road-runoff sites and with similar hydrological and biological characteristics but unconnected to the road. These were also included in the hydrobiological study to establish baseline situations.
Deliverables	Report-6 : Baseline hydrobiological status of subcatchments. Report -7 : Changes in hydrobiological status and relationship with road runoff. (analysis of temporal behaviour of catchments and of comparison between road-runoff and ”control” catchments)

Table 1.6: Activity 2.2 Set up and operate 2 representative road drainage sub-catchments

Partners	TCD, UCD
Description	Set up and operate two representative road drainage sub-catchments with instrumentation for monitoring rates of runoff and corresponding quality for a range of indicative parameters. These include at least two types of drainage system, eg filtration drain, swale or constructed wetland, for inclusion in the sites. A device for collecting and measuring flows from the road was installed. Sampling was required at the inflow to the drain as well as at the discharge outlet from the system. From the proposers' previous experience, the number of 'successful storms' from which complete data sets can be collected over a year may be less than 10. Flow and meteorological data were automatically logged and downloaded as appropriate. Water samples were collected from the automatic stations after each significant rainfall event and transported to the laboratory (UCD and commercial lab) for analysis.
Deliverables	2 functioning monitoring stations Quality controlled data-set

Table 1.7: Activity 2.3 Analysis of data

Partners	UCD,TCD, WSA, TRL
Description	The data collected from the 2 monitoring sites was analysed under two major headings(i) Rainfall/runoff relationships and quantity and temporal distribution of water to the receiving environment.(ii) Water quality of road runoff and its relationship with rainstorms and with road drainage system design. Methodology Part (i) includes a quantitative analysis of the rainfall and runoff data collected. It allows an evaluation of current hydrologic runoff design practice at the particular sites. Results are related to regional rainfall statistics, supplied by Met Eireann, so that the overall project results can be put in the context of the Irish Climate. A predictive model for runoff based on these storms was made using conventional software. Part (ii) considers all the water quality parameters analysed in the study and relates them to their concentrations to the flow regiem. Particular attention was paid to establishing any differences between water quality during the rising limb and the recession of the flows. It also gives insight into the dynamic nature of loadings on the receiving environment which may have a big influence on how the pollutants impact on aquatic life in particular. An inter-site comparison of drainage performance was completed. A simple model of their performance based on existing approaches for modelling wastewater treatment systems was developed. Alternative treatment methods were reviewed and compared in the light of the measured information.
Deliverables	Report 8 - Rainfall/ runoff and water quality from major Irish Roads.

Table 1.8: Activity 2.4 Management of Phase 2

Partners	UCD,TCD
Description	Coordination and reporting of phase 2 of project, including arranging meetings
Deliverables	Completed project. Report - 9 : Project completion (final) report (this document)

1.7 Organisation of this report

The project work can be divided into four stages; (i) review, (ii) impact studies, (iii) detailed site monitoring (iv) treatment options (review and monitoring) (v) analysis and conclusions. This report mirrors that structure.

Review: Chapter 2 review the current literature on road runoff and its impacts. Chapter 3 reports on the study of current practice in Ireland and Chapter 4 summarises European experience, and draws on European wide studies, such as Transport Research Laboratory (ed.) (2002).

Impact Studies: This involved field investigation, sampling and laboratory analysis. The field site selection methodology, criteria and site lists are given in Chapter 5. Surface water impacts are described in two parts. Chapter 7 describes the sites studied for the hydrobiological part of the project and reports on the study of macroinvertebrates and fish. Chapter 6 reports on river sediment and a special study of vegetation.

Detailed site monitoring The three sites used for the intensive storm event monitoring are described in Chapters 8 to 10. The results are compared in Chapter 11.

Treatment of road runoff Various treatment methods are discussed and assessed, both from the literature and from the projects own results in Chapter 12.

Analysis and Conclusions: Conclusions and recommendations are given in Chapter 13.

A number of Appendices give supporting details, e.g. of the sampling protocols, Appendix E, and show the detailed event hydrographs for selected storm events, Appendix F. The questionnaire form used to assess Irish practice is reproduced in Appendix C and a summary of the responses to each question is given in Appendix D. The status of all the project deliverables is reviewed in Appendix G.

Chapter 2

Literature review

2.1 Introduction

Highway runoff has been identified as a significant source of diffuse pollution contaminating receiving waters since the early 1970s (Hedley and Lockley (1975), Laxen and Harrison (1977), Smith and Kaster (1983), Gjessing et al. (1984), Hoffman et al. (1985)). It contains significant loads of de-icers, nutrients, heavy metals, polycyclic aromatic hydrocarbons (PAHs), Volatile Organic Compounds (VOCs) such as benzene, toluene, ethylbenzene, xylene, and methyl tert-butyl ether (MTBE). Ellis et al. (1987) estimated that drainage from highway surfaces contributes as much as 50% of the total suspended solids, 16% of total hydrocarbons and between 35 and 75% of the total pollutant inputs to urban receiving watercourses in the UK. Regular highway operation and maintenance activities are the most common sources of these pollutants. These activities result in dropping of oil, grease, rust, rubber particles and wear and tear of vehicle parts. Storm runoff picks up these pollutants and carries them to local streams, lakes or wetlands.

Several studies have been carried out in the USA and Canada, Europe and some other parts of the world documenting the potential impact of untreated road runoff on the receiving aquatic environment. In Irish road design practice, environmental impact assessments are generally made prior to the road construction which often do not include the quality of road runoff and attention is usually given to larger rivers. This is essentially due to the fact that little or no information is available to the designer about the water quality impacts of road runoff. This research is the first ever to be undertaken to study the effect of road runoff on Irish major ways (dual carriageways and motorways).

The impacts of highway runoff on receiving streams are described in terms of the water quality or biological changes induced by the toxicity levels exhibited or both. Maltby et al. (1995a) documented that small streams receiving runoff from the British M1 motorway had higher pollutant concentrations in both the sediment and overlying water and less diverse macroinvertebrate assemblages downstream of the highway runoff discharging point. Maltby et al. (1995b) and Boxall and Maltby (1997) subsequently showed that these elevated concentrations produced toxic effects to aquatic organisms. The toxicity observed was due to the hydrocarbons, Copper, and Zinc contained in the sediment, 65% of which was due to the PAHs: pyrene (45%), fluoranthene(16%), and phenanthrene(3.5%) alone. In a separate study, Shinya et al. (2000) reported that positive mutagenic activity was associated with PAHs in the particulate fraction of the runoff water and that the three predominant PAHs (pyrene, fluoranthene, and phenanthrene) made up about 50% of the 15 total quantified PAHs.

The constituent levels and the associated impacts of highway runoff on receiving waters are usually compared to that of urban runoff. The main difference between the two is the land use pattern of the contributing area. Urban runoff consists of wastewater and runoff from urbanised areas such as residential, commercial, parking lots, roofs, and roads, while roads alone are the major sources of runoff in highways. Barrett et al. (1998a) and Wu et al. (1998) found that highway runoff was generally similar to urban runoff and did not contain appreciably higher levels of heavy metals and hydrocarbons. In contrast, Marsalek et al. (1999) showed that 20% of the samples from heavy-travelled, multi-lane, divided roads with a traffic count of more than 100,000 vehicles per day showed severe toxicity responses compared to 1% of the corresponding urban storm water runoff. It may therefore be necessary to make

Table 2.1: AADT on Some Major Irish Roads (National Roads Authority, Ireland, 2003)

Road Name	Code no.	AADT
Tymon	M50-17	65,834
Red Cow	M50-19	71,188
Blanchardstown Toll	M50-20	75,333
Blanchardstown North	M50-21	80,698
Finglas	M50-22	75,439
Turnapin	M50-23	59,483
Turnapin Nth	M01-24	65,009
Finglas Nth	N02-23	21,477
Maynooth West	M04-34	25,204
Portlaoise West	N07-18	11,665
Arklow South	N11-12b	12,429

a distinction between the two particularly on the basis of traffic count. The UK Design Manual for Roads and Bridges (DMRB-UK, 1998) restricts pollution impacts on receiving waters to roads mainly with more than 30,000 average annual daily traffic (AADT), although the level of pollution associated with roads carrying more than 15,000 AADT could be of concern. In the USA, the 30,000 AADT cut off is used to determine whether a given road requires a certain type of runoff treatment system before discharging to receiving streams. According to these criteria the M50 in Ireland which has AADT between 60, 000 and 80, 000 would require runoff treatment facilities. Most other national primary roads and motorways in Ireland have less than 30, 000 AADT at most of their sites. Table 2.1 lists the major roads and corresponding traffic counts for Ireland.

Both surface and subsurface waters are susceptible to contamination from road runoff, surface waters being more vulnerable. The impact on ground water is generally low due to absorption, immobilisation by the soil, bacterial degradation and storage effects. The risk can however be higher in karst areas where the runoff may drain directly in to the aquifer with little or no natural attenuation (Stephenson et al., 1999). Once these water resources are polluted, the water poses a threat to public health, either through consumption of the water or body contact, the cost for treatment increases and the aquatic environment is impaired or destroyed (Overton and Meadows, 1976).

This chapter reviews the existing scientific literature on the topic of

- the effect of highway drainage on the quality of receiving waters,
- the characterisation (quality, quantity and sources) of highway runoff constituents and the factors affecting their concentrations, and
- the efficiencies of best management practices used to reduce pollution impact of road runoff.

2.2 Background

The impact of road runoff on receiving waters in Ireland has been considered insignificant as compared to the widespread problem of eutrophication from agricultural activity (EPA, 2000). This could be because the country used to have a high road density for its population, and thus a small vehicle density per kilometre of road. In recent years, however, this situation has changed dramatically. For instance, between 1980 and 1990, the total number of vehicles in the country increased by only 14% (from 911, 031 to 1,054, 259) but by more than 37% between the years 1990 and 2000 (from 1,054, 259 to1, 682, 221) (CSO, 2002). The Irish motorway network has also increased from 0.1 km/km^2 to 1.3 km/km^2 between 1987 and 1997 (National Roads Authority, Ireland, 2001). Moreover, the Government of Ireland, under the National Development Plan (NDP) 2000-2006, has outlined plans to improve the network of the national roads by upgrading the major inter-urban routes to motorways or high quality dual carriageways. This intensification justifies revisiting the question of what effect may be expected on receiving waters under the existing drainage practice. The current road drainage practice in Ireland is mainly to discharge the water collected through gullies, ditches or filter (French) drains into local streams, the performance and impacts of which have, prior to the commencement of this project, not been studied fully, viz. Chapter 3.

In addition, the EU-Water Framework Directive (Community, 2000) requires member states to ensure that "basic measures" be taken to prevent or control the input of pollutants into surface and ground waters from diffuse sources. The directive sets the objectives of achieving good ecological and chemical quality status for both surface water and groundwater sources from the control of diffuse pollution sources. Control of highway-related pollutants should, therefore, be placed in perspective with other primary activities (such as control of runoff from agricultural lands) to fulfill the criteria of "good ecological status" in all the member states.

2.3 Highway runoff constituents and their impacts

Highway runoff constituents are known to vary from place to place depending on the rainfall characteristics, nature and intensity of traffic and the drainage system used. This calls for a site-specific study to ensure technically defensible interpretations of study results and develop effective control strategies that minimise the impacts on the receiving aquatic environment. Heavy metal elements, polycyclic aromatic hydrocarbons (PAHs), Volatile Organic Compounds (VOCs) such as benzene, toluene, ethylbenzene, xylene, and methyl tert-butyl ether (MTBE) are most frequently reported in highway runoff studies. Event Mean (Median) Concentration (EMC) is often used to report highway runoff quality data. During a storm water samples are collected in proportion to flow rate or based on predetermined intervals of time. These sets of samples are composited into a single sample for analysis from which an "event mean concentration" (EMC) is estimated. This is a kind of average value since the concentrations of the pollutants carried with the storm flow vary throughout a storm event. Pollutant concentrations are generally higher in the first runoff from a storm than those observed at later stages of the same event. This phenomenon is called the "first flush effect". EMCs may not be used to examine the level of impact of a particular constituent since aquatic biota is actually exposed to the fluctuating chemical concentration and not just to the average concentration. EMC is however a useful parameter used to compare data from different sites and events and to estimate the total pollutant load of an event to the receiving water (Wu et al., 1998).

2.3.1 Heavy Metals

Heavy metals in highway runoff are the most persistent constituents that are never lost from the environment. Metals such as Lead, Cadmium, Copper, Aluminium, Iron, Nickel, Zinc, Chromium and Manganese are some of the ones most frequently reported and come from the wear and tear of vehicle parts (Sansalone et al., 1996). For example, tire wear is a source of Zinc and Cadmium. Brake wear is a source of Copper, Lead, Chromium and Manganese. Engine wear and fluid leakages are sources of Aluminium, Copper, Nickel and Chromium. Vehicular component wear and detachment are sources of Iron, Aluminium, Chromium and Zinc (Ball et al. (1991), Legret and Pagotto (1999). The concentration of Lead in runoff waters in recent years has shown a sharp decrease following the ban of tetra-ethyl Lead (TEL), a petrol additive, due to health concerns (Legret and Pagotto, 1999). Leaded petrol contained about 340 mg/l, but now only unleaded petrol is sold in Ireland. Cadmium concentrations reported in the literature are usually too low (less than 1mg/L) to cause any harm (Mungur et al. (1995), Barbosa and Hvitved-Jacobsen (1999). The mode of transport of the metal ions depends on the nature/type of the metal concerned and the prevailing hydrology. Cadmium, Copper and Zinc are primarily found in soluble forms and are transported with the water while Iron and Lead are mostly attached to sediment particles where the sediment serves as a sink (Sansalone et al., 1996). Runoff resulting from short intense rainfall following a long dry period is likely to wash off all forms of the metals deposited on the road surface and may cause severe stress to the receiving stream ecology. The fractionation of the metal into particulate and dissolved phases affects the impact of the runoff since their environmental mobility and bioavailability depends upon the level of aqueous concentration (Mungur et al., 1995).

Soluble metals usually exert the greatest impact or toxicity to aquatic life. This has implications for the development of control strategies to protect aquatic life.

2.3.2 Polycyclic Aromatic Hydrocarbons (PAHs)

PAHs are products of the incomplete combustion of oils and fuels. When released directly into the atmosphere through burning, lower molecular weight PAHs are generally dispersed much more quickly than those of higher molecular weight ones before returning to the road or surrounding land directly or in rainfall. PAHs enter water directly from the air with dust and precipitation, or particles washed from the road surface by runoff. Most PAHs do not dissolve easily in water but lower molecular weight PAHs are more water-soluble than the higher molecular weight PAHs. PAHs are slow to degrade in the environment, and sediments in particular are sinks where these chemicals tend to concentrate.

The following 15 PAHs are considered as a group and reported in highway runoff studies: Acenaphthene, Acenaphthylene, Anthracene Benzo(a)anthracene, Benzo(a)pyrene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Chrysene, Fluoranthene, Fluorene, Indeno(1,2,3-cd) pyrene, 2-Methylnaphthalene, Naphthalene, Phenanthrene, and Pyrene. PAHs in highway runoff originate primarily from used crankcase oil, lubricating oils and fuels. Two of the predominant PAHs (pyrene and fluoranthene) have been shown to be important components of crankcase oil (Latimer et al. (1990) cited in Maltby et al. (1995a). PAHs are of major concern because they are responsible for the larger percentage of toxicity to fresh water organisms. Maltby et al. (1995b) identified PAHs as the major toxicants in sediment contaminated with road runoff. Boxall and Maltby (1997) found that the three predominant PAHs (Fluoranthene, Pyrene, and Phenanthrene) account for a significant proportion of the toxicity (30% to 120%).

2.3.3 The Fuel Oxygenate Methyl-Tert-Butyl Ether (MTBE)

Since the phasing out of Leaded octane additives in petrol in the 1980s, many refineries replaced them with aromatics, a low cost alternative at the time. Towards the end of 1990s, the introduction of "Clean air acts" in Europe and the USA limited the aromatic content of petrol and oxygenated compounds such as MTBE became easy options for the refinery industry to reach the new standards. MTBE is used as an octane enhancer to achieve the required octane level and cleaner-burning petrol thereby reducing toxic exhaust emissions (carbon monoxide and ozone) and improving air quality. It has many attractive properties (such as excellent solubility in petrol) that makes it a good alternative to other petrol components and an ideal substitute for other octane enhancers e.g. Lead. The EU Directive No. 85/536 of 5 December 1985 allows the use of oxygenates such as MTBE as gasoline additives up to 15% by volume without any supplementary labelling. UK refineries add between 0.0-10% with an average of 1.08% by volume. The same percentage applies to Ireland since most of the petrol used is imported from the UK. The sole Irish refinery, in Whitegate, "adds less than 1% MTBE to its stocks in winter, a little more in summer" (e-mail from Mr. John McDermott, DEHLG, May 2002).

Leaking underground/aboveground storage tanks and accidental spills are identified as major point sources of MTBE in the USA (Squillace et al., 1997). Surface water and shallow groundwater resources receive from different diffuse pollution sources including atmospheric precipitation and urban stormwater (Lopes and Bender, 1998). MTBE has also been detected in precipitation of up to 85ng/L in winter times in urban areas in Germany (Achten et al., 2001). Currently there are no documented studies exclusively done to test the occurrence of MTBE in highway runoff. Very limited studies have shown its existence in urban storm runoff at a detectable concentration range of 0.2 to 8.7μ g/L with a median value of 1.5μg/L (USGS (1996), Squillace et al. (1997) and Borden et al. (2002)).

Most of the environmental impact of MTBE is derived from its physical and chemical properties. When petrol that contains MTBE comes into contact with water, large amounts of it can dissolve in water. For petrol oxygenated by 10% by weight of MTBE, the solubility is about 5,000 mg/L at room temperature, whereas for non-oxygenated petrol the total hydrocarbon solubility in water is about 120 mg/L (Squillace et al., 1997). It sorbs weakly to soil and therefore its transport by groundwater is not retarded by sorption. In addition, indigenous bacteria in the natural groundwater only slowly degrade

MTBE. Once it is in the soil and groundwater systems MTBE tends to migrate much faster and further than equal amounts of other petrol compounds.

Increased detection rates in both surface and groundwater sources in the USA (serious in California) lead the US EPA to campaign against MTBE to significantly reduce or eliminate it from petrol under the Toxic Substances Act. Although there are some similar incidents in Europe (Denmark, Germany and the UK) as in the US, there is little pressure in the EU to phase out MTBE. One argument is that the current EU average concentration is only 1.6% (varying from 0.0% in Portugal to 10.78% in Finland) by volume while the corresponding value in the USA is 11%. Several factors have contributed to the wider use of MTME in the USA than in Europe:

- The Clean Air Act Amendments of 1990 require oxygenates (such as MTBE) be included in some big cities due to health concerns.
- In the USA, unlike in the EU, laws in favour of ether and alcohol additives restrict high aromatic blend stocks and tax subsidies are in place to make MTBE cheaper.
- The insufficient supply of the alternative (ethanol) and the possible fuel price increase if MTBE is banned.

The occurrence of MTBE in groundwater in the EU countries has been described as scarce (generally less than 10μg/L), but concentrations as high as 700μg/L have been detected in Germany (Klinger et al., 2002). Although MTBE is considered as a potential health risk, there is little or no evidence for human carcinogenicity (Hartley et al., 1999). MTBE is toxic to marine organisms but the concentrations normally detected in the receiving waters (34μg/L) are much less than the threshold effect level (34 mg/L) of most sensitive species (Brown et al., 2001). At most commonly observed environmental exposure levels (<0.1mg/L) in surface waters acute toxicity of MTBE to freshwater organisms is low. It is unlikely to cause harmful, acute or developmental effects in a variety of freshwater organisms (Werner et al., 2001). It is however possible that these conclusions may change due to intensification of traffic load and it is necessary to fully understand how MTBE and its degradations impact on the environment.

For MTBE, taste and odour matters more than health effects. MTBE has a strong taste and odour that can be detected by humans at relatively low concentrations in water, typically at 5-15μg/L. The risk of consuming large amounts of MTBE in drinking water is therefore unlikely. The US EPA recommends a maximum of 20 μg/L MTBE to be used for drinking water based on taste and odour thresholds. Hartley et al. (1999) suggested a maximum drinking water level of 100μg/L of MTBE based on toxicological information, reproductive and developmental effects.

2.3.4 Conventional Pollutants

Highway runoff contains significant loads of other pollutants such as solids (particulate and dissolved), organic compounds and nutrients that can affect the quality of the aquatic environment. Total solids is defined as the material residue left in a vessel after evaporation of a sample and its subsequent drying in an oven at a defined temperature (103^{o}C-105^{o}C). Total solids includes total suspended solids (TSS), the fraction of total solids that is retained on a filter with a pore size of about 1.2μm and total dissolved solids, the portion that passes through the filter. Volatile suspended solids (VSS) consist of the organic fraction of TSS. Highway runoff studies typically report values for both TSS and VSS (APHA (1998) and Irish et al. (1998)).

Solids can affect aquatic life in many ways. Water tends to move out of the cells of aquatic organisms if placed in a higher concentration of total dissolved solids. This will affect the organism's ability to maintain proper cell density making it difficult to keep its natural position in the water column. Higher concentrations of suspended solids may also serve as a sink or carrier for toxins. Water with higher concentration of solids retards photosynthesis due to loss of transparency (APHA, 1998). Waters high in suspended solids are generally unsuitable for such purposes as drinking and bathing.

The organic content of road runoff is expressed by biochemical oxygen demand (BOD), chemical oxygen demand (COD) and the total organic carbon (TOC). BOD is the measure of the amount of oxygen consumed by microorganisms in decomposing organic matter in the water over a specified period of time, usually five days. BOD also measures the chemical oxidation of inorganic matter. Higher BOD values mean that there may be insufficient oxygen left for higher forms of aquatic life to survive.

COD measures the oxygen required to completely oxidise all organic materials in a sample under rigorous, hot and aggressive acid digestion. TOC is the measure of organic carbon in a sample. In many cases it is possible to correlate any two or more of BOD, COD and TOC (APHA, 1998). The major impacts associated with organic matter are colour, taste, odour and oxygen depletion.

Phosphorus and nitrogen compounds are essential nutrients for plant and animal growth. Where phosphorus is the nutrient in short supply, it limits the growth of aquatic plants in the receiving streams. A slightest increase in phosphorus can result in accelerated plant growth, algael blooms, low dissolved oxygen, and the death of certain fish, invertebrates, and other aquatic animals. Nitrogen and phosphorus compounds are the typically observed nutrients in highway runoff where the application of roadside fertilisers is practised as part of landscaping.

Other parameters such as temperature, pH, dissolved oxygen, and faecal bacteria are reported in highway runoff studies (Maltby et al. (1995a), Barrett et al. (1998a)). Although these and other related parameters discussed under this subheading are good indicators of water quality changes in the receiving waters, highway runoff does not contain any more appreciable values than that of, say, urban runoff (Barrett et al., 1998a).

Table 2 shows summary of event median contaminant concentrations (EMCs) documented in the literature and corresponding abstraction standards according to the EU surface water abstraction directive (75/440/EEC). The values displayed are based on the consideration of normal physical /chemical treatment and disinfection required before the water is suitable for public supply. Table 2.2 shows the range of Event Median Concentrations (EMCs) of pollutants reported from roads around the world.

2.4 Factors affecting highway runoff contaminant concentrations

Contaminant concentrations in highway runoff are affected by several factors such as the traffic volume, rainfall characteristics, the type of pavement and the nature and type of the pollutant. Many pollutants are primarily found in soluble forms while others are mostly attached to sediment particles. Pollutant concentrations are also influenced by the dry period preceding the storm, the antecedent storm, and the conditions during the storm event. The relative importance of each factor is dependent on the type of contaminant in question. For example, Irish et al. (1998) reported that solids load increased with the increase in the duration of the antecedent dry period and decreases with increased in the intensity of the previous storm event. Copper and Lead are highly influenced by the volume of traffic during a storm, Iron is controlled by conditions in the preceding dry period, and Zinc is influenced by the traffic count during the dry period and the runoff characteristics of the preceding storm. It is therefore necessary to understand the effect of each factor to effectively control the impacts of runoff.

2.4.1 Traffic Volume

Traffic volume is a measure of the highway usage. It is described by the annual average traffic (vehicle) count on the highway per day (AADT). It is believed that heavy travelled roads such as motorways and multilane divided highways (AADT>30,000) produce higher concentration of pollutants than roads located in rural areas (Barrett et al., 1998a). Marsalek et al. (1999) also found most severe toxic responses from the drainage of multi-lane divided highways in Ontario, Canada. This may well suggest that AADT is one of the variables that control the concentration of constituents of highway runoff. Drapper et al. (2000), in contrast, documented that in many of their study sites with AADT well below 30,000, the pollutant concentrations were as much as those with higher AADTs. Moreover, they found a poor correlation between chemical concentrations in road runoff and traffic volume ($R^2 = 0.3775$ for TSS and 0.2432 with Zinc and less than 0.2 with all other pollutant concentrations). It is important to note also that the effect of traffic volume is difficult to discern from that of the surrounding land-use in urbanised areas since heavily travelled highways tend to be found in more urbanised areas than rural highways (Barrett et al., 1998a). Drapper et al. (2000) report a relationship between traffic volume and

Table 2.2: Ranges of Event Median Concentrations of pollutants from roads around the world

Constituent	Driscoll et al.(1988) USA	Barrett et al.(1998) USA	Wu et al. (1998) USA	DMRB(1998) UK	Drapper et al. (2000) Australia	Shinya et al. (2000) Japan	WRc (2002) UK	Abstraction Standards EC
A. Solids, mg/L								
Dissolved, total			70-107					25
Suspended, total	12-135	19-129	14-215	12-135	60-1350	41-87	53-318	
Volatile, suspended	6-25	9-36		6-25				
B. Metals(Total)μg/l								
Zn	35-185	24-222		35-185	150-1850	427-1191	53-322	1000
Cd			2.5			1.00-3.00	0.47	1
Ni			2.5-9.0			2.0-9.0	5.81	
Cu	10-50	12-37	2.5-150.0	10-50	30-340	39.0-100.0	24-64	50
Fe		249-2824				2.307-5.168		
Pb	24-272	3.0-53.0	6.0-15.0	24-272	80-620	17.0-39.0	4-45	50
Cr			2.5-6.5			2.0-10.0		
Al						1394-2727		
Mn						56.0-109.0		
C. Nutrients								
Ammonia, as N			0.42-0.66					1
Nitrate, as N		0.37-1.07						25
Nitrite + Nitrate			0.08-0.38	0.2-0.9				
TKN (Total Kjeldhal Nitrogen)			0.95-1.02		1.7-11			2
Ortho Phosphate			0.08-0.26					
Total Phosphorous		0.1-0.33	0.2-0.37	0.1-0.5	0.19-1.8			0.7
D. Miscellaneous								
Total coliforms per 100mL		5700-6200						5000
Faecal Coliforms per 100mL		50-590						2000
pH		7.1-7.2						5.5-9.0
Total Organic Carbon (mg/l)	4-17	46		3-17		11-55		
COD (mg/l)	28-85	37-130	24-48	28-85			70-138	
BOD5 (mg/l)		4.0-12.0					6.59	¡5
Total PAHs(mg/l)						0.676-2.351	1.46	0.2
MTBE (μg/l)						0.2-13.5		20-40(drinking water)
Oil and Grease(mg/l)			2.7-27	1.1-3.3				

total suspended solids (TSS) and acid extractable zinc, Figures 2.1 and 2.2

Figure 2.1: Correlation of TSS Concentration to Traffic Volumes (Note single outlier, ignored in regression equation) Data from Drapper et al. (2000)

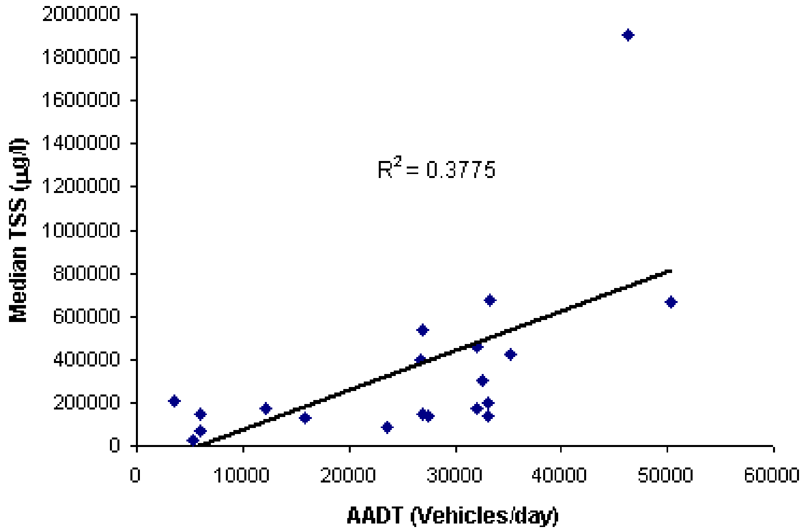
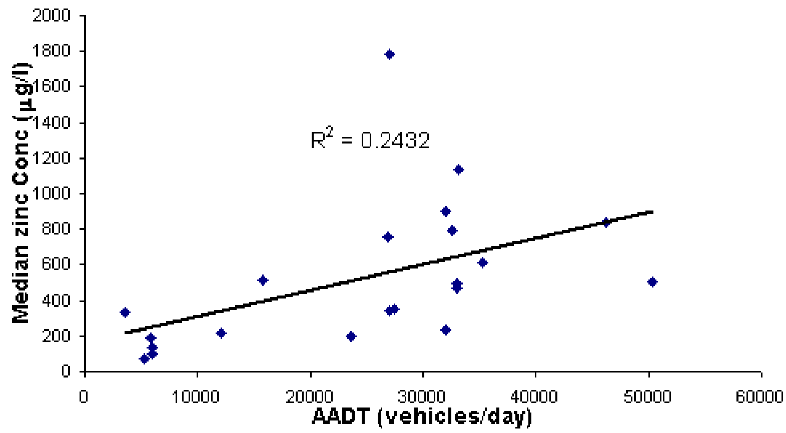


Figure 2.2: Correlation of Acid-Extractable Zinc conc to Traffic Volumes. Data from Drapper et al. (2000)



2.4.2 Rainfall Intensity/Volume

Since pollutants are removed from the road surface during storm events, it is reasonable to assume that larger runoff volume and velocity as a result of high intensity rainfall would wash off larger amount of pollutants leading to higher concentrations of pollutant and higher total load. However, constituent concentrations in a single event can considerably be influenced not only by storm volume/intensity but also by the length of a previous dry/storm period. If the antecedent dry period is long, a large amount of pollutant is continuously deposited on the road waiting for the next storm event to be washed-off. Pollutant concentrations can therefore vary from storm to storm and within a single storm event itself. There is also the "first flush phenomenon" where the concentration of pollutants in the first runoff from a storm is substantially higher than those observed at later stages of the storm event. Lee et al. (2002) found that the first flush phenomenon is not the same for all types of pollutants, greater for suspended solids and less for others (say COD). In Barrett et al. (1998a) study, the first flush effect was evident in all storm events but was generally limited to small volumes of runoff (see also Lee et al. (2002)). In general, highway runoff constituent concentrations show a complex temporal variation related to rainfall intensity/volume.

2.4.3 Type of Pavement

The effect of highway paving material (e.g. conventional versus porous) on the quality of highway runoff has not been well studied. Rob et al. (1999) and Pagotto et al. (2000) demonstrated that porous pavement improved the water quality slightly for the main pollutants of runoff water (such as Cu, Pb, Zn, solids and hydrocarbons) in Dutch and French motorways respectively. It is generally believed that highway surface type is relatively unimportant compared to such factors as whether the road is in a rural or urban location. It has also been reported that the type of collection and the drainage system, kerbs and age of the road has a greater effect on runoff quality than pavement type (Wu et al., 1998).

2.5 Assessment of impact of highway runoff

Impact assessment of highway runoff on the receiving aquatic environment involves the measurement of its physical, chemical and biological characteristics and comparing these to previously measured or desired "baseline" constituent levels and/or aquatic communities. The baseline can be an established standard (guideline) or a measured value of similar component from a similar (same) site virtually "unaffected" by human activities. Such conditions are hard to find. The other option is to use the upstream of a river, where the road drainage is discharged, as reference to compare measured constituents at the downstream of the discharge point (see also Maltby et al. (1995a)).

The traditional assessment approaches use the physical and chemical characteristics of the runoff alone to compare with the established criteria or guidelines (Ellis (2000), Sriyaraj and Shutes (2001)). While this approach is very easy to formulate, it does not protect aquatic biota efficiently since it ignores the effects of chemical interactions and other complicating factors on toxicity such as bioavailability and duration of exposures (Lee and Jones-Lee (1993), APHA (1998)). It is understood that fluctuating pulse exposures, such as the case in road runoff, produce greater effects than continuous exposures of constant concentration, pointing to the inadequacy of water quality standards (Burton, 1999). Moreover, it is impractical to regulate all the overwhelming number of pollutants potentially reaching surface waters with individual water quality standards and/or criteria. Some unsuspected pollutants may do damage without their presence being anticipated or detected. It is, therefore, important to know that exceedance of these standards may not necessarily result in an adverse biological effect (Chapman, 2000). As suggested by many researchers, chemical constituent values alone should be used for identifying potential contaminants and sources but not for ultimate decision making (Chapman and Mann, 1999).

Other researchers followed chemical and biological (Perdikaki and Mason (1999), biological and toxicological (Maltby et al. (1995a,b)) or chemical and hydrological criteria (Mulliss et al. (1996) together as provided in the respective guidelines to assess the impact of road runoff on water quality. An ideal and reliable evaluation of the impacts of highway runoff-associated chemical constituents that cause pollution on the receiving aquatic environment would have been to gather information on, but not limited to, chemical, biological communities, water and sediment toxicity and hydrology. But, this approach is still not widely used and may also be costly (Burton, 1999).

The issue of impact assessment of highway runoff on the receiving waters is complicated by environmental factors that are unconnected to road runoff quality (Maltby et al., 1995a). The first of these is the habitat change that may result from the altered hydrological regime at the road crossing. Hydrological regime changes are associated with increased flood and reduced low flows that can significantly alter aquatic life habitat. The second is the biological changes that normally occur as a natural characteristic of aquatic ecosystems. These changes may occur due to competition, introduction of new species, predation or other stresses. The third is the chemical change that may occur due to the above changes.

The impact of highway runoff on the receiving waters is dependent upon both the concentrations of constituents in the runoff and the receiving waters. The level of the pollutant concentration in the runoff can be elevated which may result in excessive input of the pollutant yet, only a small portion of the input may be bioavailable. A considerable volume of literature reported pollutant concentrations in total quantity terms without due regard to the fraction of the soluble form independently. Several studies have, however, stated that only a fraction of the soluble form is bioavailable and exerts the greatest impact or toxicity to aquatic life (Lee and Jones-Lee (1993), Scholze et al. (1993)). Small size streams allow less dilution if the pollutant input is high even if the concentration in the receiving water is very low. Many researchers focussed their studies on small receiving waters (rivers or streams) where the effect of dilution is less and worst case scenarios may clearly be depicted (Maltby et al., 1995a).

2.6 Highway drainge practice and pollution control options

Road drainage practices are primarily designed to remove surface and sub-surface water to provide safety and minimum nuisance for the motorist and maximise longevity of the pavement and its associated earthworks DMRB-UK (1996). Drainage practices are either surface or subsurface. Some systems such as filter drains have dual functions of surface water runoff control and control of groundwater below the road level. Specific structures of drainage systems include kerbs and gully pots, filter drains, informal verge systems, infiltration pavements, swales and ditches, oil and grit separators, detention or retention ponds, soakaways and infiltration basins, drainage ditches and natural/artificial wetlands. Drainage systems generally perform one or more of the following functions: collection of water, conveyance of water, disposal of collected water, storage of water to reduce peak flows, removal of coarse sediment and CIRIA (1994).

Almost all established drainage systems remove pollutants that can be physically separated from the runoff water. This is achieved by trapping or settling pollutants with or without a physical structure. Soluble pollutants can not however easily be treated with conventional drainage systems. The efficiency of these systems is very much limited by their ability to contain, infiltrate biodegrade all of dissolved pollutants contained in the runoff. Several pollution control strategies referred to as Best Management Practices are developed to substantially reduce both particulate and dissolved forms of pollutants contained in the runoff.

2.6.1 Review of Best Management Practices

Best management practices (BMP) are measures that can be taken to reduce any impacts of highway runoff constituents on receiving waters and the aquatic life. BMP are based on principles of sedimentation, infiltration, filtering systems, wetland systems or some form of a combination of these (Scholze et al., 1993). BMPs also involve non-structural measures such as cleaning operations and pollution control at source. The realisation of certain vehicle components and fuels as sources of heavy metals, PAHs and some other pollutants may lead to modifications in the composition of tires, oil fuel and brake pads (Lee and Jones-Lee, 1993). Ban of leaded fuel from the fuel market can be a good example of this effort.

Detention/retention ponds were originally developed for runoff control in urban areas. Urbanisation reduces the rate of infiltration due to a substantial increase in area of impervious and smoother surfaces. As a result, the volume and peak of floodflow increases substantially compared with pre-development flows. This in turn requires larger pipes or channels to safely discharge the flood flow without causing any harm. This is rather a costly option; instead detention/retention ponds were introduced to temporarily hold the flood thereby reducing the peak flow and the time to peak. Later, it was discovered that these ponds have an additional advantage of improving the water quality of the stormwater. Detention ponds are normally dry outside the storm period while retention ponds are permanently wet. However, these definitions are sometimes interchanged (Nascimento et al., 1999). To avoid confusion, some authors prefer to use phrases like wet detention and wet retention ponds. There is a clear difference between wet ponds and wetlands. In wet ponds vegetation may grow along the pond edge only and the depth is much higher than for constructed wetlands. Constructed wetlands have a more uniform shallow depth and heavily vegetated throughout the pool that facilitate the removal of suspended solids, nutrients and toxic substances (Scholze et al., 1993).

Although constructed wetlands were designed mainly to treat municipal and industrial wastewaters, they are now being used for the treatment of urban runoff (Mungur et al. (1995), Shutes et al. (1997)). Both natural and constructed wetlands have been used but, the use of natural wetlands for road runoff treatment is inadvisable because of the possible metal accumulation (Sriyaraj and Shutes, 2001). After all, natural wetlands themselves are considered as receiving water bodies. In wetlands, runoff is treated by mechanisms such as sedimentation, filtration, biodegradation (bacteria and plants) and chemical precipitation. Barrett et al. (1998a) and Mungur et al. (1995) suggested that the same types of treatment systems used for urban runoff may be assumed appropriate for highway runoff treatment. Constructed wetlands for the treatment of highway runoff are popular in the US and are becoming the most commonly used methods in the UK and other parts of Europe, Mungur et al. (1995), Shutes et al. (2001), Cheng et al. (2002)). They have shown some positive percentage removal of runoff constituents for certain types of pollutants and sources for some others (Copper). Nu Hoai et al. (1998) reported a removal efficiency of 24-51% for Lead and 35-86% for suspended solids during dry weather periods. Metal removal efficiencies are generally higher in storm events than in dry weather conditions, Schutes et al. (2001). In Sweden, wet detention ponds are the most widely used methods for the treatment of highway runoff (Lundberg et al., 1999).

BMPs differ in their capacity to remove/reduce suspended solids, nutrients, heavy metals and other pollutants. The characterisation of the pollutant is therefore an important element in the selection of a suitable BMPs. The site-specific nature of highway runoff pollutants prevents a direct adoption of any single successful BMP in another place. Some pollutants are best removed by ponds or wetlands and some others by infiltration practices and still others by filtering systems. However, there is no single BMP that is effective for all types of pollutants and selection of the appropriate type require detailed study.

2.6.2 Performance Evaluation of BMPs for Treatment of Highway Runoff

The primary objective of implementing BMPs is to enhance the beneficial uses of the receiving waters and protect the downstream aquatic ecosystem by treating the runoff. The pollutants removed from the runoff are disposed in a place where they pose no more threat to surface or groundwater sources (Scholze et al., 1993). The problem is that there are no well-established performance criteria to indicate whether or not these BMPs have met their objectives, above all the environmental benefits. Although efficiency may be measured against two criteria: constituent removal and toxicity reduction, the usual approach is based solely on the former. In this approach the concentration reduction of total constituents across the BMP unit are measured and reported as percentage removal performance (Sansalone and Buchberger (1995), Barrett et al. (1998b), Barbosa and Hvitved-Jacobsen (1999), Shutes et al. (2001), Cheng et al. (2002), Walker and Hurl (2002). Though this approach is relatively simpler and appropriate for some constituents, it may not guarantee the reduction of the potential toxicity due to other constituents such as aqueous (bioavailable) form of heavy metals. Thus evidence of considerable reduction of the percentage of solids across a BMP doesn't necessarily remove toxicity Scholze et al. (1993). Mungur et al. (1995) reported that aqueous metal concentration across a natural wetland remained unchanged showing that further heavy metal removal mechanisms were necessary to reduce toxicity. Shutes et al. (1999) emphasised that performance prediction of constructed wetlands is difficult if not impossible because of the fluctuations in influent flows and pollutant concentrations. Tables 3, 4 and 5 show removal efficiencies of grassy swale, constructed wet land and detention pond respectively.

2.7 Summary

This review outlined that motorway runoff may contain a variety of chemical constituents that may have the potential to affect beneficial uses and alter the biological composition of receiving waters. The major contaminants encountered are heavy metals, polycyclic aromatic hydrocarbons (PAHs) and Volatile Organic Carbons (VOCs). PAHs carried by the sediment are responsible for the majority of the toxicity exhibited by highway runoff. The impact of the runoff is dependent on the characteristics of both the runoff and the receiving waters. The characteristics of the runoff in turn depend on such

Table 2.3: Removal efficiencies (%) of grassy Swale: (source:Barrett et al. (1998b))

Constituent	Median of US183	Median of MoPac expressway	Walnut Creek
TSS	87	85	87
Turbidity	69	78	81
Fecal Coliform	-192	NA	NA
Fecal Strep	-74	-477	-380
COD	61	63	69
TOC	51	53	61
Nitrate	50	23	36
TKN	33	44	54
Total P	44	34	45
Zinc	91	75	79
Lead	41	17	31
Iron	79	75	79

Table 2.4: Pollutant removal efficiencies of Constructed Wetland: Schutes et al. (2001)

Parameter	Wet weather		Dry weather	
	Short intense	Long steady	Short intense	Long steady
SS	75	40.3	-6.4	-75.8
Cd	90.3	99.4	8.2	23.8
Cr	48.5	24.2	-337.5	49.8
Cu	-97.1	-88.4	-75.2	-15.9
Ni	77.5	84.8	-0.1	-9.0
Pb	97.9	97.6	51.7	66.4
Zn	66.2	59.7	29.2	12.1

Table 2.5: Comparison of wet biofiltration and dry balancing pond: Hares and Ward (1999)

% removal of Element	Wet pond Biofiltration	Dry Pond Balancing
V	93	88
Cr	91	84
Mn	88	88
CO	91	88
Ni	91	90
Cu	93	88
Zn	87	84
Mo	88	84
Cd	90	95
Sb	91	86
Pb	89	89

factors as traffic volume, antecedent dry/storm period, and the nature of pollutant. Although some evidence suggests that highway runoff-associated constituents result in loss of biodiversity, the cause-effect relationship between reduction in macroinvertebrate assemblage and motorway runoff induced toxicity is complicated by other environmental factors unconnected to motorway runoff capable of causing such changes. For instance sediment washed of the road (clean or contaminated) may alter the structure of the natural habitat, bridge and drainage structures may change the flow pattern in the streams. The evidence can, however, identify certain factors as important and serves as a trigger to indicate the need for further investigation.

There are basically two assessment approaches of the effects of highway runoff associated constituents on the receiving waters. The first of these use chemical concentrations or, in a few cases, biological community indices such as diversity and abundance to establish criteria or standards. The other approach considers toxicological information with or without chemical criteria. Some authors suggested an integrated approach that considers data pertaining to the physicochemical, water and sediment quality, flow, biological and toxicological information. The integrated approach appears to provide the ultimate tool for decision making but may be costly and practically difficult.

Highway runoff associated impacts may be controlled by implementation of best management practices (BMPs). However, it is not generally possible to control all pollutants present in runoff by a single BMP. A combination of two or more units may be required to achieve the maximum possible result. Moreover, most of the BMPs are best at removing the particulate forms of the pollutants and have little effect on the aqueous forms. This is important for heavy metals since the soluble form exerts the maximum toxicity to aquatic life. The usual approach to measuring the efficiency of BMP is percentage removal of total metal and other constituents across the BMP. It is difficult to find any study that addressed toxicity reduction as well. In addition, BMPs face a number of practical problems. Land requirement, responsible body to carry out the maintenance, disposal of contaminated sediment, and liability issues if these practices do not perform as expected are some of these problems.

This is by no means an exhaustive review of the available literature in the topic. It is rather a survey of relevant literature that could be easily accessed and available during the first year of the project. It is hoped that it gives a brief review on the characteristics, effect and assessment of highway runoff related contaminants and mitigation measure that can be taken to alleviate the impacts.

Chapter 3

Current Road drainage practice in Ireland

3.1 Introduction

Historically, highway drainage designs were based on hydraulic considerations for the speedy removal of surface and subsurface waters to ensure safety and prevent water-related failure of the pavement and associated structures (DMRB-UK, 1999). The quality of the discharge was not then a major concern since the effect of highway runoff on receiving waters was not considered significant compared to that of other traditional sources. Progress in the control of traditional sources and awareness of highway runoff contaminants and their possible impacts have, however, attracted considerable attention to the study of their effects on receiving waters.

Research has shown that highway runoff may contain heavy metals and hydrocarbons that are toxic to biota at relatively lower concentrations (Maltby et al. (1995b) and Boxall and Maltby (1997). Rainfall intensity, antecedent dry period and traffic volumes are among the major factors that affect pollutant concentration in the runoff (Irish et al. (1998), Drapper et al. (2000)). Traditionally, traffic volume has been considered the main indicator of the risk of pollution road runoff poses to receiving waters. Volume 11, Section 3 of the DMRB-UK (1998) asserts that discharge from roads with Average Annual Daily Traffic (AADT) less than 15,000 have no noticeable effect on receiving waters. Roads between 15,000 and 30,000 AADT have only minor impacts and discharges from roads exceeding 30,000 AADT require additional treatment to reduce the impact on receiving waters. In Ireland, AADT values exceeding 30,000 are found only on some national roads (Motorways and Dual Carriageways), with the highest exceeding 90,000 on the M50 at the exit to the M1 with a 10% Heavy Goods Vehicles (HGV) component. The traffic volumes on these roads grow by about 6 to 7% annually (National Roads Authority, Ireland, 2005).

Nearly all types of drainage systems provide some degree of pollutant removal, as a secondary function, through natural processes such as sedimentation, filtration, absorption or biodegradation. Their performance can however be impaired due to hydraulic overloading and poor maintenance conditions. In the absence of regular maintenance and an effective mechanism of removing trapped pollutants, drainage systems can even act as sources of pollution during storms due to resuspension and flushing. For example, in kerb and gully systems, pollutants trapped in the pot can undergo significant biochemical changes between rainfall events that may result in degradation of the bottom sediment. The degraded sediment releases toxic chemicals and soluble organic compounds from the sediment into the overlying water to form a polluted liquor (Morrison et al. (1995), Butler et al. (1995)). The liquor, containing elevated concentrations of pollutants, is washed out in the early period of a storm event and may pollute receiving waters.

The environmental effects of road runoff in Ireland are included with other effects in their Environmental Impact Statements (EIS). EIS are submitted with the planning application for road schemes subject to Environmental Impact Assessment (EIA) under the EU Directive 85/337/EC (as amended by Directive 97/11/EC) or the existing Roads Act, 1993. The EIS describes the likely effects of the road scheme on the environment for the selected route corridor and includes effects on water. Con-

Table 3.1: Lengths of motorways, national primary and secondary roads in Ireland(source: National Roads Authority, Ireland (2005))

Type of Road	Length (km)	Percentage of National Network
Motorways	192	3.5
National primary (dual carriageway)	278	5
National Primary (single carriageway)	2,307	42
National Secondary (dual carriageway)	8	-
National Secondary (single carriageway)	2,679	49
Total National Primary Roads	2,776	50.8
Total National Secondary Roads	2,687	49.2
Total National Primary and Secondary Network	5,464	100

tractors and designers are required to provide surface water treatment provisions at outfall locations as identified and recommended by the EIS. Runoff treatment systems, such as petrol interceptors, balancing ponds, soakaways and silt traps are installed on some roads in Ireland. However, EIS do not always prescribe the environmental monitoring necessary to study the impacts of the runoff after the scheme is completed. Such concepts were included only in more recent legislation (e.g. Protection of the Environment Act, 2003).

The objective of this chapter is to present a review of current road drainage design and maintenance practice for motorways and rural dual carriageways and its impact on receiving water quality in Ireland. County Councils (which have direct responsibility for roads) and regional road design offices were consulted and sent questionnaires concerning their road drainage design practice, treatment systems, maintenance practices and environmental impacts of road runoff. The experience and practice of consulting engineering firms involved in road design was communicated by Atkins, a project partner. This chapter summarises the responses of these organisations and makes some observations and recommendations on road drainage design and maintenance practice in Ireland.

3.2 Roads in Ireland

In England, "highway" usually refers to a main public road connecting towns and cities. In this report, the terms highway and road are used interchangeably to refer to national roads.

The total length of roads in Ireland is about 92,500km (Central Statistics Office, 2002). A total of about 1.9 million vehicles use this network. National primary roads (includes motorways, dual and single carriageways) comprise only 3% of the total road network but carry about 27% of the total road traffic. The total road network carries 96% of passenger traffic and 90% of freight traffic. These figures place Ireland among those countries in the EU with the highest reliance on road transport. The corresponding figures for the EU as a whole are 88% and 72% respectively. Figures 3.1 and 3.2 show a comparison of total road network and density of motorways in the EU.

Table 3.1 lists lengths of national primary and secondary roads in Ireland. The system for identifying Irish roads is as follows. A prefix M and a number designate motorways in Ireland. These are the M1 (Dublin-Belfast), M4 (Dublin-Sligo), M7 (Dublin-Limerick), M9 (Dublin-Waterford), M11 (Dublin-Wexford) and the M50 (Dublin ring road). National primary routs (single or dual carriageways) are designated by the prefix"N"and a number (1-11) such as N1, N2, N3, etc. National secondary roads are designated the same way as the primary but with higher numbers. This review focuses only on rural dual carriageways and motorways in the country.

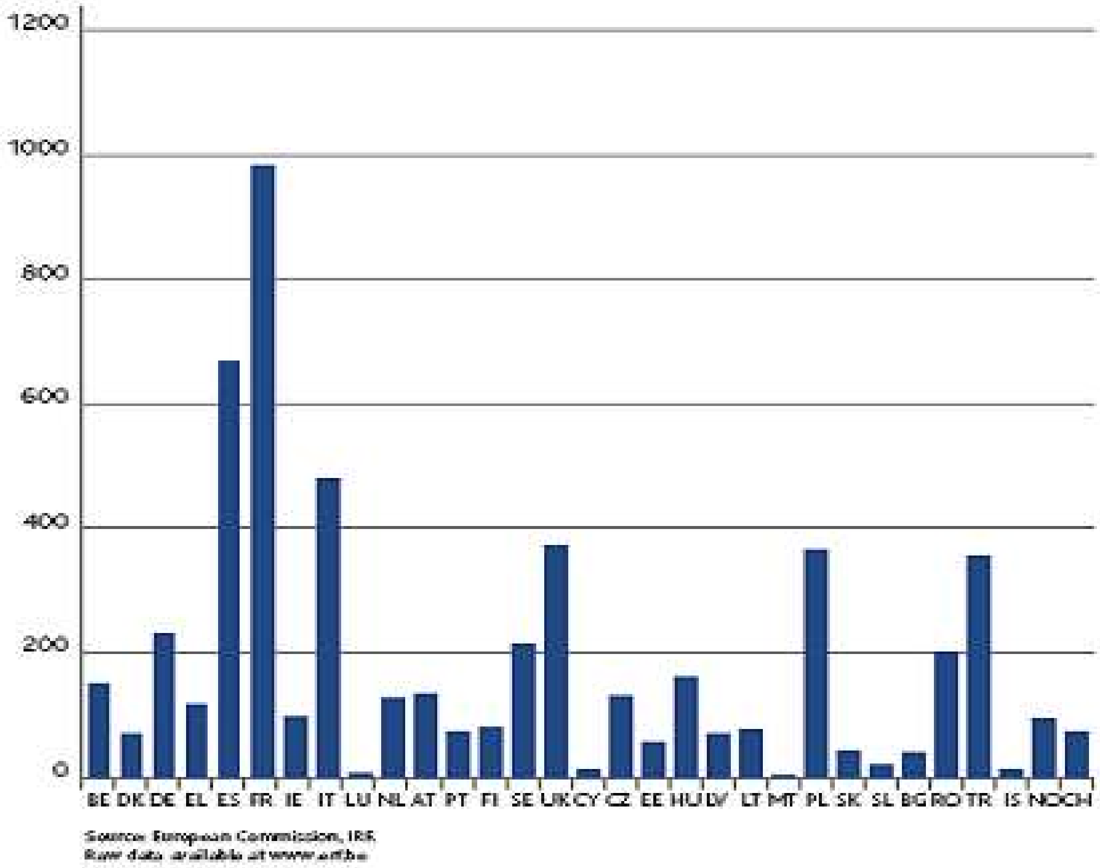


Figure 3.1: Length of total road network in the EU per country - 2002 (thousand km)

3.3 Legal aspects of road drainage in Ireland

3.3.1 National Legislation

This section outlines the relevant environmental legislation for the protection of surface and groundwater sources from pollution sources. National legislations introduced under relevant headings at different times ensure the protection of surface and groundwater sources in Ireland. The Fisheries (Consolidation) Act, 1959 and The Local Government (Water Pollution) Acts 1977 and 1990 constitute the main national legislations in this regard. Sections 171 and 172 of The Fisheries (Consolidation) Act 1959 provide that:

Section 171 Any person who

1. steeps in any waters any flax or hemp, or
2. throws, empties, permits or causes to fall into any waters any deleterious matter

shall, unless such act is done under and in accordance with a licence granted by the Minister under this section, be guilty of an offence under this section and shall be liable on summary conviction thereof to a fine not exceeding twenty-five pounds or at the discretion of the court to imprisonment for a term not exceeding six months or to both such fine and such imprisonment.

Section 172 In this section, the expression "deleterious liquid" is defined to mean any deleterious or poisonous liquid or washings or drainage from any deleterious matter.

This was an important introductory legislation though it did not explicitly indicate how this legislation could also be extended for the protection of groundwater. A principal legal framework for the protection of surface and groundwater was laid in the Local Government (Water Pollution) Acts 1977 and 1990. Section 3 of this Act provides:

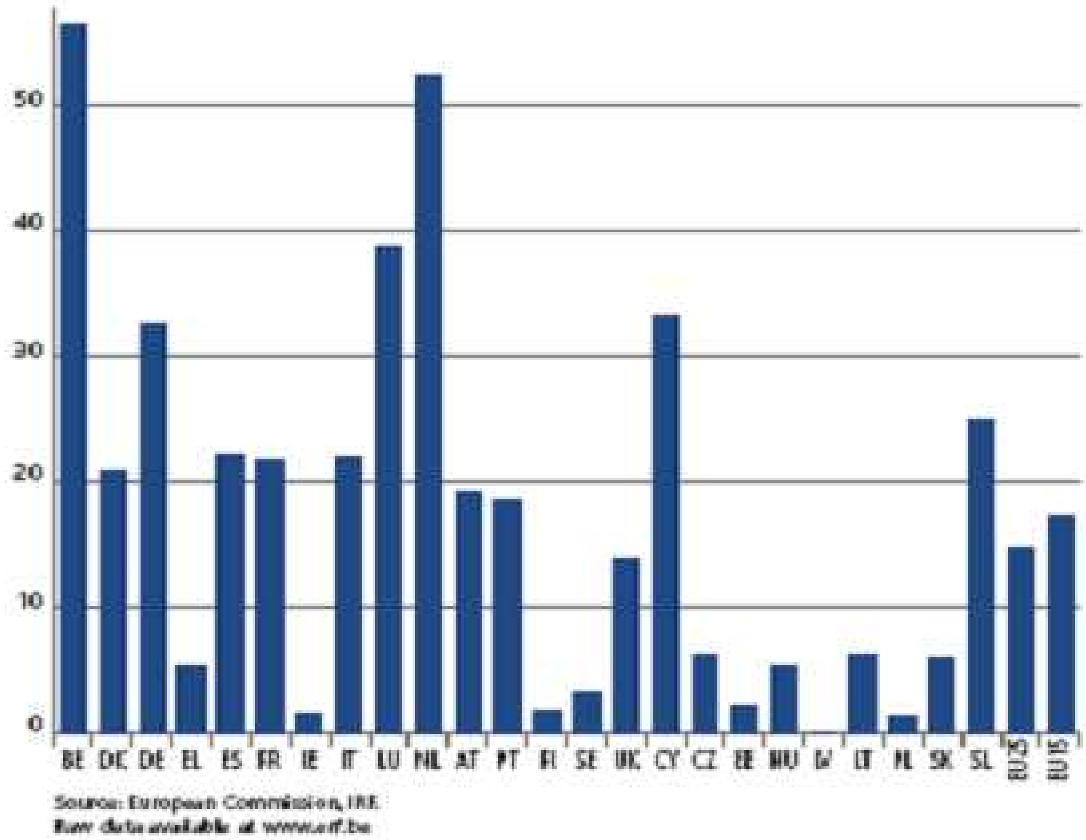


Figure 3.2: Density of motorways in the EU - 2002 (km per thousand km^2) 2002 (thousand km)

1 Subject to subsection (5), a person shall not cause or permit any polluting matter to enter waters.

2 A person who contravenes subsection (1) shall be guilty of an offence and shall be liable - (a) on summary conviction to a fine not exceeding 1,000 or imprisonment for a term not exceeding 6 months, or both, or (b) on conviction on indictment, to a fine not exceeding 25,000 or imprisonment for a term not exceeding 5 years, or both.

Section 1 of this Act defines water as

(a) any (or any part of any) river, stream, lake, canal, reservoir, aquifer, pond, watercourse or other inland waters, whether natural or artificial (but not a sewer),

(b) any tidal waters, and

(c) where the context permits, any beach, river bank and salt marsh or other area which is contiguous to anything mentioned in paragraph (a) or (b), and the channel or bed of anything mentioned in paragraph (a) which is for the time being dry,

The amendments introduced later in 1990 referred to as The Local Government (Water Pollution) Amendment Act, 1990 increased the penalties (shown above) for offences committed in contravention of Section 3 of the Act as of 18 July 1990. These Acts empower local authorities to prosecute offenders, issue notices of measures to be taken, or seek court orders to discontinue discharges into receiving waters suspected of causing pollution. Local authorities, however, had both a developmental role and a role in protecting the environment that sometimes resulted in conflicts of the two interests. The conflict reached climax in the early 1990s marked by dissatisfaction of the general public and environmentalists (Shipan, 2003). The situation showed the need for the establishment of an independent body responsible for the protection of the environment alone. Due to pressure from the public and the European Commission, the Environmental Protection Agency Act 1992 was passed and the Agency itself was established the following year. Its most important functions are laid out in section 52 of the Act and include

(a) the licensing, regulation and control of activities for the purposes of environmental protection,

(b) the monitoring of the quality of the environment, including the establishment and maintenance of databases of information related to the environment and making arrangements for the dissemination of such information and for public access thereto,

(c) the provision of support and advisory services for the purposes of environmental protection to local authorities and other public authorities in relation to the performance of any function of those authorities,

(d) the promotion and co-ordination of environmental research, the provision of assistance and advice in relation to such research and the carrying out, causing to be carried out, or arranging for, such research,

(e) liaison with the European Environment Agency provided for under Council Regulation 1210/90/EEC ,

(f) such other functions in relation to environmental protection as may be assigned or transferred to it by the Minister under section 53 or 54 including functions arising from any obligations under any treaty governing the European Communities or an act adopted by the institutions of those Communities or other international convention or agreement to which the State is, or becomes, a party.

Part (a) of this provision was responsible for the concept of Integrated Pollution Control (IPC), in which all types of pollution emitted by a facility are examined at together before licensing. There is also progress in terms of pollution prevention. Most previous Acts and national regulations followed more of a reactive approach (imposing penalties) while this Act introduced the concept of protective approach where pollutants are controlled or minimised at the source to achieve the required environmental protection. This concept has been extended, refined and reintroduced under the Integrated Pollution Prevention and Control (IPPC) Directive (96/61/EC). This directive was adopted into Irish law and enacted as Protection of the Environment (PoE) Act 2003. The PoE Act came into effect as of 12 July 2004. While there are some similarities between IPC and IPPC, major additions in the IPPC Directive include:

- Many more activities are covered by IPPC than IPC
- Best available techniques must be utilised to prevent or reduce pollution. IPC allowed use of techniques with in the economic reach of the licensee
- While the IPC is concerned with the immediate effect of an activity, IPPC also considers pollution risks even after an activity is discontinued.
- IPPC requires facilities to be in place to reduce accidental spills
- IPPC requires the use of energy efficient systems to reduce emissions

Section 96 of the Act empowers the Agency to carry out environmental quality monitoring to study the effects of emissions to the environment. It can then impose discharge consent (in case of water) or serve a notice prohibiting the discharge if necessary. Road runoff outfalls can be subject to such requirements and a water treatment system may be mandated. It is however difficult to issue such notices at the moment due to the complex nature of road runoff and limited knowledge of its effects on the receiving surface or groundwater sources. The monitoring process takes time and the effects may not be as directly observable as those from other types of pollution, such as fish kills or eutrophication.

3.3.2 Relevant EU legislation

There are a number of EU Directives enacted for the protection of surface and groundwater sources from pollution including:

- Bathing Waters (76/160/EEC),
- Dangerous Substances (76/464/EEC),
- Freshwater Fish (78/659/EEC),
- Shellfish Waters (79/923/EEC),
- Groundwaters (80/68/EEC),
- Drinking Water (80/778/EEC),
- Urban Waste Water Treatment (91/271/EEC)
- Nitrates (91/676/EEC)

The most relevant ones are the Discharge of Dangerous Substances Directive (76/464/EEC) and the Groundwater Directive (80/68/EEC). The Groundwater Directive was taken out of the Dangerous Substances Directive to regulate groundwater pollution caused by certain dangerous substances. The Discharge of Dangerous Substances Directive identifies list I and list II substances and aims to eliminate pollution from list I substances and reduce pollution from list II substances. Both Directives are now fully integrated in the Water Framework Directive (2000/60/EC). The Minister for the Environment, Heritage and Local Government transposed the Water Framework Directive (WFD) into Irish National Law in December 2003. The Directive establishes a new framework for integrated management and protection of water quality at river basin level. It sets out the transitional provisions for the existing discharges of certain dangerous substances of Directive (76/464/EEC) until 2013. It lists metals (such as cadmium, lead, nickel and their compounds), Polycyclic Aromatic Hydrocarbons (Anthracene, Fluoranthene, Benz0(a)pyrene, Benzo(b)Fluoroanthene, Benzo(ghi)pyrelene, Benzo(k)fluoranthene, Indeno(1,2,3-cd)pyrene), and pesticides among others, as Priority Substances and prohibits the direct discharge of these to groundwater. Articles 16 and 17 of the Directive set out strategies for the prevention and control of pollution of surface and groundwater sources respectively to maintain good status of all water sources. Good status for surface waters refers to good chemical and ecological status whereas good chemical and quantity status applies for groundwater. This entails the general protection of aquatic ecology, valuable habitats, and water used for abstraction of drinking water and bathing.

3.4 Highway drainage systems in Ireland

Drainage practices are classified as surface and subsurface systems based on whether they are used for surface or subsurface drainage. These classes are not totally unrelated since combined systems exist which are used for both surface and subsurface drainage. The type of drainage system to be used in an area depends primarily on whether the road is in an urban or rural setting, in a cutting or an embankment or if any ground water problems exist. The main types of drainage systems used on rural dual carriageways and motorways use in Ireland include: -

1. Filter (French) Drain,
2. Kerbs and Gullies,
3. Combined Surface Water Channel and Pipe Systems,
4. Over-the-edge Drainage, and

Table 3.2: Drainage system usage in some Counties (highways only)

	Length of highway (km)					
Drainage system	Kerry	S. Tipp.	Carlow	Sligo	Louth	Total
Filter Drain	25	5.8	13	3.5	23	70.3
Kerb and Gully 10		12	0.2	6	28.2	
Open Ditch	40	1.6	45			86.6
Surfacewater Channel				1.0		1.0
Over-the-edge Drainage	25	0.5		13		38.5
Combined kerb and Drainage Block					4	4.0

5. Fin or Narrow Filter (NF) Drains

Fin or Narrow Filter (NF) Drains are used independently or in combination with other types of drainage systems to drain the pavement layers to prevent premature failure of the road due to water-related deterioration. The DMRB-UK (2000) gives guidance on choosing a specific type of drainage system for site-specific conditions, e.g. Figure 3.4 . The survey indicated that Road Authorities in Ireland do not have exact estimates of the lengths of roads drained by each type of drainage system in their regions. It is however estimated that a substantial length of the motorways and dual carriageways in the country use filter drains as the principal type of drainage system. For instance 71% of the road from Dublin (starting from its junction with the M50) to Portlaoise (about 80km) is drained by filter drain systems. The remainder is drained by kerb and gully (17%), over-the-edge drainage (13%) and combined surface water and pipe systems (6%). Five of the County Councils surveyed gave the types of the drainage systems and estimated lengths of roads drained by each type, Table 3.2.

The following sections discuss these drainage systems and condition under which they are used, the water quality benefits and associated problems.

3.4.1 Filter (French) Drain

This is the most popular type of drainage system used in rural dual carriageways and motorways in Ireland. It consists of either a porous, perforated or open-jointed non- porous pipe at the bottom of a trench filled with gravel laid at the edge of the pavement or close to it, Figure—3.3. It serves both purposes of surface and subsurface drainage and is called a "combined filter drain". It is mainly used in cuttings or areas with groundwater problems. It also provides storage of runoff during storms that may help to attenuate flood peaks at the receiving stream due to the time lag between groundwater flow and stormwater flow. Road authorities in Ireland do not have exact estimates of the total length of roads drained by this system in their regions. Visual inspection however suggests that a significant percentage (>40%) of dual carriageways and motorways in Ireland use this system.

A geotextile membrane is used to prevent fine material entering the filter drain while permitting free flow of water into the drainage medium. It limits plant root growth into the filter media and also has some oil retention capacity. Problems associated with the use of geotextile membrane are discussed later in this report.

The advantages of filter drain over other systems are listed in section 4.7 of HD 33/96 (DMRB-UK, 1996) as:

- early installation and usage for collection of drainage runoff during the construction stage.
- removal of groundwater beneath the pavement to a greater depth than would be possible with fin or narrow filter drains.
- easier construction than other systems incorporating both surface water carrier drains and fin or narrow filter drains.
- easier inspection and maintenance than is possible with fin or narrow filter drains.

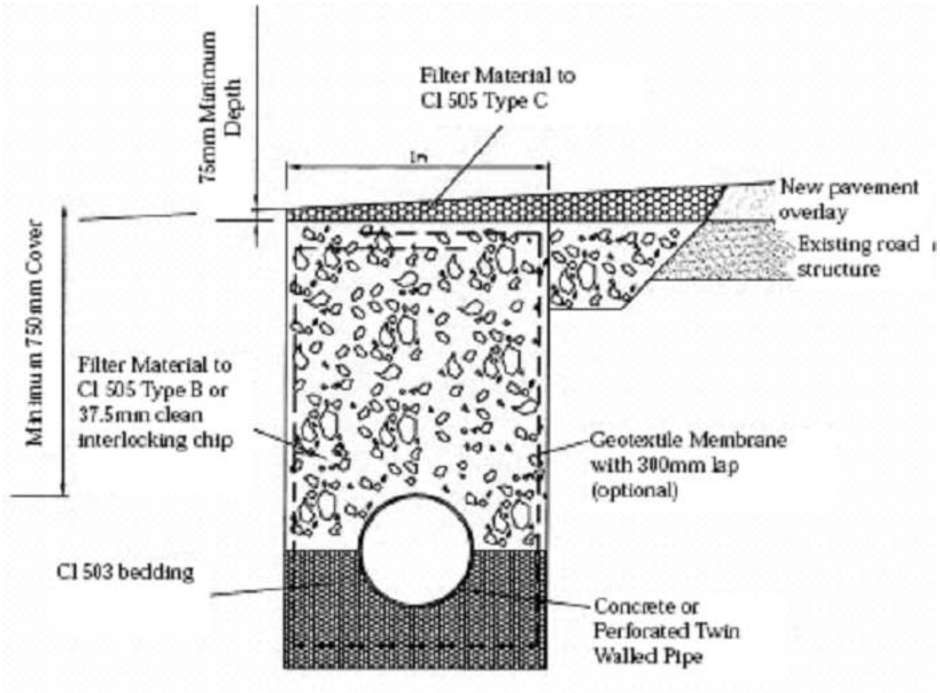


Figure 3.3: Typical design drawing of filter drain wrapped with geotextile membrane (source: DoEHLG (2004)

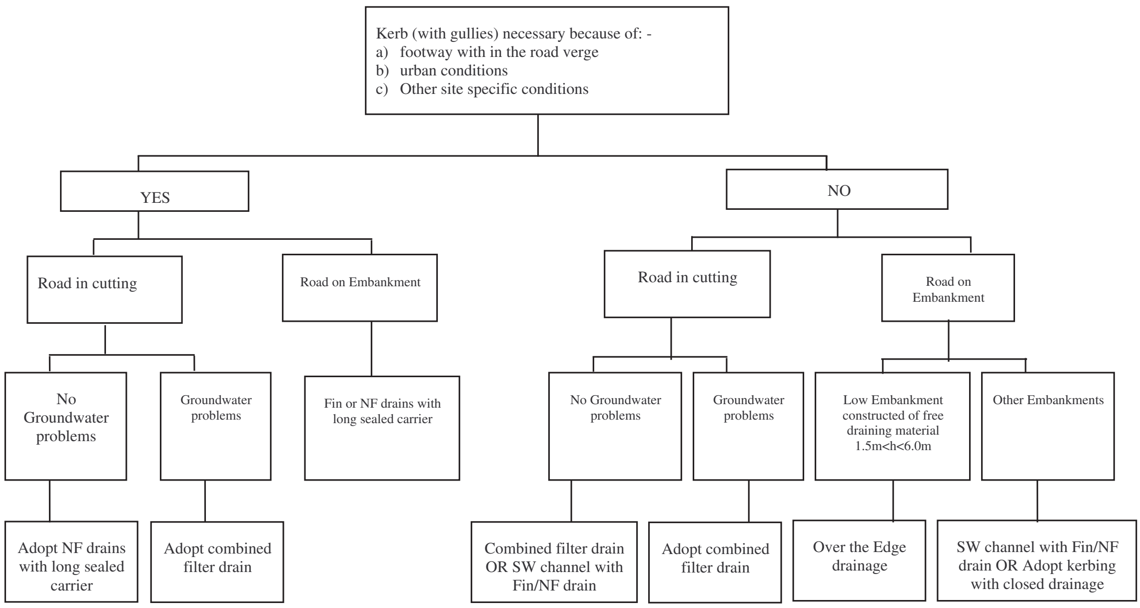


Figure 3.4: Recommendations for verge-side edge drainage (source:DMRB-UK (2000)

Figure 3.5: Filter Drain

Figure 3.6: Filter Drain compacted by heavy goods vehicle

- facility for collection of water from drainage measures installed separately in the side-slopes of cuttings.

The design of filter drains generally follows the same principles as other pipe drainage systems. However, filter drains have relatively larger pipe diameters to cater for intercepted groundwater. The use of combined filter drain systems in new construction has been discouraged in the UK (following publication of a DOT report, 1991) due to the high cost of the filling material, pollution risk to groundwater, stone scatter and maintenance problems (CIRIA, 1994). In Ireland, though, its use is widely continued in new roads. Neither the cost of filling material and maintenance nor the risk to groundwater seemed to have affected its popularity.

The estimated effective life of filter drains is 10 years after which period the void space is filled with fine material effectively blocking the system. This period can be significantly shorter on Motorways or Dual Carriageways due to compaction by vehicular overrun. The 3m wide hard shoulder does not seem to give enough clearance (or the motorist does perceive it to) particularly for heavy goods vehicles when pulling into the hard shoulder. After this compaction, the hydraulic efficiency of the system decreases allowing little or no water to permeate to the drainpipe, Figure 3.6.

In addition to their primary functions, filter drains can provide some degree of runoff treatment. They can retain some solids and pollutants associated with the suspended solids. There is very little research done on the pollutant removal potential of filter drains. The tests of Colwill et al. (1984), reproduced in Atkins (1998) is probably the oldest and the most comprehensive one. They compared the performances of filter drains, lagoons and sedimentation tanks. The filter drain performed better than the sedimentation tank but was not better than the lagoon. The mean annual removal efficiencies reported are 85% for total suspended solids, 83% for total lead, 81% for total zinc, 84% for solids associated zinc, 56% for dissolved zinc and 59% for chemical oxygen demand (COD). WRc (2002) published the most recent performance data for the filter drain as 11% to 50% reduction for metals and 60% to 70% for Polycyclic Aromatic Hydrocarbons (PAHs). This project has shown (viz. Chapter 11that the total suspended solids and heavy metal concentrations in flows from filter drains are significantly lower compared to those of kerb and gully systems. Note that, in this study, PAHs were detected on a few occasions from the newly constructed Monasterevin Bypass but not in the Maynooth Bypass.

The filter drain is the best type of drainage system to deal with groundwater problems in cuttings and in terms of the treatment benefit it can provide. All these benefits can reduce if the drain is not maintained properly. The filter drains on some dual carriageways and motorways in Ireland are more than 10 years old and are now effectively blocked. In addition, some design problems are apparent that could have serious implications for the quality of the drainage water. These include:

- The use of combined systems of kerb and gullies with filter drains, Figure 3.8 and connection of gully or surface water channel carrier pipes directly into filter drain pipes. In these cases, the runoff is allowed to by-pass the filter material.

- The use of grass verge with filter drains Figure 3.7. The grass verge forms a “grass kerb” effectively forming a kerb at the edge of the road. The width of the flow at the edge can be excessive which can create ponding (not desirable from the point of view safety) during intense storms. The collected runoff at the edge is discharged at a point into the filter drain overloading the filter media. The grass kerb is cut during maintenance activities to facilitate drainage and herbicides are applied to prevent re-growth. This facilitates the introduction of pollutants into the drainpipe.

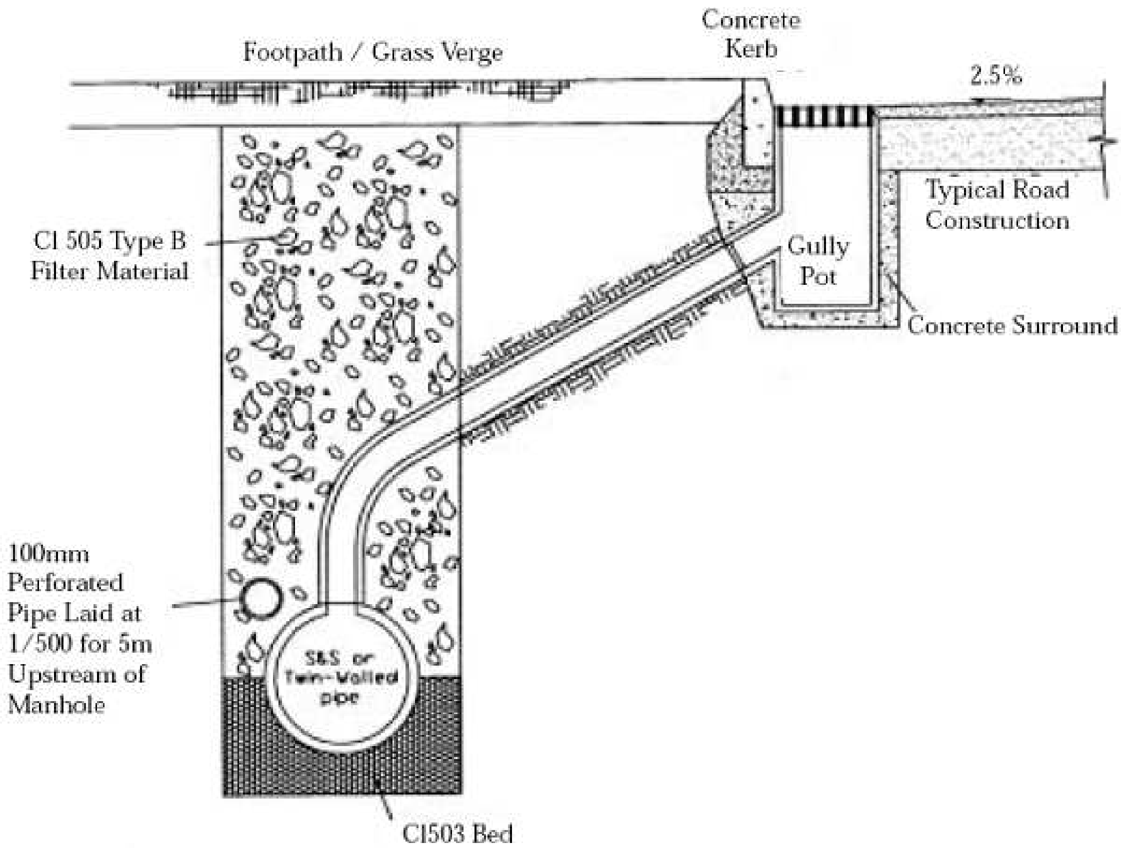
- Drains receiving drainage from adjacent land where herbicides and other agricultural chemicals may be applied, Figure 3.10). In some places, field drains are connected to the filter drain. Such connections can easily introduce fertilisers, pesticides, and herbicides to the groundwater.

- Filter drains wrapped around with geotextile membrane (overlapping at the top) facilitates silting up and creates maintenance problems, Figure 3.11.

In all these cases, the risk is probably higher in older roads where the medium surrounding the drainpipe is not properly sealed and pipe joints are cracked or broken. This complicates the characterisation of the filter drains pollutant removal efficiency.

Figure 3.7: Grass verge preventing over the edge drainage to filter drain

Figure 3.8: Field drain connected to filter drain conduit



Notes:

1. An alternative pipe system using a semi-perforated pipe, in lieu of sealed carrier pipe, may be used

Figure 3.9: Combined filter drain/kerb and gully system (source: DoEHLG (2004))

Figure 3.10: Combined filter drain and surface water channel

3.4.2 Kerbs and gullies

Conventional gullies, incorporating a gully grating and a gully pot, are located at the edge of the road provided with concrete kerbs to facilitate the flow of surface runoff into the gullies , Figure 3.12. Runoff collected at the gully pots is discharged through a connection pipe into a longitudinal carrier pipe. The carrier pipe then discharges into an outfall. Gully pots serve as a trap for sediment that might otherwise cause partial or total blockage of the carrier pipe or deposition of sediment in the receiving water. The inlet to the carrier pipe may be provided with some kind of weir to prevent floating debris and oil flowing into the pipe. Such type of gully is called a trapped gully. Another less common type is a simple connection of the pot to the pipe without the weir. This type does not have oil retention capacity but can retain coarse sediments.

Kerb and gully systems are generally used in urban areas where footpaths must be protected from vehicular overrun. It is applied to Motorways and Dual Carriageways in embankment conditions where the road verge needs some structural support. It has the advantage of allowing the longitudinal gradient of the road to be formed independently of the slope of the carrier pipe.

The design of kerb and gully system involves the determination of gully spacing, pot size (diameter), size of connection pipe width/depth of flow. Gully spacing is determined by requirements necessary to avoid standing water on the road. Physical site characteristics and maintenance considerations determine the location of the first and terminal gullies more than hydraulic factors. Unlike intermediate gullies, no portion of the flow is allowed to pass the grating at the terminal gully. Design guidelines to determine spacing of road gullies are given in HA 102/00 ((DMRB-UK, 2000). Gullies are ideally spaced at one per $200m^2$ area drained and no more than 40m apart. The maximum height of kerbs allowed on Motorways and Dual Carriageways is 75mm (150 on other roads) because of safety reasons due to the high speed of vehicles on these roads. The maximum allowable flow width is 1.5m for a hard shoulder and 1m for a hard strip.

Gully pots can have both positive and negative effects on the quality of road runoff depending on the management strategy. They can remove sediments of particle size greater than 300 μm (DMRB-UK,

2004) and pollutants associated with solids. A total suspended solids removal of up to 40%, 20% of COD and a 10% of ammonium load has been reported (Memon and Butler, 2002). Under poor maintenance conditions, however, pots can be source of pollutants due to erosion and biodegradation of the sediment trapped in the pot. This is discharged during the first flush of a storm and can impact receiving waters with its high Biochemical Oxygen Demand (BOD) and toxicity. There is also a possibility of discharging contaminated sediment and polluted water downstream during cleansing. Sumpless gullies are used instead to avoid such risks. Sumpless gullies are shaped in such a way that sediment deposition is minimised anywhere around and pot base. Sediment and other debris are carried down the pipe where they can be collected in catchpits. Sumpless gullies minimise the need for gully cleansing and lower the risk of pollution due to silt and liquor accumulation in the pot. Catchpits collect more sediment than conventional gullies. It is therefore important that they are emptied more regularly than conventional gullies to maximise the benefits.

Cleaning of gully pots generally takes place once or twice a year, which normally involves emptying of pots and flushing of connection pipes. The frequency of cleaning has been shown to have significant effect on the runoff quality and varies with the contaminant in question. Frequent cleaning (say every week) appears to help reduce dissolved pollutants that originate from biochemical degradation of the sediment during dry periods (Memon and Butler, 2002). To those associated with the solids, increasing the pot volume appears to be more important than frequently cleaning. Increasing volume improves the retention capacity of the pot. It is also a cost-effective option compared to increasing the frequency of cleaning (Memon and Butler, 2002).

Preliminary results from this research project suggest that Kerb and Gully systems are inferior to filter drains in terms of water quality improvement. Analysis of water samples taken from these two systems indicated that runoff from the Kerb and Gully system are highly polluted with heavy metals, polycyclic aromatic hydrocarbons, and other pollutants,Figure 3.13.

3.4.3 Combined surface water channel and pipe system

Combined surface water channel and pipe systems consist of concrete channels, triangular, rectangular or trapezoidal in shape, slip-formed at the edge of the hard shoulder and flush with the road surface and an internal pipe formed within the base of the unit that carries the collected flow. Combined surface water channels have larger flow capacity, which may reduce or eliminate the need for additional carrier pipes. The channel consists of gully gratings at the base with water dropping into a chamber (pot) constructed on the line of the pipe. Combined surface water channel and pipe system is very similar to the kerb and gully system except that this allows flow to be carried longer distances between outfalls to ditches or natural watercourses without exceeding the maximum allowable width of flow. Another key difference is that, unlike kerb and gully system, the longitudinal gradient of the road, the pipe and the channel are the same, The channel shape and dimension are limited by the requirement of vehicle safety. Maximum depth is 150mm except behind a crash barrier. Width of flow is 1.5m on hard shoulder and 1.0m on hard strip, Figure 3.14.

The hydraulic design of combined surface water channel involves the determination of the size of the pipe, geometry and size of the surface channel, and length of the road to be drained by the channel. Key data needed to determine these parameters include (DMRB-UK, 2005):

- longitudinal gradient of the road, S,
- effective width of the catchment drained by the combined system, taking account, if appropriate, of any run-off from cuttings,
- hydraulic roughness values of the channel and the pipe;
- statistical rainfall characteristics at the site, i.e. the relationship between the rainfall intensity, the duration of the design storm and its frequency of occurrence, and
- variation of rainfall intensity with time during the design storm.

Figure 3.11: Geotextile wrapped around filter drain

Combined surface water channel and pipe systems are constructed at the edge of the road with concrete, which effectively block the horizontal movement of water at the pavement edge. Subsurface drainage systems are then provided between the pavement construction and the channel contrary to the normal practice of locating subsurface drainage systems at the edge of the road.

3.4.4 Over-the-edge drainage

In this system, surface water drains into the grass verge and the water is allowed to drain down the side slopes and into ditches at the base of the embankment, Figure 3.15. This type of drainage system is used in areas where the embankment is made of granular material which can stand severe erosion. Over-the-edge drainage is a relatively cheap option if ample granular material is available from cuts and can be obtained at a reasonable cost. Since the surface runoff is dissipated at the edge of the road before reaching into a watercourse, the water quality benefit of this system can be significant. The major disadvantage is the formation of grass kerb which prevents free drainage. The risk of groundwater contamination can be higher if excessive infiltration occurs due to the geology of the area.

Over-the-edge drainage is used in combination with filter drains on major Irish roads.

3.4.5 Fin or Narrow Filter Drain

Fin or Narrow Filter Drains are mainly required to drain water that may permeate through the pavement layers and remove groundwater from the road foundation to a sufficient depth. They also prevent flow of water from verge areas into to pavement layers and foundation. These systems are used independently or in combination with kerb systems or combined surface water channel and pipe system. Since Fin/Narrow Filter drain is mainly concerned with subsurface drainage, they are not intended to remove pollutants from the drainage water.

3.5 Road Drainage Design Practice

For road lengths up to 200m and if there are no other flows from the verge, the minimum sizes of drainage elements (pipes, channels, outlets, and chambers) are applied to cater for the runoff from the road. The minimum diameter of drainage pipe used is 225mm but can be smaller (=150mm) for gully connections. The maximum diameter is 900mm, although larger pipes may be used subject to structural assessment. Drainage water is normally allowed to flow towards the edges (not to the central

Figure 3.12: Kerb and gully

Figure 3.13: Water samples from filter drain (3 on left) and from kerb and gully (3 on right)

Figure 3.14: Combined surface water channel and pipe system

Figure 3.15: Over the edge drainage

reservation). Drainage lines in the central reservation are designed to flow-full without a surcharge to protect the adjacent fast lane from encroaching water. The maximum permissible widths of flooding are 1.0m for all-purpose roads and 1.5m for motorways.

The questionnaire survey indicated that, in Irish practice, the following documents are the main sources of information for road drainage design.

1. NRA DMRB Volume 4, Section 2
    - HD 33/96 - Surface and sub-surface drainage for highways,
    - HA 103/01- Vegetative Treatment Systems for Highway Runoff,
2. CIRIA Report 142: Control of Pollution from Highway Discharges,
3. CIRIA Report C523: Sustainable Urban Drainage Systems,
4. Guidelines for Road Drainage, citepdoehlg2004,
5. Road Note 35- Surfacewater Drainage Design

The NRA DMRB is the most commonly used document.

More detailed design and analysis techniques are normally necessary for motorways and dual carriageways drainage systems since carriage ways are wider and longer and flows are complicated by surface and subsurface drainage. Volume 4 of the Design Manual for Roads and Bridges outlines drainage design techniques for national roads. Detail design of drainage systems involve determination of the design storm, calculation of the runoff from the design storm, checking the hydraulic adequacy of drainage elements for the calculated flow, and determination of structural adequacy of the drainage pipe for the loading placed up on it. The following sections deal with the selection of design storm, runoff calculation and hydraulic design of road drainage systems.

3.5.1 Determination of the design storm

The selection of storm return period for the design of road drainage system is a matter of experience and judgement. Overseeing authorities may however recommend return period of the storm to be used for design and analysis purposes. In the DMRB-UK (1998), it is recommended that return period of 1 year should be used for the design of road drainage systems. Drainage elements are then checked for a 5-year return period storm for surcharge except for channels in the central reserve where no surcharge is allowed.

Design storms are obtained from reasonably long historical rainfall records. Lack of such records is an inherent problem and should be tackled appropriately. In Ireland, 15 meteorological stations record rainfall on hourly basis and the remaining 750 of them record per day (Meteireann, 2005). Such data have a very limited use for road drainage design where rainfall durations are required as small as 2 minutes. Some of these stations can be upgraded to record rainfall over shorter durations, using readily available data logging equipment, at reasonable cost. It is also possible to commission rain gauge stations at proposed road schemes during the planning application to obtain at least a one or two years data for use in road drainage design. Such action can save a significant amount of the budget that could have been spent on uneconomically designed system.

Summer storms, which are heavy and short period, tend to produce largest flows and are more useful for drainage design than winter storms. Intensity-Duration-Frequency (IDF) curves are prepared for each location from the available record. IDF curves allow estimation of design rainfall intensity corresponding to the return period for various durations to be used in equations such as the Rational Formula. The duration to be used in the Rational Formula is taken to be the time of concentration (called critical duration), the time at which all the catchment area starts to contribute to the flow gauged at the outlet. Such curves are not readily available for different geographic locations in Ireland. Empirical approaches are used instead to determine the rainfall intensity. The recommend values are I = 38mm/hr for a time of concentration less than 10 minutes and 25mm/hr otherwise (DoEHLG, 2004). In the UK the effect of geographic location is accounted for by considering the so called "2min-M5" as a basis of calculating the rainfall depth for the required duration T and return period N. The 2min-M5 depth is defined as the depth of rainfall (in mm) which occurs at a specified geographical location during a period of 2 minutes with a return period of N = 5 years.

A general procedure for calculating the mean rainfall depth of given duration based on 2min-M5 rainfall is given in the DMRB-UK (1997) as:

1. Determine from a map (UK map given in the manual) the value of rainfall depth (2min-M5) occurring in 2 minutes with a return period of 5 years at the chosen location.

2. Calculate (using a table and the value of 2min-M5) the rainfall depth for the required duration T and a return period of 5 years (i.e. Tmin-M5)

3. Calculate (using a graph and the value of Tmin-M5) the rainfall depth for the required duration T and return period N (i.e. TminMN).

4. Divide the rainfall depth TminMN by the duration to give the mean intensity I_0 (mm/hr).

An equation for predicting I_0 is obtained for the UK by curve-fitting the tabular and graphical data generated by these steps. The equation is optimised for values of T = 2-20 minutes and N = 1-20 years can still be applicable up to 30 minutes duration and 50 years return period with a slight overestimation.

The equation has the following form (IDF function):

$$I_0 = 32.7\,(N - 0.4)^{0.223}\,\frac{(T - 0.4)^{0.565}}{T} 2minM5 \tag{3.1}$$

The largest flow peaks from roads are due to short-period summer storms, rather than winter storms. The average intensity shall thus be multiplied by a factor to obtain the maximum intensity at mid point of the storm. In the UK, the term 50% summer profile is used to represent the intensity used in the calculation of peak flows, which is 3.9 times higher than the average intensity. Figure 1. shows Intensity/Duration curve for UK for a return period of 1 year.

Equation 3.1 is plotted here for a return period of 1 year and 2min-M5 values of 1mm, 2mm, 3mm and 4mm from UK rainfall data for comparison purposes with the Irish practice. As it can clearly

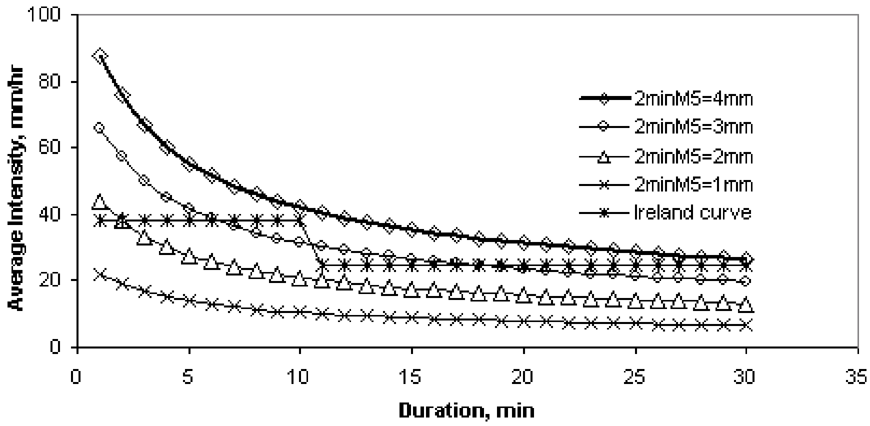


Figure 3.16: Intensity duration curve T=1 year

be seen, the empirical approach used in Ireland is very approximate and does not take geographical differences into account.

In the design of road drainage systems, in addition to the intensity, duration and frequency of a rainfall, the inter-event dry periods also affect the pollutant concentration and sizing of runoff treatment facilities. Climate change also affects both the return period and the rainfall intensity. Global climate models estimate that the average return period of a rainfall intensity becomes shorter by a factor of 2 - 5 and the intensity of a rainfall of given return period increases by 10-25 percent ((Hennessy and Suppiah, 1997). These effects have to be considered in future road drainage design, in Europe.

3.5.2 Runoff determination methods

Wide ranges of techniques are suggested in the DMRB-UK (2000) for calculating runoff flows once the design storm is selected. The simplest technique available is the Rational Method, which is used to calculate the peak flow without the runoff volume or hydrograph shape. The Rational Method is used only for pipe sizing of simple systems and preliminary design of large systems. Other methods mentioned include The Modified Rational Method, The TRRL Hydrograph Method, and The Wallingford Procedure. The modified Rational Method requires the subdivision of the road catchment to apply The Rational method incrementally. This is adopted because of the limited use of The Rational Method to small catchments (<1.3km^2). The Modified Rational Method is applicable up to a catchment area of $2.5km^2$ (Ponce, 1994). The TRRL Hydrograph method, though obsolete, is based on the Time Area Method, which requires a design hyetograph and mapping of isocrones (lines of equal travel time to the catchment outlet). The method assumes 100% runoff from paved surfaces from rainfall intensity increments corresponding to the time interval between isocrones. Its application for road drainage system design is limited because the time of entry and time of flow in the road catchment are too short to develop the isocrones. The Wallingford procedure, first published in 1981, consists of a number of methods and research-based improvements since then and is more accurate than the preceding TRRL hydrograph method in simulating runoff volume and peak discharge. The Wallingford procedure is suitable for the urban and road drainage design alike. There are other computer programs developed based on the procedure and are available as commercial softwares.

In Ireland, consultants and design engineers use software packages such as WinDes, DOER, and other in-house packages for detailed drainage design. The minimum requirement of any software package or computer program used in road drainage design is its ability to design a drainage system and permit analysis of the system under surcharge conditions.

Table 3.3: Time of entry and intensity relationship

No	Intensity, mm/hr	Time of entry, min
1	50	1.06
2	40	1.15
3	30	1.29
4	25	1.38
5	20	1.50
6	15	1.67
7	10	1.95
8	3.23	3.00

3.5.3 Hydraulic design of drainage systems

This involves, for the type of drainage system selected, determination of the time of flow, pipe sizes, channel shape and dimension, flow velocity, and storage capacity of drainage elements. Pipes are designed to flow full at peak flow resulting from the design storm. The selected open channel section should carry the given discharge on the available slope. Uniform flow is generally assumed in all cases and such equations as the Mannings and the Colebrook-White are used because the error involved due to this assumption of uniform flow is relatively small.

Time of concentration is the sum of the time of entry to the drainage pipe and the time of flow in the pipe or gutter. Time of entry, the time taken by a drop of water at the farthest side of the road to the kerb in the nearest side, is normally taken as 3 minutes as recommended in the (DMRB-UK, 2000). Major factors that affect this time of flow include the width of the road, the cross/longitudinal slope, surface roughness, and rainfall intensity. A number of empirical approaches are available to estimate time of entry. An empirical kinematic wave equation developed based on US Soil Conservation Service (SCS) data is given by Papadakis and Kazan (1987) as:

$$T_e = \frac{C\sqrt{nL}}{S^{0.31}i^{0.38}} \tag{3.2}$$

where: T_e is the time of entry(min); L is the flow length (width of the road)(m); $n =$ is a roughness coefficient; S is the slope of the road surface (m/m); i is the rainfall intensity, (mm/hr); C is a constant (4.09).

For example, for a road width of 11m, Mannings n value of 0.016 (asphalt) and a cross fall of 3%, the time of entry are calculated for different intensities in Table 3.3 showing that time of entry can be significantly shorter than 3 minutes.

Other empirical approaches give similar values as the one used here. This can lead to an under-design since longer times of concentration mean lower design rainfall intensities. It is also important to note that an accurate estimate of the time of concentration is necessary to avoid flooding and ensure economic design. The accuracy of the estimated peak discharge is sensitive to the time of concentration. These equations need to be verified for Irish conditions.

Erosion or siltation may result due to excessive or low velocity. The minimum velocities allowed in drainage pipes is governed by the requirement of self-cleansing to prevent sediment build up. The minimum velocity for a gully connection pipe flowing full is 0.67m/s and 0.71m/s for carrier pipes in combined systems. The maximum velocity is important because of the need for energy dissipation and prevention of scour. The maximum velocity allowed in pipes flowing full is not given in the DMRB. Other sources set the value at 3.1m/s (CIRIA, 1997).

The minimum longitudinal gradient allowed is 0.5% and a minimum cross-fall of 2.5% to allow free drainage.

3.6 Responsibilities of the Roads Authorities

The National Roads Authority (NRA) main functions, as given in Section 17 of the Roads Act 1993 (as amended), includes overall responsibility for the planning and supervision of works for the construction and maintenance of national roads.

With regard to road drainage, Section 76 of the Roads Act (1993) gives absolute power to a road authority to construct and maintain drains in, on, under, through or to any land for the purpose of draining water from, or preventing water flowing onto a public road. In this document, "drain" includes

- A ditch, channel, gutter, pipe, tunnel, culvert, soakpit, percolation area or percolation trench,
- a barrier to divert water into a drain.

It is however not clear whether or not the road authority is allowed to discharge road drainage into surface or groundwater. In the UK, for instance, The Water Resources Act 1991 under section 89(5) exempts the Highway Authority from penalty for discharging highway drainage into inland waters, natural or artificial, or into tidal waters unless the discharge is made in contravention of the prohibition imposed under Section 86 of the Act.

The impact of road runoff on water quality should be covered in the Environmental Impact Statement of road schemes. Road Authorities prepare an Environmental Impact Statement (EIS) for any proposed road development consisting of motorways, busways and any improvements to existing public roads as required under Section 50 of the Roads Act 1993. The Planning and Development Act, 2000 (Section 172), makes submission of EIS mandatory, in addition to meeting the requirements of the permission regulations, consolidating the Roads Act 1993. Section 173 of the Act stipulates that any planning application in respect of which an EIS is submitted to a relevant planning authority are first dealt with the planning authority and by the An Bord Pleanala (Irish Planning Board) on appeals. The approval is accordingly made considering the EIS for the proposed scheme. EIS are prepared with reference to Article 25 of the European Communities (Environmental Impact Statement) Regulations 1989, and includes the schemes likely impacts on the major environmental elements including waters and the biota living in them. This procedure was transposed from the European Council Directive of 27 June 1985 (85/337/EEC) and its Amendment (1997).

Under the current condition, road drainage is discharged into the nearest watercourse with minimal treatment. Road authorities however are bound to relevant National legislations and EU directives and have the responsibility of protecting the nations water from pollution. To this end, the National Roads Authority has co-sponsored this research with the EPA to assess the effects of road runoff, under the current drainage conditions, on receiving waters and recommend treatment options to mitigate pollution. Local authorities understand pollution problems of road runoff on receiving waters and all want to see some form of treatment to be put in place before the water is discharged into receiving waters.

3.6.1 Road drainage maintenance practice

Drainage structures can give the required level of service only for a limited period of time, which can be longer or shorter depending on the drainage system type and drainage conditions. Poor drainage conditions facilitate premature failure due to water related deterioration and can cause accidents. The most common problem with drainage systems is blockage, which results in water ponding on the road surface. Water ponding on the road surface can create sudden and dangerous changes in road holding and reduce visibility due to spray (Atkinson, 1990). It has also a lubricating effect that can significantly reduce friction (skid resistance) between the vehicle tyres and the road. Drainage systems are thus designed to self-cleans and slightly oversized to avoid blockages. Systems are also provided with grit traps, silt traps, gravel or grass filters to allow sufficient time between cleansing operations. Maintenance is therefore necessary to ensure long and trouble free service by repairing and improving drainage conditions to cope with natural and vehicle induced activities.

Maintenance of drainage systems should be carried out not only to avoid flooding (ponding) on the road surface but also to reduce the impacts of the runoff on receiving waters. Poorly maintained system can discharge heavy load of pollutants due to resuspension, leakage or biochemical degradation of pollutants retained in the drainage units. Pollutants can also be introduced into receiving waters during cleaning operations. For instance, it is reported that some 10% of the sediment contained in gullies are flushed downstream during cleaning operation (Atkins, 1998). Excessive herbicides applied at roadsides for landscaping can also wash into the drain if sprayed onto impermeable surfaces or directly onto the drains. The use of de-icing salts as a winter maintenance practice is also found to be a source of some concern. Road salt is identified as a significant source of dissolved solids and suspended solids (Colwill et al. (1984) cited in Atkins (1998)). It also contains, in addition to its principal ingredients, iron, nickel, lead, zinc, chromium and cyanide (CIRIA, 1998). Street sweeping, while it is effective in removing large debris, has been shown to increase the pollutant washoff by releasing finer materials making them readily available to be washed off by the following storm (Vaze and Chiew, 2002). Adequate drainage provision should also be ensured during highway resurfacing and other road maintenance activities to reduce the concentrations of suspended solids in the runoff. Effective maintenance strategy can therefore substantially improve the quality of runoff.

The effectiveness of a maintenance activity can be increased if it is done on a preplanned basis before significant deterioration of the system occurs. It is not however practicable to develop a single maintenance routine for all types of drainage systems and settings. This should be done based on local experience and maintenance objectives. It is therefore necessary to carry out periodic inspection to come up with a program suitable to all types of drainage systems and settings and water quality objectives. Blockage (or ponding) and malfunctioning of drainage systems should not be seen as the only reasons to initiate maintenance. The need to improve the quality of the drainage water should also be a major consideration. Most local authorities in Ireland do not carry out maintenance activities on a regular, programmed, basis. Few of them reported that they carry out regular inspection and maintenance. Others act as required to dal with reported problems that disrupt traffic, e.g. due to flooding, or follow standard UK practices. Currently, there is no standard practice or a requirement for inspection and maintenance from the NRA or any other overseeing organisation. The authors feel that there should be road drainage maintenance guidelines to maintain the level of service of the existing drainage systems and improve water quality benefits.

3.6.2 Current maintenance practice

The objectives of maintaining drainage systems are to protect the road from premature failure due to water related deterioration and avoid accidents. The most common problem with drainage systems is blockage, which usually results in water ponding on the road surface. Water ponding on the road surface can create sudden and dangerous changes in road holding and reduce visibility due to spray (Atkinson, 1990). It has also a lubricating effect that can significantly reduce friction (skid resistance) between the vehicle tyres and the road. Drainage systems are designed to self-cleans or are oversized to avoid blockages and allow sufficient time between cleansing operations. They are also provided with grit traps, silt traps, gravel or grass filters to minimise blockages and reduce the need for maintenance. Drainage structures can, however, give required level of service only for a limited period of time depending on their type and drainage conditions. Maintenance is therefore necessary to ensure long and trouble free service by repairing and improving drainage conditions to cope with natural and vehicle induced activities.

Under the current practice, County Councils maintain National Roads, including Motorways, on behalf of the National Roads Authority. According to this survey, maintenance of drainage systems in the counties is carried out on a reactive basis (i.e. when problems occur). Inspections are done once or twice per year as a good practice form experiences in the UK. There are no requirements from the National Roads Authority or any other organisation with respect to the frequency of inspection.

In our survey, five out of the 10 respondents of the survey said they don't keep any records of the maintenance work done or any other details. Of the six problems outlined as the possible cause for initiating immediate (with in 24hr) maintenance of the drainage systems (See questionnaire 4.6 in Appendix A), all but one (flooding of land, etc.) were seen as one which require programmed work. Two out of 11 respondents didn't consider "accidental spill" a problem that requires immediate action.

Some of the most common drainage problems reported by local authorities include:

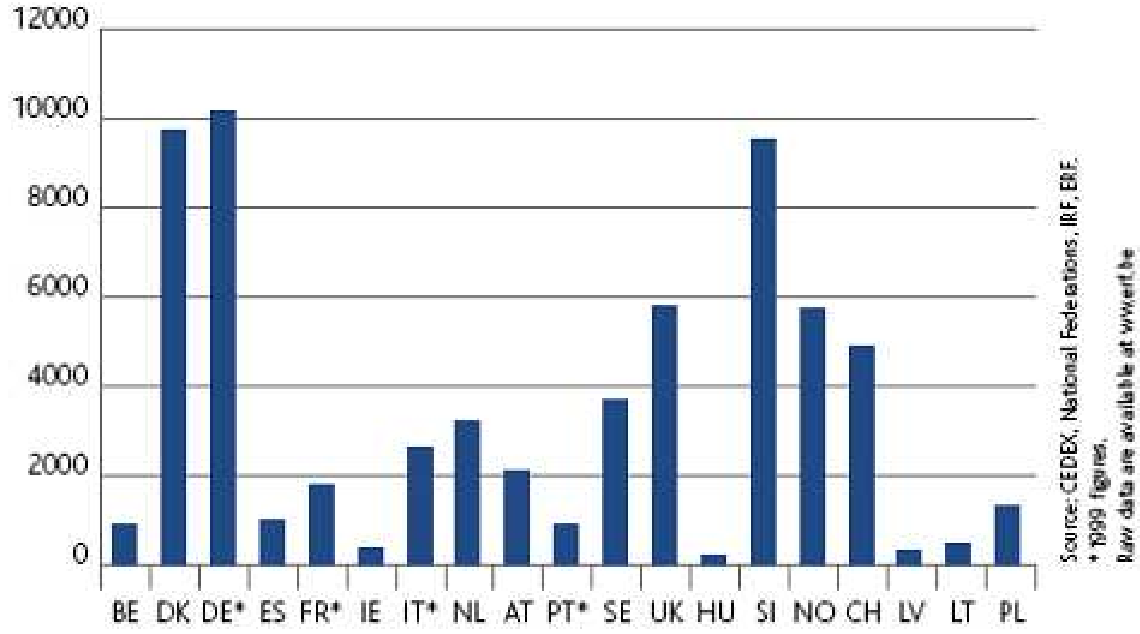


Figure 3.17: National Investment in road maintenance per km of road network- 2003 (EUR)

- blockage of road gullies, pipes and filter media
- Flooding in flat or sagged section of a road
- constant encroachment of grass verge
- blockage due to collapse of pipes
- Lack of regular maintenance
- Oil spills
- Landowners diverting land drainage onto carriageways or maintenance of drains not carried out by landowners.
- Culverts not capable of coping with blockages and not self cleansing

Remedial measures taken were gully emptying, pipe cleaning, street sweeping, removing grass kerb, application of herbicides, and filter drain cleaning manually or mechanically as required. There were two cases where the layout of the drainage system was difficult to clearly figure out as to which pipes feed the drainpipe in question and where the water is discharged. Dying the line or use of CCTV and local knowledge solved the problems. The three most important factors which prevented local authorities from carrying out regular inspection and maintenance activities were lack of staffing, absence of dedicated funding, and limitation of resources, in order of priority. This may be seen from the fact that Ireland spent less than 2000/km for road maintenance in 2003, one of the least in the EU (European Road Statistics, 2005), Figure 3.17.

3.7 Highway runoff treatment systems

The most popular type of treatment system, as reported by county councils, is the oil interceptor. There were seven cases of the oil interceptors, six silt traps (gully pots), four filter strips (filter drains), five detention ponds, two soakaways and two swales, Table 3.4. These systems are usually referred to as Best Management Practices (BMPs) and are installed as required by the EIS and where conditions permit. Chapter 12 reviews the design and performance of BMPs considered in this project. Respondents of

Table 3.4: Highway runoff treatment systems used in Ireland

Treatment System	Number of uses	Counties
Oil Interceptors	7	S.Tipp., Fingal, Mayo, Kerry, Louth, Clare
Silt traps	6	Mayo, Sligo, Louth
Ponds	5	S.Tipp.,Louth, Clare
Filter Strips	4	Sligo, Louth
Swales	2	Mayo, Louth
Soakaways	2	Mayo, Sligo

the questionnaire listed the long-term maintenance needs of these treatment systems, as one of their future research needs (see Appendix D for the complete list).

In Design & Build and Public Private Partnership contracts, the parameters for road drainage are usually set out in the Employer's Requirements documentation and are summarised in Appendix B (supplied by Atkins).

3.8 Conclusions and recommendations

3.8.1 Conclusions

This review compiled the current highway drainage design and maintenance practice and associated environmental impacts on receiving waters under the current practice in Ireland. It was conducted by sending a questionnaire to County Councils and Regional Road Authorities. Motorways and rural dual carriageways were the main categories of roads covered in the survey. These categories of roads exist in significant lengths only in few counties. The issues included were the current design and maintenance practice and legal aspects of road drainage. The conclusions drawn from this survey are as follows:

1. Highway drainage systems in Ireland are designed based on hydraulic considerations with little emphasis on the quality of the drainage water. The questionnaire survey showed that local authority road engineers expected that natural processes such as sedimentation, filtration or biodegradation would occur in the drainage units and would remove some of the pollutants.

2. Filter drains are the most popular type of drainage system used on motorways and rural dual carriageways and was regarded, by questionnaire survey respondents, as effective in removing most of the pollutants.

3. The issue of road runoff is considered in the Environmental Impact Statement with other effects. Runoff treatment systems such as petrol interceptors, soakaways, ponds etc. are installed in some places where the traffic volume is known to be high and where the drainage is directly into a receiving stream. It is however not known which type(s) of treatment system(s) is (are) appropriate (best) for a given outfall. There were no reported cases where impacts have been studied after a road scheme is completed nor the performance of these systems measured.

4. Survey respondents believed that National and EU legislation give sufficient coverage to the protection of surface and groundwater sources from pollution. However, none of this legislation specifically identified road runoff as a pollution source. Nevertheless, the groundwater protection strategy in Ireland has identified road runoff as a potential source of groundwater contamination.

5. There is no programmed inspection and maintenance program in Ireland. Drainage systems are cleaned "as required" due to blockage of pipes and flooding of road surface. Lack of personnel, resource and absence of dedicated funding has been blamed by local authorities for failing to carryout inspection and maintenance activities on a programmed basis.

6. Most of the local authorities understood the pollution risk of discharging untreated runoff into receiving waters. They would like to see some kind of treatment system to exclude sediment and hydrocarbons from the runoff using either existing or a new systems.

3.8.2 Recommendations

1. The design of highway drainage systems, in addition to hydraulic considerations, should also take water quality considerations into account. Such considerations may require increasing the pot size of a kerb and gully system, improving the geometry of the road, reducing the catchment area contributing to an outfall, or facilitating conditions for over-the-edge drainage, etc.

2. Filter drains removes pollutants associated with suspended matter from the runoff. This function can however be impaired by blockage due to vehicular overrun and poor maintenance conditions. If the use of filter drain system has to continue, the following problems have to be addressed:

    - The use of combined systems (Filter Drain and Kerb and Gully, Filter Drain and Surfacewater Channel and Pipe System, and Filter Drain and Over-the-edge Drainage) have to be carefully examined to avoid the risk of groundwater contamination
    - The use of a geotextile membrane to wrap the filter media facilitates blockage and creates maintenance problems. The top should be left open to avoid this problem.
    - In addition to the well-known problem of stone scatter with the Filter Drain System, compaction of the filter media is equally a serious problem in Rural Dual Carriageways and Motorways in Ireland. This also facilitates clogging. This problem has to be addressed by either increasing the frequency of cleaning, using a barrier or even allowing a wider hard shoulder.
    - Land drains connected to filter drains should be inspected carefully if they can introduce contaminants into the system.

3. Rainfall intensity and the antecedent dry period (ADP) have to be included in assessing the risk of pollution to receiving waters from road runoff in addition to traffic volume.

4. Although the effect of road runoff on water quality is included in the EIS, it is necessary to continue monitoring even after the road scheme is completed until the impacts are studied to a satisfactory level. This helps to prevent further damage to the environment from causes that might have been overlooked during the preparation of the EIS. The EPA has the legal right to make such monitoring to continue.

5. Maintenance is a very important aspect of highway drainage that can improve the quality of the runoff and should be done on a programmed basis. If highway drainage systems are not properly and regularly maintained, they can act as sources of pollution. Blockage and ponding should not be the only reasons to initiate maintenance. Programs should aim at improving the hydraulic efficiency of the system and the water quality of the drainage water.

6. Programmed inspection and maintenance activities reduce an unnecessarily high cost of maintenance after a problem has occurred. Minimum cleaning frequency has to be established for the different types of systems even if there are no blockages or ponding. Problem sites should be identified and cleaning frequency should be increased for such sites.

7. Easy access for maintenance operations should always be ensured to avoid disruption of traffic.

8. Sufficient records of the maintenance work done should be kept to estimate costs of future work and comparison of methods.

9. Care must be exercised to avoid the introduction of pollutants into receiving waters during maintenance, road widening or the construction of new drainage or treatment systems.

Chapter 4

The European Experience

4.1 Introduction

Management of the quality and quantity of runoff from highways has long been a concern of many countries in the EU, particularly those with traffic control problems. This aspect of transport management was recognized as part of a research project under the Transport RTD agenda of the EU 4th Framework Research Programme. The Transport Research Laboratory of the UK coordinated a 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) which reported on the European experience to date in the management of highway runoff. This collated material from seven European countries (UK, Netherlands, Denmark, Sweden, Finland, France and Portugal), derived from the TRL report, forms the basis of the state of the art described in this section. While practice in terms of the removal of runoff from the road varies widely across Europe, it is nowhere consistent and often occurs in an ad hoc manner. Moreover, the specific inclusion of treatment for the road runoff in a drainage system is more often through happenstance than by deliberate design. At best some form of sediment trapping may be employed. Thus, it was felt that the European dimension might best be represented by this contribution from the TRL coordinated project which attempted to assess the overall mass balance between contaminant sources in road transport and the roadside environmental receptors. The deliberate exclusion of direct discharge to surface water enabled a simpler mass balance to be assessed. As revealed by the present investigation, even where direct discharge to surface water is allowed, the pathways involved frequently mean that much of the contamination leaving the road does not necessarily arrive at the discharge point. Moreover, throughout much of Europe, it is apparent that the subsurface environment may be the ultimate receptor for road drainage, rather than surface water.

4.2 Sources of contamination

Over the period of the design life of a road, both the road itself and the traffic that use it are the sources of compounds with potential to contaminate the environment. These compounds may be derived from the combustion of fuel, wear of vehicle components, wear of road infrastructure (eg crash barriers), degradation of road surfaces, and the application of chemicals under road maintenance (eg de-icing salts). The principal drivers for moving these potential contaminants to environmental receptors are the traffic densities involved and the accompanying climate (eg rainfall and hydrological regime).

Much effort in the past has been directed towards understanding how and what concentrations of gaseous and fine particulate material are released into the atmosphere through fuel combustion processes with a view to regulating these emissions at source, (Transport Research Laboratory (ed.), 2002). The result has been regulation of fuel combustion processes (eg catalytic converters) principally with respect to atmospheric emissions.

For the large number of remaining compounds released to the terrestrial environment, direct links between transport emissions and impacts on the environment/public health are more difficult to identify. For terrestrial discharges, past studies have focussed on determining concentrations of pollutants in highway runoff, rather than on concentrations emitted from particular sources. Mitigation measures have been aimed at the treatment of highway runoff rather than on the implementation of source control measures.

The integrated study reported by Transport Research Laboratory (ed.) (2002) represents a first attempt in Europe to investigate the complete source-pathway-receptor framework in the context of potential pollution emanating from roads. On the basis of a mass balance approach, the study attempted to assess the quantities of unregulated compounds that are released, what proportion of these emissions enter the local roadside environment, the relative importance of each transport mechanism and where in the environment these compounds are likely to interact. The 'POLMIT' project was a comprehensive attempt to gather up-to-date information on road and vehicle emissions and to identify the relative importance of roads and vehicles as a source of terrestrial pollution. While monitoring at the 14 test sites across Europe was not continuous, the annual loading of pollutants into the roadside environment was assessed and evaluated so as to identify if and where in the environment pollutants are likely to impact. Thus an objective was to identify those pathways by which road and vehicle pollutants are transported into the local roadside environment and any factors which influence the relative importance of each pathway. The proportion of each pollutant released that enters the terrestrial environment was evaluated so as to identify where mitigation measures should be targeted in order to be most effective.

The basis of the study was the set of 14 test sites across Europe, in seven countries covering a range of characteristics in terms of climate, traffic volumes, maintenance activities and road pavement types. Field monitoring of the movement and accumulation of compounds derived from roads and vehicles as well as a desk study were undertaken over a 30-month period.

4.3 Pollutant emissions

Emission values were calculated for each of the 14 sites, Table 4.1. The lack of reliable data meant that the reported values should only be regarded as broad estimates of actual emissions. Metal emission rates were primarily dependent on traffic volumes. PAH emission rates depended primarily on traffic volume and road type, and chloride emission rates primarily on the severity of the winter conditions during the monitoring period and hence on the application of de-icing salts during the period.

Table 4.1: Reported emission rates of potential pollutants - Europe

POTENTIAL POLLUTANT	CALCULATED EMISSION RATES (g/km road/year)*
Total PAHs	65 - 721
Cd	1 - 10
Cr	14 - 162
Cu	9,248 - 108,893
Pb	7,391 - 110,984
Zn	2,479 - 61,369
Cl	1,225 - 15,249

** One carriageway (downwind side) only*

Transport Research Laboratory (ed.) (2002) reported that comparisons with emissions from other sources were difficult to make due to the lack of systematic reporting or monitoring of PAHs and heavy metals undertaken in Europe at the present time. Comparisons of reported atmospheric emissions in the UK indicate that road transport contributes little (if any) Cd or Cr, very small amounts of Cu (2%), but significant amounts of Pb (59%) and Zn (23%). To determine the significance of roads and vehicles to soil and groundwater pollution, concentrations of road/vehicle derived substances reaching surrounding soil and groundwaters were compared with recognized threshold levels (based on Dutch guidelines) to determine their pollution potential. Note that by design the common receptor for road runoff from these sites was ultimately the roadside soil or nearby groundwaters.

4.4 Mechanisms of movement

4.4.1 General

Once released from source, the two principal mechanisms for transport to the roadside environment were highway runoff or short distance aerial dispersion followed by deposition. Monitoring of the total annual movement of pollutants by each of these mechanisms was undertaken at each of the 14 test sites. The total annual transfer rate of each pollutant, by both highway runoff and aerial dispersal, was calculated. The range of transfer rates for each pollutant was determined as a mass flux, Table 4.2.

Table 4.2: Reported transfer rates of potential pollutants - Europe

POLLUTANT	TRANSFER RATES (g/km road/yr)	
	Highway runoff	Aerial dispersal
Total PAHs	1 - 7	1
Cd	<3 - 6	<1 - 35
Cr	<1 - 30	<1 - 156
Cu	<1 - 1,125	<26 - 539
Pb	14 - 1115	<10 - 541
Zn	111 - 8091	<98 - 2,447
	(kg/km road/yr)	
Cl*	<1 - 9,261	<1 - 2,523

It should be emphasized that these reported fluxes were based on a mass balance approach, not direct measurement, to determine what proportion of the calculated pollutant emissions entered the local terrestrial roadside environment. It was recognized that the difficulties encountered in field monitoring and the weaknesses in emission calculations meant that the calculated recovery rates for each pollutant varied greatly and that only general interpretations could be made. Nevertheless, highway runoff was the dominant transfer mechanism to roadside drainage systems albeit enhanced by aerial deposition.

4.4.2 PAHs

Except for a few individual PAHs (indeno- 1,2,3-pyrene and benzo-k-fluoranthene), the total transfer rates (mass fluxes) were generally below 10% of the emissions, showing a low recovery of the components in the vicinity of the road. However, problems were encountered during the analysis of these compounds, and it was reported as difficult to determine whether the low concentrations of PAHs recovered were due to natural degradation in the environment (in the presence of sunlight) or degradation during sample storage. It was concluded that further investigation was needed to decide whether or not PAHs are transported into the local roadside environment in significant concentrations.

4.4.3 Metals

Of the metals, Zn was transported in the greatest quantities followed by Cu and Pb (although the positions of these two elements were sometimes reversed) and finally by Cr and Cd. This generally reflected the magnitude of the emissions of these elements, except in the case of Pb. As Pb is primarily released in fine particulate form from exhaust emissions, it is prone to long distance transport and hence a smaller proportion is found in the local roadside environment. Strong correlations were found between traffic volume and metal transport, reflecting the vehicle sources of these pollutants. However, road surface type had a marked influence on quantity of metals transported in highway runoff, with porous asphalt appearing to trap sediment in highway runoff, reducing the total quantity of pollutants transported into the local roadside environment. In most cases, the recoveries of Cd were greater than 100%, suggesting that either the emissions were underestimated or that sources of Cd other than roads and vehicles (eg atmospheric deposition) contributed to the measured fluxes. This was supported by the fact that greater quantities of Cd were found in atmospheric deposition compared to highway runoff.

The variation in Cr percentage recovery between the sites was great, but again ranged to over 100%. In a similar manner to Cd, greater quantities of Cr were found in atmospheric deposition compared to highway runoff. A similar explanation to that proposed for Cd could, therefore, be responsible for the observed Cd recovery rates.

Recovery rates for Cu and Pb were relatively low (less than 10% and 5% respectively of the calculated emissions). As Pb is emitted primarily as fine particulates from vehicle exhausts, this material is easily transported large distances away from the local roadside environment. Cu is derived primarily from the wear of brakes and hence would be expected to be transported in highway runoff following deposition onto the road surface. However, the amount of braking used in motorway driving is much less than in urban driving. It is possible that the emission rates calculated overestimated the amount of Cu released at the test sites, leading to a lower apparent recovery rate for Cu.

The recovery of Zn varied greatly, but was generally below 50% of the calculated emission rates. Zn is derived primarily from tyre wear, and released in the form of particulate material deposited on the road surface. However, the particle size range of worn rubber is unknown and a significant proportion could be released in the form offine particulates and transported away from the local roadside environment in a similar manner to Pb.

For chloride, at sites where salt was applied, recovery rates again varied, with recovery rates being 60% or greater where large applications were made, and less than 35% where smaller applications were made. Although the majority of the applied chloride was transported by highway runoff, significant proportions of chloride were also transported by aerial dispersal. However, poor application methods can result in salt being thrown directly into the roadside environment. Explanations for the low recovery rates at some sites could be that chloride is transported as aerosols over quite long distances, away from the local roadside environment.

4.4.4 Hydrocarbons

Although total hydrocarbons (THC) concentrations were monitored at each of the 14 test sites, trends were difficult to distinguish as different methods of analysis were used by different agencies and/or concentrations were below detection limits. Consequently detailed results were reported only for a small number of sites. Wide variations found between sites were thought to be the result of possible accidental spills.

4.5 Soil and groundwater pollution

Concentrations of contaminants were measured in both soil and groundwater samples at each of the 14 test sites, to determine whether they exceeded recognised threshold levels for soil and groundwater quality. The threshold levels used were the Dutch 'intervention and target levels' originally developed for the investigation and remediation of contaminated land.

Soil intervention levels were only exceeded for Pb, with most of the Pb probably having been deposited when leaded fuel use was at a peak. At some sites, Cu and Zn 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.

Problems were encountered with the determination of both total hydrocarbons (THC) and PAHs in soils. Consequently, although the concentrations of THC and PAHs appeared to be low in many sites, it was not certain whether this was representative of the true situation.

In general, concentrations of heavy metals found in groundwaters were low even in areas located close to and downstream of the road. Most of the metal concentrations were well below the Dutch intervention levels for groundwater. Metals are strongly adsorbed to soil particle surfaces and are difficult to leach down the soil profile into groundwater. However, elevated concentrations were found when large amnounts of de-icing salts were applied, indicating that Cl does facilitate the movement of adsorbed metals. The intervention level for chloride was exceeded at most sites at which de-icing salts were applied. At some sites, the maximum recorded concentration was almost five 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 five sites. Three of these sites also had elevated concentration in soil. However, two sites had excessively high concentrations (over 30,000μg/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.

4.6 Methods of control

Currently treatment systems are designed to reduce the concentrations of contaminants found in highway runoff. The range of systems available and their relative efficiencies at removing contaminants was reviewed under this EU project. A similar review was conducted under this project for relevance to Irish conditions and is reported in Chapter 3. Nevertheless, the deliberate inclusion of methods for the full and specific treatment of roadside runoff is a relatively recent part of road design. Until recently, it often happened as a result of road drainage practice. However, in the light of the reported sources of roadside contaminants, no treatment systems currently exist for direct management of contaminants transported by aerial dispersal. Although the reported fluxes do not reflect aerial dispersal as the dominant mechanism of transfer into the local environment, significant quantities of especially zinc and chloride are transported by aerial dispersal. The presence of porous road surfaces was shown to reduce transfer rates by this mechanism although the ultimate pathway for such a route was not investigated. At present, the only practical method of treatment for contaminants transported by aerial dispersal is source control.

Chapter 5

Selection of Sites

5.1 Introduction

In the project proposal, a two stage site selection process was envisaged in which, first, a list of suitable sites would be prepared and investigated. From this, two or three would be chosen for detailed investigation, including monitoring of the treatment options. However, a three stage process became necessary because of the large number of candidate sites which had to be visited in order to generate a satisfactory list of suitable sites for baseline investigation.

1. Initially a ”long“ list of sites was generated and each visited and inspected visually for suitability.
2. Sites from the long list which were deemed ”suitable“ became sites for the baseline investigation and water, sediment and macro-invertebrate samples were taken and analysed. For some sites, special investigations of vegetation and fish were undertaken and some more detailed sediment studies.
3. Sites used in the baseline investigation were also candidates for the detailed monitoring sites. However, additional sites, which became available during the project were also considered

Following preliminary presentation of the baseline results, it became apparent that most of the chosen sites were already impacted by upstream sources of contamination. It was recommended that some additional, un-impacted, sites be added to the project. With some difficulty some suitable sites were identified and included in the project.

The following sections explain the site selection process in more detail.

5.2 Long list of sites

5.2.1 Approach

The project team travelled along the major roads leading north (as far as Dundalk), west (up to 75 km) and south (as far as Enniscorthy) and visually identified sites for potential inclusion on the ”long“ list. Later in the project, areas in Leitrim, Roscommon and Sligo were investigated in the search for sites without upstream pollution impacts.

5.2.2 Criteria

The criteria used in the visual selection were

- The site had to have road drainage entering a river or stream.
- The road catchment area should be significant and identifiable.
- The river or stream should not be too large (too much dilution) or too small (insufficient diversity). Typically stream with bankfull widths between 2 and 4 m were preferred.

- The sites should not have any additional sources of contamination, e.g. farmyards draining onto the road, or its drains.
- Accessibility and suitability for monitoring and sampling
- Type of road drainage system

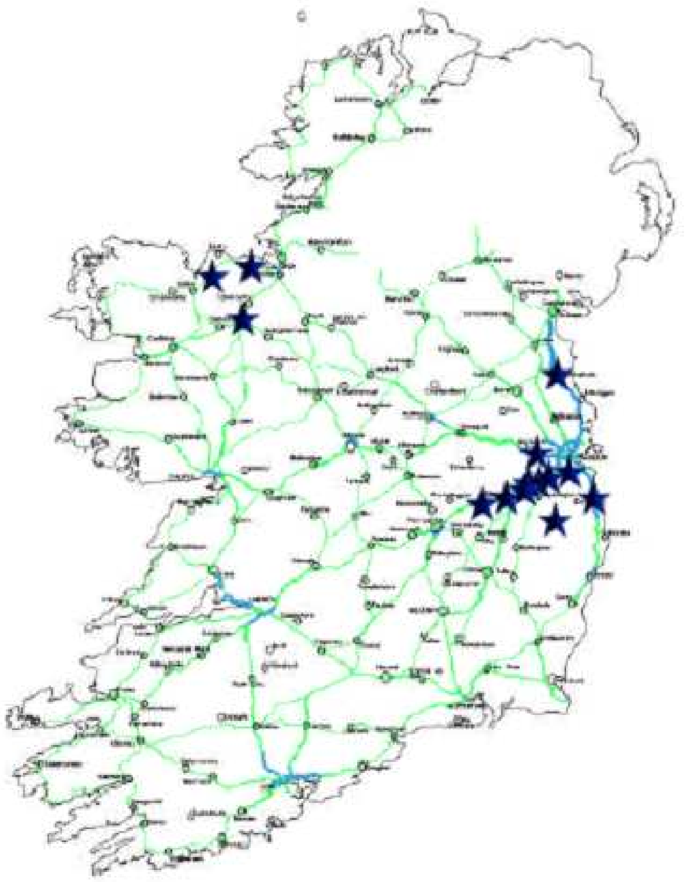
5.2.3 Long list of sites

Over 46 sites were visually inspected to identify those suitable for studying the impact of road runoff on receiving watercourse and for highway runoff monitoring, Table 5.1. Out of these, 14 sites were identified for water, sediment and biological sampling, Table 5.2 and five sites for road runoff monitoring, Table 5.3 Figure 5.1 shows the locations of the selected sites.

Table 5.1: Long list of sites surveyed for sampling water sediment and biology.

No.	Name	Road	Assessment
1	River near Newhall	M7	Not suitable
2	River Liffey Near Walshes town	M7	Not suitable
3	River Liffey at Greenhills	M9	Not suitable
4	Unnamed river at Hilsbrough Bridge	M7 and M9	Not suitable
5	Grand Canal feeder near Ladytown	M7	Not suitable
6	Hartwell river at Tobenavoher Bridge	N7	Suitable
7	Morell river at Morell Bridge	N7	Suitable
8	Kill river at Kill	N7	Not suitable
9	Tributary of Painstown river at Bohernphilip Bridge	N7	Suitable
10	Unnamed river at Blackhill	N7	Not suitable
11	Tributary of Slane river at Dunbawin Bridge	N7	Suitable
12	Unnamed river South of Tootenhill	N7	Not suitable
13	Unnamed river at SW of City West Bridge	N7	Not suitable
14	Unnamed river SW of Kingswood	N7	Not suitable
15	Unnamed river at Kingswood	N7	Not suitable
16	Owendoher river NE Newtown	M50	Suitable
17	Little Dargle SE Marely Park	M50	Not suitable
18	Rowanstown at Maynooth Bypass	M4	Suitable
19	Lyreen River Maynooth Bypass	M4	Suitable
20	Unnamed river Turvey Bridge	N1	Not suitable
21	Unnamed river at Daws Bridge	N1	Not suitable
22	Boghall river at Carduff Bridge	N1	Not suitable
23	White river at Dunleer Bypass before exit	M1	Suitable
24	Unnamed river at Dunleer Bypass at exit	M1	Suitable
25	River Dee at end of M1	N1	Not suitable
26	River Glyde South of Castle Bellingham	N1	Not suitable
27	Mattock river before Emerson's bridge-East of Broomfield	N2	Not suitable
28	Delvis river at Delvis Bridge	N2	Not suitable
29	Balarath river at Balarath Cross road	N2	Not suitable
30	Ballyduff stream at Arklow Bypass	N11	Not suitable
31	Unnamed stream Enfield Relief Road	N4	Suitable
32	Glen O'Downs stream	N11	Suitable
33	Glenview stream	N11	Suitable
34	Doonfin Stream	N11	Suitable
35	Lugdoon stream	N59	Not suitable
36	Tributary of Unshin at Drumderry	N17	Not suitable
37	Tributary of Unshin at N4	N4	Not suitable
38	Sonnagh Tributary	N5	Not suitable
39	Spaddagh Tributary (two locations)	N5	Suitable
40	Killeen river	N5	Not suitable
41	Mullaghanoe Tributary	N17	Not suitable
42	Stream near Knock Airport	N17	Not suitable
43	Tributary of Lough Arrow	N4	Not suitable
44	Tributary of Lough Key- Tawnytaskin	N4	Not suitable
45	Tributary of River Barrow at Monasterevin	M7	Not suitable
46	Tributary of Ardnaglass stream	N59	Suitable

Figure 5.1: Locations of selected sites



5.3 Description of the sediment and water quality study sites

5.3.1 Sites on the N7

The N7, which forms part of the Trans European Road Network, is a national primary road that runs from Dublin M50 to Limerick. Part of the N7 bypassing Naas, Newbridge, Monasterevin and Portlaoise has been upgraded to motorway and is known as the M7 Motorway. Section of the same road between Naas and Rathcoole is being widened to six lanes. Constructed almost 30 years ago, the N7 is one of the busiest national primary routes carrying 50,729 AADT with HCV of 12.8%, (National Roads Authority, 2004).

Stream sampling sites on this road lie between Rathcoole and Johnstown and include the Hartwell River at Tobernavore Bridge, the Morell River near Johnstown, Tributary of the Painstown River near Boherphilip, and Tributary of the Slane River at Dunbauin Bridge where the rivers cross the N7, Figure 5.2. The drainage system in this section of the road is mostly over-the-edge drainage. Open ditches are also visible in some locations, which are in poor conditions due to lack of maintenance, Figure 5.3. The ditches on the side of the road are covered with vegetation and some of the drainage pipes are blocked. A filter drain system is visible near Dunbauin Bridge. Surface runoff is collected mainly at the edge of the road and discharge directly into these streams.

Water and sediment samples were collected from these sites in 2002/3 and 2005 from upstream and downstream of the runoff discharge points. The sediment samples were collected at three downstream and three upstream locations. Two sites (tributary of Painstown River at Bohrenphilip and Morell River near Johnstown) are disturbed during the widening of the N7 and were not sampled in 2005.

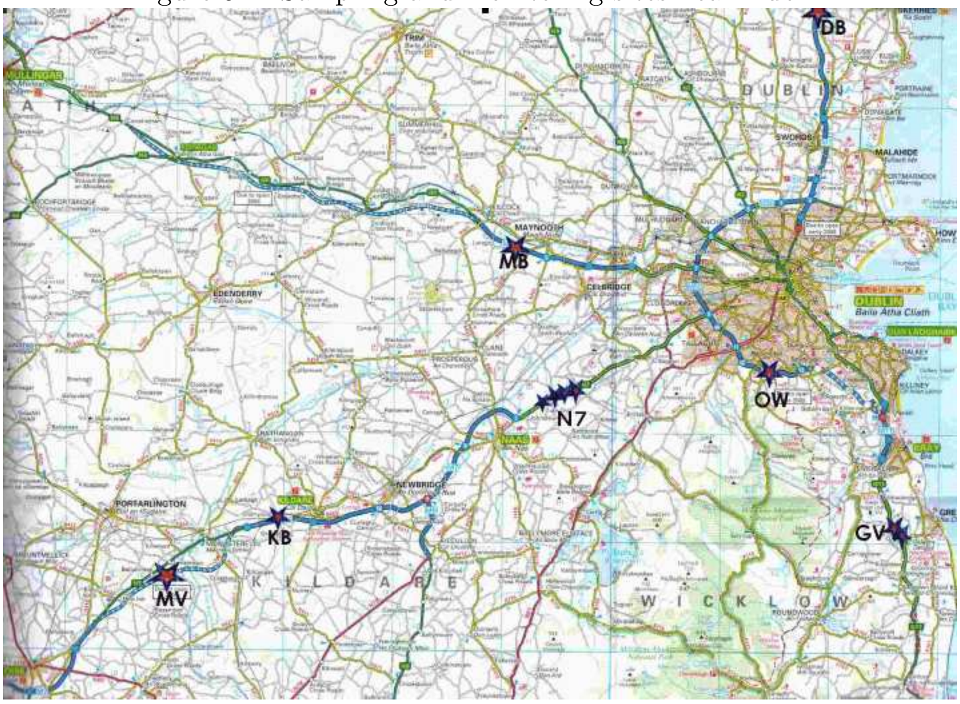
Table 5.2: Sites selected for water, sediment and biological sampling. **Control sites**2004 Data*

Site No.	Site name	Monitoring period	AADT/HGV%**	OS NGR	Drainage system
S-1	Tributary of Slane River at Dunbauin Bridge (N7)	2002-2003 and 2005	50,729/12.8	N 970 242	filter drain and over the edge
S-2	Hartwell River at Tobernavore Bridge (N7)	2002-2003 and 2005	50,729/12.8	N 925 220	over the edge
S-3	River near Rowanstown at Maynooth Bypass (M4)	2003 and 2005	39,088/7.5	N 934 363	filter drain
S-4	Lyreen River at Maynooth Bypass (M4)	2002-2003 and 2005	39,088/7.5	N 913 370	filter drain
S-5	White River at Dunleer Bypass (M1)	2003 and 2005	24,369/12	O 135 260	filter drain
S-6	Owendoher North East of Newtown (M50)	2003 and 2005	43,624/6.0	O 135 255	filterdrain
S-7	Tributary of Painstown River near Bohrenphilip (N7)	2002-2003 and 2005	50,729/12.8	N 955 235	over the edge
S-8	Morell River near Johnstown (N7)	2002-2003 and 2005	50,729/12.8	N 919 216	filter drain
S-9	Tributary of the Pollaphuca Reservoir*	2003	N/A	O 012 110	N/A
S-10	Glen O' Downs Stream (N11)	2005	34,540/6.8	O 266 105	filter drain and kerb +linear drainage
S-11	Glenview Stream (N11)	2005	34,540/6.8	O 256 117	filter drain and kerb + linear drainage
S-12	Doonfin Lower Tributary (N59)*	2005	2,513/6.8	G 508 325	over the edge
S-13	Tributary of Ardnaglass Stream at Carrowree (N59)*	2005	2,513/6.8	G 544 330	over the edge
S-14	Spaddagh Tributary (N5)*	2005	5,875/11.3	M 370 979	over the edge

Table 5.3: Road runoff monitoring sites

Site No.	Site Description	Road	Drainage Area, m^2	Type of Drainage System	OS NGR
1	Kildare Bypass	M7	14184	Kerb and Gully	N 667 113
2	Maynooth Bypass	M4	9760	Filter Drain/Over-the-edge drainage	N 913 370
3	Maynooth Bypass	M4	1100	Over-the-Edge Drainage	N 913 370
4	Monasterevin Bypass	M7	9600	Filter Drain	N 569 059
5	Monasterevin Bypass	M7	11368	Wetland	N569 059

Figure 5.2: Sampling and monitoring sites near Dublin



5.3.2 Sites on the M4

There are two sites on the M4: Lyreen River near Maynooth town and a river near Rowanstown. The M4 Motorway crosses both. The National Grid References for the sites are given in Table 5.2. The M4 runs from West of Dublin to Kilcock and extends to Kinnegad as N4 and continues to Sligo. The Lexilip-Maynooth-Kilcock section of the Motorway was opened in December 1994. The AADT of the M4 at the Kilcock junction interchange is 28,392 with an HCV of 9.6% in both directions, (National Roads Authority, 2004).

Both Lyreen and the river near Rowanstown are tributaries of the Rye Water, which flows into the River Liffey. The biological qualities of these streams have been described as unsatisfactory due to agricultural and urban influences, (Environmental Protection Agency, 2002). These rivers receive road runoff (from a filter drain system) from both directions of the Motorway. Water and sediment samples were collected from these sites from three locations at upstream and downstream points of road runoff discharge.

Figure 5.3: Edge drainage to Slane River

5.3.3 Site on the M50

This site is located on the south side of the M50 where the Motorway crosses the Owenadoher River. The Owenadoher River is a tributary of the Dodder River. This section of the M50 (called Southern Cross Route), with a length of 8.75km, was opened in August 2001. The AADT estimate for this site is 59,997 with HCV of 4.9% (National Roads Authority, 2004). A road drainage outfall from the motorway is visible at the downstream side of the river. The river under and downstream of the Motorway bridge is artificially channelled and the banks are protected with gabion. The steep gradient at the end of the channel is provided with baffle blocks before the water flows into the river. Access to this site is relatively easy and both upstream and downstream sides were sampled for water and sediment.

5.3.4 Site on the M1

The site on the M1 is located on White River at OS NGR of O135 260 before the river enters Dunleer town. The M1 is part of a major route running from Dublin to Belfast. The 17km stretch of M1 between Dunleer and Dundalk was opened in January 2001. The AADT for the Motorway at Woodland Interchange is 24, 369 with an HCV of 12% (National Roads Authority, 2004). Water and sediment samples were collected at three locations in both upstream and downstream sides of road runoff discharge point.

5.3.5 Control sites

It was necessary to include some sites that are relatively in pristine conditions to be able to compare the water and sediment qualities of those sites connected with road runoff. For this purpose, three sites were identified in the Glen of the Downs Nature Reserve, a tributary of the Pollaphuca Reservoir in County Wicklow and three sites from less travelled roads in Sligo and Mayo Counties. Details about the location of these sites are given in Table 5.2. Water and Sediment samples were collected from these streams in exactly the same way as the other sites. The samples were tested for same parameters as the other sites.

5.4 Detailed runoff monitoring sites and monitoring specification

Of the sites listed above, five sites were selected from different locations with relatively easy access from Dublin City for detailed road runoff monitoring. There were two sites on the M4 Motorway at

Maynooth Bypass, one site on the M7 Motorway at Kildare Bypass and two sites on the recently opened Monasterevin Bypass. The first site on the Maynooth Bypass was set up to sample road runoff from a filter drain and the second was to sample direct runoff from the edge of the road. Both sites are on the North bound of the M4 Motorway. The Kildare site consisted of a set up for sampling runoff from a Kerb and Gully system. The Monasterevin Bypass sites include a set up for monitoring runoff from a filter drainpipe and another set up for monitoring the constructed wetland adjacent to the River Barrow. The physical description of these sites and monitoring specifications are outlined below.

5.4.1 Kildare Bypass on the M7

This site was established following the opening of the new 13km Kildare Bypass Motorway on the 6th of December 2003. It is a wide median motorway with an Annual Average Daily Traffic (AADT) of 25,755 with HCV of 12.7%. The type of drainage system used at the site is Kerb and Gully. This site has the highest annual rainfall compared to the other sites. The total rainfall recorded at the site between 1st June 2004 and 31st May 2005 was 638.2mm. The length of the road contributing to the sampling point is approximately 1200 meters with a road width of 11meters. The instrument (ISCO 6712) is situated in a manhole (behind a crash barrier) with the flow meter fitted into a 0.375m diameter concrete pipe on a spring ring. The rain gauge is located adjacent to the manhole (where the sampler is installed) on a plane area at the foot of the road embankment. The pipe is dry except during rain events. The sampler is powered with a 12V, 45Ah Lead Acid Deep Discharge Battery which lasts between 10 to 20 days at normal operating conditions. The batteries are recharged back in office with Automatic 3-stage maintenance charger- de sulphator.

The sampler is equipped with 24, 350mL glass bottles. The 24 bottles were divided in two parts: 1-6 and 7-24 for convenience. The first six bottles were used to sample the first flush and the last 18 were used for the rest of the event. Initially, the sampler was programmed to sample at uniform time interval (5min for the first part and 10minutes for the second) but this was later converted to flow-weighed sampling. This later option was found convenient in terms of collecting flow proportional samples and flexibility of the program to hold on sampling if events don't last long enough to fill up all the 24 bottles.

5.4.2 Maynooth Bypass on the M4

The sampler at this site is located in Lyreen River on the downstream side of the bridge secured at the bridge wall. A highway runoff outfall exists underneath the sampler. The type of drainage system employed in the area is filter drain. The width of the road is 11m with two lanes and a hard shoulder on each bound. The drainage area contributing to this outfall is about $9760m^2$. Installation of the instrument at this site was completed on the 18th of December 2003. The same program and set up of instrument is used here to that of the Kildare site except the difference in the rainfall level for triggering and volume of runoff for sample pacing. In this site 2.5mm of rain in 30 minutes is used for triggering and 1000 litres for part A and 2000 litres for part B.

A second site was set up for direct runoff monitoring. A 100m length of road was delineated for direct runoff monitoring by cutting the grass verge. The grass verge serves as a kerb to channel the runoff down to the sampling point through a gutter constructed at the end. Water samples were taken from the channel before the water flows into the box.

5.4.3 Monasterevin Bypass on the M7

A month before the opening of the Monasterevin Bypass, an automatic sampler was installed at a site to monitor runoff from the filter drain. The sampler was located in a manhole in similar conditions as in the Kildare Bypass site. Sampling programs and bottle allocation is similar to the other sites. The difference lies in the rainfall amount used to trigger the sampler and pacing between sampling bottles. The rainfall amount and the contributing area in this site are relatively smaller. This prompted the specification of 0.8mm rainfall in 30 minutes as a trigger for the automatic sampler and 1000 and 500 litre volumes for sample spacing for part A and Part B respectively.

The second site at the Monasterevin bypass is at the entrance and out let to the constructed wetland. The contributing area to the wetland is 11368m^2 the type of drainage system used is Kerb and Gully. The wetland was monitored during rainfall events. Samples were taken almost at the same time at the inlet and outlet to study its effectiveness in removing pollutants.

5.5 Data Collection/Monitoring Devices

The data collection and monitoring devices used include:

- Rain gauge (0.01" Tipping Bucket)
- Runoff Sampler (ISCO 6712 Automatic Sampler)
- Flow Measuring (ISCO 750 and 730 Flow Modules)
- Multiparameter Probe (for Dissolved Oxygen, pH, Specific Conductivity, and Temperature)

Rainfall data is recorded every minute and is used for sampling initiation. The Auto sampler has 24, 350ml glass bottles with Teflon lined cups. Data acquisition is effected through either a direct connection through an interrogator cable to a Lap Top computer or a mobile phone modem from a remote location. The advantage of the mobile phone modem is that it avoids unnecessary visit to the site for checking sample collection or data downloading.

5.6 Hydrobiological Site Descriptions

Some of the "long-listed" sites were selected for the core baseline impacts part of the hydrobiological study. Additional sites were added to this "core" as opportunities arose. A total of 14 sites were used for the hydrobiological study, Table 5.2 and each are described briefly below;

5.6.1 Glen of the Downs Stream

Upstream: GD-US

The GD-US site was located on a tributary of the Glenview stream which flows south of Delgany and enters the sea south of Greystones. This site was located upstream of the N11 dual carriageway at the south end of the Glen O' Downs woods. The channel width was 1m. Canopy cover was quite dense with 80% shading, Figure 5.4(a). The instream riparian vegetation was mainly composed of moss (Rhynchostegium ripariode). Instream substrate consisted mainly of embedded cobble/bedrock.

Downstream: GD-DS

The site GD-DS was located downstream of the confluence between the Glenview tributary and the smaller Glen O' Downs stream and consequently had a slightly wider channel width of 2m. There was considerably less canopy cover 5-10% mainly composed of bramble, nettles, ash and hawthorn. Instream substrate was dominated by cobble and coarse gravel. There was 5% instream filamentous algae cover around the pipe, Figure 5.4(b).

5.6.2 Glenview

Stream Upstream: GV-US

This site was located on a tributary which rises at Calary Lower, south of Kilmacanogue and flows under the N11 dual carriageway near the Glenview Hotel at the north end of the Glen O' Downs, Figure 5.5(a). The stream crosses under the N11 before it is channelled back across the dual carriageway where it meets the smaller Glen O' Downs stream before continuing south of Delgany entering the sea south of Greystones. The channel width was 2m and 10cm deep. The stretch was fast flowing and there

Figure 5.4: Glen O'Downs

(a) Upstream site (b) Pipes at downstream site

was 70% open shading, Figure 5.5(b). Riparian vegetation included nettles, wild garlic, raged robin, hogweed, bramble, buttercup and gorse. Instream substrate consisted of predominantly cobble and coarse gravel with the odd bolder.

Figure 5.5: Glenview upstream

(a) Pipes located upstream (b) upstream site

Downstream: GV-DS

This site was located downstream of the N11 drainage pipe in the Glen of the Downs woods and ran along the edge of the N11, Figure 5.6. It had a similar channel width of 2m and a similar depth 10-15cm. There was around 75% shading. The instream vegetation was mainly composed of mosses while the riparian vegetation was consisted of nettles, bramble, wild garlic, fern, beech and laurel. Instream substrate consisted mainly cobble and coarse gravel.

Figure 5.6: Glenview downstream site (GV-DS)

5.6.3 Owendoher

River Upstream: OW-US

This site was located under the M50 motorway flyover near Rockbrook upstream of the drainage network, Figure 5.7. Riparian vegetation consists of deciduous trees. Instream vegetation consisted of filamentous algae and Fontinalis sp.. This stretch was composed of riffles and there were a number of large pools (circa 0.5m deep).

Figure 5.7: Owendoher River-Upstream Site OW-US

Downstream: OW-DS

This part of the river runs below a man-made weir, Figure 5.8. The water here was fast flowing with a number of large pools (depth circa 0.8m) along with well-defined riffles. Canopy cover increased as the water moved further downstream and reached almost full coverage as the lower end of the stretch. The river was slightly wider downstream, approximating 3m wide in comparison with 2.5m upstream. There was growth of Cladophora sp. at certain points.

Figure 5.8: Owendoher downstream

(a) Downstream site (b) Downstream of road pipe

5.6.4 Tributary of Poulaphuca Reservoir Upstream and Downstream

PP-US, PP-DS. This control site had no road runoff but received water from a small field drain, Figures 5.9. This stream was 2 to 3m wide and was heavily shaded on the left bank. The substrate consisted of cobbles with some boulders and small amounts of gravel and sand. The instream habitats consisted mainly of short riffle-pool sequences, with fast-flowing water. Canopy cover was approximating 50% with willow (Salix sp.), blackthorn (Prunus spinosa), fuschia (Fuschia magellanica), sycamore and grasses being the predominant bankside vegetation. Mosses were to be found instream on some of the boulders with coverage less than 10%.

Figure 5.9: Near Poulaphuca Reservoir

(a) Upstream Site (PP-US)

(b) Downstream Site (PP-DS)

5.6.5 Doonflin Lower Tributary

Upstream DF-US

The Doonflin stream rises at Knockalongy in the Ox mountains and flows north where it crosses the N59 at Doonflin Lower in Sligo before entering the sea at Cartronofarry, northwest of Dunmoran strand. This site (DF-US) was located upstream of the N59 roadway Tributary. The surrounding land use was primarily farmland and cattle pasture. The average channel width was 4.2m. Instream vegetation consisted of mainly mosses with sycamore and bramble occurring along the banks, Figure 5.10(a).

Figure 5.10: Glen O' Downs

(a) Upstream site (DF-US)

(b) Downstream site (DF-DS)

Doonfin Downstream: DF-DS

This site was located downstream of the N59 bridge. This site was dominated by a fast flowing riffle stretch with a channel width of 4m, Figure 5.10(b). There was around 50% shading and some algal cover was noted near the bridge.

5.6.6 Carrowree Tributary

Upstream: CR-US

The Carrowree stream rises south of Carroward in the Ox mountains and flows north where it crosses the N59 at Crooked bridge before joining the Ardnaglass river further downstream before entering the sea at Dunmoran strand in Sligo. This site (CR-US) was located upstream of Crooked bridge Figure 5.11.

The average channel width was 3.3m. Instream vegetation was primarily (Apium) and moss. Bank cover was chiefly composed of sycamore, beech and bramble.

Figure 5.11: Carrowree upstream

(a) upstream site (CR-US)

(b) N59 bridge near (CR-US)

Downstream: CR-DS

The site CR-DS was located downstream of Crooked bridge and had a slightly wider channel width of 3.5m. There was considerable shading 80% and mainly composed of hawthorn, gorse, beech, ivy and bramble, Figure 5.12. Instream vegetation was again primarily (Apium) and moss.

Figure 5.12: Carrowree stream downstream site (CR-DS)

5.6.7 Spaddagh Tributary

Upstream: SP-US

The Spaddagh tributary rises near Castlesheenaghan, South of Swinford flows north west where it crosses the N5 at Carrowbaun before joining the Spaddagh river which flows into the River Moy in Mayo. The average channel width was 3m and the stretch was quite slow flowing and deep, Figure 5.13(a). Canopy cover was absent and riparian vegetation was mainly composed of gorse, grass and sphagnum moss.

Figure 5.13: Spaddagh tributary

(a) Upstream site (SP-US)

(b) Downstream site (SP-DS)

Downstream: SP-DS

This site (SP-DS) was located downstream of the N5. This site had a channel width of 3.1m. There was little shading present Figure 5.13(b). Aquatic vegetation included Iris (yellow flag) and Apium. Riparian vegetation consisted of grass, gorse and bramble.

5.6.8 Hartwell River

Upstream: HW-US

This river site was located upstream of the Tobernavoher Bridge on the N7, north of Johnstown in Kildare, Figures 5.14. Cattle and sheep farming was the predominant landuse in the area. The site had a combination of open and dense shading by hawthorn and this section comprised mainly riffles and glides.

Figure 5.14: Hartwell River upstream site (HW-US)

(a)

(b)

Downstream: HW-DS

The downstream site (HW-DS) was largely influenced by recent earth movement Figure 5.15(a) the river became increasingly wide, reaching over 2.5m wide in parts, but the water became shallower at circa 0.15m. Canopy cover has also been influenced since the first visit in 2002, Figure 5.15(b).

Figure 5.15: Hartwell River -Downstream Site (HW-DS)

(a) in 2002

(b) in 2005

5.6.9 Slane River Tributary

Upstream: SL-US

The site (SL-US) was located on the Slane River upstream of the N7 dual carriageway. This upstream site was surrounded by grassland grazed mainly by cattle. As a consequence of the riverbank and surrounding vegetation has been impacted Figure 5.16(a). The banks had been cleared of vegetation and there was severe bank erosion on both sides. The river was also wider upstream, circa 3m wide compared with the average downstream width of 2m. This stretch of river was composed of glides interspersed with riffle areas. Canopy cover was virtually nonexistent ($< 5\%$) and there was no instream vegetation apart from isolated patches of filamentous algae.

Figure 5.16: Tributary Slane River

(a) Upstream Site (SL-US)

(b) downstream site (SL-DS) in 2005. Note the piles of gravel along the bank.

Downstream: SL-DS

The downstream section of this site was, as stated, narrower but had areas of deep pools (depth circa 0.1m) and fast flowing water. More than 50% of this site was composed of riffles, and pools comprised approximately 30% of the stretch. It had slightly more canopy cover than upstream, provided by tall grasses rather than trees. The banks were generally undisturbed with more lush vegetation, riparian vegetation including willow herb (Epilobium sp.) and vetch (Vicia sp.). There was no evidence of cattle entering the river at this point. On revisiting the site in 2005, it was noted that there was considerable changes to the surrounding riparian zone due to ongoing major road construction, Figure 5.16(b).

5.6.10 Whites River

Upstream: WH-US

The embankment here was steep and the river was relatively narrow, being 2.5m at its widest point, Figure 5.17.A wire mesh was in position on the riverbed and a retaining wall had been constructed for a distance above the road bridge. It was clear that the site had been modified, possibly as part of the road works. In parts canopy cover was approximately 70%, consisting mainly of hawthorn. Riparian vegetation consisted of nettles (Urtica sp.), gorse (Ulex europaeus) and ivy (Hedera helix). Instream vegetation comprised a variety of mosses and Cladophora sp. Glides made up the majority of the stretch followed by riffles. It was difficult to sample for invertebrates and especially for fish due to the wire overlying the riverbed.

Figure 5.17: Whites River- Upstream Site (WH-US)

Downstream: WH-DS

This section was more natural looking than the upstream section. The river was slightly deeper here at 0.8m and it was also much wider, reaching 4m or more in parts. This site had numerous riffles and pools, some of which were quite deep (circa 0.9m) . Canopy cover of horsechestnut (Aesculus hippocastanum) and sycamore was quite dense and there was lush plant growth of gorse and nettles on the riverbanks.

5.6.11 Painestown River Tributary

Upstream-PA-US

This river travels under the N7 and the upstream section of it was located adjacent to, but above, a petrol station. The upstream part of this river was narrow (<1m) and shallow (average depth circa 0.08m), Figure 5.18(a). At the time of sampling it had a dense canopy cover mainly of hawthorn (Crataegus monogyna). The stretch comprised mainly of riffles and glides.

Figure 5.18: Painestown River

(a) Upstream (PA-US)

(b) Downstream (PA-DS)

Downstream: PA-DS

The downstream stretch was 1.5m wide and slightly deeper. Some bank trampling at one point was evident but no cattle were observed during site visits. There was also a relatively dense canopy cover of approximately 30%, Figure 5.18(b).

5.6.12 Morell River

Upstream MO-US

The Morell River also crosses under the N7. The upstream site (MO-US) flowed adjacent to a small housing estate. There was substantial (up to 80%) canopy cover (and over 40% of this site was made up of riffles). Midstream, the water became quite deep (circa 0.6m) and there were some large pools, Figure 5.19(a). There were also scattered boulders and large cobbles which enhanced the riffles here.

Figure 5.19: Morell River

(a) Upstream Site (MO-US)

(b) Downstream Site (MO-DS)

Downstream: MO-DS

Downstream the river flowed alongside a private estate (Kerdiffstown House). The banks rose sharply in this section and the river widened, reaching between 3 and 4m in parts and deepened as it moved downstream. There were few riffles here as the stretch was mainly composed of glides, Figure 5.19(b). There was substantial canopy cover of approximately 50% provided by many trees such as sycamore (Acer pseudoplatanus) and alder (Alnus glutinosa.) Instream there was slime on many of the boulders and coverage by Ranunculus sp. was circa 30%. On visiting the site in 2005, a decision was made to omit this stream from the survey due to major earth movement as part of the roadworks along the streams banks.

5.6.13 Rowanstown River

Upstream: RO-US

This upstream site was located upstream of the Maynooth bypass on the M4, heading west from Dublin. The upstream section was located at the base of a steep embankment, which had a dense canopy of hawthorn (Crataegus monogyna), sycamore (Acer pseudoplatanus) and ash (Fraxinus excelsior), and was relatively difficult to walk through, Figure 5.20(a). The water was quite shallow, ranging in depth from 0.25-0.75m. The instream habitat included riffles, glides made up approx. 35% of the habitat and there were one or two small pools which were also sampled. Instream substrate was dominated by silt and mud.

Figure 5.20: Rowanstown River

(a) Upstream Site (RO-US)

(b) Downstream Site (RO-DS)

Downstream: RO-DS

A tunnel under the road bridge was used as an access to the downstream site. It flowed through a housing estate and there was evidence of severe channelling or some other form of modification to the riverbank. Discarded trolleys, car parts and a thick oil slick were observed here. There were a scarcity of riffles, no canopy cover and the water was deep (circa 2m) with sludgy flow. The riverbed had 100% coverage of silt and was difficult to walk through, Figure 5.20(b). The river was much wider downstream, reaching up to 4m plus in some sections.

5.6.14 Intensive Site-Lyreen River

Upstream: LY-US

This site was selected by the Department of Civil Engineering, UCD for installation of autosampling equipment to take water during stormwater events. As a result, this site was sampled on three occasions for macroinvertebrates whereas all the other sites were sampled once. This site runs under the motorway which bypasses Maynooth town. The embankment here was steep and overgrown, and there was a good deal of canopy cover, ranging from 50-70%, Figure 5.21(a). Water flow was relatively slow and there were few riffles, most of the sampled section consisted of glides and shallow pools.

Figure 5.21: Lyreen River

(a) Upstream Site (LY-US)

(b) Downstream Site (LY-DS)

Downstream: LY-DS

The river widened in this section. Drainage pipes from the motorway can be seen in Figure 5.21(b). The water was much murkier and there was a deposit of sediment below the bridge. This site was more exposed than upstream, having virtually no canopy cover on the right hand bank looking downstream, but coverage on the other side was quite dense, yielding 30-50% coverage in the stretch. The river was considerably wider downstream than upstream, reaching over 5m at some points. Instream habitats comprised a large proportion of glides, followed by riffles. There were one or two deep pools of water along the margins (circa 0.8m deep).

5.7 Sites for runoff quality and treatment options studies

5.7.1 criteria

Notwithstanding the aerial routes for contaminant dispersal from road transport sources, the concern in this research project has been to investigate the nature of contamination associated with runoff from the road surface, driven by rainfall. Thus the source may be defined in terms of the quality of runoff water as it leaves the road surface and enters the roadside environment. The pathway followed by this runoff water depends largely on the drainage system (natural or designed) at the margin of the road. Given the common practice in new road design in Ireland, the receptor for installed drainage was surface water, usually at a river or stream crossing. It was recognized that attenuation and dispersion of contamination levels in the runoff water may occur along the drainage pathway. What was not recognized at an early stage was that there were other receptors, which may have equal significance in the drainage system, namely the roadside soil and groundwater. Nevertheless, the criteria used for site selection for the evaluation of roadside runoff allowed for the role of these other receptors to emerge. Given the initial target of the impact of road runoff on surface water receptors, an initial selection of sites was made on the basis of likely impact, as described in Section 5.3. One of these sites was also selected as 'typical' for the investigation of the attenuation of roadside drainage along the conventional drainage pathway used in Irish motorway design, which employs a French drain. This site, the M4 at Maynooth, also had the benefit of a short section (approximately 300m) of carriageway in which the roadside drainage moved along a grass-soil 'kerb' before discharging into the French drain system. This allowed some collection of road runoff directly from the road surface, which could be compared to what emerged at he discharge point on the river. Nevertheless, it was recognized that there may be some compromise in making that analysis because of the soft nature of the 'kerb' and because the under-road drainage system was complex and uncertain. Thus, the other sites chosen were on the basis of the ability to capture the road runoff at source and provide a comparison to simple and uncompromised discharge from the accompanying drainage system including French drains. It was unlikely that one site would be able to provide data for both situations as runoff water is normally collected linearly along the edge of the road and directed to a parallel French drainage system.

The selection criteria included:

- Traffic characteristics;
- Surrounding land use activities;
- Precipitation characteristics/geographical location;
- Highway pavement type/condition;
- Drainage area and highway design characteristics;
- Highway maintenance practices;
- Logistical considerations such as easy accessibility, safety, power availability, and any future construction/improvement plan activities.

In addition, sites at the construction phase (no traffic) conferred the benefit of being more easily able to install connections and monitoring equipment.

5.7.2 Sites chosen

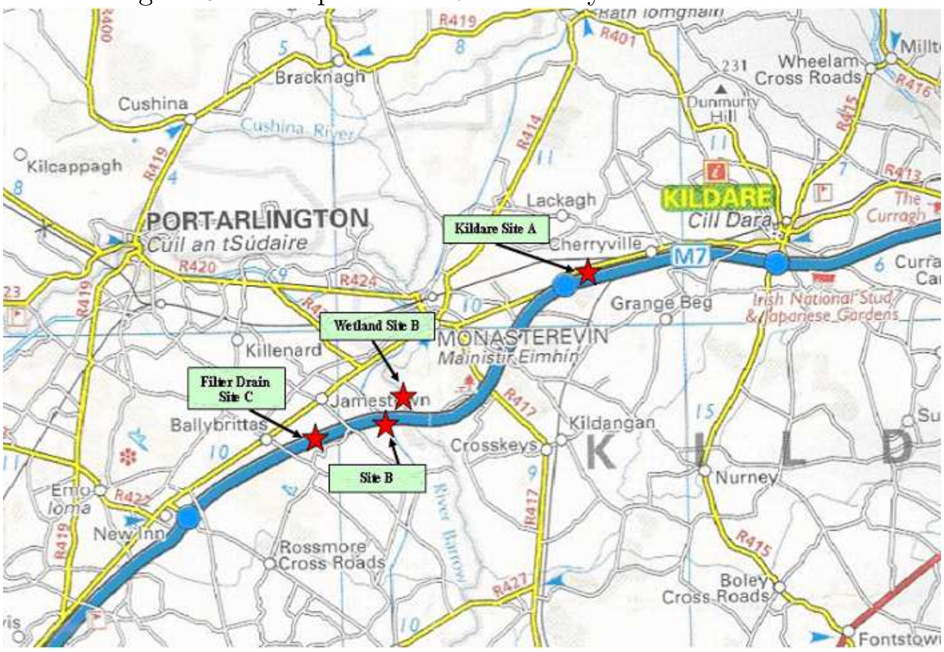
Through the valuable cooperation of Kildare County Council and the NRA, the solution was found in the identification of two sites on the M7 relatively close to each other so that rainfall for any given storm event might be similar. One site on the embankment of the Kildare Town Bypass had concrete kerb and gully drainage directly from the road surface which was conveyed via a manhole into a piped drain, thus involving no French drainage system. The second site further west along the same M7 on the Monasterevin bypass, was drained conventionally through a French drain which ran along parallel to the road surface margin. For experimentation with treatment systems, namely a constructed wetland, a further site was identified on the Monasterevin bypass, similar to the Kildare bypass site, taking road runoff directly to a manhole and piped drain via a concrete kerbed system along the road margin. This allowed the treatment system to receive the 'worst case' source input, that is runoff directly from the road surface, uncompromised by any intervening infiltrating drainage. These four sites occur in the Eastern half of the country and therefore could be expected to have less rainfall than in the West. However, the traffic densities are some of the highest on the Irish road network, which might be expected to provide a worst case in terms of runoff quality for a given rainfall event. Moreover, the sites are located relatively close together and were chosen so as to enable a comparison to be made between source runoff quality and the quality that might be arriving at a receptor, depending on the pathways involved. The treatment system would also operate on the worst case quality, ie from the source. Careful separation of source, pathway and receptor was essential to the successful analysis of the later observations.

Three of the selected sites are located on the M7 Dublin to Portlaoise motorway approximately 60 to 70 kilometres south west of Dublin. The surrounding area is a flat rural landscape with mainly agricultural practices.

The main river that the motorway discharges to is the River Barrow which it intersects on the Monasterevin section of the highway. The towns nearest the sites are Kildare and Monasterevin.

The AA road map below pin points the exact location of the three sites in relation to the motorway and the River Barrow.

Figure 5.22: Map of the M7 motorway and selected sites



Chapter 6

Surface Water Impact Studies : Sediment and Vegetation

6.1 Introduction

This baseline study was conducted to establish the background chemical and ecological status of the study sites, record any evidence of changes that occurred during the study period and to determine if road runoff has a detectable impact on the receiving water quality or ecology.

Heavy metals and hydrocarbons contained in highway runoff are predominantly in or associated with the particulate phase of the runoff (Roger et al., 1998) and accumulate in receiving-water sediments'. Some researchers (Maltby et al. (1995b), Perdikaki and Mason (1999) measured the levels of heavy metals and Polycyclic Aromatic Hydrocarbons (PAHs) contained in sediment sampled from upstream and downstream of road runoff discharge point and attempted to determine if this has changed the macroinvertebrate assemblage of the streams. Maltby et al. (1995b) documented a decrease in the diversity and composition of downstream of a highway discharge point in four out the seven streams they studied. The changes in the downstream conditions might be attributed to the toxicity produced due to the elevated concentrations of the heavy metals and Polycyclic Aromatic Hydrocarbons (PAHs) contained in the sediment. It is therefore reasonable to expect higher concentration of pollutants in the downstream than the upstream of the discharge point and this would be reflected in the composition and diversity of the freshwater organisms.

Not all the heavy metals contained in the sediment contribute to toxicity. A number of physical, chemical and biological factors come in to play to increase or attenuate the toxicity of metals to freshwater organisms. Some of the commonly known factors include the organic content of the sediment, pH, alkalinity and hardness of the overlying water. Organic materials contained in the sediment may have a chelating effect (binding with the toxic metals) effectively reducing the toxicity of the metals. Metals are released from or adsorbed to the sediment depending on pH and redox conditions. Decreasing pH and redox potential releases free metal ions in to the overlying water. High alkalinity and hardness reduce toxicity of heavy metals due to the complexation of metal ion with carbonates and/or the competition between metal ions and Ca and Mg ions. Certain plants can absorb contamination from water through their roots (rhizofiltration). This ability (phytoextraction) can be used to clean up contaminated water bodies (phytoremediation) or to form organic filters (e.g. constructed wetlands). Trees such as popular, willow and cottonwood are used for their large water extraction rates. Popular, Cottonwood and Aspen have been used to remediate heavy metal contamination, as have mosses such as Hylocomium splendens and Rhytidialdephus loreus (Baldantoni et al. (2003), Mungur et al. (1995), Schutes et al. (2001) and ?). Apium Nodiflorum (Fool's water cress or European marshwort) has been used as an indicator/accumulator of Chromium and Nickel and is investigated here as an indicator of Cadmium, Lead and Zinc, more common in road runoff. It is used here because it is commonly found in Irish rivers and has been used in other studies. An aquatic plant, it can be expected to have a high water use and to accumulate metals from the water or sediment. The freshwater plant Apium Nodiflorum was chosen as the vegetation impact indicator and Gammarus Duebeni (Lilljeborg) as the macro invertebrate indicator. Apium grows in colony clumps as it propagates vegetatively.

In this study, upstream of heavy metals (Cd, Cu, Pb, and Zn) concentrations and macroinvertebrate communities were compared to that of the downstream to determine if road runoff had any impact on these streams. Samples from a control site, a site reasonably free from the possible effect of road runoff, has been incorporated to study if any of the study sites have significant difference from the control site.

6.2 Parameters studied

6.2.1 Heavy metals studied

Cadmium

Cadmium (Cd) has no essential biological function and is highly toxic to plants and animals. It is a normal constituent of soil at about 1 mg/kg. It is listed as a priority substance for which a sediment environmental quality standard is required.

Copper

Copper (Cu) is an essential trace element for plans and animals and is found in soil (from 20 to 30 mg/kg). It is included in List II of the Dangerous Substances Directive for surface waters.

Lead

Lead (Pb) is neither essential nor beneficial for plants and animals and is found in soil at levels of around 16 mg/kg. It is included in List II of the Dangerous Substances Directive for surface waters and is highly toxic.

Zinc

Zinc (Zn) is essential, in trace amounts, for living organisms. It is found in soil with typical concentrations of from 10 to 300 mg/kg. It is included in List II of the Dangerous Substances Directive for surface waters but is one of the least toxic of the heavy metals (Karntanut and Pascoe, 2002).

6.2.2 Nutrients studied

Nitrates and Phosphorus

Nitrogen and phosphorus in water bodies are normally associated with agricultural, industrial or wastewater treatment processes.

6.2.3 Others

Other parameters studied included; Dissolved oxygen, Temperature, pH, Specific conductivity, Total Organic Carbon, Total Alkalinity.

6.3 Monitoring Sites

Fourteen small stream sites (from the "long list" of 46) were selected for this background monitoring, Table 6.1 and are described in Chapter 5. The Lackan River, a tributary of the Pollaphuca Reservoir in County Wicklow, and which does not receive road runoff, was selected as a control site.

6.4 Methodology

6.4.1 Scope

Water, sediment and biological samples were collected from upstream and downstream locations of selected highway discharge points. In-situ measurements of pH, specific conductivity, temperature and

Table 6.1: Sites selected for sampling

Site No.	Name	Road	AADT(HGV%)**	OS NGR
S-1	Tributary of Slane River at Dunbauin Bridge	N7	50,729(12.8%)	N 970 242
S-2	Hartwell River at Tobernavore Bridge	N7	50,729(12.8%)	N 925 220
S-3	River near Rowanstown at Maynooth Bypass	M4	39,088(7.5%)	N 934 363
S-4	Lyreen River at Maynooth Bypass	M4	39,088(7.5%)	N 913 370
S-5	White River at Dunleer Bypass before exit	M1	24,369(12%)	O 135 260
S-6	Owendoher North East of Newtown	M50	43,624(6.0%)	O 135 255
S-7	Painstown River near Boherphilip	N7	50,729(12.8%)	N 955 235
S-8	Morell River near Johnstown	N7	50,729(12.8%)	N 919 216
S-9	Tributary of the Pollaphuca Reservoir*	NA	NA	O 012 110
S-10	Glen O' Downs Stream	N11	34,540(6.8%)	O 266 105
S-11	Glenview Stream	N11	34,540(6.8%)	O 256 117
S-12	Doonfin Lower Tributary	N59	2,513(6.8%)	G 508 325
S-13	Tributary of Ardnaglass Stream at Carrowree	N59	2,513(6.8%)	G 544 330
S-14	Spaddagh Tributary	N5	5,875(11.3%)	M 370 979

Control Site2004 values*

DO were also made. Additional sediment samples were collected from the edge of the M4 Motorway (near Maynooth Town) and soil samples from the adjacent land to determine if these are related to the stream sediment metal concentrations. Comparisons were made between upstream and downstream determinands to assess the impacts of road runoff on the receiving streams.

Samples from a control site, a site remote from the possible effects of road runoff, was included in the study to check for significant differences. Sediment, biological, and soil samples were analysed for Cd, Cu, Pb, and Zn and the water samples were analysed for Total Alkalinity, Non-purgeable Organic Carbon, Nitrate and Nitrite, and Total Phosphorous. Comparisons were made between upstream and downstream determinands to assess the impacts of road runoff on the receiving streams.

Additional, focussed, studies of heavy metals in sediments, in tissues of the macroinvertebrate Gammarus Duebeni (Lilljeborg) and in aquatic vegetation, were undertaken at specific sites.

To study the temporal variation of determinands, six sites, which were sampled at the beginning of the project, were again sampled (for sediment and water) between April and June 2005. Two of the sites were not sampled in the second period because the sites were disturbed by new road construction (the N7 widening). Additional sites, which are considered to be in relatively pristine conditions, were also included this time. Water and sediment samples were taken and analysed using the same techniques for the same parameters as previous. Sixteen US EPA selected Polycyclic Aromatic Hydrocarbons (PAHs) were tested for some sites to add more information to what is already available from the previous period.

6.4.2 Sampling methods

Sediment and water

At each site, sediment samples were collected from three locations upstream and three locations downstream of the runoff discharge points. The downstream samples were collected beginning from adjacent to the drainage outfall and further downstream 30 to 40 metres apart depending on availability of deposited sediment. The upstream samples were similarly collected from upstream of the road drainage discharge point at similar distances as the downstream side. The top 2-5cm of the sediment was collected at each point using a plastic scoop and transferred to pre-labelled clean plastic bags. The samples were stored in a refrigerator until analysis. Roadside sediment samples were collected from each side of the M4 Motorway at the Maynooth site. Water samples were also collected at the same time but prior to sediment collection to avoid effects on the water of resuspension during sediment sampling.

Vegetation

Two rivers, the Lyreen and tributary of the Painestown, were sampled for vegetation. In each case, an outflow pipe brings road runoff directly into the river at the downstream side of each culvert. In each case samples of Apium Nodiflorum were collected from (i) up to 50 m upstream of the road, (ii) within 10 m of the road runoff outflow pipe and (iii) a reach more than 80 m downstream of the culvert. From one to three samples were taken from each population cluster at each location and including samples representative of both banks and the centre of the channel. Figures?? and ??. At least 8 plants were taken from each location.

Macroinvertebrates

Sampling technique Due to lack of population densities the analysis was carried out on four pool sites in the tributary of the Painstown River only. The amphipod Gammarus duebeni was used in the analysis. The Gammarids were collected using the method of 3-minute kick- sampling starting downstream and working upstream. Fifty individual organisms were collected at each of the three upstream sites. Only seven gammarids were collected at each of the three upstream sites. Only seven gammarids were collected in the downstream site. Gammarids were collected with a pond net, from as near as possible to the same sampling points as to that of the sediment.

Analysis technique Invertebrate samples were held for 48 hours in aerated tanks, so as to remove any undigested matter that may be inside the gut as these could contain heavy metals and so contaminate the final analysis of heavy metal concentration in tissue. The four sample groups were each placed in four separate plastic snap jars with a reasonable quantity of distilled water and labelled, being careful not to fill beyond 90% of the volume of the snap jar as the samples would be freeze-dried for 24 hours. The samples were then sent off to an external laboratory for analysis.

Results The mean concentration of the heavy metals recorded in G. duebeni at the upstream and downstream sites of the Tributary of the Painstown River are given in Table ??

Table 6.2: Mean conc. heavy metals in Gammarus (μg/g

Metal	US/DS	Mean	Standard Deviation	Coefficient of Variation
Cu	US	71.37	8.41	11.78
	DS	46.10		
Zn	US	89.68	19.2	21.41
	DS	79.00		
Cd	US	0.52	0.006	1.11
	US	0.40		
Pb	US	2.45	1.19	48.47
	DS	2.50		

Conclusion There was an absolute decrease in the concentration of Zn, Cu, and Cd in Gammarus tissue in the tributary of the Painstown River downstream of the discharge pipe compared with samples taken from the upstream. This may be indicative of the development of an evolutionary tolerance to heavy metal pollution in Gammarus Duebeni.

Table 6.3: Chemical characteristics of rain in study area

date	Cd (mg/l)	Cu (mg/l)	Pb (mg/l)	Zn (mg/l)	PAHs
19 Oct 2004	nd	nd	nd	0.038	nd
24 Oct 2004	0.01	0.012	0.042	0.04	nd
2 Nov 2004	0.04	nd	0.025	0.138	nd

Water and sediment

The water samples were analysed as described in the Standard Methods for the Examination of Water and Wastewater (APHA, 1998) for each parameter. Summary of the methods used in this project are presented in Appendix E

The chemical characteristics of the rainfall was characterised by collecting a number of samples during rain events on three separate days, Table 6.3.

The procedure used for extracting metals from the sediment is based on the method described in Sriyaraj and Shutes (2001) and Part 3030E of the Standard Methods (APHA, 1998). Samples were oven dried at 103-105^{o}C for 24 hours and cooled in a desiccator. The dried samples were ground and sieved to a fraction size of $\leq$ 250mm. Exactly 2.0g of each sample was transferred into a beaker and approximately 75ml of distilled water was added. Five mls of conc. HNO_3 (69%, w/w) was then added and allowed to stand overnight. The mixture was evaporated on a hot plate to a volume of 10 to 20mL. The samples were then filtered through Whatman 934-AH Glass Microfibre Filter. The filtrates were made up to 100mL with distilled water and stored in acid-rinsed plastic containers. Each sample was done in duplicates. Blank samples subjected to the same process were also analysed.

Determination of metal concentration the solution was carried out by Atomic Absorption Spectrometry in accordance with Part 3111B of APHA (1998). All Samples were analysed for Cd, Cu, Pb and Zn. The working standard solutions were 2, 1, and 0.1mg/L from a stock solution of 1000mg/L. Product LGC 6139 (river clay) of Laboratory of the Government Chemist, Teddington, Middlesex (UK) was used as standard reference sediment. The recovery of heavy metals from this reference was 104% for Cd with a coefficient of variation (CV) of 1%, 96% for Cu with CV of 2%, 98% for Pb with CV of 4% and 96% for Zn with a CV of 1%.

Vegetation

Prior to analysis, the plants were stored in a cold room at 4^{o}C. The plants were washed five times in distilled water, sediment and algae were removed from the roots. Leaf shoots were opened and washed. When clean, the roots and shoots were cut off and washed in a solution of 10 mmol l-1 1 $CaCl_2$ at 0^{o}C for 30 minutes to remove wall bound metals. The plant parts were individually sealed in envelopes and dried by heating to 100oC, and weighed. The dried roots and shoots were ground through a fine 1mm mesh and dried again at 100^{o}C. This gave four main groups of samples, each with three subgroups, covering all the possible combinations of (i) Lyreen or Painestown and (ii) roots or shoots and (iii) upstream, at culvert or downstream. Each sample was transferred to a 100 ml screwtop jar to which was added 10 ml of 69% nitric acid. Each jar was heated for 45 minutes at 90^{o}C and before the temperature was increased to 140^{o}C until 1 ml of sample remained. This was repeated 8 times with 12 samples each time. After cooling, any particles remaining in the sample were filtered with cellulose-based ashless filter paper, made up to 20 ml with nitric acid and transferred to plastic bottles.

An atomic absorption spectrometer took three separate readings from each sample and reported the mean values, of Copper, cadmium, Zinc, and Lead concentrations. The spectrometer was calibrated with standard concentrations of 0.1, 1.0 and 2.0 mg/l for all four metals.

Table 6.4: Average of water quality parameters u/s and d/s at monitoring sites: first test

	pH		Sp. Cond. Sp. Cond. mS/cm		Total Alkalinity mg/L $CaCO_3$		BOD5 BOD5 mg/L		NO3-N NO2-N mg/L		NPOC NPOC mg/L		Total phosphate mg/L	
Site	US*	DS*	US *	DS	US	DS	US	DS	US	DS	US	DS	US	DS
S1	8.2	8.1	491	509	131	140	<2	<2	3.0	3.4	2.9	2.8	60	60
S2	7.8	8.1	546	529	221	215	<2	<2	2.3	2.0	1.8	1.3	60	40
S3	7.6	7.9	686	689	317	323	2.5	3.4	1.0	0.9	2.9	2.9	190	200
S4	7.9	8.1	706	707	281	274	2.70	4.7	1.8	1.8	4.6	4.7	200	210
S5	8.1	8.1	627	626	255	252	<2	<2	0.7	0.6	3.0	2.8	80	70
S6	8.1	8.3	280	270	97	89	<2	<2	1.3	1.4	2.6	2.6	60	60
S7	8.1	7.4	791	661	133	130	<2	2.1	2.4	1.5	4.9	4.3	240	130
S8	8.4	8.0	567	624	213	212	<2	<2	3.2	4.6	1.8	1.2	30	30
S9v	6.0	6.0	71	70	12	9	<2	2	0.7	0.5	3.5	3.6	70	30

*US = upstream; DS = downstream of discharge point
v Control site

6.4.3 Macroinvertebrates

6.5 Results

6.5.1 Comparison of upstream and downstream pollution concentrations in water

Measured concentrations of the physical and chemical parameters in water are presented in Tables 6.4, 6.5 and 6.6. There was no significant difference between concentration levels at the upstream and downstream sites although these samples do not necessarily reflect the whole metal-mobilisation potential of the streams. This is expected because all samples were taken during dry days where there was little or no flow from highway drainage pipes into these streams. Comparisons of the two test periods also show no significant variation in other parameters between the two with the exception of total alkalinity, Table 6.5. The difference with total alkalinity can however be attributed to the seasonal variation of the parameter.

6.5.2 Comparison of metals in upstream and downstream sediment

Average concentrations of Cd, Cu, Pb and Zn, expressed in μg/g dry weight, of upstream and downstream samples are given in Table 6.7. Concentration ranges are 0.8 - 4.3μg/g for Cd, 11.2 -53.7 μg/g for Cu, 16.8 - 45.6 μg/g for Pb, and 65.6 - 216.9 μg/g for Zn. The levels detected at the river near Rowanstown and Lyreen River (S3 and S4) are generally higher than the other sites. Figure 6.1 shows the variation of metals upstream and downstream of the sampling sites.

Some of sites studied exhibited slight increase in the downstream concentrations although statistically significant only at S6 for Cd, S7 for Cu and Zn (at p=0.05). However, the means all the downstream concentrations were not significantly higher than the upstream sites at p=0.05. All the tested metals showed some degree of correlation to each other (multiple or single), the strongest being a coefficient of determination (R^2) of 0.87 between Cu and Zn and a smallest of 0.38 between Cd and Pb. The multiple correlation of Cd against Cu, Pb, and Zn produced R^2 of 0.59. Sites along the N7 (S1, S2, S7 and S8) showed little variation of metal concentrations among themselves.

This is expected since all sites are located along the same road and the parent material they are derived from and the processes that generated them are similar.

Figure 6.2 shows comparison of upstream and downstream concentrations of the four tested metals for the second period. The overall comparison of upstream and downstream concentrations show significant variations only in two sites; S6 (Owendoher North-East of Newtown) and S12 (Doonfin Lower Tributary). The Owendoher river is crossed by M50 at the sampling site. This site had a similar history in the previous study too. The Doonfin Lower Tributary is on the N59 in the North-West of Ireland.

Table 6.5: Water quality results for the two periods

		Total Alkalinity mg/L $CaCO_3$		NPOC, mg/L		Nitrate + Nitrite as N, mg/L		Total PO4-P, ug/L	
		1st test	2nd test	1st test	2nd test	1st test	2nd test	1st test	2nd test
S1	US	131	257	2.9	2.2	3.0	1.5	60	92
	DS	140	259	2.8	2.3	3.4	1.8	60	102
S2	US	221	285	1.8	2.1	2.3	1.5	60	72
	DS	215	280	1.3	2.1	2.0	1.7	40	104
S3	US	317	357	2.9	3.2	1.0	4.0	190	181
	DS	323	357	2.9	1.5	0.9	3.0	200	46
S4	US	281	355	4.6	4.0	1.8	3.6	200	218
	DS	274	353	4.7	4.1	1.8	3.9	210	170
S5	US	255	166	3.0	4.4	0.7	4.7	80	76
	DS	252	167	2.8	4.2	0.6	5.0	70	52
S6	US	97	108	2.6		1.3		60	54
	DS	89	115	2.6		1.4		60	42
S7	US	133		4.9		2.4		240	
	DS	130		4.3		1.5		230	
S8	US	213		1.8		3.2		30	
	DS	212		1.2		4.6		30	
S9**	US	12		3.5		0.7		70	
	DS	9		3.6		0.5		30	
S10**	US		28		1.1		3.8		42
	DS		70		1.2		3.5		33
S11**	US		26		1.4		3.5		42
	DS		28		1.6		2.8		37
S12**	US		105*		7.2		0.2		19
	DS		100*		7.4		0.2		17
S13**	US		172*		4.0		0.3		24
	DS		173*		4.1		0.3		31
S14**	US		217*		6.6		0.6		31
	DS		221*		6.0		0.6		38

Total Hardness Control Sites*

Table 6.6: Average concentrations of metals in water upstream and downstream two periods

Site		Cadmium,μg/g		Copper,μg/g		Lead,μg/g		Zinc,μg/g	
		1st test	2nd test	1st test	2nd test	1st test	2nd test	1st test	2nd test
S-1	US	2.6	3.0	15.8	15.6	28.6	35.6	70.6	84.0
	DS	3.2	2.7	16.4	18.6	30.3	43.7	73.0	84.2
S-2	US	3.0	3.1	14.0	9.8	21.2	27.4	78.4	61.6
	DS	2.8	2.8	17.5	11.6	21.0	33.4	89.4	68.3
S-3	US	4.0	-	38.5	-	39.5	-	191.8	-
	DS	3.7	-	53.7	-	38.8	-	216.9	-
S-4	US	4.3	5.1	27.5	26.7	24.3	32.9	136.1	173.3
	DS	4.1	4.8	24.0	21.3	29.1	31.3	142.2	161.9
S-5	US	0.8	1.53	23.3	16.7	34.8	25.5	92.9	57.7
	DS	0.8	1.08	17.7	16.0	26.0	26.8	70.4	63.7
S-6	US	1.3	1.4	15.3	12.6	31.0	33.2	131.6	135.9
	DS	2.2	1.9	18.7	14.7	33.4	36.2	135.8	140.1
S-7	US	2.8		20.6		40.6		99.0	
	DS	2.7		30.7		45.6		167.7	
S-8	US	3.3		22.0		30.2		65.6	
	DS	2.9		20.0		19.4		73.2	
S-9	US	1.7		11.5		16.8		97.4	
	DS	1.7		11.2		18.5		123.6	
S-10	US		1.1		9.8		22.3		77.8
	DS		1.4		9.1		21.9		62.5
S-11	US		1.1		9.8		22.3		77.8
	DS		0.9		8.9		22.3		66.0
S-12	US		0.5		6.3		15.5		39.6
	DS		0.8		8.5		46.9		56.4
S-13	US		1.1		4.2		14.1		57.4
	DS		0.7		3.1		12.4		47.2
S-14	US		1.3		3.6		10.6		23.9
	DS		1.3		4.2		12.5		32.8

US = upstream of discharge; DS = downstream of discharge

The stream is found in a valley where road runoff from both sides of the valley drain into the stream from open drain system. The other sites show such variations in only one or two of the metals tested. S1 (Cu, Pb, and Zn) and S4 (Cd, Pb, and Zn) showed slight increase in three out of the four metals, S5 (Cd and Pb) and S6 (Pb and Zn) showed in 2 out of the four metals and S2 (Pb) showed in only one out of the four metals. The overall comparison of the two periods didn't show statistically significant difference (p=0.05). Graphs of the comparison of sediment metal concentrations from the two sampling periods are shown in Fig. 6.3

6.5.3 Comparison with road deposited sediment and site soil

The data from the first test was compared with road deposited sediment and natural soil in the surrounding area, Table 6.8. Road-deposited sediment samples from the M4 motorway (at Lyreen River) produced elevated concentrations of Cd (2.9μg/g), Cu (87.5μg/g), Pb (120.6μg/g), and Zn (450.1μg/g). These concentrations are significantly higher than found in the Lyreen River. Soil samples were also collected from the bank of the stream and the surrounding area. The metal concentrations found were well with in the range of natural levels except for Cd (= 2.3μg/g). This value is admittedly very high. A possible justification for this is that some Irish soils reportedly have naturally high Cd levels (3-4μg/g) arising generally from parent material (Dept. Agric. Food and Rural Devel. (Ire.), 2000). Figure 6.8 shows heavy metals concentration in stream sediment, site soil and road deposited sediment.

Table 6.7: Average concs. of metals in sediments u/s and d/s of the sites : first test

	Cd mg/g		Cu mg/g		Pb mg/g		Zn mg/g	
Site	US	DS	US	DS	US	DS	US	DS
S1	2.6	3.2	15.8	16.4	28.6	30.3	70.6	73.0
S2	3.0	2.8	14.0	17.5	21.2	21.0	78.4	89.4
S3	4.0	3.7	38.5	53.7	39.5	38.8	191.8	216.9
S4	4.3	4.1	27.5	24.0	24.3	29.1	136.1	142.2
S5	0.8	0.8	23.3	17.7	34.8	26.0	92.9	70.4
S6	1.3	2.2	15.3	18.7	31.0	33.4	131.6	135.8
S7	2.8	2.7	20.6	30.7	40.6	45.6	99.0	167.7
S8	3.3	2.9	22.0	20.0	30.2	19.4	65.6	73.2
S9	1.7	1.7	11.5	11.2	16.8	18.5	97.4	123.6

US = upstream of discharge; DS = downstream of discharge

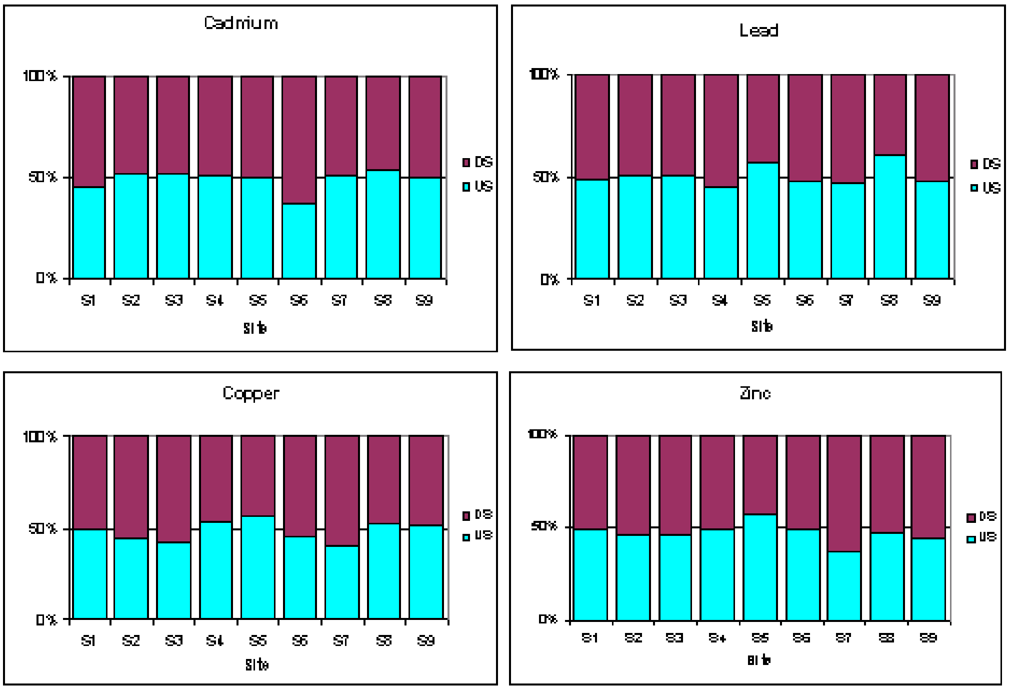


Figure 6.1: Changes in metals in sediments u/s and d/s of outfalls, First test

Table 6.8: Heavy metals in site soil and road deposited sediment, μg/g

Site	Cd	Cu	Pb	Zn
Site Soil	2.3	25.6	33.8	104.7
Sites mean	2.7	22.1	29.4	114.2
M4NB	3.0	75.1	98.1	406.6
M4SB	2.7	99.8	143.1	493.6

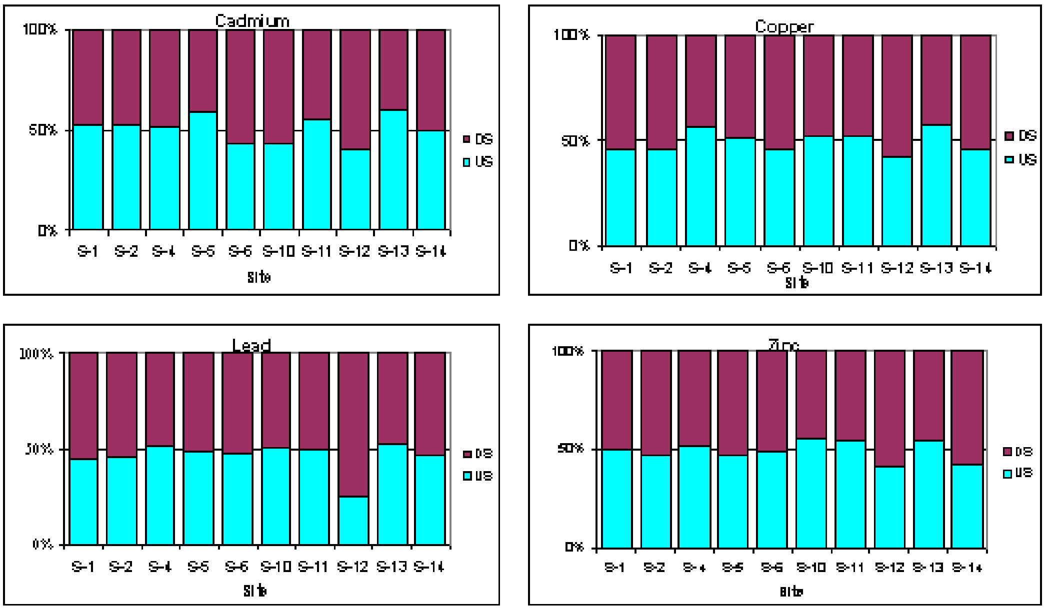


Figure 6.2: Changes in metals in sediments u/s and d/s of outfalls, Second test

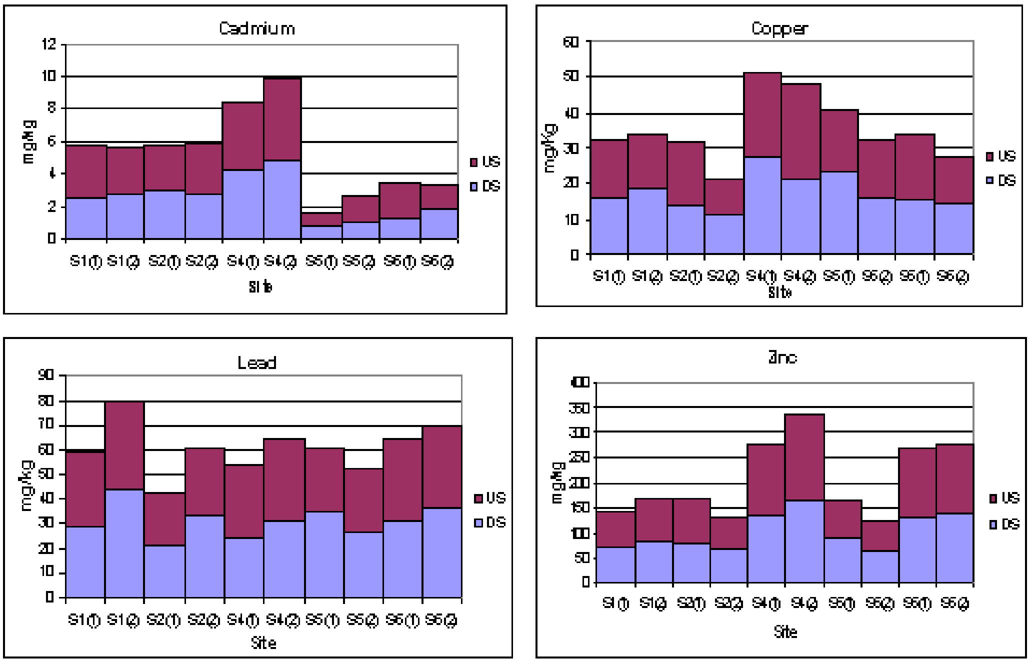


Figure 6.3: Comparison of metal concentration from the two periods S1 (1)= Site 1 period 1;S1 (2)= Site 1 period 2; US = upstream; DS = downstream

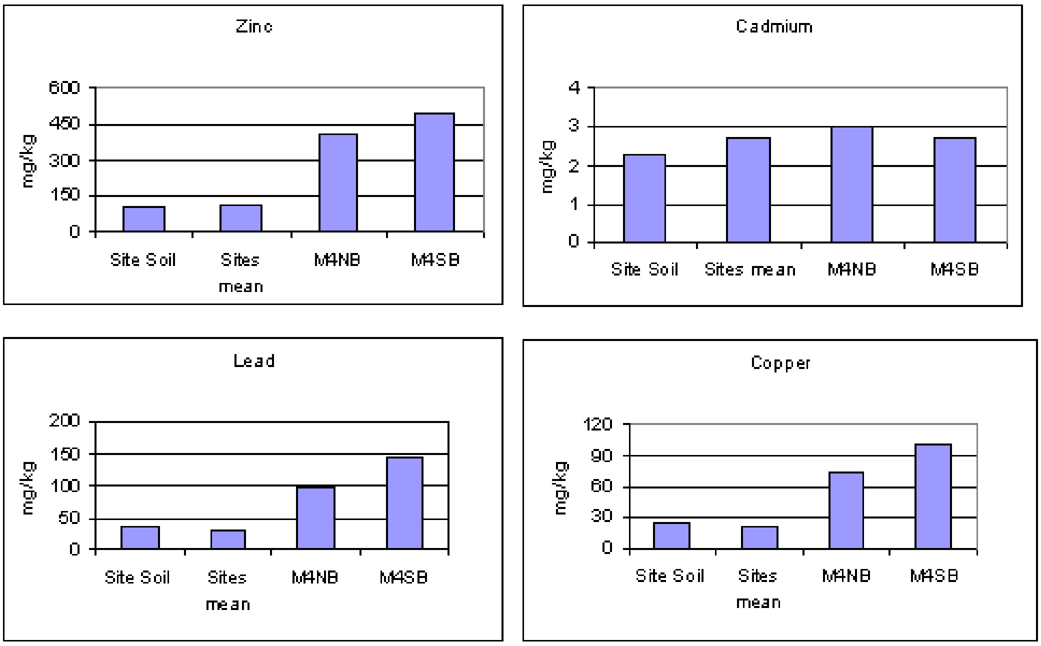


Figure 6.4: Heavy metals in site soils and road deposited sediment, mg/kg

6.5.4 Comparison with the control site

The water quality of the control site is reasonably good, Table 6.6. The measured values are similar to that of rainwater. The heavy metal concentrations in the sediment for the control site is also well below most of the sites except for Zn.

6.5.5 PAHs content of the sediment

The Polycyclic Aromatic Hydrocarbons (PAHs) content of the sediment is presented in Table 6.9 Sites S6, S10 and S11 have shown significant differences between upstream and downstream concentrations. S6 is the Owendoher stream on the M50 and sites S10 and S11 are two sampling sites on the Glen O'Downs stream along the N11. The Owendoher stream also had higher heavy metals concentrations in the downstream than in the upstream reaches.

6.5.6 Comparison with the control site

The water quality of the control site is reasonably good. The reported values of the parameters tested are similar to that of rainwater. The heavy metal concentrations in the sediment for the control site is also well below most of the sites except for Zn.

6.5.7 Comparison with environmental quality standards

There are no Irish or EU sediment quality guidelines for freshwater organisms as yet (Company (2002),Crane (2003). Some EU countries (Germany, Holland, Norway, Sweden and the UK) have developed their own standards and targets independently (Ahlf et al., 2002). The first explicit standards were developed in Canada and the USA for monitoring and regulating sediment contamination (Crane et al., 1996). The Canadian Sediment Quality Guidelines for the Protection of Aquatic Life (CCME, 2003) derives Threshold Effect Levels (TELs), also called Interim Freshwater Sediment Quality Guideline (ISQG), and Probable Effect Levels (PELs) from an extensive database containing direct measurements of toxicity of contaminated sediments to a range of aquatic organisms exposed in laboratory tests and under field conditions. According to this guideline, effects may be observed in some sensitive species exposed to the TEL, whereas the PEL is likely to cause adverse effects in a wider range of organisms. Table 6.10 summarises the sediment quality guideline values for Cd, Cu, Pb and Zn.

The contamination levels for most of the sites investigated were found to be below the TEL, except for Cd, which is above the PEL. The worst affected sites are S4 (average = 4.3mg/g) and S3 (average = 4.0mg/g). S5 (White River at Dunleer Bypass) has been identified as the least impacted of all the sites examined. Some of the metals detected at this site were even less than that of the control site (S9).

6.6 Further studies: Heavy metals in sediments

If road runoff is contaminated with heavy metals, then both the in-stream sediment and biota might be expected to show some signs of the impact. This theme was investigated in a special investigation of a number of the study sites by Mr. James Lynch, as part of his M.Appl.Sc. project, under the supervision of Drs. M.Bruen and M. Kelly-Quinn. Sediment samples were taken from an number of locations, both upstream and downstream of discharges of road runoff into the channel. These were analysed for the presence of heavy metals. In addition, samples of Gammarus duebeni (Lilljeborg) were taken and also analysed for heavy metals. One method of quantifying the impact is to study the uptake of the contaminants by materials and organisms likely to accumulate them over time. Sediments, aquatic organisms and aquatic vegetation are potential accumulators of the contamination. This may cause stress in living organisms and leads to the disruption of vital systems, (Karntanut and Pascoe (2002), Goodyear and McNeil (1999)).

6.7 Further studies: macroinvertebrate tissue

6.8 Further studies: Vegetation

If road runoff is affecting aquatic ecosystems, then the in-stream or riparian vegetation might be expected to respond and to show some signs of the impact. This theme was investigated in a special investigation of a number of the study sites by Mr. Eoin Burke, as part of his M.Appl.Sc. project, under the supervision of Drs. M.Bruen and M. Kelly-Quinn.

6.8.1 Methodology

Bio-indicators

Certain plants can absorb contamination from water through their roots (rhizofiltration). This ability (phytoextraction) can be used to clean up contaminated water bodies (phytoremediation) or to form organic filters (e.g. constructed wetlands). Trees such as popular, willow and cottonwood are used for their large water extraction rates. Popular, Cottonwood and Aspen have been used to remediated heavy metal contamination, as have mosses such as Hylocomium splendens and Rhytidialdephus loreus. (Baldantoni et al. (2003),Mungur et al. (1995),Schutes et al. (2001) and Steinborn and Breen (2001)). Apium Nodiflorum (Fool's water cress or European marshwort) has been used as an indicator/accumulator of Chromium and Nickel and is investigated here as an indicator of Cadmium, Lead and Zinc, more common in road runoff. It is used here because it is commonly found in Irish rivers and has been used in other studies. An aquatic plant, it can be expected to have a high water use and to accumulate metals from the water or sediment. The freshwater plant Apium Nodiflorum was chosen as the vegetation impact indicator and Gamm as the macro invertebrate indicator. Apium grows in colony clumps as it propagates vegetatively.

Sampling locations

Two rivers are studied, the Lyreen (ADT 50,000) and Painestown (ADT 35,000), both of which pass under the N7 through culverts. In each case, a outflow pipe brings road runoff directly into the river at the downstream side of each culvert. In each case samples of Apium Nodiflorum were collected from (i) up to 50 m upstream of the road, (ii) within 10 m of the road runoff outflow pipe and (iii) a reach more than 80 m downstream of the culvert. From one to three samples were taken from each population cluster at each location and including samples representative of both banks and the center of the channel. At least 8 plants were taken from each location.

Preparation

Prior to analysis, the plants were stored in a cold room at 4^oC. The plants were washed five times in distilled water, sediment and algae were removed from the roots. Leaf shoots were opened and washed. When clean, the roots and shoots were cut off and washed in a solution of 10 mmol l^{-1} $CaCl_2$ at 0^oC for 30 minutes to remove wall bound metals. The plant parts were individually sealed in envelopes and dried by heating to 100^o, and weighed. The dried roots and shoots were ground through a fine 1mm mesh and dried again at 100^oC. This gave four main groups of samples, each with three subgroups, covering all the possible combinations of (i) Lyreen or Painestown and (ii)roots or shoots and (iii) upstream, at culvert or downstream.

Each sample was transferred to a 100 ml screwtop jar to which was added 10 ml of 69% nitric acid. Each jar was heated for 45 minutes at 90^oC and before the temperature was increased to 140^oC until 1 ml of sample remained. This was repeated 8 times with 12 samples each time. After cooling, any particles remaining in the sample were filtered with cellulose-based ashless filter paper, made up to 20 ml with nitric acid and transferred to plastic bottles.

An atomic absorption spectrometer took three separate readings from each sample and reported the mean values, of Copper, cadmium, Zinc and Lead concentrations. The spectrometer was calibrated with standard concentrations of 0.1, 1.0 and 2.0 mg/l for all four metals.

6.8.2 Results

Lead

In general, lead concentrations were quite small, but the lowest values were found upstream of the road crossing and highest near the outflow pipe. Downstream concentrations were slightly higher than upstream, Table 6.11. Lead concentrations in the roots were significantly higher than in the shoots.

Copper

Similarly copper concentrations were lowest upstream of the road crossing and highest near the outflow pipe. Downstream concentrations were slightly higher than upstream, Table 6.12. Concentrations in the roots were significantly higher than in the shoots.

Cadmium

Similarly, cadmium concentrations were lowest upstream of the road crossing and highest near the outflow pipe. Downstream concentrations were slightly higher than upstream, Table 6.13. Concentrations in the roots were significantly higher than in the shoots.

Zinc

Unlike the other metals, zinc concentrations are very high. The roots have higher concentrations than the shoots and the highest concentrations in the Lyreen are found near the outflow pipe and the lowest at the downstream location, Table 6.14. In contrast, the highest zinc concentrations in the roots at the Painestown site are at the upstream location and concentrations decrease in the downstream direction. In the shoots however, the pattern of highest levels at the outflow reappears.

6.8.3 Discussion of vegetation results

Concentrations

The relatively high levels of zinc indicate that (i) there is a source of zinc and (ii) that Apium accumulates zinc well. In contrast, the significantly lower levels of lead, copper and cadmium indicate either that (i) there is not much contamination with these metals , or (ii) Apium does not accumulate large amounts of these metals.

6.9 Conclusions

A baseline hydrobiological status of streams receiving road runoff was established from water, sediment and biological samples taken from upstream and downstream locations of the discharge points. The background water quality values lie well with in the surface water for abstraction standard. With the exception of PAHs for one area, there wasn't any significant systematic difference between upstream and downstream values of most parameters. However, some differences in sediment metal concentration were noted in the downstream samples though this was statistically significant only in two sites (S6 and S7). The overall mean of downstream sediment metal concentrations were not significantly higher than the upstream sites at p=0.05. Comparison with Environmental Quality Standards indicated that there wasn't any serious heavy metal pollution in the stream sediment studied. High concentrations of Cd were detected in most of the sites (the highest being in S4 and S5). This is explained by the fact that the natural background Cd concentrations in Irish soils is known to be as high as 3-4μg/g.

The PAH concentrations of the sediment samples show significant differences between upstream and downstream concentrations for some of the tested sites. The Owendoher River was the most affected.

The relatively high levels of zinc in Apium vegetation indicate that (i) there is a source of zinc and (ii) that Apium accumulates zinc well. In contrast, the significantly lower levels of lead, copper and cadmium indicate either that (i) there is not much contamination with these metals, or (ii) Apium does not accumulate large amounts of these metals.

Table 6.9: PAHs in the stream sediment samples

	S-2		S-4		S-5		S-6		S-10*		S-11*		S-12		S-13		S-14	
Compound	US	DS	US	DS	US	DS	US	DS	US	DS(2)	US	DS(1)	US	DS	US	DS	US	DS
Naphthalene	<1	<1	<1	<1	<1	<1	<1	10	14	<1	<1	14	<1	<1	<1	<1	<1	<1
Acenaphthylene	<1	<1	<1	<1	<1	<1	<1	32	17	<1	<1	17	<1	<1	<1	<1	<1	<1
Acenaphthene	<1	<1	<1	<1	<1	<1	<1	62	178	<1	<1	178	<1	<1	<1	<1	<1	<1
Fluorene	<1	<1	<1	<1	<1	<1	<1	23	53	<1	<1	53	<1	<1	<1	<1	<1	<1
Phenanthrene	<1	<1	50	27	<1	<1	32	187	262	383	<1	262	<1	<1	<1	<1	<1	<1
Anthracene	<1	<1	31	10	<1	<1	12	86	48	45	<1	48	<1	<1	<1	<1	<1	<1
Fluoranthene	<1	<1	85	29	<1	<1	57	573	555	1075	<1	555	<1	<1	<1	<1	<1	<1
Pyrene	<1	<1	74	24	<1	<1	43	527	496	698	<1	496	<1	<1	<1	<1	<1	<1
Benzo(a)anthracene	<1	<1	40	18	<1	<1	50	302	297	456	<1	297	<1	<1	<1	<1	<1	<1
Chrysene	<1	<1	64	27	<1	<1	80	339	394	559	<1	394	<1	<1	<1	<1	<1	<1
Benzo(b)+Benzo(k) fluoranthene	<1	<1	52	17	<1	<1	74	346	434	710	<1	434	<1	<1	<1	<1	<1	<1
Benzo(a)pyrene	<1	<1	57	18	<1	<1	59	240	268	405	<1	268	<1	<1	<1	<1	<1	<1
Indeno(123cd)pyrene	<1	<1	24	10	<1	<1	37	81	139	296	<1	139	<1	<1	<1	<1	<1	<1
Dibenzo(ah)anthracene	<1	<1	13	5	<1	<1	20	44	69	120	<1	69	<1	<1	<1	<1	<1	<1
Benzo(ghi)perylene	<1	<1	36	11	<1	<1	52	107	159	392	<1	159	<1	<1	<1	<1	<1	<1
hline Total	<1	<1	526	197	<1	<1	516	2959	3383	5139	<1	3383	<1	<1	<1	<1	<1	<1

**S-10 and S-11 are two points on the same stream. The stream crosses the road twice. Note that downstream for S-11 is upstream for S-10.*

Table 6.10: Percentage incidence of adverse biological effects related to ISQGs and PELs : from CCME (2003)

Metal	ISQG	PEL	Percentage Incidence		
	μg/g*	μg/g*	%<ISQG	ISQG<%<PEL	%>PEL
Cd	0.6	3.5	11	12	47
Cu	35.7	197	4	38	44
Pb	35.0	91.3	5	23	42
Zn	123	315	5	32	36

** for dry sediment*

Table 6.11: Lead concentrations in vegetation

River	part	quantity	upstream (mg/l)	outflow (mg/l)	downstream (mg/l)
Lyreen	root	mean	0.161	0.270	0.140
		std	*0.172*	*0.247*	*0.141*
	shoot	mean	0.078	0.166	0.113
		std	*0.065*	*0.110*	*0.100*
Painestown	root	mean	0.148	0.194	0.169
		std	*0.069*	*0.134*	*0.049*
	shoot	mean	0.051	0.078	0.054
		std	*0.007*	*0.036*	*0.024*

All values calculated from 8 samples at each location.

Table 6.12: Copper concentrations in vegetation

River	part	quantity	upstream (mg/l)	outflow (mg/l)	downstream (mg/l)
Lyreen	root	mean	0.063	0.197	0.100
		std	*0.031*	*0.312*	*0.110*
	shoot	mean	0.030	0.045	0.033
		std	*0.010*	*0.034*	*0.009*
Painestown	root	mean	0.058	0.083	0.092
		std	*0.014*	*0.079*	*0.017*
	shoot	mean	0.032	0.050	0.032
		std	*0.035*	*0.060*	*0.010*

All values calculated from 8 samples at each location.

Table 6.13: Cadmium concentrations in vegetation

River	part	quantity	upstream (mg/l)	outflow (mg/l)	downstream (mg/l)
Lyreen	root	mean	0.017	0.032	0.024
		std	*0.013*	*0.037*	*0.025*
	shoot	mean	0.011	0.018	0.013
		std	*0.009*	*0.013*	*0.011*
Painestown	root	mean	0.022	0.034	0.018
		std	*0.010*	*0.034*	*0.007*
	shoot	mean	0.010	0.027	0.015
		std	*0.008*	*0.013*	*0.006*

All values calculated from 8 samples at each location.

Table 6.14: Results for Zinc

River	part	quantity	upstream (mg/l)	outflow (mg/l)	downstream (mg/l)
Lyreen	root	mean	3.078	4.104	2.206
		std	*1.928*	*4.447*	*2.147*
	shoot	mean	5.242	7.374	3.558
		std	*6.832*	*7.725*	*3.071*
Painestown	root	mean	12.372	6.085	3.665
		std	*15.494*	*5.722*	*1.921*
	shoot	mean	6.371	6.574	4.355
		std	*6.063*	*4.130*	*1.549*

All values calculated from 8 samples at each location.

Chapter 7

Surface Water Impact studies : Macroinvertebrates and Fish

7.1 Macroinvertebrate studies

7.1.1 Objectives

The objectives of this part of the study were

- To describe the macroinvertebrate and fish populations upstream and downstream of road runoff drainage pipes,
- To assess potential impacts on these aquatic biota

7.1.2 Methodology

Site Descriptions

A total of 28 sites representing 14 streams were sampled between 2002 and 2005. Eight of the streams sampled by Burns (2004) were revisited in April 2005. Six of these streams were resampled for macroinvertebrate fauna, Table 7.1. On visiting the Painstown and Morrell streams, it was noted that due to the major road works the upstream/downstream sites were being impacted by the large movement of earth and clearfelling of bankside vegetation. It was decided therefore to abandon sampling these streams. Five new unimpacted sites were selected along the N11, N59 and N5 and sampled in May/June 2005, Table 7.1. These new sites were added so that the potential impacts of road-runoff could be assessed in the absence of other anthropogenic inputs.

7.1.3 Biological Sampling: Macroinvertebrates

Macroinvertebrates were collected using a 3-minute, multi-habitat kick sampling technique . This involved surveying a 50m reach for different habitat types - riffle, glide, pool, backwater, vegetated area and margin. The time allotted to sampling each habitat type depended upon the percentage representation of each in the 50m reach. Habitats contributing less than 5% of the stable habitat in the reach were generally not sampled . Three replicate samples were collected, labeled and preserved in 70% alcohol. Hand searches were also undertaken to provide intact specimens for species confirmation.

On return to the laboratory, samples were sieved through a 850mm sieve and transferred to a white tray. All macroinvertebrates were removed and stored into labeled glass tubes containing 70% alcohol. Counting and species identification of the macroinvertebrates to the lowest possible taxon using standard Freshwater Biological Association (FBA) identification keys.

Table 7.1: Details of sites locations and macroinvertebrate sampling periods

Grid Ref.	Code	Site Description and Road	2002	2003	2005
O266 105	GD-US	Glen O'Downs stream south on N11 (U/S of pipe)			*
O267 105	GD-DS	Glen O'Downs stream south on N11 (D/S of pipe)			*
O256 117	GV-US	Glenview stream on N11 (U/S of pipe) (Hotel)			*
O256 116	GV-DS	Glenview stream on N11 (D/S of pipe) in GlenO'Downs Woods			*
O136 255	OW-US	Owendoher river, U/S of the M50	*		*
O135 259	OW-DS	Owendoher river, D/S of the M50	*		*
0 3017 21030	PP-US	Poulaphuca Reservoir tributary, U/S		*	
0 3019 21035	PP-DS	Poulaphuca Reservoir tributary, D/S		*	
G54356 32981	CR-US	Tributary of Ardnaglass stream at Carrowree, U/S of the N59			*
G54281 33020	CR-DS	Tributary of Ardnaglass stream at Carrowree, D/S of the N59			*
G50803 32480	DF-US	Doonfin lower tributary U/S of the N59			*
G50815 32512	DF-DS	Doonfin lower tributary D/S of the N59			*
M37009 97949	SP-US	Spaddagh tributary, U/S of the N5			*
M36981 98010	SP-DS	Spaddagh tributary, D/S of the N5			*
N 925 219	HW-US	Hartwell river, U/S of the N7 at Tobernavoher Br, N of Johnstown	*		*
N 925 220	HW-DS	Hartwell river, D/S of the N7 at Tobernavoher Br, N of Johnstown	*		*
N 970 241	SL-US	Slane tributary U/S of Dunbauin Br on N7	*		*
N 969 241	SL-DS	Slane tributary D/S of Dunbauin Br on N7	*		*
N 912 369	LY-US	Lyreen river, U/S of M4 Maynooth bypass	*	*	*
N 913 370	LY-DS	Lyreen river, D/S of M4 Maynooth bypass	*	*	*
O 055 845	WH-US	Whites river, U/S of M1 at Dunleer bypass		*	*
	WH-DS	Whites river, D/S of M1 at Dunleer bypass		*	*
N 919 214	MO-US	Morell river U/S of the N7 near Johnstown / Naas	*		
N 918 316	MO-DS	Morell river D/S of the N7 near Johnstown / Naas	*		
N 956 234	PA-US	U/S of N7 on the Painstown tributary at Boher-philip	*		
N 955 234	PA-DS	D/S of N7 on the Painstown tributary at Boher-philip	*		
N 933 361	RO-US	Rowanstown river, U/S of the bypass M4 near Maynooth	*		*
N 933 363	RO-DS	Rowanstown river, D/S of the bypass M4 near Maynooth	*		*

7.1.4 Data Analysis

Sorensen Coefficient of Similarity (S)

The Sorensen Coefficient of Similarity compares the number of species that are common to two communities. Values range from 0 i.e. no species in common, to 1, i.e. two communities have identical species composition. It does not take any account of species absent between communities. It is calculated using the following formula:

$$S = \frac{2c}{a+b} \tag{7.1}$$

where , a = number of taxa in community a; b = number of taxa in community b; c = number of taxa common to both communities.

Biotic Indices:The EPA Quality Rating System

The EPA Quality Rating system (Q-Values) was developed and is used by the EPA for the rapid assessment of water quality since 1971 (Forbartha, 1972). The Q-Rating system is a biological water quality classification, which relates the diversity and relative abundance of key groups of macroinvertebrate, viz Table 7.2 within the benthic community to five basic water quality classes - Q5 - good quality, Q4 - fair quality, Q3 - doubtful quality, Q2 - poor quality and Q1 - bad quality, Table 7.3. Intermediate ratings 1-2, 2-3, 3-4 and 4-5 are also used where appropriate (Tables 7.4 and 7.5. Sampling is generally carried out using a standard kick net for 2-5 minutes. Riffle areas are sampled in preference to other habitats as the resident communities are most sensitive to the effects of organic pollution (Lucey, 1991). The EPA river surveys and the Q-Rating system are adequate in providing a reliable indication of pollution status of a river but do not evaluate the community diversity.

Biotic Indices: BMWP & ASPT Biotic Scoring System

Macroinvertebrate data are summarized throughout the United Kingdom using the Biological Monitoring Working Party (BMWP) biotic score system. The biological quality is described using the number of BMWP scoring taxa present and the Average Score per Taxon (ASPT) which is derived from the community BMWP score divided by the number of scoring taxa represented, Table 7.6. The resulting ASPT value is between 1 and 10.

7.1.5 Independent T-Tests

The raw data were tested for normality and transformed were necessary. Independent t-tests were performed using SPSS version 11.01 to examine for any significant differences between the results recorded at the upstream and downstream sites.

Tools: TWINSPAN Classification

Two-Way Indicator Species Analysis (TWINSPAN), which is a polythetic divisive technique (Hill, 1979), was performed on transformed data. This clustering programme groups samples together in one cluster initially and then divides the samples into a hierarchical structure of smaller clusters according to their similarities. This was employed to examine whether the upstream and downstream sites would pull into separate groups on the dendrogram.

Tools: TWINDEND

TWINEND is a small MSDOS-based program designed specifically for testing the internal homogeneity of end groups. It measures dispersion (Legendre and Legendre, 1998) within end groups as a percentage of the total dispersion within the whole data set. If a group has a dispersion of 50% or more, it is usually considered to be adequately homogenous as an end group.

Table 7.2: EPA Q-Value System Macroinvertebrates grouped according to their sensitivity to organic pollution (After McGarrigle et al. (2002)

Taxa	Group A Sensitive	Group B Less Sensitive	Group C Tolerant	Group D Very Tolerant	Group E Most Tolerant
Plecoptera	All except Leuctra spp.	Leuctra spp.			
Ephemeroptera	Heptageniidae	Baetidae (excl. Baetis rhodani)	Baetis rhodani		
	Siphlonuriidae	Leptophlebidae	Caenidae		
	Ephemera danica		Ephemerellidae		
Trichoptera		Cased spp.	Uncased spp.		
Odonata		All taxa			
Megaloptera				Sialidae	
Hemiptera		Apheilecheirus aestilvalis	All except A. aestivalis		
Coleoptera			Coleoptera		
Diptera			Chironomidae (excl. Chironomus spp.)		Chironomus spp.
			Simuliidae		Eristalis sp.
			Tipulidae		
Hydracarina			Hydracarina		
Crustacea			Gammarus spp.	Asellus spp.	
			Austropotamobius pallipes	Crangonyx spp.	
Gastropoda			Gastropoda	Lymnaea peregra	
		(excl. Lymnaea peregra	Physa spp.)	Physa sp.	
Lamellibranchiata	Margaritifera margaritifera		Anodonta spp.	Sphaeriidae	
Hirudinea			Piscicola sp.	All except Piscicola sp.	
Oligochaeta					Tubificidae
Plathyhelminthes			All		

Table 7.3: Biotic Indices (Q Values) and typical associated macroinvertebrate community structure and abundance levels. (After McGarrigle et al. (2002))

Macroinvertebrate Faunal Group	Q5	Q4	Q3-4	Q3	Q2	Q1
Group A	At least 3 taxa well represented	At least 1 taxon in reasonable numbers	At least 1 taxon, Few - Common	Absent	Absent	Absent
Group B	Few to Numerous	Few to Numerous	Few/Absent to Numerous	Few/Absent	Absent	Absent
Group C	Few	Common to Numerous Baetis rhodani often abundant. Others never Excessive	Common to Excessive (usually Dominant to excessive)	Dominant to excessive	Few or Absent	Absent
Group D	Few or Absent	Few or Absent	Few/Absent to common	Few/Absent to common	Dominant to excessive	Few or Absent
Group E	Few or Absent	Few or Absent	Few or Absent	Few or Absent	Few / Absent to common	Dominant

Table 7.4: Abundance categories and relationship to percentage frequency of occurrence (After McGarrigle et al. (2002))

Abundance Category	Approx. Percentage Frequency of occurrence
absent	no specimens
Present	1 or 2 individuals
Scarce/few	$< 1\%$ of the total fauna
Small numbers	$< 5\%$ of the total fauna
Fair Numbers	5-10% of the total fauna
Common	10-20% of the total fauna
Numerous	25 -50% of the total fauna
Dominant	50 -75% of the total fauna
Excessive	$> 75\%$ of the total fauna

Table 7.5: Interpretation of quality ratings (After McGarrigle et al. (2002))

Quality ratings	Pollution status
Q5, Q4-5 and Q4	Unpolluted
Q3-4	Slightly polluted
Q3 and Q2-3	Moderately polluted
Q2, Q1-2 and Q1	Serious pollution

Table 7.6: The UK Biological Monitoring Working Party (BMWP) biotic score system

FAMILIES	SCORE
Siphlonuridae Heptagenidae Leptophlebiidae Ephemerellidae Potamanthidae Ephemeridae Taeniopterygidae Leuctridae Capniidae Perlidae Chloroperlidae Aphelocheiridae Phryganeidae Molannidae Beraeidae Odontoceridae Leptoceridae Goeridae Lepidostomatidae Brachycentridae Sericostomatidae	10
Astacidae Lestidae Agriidae Gomphidae Cordulegasteridae Aeshnidae Corduliidae Libellulidae Psychomyiidae Philopotamidae	8
Caenidae Nemouridae Rhyacophilidae Polycentropodidae Limnephilidae	7
Neritidae Viviparidae Ancylidae Hydroptilidae Unionidae Corophidae Gammaridae Platycnemididae Coenagriidae	6
Mesovelidae Hydrometridae Gerridae Nepidae Naucoridae Notonectidae Pleidae Corixidae Haliplidae Hygrobiidae Dytiscidae Gyrinidae Hydrophilidae Clambidae Helodidae Dryopidae Elminthidae Chrysomelidae Curculionidae Hydropsychidae Tipulidae Simuliidae Planariidae Dendrocoelidae	5
Baetidae Sialidae Piscicolidae	4
Valvatidae Hydrobiidae Lymnaeidae Physidae Planorbidae Sphaeriidae Glossiphoniidae Hirudidae Erpobdellidae Asellidae	3
Chironomidae	2
Oligochaeta (Whole Class)	1

Table 7.7: Sorensen Similarity Index comparisons between the upstream and downstream sites.

Sites compared	year	Index value
GD-US + GS-DS	2005	0.76
GV-US + GV-DS	2005	0.85
OW-US + OW-DS	2002	0.67
OW-US + OW-DS	2005	0.81
PP-US + PP-DS	2002	0.68
CR-US + CR-DS	2005	0.80
DF-US + DF-DS	2005	0.75
SP-US + SP-DS	2005	0.68
HW-US + HW-DS	2002	0.78
HW-US + HW-DS	2005	0.76
SL-US + SL-DS	2002	0.68
SL-US + SL-DS	2005	0.76
WH-US + WH-DS	2003	0.75
WH-US + WH-DS	2005	0.68
LY-US1A + LY-DS1A	2002	0.72
LY-US2S + LY-DS2S	2002	0.73
LY-US3S + LY-DS3S	2003	0.69
LY-US + LY-DS	2005	0.84
MO-US + MO-DS	2002	0.61
PA-US + PA-DS	2002	0.54
RO-US + RO-DS	2002	0.82
RO-US + RO-DS	2005	0.60

7.1.6 Biological Results

Taxonomic Composition: Number of Individuals

The mean number of individuals per sample at a site ranged from 169 (PA-DS02) to 2536 (LY-US202), Figure 7.1. Independent t-tests, comparing the number of individuals per sample at the upstream and downstream sections of each stream, demonstrated that there were no significant differences between the two stretches (stats P¿0.05).

Taxonomic Composition: Number of Taxa

The mean number of taxa at a site ranged from 14 (SL-US05) to 47 (OW-US02), Figure 7.2. Only 8 of the streams compared had higher mean taxon richness at the upstream site (GV-US05 & GV-DS05, OW-US02 & OW-DS02, CR-US05 & CR-DS05, DF-US05 & DF-DS05, HW-US05 & HW-DS05, WH-US05 & WH-DS05, LY-US303 & LY-DS303 and LY-US202 & LY-DS02). Independent t-tests demonstrated that there were no significant differences in taxon richness between upstream and downstream sites except for one occasion on the Lyreen river in summer 2002 (LY-US2S02 & LY-DS2S02, ($P<0.05$)).

The Sorensen Similarity index was also employed to compare the differences between the taxa assemblages recorded at the upstream and downstream sections of the streams, Table 7.7. The Sorensen Index compares the number of species that are common to two communities. The calculated index values ranged from 0.54 (PA-US02 & PA-DS02) to 0.85 (GV-US05 & GV-DS05) indicating a high degree of similarity between the sites upstream and downstream of the roadway examined.

A brief examination of the percentage abundance of the major macroinvertebrate taxonomic groups present demonstrated that the abundance of some groups differed between the upstream and downstream sites. The majority of sites however did not differ in the occurrences of these groups, Figure 7.3.

It should be noted however that the % abundance of the Ephemeroptera varied between sites. Lower ephemeropteran abundances were apparent at the Ronanstown and Lyreen sites in particular while the order Plecoptera was not widely represented at many sites. The Order Diptera was present at all sites,

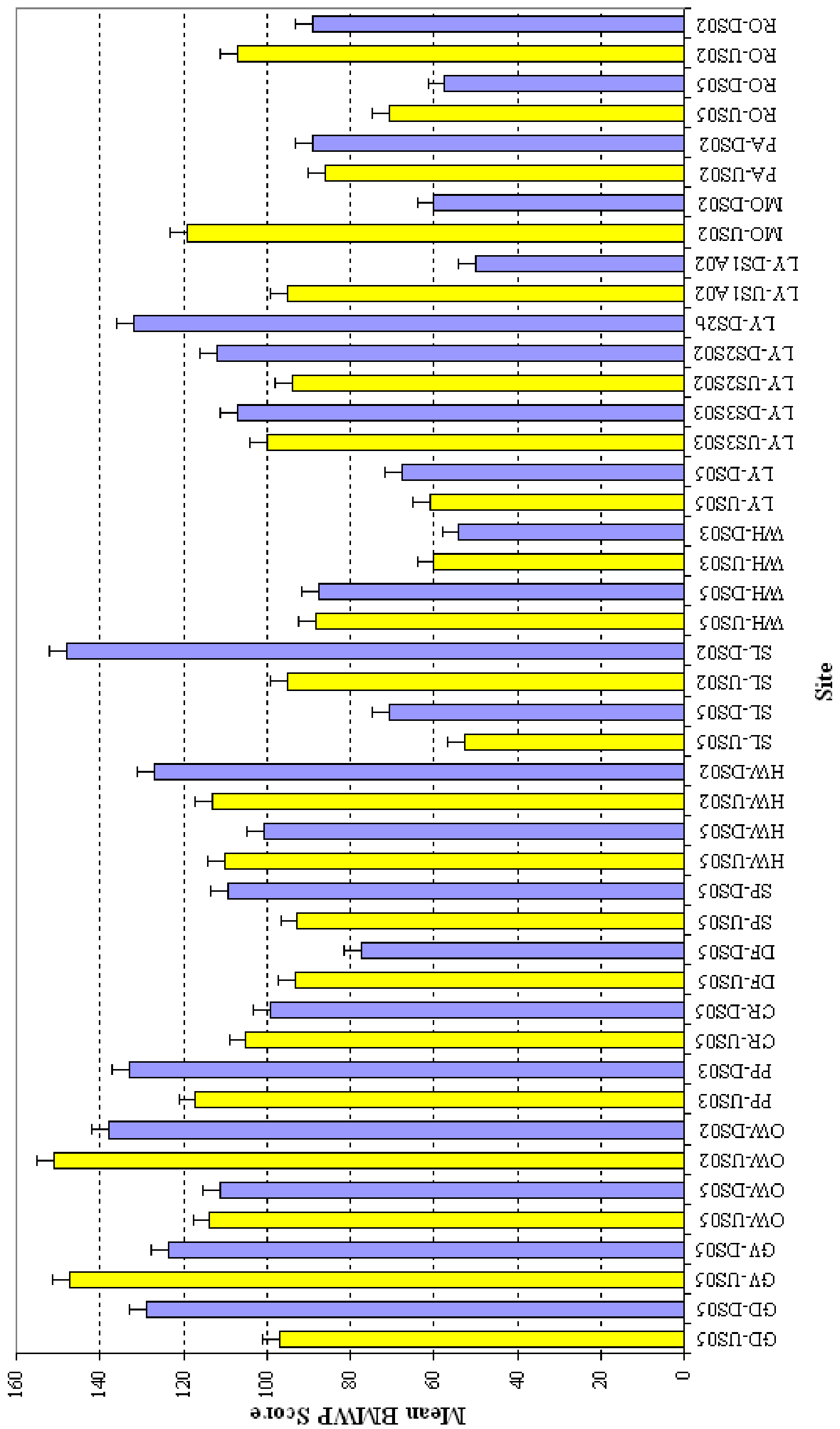


Figure 7.1: Mean number of Individuals at each site upstream (yellow) and downstream (blue) with standard error bars.

Figure 7.3 with larger % abundances present at several sites of lower quality (Whitestown, Ronanstown, Lyreen, see later section).

Quality Indices

To further investigate whether the macroinvertebrate fauna are affected by the road runoff, water quality indices were assigned to both of the sites located upstream and downstream of the roads examined.

EPA Q-value system The EPA Q-value system was applied to each site on all sampling occasions.

Class A and Class B include the most pollution sensitive taxa therefore if absent the site would normally be considered to be impacted, Table7.2. The % abundance of class A taxa ranged from 0 (Lyreen, Ronanstown, Painstown, Morrell and Slane) to 29% at the downstream Glenview site (GV-DS05) Table 7.8. The majority of sites had less than 10% Class A taxa present. The Class B taxa ranged from <1% to 29% (GD-DS05) with the majority of sites having at least 2% of Class B taxa present.

The assigned Q-values ranged from Q5 (Glenview, Glen O 'Downs, Owendoher and Doonfin streams) indicating unpolluted conditions to Q2 (Ronanstown, downstream site) highlighting serious pollution (Table 8). There were no major differences in quality according to the EPA Q-value rating system between the upstream and downstream sections of each stream. Only one site scored slightly higher (GV-DS05) in the downstream section and this was probably due to differences in habitat availability. Three streams Whites, Ronanstown and Morrell scored slightly lower in their downstream sections when compared to their upstream counterpart. They however did not differ in their overall quality classification (Table 8).

In comparing the Q-value ratings between the years, three streams including the Owendoher, Hartwell and to a lesser extent Whites river all improved in their Q-value rating (Table 8). The Ronanstown downstream site also improved slightly from serious to moderate pollution status while the Slane tributary decreased from a classification of slight (2002) to moderately polluted in 2005.

BMWP Scores The total BMWP scores ranged from 54 (WH-DS03) to greater than 160 (GV-US05, GV-DS05 & SP-DS05) Tables 7.8 and 7.9. The majority of sites had at least a total BMWP score of 100. The mean BMWP scores ranged from 40 (WH-DS02) to 148 (GV-US05), Figure 7.4. Nine of the streams compared had higher BMWP scores in their upstream sections compared to their downstream section. Independent T-tests however demonstrated that none was significantly different (P¿0.05). Three streams including the Glen O'Downs, Hartwell in 2002 and Slane 2002, which scored higher BMWP scores in their downstream sections were shown to be significantly different ($P<0.05$) when compared to the corresponding upstream section.

ASPT Scores The total ASPT scores ranged from 4.44 (RO-DS05) to greater than 7 (OW-US05, OW-DS05) , Tables 7.8 and 7.9. The mean ASPT scores ranged from 4.10 (RO-DS05) to greater than 7 (GD-DS05, OW-US05), Figure 7.5. The majority of sites had an ASPT score greater than 5.5. Differences were evident between some of the streams upstream and downstream sites however only four of them demonstrated significant differences when compared using an independent T-test (GD-US05 & GD-DS05, PP-US02 & PP-DS02 where the upstream site scored lower and RO-US05 & RO-DS05 and PA-US02 & PaDS02 where the downstream section scored lower).

% EPT and EPT taxa numbers The % EPT values were calculated for all stream sections. The total % EPT ranged from 3% in the Ronanstown downstream site and the Lyreen stream in 2005 to greater than 70% in the Owendoher river (OW-US02 & OW-US05) and Hartwell upstream site in 2002, Tables 7.8 and 7.9. The mean % EPT abundances also ranged from a low 3% (RO-DS05 & LY-DS05) up to 76% at the upstream Owendoher (OW-US05) and Hartwell (HW-US02) sites, Figure 7.6. The majority of streams did not differ significantly when the upstream percentage abundance was compared to the downstream results. Higher % EPT values were seen at 13 of the upstream sites when compared to their lower sections. Independent t-tests carried out on the ranges observed at both stretches of

Table 7.8: EPA Q - Rating, % abundance within each of the EPA Q-value quality classes and the number of taxa classified as class A, part 1

Site	Class A %	Class B %	Class C %	Class D %	Class E %	No. Class A Taxa (Species)	No. Class A Taxa (Genus)	Q-Value	% EPT	No. EPT taxa	BMWP Total	ASPT Total
GD-US05	5.24	6.00	87.32	0.00	0.00	3	3	Q4-5	48.19	18	128	6.40
GD-DS05	6.60	29.14	63.49	0.00	0.00	6	6	Q5	48.21	23	149	6.48
GV-US05	20.22	11.74	65.96	0.36	0.00	6	6	Q5	63.92	26	166	6.92
GV-DS05	28.85	11.76	54.14	0.54	0.76	7	7	Q5	63.88	28	164	6.56
OW-US05	28.00	8.04	63.85	0.10	0.00	10	10	Q5	76.27	22	136	7.16
OW-DS05	25.79	2.02	71.70	0.00	0.00	8	8	Q5	69.39	21	151	7.19
OW-US02	3.54	1.42	94.47	0.06	0.00	3	3	Q4-5	73.83	21	146	6.08
OW-DS02	1.91	1.46	95.70	0.11	0.01	4	4	Q4-5	65.46	23	138	6.27
PP-US02	0.92	1.12	97.96	0.00	0.00	3	3	Q4-5	54.29	11	117	6.16
PP-DS02	0.81	3.13	95.83	0.00	0.00	3	3	Q4-5	66.55	15	133	6.65
CR-US05	1.61	3.62	94.16	0.18	0.00	4	4	Q4-5	29.88	19	124	5.90
CR-DS05	0.91	6.02	91.55	0.06	0.00	3	3	Q4-5	23.66	20	112	5.60
DF-US05	18.12	7.66	73.74	0.00	0.00	7	7	Q5	45.35	17	124	6.89
DF-DS05	8.05	7.33	83.90	0.10	0.00	4	4	Q5	29.21	12	103	6.44
SP-US05	0.58	2.46	96.86	0.10	0.00	2	2	Q4	4.13	18	140	6.67
SP-DS05	0.43	7.66	90.45	0.23	0.00	2	2	Q4	9.35	21	167	6.68
HW-US05	6.74	11.06	77.42	0.92	1.03	5	5	Q4-5	39.61	24	138	5.75
HW-DS05	9.44	7.85	79.77	0.23	0.00	5	5	Q4-5	61.37	14	118	5.36
HW-US02	1.79	1.73	96.23	0.06	0.12	3	3	Q3-4	76.41	15	110	5.79
HW-DS02	0.69	2.84	95.81	0.40	0.13	3	3	Q3-4	62.91	16	127	5.52
SL-US05	0.00	2.31	94.64	1.36	0.07	0	0	Q2-3	10.79	9	73	4.87
SL-DS05	0.00	4.26	94.15	0.66	0.00	0	0	Q2-3	30.19	12	91	5.35
SL-US02	0.20	1.24	98.15	0.00	0.40	2	2	Q3-4	67.18	11	100	6.25
SL-DS02	0.31	0.56	98.94	0.06	0.06	4	4	Q3-4	32.87	18	148	5.92

Table 7.9: EPA Q - Rating, % abundance within each of the EPA Q-value quality classes and the number of taxa classified as class A, part 2

Site/ year	Class A %	Class B %	Class C %	Class D %	Class E %	No. Class A Taxa (Species)	No. Class A Taxa (Genus)	Q-Value	% EPT	No. EPT taxa	BMWP Total	ASPT Total
WH-US05	3.93	13.80	72.98	1.43	3.36	5	5	Q4	36.36	17	118	5.36
WH-DS05	0.68	7.12	87.18	0.80	0.43	1	1	Q3-4	30.65	16	132	5.74
WH-US03	0.07	1.59	92.25	4.35	1.59	1	1	Q3-4	12.97	5	60	4.62
WH-DS03	0.42	2.44	88.46	3.37	3.12	2	2	Q3-4	9.52	7	54	4.50
LY-US05	0.00	2.46	77.35	16.72	2.46	0	0	Q3	3.34	6	74	4.63
LY-DS05	0.00	2.04	82.16	11.98	3.50	0	0	Q3	2.86	9	100	4.76
LY-US3S03	0.00	5.50	69.10	18.84	5.69	0	0	Q3	45.84	18	104	5.20
LY-DS3S03	0.00	1.84	81.26	14.73	1.30	0	0	Q3	59.70	10	100	5.00
LY-US1A03	0.00	0.57	82.39	16.63	0.40	0	0	Q3	8.43	15	98	5.16
LY-DS1A03	0.00	1.02	79.90	18.40	0.32	0	0	Q3	30.43	10	116	5.27
LY-US2S02	0.08	3.19	80.73	13.09	1.68	1	1	Q3	40.35	17	125	5.68
LY-DS2S02	0.00	1.73	86.73	10.72	0.00	0	0	Q3	37.30	11	94	5.22
LY-DSb	0.00	0.68	79.05	14.19	2.03	0	0	Q3	14.86			
RO-US05	0.00	7.28	24.51	67.02	0.10	0	0	Q2-3	8.21	7	82	4.82
RO-DS05	0.04	3.05	26.69	62.77	0.00	1	1	Q2-3	3.21	10	80	4.44
RO-US02	0.00	6.33	58.56	34.25	0.52	0	0	Q2-3	8.77	9	99	5.21
RO-DS02	0.00	0.81	16.39	78.68	3.64	0	0	Q2	4.88	5	89	4.68
PA-US02	0.00	1.46	97.91	0.55	0.00	0	0	Q3	4.28	11	86	5.38
PA-DS02	0.00	1.98	92.89	3.95	0.59	0	0	Q3	22.53	6	86	4.78
MO-US02	0.62	3.92	93.09	0.52	1.44	1	3	Q3-4	64.50	15	113	6.28
MO-DS02	0.00	2.10	91.43	1.65	4.66	0	0	Q3	57.20	7	60	5.45

each river demonstrated that only two of these streams (Doonfin - DF-US05 & DF-DS05 and the Slane tributary -SL-US02 & SL-DS02) differed significantly in % EPT abundance between the upstream and downstream sections examined. The Hartwell upstream site (HW-US05) also differed significantly with its corresponding downstream site (HW-DS05) exhibiting a higher % EPT abundance.

The total number of EPT taxa ranged from 5 (WH-US03 & RO-DS02) to 28 (GV-DS05), Tables 7.8 and 7.9. The mean number of EPT taxa ranged from 3 (RO-DS02) to 21 (GV-US05), Figure 7.7. Independent T tests demonstated that there was no significant differences between the upstream and downstream sections of any of the streams examined.

TWINSPAN Classification TWINSPAN analysis is a clustering technique which groups sites with similar species composition together. TWINSPAN was performed on the combined dataset consisting of a total of 43 sample points representing 28 sites. The 43 samples initially divided into two clusters consisting of 28 and 15 samples respectively due to the presence of the water louse Asellus aquaticus in the group of 15 and the more sensitive mayfly Rhitrogena semicolorata in the group of 28 samples, Figure 7.8. In the second division, TWINSPAN groups both the upstream and downstream Glenview and Glen O' Down sites together. The low TWINDEND % dispersion value indicating that the sites are similar in species abundance and composition. TWINSPAN continued to divide the sites into groups of similar species composition with the majority of the higher quality sites clustering together on the left side of the dendrogram (Figure 8). TWINSPAN successfully divided the samples into two general groups of seriously and moderately polluted sites and unpolluted sites. It also showed that the upstream and downstream sites for the majority of the streams examined had similar species composition.

7.1.7 Conclusions

In examining the taxa numbers, numbers of individuals, percentage abundance of the major taxonomic groups and the biotic indices including the EPA Q-value rating, BMWP and ASPT scores and the % EPT and EPT taxa numbers, there was no evidence to support the argument that road runoff drainage was negatively impacting on the macroinvertebrate communities in the downstream sections of the streams examined. All of the potential sites on the Eastern side of Ireland were already impacted upstream due possibly to diffuse sources. Consequently, in 2005, although difficult to locate, it was decided to visit additional sites of better quality. These streams including the Glenview, Glen O' Downs, Carrowree, Doonfin and the Spaddagh demonstrated unpolluted conditions both upstream and downstream of their respective roadways. Any observable differences highlighted e.g. at Glen O' Downs stream was probably due to physical differences in the available habitat and substrate structure between the upstream and downstream sections.

A TWINSPAN clustering technique was also applied to the data in order to highlight the groups of sites with similar species composition. TWINSPAN grouped the majority of the streams upstream and corresponding downstream sites together and the overall low % heterogeneity results demonstrated that the sites did not differ significantly in species composition and abundance. Therefore no adverse effects from road drainage could be discerned from the macroinvertebrate fauna.

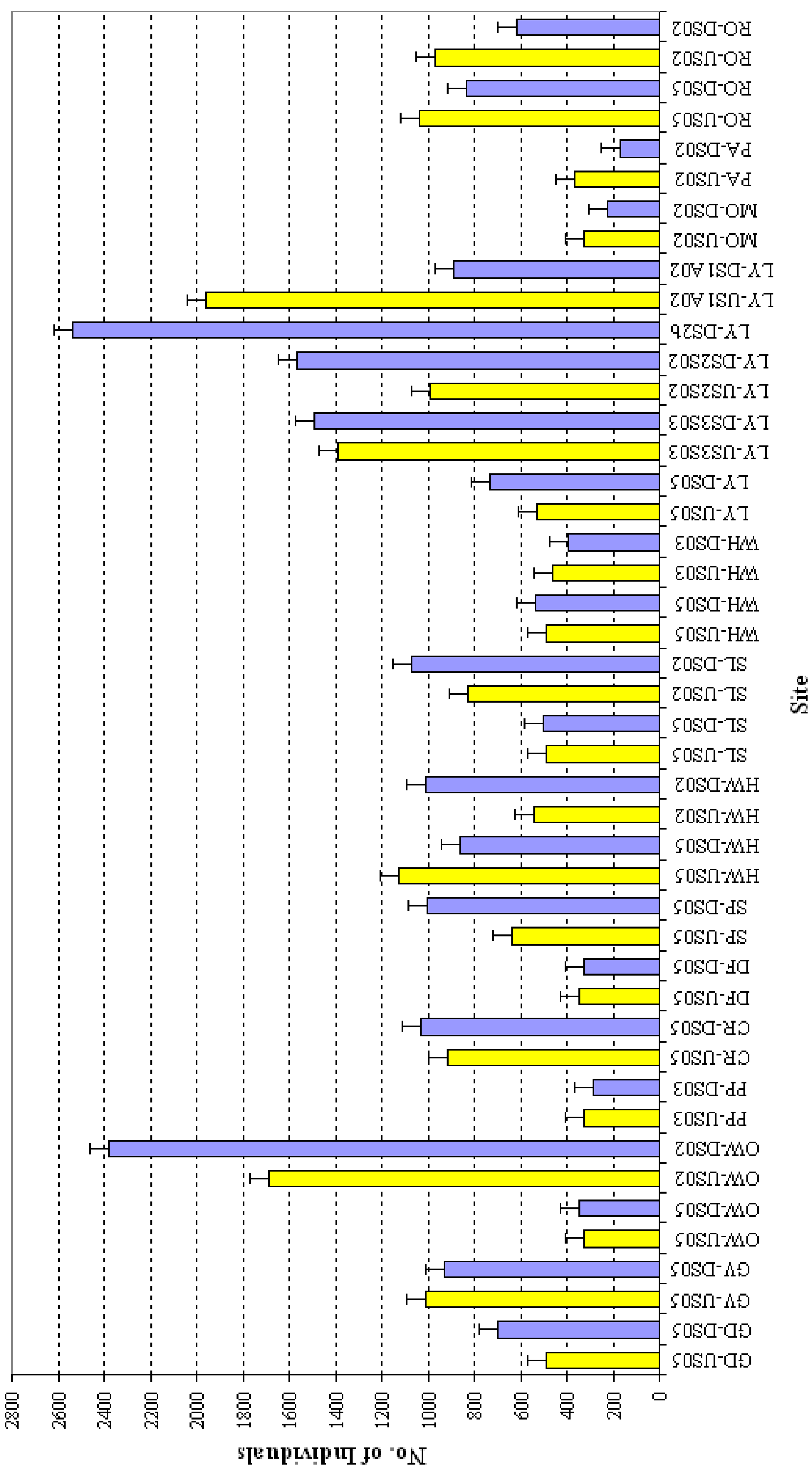


Figure 7.2: Mean number of Taxa at each site upstream (yellow) and downstream (blue) with standard error bars.

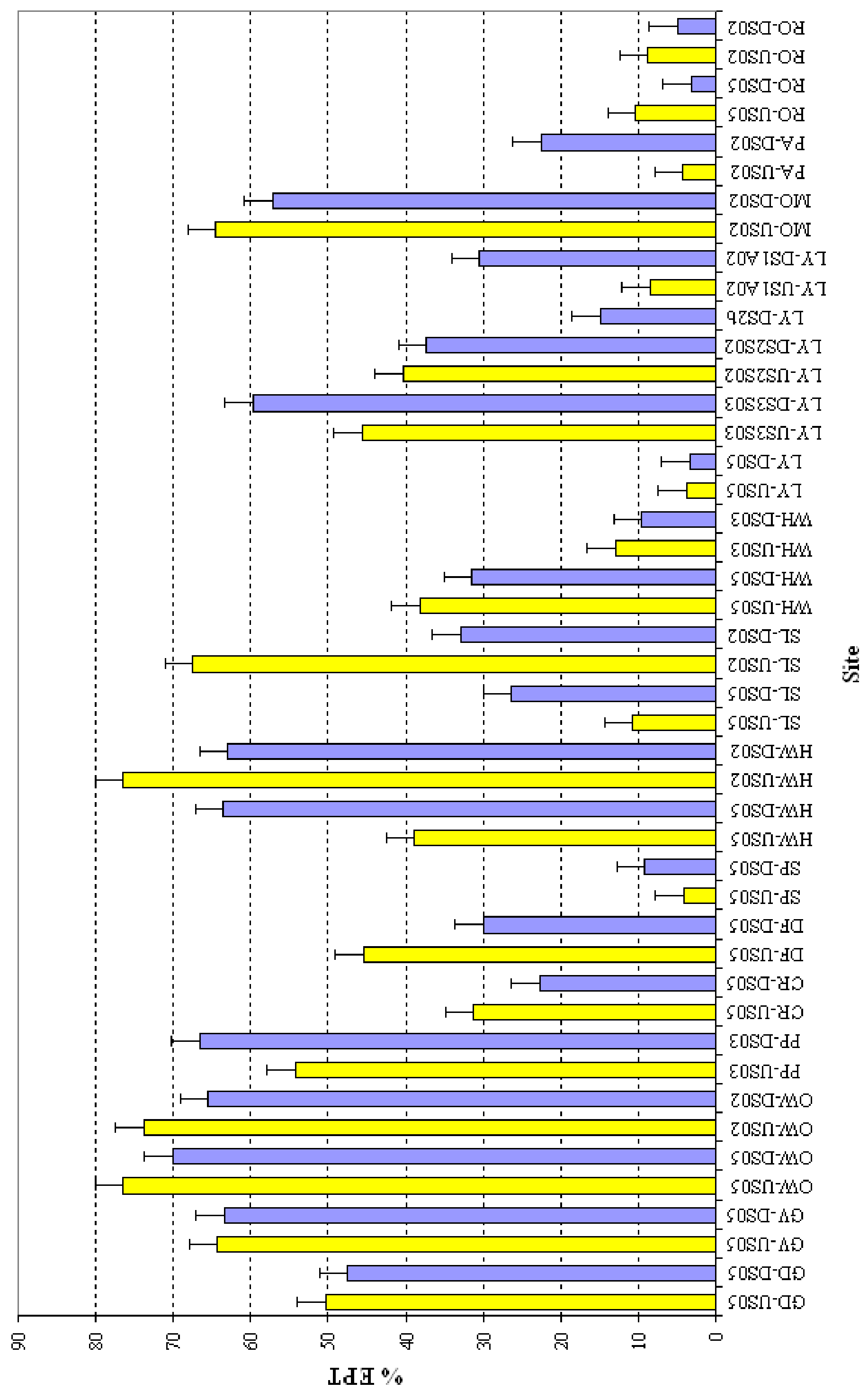


Figure 7.3: % macroinvertebrate abundance of the major taxonomic groups present at each site on each sampling occasion.

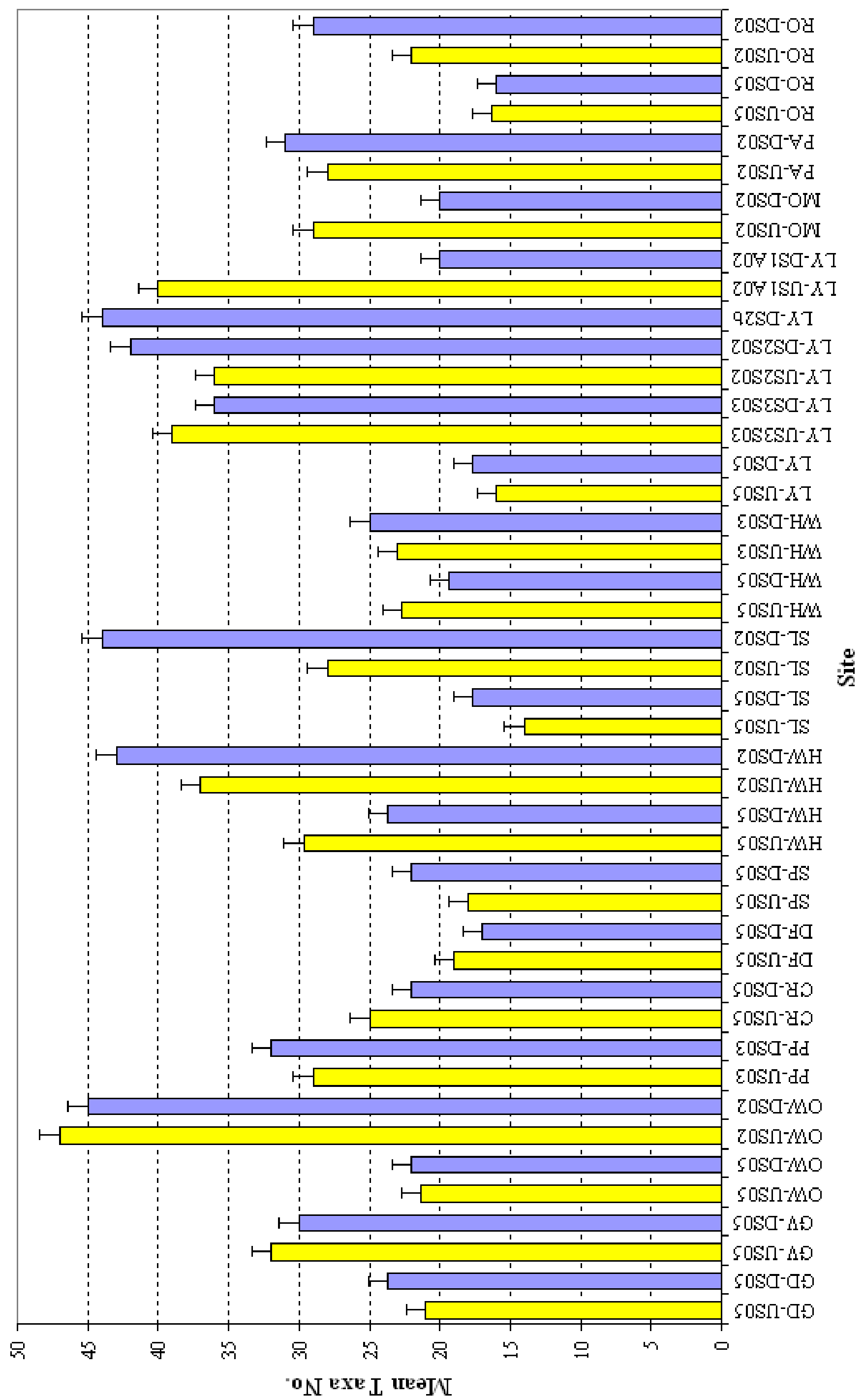


Figure 7.4: Mean BMWP scores with error bars for each site.

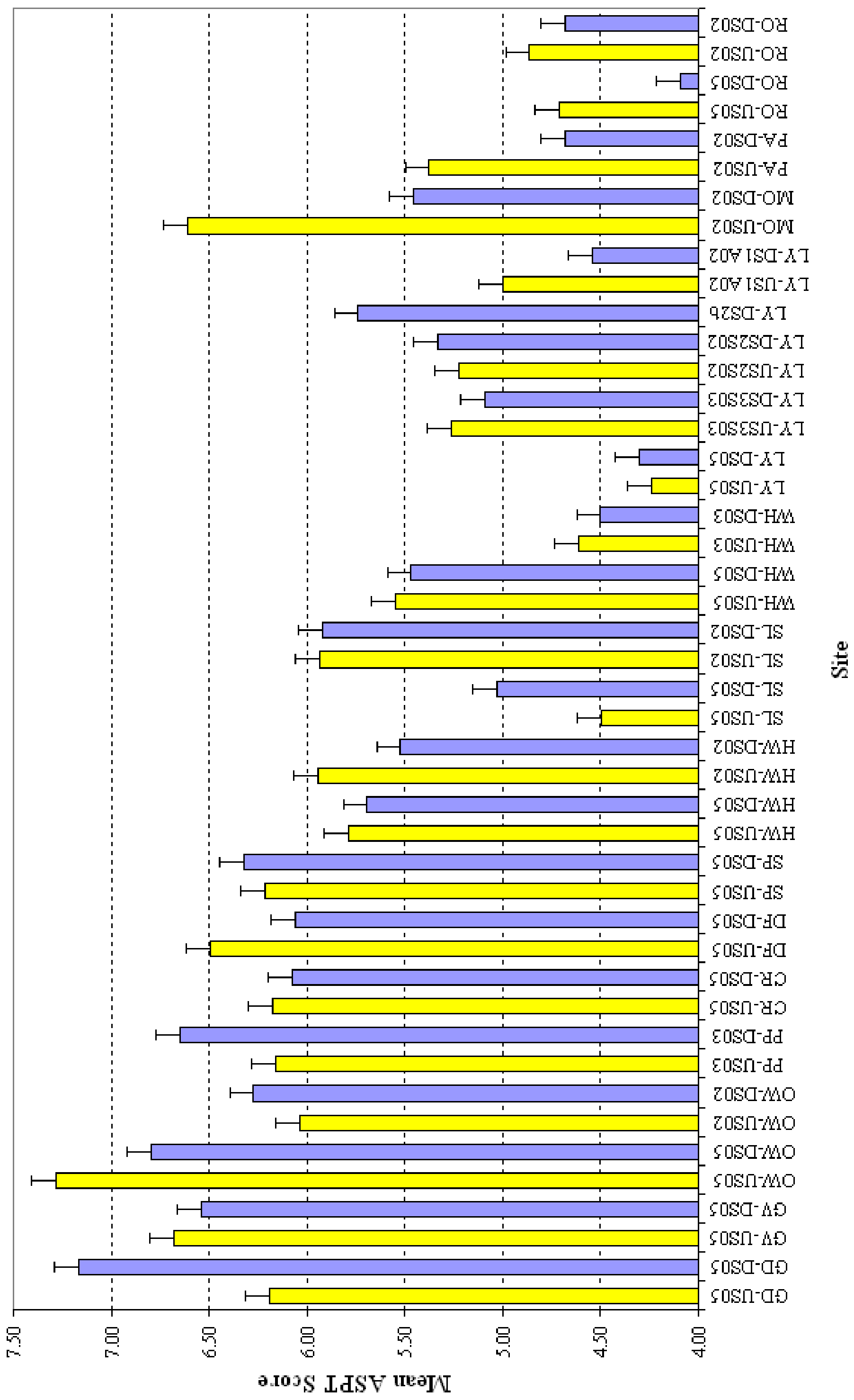


Figure 7.5: Mean ASPT scores with error bars at each site.

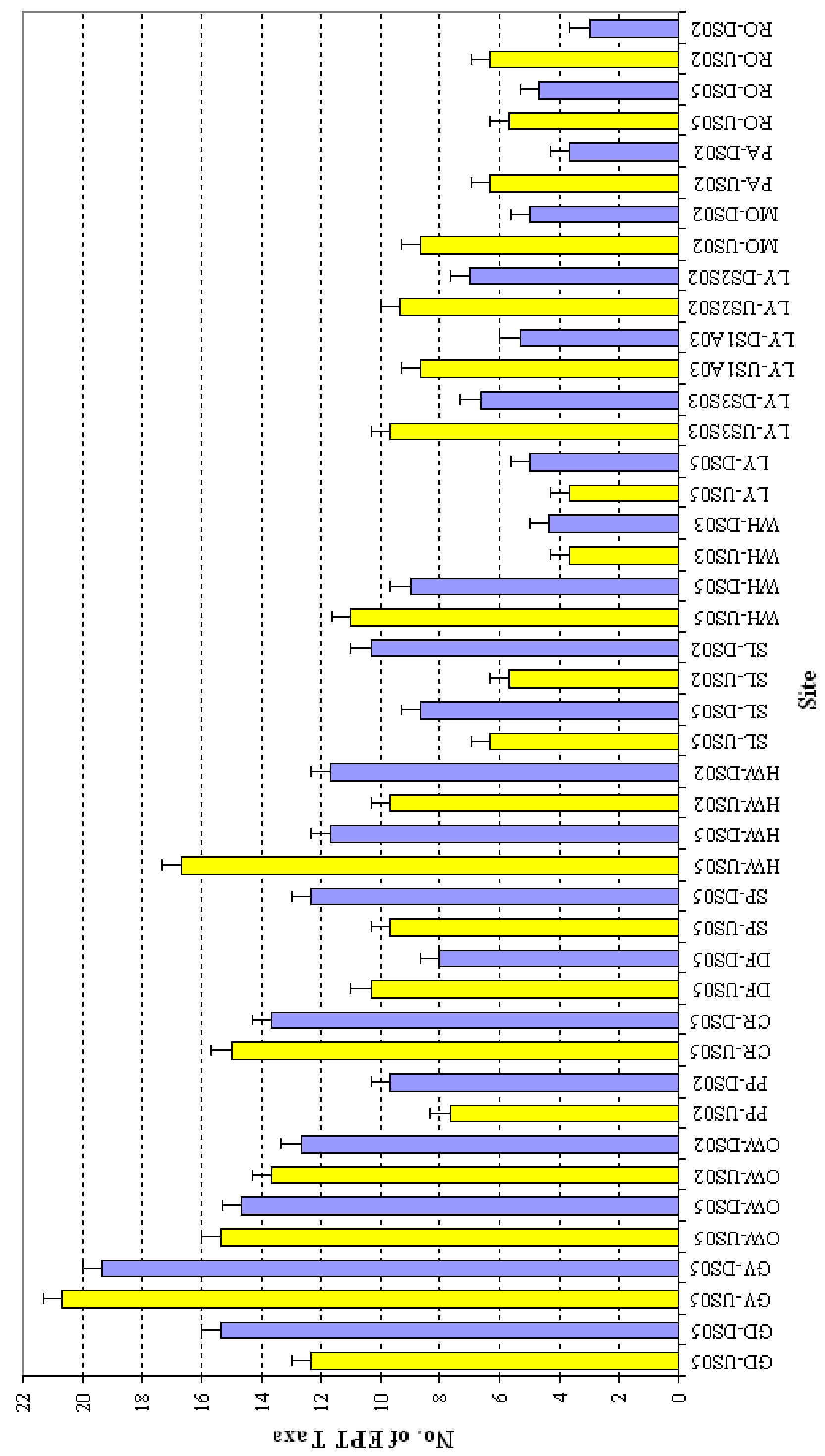


Figure 7.6: Mean % EPT abundance present at each site.

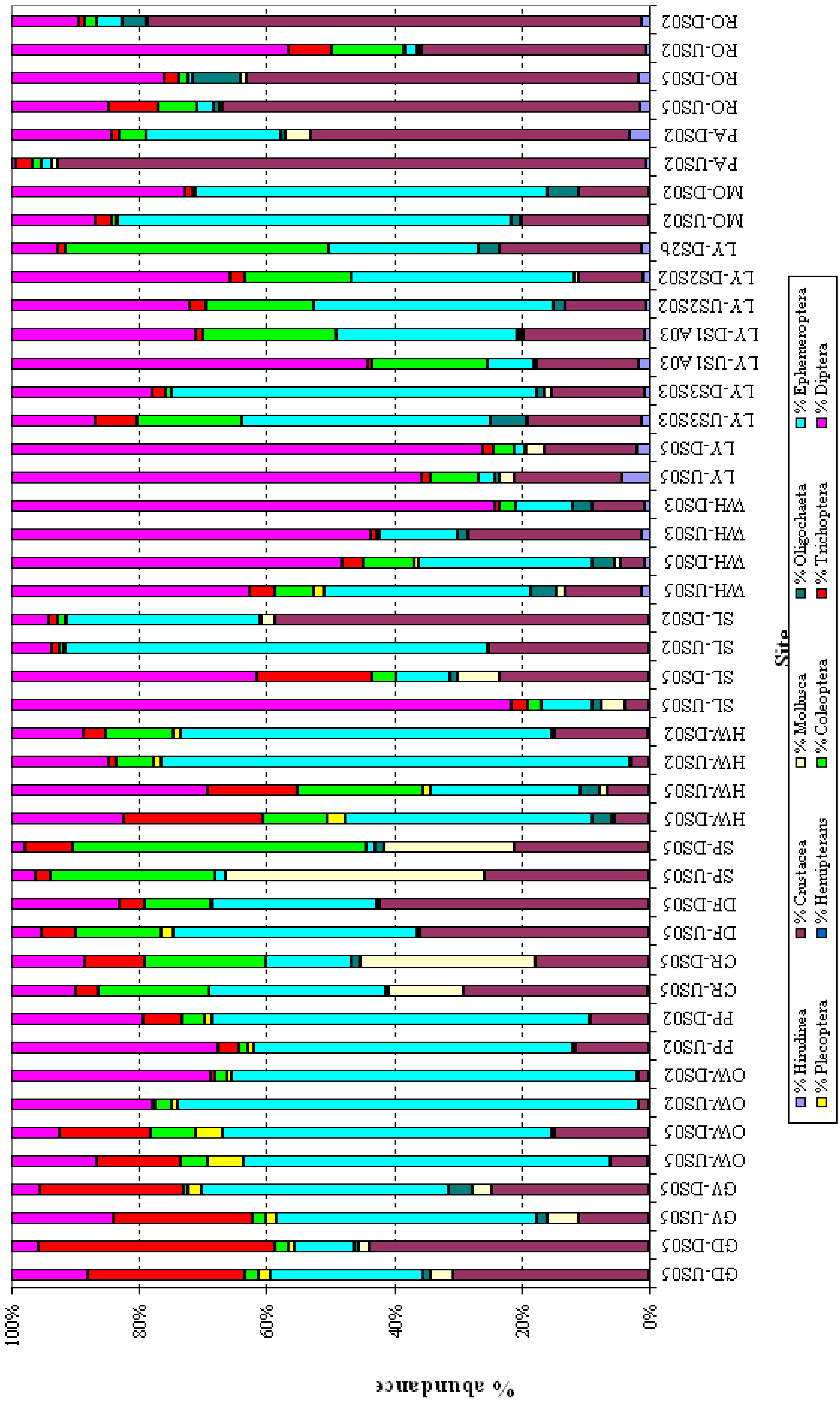


Figure 7.7: Mean EPT taxa numbers recorded at each site.

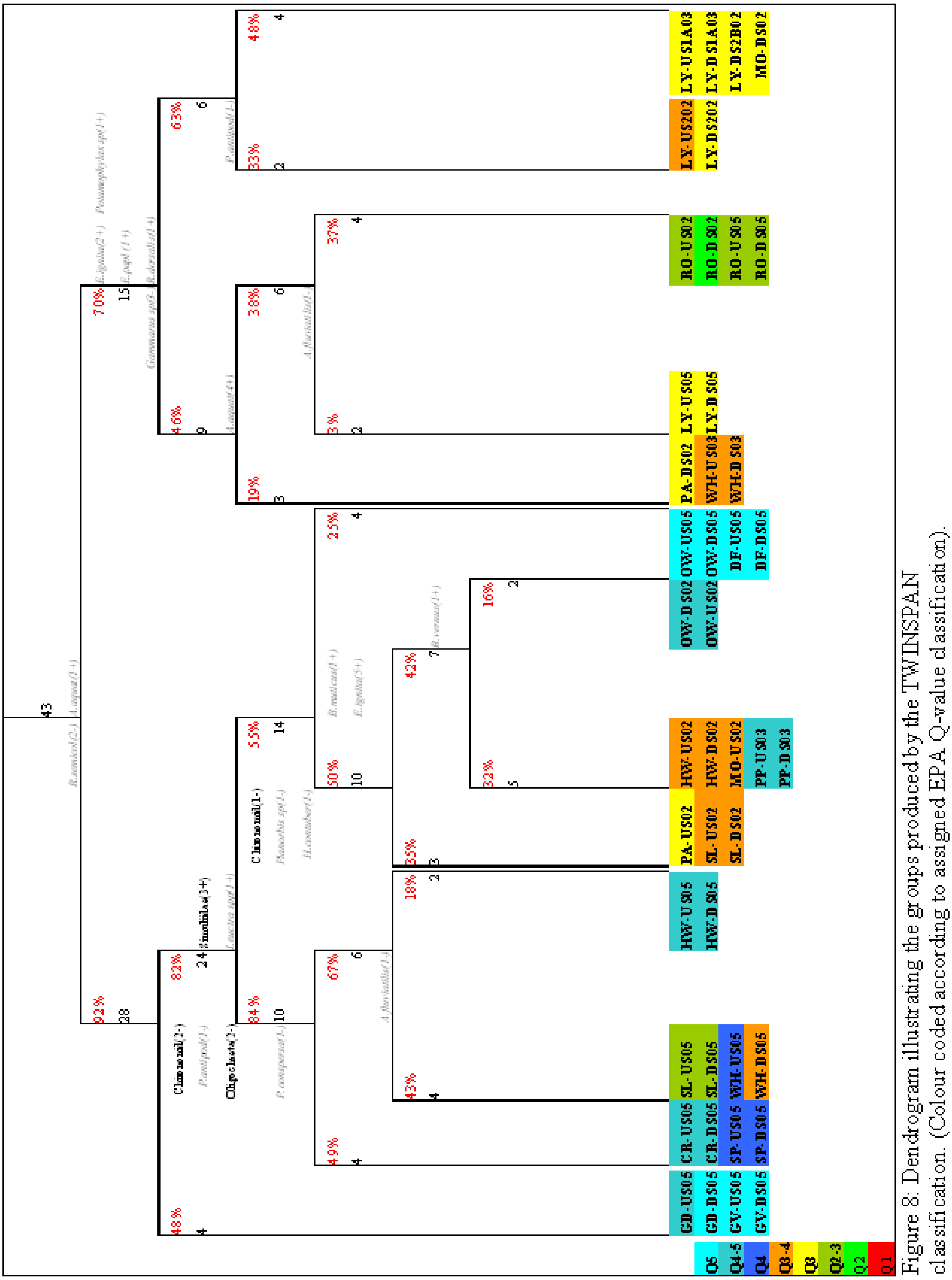


Figure 7.8: Dendrogram illustrating the groups produced by the TWINSPAN classification. *(Colour coded according to assigned EPA Q-value classification).*

7.2 Fish Studies

7.2.1 Methodology

Electrofishing was conducted at all sites during the autumn of 2003. Sections upstream and downstream of road runoff outlets were fished separately. The sections ranged in length from 26 to 120m. Each section was enclosed, using stop nets, to prevent fish from leaving the area being fished, a critical factor in the population estimation procedure. The removal or depletion method, using two successive catches, was used to quantify the population of salmonids present. A visual estimate was made on the relative abundance of the size classes of other species.

On completion of the electrofishing, all salmonids were measured (fork length) and weighed. A small sample of scales was removed from all salmonids over 9cm in length and retained for age analysis. After handling, the fish were held in keep-nets to ensure their complete recovery before being returned to the river.

In the laboratory the scales were viewed on a Microfiche viewer to determine the age of the fish. This was achieved by counting the number of annuli present. An annulus is defined as a distinct aggregation of circuli, the outer edge of which corresponds to one year's growth. Back-calculations of growth were also made using standard procedures (Bagenal and Tesch, 1978) and involved taking the following scale measurements:

RC distance from the centre of the scale to the outermost part (width)

R1 distance to the end of the first winter growth ring

R2 distance to the end of the second winter growth ring

Condition factor, which relates weight to length, was used to evaluate the 'plumpness' or 'well being' of the fish (Bagenal and Tesch, 1978). Fulton's condition factor (weight x 100/length^3) was calculated for each salmonid age group.

7.2.2 Population Size and Density

The estimate of the population size of salmonids was derived using the two-catch depletion model (Seber and LeCren, 1967). The successive removal methods are based on the principle that a known number of fish are removed from the river in a series of successive catches. The number of fish in each catch should fall. The rate of fall off is related to the size of the population (unknown) and the number removed (known). The removal method may be based on two or more catches and is subject to a number of assumptions:

- No emigration or immigration should occur during the sampling period
- Individual fish must have equal probabilities of being caught during successive fishings
- All members of the population must be equally vulnerable to the gear
- A significant proportion of the population must be removed during each fishing.

The population size (N_0) is calculated as follows:

$$N_0 = \frac{c_1^2}{(c_1 - c_2)^2} \tag{7.2}$$

where, c_1 is the number of fish in the 1st catch and c_2 is the number in the 2nd catch (Seber and LeCren, 1967).

Table 7.10: Catches of brown trout and stickleback

Site	code	Brown Trout (Salmo trutta L.)	Stickleback (Gasterosteus aculeatus L.)
Slane-US	SL-US	35	200-400
Slane-DS	SL-DS	8	15
Painestown-US	PA-US	0	50-100
Painestwon-DS	PA-DS	0	50-100
	HW-US	18	0
	HW-DS	58	0
Morell-US	MO-US	25	30
Morell-DS	MO-DS	40	100-200
Rowanstown-US	RO-US	0	30
Rowanstown-DS	RO-DS	0	50-100
Owendoher-US	OW-US	21	0
Owendoher-DS	OW-DS	12	0
Whites River-US	WH-US	0	5
Whites River-DS	WH-DS	23	0
	PP-US	18	0
	PP-DS	12	0
Lyreen-US	8	50	
Lyreen-DS	0	30	

7.2.3 Results and Analysis

Fish Catches

Brown trout (Salmo trutta L.) was the only salmonid encountered and it was present in all but six sites across four rivers, Table 7.10

There were no trout at the Painestown, Rowanstown Rivers, the Lyreen downstream (LY-DS) and Whites upstream (WH-US) sites. Estimates of the relative abundance of sticklebacks (Gasterosteus aculeatus L.) were made and they were placed in size classes ranging from 3-5cm. The largest catches of stickleback were in the Slane (upstream), Painestown, Morell (downstream) and Rowanstown (downstream).

Age and Growth

Observed and back-calculated lengths for brown trout are presented in Table 7.11. Four age classes (1+ to 4+) of trout were present. The mean observed lengths for 1+ fish were slightly higher, overall, upstream when compared with downstream, varying from 11.0 cm upstream to 10.5 cm downstream and there was a much greater range of lengths of 1+ trout upstream, with sizes ranging from 9.00 to 18.8 cm. The mean length at the end of year one ranged from 6.9cm upstream to 7.5cm downstream.

The mean lengths of 2+ fish were equally variable ranging from 14.8 upstream to 15.5 cm downstream. This is fairly typical of juvenile trout. These lengths were seen to vary little between upstream and downstream. Overall there were minor, but insignificant (ANOVA, $P>0.05$) differences in growth between upstream and downstream locations. There were no 3+ or 4+ fish at the upstream sites. There were five 3+ found at MO-DS, and one 4+ fish and they reached reasonable sizes for their age.

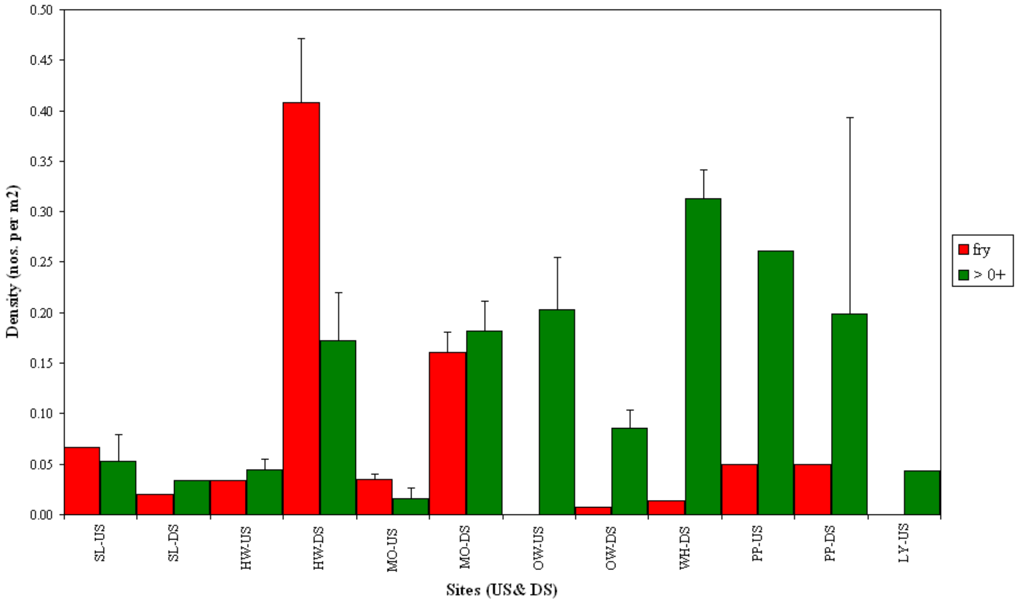
Population Densities

There was no consistent pattern with regards to upstream and downstream differences in trout population density. Total trout densities are given in Table 7.12 and Figure 7.9 illustrates the densities of the fry and >0+ trout. The highest total density figure was 0.6 fish/m2 at the downstream section

Table 7.11: Observed and back-calculated lengths of Salmo trutta L.

Age	Observed length (cm) (mean and ranges)	n		Back calculated length (cm) (mean and ranges)	n
Upstream Sites					
1+	11.0 (9.0-18.8)	69	L1	6.9 (3.2-10.2)	79
2+	14.8 (12.8-20.2)	10	L2	12.6 (8.6-16.3)	10
Downstream Sites					
1+	10.5 (9.1-14.5)	59	L1	7.4 (6.5-8.0)	80
2+	15.5 (12.5-20.3)	15	L2	11.8 (8.9-18.7)	21
3+	20.2 (17.4-25.2)	5	L3	18.9 (15.9-26.2)	6
4+	31.5	1	L4	28.3	1

Figure 7.9: Brown trout (Salmo trutta L.) densities at sites fished (error bars =95% confidence limits)



of the Hartwell. Two other sites (MO-DS and WH-DS) had reasonable densities circa 0.3 fish/m2. The control sites on the Poulaphuca and the Owendoher (upstream) were circa 0.2 fish/m2, all other upstream sites had extremely poor densities values below 0.1 fish/m2.

Fry densities ranged from 0.01 fish/m^2 at Owendoher (OW-DS) and Lyreen (LY-US) to 0.4 fish/m^2 at Hartwell (HW-US). Densities varied greatly between upstream and downstream for the sites. Both Hartwell (HW-DS) and Morell (MO-DS) had much greater densities of fry downstream than upstream. The Owendoher (OW-US) was the only upstream site which had a much greater density of >0+ trout. Densities for all older trout ranged from 0.02 fish/m^2 at MO-US to 0.3fish/m^2 (WH-DS).

Biomass

Biomass estimates were calculated for all trout by multiplying the mean weight of fry and >0+ fish (at each site) by their corresponding density population values. Fry biomass ranges varied considerably, with the Hartwell downstream site yielding the highest value, at 0.9 g/m^2. The Owendoher Site (OW-US) had a zero reading here as no fry were caught upstream. Only one site (SL-US) had a higher biomass of trout fry at the upstream site when compared with the downstream site. The biomass of >0+ trout also varied considerably among sites. The highest figure (20.2 g/m^2) was in the downstream section of the Morell, was due to the presence of a 4+ fish weighing 298g. Two of the six rivers, the

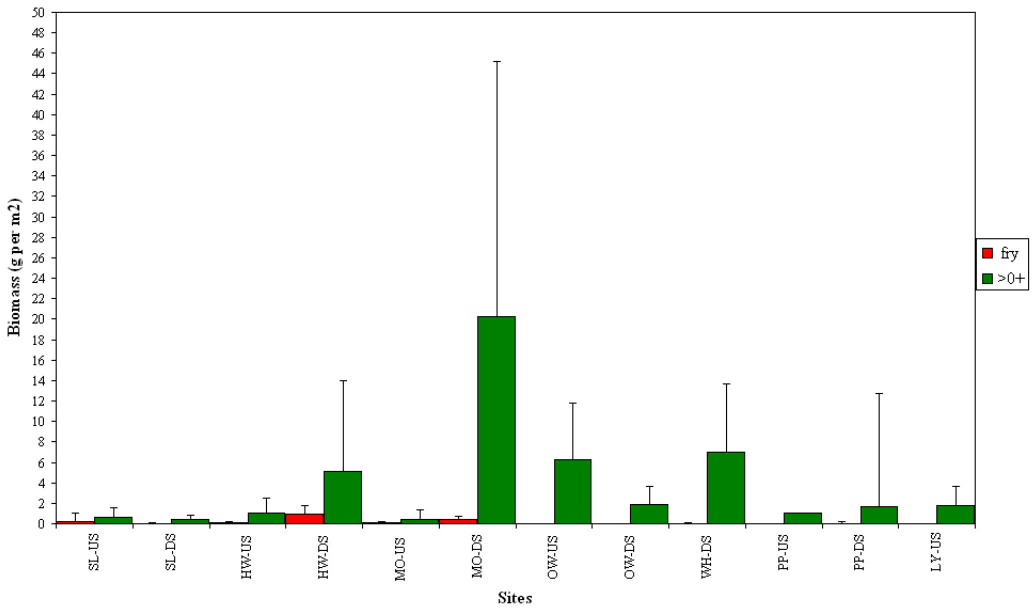
Table 7.12: Total brown trout densities at all sites

Code	Site	Date	Nos/stretch fished	S.E.	95% CL	Surface area	Density (m^2)	95% C.L.
S1	SL-US	26.09.03	35.59	1.01	1.97	315.00	0.113	0.006
	SL-DS	26.09.03	8.00	0.00	0.00	147.40	0.054	0.000
S2	HW-US	26.09.03	18.29	0.69	1.36	240.00	0.076	0.006
	HW-DS	26.09.03	63.28	4.35	8.53	109.13	0.580	0.078
S4	LY-US	29.09.03	8.00	0.00	0.00	186.00	0.043	0.000
S5	WH-DS	7.11.03	23.53	1.00	1.95	72.00	0.327	0.027
S6	OW-US	6.10.03	23.27	3.03	5.94	114.75	0.203	0.052
	OW-DS	6.10.03	12.50	1.08	2.12	135.00	0.093	0.016
S8	MO-US	26.09.03	26.67	2.22	4.36	532.00	0.050	0.008
	MO-DS	26.09.03	41.88	2.16	4.24	122.50	0.342	0.035
S9	PP-US	10.10.03	21.13	4.31	8.45	100.80	0.210	0.084
	PP-DS	10.10.03	13.50	2.60	5.09	60.45	0.223	0.084

C.L.= confidence limits

Slane (SL-US) and Owendoher (OW-US) had higher biomass values for >0+ fish than the downstream site.

Figure 7.10: Biomass (g/m^2) of trout fry and >0+ at all sites fished (error bars = 95% Confidence Limits)



Condition Factors

Condition factors were calculated to determine the 'plumpness' or 'well-being' of the trout in a quantifiable manner. This is based on the belief that a plumper fish at a given length is healthier (Bagenal and Tesch, 1978). Fulton's Condition Factor was calculated for each trout caught over 9cm (1+ and older fish) in length, Table 7.13. Fish in poor condition have Fulton condition factors (K values) < 1, while those in good condition have K values >1. The 1+ fish from all upstream and downstream sites had mean condition factors >1. A small number of fish had values < 1.

The 4+ fish that was caught at the downstream site on the Morell had a condition factor of 0.95, only slightly below the acceptable value of 1. There was no noticeable difference in the condition of fish from the various sites.

Length frequency and age class representation

Figure 7.11: Percentage composition of brown trout at sites fished

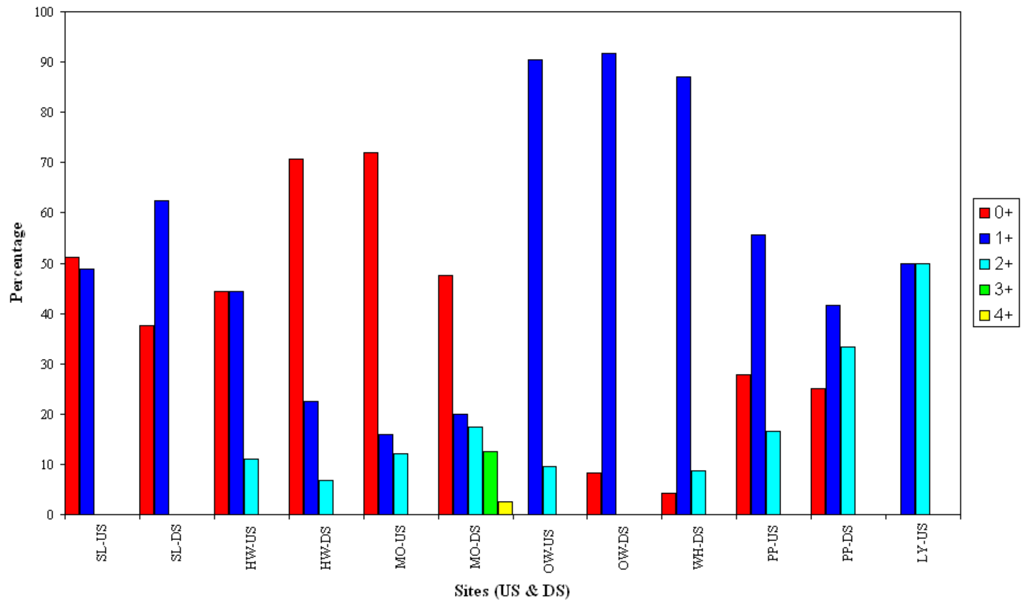


Figure 7.11 illustrates the percentage age representation at the sites. Length frequency distributions of the various age groups recorded were plotted for each site, Figures 7.12 to 7.20. These graphs illustrate the lengths of the trout within each age class.

The fry were the most abundant age class at most of the sites, followed by the 1+ fish. The populations at Slane (SL-US 51.2%), Hartwell (HW-DS 70.7%), Morell (MO-US 72%; MO-DS 47.5%) were dominated by fry. Fry were also well represented in the Poulaphuca tributary (PP-US and DS). Owendoher (OW-DS) had no fry present which is possibly due to the habitat which comprised some pools.

At the other sites, Owendoher (OW-US 90.5% and OW-DS 91.7%), Whites (89.7%) and Lyreen (50%), the 1+ fish formed a substantial proportion of the population. The 2+ and older age groups generally accounted for less that 20% of the population except at two sites Poulaphuca (PP-DS-33.3%) and Lyreen (LY-US-50%). The downstream section of Lyreen (LY-DS) had no salmonids present which illustrates a potential problem with water/habitat quality. The Whites River had no fish upstream but this may be due to the mesh in the stream which prevented fish capture. No fish were seen in this section. The Rowanstown and Painestown sites had no brown trout present when fished.

Discussion

Some authors report that habitat availability was the primary regulator of salmonid population density during winter when low temperatures decreased the demand by fish for food. Brown trout densities ranged from zero to 0.38 fish/m^2 . Densities as high as 1 fish/m^2 can be expected in rivers such as those in the present study (Kelly-Quinn pers. comm.). An interesting effect was observed from metal contamination on rainbow trout, i.e. that elevated Cd levels induce the MT (metallothionein) gene. This is a low molecular weight metal-binding protein which is involved in zinc and copper homeostasis and metal detoxification . Another study on salmonids found that trace metals can affect salmonid behaviour, by influencing competitive ability which could have serious implications for population stability. It is possible therefore, that a salmonid that was negatively affected by elevated aquatic metal

Table 7.13: Fulton's condition factor (K) for brown trout

		SL		SL		SL		SL		SL		SL	
Age	Statistic	US	DS	US	DS	US	DS	US	DS	US	DS	US	DS
1+	Average	1.16	1.30	1.24	1.24	1.26	1.18	1.22	1.12	1.25	1.20	1.22	1.30
	Min	0.68	1.20	1.06	0.90	1.19	0.76	1.02	0.80	1.04	0.99	0.99	1.13
	Max	1.46	1.47	1.43	1.43	1.26	1.33	1.51	1.38	1.90	1.40	1.81	1.64
	Count	20	5	8	13	4	8	19	11	20	10	5	4
2+	Average	-	-	1.03	1.21	1.24	1.25	1.20	-	1.26	1.25	1.17	1.21
	Min	-	-	0.70	1.07	1.23	1.14	1.14	-	1.23	1.13	1.07	1.07
	Max	-	-	1.36	1.31	1.26	1.43	1.26	-	1.28	1.40	1.28	1.31
	Count	0	0	2	4	3	7	2	0	2	3	4	4
3+	Average	-	-	-	-	-	1.17	-	-	-	-	-	-
	Min	-	-	-	-	-	1.06	-	-	-	-	-	-
	Max	-	-	-	-	-	1.29	-	-	-	-	-	-
	Count	0	0	0	0	0	5	0	0	0	0	0	0
4+	Average	-	-	-	-	-	0.95	-	-	-	-	-	-
	Min	-	-	-	-	-	0.95	-	-	-	-	-	-
	Max	-	-	-	-	-	0.95	-	-	-	-	-	-
	Count	0	0	0	0	0	1	0	0	0	0	0	0

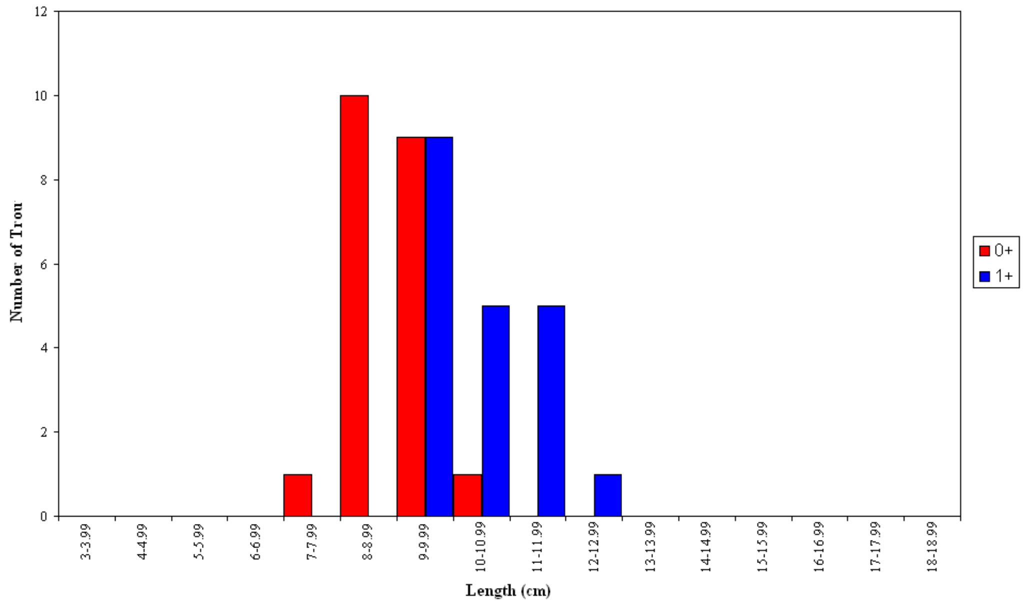


Figure 7.12: Length frequency distribution of trout at Site SL-US (Slane River)

levels may be at a social disadvantage when competing for resources and refuge and may slip down the hierarchy.

Although salmonid diets are diverse and include invertebrates, fish and even amphibians and crayfish, they are mainly dependent on invertebrates . Invertebrates are dependent on primary productiviy and stream inputs. It can thus be ascertained that if stream inputs are detrimental to water quality, instream habitats can deteriorate with consequent effects on fish biomass.

Salmonid biomass is determined by habitat quality and if conditions are optimum, the fish populations will be expected to thrive. The maximum trout production in any stream is likely to range at approximately $20/m^2$/yr . Biomass values ranged from 0.02g/m^2 (OW-US) to 0.94g/m^2 (HW-DS) for fry and 0.39g/m^2 (SL-DS) to 20.24 g/m^2 (MO-DS). It can thus be seen from these results, that MO-DS exhibited very high production, this can be attributed in particular to the 3+ and 4+ fish that were caught here.

The Condition Factor (K) is a measure of the individual fishes well-being, its fatness, and the state of its gonads; K is high in mature fish with ripe gonads and low in spent fish . Fish condition was found to be good (K>1) for virtually all trout fished with the exception of a 4+ fish found at MO-DS (K=0.95). A study on fish condition and its correlation with water conductivity yielded inclusive results. It has been found in a previous study on brown trout Salmo trutta L., that water conductivity can be used as a surrogate (or correlate) of water productivity. Conductivity levels ranged considerably between the sites from 70-852 μS/cm and this was attributed to the underlying bedrock at the sites. The majority of the sites with the exception of OW and PP (granite) sites were limestone and the condition of the fish in all of these sites were within healthy ranges.

Length frequency distributions are usually used to determine population dynamics. These distributions can illustrate growth, reproduction and mortality rates of the different age groups present. Overall it was seen that there were not great differences in the distributions between the upstream and downstream sites, with the exceptions of Lyreen (LY-DS) and Whites (WH-US) which did not have any salmonids present. Age classes showed quite noticeable differences from site to site. Fry were seen to be the most abundant age class found overall. Site MO-DS supported the greatest range in age classes with fish up to 4+ recorded there.

Growth rates upstream and downstream were found to be very similar as were the numbers of trout in the 1+ and 2+ age classes. The only real difference seen was the presence of 3+ and 4+ fish at MO-DS and this had an influence on the results for the downstream sites when the data were pooled.

Overall the analyses of the fish did not reveal a negative impact of road-runoff on these biota. One of

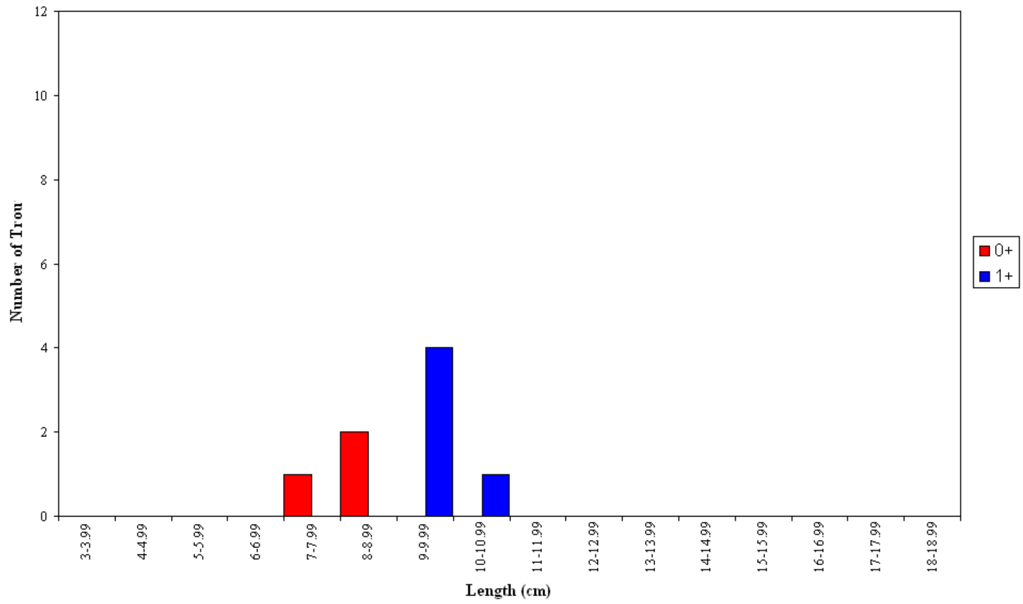


Figure 7.13: Length frequency distribution of trout at Site SL-DS (Slane River)

the major difficulties in the present study was that most sites were already impacted by nutrient/organic pollution making it extremely difficult to isolate possible effects of the road-runoff from other pollution effects.

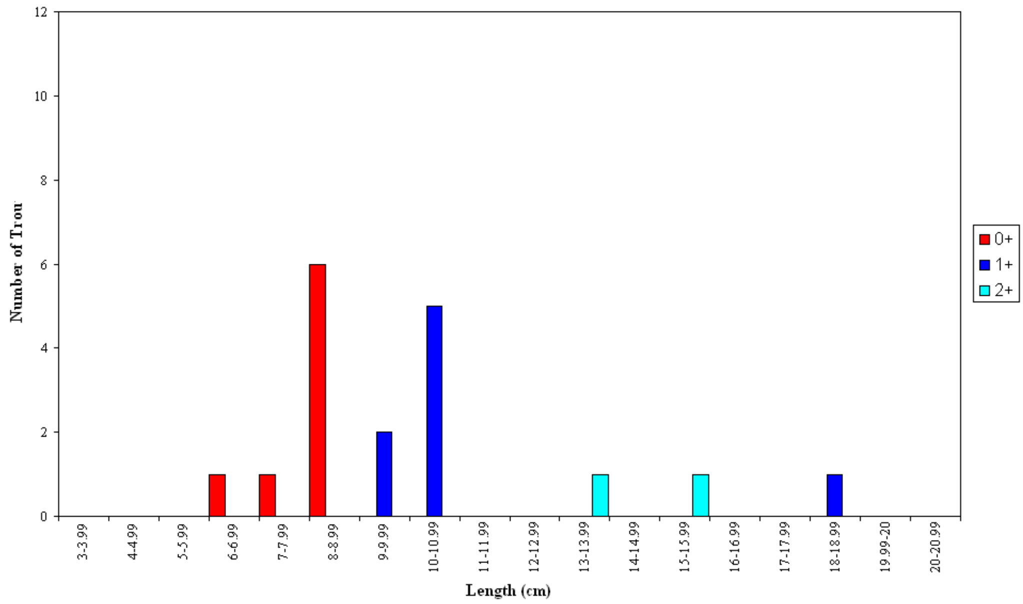


Figure 7.14: Length frequency distribution of trout at Site HW-US (Hartwell River)

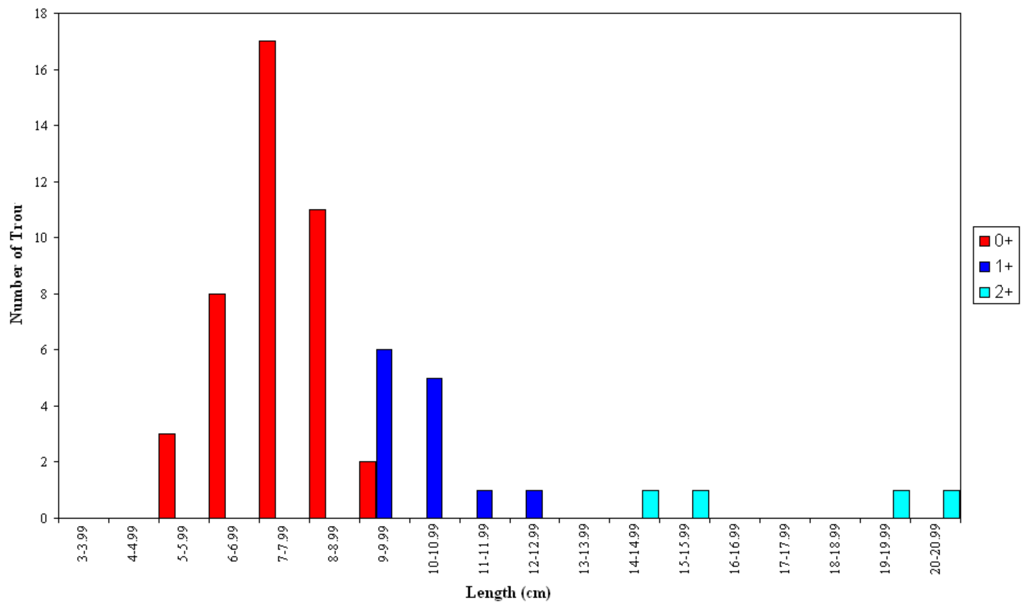


Figure 7.15: Length frequency distribution of trout at Site HW-DS (Hartwell River)

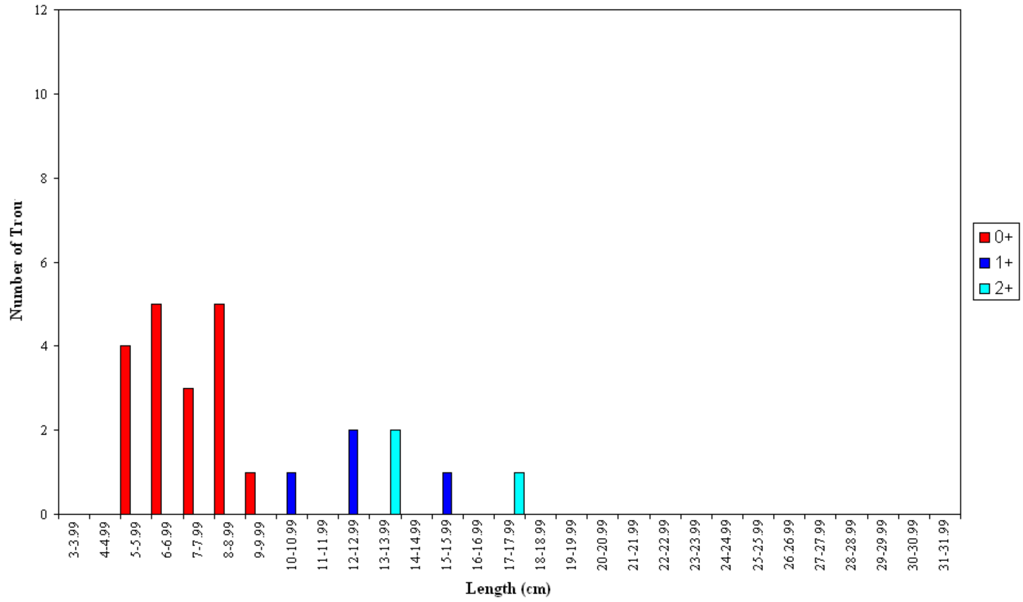


Figure 7.16: Length frequency distribution of trout at Site MO-US (Morell River)

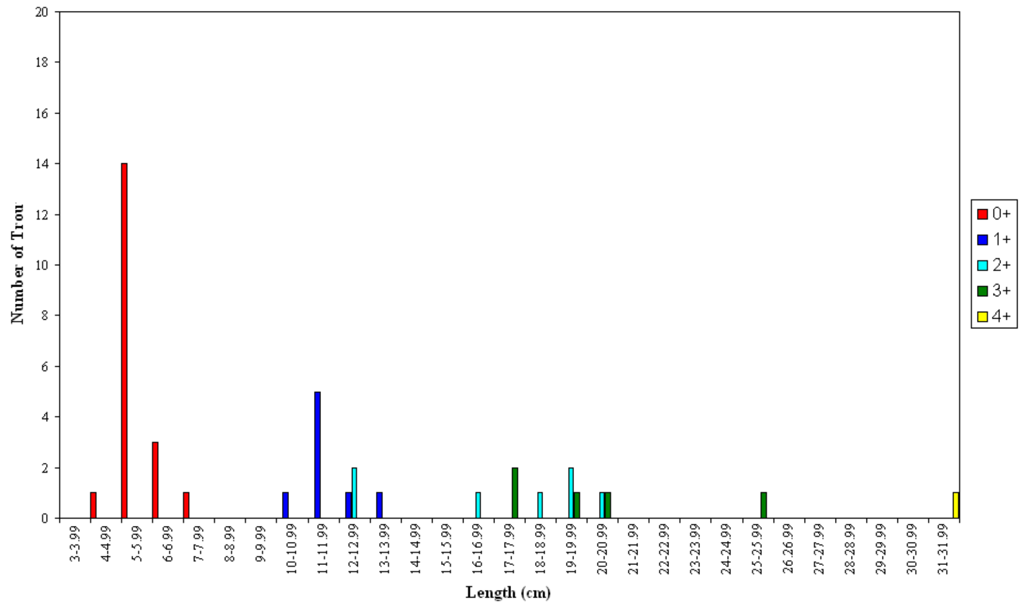


Figure 7.17: Length frequency distribution of trout at Site MO-DS (Morell River)

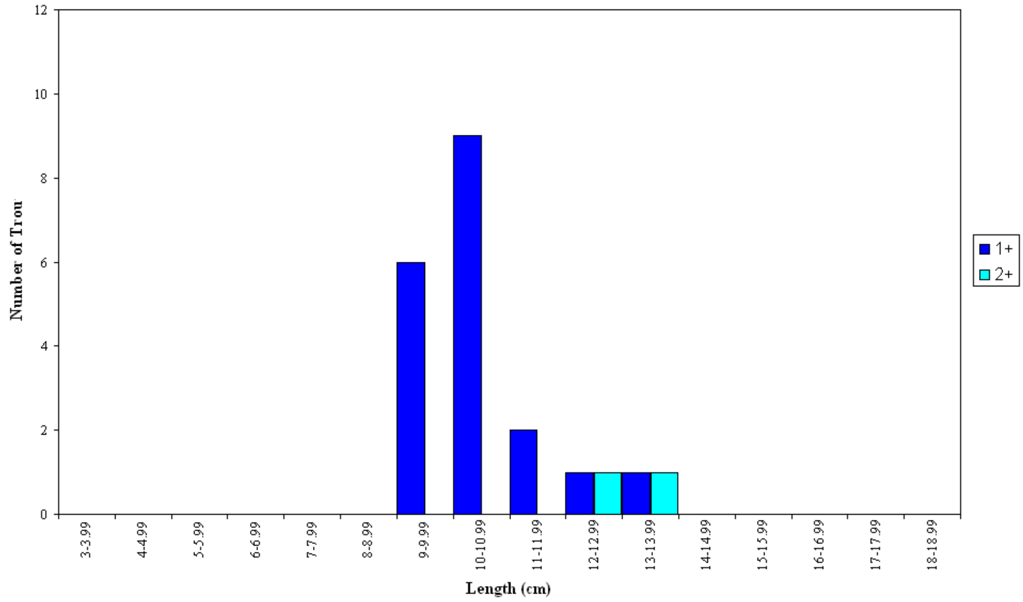


Figure 7.18: Length frequency distribution of trout at Site OW-US (Owendoher River)

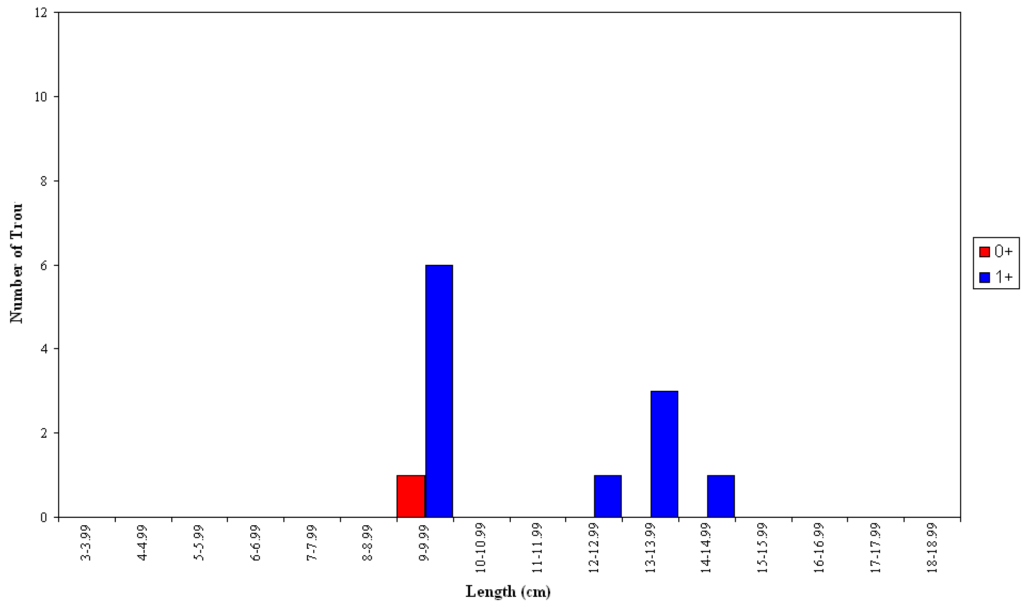


Figure 7.19: Length frequency distribution of trout at Site OW-DS (Owendoher River)

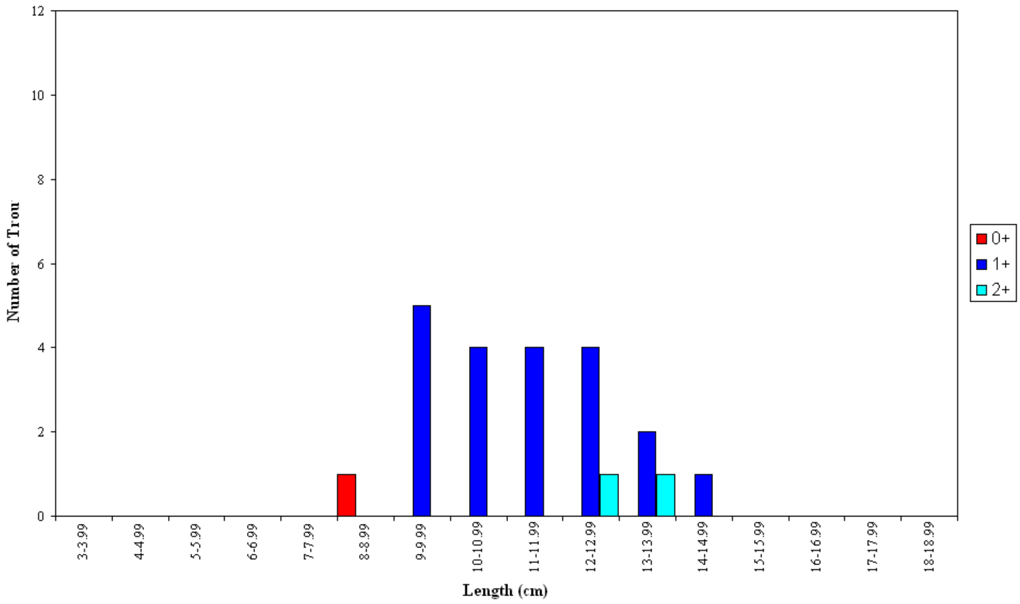


Figure 7.20: Length frequency distribution of trout at Site WH-DS (White's River)

Chapter 8

Maynooth study site study

8.1 Description of the Maynooth site

The Maynooth Bypass sampling site is located where the M4 Motorway crosses the Lyreen River near Maynooth Town (OS NGR N 913 370). The M4 runs from West of Dublin to Kilcock and extends to Kinnegad as N4 and continues to Sligo. The Lexilip-Maynooth-Kilcock section of the Motorway was opened in December 1994 with two lanes and a hard shoulder, hot rolled asphalt, Figure 8.1. The Annual Average Daily Traffic (AADT) at Maynooth interchange is 39,088 with HCV of 7.5% in both directions (National Roads Authority, 2004). The drainage system used in the monitoring section is a Filter Drain and discharges into the Lyreen River through a carrier pipe of 600mm diameter from both sides of the Motorway. The Lyreen River is the tributary of the Rye Water. The biological quality of the River was described as unsatisfactory due to agricultural and urban influences (Environmental Protection Agency, 2002). It was however found convenient for instrumentation and road runoff monitoring.

Figure 8.1: Catchment of the Maynooth bypass intensive site

8.2 Rainfall Characteristics

The nearest weather station to the Maynooth sampling site is the Mullingar station. The total rainfall recorded in this station between October 2004 and September 2005 is 930.1 mm. However, the total rainfall recorded at the Maynooth sampling site during the same 12-month period is only 546.2mm (See Table 1). The Mullingar weather station indicates that the wettest month is October 2004 so do the Maynooth site. The driest month according to the Mullingar station is February 2005 with a total rainfall record of 36.5mm. Where as the Maynooth site recorded only 19.6 mm in the month of June 2005. The greatest point rainfall record during the monitoring period (December 2003 to October 2005) in the Maynooth site is presented in Table 2.

Table 8.1: Monthly rainfall of the Maynooth site and the Mullingar National weather station

	Precipitation (mm)		30 years mean
Month	Maynooth	Mullingar	1961-90) for Mullingar
Oct'04	109.6	156.3	94.1
Nov'04	34.6	69.1	87.9
Dec'04	45.6	86.4	92.2
Jan'05	64.0	127.3	92.4
Feb'05	34.1	36.5	66.3
Mar'05	38.4	63.5	72.6
Apr'05	50.2	81.6	59.0
May'05	44.0	87.6	70.9
Jun'05	19.6	36.9	67.0
Jul'05	40.9	67.3	61.2
Aug'05	29.8	58.0	82.9
Sept'05 35.4	59.6	85.1	
Total	546.2	930.1	931.6

Table 8.2: Greatest point rainfall records at the Maynooth sampling site

Duration	Depth, mm	Start Date
5 min	1.8	1/01/05
10 min	2.7	12/08/04
		and 1/01/05
30 min	4.5	12/08/05
		and 15/08/04
1 hr	7.2	4/10/04
2 hr	11.1	4/10/04
6 hr	17.3	3/05/05
12 hr	25.4	7/01/05
1 day	25.9	7/01/05
2 days	29.7	28/07/05
15 days	73.7	21/10/04

8.3 Instrumentation

Two sampling sites were established in this study site. The first site was set up to monitor runoff from a Filter Drain. The contributing area for this sampling point is $9760m^2$. The sampler at this site is attached to the downstream side of the bridge and secured at the bridge wall above the drainage outfall.

Installation of the instrument at this site was completed on the 18th of December 2003, Figure 8.2. Samples were collected during storm events using automatic sampler (ISCO 6712). A flow meter (ISCO 750) and a rain gauge (ISCO 674) were also installed to measure flow and rainfall. The whole set up is powered by a 12V, 45Ah Lead Acid Deep Discharge Battery which lasts between 10 to 20 days at normal operating conditions. Spare batteries are recharged with Automatic 3-stage maintenance charger-desulphator. A rainfall amount of 1mm falling in 30 minutes was set to trigger the sampler. Initially, the sampler was programmed to take samples at uniform time intervals once it is triggered. This was later converted to collect flow weighted composite samples to allow investigation of pollutant concentrations as a function of volume. Flow and rainfall samples were monitored every minute but were stored every five minutes.

The 24 sampling bottles were configured in such a way that the first six bottles would be filled with the first flush. To achieve this, the sampler was programmed to quickly fill the first six bottles. The remaining 18 bottles were filled at longer intervals for the rest of the event. Composites were made in the laboratory with reference to the hydrograph to correctly reflect variation of pollutant concentrations in the event.

Figure 8.2: Monitoring equipment at the Maynooth bypass intensive site, Lyreen River

A second site was set up at the edge of the Motorway for direct runoff monitoring. This is effectively an over-the-edge drainage combined with the Filter Drain. A 100m length of the road was delineated for this purpose by cutting the grass verge. The grass verge serves as a kerb to channel the runoff down to the sampling point through a gutter constructed at the end. The runoff is collected in a watertight wooden box where the flow rate is measured using a V-notch weir, Figure 8.3. Water samples were taken from the channel before the water flows into the box.

8.4 Rainfall-runoff relationship

An Area-Velocity Flow Module (ISCO 750) was installed and operated at this site for more than 18 months. The flow meter was mounted onto a spring ring and placed in the drainage pipe. The device measures the average velocity (using the Doppler principle) and depth (hydrostatic pressure) of the flow in the pipe and calculates the flow based on the geometry of the channel. The module was connected to the sampler that stores the data. The information was later downloaded into a laptop computer for processing and analysis.

An ISCO 674 Rain Gauge (0.1mm tip) was also installed at the site to measure the rainfall. It was assumed that only one rain gauge would suffice for the size of the catchment considered. The site of the gauge was chosen to avoid the effects of vehicle-induced wind and vegetation on the rain gauge.

The average runoff coefficient for this site was estimated as 0.52, Figure 8.4. This value is slightly lower than expected for the type of surface and the drainage system used in the area. Experience on the area reveals that the filter media is effectively blocked due to lack of maintenance. This might have contributed to the loss of water to the surrounding soil. Further investigation is needed to confirm this or locate other causes of water loss. It was noticed that, even during dry conditions, there was some flow in the drains. This indicates that the drains intersect the groundwater table and their is some leakage into the drains. During storm events, when water pressure are much higher, water may escape from the drains into the groundwater, causing a reduction in the measured runoff coefficient.

Figure 8.3: Direct runoff monitoring at the Maynooth bypass intensive site

8.5 Chemical quality of the storm runoff

All samples collected, with the exception of PAHs and VOCs, were analysed in the Water and Effluents Laboratory in UCD. PAHs and VOCs were analysed by ALcontrol Laboratories. Water quality parameters analysed in UCD include Cd, Cu, Pb, Zn, NPOC, Total Phosphorous, and TSS etc. Detailed description of the parameters analysed and methods used are given in Appendix E.

A summary of the contaminants in the runoff from each site is given Tables 8.3 and 8.3. Samples from each event were used to calculate weighted mean concentrations for each parameters. These values do not necessarily represent the event mean concentration (EMC) as commonly reported in the literature. It would be inappropriate and inaccurate to report these values as EMC because for long duration events, sampling could not continue after all 24 bottles were filled. Sampling times are normally shorter than runoff durations. This was because the time lapsed before the rainfall amount specified for initiating sampling can some time be longer. During this period the runoff generated can be high enough to wash off most of the pollutants from the road.

Cadmium was rarely present above the detection levels both in the filtered and unfiltered samples. Chloride was measured during winter months to see the effects of road salting on water quality. A value of 367mg/L was measured from a sample taken on the 23rd of February 2005 from the Filter drain site. The corresponding Specific Conductivity value was 7592us/cm. PAHs were not detected at the Maynooth Filter Drain site. MTBE and other volatile organic compounds were not detected in any event. Rainfall samples were also analysed for PAHs and other parameters. No PAHs were detected in the rainfall samples.

8.6 Conclusions

Road runoff quality was monitored from Maynooth Bypass on the M4. The site has both a filter drain and over the-edge-drainage, which was modified for direct runoff monitoring. The traffic volume for the site is estimated at 25000 to 30000 vehicles per day with an HGV composition of 7.5%.

The runoff coefficients obtained for this site from the filter drain was 0.52 The value obtained is slightly less than expected, based on values reported in the literature. The drainage pipe in this site

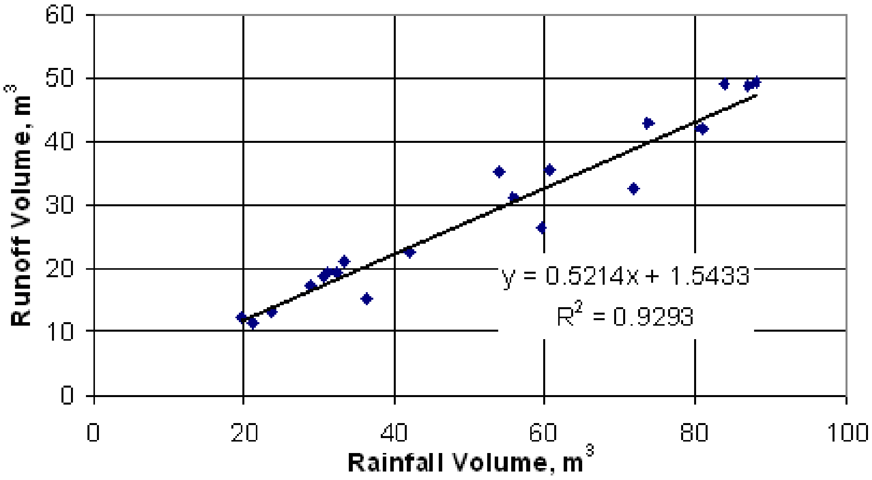


Figure 8.4: Estimating the runoff coefficient for the Maynooth bypass intensive site

has a baseflow that indicates a direct connection between runoff and the ground water. Consequently, there might be seepage into or out the drainage pipe depending on the meteorological conditions.

Samples were collected using an automatic sampler following storm events. Flow and rainfall values were also measured on a continuous basis. A number of parameters were measured from the samples including heavy metals (Cd, Cu, Pb, and Zn), total phosphorous, non purgeable organic carbon, chloride, total suspended solids, 16 EPA specified PAHs and volatile organic compounds such as MTBE.

Neither PAHs nor Volatile Organic Compounds (including MTBE) were detected in the discharge at this site. The suspended solids load from the filter drain is relatively high (max = 769mg/L). The parameters measured tend to vary with the form of the runoff hydrograph indicating the effect of rainfall intensity. The first flush effect was evident for selected storms and parameters.

Table 8.3: Flow Weighted Mean Concentration at Maynooth Bypass (Filter Drain Site)

	Flow Weighted Mean Concentration (FWMC)											
Event Date	TSS mg/L	TP mg/L	Cl- mg/L	NPOC mg/L	Total Cd mg/L	Total Cu mg/L	Total Pb mg/L	Total Zn mg/L	Filtered Cd mg/L	Filtered Cu mg/L	Filtered Pb mg/L	Filtered Zn mg/L
11-Jun-04	556	0.25	NA	7.12	0.01	0.03	0.06	0.12	NA	NA	NA	NA
27-Jun-04	NA	NA	40.19	NA	0.01	0.04	0.03	0.07	NA	NA	NA	NA
05-Jul-04	NA	NA	NA	NA	ND	0.03	ND	0.11	NA	NA	NA	NA
29/30-Sep-04	65	0.13	15.43	2.38	ND	0.02	0.04	0.09	NA	NA	NA	NA
06-Apr-05	NA	NA	NA	NA	ND	0.02	0.06	0.08	NA	NA	NA	NA
03-May-05	409	0.55	NA	2.91	ND	0.06	0.11	0.37	ND	0.02	0.02	0.01
21-Mar-05	114	0.13	19.38	2.77	0.01	0.02	0.05	0.09	NA	NA	NA	NA
23-Jul-04	32	NA	NA	NA	0.01	0.01	0.08	0.07	NA	NA	NA	NA
28-Jul-05	59	NA	NA	4.31	0.01	0.020	0.04	0.070	ND	ND	0.03	0.020
09-Sep-05	121	0.26	NA	NA	0.01	0.030	0.06	0.110	NA	NA	NA	NA

Table 8.4: Flow Weighted Mean Concentration at Maynooth Bypass (Direct Runoff)

	Flow Weighted Mean Concentration (FWMC)										
Event Date	TSS mg/L	TP mg/L	NPOC mg/L	Total Cd mg/L	Total Cu mg/L	Total Pb mg/L	Total Zn mg/L	Filtered Cd mg/L	Filtered Cu mg/L	Filtered Pb mg/L	Filtered Zn mg/L
30-Aug-05	79	NA	12	0.01	0.04	0.07	0.15	NA	NA	NA	NA
11-Oct-05	69	0.21	6.26	0.01	0.04	0.07	0.18	ND	0.01	0.03	ND
24-Oct-05	NA	0.11	2.87	ND	0.02	0.03	0.11	NA	NA	NA	NA
2-Nov-05	NA	0.1	1.97	ND	0.04	0.04	0.17	NA	NA	NA	NA

Chapter 9

Kildare study site study

9.1 Kildare Site (Site A)

The Kildare By-pass is a section of M7 Dublin to Portlaoise motorway opened in December 2003 with 2 lanes per carriageway and with a total length of 13km. The Kildare By-pass carries an average flow of traffic for a motorway in Ireland with site traffic flow usually between 25,000 and 30,000 vehicles per 24 hour day with a 12.7 percent of heavy goods vehicles, Figure 9.1. The embankment and subsoil consist of clay.

Figure 9.1: Kildare Site looking westwards

9.1.1 Highway Details

The section of highway selected for this study is immediately east of the Mayfield roundabout, Figure 9.2. It is situated in a rural area approximately 58km south west of Dublin and 4km west of Kildare town. The drainage area under study consisted of a straight length of 1200m two lane eastbound carriageway of total width 11.82m. The carriageway has cross longitudinal carriageway slopes of 3% cross fall and 0.94% down slope, Figures 9.3 and 9.4. The highway is surfaced with hot rolled asphalt, and the edge of the hard shoulder is delineated by a 90 sloping kerb face, 90 mm deep. The total area from which runoff was collected was approximately 14 184 square metres.

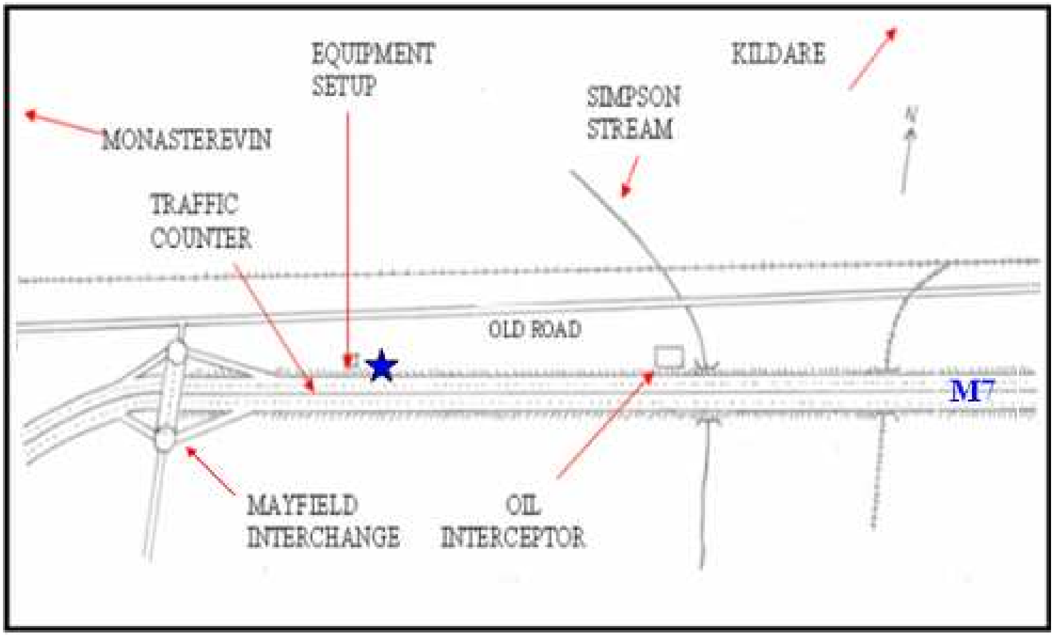


Figure 9.2: Position of the study area in relation to the Mayfield Interchange and Simpson's Stream

9.1.2 Drainage System

The drainage system in place is a standard kerb and gully structure constructed to Design Manual for Roads and Bridges guidelines, Figure 9.5. The surface runoff collects at the kerb surface and then discharges to a pipe drainage system via on line trapped gullies, installed at 20 m intervals. These pipes in turn discharge to a series of sedimentation tanks via pre-fabricated oil separators. The runoff is then gradually released into Simpson's stream, which is a tributary of the River Barrow.

The kerb and gully drainage system is frequently used on Irish Highways. Their main function is to act as a barrier to retain the surface runoff from the highway surface and then discharge it to a suitable outfall generally via a longitudinal carrier pipe set within the verge. They also provide some structural support during pavement construction and protect footpaths and verges from vehicle over run. The gully pot acts as a sediment trap so that the pipe does not become blocked.

This arrangement satisfied the project criteria as it gave direct runoff from an average trafficked highway surface. It was also easily accessible for locating the equipment and monitoring the runoff.

9.2 Data Collected

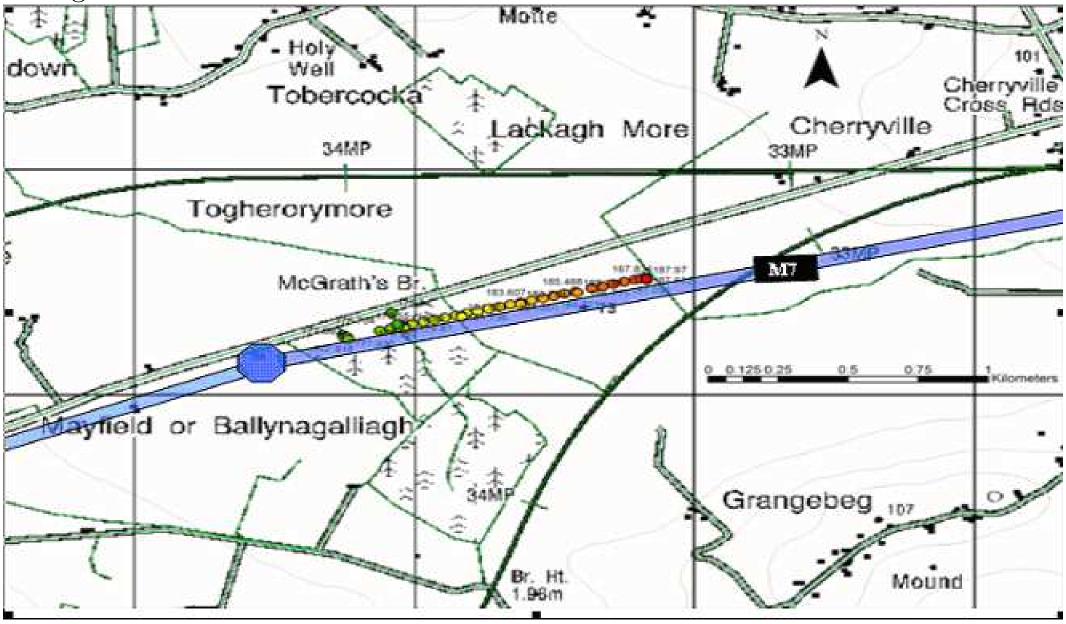
9.2.1 Rainfall

Continuous rainfall was recorded using a logging 0.1mm tipping bucket rain gauge (ISCO 674) located within the catchment, Figure 9.6. A total of 805.3 mm of rainfall fell during the 15 month monitoring period, Table 9.1. For the twelve month period of intense monitoring a total of 717.8 mm were recorded, this is comparable with the annual area average of 711.2 mm recorded at the Met Eireann Casement site. The full rainfall listings of 1 minute data are contained in the project database. The summary of the rainfall data including dry days, days with less than 1 mm, days with less than 5 mm etc are also included.

9.2.2 Traffic Density

Traffic density data have been provided by the National Roads Authority from a monitoring station located on the Kildare By-pass. Table 9.2 lists the 24 hour, 7 day average daily totals for the months corresponding to the intensive monitoring period.

Figure 9.3: Positions for the Kildare Site from which the longitudinal down slope and cross fall where calculated using GPS



9.2.3 Road Salt Application

Road salting is carried out by the Kildare County Council on behalf of the National Roads Authority. It is carried out on a reactive basis i.e. when a problem arises. The main application of road salt was during the months of January and February when temperatures plummeted to freezing conditions.

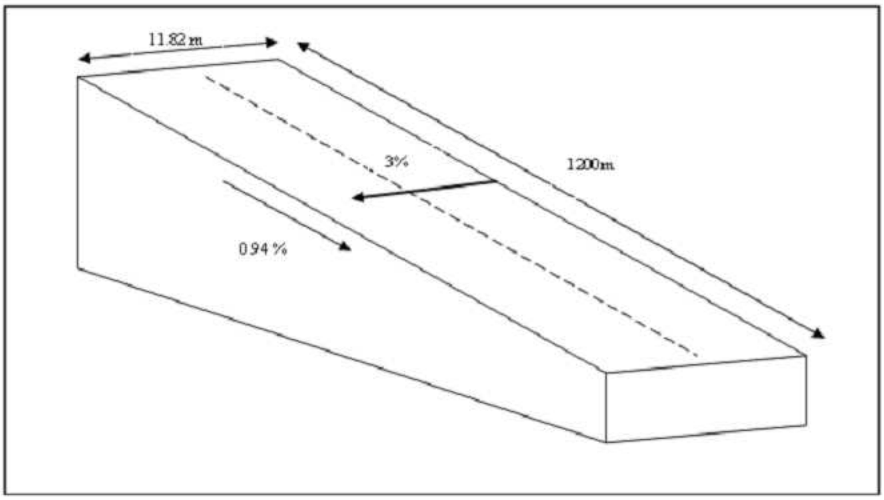


Figure 9.4: Longitudinal down slope and cross fall of the catchment Drainage System

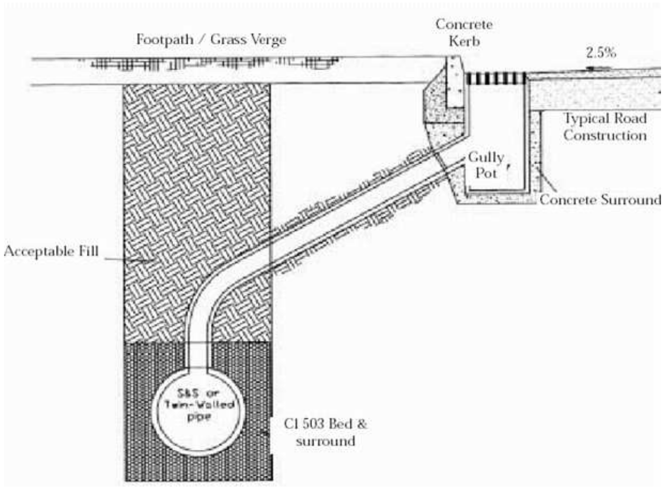


Figure 9.5: Usual design details of kerb and gully system (source: DMRB)

Figure 9.6: Rain gauge located within the catchment

Table 9.1: Monthly Rainfall Data for Kildare site; May 2004 to July 2005

Month	Total Rainfall
May 2004	36.6
June 2004	58.9
July 2004	33.0
August 2004	109.7
September 2004	41.7
October 2004	111.8
November 2004	27.5
December 2004	41.4
January 2005	56.7
February 2005	24.8
March 2005	63.2
April 2005	46.1
May 2005	66.4
June 2005	35.8
July 2005	51.7
Total	805.3

Figure 9.7: Automatic sampler (located in manhole) at Kildare site

Table 9.2: Monthly summary of two way traffic volumes from Kildare Site

Month	Two Way Total Traffic
May 2004	25792
June 2004	26613
July 2004	27032
August 2004	27140
September 2004	26654
October 2004	25979
November 2004	27032
December 2004	24744
January 2005	24575
February 2005	27097
March 2005	27684
April 2005	29079
May 2005	29219
June 2005	30533
July 2005	30486

note HGV composition was 12.7%

Table 9.3: Chemical analysis determinands

Total Suspended Solids
Total Organic Content
Total Phosphate
Chloride
PAHS (16 in all)
Total and Dissolved Copper
Total and Dissolved Zinc
Total and Dissolved Cadmium
Total and Dissolved Lead

Table 9.4: Storm Events that were sampled and analysed for chemical constituents

Event No.	Date of event	Start Time	Rainfall (mm)	Duration (mins)
1	3-Aug-2004	15:00	21.3	600
2	10-Aug-2004	12:04	3.6	270
3	2-Oct-2004	11:35	4.3	35
4	28-Oct-2004	16:42	4.3	43
5	20-Mar-2005	22:55	25.4	1295
6	23-Mar-2005	20:09	6.5	70
7	17-Apr-2005	04:52	18	800
8	3-May-2005	00:20	14.2	1024
9	21-May-2005	13:43	7.5	46
10	24-June-2005	01:14	8.1	294
11	29-June-2005	05:36	3.5	80
12	30-June-2005	04:04	4.5	110
13	2-July-2005	20:59	2.5	11
14	5-July-2005	06:25	3.4	153
15	23-July-2005	12:04	5.9	219
16	29-July-2005	00.06	11.5	625

9.2.4 Water Quality Sampling during Storm Events

Samples were collected during storm events using an automatic water sampler (ISCO 6712) located within the manhole, upstream of the sedimentation tank and petrol interceptor, Figure 9.7. The highway runoff flow in the pipe was measured using a low profile flow meter (ISCO 750) which was firstly mounted on a stainless steel spring and then inserted into the drainage pipe via the manhole. The unit was powered by a rechargeable 12 volt battery that was changed once a fortnight. The sampler contained 24 glass bottles each with the capacity to store 300 ml of highway runoff. The automatic sampler was programmed to start taking samples based on a trigger of either rainfall amount or volume of water passing the unit in the pipe. The sampler was programmed to capture the first section of the runoff (the "first flush") in the first 6 bottles (every 3 m^3 of water passing) and then stagger the use of the remaining bottles over longer periods (every 5 m^3 of water).

The water quality analysis was carried out in the University College Dublin (UCD) Water Labourites for the chemical constituents listed in Table 9.3. The hydrocarbon analysis which included PAH's and MTBE was carried out in AL Control, a special water laboratory in Dublin.

Table 9.4 lists the storm events that were sampled at the Kildare site with the storm event number, the date it occurred and the time the storm started. It also includes the rainfall amount and the duration of the storm.

9.3 Results of Analysis of Kildare Storm Event Data

9.3.1 Water Quality

Highway runoff samples were collected for 16 storm events dating from August 2004 to July 2005, Table 9.4. They were then analysed for the chemical determinands listed in Table 9.3 and the results are shown in Table 9.5. Table 9.6 summarises the minimum, maximum and average results for the 28 chemical determinants that were analysed over the 12 month time span. These values are then compared with other research findings for the same chemicals found in direct runoff throughout the world. Tables 9.7 to 9.13.

9.3.2 Hydrological Data

The hydrological characteristics of 60 storm events from August 2004 to July 2005 in terms of total rainfall, storm duration, rainfall intensity, rainfall volume, and runoff volume and runoff coefficient are summarised in Tables 9.14 to 9.15 The data presented covers a twelve month period during which the majority of major seasonal variations in site conditions were experienced.

The runoff coefficient is basically the ratio of runoff in the pipe measured by the flow meter to the total rainfall falling on the catchment.

9.4 Discussion of Results at Kildare Site

9.4.1 Water Quality

Total Suspended Solids (TSS)

The total suspended solids (TSS) determined for the 16 storm events are presented in Table 9.5 as minimum, maximum and average values. The overall mean for the 16 sampled storm events from August 2004 to July 2005 was 425.48 mg/l. Such an average value is very high for TSS and this is highlighted when compared with other research findings.

The possible reasons for such a high value are varied and could be linked to the drainage system (kerb and gully) in place which can contribute sediment build up from previous small storms that is eventually washed out by a bigger storm. Another reason could be the water sampling technique for a number of storm events. As the sampler is a two stage setup to take 6 samples after every 3 cubic metres and then 18 samples after every 5 cubic metres of runoff has passed the sample unit, in very intense rainfalls the volume of runoff could be so great all the 24 bottle samples were filled in a matter of minutes with technically the first flush of the runoff. As a large percentage of TSS is associated with the first flush the average TSS values of these samples will be high and therefore contribute to an increase in the overall average value.

Chloride

The chloride values are small compared to other research findings. One reason for this could be the lack of storm events that were sampled during the winter months. As chloride is associated with the highway surface in the winter months in the form of sodium chloride (road salt) and is only dispensed on the highway in a small number of days it was hard to detect.

Total Phosphate

Total phosphate values are comparable with other research findings both in an America and Europe. The mean value found in this project was 0.46 mg/l which is in between findings of 0.3 mg/l in America and 0.79 mg/l in Europe respectively.

Table 9.5: Flow weighted mean concentrations at Kildare Town Bypass

Date	ADP hr	Rain ,mm	Event Dur. hr	Sampling Dur. hr	TSS mg/L	TP mg/L	Cl- ,mg/L	NPOC mg/L	Total Cdmg/L	Total Cumg/L	Total Pb mg/L	Total Zn mg/L	Filtered Cd mg/L	Filtered Cu,mg/L	Filtered Pb,mg/L	Filtered Zn,mg/L
25-May-04	480	2.9	0.25	0.5	3342	1.63	25.70	23.12	0.02	0.26	0.29	1.24	NA	NA	NA	NA
28-May-04	1	1.8	1.00	1	277	0.19	11.62	12.90	ND	0.04	0.02	0.16	NA	NA	NA	NA
18-Jun-04	144	6.4	1.75	3	617	0.38	14.43	30.49	ND	0.08	0.07	0.28	NA	NA	NA	NA
03-Aug-04	72	21.4	7.33	4	196	NA	1.20	8.63	ND	0.05	0.03	0.23	NA	NA	NA	NA
10-Aug-04	120	3.6	0.48	0.98	NA	0.14	1.86	6.89	0.01	0.08	0.08	0.39	NA	NA	NA	NA
02-Oct-04	22	4.3	0.57	1	368	0.48	10.17	4.57	0.01	0.09	0.07	0.47	NA	NA	NA	NA
19-Oct-04	62.5	6.3	2.37	1.40	133	0.31	2.57	1.86	0.01	0.05	ND	0.18	NA	NA	NA	NA
28-Oct-04	1	4.5	1.3	2.33	476	0.53	6.04	1.21	NA	NA	NA	NA	NA	NA	NA	NA
23-Mar-05	41	6.4	1.2	1.02	1390	1.06	4.05	3.90	0.01	0.20	0.20	1.13	NA	NA	NA	NA
17-Apr-05	0	18.0	12.6	1.03	1835	1.81	NA	10.79	0.01	0.27	0.33	1.58	ND	0.01	0.01	0.01
03-May-05	0	12.4	6.9	1.28	NA	0.98	NA	1.97	0.01	0.16	0.20	1.02	NA	NA	NA	NA
21-May-05	13	7.5	1.2	1.3	NA	1.77	NA	2.61	0.01	0.29	0.37	1.73	ND	0.01	0.01	0.03
24-Jun-05	120	8.3	5.9	2.72	239	0.30	NA	12.14	0.01	0.06	0.11	0.35	ND	0.01	0.02	0.03
29-Jun-05	120	3.5	1.65	0.77	137	0.28	NA	11.34	0.01	0.05	0.07	0.23	ND	0.01	0.03	0.04
30-Jun-05	21	4.5	1.85	1.13	444	0.42	NA	5.38	0.01	0.07	0.12	0.46	ND	0.02	0.04	0.03
30-Jun-05	9	3.3	0.25	0.85	2217	1.68	NA	7.85	0.02	0.25	0.30	1.54	ND	0.01	0.03	0.02
02-Jul-05	26	2.5	0.18	0.52	426	0.41	NA	9.36	0.01	0.07	0.10	0.39	ND	0.01	0.01	0.05
05-Jul-05	34	3.6	0.92	1.2	120	0.23	NA	9.1	0.01	0.05	0.08	0.23	ND	0.01	0.03	0.04
23-Jul-05	1.23	5.9	2.3	1.63	1071	0.82	NA	8.66	0.01	0.14	0.15	0.85	ND	0.02	0.03	0.07
29-Jul-05	0	13.3	9.15	4.17	19	0.06	NA	1.18	0.01	0.02	0.06	0.12	ND	ND	0.03	ND
21 & 22-Mar-05	0	26.3	20.6	2	398	0.43	1.09	2.09	0.01	0.09	0.12	0.55	ND	ND	0.01	0.07

Table 9.6: Summary of the minimum, maximum and mean values of chemical determinands in highway runoff at the Kildare site

Determinand (unit)	Minimum value	Maximum value	Mean value
Total Suspended Solids (mg/l)	4	3325	425.48
Total Organic Carbon (mg/l)	0.75	47.93	5.77
Chloride (mg/l)	0.87	17.44	4.25
Total Phosphate (mg/l)	0.029	3.00	0.46
Total Copper (mg/l)	0.008	0.393	0.0895
Dissolved Copper (mg/l)	ND	0.031	0.011
Total Zinc (mg/l)	0.048	2.36	0.461
Dissolved Zinc (mg/l)	ND	0.045	0.035
Total Cadmium (mg/l)	ND	0.02	0.008
Dissolved Cadmium (mg/l)	ND	0.006	0.0017
Total Lead (mg/l)	0.041	0.485	0.098
Dissolved Lead (mg/l)	ND	0.05	0.024
Total PAH (μg/l)	<0.01	84.79	5.29
Acenapthene(μg/l)	<0.01	1.183	0.038
Acenaphthylene(μg/l)	<0.01	0.205	0.035
Anthracene(μg/l)	<0.01	1.749	0.158
Benzo(a)anthracene(μg/l)	<0.01	8.147	0.376
Benzo(b)+(k)fluoranthene(μg/l)	<0.01	7.029	0.343
Benzo(ghi)perylene(μg/l)	<0.01	2.936	0.141
Benzo(a)pyrene(μg/l)	<0.01	4.789	0.233
Chrysene(μg/l)	<0.01	10.727	0.544
Dibenzo(ah)anthracene(μg/l)	<0.01	0.975	0.073
Fluoranthene(μg/l)	<0.01	20.57	1.123
Fluorene(μg/l)	<0.01	0.644	0.030
Indeno(123cd)pyrene(μg/l)	<0.01	2.545	0.122
Naphthalene(μg/l)	<0.01	3.048	0.479
Phenanthnene(μg/l)	<0.01	15.082	0.729
Pyrene(μg/l)	<0.01	13.319	0.861

Table 9.7: Comparison of Irish Results with Reported Concentrations Arising From Highway In Runoff Water - 1

Determinand	Location	Minimum	Maximum	Mean	Reference
Total Suspended Solids (mg/l)	England	110	5700	NR	CIRIA (1994)
	England	15.5	1350	117.3	WRc (2002)
	N.America	2	1373	94.4	Caltrans (2001)
	Europe	4	1656	261	Transport Research Laboratory (ed.) (2002)
	Ireland	4	3325	425.48	this project
Total Organic Carbon (mg/l)	N.America	1.4	137	17.7	Caltrans (2001)
	Ireland	0.752	47.93	5.77	this project
Chloride (mg/l)	England	159	2174	NR	CIRIA (1994)
	Ireland	0.87	17.44	4.25	this project
Total Phosphate (mg/l)	N.America	0.03	4.7	0.3	Caltrans (2001)
	Europe	0.05	3.55	0.79	Transport Research Laboratory (ed.) (2002)
	Ireland	0.03	3	0.46	TCD/UCD (2005)
Total PAH (μg/l)	Ireland	<0.01	84.79	5.292	this project
Acenaphthene (μg/l)	England	<0.01	0.03	0.01	WRc (2002)
	Ireland	<0.01	1.183	0.04	this project
Acenaphthylene(μg/l)	England	<0.01	0.13	0.03	WRc (2002)
	Ireland	<0.01	0.21	0.04	TCD/UCD (2005)
A Anthracene (μg/l)	Norway	ND	0.379	NR	Gjessing et al. (1984)
	Japan	ND	0.512	0.05	Shinya et al. (2000)
	England	<0.01	0.12	0.02	WRc (2002)
	Ireland	<0.01	1.75	0.16	this project
Benzo(a)anthracene (μg/l)	Norway	1	0.677	NR	Gjessing et al. (1984)
	Japan	ND	0.832	0.053	Shinya et al. (2000)
	England	<0.01	0.48	0.11	WRc (2002))
	Ireland	<0.01	8.15	0.38	this project

Table 9.8: Comparison of Irish Results with Reported Concentrations Arising From Highway In Runoff Water - 2

Determinand	Location	Minimum	Maximum	Mean	Reference
Benzo(b)fluoranthene (μg/l)	Norway	1	1.171	NR	Gjessing et al.(1984)
	Japan	ND	1.803	0.09	Shinya et al. (2000)
	England	<0.01	0.6	0.16	WRc (2002)
Benzo(k)fluoranthene (μg/l)	Norway	1	1.171	NR	Gjessing et al. (1984)
	Japan	ND	0.896	0.048	Shinya et al. (2000)
	England	<0.01	0.25	0.1	WRc (2002)
Benzo(b)+Benzo(k) Fluoranthene (μg/l)	Ireland	ND	7.03	0.34	this project
Benzo(ghi)perylene (μg/l)	Norway	ND	1.811	NR	Gjessing et al. (1984)
	Japan	ND	0.551	0.143	Shinya et al. (2000)
	England	<0.01	0.29	0.11	WRc (2002)
	Ireland	<0.01	2.94	0.14	this project
Benzo(a)pyrene (μg/l)	Norway	ND	0.602	NR	Gjessing et al. (1984)
	Japan	ND	0.844	0.055	Shinya et al. (2000)
	England	<0.01	0.6	0.24	WRc (2002)
	Ireland	<0.01	2.94	0.23	this project
Chrysene (μg/l)	Norway	ND	1.147	NR	Gjessing et al. (1984)
	Japan	ND	2.271	0.1	Shinya et al. (2000)
	England	<0.01	0.26	0.095	WRc (2002))
	Ireland	<0.01	10.73	0.54	this project
Dibenzo(ah) anthracene (μg/l)	Norway	ND	0.214	NR	Gjessing et al. (1984)
	Japan	ND	0.209	0.025	Shinya et al. (2000)
	England	<0.01	0.58	0.07	WRc (2002)
	Ireland	<0.01	0.98	0.07	this project
Fluoranthene (μg/l)	Norway	2.665	4	NR	Gjessing et al. (1984)
	Japan	ND	6.29	0.19	Shinya et al. (2000)
	England	<0.01	0.36	0.16	WRc (2002)
	Ireland	<0.01	20.57	1.12	this project

Table 9.9: Comparison of Irish Results with Reported Concentrations Arising From Highway In Runoff Water - 3

Determinand	Location	Minimum	Maximum	Mean	Reference
Fluorene (μg/l)	Norway	ND	0.96	NR	Gjessing et al. (1984)
	England	<0.01	0.05	0.02	WRc (2002)
	Ireland	<0.01	0.64	0.03	this project
Indeno(123cd) pyrene (μg/l)	Japan	ND	0.983	0.075	Shinya et al. (2000)
	England	<0.01	0.25	0.1	WRc (2002)
	Ireland	<0.01	2.55	0.12	this project
Napthalene (μg/l)	Norway	ND	0.067	NR	Gjessing et al. (1984)
	England	<0.01	4.75	0.52	WRc (2002)
	Ireland	<0.01	3.05	0.48	this project
Phenanthrene (μg/l)	Norway	ND	1.385	NR	Gjessing et al. (1984)
	Japan	ND	6.85	0.283	Shinya et al. (2000)
	England	<0.01	0.31	0.1	WRc (2002)
	Ireland	<0.01	15.08	0.73	this project
Pyrene (μg/l)	Norway	ND	2.002	NR	Gjessing et al. (1984)
	Japan	ND	5.334	0.18	Shinya et al. (2000)
	England	<0.01	0.38	0.14	WRc (2002)
	Ireland	<0.01	13.32	0.86	this project
MTBE (μg/l)	N.America	0.2	8.7	1.5	Delzer et al. (1996)
	Ireland	<0.01	<0.01	<0.01	this project

Table 9.10: Comparison of Irish Results with Reported Concentrations Arising From Highway In Runoff Water - 4 - Copper

Determinand	Location	Minimum	Maximum	Mean	Reference
Copper (μg/l)	England	13	242	55	WRc (2002)
	England	83	259	NR	Boxall (1996)
	England	50	690	NR	CIRIA (1999)
	Sweden	2.2	98	17	Lundberg et al (1999)
	Sweden	6.6	9.4	8	Lundberg et al (1999)
	Sweden	18	25	22	Lundberg et al (1999)
	Portugal	<1	54.3	10.7	Barbosa et al. (1999)
	France	11	146	45	Legret and Pagotto (1999)
	France	40	160	NR	Dierkes and Geiger (1999)
	N.America	3	780	46.5	Thomson et al. (1997)
	N.America	1.2	230	22.3	Caltrans (2001)
	Japan	ND	620	66	Shinya et al. (2000)
	Europe	10	880	103	Transport Research Laboratory (ed.) (2002)
	Ireland	8	393	89.5	this project
Copper (μg/l) (Dissolved)	England	ND	90	17	WRc (2002)
	France	7.3	139	25	Legret and Pagotto (1999)
	N.America	1.1	121	11.4	Caltrans (2001)
	Ireland	ND	31	11.4	this project

Table 9.11: Comparison of Irish Results with Reported Concentrations Arising From Highway In Runoff Water - 5 -Zinc

Determinand	Location	Minimum	Maximum	Mean	Reference
Zinc (μg/l)	England	9	688	213	WRc (2002)
	England	449	801	NR	Boxall (1996)
	England	170	3550	NR	CIRIA (1999)
	Sweden	29	782	9.6	Lundberg et al (1999)
	Sweden	21	26	24	Lundberg et al (1999)
	Sweden	167	574	446	Lundberg et al (1999)
	Portugal	50	1462	172	Barbosa et al. (1999)
	France	104	1544	356	Legret and Pagotto (1999)
	France	200	41000	NR	Dierkes and Geiger (1999)
	N.America	10	1200	173.9	Thomson et al. (1997)
	N.America	7.5	1245	129.8	Caltrans (2001)
	Japan	ND	7639	648	Shinya et al. (2000)
	Europe	10	3400	410	Transport Research Laboratory (ed.) (2002)
	Ireland	48	2358	461	this project
Zinc (μg/l) (Dissolved)	England	ND	536	82	WRc (2002)
	France	57	1405	222	Legret and Pagotto (1999)
	N.America	3	1017	59.4	Caltrans (2001)
	Ireland	ND	45	35	this project

Table 9.12: Comparison of Irish Results with Reported Concentrations Arising From Highway In Runoff Water - 6 - Cadmium

Determinand	Location	Minimum	Maximum	Mean	Reference
Cadmium (μg/l)	England	ND	5	2	WRc (2002)
	England	3	3.41	NR	Boxall (1996)
	Sweden	0.14	0.84	0.36	Lundberg et al (1999)
	Sweden	0.12	0.19	0.16	Lundberg et al (1999)
	Sweden	0.13	0.21	0.17	Lundberg et al (1999)
	France	0.2	4.2	1	Legret and Pagotto (1999)
	France	0.5	7.6	NR	Dierkes and Geiger (1999)
	N.America	0.17	12	1.73	Thomson et al. (1997)
	N.America	0.2	5	0.7	Caltrans (2001)
	Japan	ND	43	1.75	Shinya et al. (2000)
	Europe	10	400	40	Transport Research Laboratory (ed.) (2002)
	Ireland	ND	20	8	this project
Cadmium (μg/l) (Dissolved)	France	0.11	3.6	0.53	Legret and Pagotto (1999)
	N.America	0.2	4.7	0.4	Caltrans (2001)
	Ireland	ND	6	1.71	this project

Table 9.13: Comparison of Irish Results with Reported Concentrations Arising From Highway In Runoff Water - 7 - Lead

Determinand	Location	Minimum	Maximum	Mean	Reference
Lead (μg/l)	England	23	178	51	WRc (2002)
	England	180	316	ND	Boxall (1996)
	England	340	2410	NR	CIRIA (1999)
	Sweden	0.21	76	9	Lundberg et al (1999)
	Sweden	5.1	7.4	6.2	Lundberg et al (1999)
	Sweden	5.9	7.7	6.6	Lundberg et al (1999)
	Portugal	<1	199.5	10.8	Barbosa et al. (1999)
	France	14	188	58	Legret and Pagotto (1999)
	France	ND	60	NR	Dierkes and Geiger (1999)
	N.America	11	2100	207.3	Thomson et al. (1997)
	N.America	1	327	21.9	Caltrans (2001)
	Japan	ND	567	34	Shinya et al. (2000)
	Europe	20	13000	96	Transport Research Laboratory (ed.) (2002)
	Ireland	41	485	98.2	this project
Lead (μg/l) (Dissolved)	France	0.5	19	0.53	Legret and Pagotto (1999)
	N.America	1	143	3.2	Caltrans (2001)
	Ireland	ND	50	23.6	this project

Hydrocarbons

The 16 PAHs that were tested for had mean values ranging from 0.03μg/l for fluorene to a high of 1.12μg/l for fluoranthene. Researchers including Shinya et al., (2000) have found that the three predominant PAHs in highway runoff are phenanthrene, fluoranthene and pyrene and they comprise about 50% of the fifteen quantified PAHs constituents in each highway runoff sample. The same findings were found in this project with the same three PAHs making up 51% of the overall mean sum of PAH constituents. The majority of the PAHs found were comparable with results from the UK (WRc, 2002).

Heavy Metals

The total metals, copper, zinc, cadmium and lead are very comparable with other research findings. The dissolved metals cadmium and lead however are quite high compared to other findings. The reason for this is to be further investigated.

9.4.2 Hydrological Data

Tables 9.14 and 9.15 show a complete list of the hydrological data including total rainfall, storm event duration, average rainfall intensity, and corresponding runoff coefficient for 60 monitored storm events at the Kildare site. Of these storm events, 16 where analysed for water quality. The total monthly rainfall at the Kildare site was comparable with the data at Casement weather station. The highest rainfall fell during the month of October with a rainfall of 111.8 mm shortly followed by August with a rainfall of 109.7, Table 9.1. The rainfall amount and the associated runoff volume for each storm event were used to calculate the runoff coefficient for that storm event. The runoff coefficient relates the total volume of runoff from the paved highway drainage area to the amount of rainfall falling on the catchment area.

The Kildare site runoff coefficients ranged from 0.517 to 1.844 with an average of 0.97. These results are similar to values reported by Gupta et al. (1981) who recorded runoff coefficients in the range of 0.40 to 1.42 from a 100% paved highway in Milwaukee, USA. Although theoretically unexpected, there are a number of practical explanations for recording runoff coefficients above 1, these include snow melt contributing to the runoff, wind steering the rain away from the rain gauge and actual blockage of the rain gauge. In January 2005 runoff coefficients were very high, up to 1.844, for a number of consecutive days. Snow fell on all these days so a plausible explanation for these high values is the addition of snow melt to rainfall runoff. The average runoff coefficient for the Kildare site was graphically calculated as 0.97, Figure 9.8. This value again is similar to reports found in other studies with similar site characteristics such as 100% closed paved area.

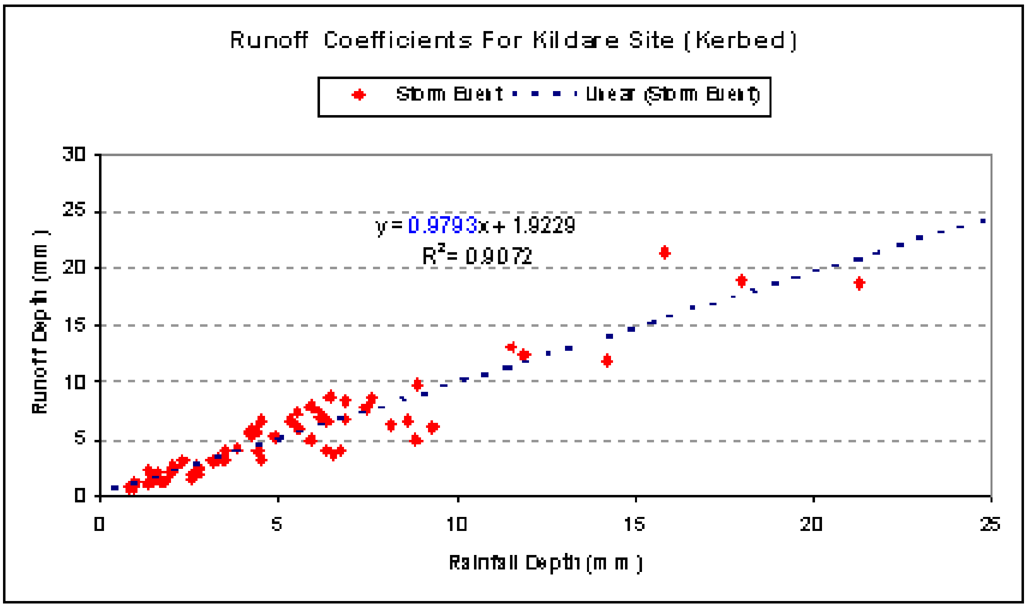


Figure 9.8: Determination of Runoff coefficient for Kildare (Site A)

Table 9.14: Summary of Hydrological data and analysis: Kildare site (events 1-40)

Storm No.	Date	Chemical Sampling	Total Rain (mm)	Storm Duration (minutes)	Rain Intensity (mm/hr)	Total Rain m^3	Total Runoff m^3	Runoff Coefficient
1	3.8.04	yes	21.3	600	2.13	302.1192	156.185	0.517
2	8.8.04		6.2	270	1.37	87.9408	64.7	0.736
3	10.8.04	yes	3.6	33	6.51	51.0624	59.57	1.167
4	15.8.04		12.5	210	3.55	177.3	221.96	1.252
5	16.8.04		7.5	30	15.04	106.38	55.94	0.526
6	17.8.04		8.9	130	4.11	126.2376	138.44	1.097
7	18.8.04		6.3	140	2.7	89.3592	110.54	1.237
8	23.8.04		5.9	20	17.72	83.6856	70.59	0.844
9	24.8.04		4.4	20	13.23	62.4096	58.04	0.930
10	16.9.04		5.5	390	0.85	78.012	82.44	1.057
11	18.9.04		7.6	280	1.63	107.7984	139.75	1.296
12	1.10.04		3.5	180	1.17	49.644	43.05	0.867
13	2.10.04	yes	4.3	35	7.42	60.9912	74.26	1.218
14	28.10.04	yes	4.3	43	5.99	60.9912	68.25	1.119
15	29.10.04		3.1	60	3.11	43.9704	27.45	0.624
16	25.11.04		1.4	440	0.19	19.8576	22.47	1.132
17	30.11.04		1.7	660	0.15	24.1128	20.75	0.861
18	15.12.04		2	55	2.15	28.368	22.17	0.782
19	17.12.04		5.6	450	0.75	79.4304	75.45	0.950
20	21.12.04		5.5	540	0.61	78.012	94.6	1.213
21	7.1.05		6.1	260	1.41	86.5224	91.36	1.056
22	11.1.05		1.6	165	0.59	22.6944	35.41	1.560
23	16.1.05		1.3	311	0.25	18.4392	34	1.844
24	17.1.05		4.2	470	0.54	59.5728	106.23	1.783
25	19.1.05		4.5	465	0.58	63.828	116.34	1.823
26	4.2.05		2.7	180	0.91	38.2968	48.54	1.267
27	9.2.05		2.3	600	0.23	32.6232	57.98	1.777
28	11.2.05		6.3	340	1.56	89.3592	97.8	1.094
29	14.3.05		5.3	320	1	75.1752	61.05	0.812
30	20.3.05	yes	25.4	1295	1.18	360.2736	197.74	0.549
31	23.3.05	yes	6.5	70	5.57	92.196	60.96	0.661
32	28.3.05		6.7	73	5.5	95.0328	65.59	0.690
33	29.3.05		1.7	82	1.24	24.1128	16.66	0.691
34	30.3.05		8.6	433	1.19	121.9824	98.77	0.810
35	1.4.05		9.3	581	0.96	131.9112	92.9	0.704
36	17.4.05	yes	18	800	1.35	255.312	148.84	0.583
37	18.4.05		1.3	69	1.13	18.4392	15.26	0.828
38	23.4.05		2.5	147	1.03	35.46	25.91	0.731
39	27.4.05		6.3	660	0.57	89.3592	68.21	0.763
40	3.5.05	yes	14.2	1024	0.83	201.4128	185.33	0.920

Table 9.15: Summary of Hydrological data and analysis: Kildare site (events 41-60)

Storm No.	Date	Chemical Sampling	Total Rain (mm)	Storm Duration (minutes)	Rain Intensity (mm/hr)	Total Rain m^3	Total Runoff m^3	Runoff Coefficient
41	18.5.05		11.9	645	1.11	168.7896	118.89	0.704
42	21.5.05		7.5	46	9.71	106.38	123.39	1.160
43	23.5.05		1.8	63	1.72	25.5312	23.48	0.920
44	23.5.05		4.9	435	0.67	69.5016	78.49	1.129
45	25.5.05		3.8	294	0.78	53.8992	60.84	1.129
46	25.5.05		2.7	434	0.38	38.2968	39.7	1.037
47	27.5.05	yes	1.3	52	1.5	18.4392	16.38	0.888
48	5.6.05		2.7	198	0.82	38.2968	28.35	0.740
49	24.6.05	yes	8.1	294	1.66	114.8904	109.3	0.951
50	29.6.05	yes	3.5	80	2.63	49.644	48.615	0.979
51	30.6.05	yes	4.5	110	2.45	63.828	50.89	0.797
52	30.6.05	yes	3.3	15	13.23	46.8072	49.211	1.051
53	2.7.05	yes	2.5	11	13.74	35.46	27.68	0.781
54	5.7.05	yes	3.4	153	1.33	48.2256	45.89	0.952
55	6.7.05		0.9	13	4.18	12.7656	10.3	0.807
56	8.7.05		0.8	45	1.05	11.3472	10.67	0.940
57	18.7.05		1.3	30	2.6	18.4392	17.79	0.965
58	23.7.05	yes	4.2	232	1.09	59.5728	66.7	1.120
59	28.7.05		6.9	448	0.92	97.8696	104.04	1.063
60	29.7.05	yes	11.5	625	1.1	163.116	188.71	1.157

Chapter 10

Monasterevin study site

10.1 Introduction

Two sites (B and C) were located on the Monasterevin By-pass. One (B) is kerbed with direct runoff (to the wetland) and the other (C) utilises a filter drain. The Monasterevin By-pass is a section of the M7 motorway opened in November 2004 with 2 lanes per carriageway and is 17.5 km in length. The motorway carries an average flow of traffic which is usually between 25,000 and 30,000 vehicles per 24 hour day with a 12.7 percentage of heavy goods vehicles. The embankment and the subsoil consist of clay.

10.2 Site B East Monasterevin By-pass - Wetland Site B

The second section of this highway selected for this study, Figure 10.1, is at the east side adjacent to the River Barrow. It is situated in a rural area 66km southwest of Dublin and 2km south of Monasterevin town. The drainage area under study consists of a straight length 480 m of west bound carriageway and 500 m of east bound carriageway each of total width 11.6 m. The road is surfaced with hot rolled asphalt and the edge of the hard shoulder is delineated by a 90^o sloping kerb face, 90 mm deep. The total area from which runoff was collected was approx 11,368 square metres, Figure 10.2.

10.2.1 Drainage System

The drainage system in place is a standard kerb and gully structure constructed to Design Manual for Roads and Bridges guidelines. The surface runoff collects at the kerb surface and then discharges to a piped drainage system via on line trapped gullies installed at 20 m intervals. This is then discharged into a constructed wetland and then into the River Barrow. The kerb and gully drainage system has already been discussed with the Kildare site.

10.2.2 Treatment System

An assessment of all the treatment options was carried out and a constructed wetland was found to be the most efficient treatment system for highway runoff. A constructed wetland provides physical, chemical, and biological water quality treatment of highway runoff. Physical treatment occurs as a result of decreasing flow velocities in the wetland, and is present in the form of evaporation, sedimentation, adsorption, and filtration. Biological processes include decomposition, plant uptake and removal of nutrients, plus biological transformation and degradation. Chemical processes include precipitation, and chemical adsorption.

10.3 Wetland Design

Hydrology is one of the most influencing factors in pollutant removal due to its effects on aeration, sedimentation, biological transformation, and adsorption onto sediments at the bottom of the wetland.

Figure 10.1: Looking westwards on the wetland site of the Monasterevin By-pass

A large surface area for the wetland is also recommended as this encourages higher levels of adsorption, absorption, filtration, microbial transformation, and biological utilization than might occur normally on a more channelised water course.

To determine the constructed wetland dimensions the hydrology data from the existing Kildare site and constructed wetland guidelines from The Halcrow Group and Environment Agency (EA) in England were used. The rainfall for a 60 minute storm event with a one year return period was determined as 16.0 mm for the region. Therefore the wetland was designed to store such a rainfall for at least an hour. The catcment area to drain into the wetland was determined to be 11 368 square metres so the wetland was designed accordingly. The dimensions worked out to be 20 metres long by 14 metres and a maximum depth of 0.6 metres, Figure 10.3.

The wetland site was first excavated and the underlying soil was compacted to form a clay liner. This clay liner was tested using the Double Infiltrometer methodology and the clay was found to be very impermeable ($< 10^{-10}$m/s). This suggested that there would be minimal vertical movement of the water into the underlying soil and a water balance could be calculated from the inflow and outflow readings.

The constructed wetland was designed as a surface follow system i.e. the influent (highway runoff) passes as free-surface (overland) flow (and/or at shallow depths) and above the supporting substrates. The wetland was planted with 500 Phragmites australis and 500 Typha latifolia. The reason behind this was to see if plant species made a difference to the overall treatment efficiency of the wetland.

The inlet pipes were constructed in such a way that the influent highway runoff was evenly distributed across the surface of the wetland. This was achieved using four T pieces laid evenly across the width of the wetland and directed onto the wetland bed, Figure 10.5.

The longitudinal slope of the wetland bed parallel to the flow path was constructed to be 1.0% of the total length to give the required gradient as recommended in the design guidelines (Halcrow, 1998).

The level at which the outlet was set was determined by the lowest water level required in the constructed wetland. This was recommended to be at least 300 mm in the design guidelines (Halcrow,

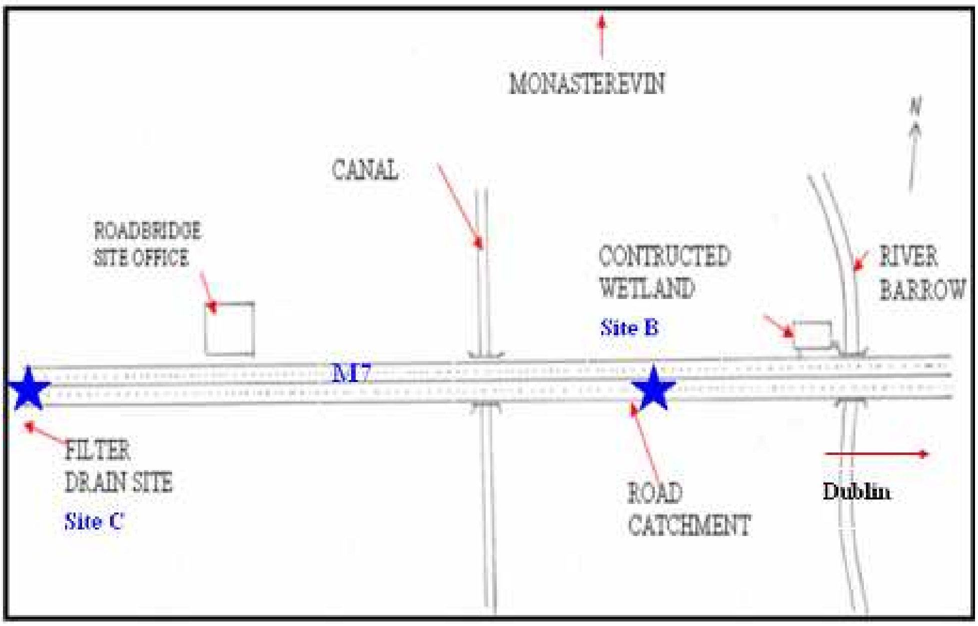


Figure 10.2: Schematic diagram of the study area in relation to Royal canal and River Barrow

1998); therefore the outlet level was maintained at this height with minor corrections easily been made in the future.

A V-shaped weir structure was designed especially for the outlet of the wetland as the flows leaving the wetland were expected to be very small and therefore a measurement system that is accurate at low flows was required, Figure 10.6

The two automatic samplers (ISCO 6712) were set-up as shown in Figure 10.4 The flow meters (ISCO 750) recorded inflow and outflow from the wetland. The rainfall gauge (ISCO 674) was a 0.1mm tip and was located within the catchment. The probes (ISCO 701) measuring Temperature, pH, Specific Conductivity and Dissolved Oxygen were placed at each end of the wetland and continuously recorded differences in these parameters from one end of the wetland to the other. The automatic water samplers were programmed to take samples during storm events at both the inlet and outlet. These samples were then be taken away for chemical analysis at UCD.

10.4 Results for Monasterevin

10.4.1 Continuous Data

The West Monastervin By-pass (Site B) and the East Monasterevin By-pass (Site C) are within 4 km of each other therefore the same rainfall would apply to both sites.

Rainfall

A complete record of rainfall was achieved using a logging, tipping bucket rain gauge located within the catchment.

A total of 414.7 mm of rainfall was recorded during the 8 month monitoring period. This is comparable with the area average of 462.1 mm recorded for the same period at the Met Eireann Casement Site, Table 10.1.

The full rainfall listings of 1 minute data are contained in the database. Also included are summaries of the rainfall data including number of dry days, days with less than 1mm of rain, days with less than 5mm of rain etc.

Table 10.1: Monthly Rainfall Data: Monasterevin site

Month	Total Rainfall
March 2005	43.1
April 2005	52.1
May 2005	59.3
June 2005	24.9
July 2005	24.3
August 2005	51
September 2005	67
October 2005	93

Storm Event Sampling

Storm events were sampled based on a number of criteria already included in the monitoring specifications. In the one year period from March 2005 to October 2005, 8 storm events at the filter drain and 6 storm events at the constructed wetland site were sampled for chemical analysis.

Traffic Density

Traffic density data have been provided by the National Roads Authority from a monitoring station located on the Kildare Bypass. Because of its proximity, these values are taken to approximate the traffic densities at the study site. Table 10.2 lists the 24 hour, 7 day average daily totals.

Table 10.2: Monthly summary of two way traffic volumes from Kildare Site (HGV was 12.7%)

Month	Two Way Total Traffic
March 2005	27684
April 2005	29079
May 2005	29219
June 2005	30533
July 2005	30486
August 2004	31517
September 2004	31209
October 2004	29578

10.4.2 Road Salt Application

Road salt was applied to the highway in times of frost conditions. This was mainly during the months of January and February so did not apply to the dates of testing.

10.5 Results for Wetland Site (Site B)

10.5.1 Hydrological results

The hydrological data including the total rainfall, total rainfall volume, total runoff volume and the corresponding runoff coefficient are represented for the 10 Storm events from the kerbed site in Table 10.3. The highway runoff from this kerbed site discharges into the constructed wetland where it is treated.

The mean runoff coefficient was 0.82 which is a typical value for a 100% paved surface, Figure 10.7. Some typical storm events are illustrated in Figures 10.8 and 10.9 (Note different scales for each Figure, because different event magnitudes). The complete set of hydrographs is given in AppendixF, showing clearly that the peak flow is reduced, by as much as 96%, in some storm events. The overall runoff volume is also greatly reduced as much as 94% of the total inflow. This will be investigated further.

Table 10.3: Hydrological data for the kerbed site discharging to the constructed wetland

Date	Total Rainfall (mm)	Total Rainfall Volume (m^3)	Total Runoff Volume (m^3)	Runoff Coefficient
9.9.05	2.6	28.7924	21.614	0.75
9.9.05	3.7	40.9738	37.3	0.91
15.9.05	4	44.296	37.272	0.84
23.9.05	1.4	15.5036	9.802	0.63
24.9.05	6.2	68.6588	38.845	0.57
26.9.05	5.9	65.3366	56.93	0.87
28.9.05	3.8	42.0812	33.373	0.79
7.10.05	3.2	35.4368	30.815	0.87
10.10.05	9.7	107.4178	99.53	0.93
11.10.05	8.4	93.0216	64.998	0.70

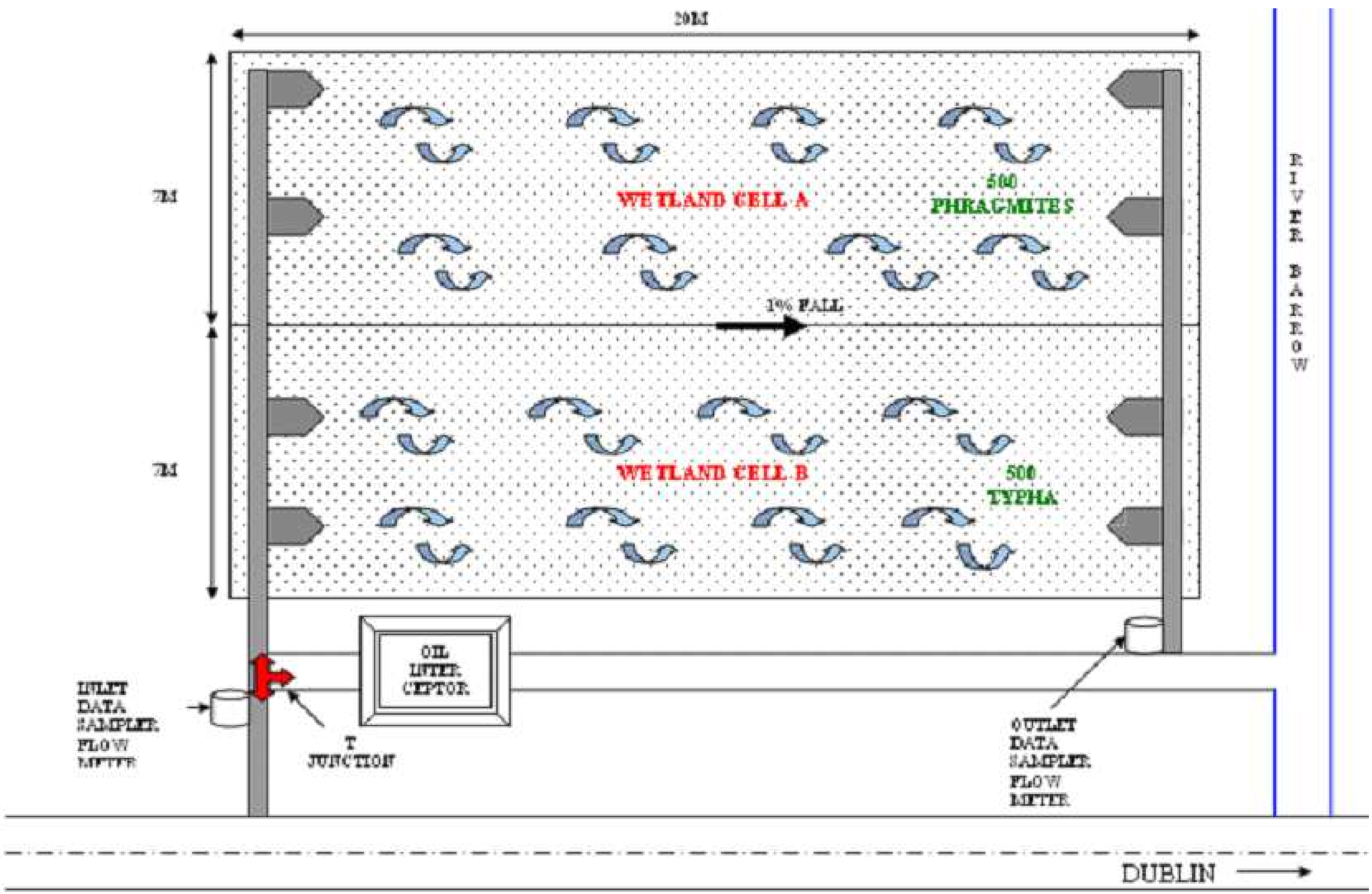


Figure 10.3: Diagram of wetland systems

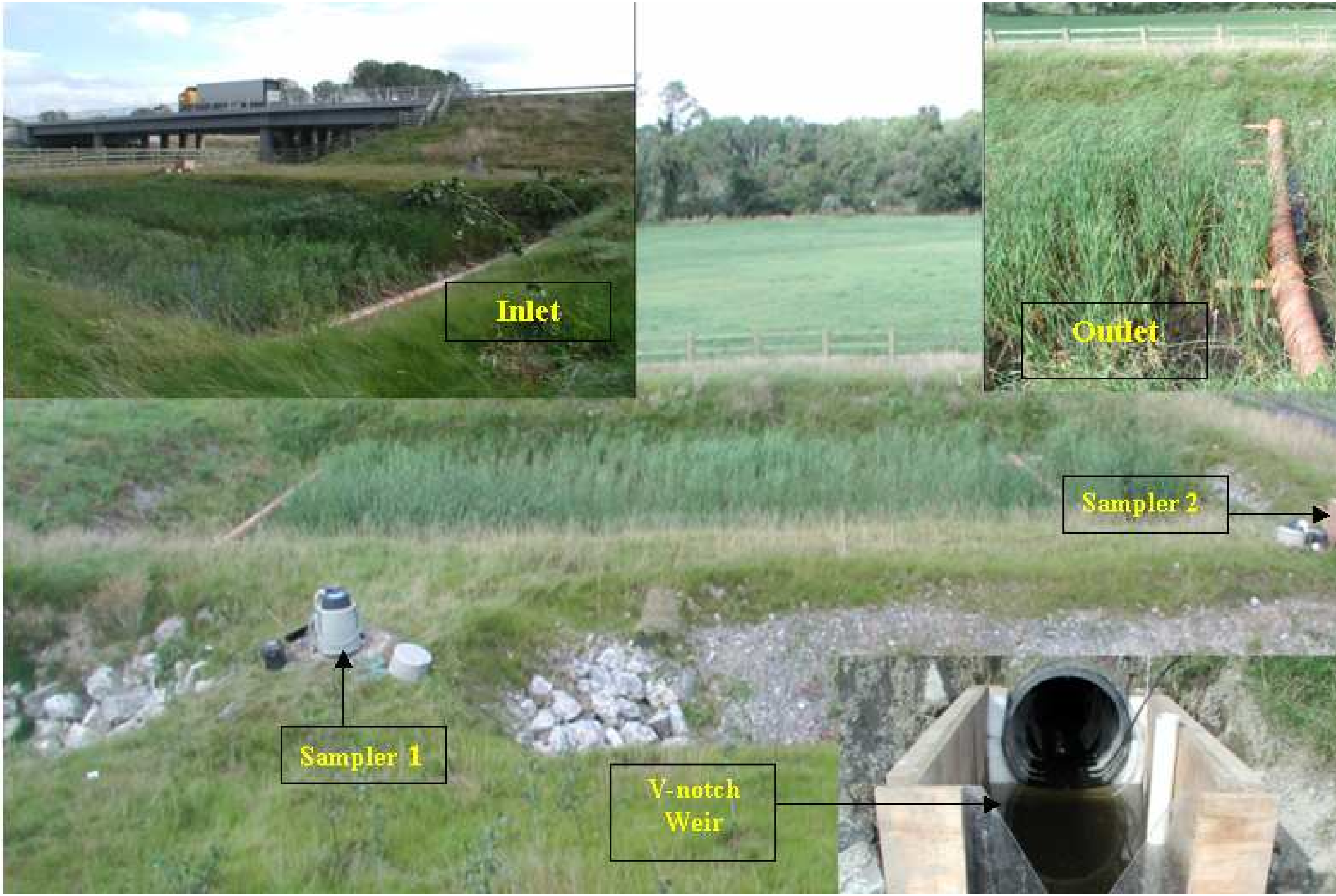


Figure 10.4: Wetland system with inlet and outlet

Figure 10.5: Highway runoff was evenly distributed over the wetland area

Figure 10.6: V-notch weir at outlet of wetland

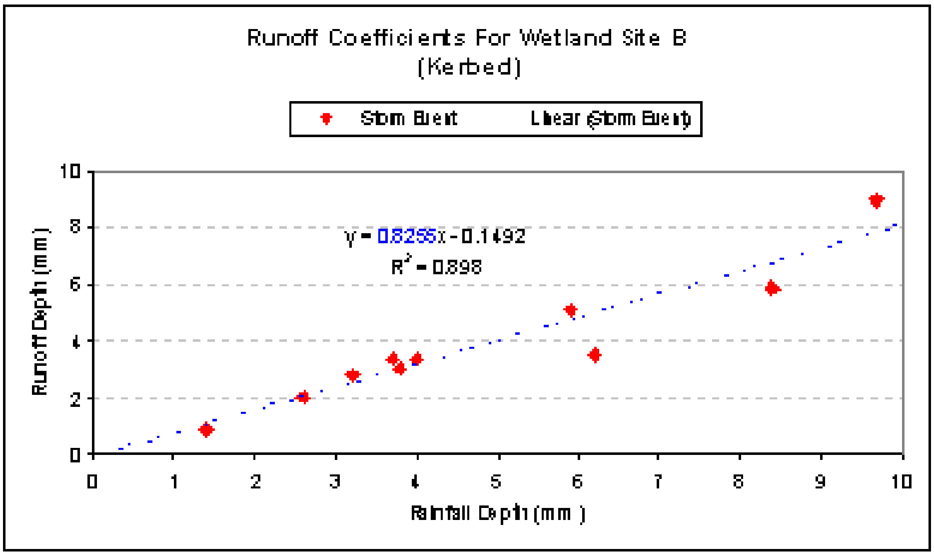


Figure 10.7: Determination of runoff coefficient for the kerbed site B

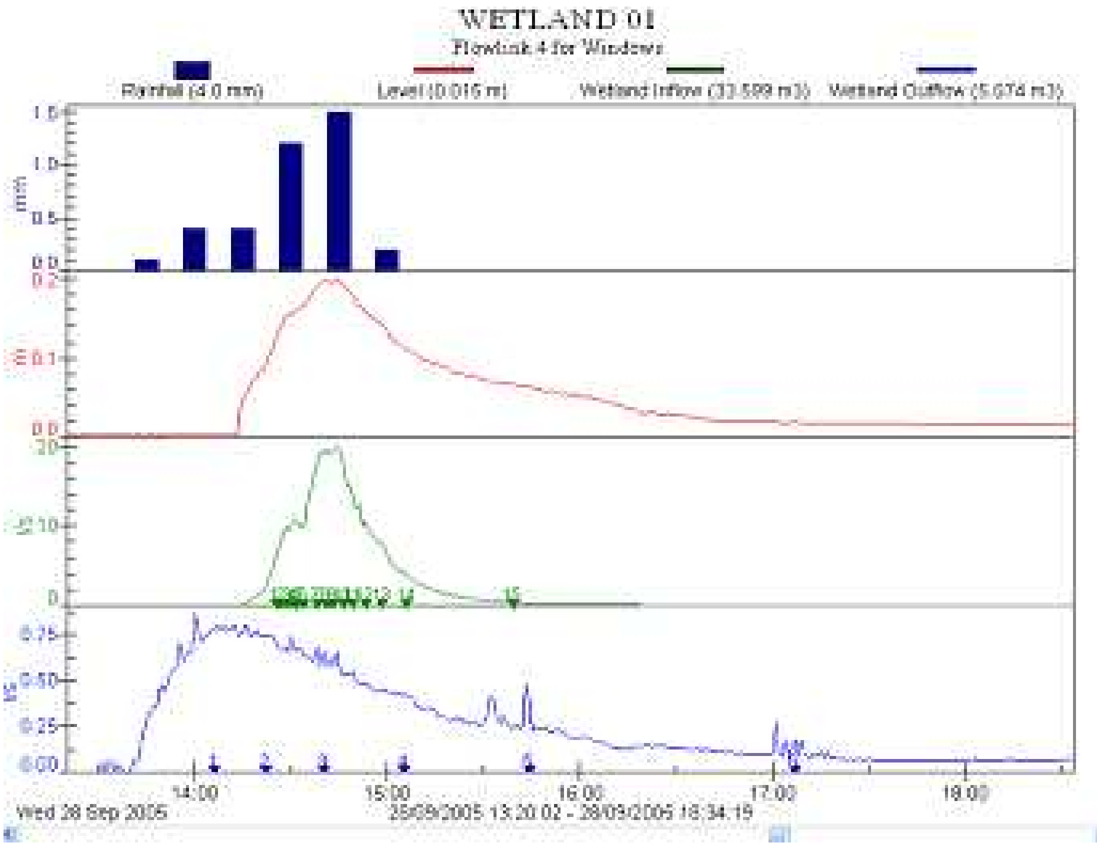


Figure 10.8: Storm Event on 28 September 2005

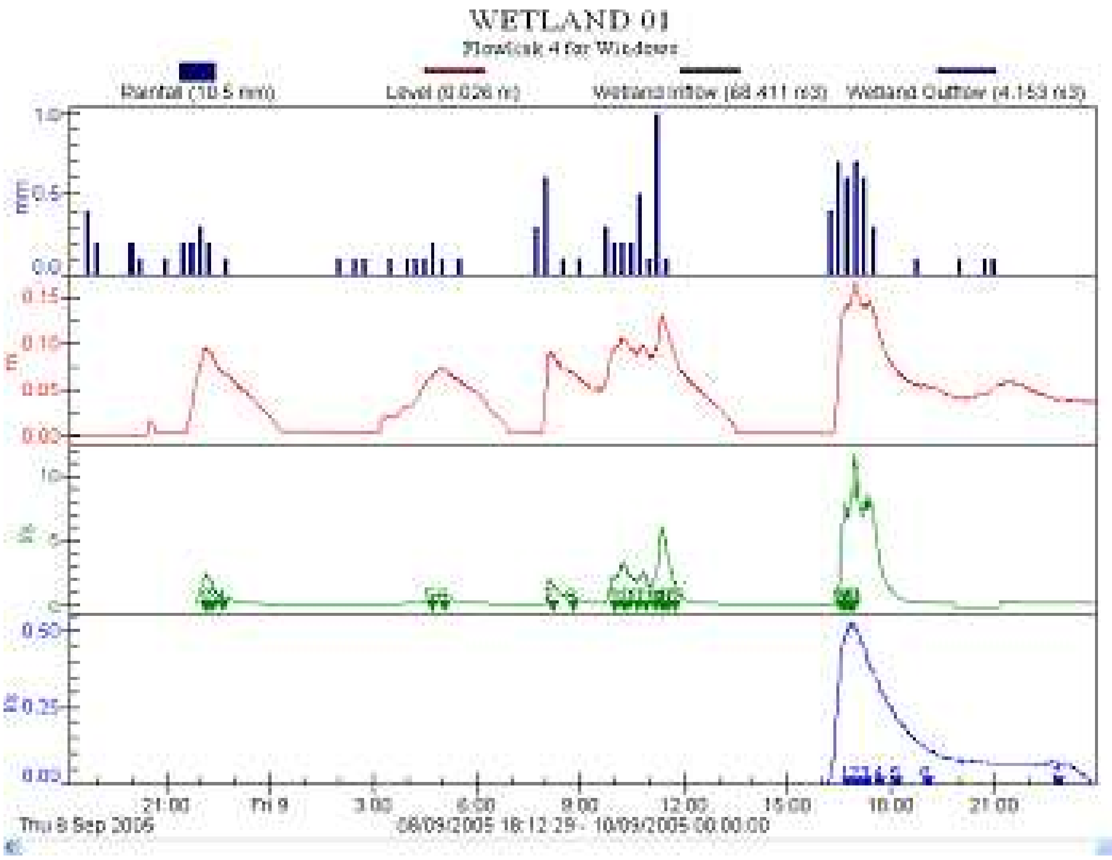


Figure 10.9: Storm Event on 9th September 2005

10.5.2 Water Quality

The constructed wetland was located adjacent to the River Barrow and received highway runoff from the kerbed Site B section of the Monasterevin By-pass. In the period from summer to autumn 2005 six rainfall events were sampled. The performance efficiency of the system as a whole was evaluated with regard to the difference of chemical water composition at the inflow and outflow. The chemical constituents analysed were total suspended solids, total phosphate, copper, zinc, cadmium and lead. The Event Mean Concentrations (EMCs) of the inflow and outflow contaminants were calculated, Table 10.4. The inflow samples were collected based on flow passing i.e. a sample was taken after every 2 cubic metres of highway runoff passed through the inlet pipe. The same protocols applied to the outflow where samples were taken after every half a cubic metre (flow rate in the outlet was much less than the inlet) had passed.

The probe to measure the temperature, pH, dissolved oxygen and specific conductivity was set up at the inlet and outlet of the wetland and monitored continuously.

10.5.3 Analysis of Results

Temperature

Inflow temperatures ranged from 2 to 22^{o}C with an average of 13.3^{o}C, Figure 10.10. The average outflow temperature was 14.3^{o}C, with the range of temperature from 10 to 20^{o}C. The overall increase was 1^{o}C. This suggests the wetland is acting as a heat sink and is discharging warmer water to the downstream water body. This may have an impact on the environment and will have to be investigated further.

pH

The average pH value of the inflow was 7.2 and 8.4 at the outflow respectively, Figure 10.10. The inflow values ranged from 4 to 8 and the outflow values ranged from 7.5 to 9. It is well documented that wetlands act as buffer zones and neutralise the acidic nature of the inflow. The pH and net acidity/alkalinity of the water are particularly important because pH influences a number of reactions within the wetland and hence a number of the treatment processes.

Dissolved oxygen content

Dissolved oxygen ranged from 0 to 22 mg/l at the inflow of the wetland, Figure 10.11. At the outlet dissolved oxygen did not vary much and ranged between 8 and 12 mg/l. Average inflow concentration of dissolved oxygen was 6.9 mg/l, increasing to 7.7 mg/l at the outflow. This is not what one would except as the plant growth and algae in the wetland would cause a rise in the demand for dissolved oxygen in wetland basin. The reason for this could be the inaccuracies in the readings recorded by the probe as dissolved oxygen is difficult to monitor.

Specific Conductivity

The average specific conductivity was 10μS/cm at the inflow and 125μS/cm at the outflow respectively, Figure 10.11. The specific conductivity monitoring is an essential condition for examining the diluting processes of highway runoff due to rainfall or runoff concentrations after a dry period and for measuring and evaluating the retention time in the constructed wetland. This will be investigated further and retention times will be calculated.

Chemical Constituents

The results are summarised in the bar chart below, Table 10.12. The five pollutants monitored and then analysed were total suspended solids, total phosphate, copper, zinc, cadmium and lead.

Table 10.4: Event Mean Concentrations of contaminants in the inflow and outflow of the wetland

	23-Aug-05		09-Sep-05		26-Sep-05		28-Sep-05	
Substance	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow
Total Suspended Solids (mg/l)	81	7	164	10	220	18	73	13
Total Organic Carbon (mg/l)	-	-	12.3	12	-	-	-	-
Chloride (mg/l)	-	-	-	-	-	-	-	-
Total Phosphate (mg/l)	-	-	0.3	0.105	0.45	0.148	0.14	0.05
Total Copper (mg/l)	0.019	0.013	0.043	0.02	0.048	0.014	0.068	0.015
Total Zinc (mg/l)	0.147	0.026	0.251	0.043	0.202	0.04	0.147	0.013
Total Cadmium (mg/l)	0.0045	0.004	0.006	0.002	0.007	0.004	0.006	0.004
Total Lead (mg/l)	0.05	0.042	0.08	0.032	0.09	0.045	0.068	0.028

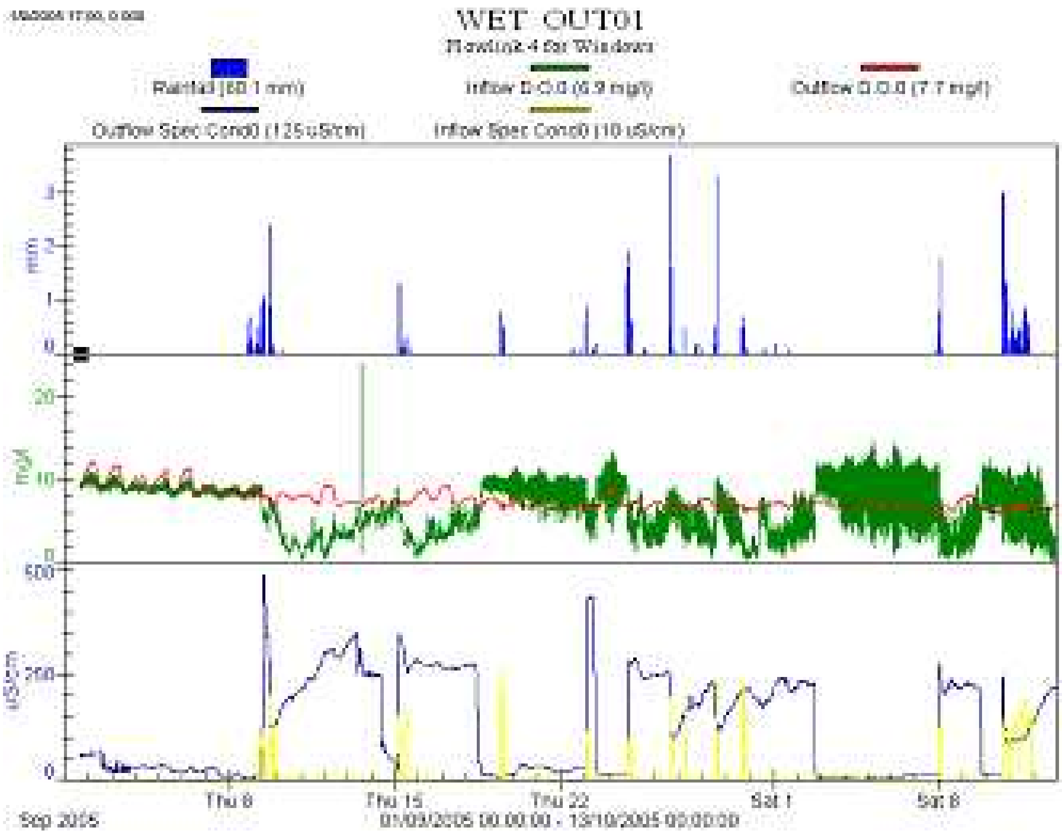


Figure 10.10: Temperature and pH records from August to October for inflow and outflow of the wetland

TSS

The removal efficiency of the constructed wetland for the total suspended solids was very high ranging from 82 to 94%. This is comparable with other research findings. Mudge and Ellis, (2001) reported removal efficiencies ranging from 70 to 95%, Figure 10.11

Total Phosphate

The removal efficiencies of total phosphate ranged from 64 to 67%. This is quite high and similar values have been reported in the literature.

Heavy Metals

The removal of zinc was high ranging from 80 to 91% this is comparable with findings from Halcrow (1998), who reported removal efficiencies of up to 98% for zinc.

The removal of cadmium ranged from 11 to 67%. This is comparable with the results of Halcrow (1998), who found removal efficiencies for cadmium ranging from 20 to 72%.

The removal of lead ranged from 16 to 60%. This is quite varied and needs further investigation.

The removal of copper ranged from 32 to 78%. This is comparable with findings by Halcrow (1998) who reported ranges of 36 to 66% for the removal of Copper.

A noticeable observation from the results was an improvement in the pollutant removal efficiency of the constructed wetland as the plants establish. This should be further investigated.

10.6 Conclusions

- The constructed wetland performed well, removing up to 94% of the total suspended solids (TSS), 67% of the total phosphate (TP), 91% of total zinc, 67% of total cadmium, 60% of total lead and

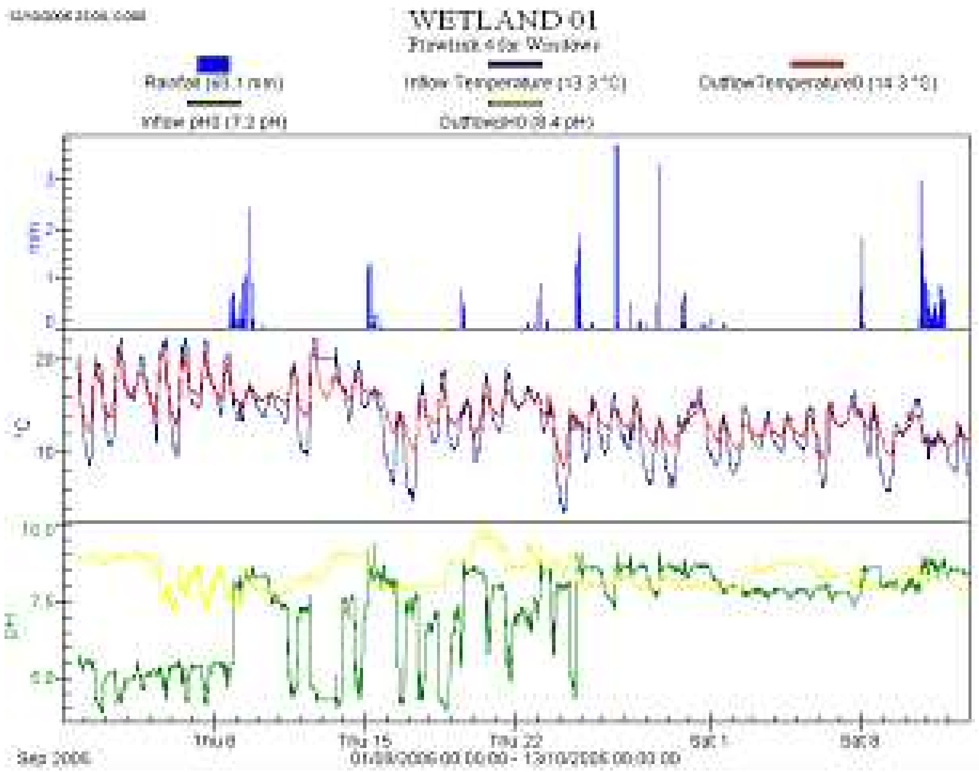


Figure 10.11: Dissolved Oxygen and Specific Conductivity records from August to October for inflow and outflow of the wetland

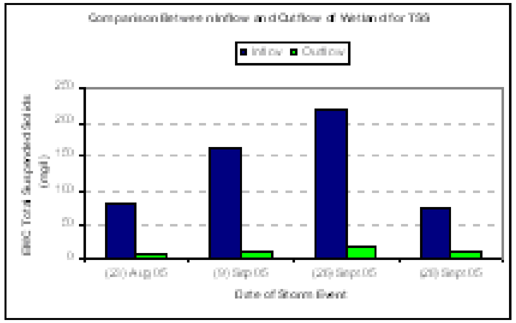
78% of total copper. It is also clear from the Figure 2 that these removal efficiencies seem to be increasing as the wetland establishes and matures. This needs further investigation

- The monitoring of the pH, Dissolved Oxygen, Specific Conductivity and Temperature at the inlet and outlet of the constructed wetland needs further investigation in order to draw conclusions.
- The peak flow and the total volume of runoff leaving the constructed wetland are substantially reduced. The peak flow at the inlet was reduced as much as 96% at the outlet and the volume of water leaving the CW was reduced as much as 94% of the volume entering the constructed wetland.
- The constructed wetland has provided a habitat for many species of wildlife including birds, frogs, snails etc.
- The constructed wetland needs to be tested further to see if it performs as well in the winter months and in the future.

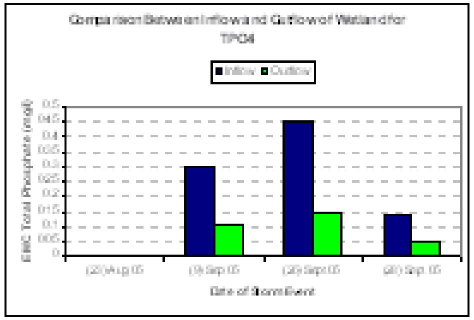
10.7 West Monasterevin Bypass Filter drain (Site C)

10.7.1 Highway Details

The first section of this highway selected for the study, Figure 10.14 is at the west side immediately east of the NewInn roundabout. It is situated in a rural area 70km southwest of Dublin and 4km south of Monasterevin town. The drainage area under study consists of a straight length of 800 m two lane eastbound carriageway with a total width of 12.0 m (including the filter drain). The road is surfaced with hot asphalt and the edge of the hard shoulder is continued with a filter drain of width 0.8 m. The total area from which runoff was collected was approximately 9600 square metres.



(a)



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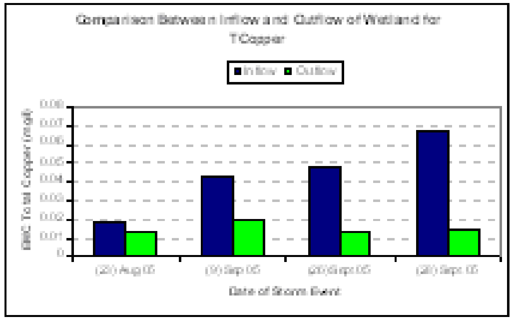

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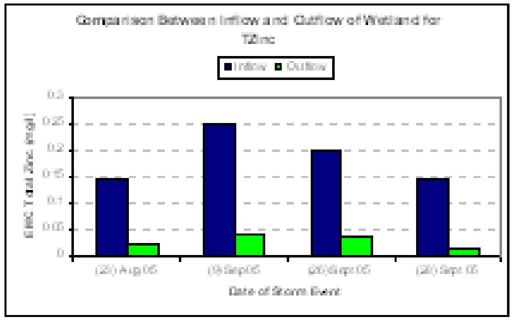

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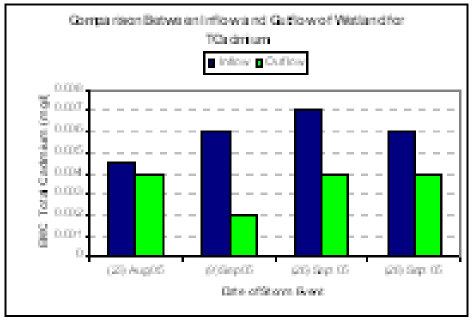

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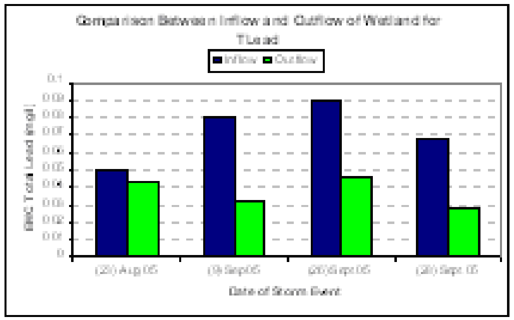


(f)

Figure 10.12: Bar charts showing the range of inflow and outflow concentrations for the wetland

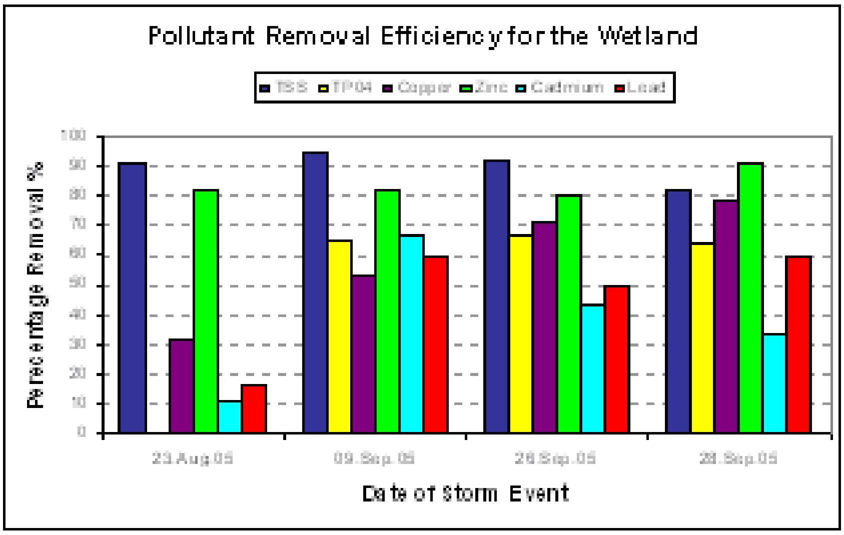


Figure 10.13: Pollutant removal efficiencies for the wetland

Figure 10.14: Looking eastwards on the Monasterevin By-pass filter drain site

10.7.2 Drainage System

The drainage system in place is a filter drain structure, Figure 10.15 constructed to Design Manual for Roads and Bridges guidelines. The surface runoff flows over and through the filter material and collects in a perforated pipe at the foot of the drain. This in turn discharges to a series of settlement ponds via an oil separator. The runoff is released into a tributary of the River Barrow.

The filter drain design as seen in the diagram above is basically an excavated trench which is firstly lined with a geotextile material which is either woven or non woven. The trench is then backfilled with CI 503 bedding material to a certain level and a perforated drain pipe or butt jointed concrete pipes are laid onto the bedding material. On top of this is a layer of coarser CI 505 type stone which is either natural or mechanically crushed. The finishing touch is an overlap of the geotextile material at roughly 300 mm from the trench surface and additional CI 505 type stone is added to bring the filter level with the road surface. The geotextile material is put in place to provide extra strength to the filter drain structure but also to stop the filter drain from becoming blocked by silt from the surrounding earth. Part of this project was to investigate the overall efficiency of this drainage system and especially to see if the overlap of the geotextile at the top section of the filter drain blocks water, particularly from the highway surface, from passing through the filter drain to the carrier pipe. It may be that the designers of the filter drain underestimated the sediment loading from the road and that runoff may be hindered

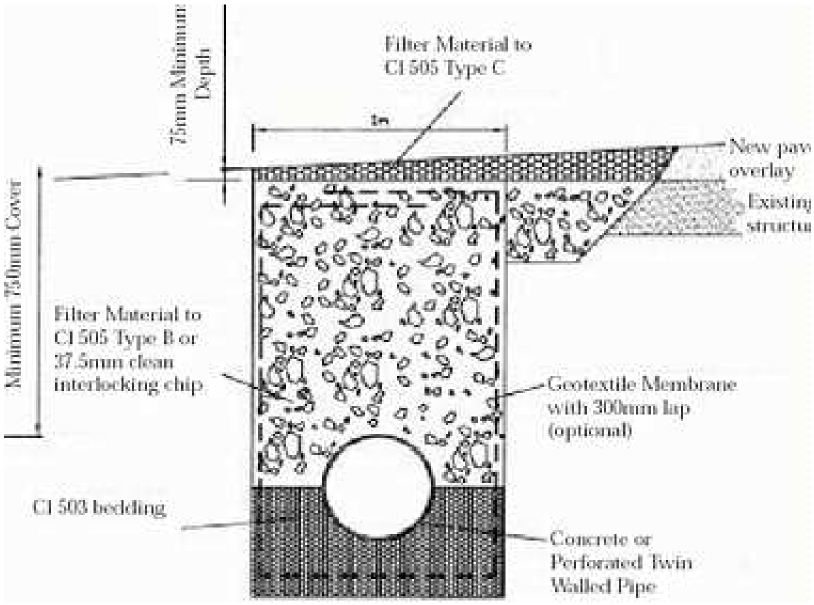


Figure 10.15: Usual design details of a filter drain system

from entering the filter drain by a sediment clogged geotextile and may be going elsewhere, possibly into underlying groundwater.

This research investigated the efficiency of these systems in terms of their ability to reduce pollutant load but also more significantly deduce whether there is a loss of pollutant load in these systems that could contaminate underlying groundwater. With this knowledge there could be a reason for design changes of these treatment systems such as the introduction of an underlying membrane liner to be made if they are to continue to be used in Ireland.

This arrangement satisfied the project criteria as it gave highway runoff discharged through a filter drain system. The site is also easily accessible for the siting of the equipment and monitoring of the runoff.

10.8 Hydrological Data: - Filter Drain(Site C)

Table 10.5: Hydrological data for 12 storm events at the filter drain site C

Date	Total Rainfall (mm)	Total Rainfall Volume (m^3)	Total Runoff Volume (m^3)	Runoff Coefficient
23.3.05	23.9	229.44	46.60	0.20
30.3.05	8.4	80.64	8.93	0.11
5.4.05	7	67.2	5.76	0.09
14.4.05	2.4	23.04	1.93	0.08
17.4.05	16.1	154.56	24.69	0.16
18.4.05	1.2	11.52	1.65	0.14
3.5.05	15.6	149.76	78.26	0.52
18.5.05	2.8	26.88	4.50	0.17
16.6.05	3	28.8	1.64	0.06
30.6.05	2.8	26.88	0.71	0.03
23.7.05	8.2	78.72	12.31	0.16
4.8.05	10.2	97.92	6.08	0.06

The hydrological data for Site C is summarised in Table 10.5 and typical hydrographs are shown in Figues 11.2 and 11.3 The mean runoff coefficient is 0.19, Figure 10.16, which is a very low value

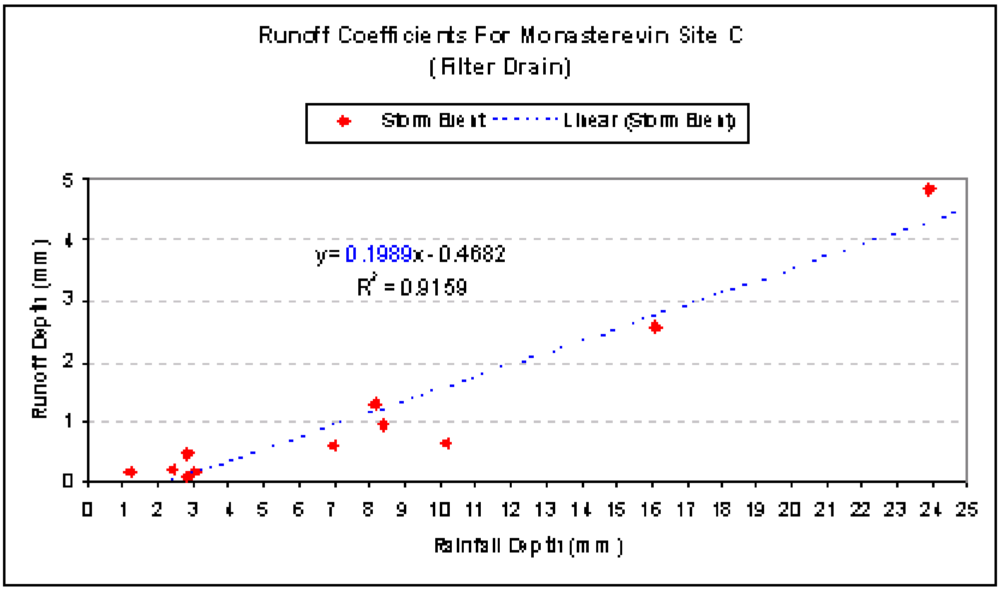


Figure 10.16: Determination of runoff coefficient for Filter Drain Site C

for a filter drain system. It indicates that a large percentage of water is going elsewhere in the system possibly into the underlying groundwater.

Table 10.6: Flow Weighted Mean Concentration at Monasterevin Bypass (Filter Drain site)

Date	TSS mg/L	TP, mg/L	Cl- mg/L	NPOC mg/L	Total Cd mg/L	Total Cu mg/L	Total Pb mg/L	Tota Zn mg/L	Filtered Cd mg/L	Filtered Cu mg/L	Filtered Pb mg/L	Filtered Zn mg/L
21-Mar-05	25	0.09	10.29	2.31	0.01	0.02	0.09	0.11	0.01	0.01	0.03	0.11
17-Apr-05	47	NA	NA	4.58	ND	0.04	0.09	0.02	ND	0.01	0.01	0.01
03-May-05	NA	0.11	NA	2.12	ND	0.01	0.08	0.02	NA	NA	NA	NA
30-Jun-05	NA	0.13	NA	11.09	0.02	0.03	0.12	0.08	NA	NA	NA	NA
23-Jul-05	122	0.19	NA	21.64	0.01	0.02	0.06	0.10	ND	0.03	0.02	0.07
29-Jul-05	16	0.07	NA	3.63	0.02	0.03	0.09	0.14	0.02	0.02	0.00	0.00
04-Aug-05	37	0.10	NA	NA	0.01	0.02	0.05	0.03	NA	NA	NA	NA

Table 10.7: Filter drain output EMCs

Determinands	21-Mar-2005	17-Apr-05	03-May-05	23-Jun-05
Total Suspended Solids (mg/l)	23	46	27	122
Total Organic Carbon (mg/l)	2.325	4.84	2.107	21.06
Chloride (mg/l)	10.6			
Total Phosphate (mg/l)	0.08		0.1138	0.19
Total Copper (mg/l)	0.024	0.044	0.0068	
Total Zinc (mg/l)	0.104	0.023	0.023	
Total Cadmium (mg/l)	0.01	0.004	0.0023	
Total Lead (mg/l)	0.086	0.091	0.085	
Total PAH (μg/l)	1.681	<0.01		
Acenapthene(μg/l)	<0.01	<0.01		
Acenaphthylene(μg/l)	0.161	<0.01		
Anthracene(μg/l)	0.09067	<0.01		
Benzo(a)anthracene(μg/l)	0.119	<0.01		
Benzo(b)+(k)fluoranthene(μg/l)	0.05467	<0.01		
Benzo(ghi)perylene(μg/l)	0.04633	<0.01		
Benzo(a)pyrene(μg/l)	<0.01	<0.01		
Chrysene(μg/l)	0.345	<0.01		
Dibenzo(ah)anthracene(μg/l)	0.07433	<0.01		
Fluoranthene(μg/l)	0.078	<0.01		
Fluorene(μg/l)	<0.01	<0.01		
Indeno(123cd)pyrene(μg/l)	0.04133	<0.01		
Naphthalene(μg/l)	0.273	<0.01		
Phenanthrene(μg/l)	0.09	<0.01		
Pyrene(μg/l)	0.124	<0.01		

Chapter 11

Water quality of storm runoff from roads: Comparative analysis

11.1 Introduction to sites

The three sites selected are all located on the M7 Dublin to Portlaoise motorway approximately 60 to 70 kilometres south west of Dublin, Figure 11.1. The surrounding area is a flat rural landscape with mainly agricultural practices.

The main river that the motorway discharges to is the River Barrow which it intersects on the Monasterevin section of the highway. The towns nearest the sites are Kildare town and Monasterevin.

The AA road map below pin points the exact location of the three sites in relation to the motorway and the river Barrow.

Figure 11.1: Map of the M7 motorway and selected sites

11.2 Comparison of site characteristics

The three sites selected for this research project where all located on the M7 Dublin to Portlaoise motorway. This motorway has gradually been constructed over the last number of years with the completion of the Kildare By-pass section in 2003 and the recent completion of the Monasterevin By-pass in 2004. The completion of two new sections of motorway gave the project team a unique opportunity to construct treatment facilities and install equipment on the motorway sections before they where opened to the public. This also allowed easy access to the site but more importantly it would give the project team a good comparison between when the highway was dormant and live with traffic.

11.2.1 Traffic Characteristics/Surrounding Land Use

According to a number of reports on highway runoff monitoring, including Gupta et al. (1981), comparative sites for the purposes of monitoring should have similar traffic characteristics such as the mix of vehicles, number of exit/entrance slipways, number of carriageway lanes, and acceleration and braking patterns, as well as a sufficient average daily traffic count on the entire stretch of highway under consideration. The surrounding land use for the sites should also be kept as similar as possible.

The three sites selected for this section of the project where all located on the same motorway, the M7 between Portlaoise and Dublin. Each of the sites has a typical mix of heavy goods vehicles and cars. Each site has also 2 traffic lanes with adequate travelling speed during non-rush hour. None of the sites encounter a build-up of rush hour traffic; therefore there are no stop-and-go traffic conditions. The traffic counter on the Kildare By-pass section records a daily traffic of between 25 000 to 30 000 cars with a slight increase in the summer months. There is no recorded traffic count on the Monasterevin By-pass section as of yet although as this is part of the same motorway the traffic numbers will be similar to that of the Kildare By-pass.

11.2.2 Precipitation Characteristics/Geographical Location

The amount or rate of highway runoff obtained during the monitoring will depend on the amount and form of precipitation, whether as snow or rainfall. The sites selected on the M7 in Kildare and Monasterevin are within 10 km of each other and share the same precipitation characteristics. The annual precipitation for the region is between 700mm and 800mm with likely snowfall in the winter months. Table 11.1 compares the monthly rainfall depths for each site and includes the corresponding values recorded by Met Eireann at Mullingar, together with the long term monthly mean. Table 11.2 lists the largest rainfall, for a range of storm durations, recorded during the project at each of the sites.

Table 11.1: Monthly rainfall for the monitoring sites

Month	Maynooth	Kildare	Monasterevin	Mullingar**	30 years mean at Mullingar**
May'04		36.6		51.6	70.9
Jun'04	17.0*	58.9		68.2	67.0
Jul'04	30.3	33.0		51.1	61.2
Aug'04	57.0*	98.3		121.9	82.9
Sep'04	29.7*	30.9*		86.8	85.1
Oct'04	109.6	111.8		156.3	94.1
Nov'04	34.6	27.5		69.1	87.9
Dec'04	45.6	29.7*	38.9	86.4	92.2
Jan'05	64.0	47.3*	33.3	127.3	92.4
Feb'05	34.1	24.6	18.5	36.5	66.3
Mar'05	38.4	63.2	50.9	63.5	72.6
Apr'05	50.2	46.1	52.1	81.6	59.0
May'05	44.0	66.4	59.3	87.6	
Jun'05	19.6	35.8	24.9	36.9	
Jul'05	40.9	51.7	24.3	67.3	
Aug'05	29.8			58.0	
Sept'05	35.4			59.6	
Oct'05	77.6			108.6	

**Storms missed due to rain gauge blockage or power failure **Source: Met Eireann (available online @ www.met.ie)*

Table 11.2: Greatest point rainfall records at the three sampling sites

Duration	Kildare Bypass		Maynooth Bypass		Monasterevin Bypass	
Duration	Depth, mm	Date	Depth, mm	Date	Depth, mm	Date
1 min	1	16 Aug'04 & 23 Aug'04	-	-	0.7	27 Jan'04
2 min	1.6	23 Aug'04 & 30 Jun'05	-	-	1.2	23 Jul'05
5 min	3.54	23 Aug'04	1.8	1Jan05	2.7	23 Jul'05
10 min	5.6	16 Aug'04	2.7	12 Aug'04 &1 Jan05	3.1	23 Jul'05
30 min	6.8	3 Aug'04	4.5	12 & 15 Aug'04	4.7	3 May'05
1 hr	7.8	6 Jul'04	7.2	4 Oct'04	5.7	3 May'05
2 hr	11.7	3 Aug'04	11.1	4 Oct'04	9.2	3 May'05
6 hr	18	3 Aug'04	17.3	3May'05	13.7	3 May'05
12 hr	18.7	22 Jun'04	25.4	7Jan'05	16.9	3 May'05
1 day	25.3	21 Mar05	25.9	7Jan'05	25.4	8 Jan'05
2 days	26.3	21-22 Mar 04	29.7	28/9Jul'05	26.7	8/9Jan'05
15 days	66.5	27Aug - 4Sept'04	73.7	21Oct - 6Nov'04	47.9	21 Jan -Feb '05
30 days	76.8	Sep' 04	86.3	Jan'05	85.1	Apr'05

11.2.3 Pavement Type/Condition

The percentage of pervious and impervious paving within a highway drainage area will affect the quantity and potential impacts of pollutants from highway storm water runoff. All the sites selected have completely impermeable surfaces. Other pavement characteristics that can affect the quality of the highway storm water runoff are the age of the pavement and the type of the pavement surface. All the pavements are rolled with hot asphalt. The Kildare By-pass site is one year older than the Monasterevin site and this will be interesting to see if such a small age gap influences the highway storm water runoff quality and quantity.

11.2.4 Drainage Area and Highway Design Characteristics

Defining the correct drainage area for a study on highway runoff is probably one of the most important of all site selection criteria. Large highway drainage areas may be difficult to isolate and define as storm water from surrounding lands may influence the overall volume of runoff. Therefore small well defined catchments are more suitable for detailed investigative analysis. The drainage area for all three sites in this research is well defined with minimal runoff from the surrounding non-highway areas.

The actual design characteristics of the highway are also important in choosing an appropriate site. Gupta et al. (1981) reported that a number of highway characteristics including vertical alignment of the freeway, type of drainage system, type of highway section (straight or intersection) and presence or absence of a median barrier all have an influence on the quality and quantity of highway runoff. All three sites selected have very similar highway characteristics except for the fact that the drainage system differs in each site. The Kildare Site has a kerb and gully system whereas the Monasterevin sites are a filter drain and a kerb and gully leading into a wetland. The reason to choose three different drainage systems was to investigate the influence the drainage system has on the quantity and quality of the highway runoff. With the majority of all the other characteristics relatively similar the three different drainage systems could be compared.

Table 11.3: Criteria for site comparisons

Criteria	Location		
	Kildare	East Monasterevin	West Monasterevin
Type	Rural	Rural	Rural
AADT	25,000-30,000	25,000-30,000	25,000-30,000
Yearly precipitation	700-800	700-800	700-800
Surface Pavement Type	Rolled asphalt	Rolled asphalt	Rolled asphalt
Drainage Area % Paved	100	100	100
Highway Surface Area	14184	11368	9600
Number of Lanes	2	2	2
Kerb/Barrier in Place	Yes	Yes	No
Section Type	Elevated	Elevated	Elevated
Surrounding Land Use	Agricultural	Agricultural	Agricultural
Regular Maintenance	Yes	Yes	Yes
Drainage Surface Type	Kerb and Gully	C Wetland	Filter Drain
Date Highway Opened	2003	2004	2004

11.2.5 Proximity to a Receiving Water Body

Preferably highway runoff sites should be located near a receiving water body if a detailed evaluation of the impacts of highway runoff contaminants on water quality is to be conducted. The location of the monitoring site should be such that contaminants from other non-highway discharges are not introduced upstream of the highway discharge point. All three sites selected discharge into nearby water courses. The Kildare By-pass site discharges into Simpson's Stream and both Monasterevin sites discharge into the River Barrow.

11.2.6 Highway Maintenance Practices

Highway maintenance practices such as grass cutting, herbicide/fertiliser use, de-icing operations and line repainting are important. All three sites for this research are maintained by Kildare County Council on behalf of the National Roads Authority; there fore the same maintenance protocol would exist for all three sites. This protocol would include inspection of the highway once or twice a year. Any maintenance that is to be carried out on the highway would be conducted on a reactive basis that is when a problem arises.

11.2.7 Logistical Considerations

This would include varied items such as accessibility to the site, vandal proofing of the monitoring equipment, power availability and the potential for constructing treatment systems at the site. According to researchers monitoring sites should be easy to access and safe for monitoring and servicing, as well as for data and water sample collection. All three sites where accessed and set up for monitoring before they opened to public transport. The constructed wetland was also built before the Monasterevin By-pass was opened which was convenient as the contractors on the highway construction helped in its excavating and planting.

All three sites met most of the requirements for suitable site selection, Table 11.3

11.3 Introduction

Direct comparisons are made between the different sites and the inflow and outflow of the wetland. Mean concentrations (the flow-weighted concentration of a water quality component during a single storm event) and pollutant removal percentages are calculated. The results are analysed in terms of event mean concentrations for the contaminants.

11.4 Comparison of Filter Drain and Kerbed site

A comparison was made between the direct highway runoff from the Kildare kerbed site and the highway runoff passing through the filter drain at the Monasterevin site. The chemical constituents investigated were total suspended solids, total phosphate, copper, zinc, cadmium and lead. Four storm events were selected for detailed analysis. The Kildare site and filter drain site at Monasterevin are close to each other, Figure 11.1. Both sites carry traffic in the same easterly direction and as it is the same motorway traffic volumes passing each site would be very similar. The precipitation characteristics are very similar as highlighted in the hydrographs for the storms shown in Figures 11.2 and 11.3. The only differences between the two sites are the drainage systems, the slope of the highway (Kildare site is steeper) and their age (the Kildare by-pass is exactly a year older than the Monasterevin by-pass).

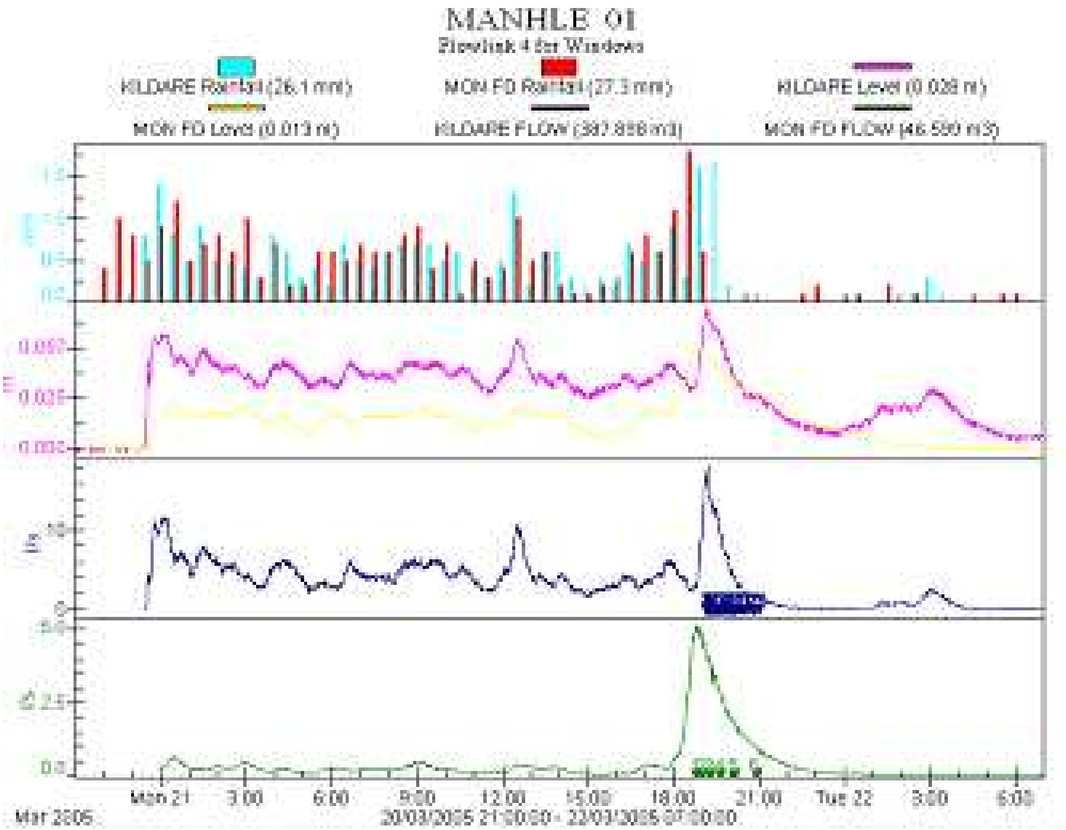


Figure 11.2: Storm Event on 21 March 2005

11.5 Results

The comparison details are shown in Table 11.4. The kerbed site consistently has much higher suspended solids, heavy metals and (when detected) PAHs. However, the filter drain occasionally has higher concentrations of TOC and Cl^-.

11.6 Comparison with Environmental Quality Standards (EQS)

Table 11.5shows the maximum PAHs concentrations detected and compares the values with the US EPA's environmental quality standards (EQSs). Some are several order of magnitude higher than the EQSs. Table 11.6 compares some other measured determinands with their corresponding EQSs.

Table 11.4: Results

Substance	21-Mar-2005		17-Apr-05		03-May-05		23-Jun-05	
	Filter Drain	Kerbed Site	Filter Drain	Kerbed Site	Filter Drain	Kerbed Site	Filter Drain	Kerbed Site
Total Suspended Solids (mg/l)	23	404.78	46	1847.61	27	1340	122	1117.97
Total Organic Carbon (mg/l)	2.325	2.101	4.84	10.47	2.107	1.958	21.06	8.785
Chloride (mg/l)	10.6	1.082						
Total Phosphate (mg/l)	0.08	0.436		1.18	0.1138	0.982	0.19	0.848
Total Copper (mg/l)	0.024	0.0957	0.044	0.27	0.0068	0.164		
Total Zinc (mg/l)	0.104	0.556	0.023	1.59	0.023	1.026		
Total Cadmium (mg/l)	0.01	0.0066	0.004	0.0125	0.0023	0.0096		
Total Lead (mg/l)	0.086	0.1181	0.091	0.3325	0.085	0.2023		
Total PAH (μg/l)	1.681	6.496	<0.01	<0.01		<0.01		
Acenapthene(μg/l)	<0.01	0.304	<0.01	<0.01		<0.01		
Acenaphthylene(μg/l)	0.161	0.069	<0.01	<0.01		<0.01		
Anthracene(μg/l)	0.09067	0.472	<0.01	<0.01		<0.01		
Benzo(a)anthracene(μg/l)	0.119	0.206	<0.01	<0.01		<0.01		
Benzo(b)+(k)fluoranthene(μg/l)	0.05467	0.309	<0.01	<0.01		<0.01		
Benzo(ghi)perylene(μg/l)	0.04633	0.157	<0.01	<0.01		<0.01		
Benzo(a)pyrene(μg/l)	<0.01	0.217	<0.01	<0.01		<0.01		
Chrysene(μg/l)	0.345	0.542	<0.01	<0.01		<0.01		
Dibenzo(ah)anthracene(μg/l)	0.07433	0.219	<0.01	<0.01		<0.01		
Fluoranthene(μg/l)	0.078	0.892	<0.01	<0.01		<0.01		
Fluorene(μg/l)	<0.01	0.232	<0.01	<0.01		<0.01		
Indeno(123cd)pyrene(μg/l)	0.04133	0.119	<0.01	<0.01		<0.01		
Naphthalene(μg/l)	0.273	0.728	<0.01	<0.01		<0.01		
Phenanthrene(μg/l)	0.09	0.972	<0.01	<0.01		<0.01		
Pyrene(μg/l)	0.124	1.052	<0.01	<0.01		<0.01		

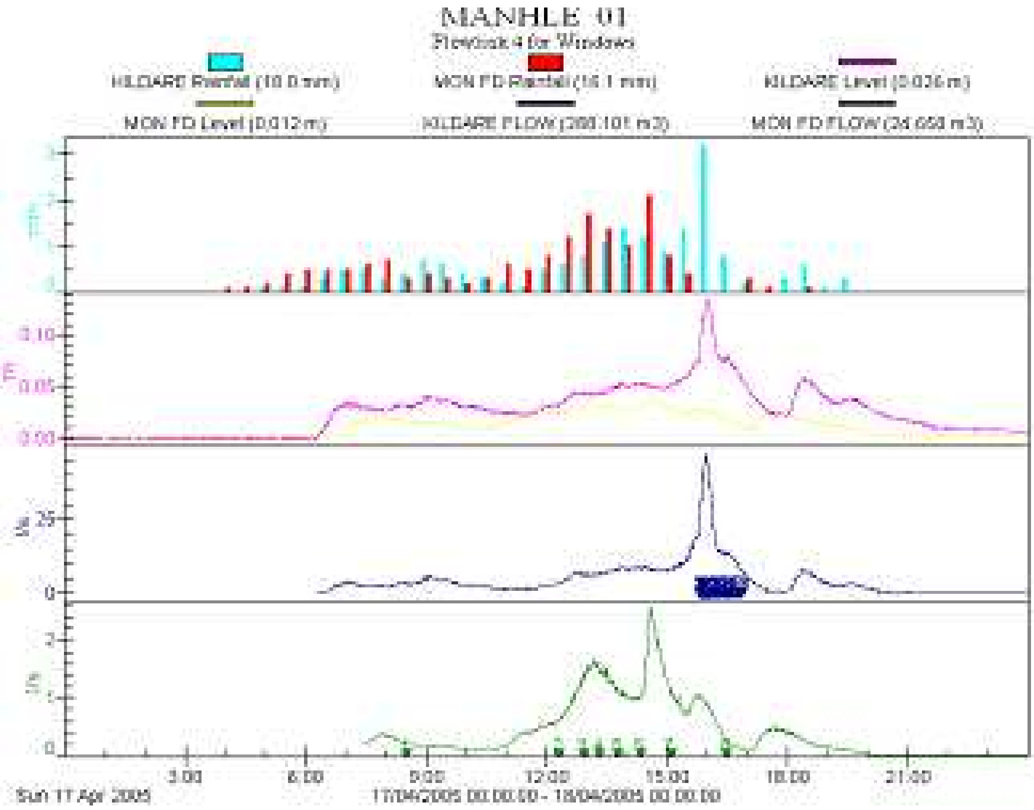


Figure 11.3: Storm Event on 17 April 2005

11.7 Comparison between the sites

The concentration of pollutants measured at Kildare Town Bypass is generally the highest. The maximum flow weighted mean concentration of total suspended solids from this site was 3342mg/L. the Maynooth and the Monasterevin sites have 556mg/L and 122mg/L respectively. This is probably because of the drainage system type used. Kerb and Gully does little or no treatment to the runoff water (if not the opposite). The other two sites have Filter Drain system.

11.8 Analysis of Results

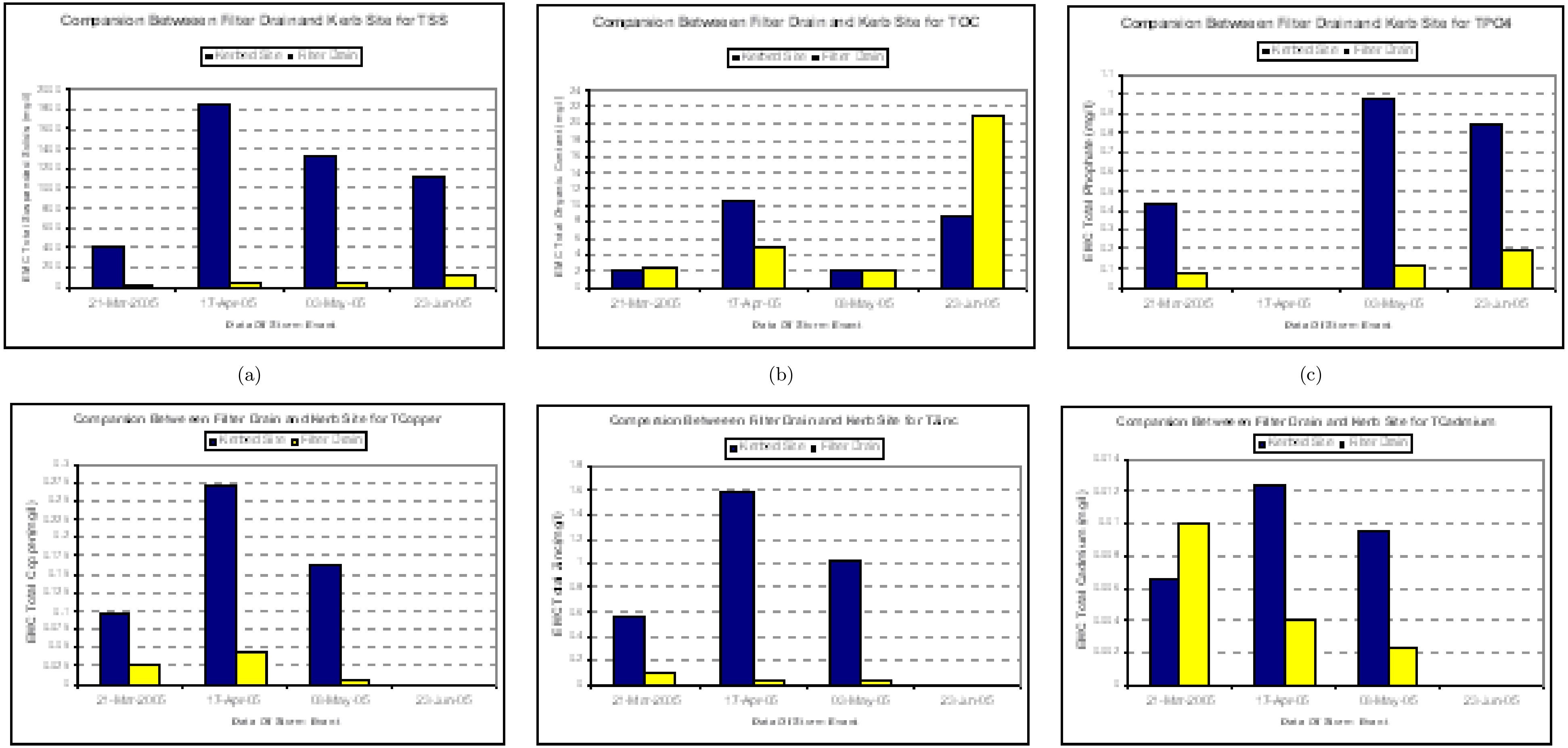
The results are summarised in Figure 11.4. The six pollutants monitored and then analysed were total suspended solids, total organic carbon, total phosphate, copper, zinc, cadmium and lead.

11.8.1 Total Suspended Solids

Comparing similar storm events between the Kildare site A and the filter drain site C suggests the removal efficiency of the filter drain for the total suspended solids was very high ranging from 89 to 98%. This is comparable with other research findings. Perry and McIntyre (1986) found removal efficiencies of 85% for TSS and Mudge and Ellis (2001) found removal efficiencies up to 90%, Figure 11.6

11.8.2 Total Organic Carbon

Removal efficiencies for total organic carbon were very varied ranging from a negative removal of -140% (not on diagram) to 54% the reasons will be investigated further.



(a) (b) (c)

(d) (e) (f)

Figure 11.4: Comparison between kerb and filter drain sites (TSS,NPOC,TP,Cu,Zn,Cd)

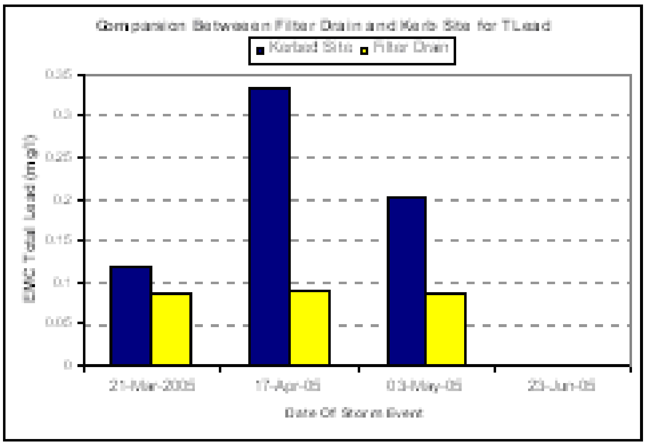


Figure 11.5: Comparison between kerb and filter drain (Lead)

Table 11.5: Maximum PAHs detected (all from the Kildare site) and EQSs (over 16 month period)

Determinand	LOD, ng/L	Max, μg/l	EQS*, μg/l
Naphthalene	10	3.048	44
Acenaphthylene	10	0.307	4840
Acenaphthene	10	1.347	9.9
Fluorene	10	2.039	3.9
Phenanthrene	10	15.082	2.1
Anthracene	10	3.778	0.029
Fluoranthene	10	20.566	8.1
Pyrene	10	13.319	0.3
Benzo(a)anthracene	10	8.147	0.0839
Chrysene	10	10.727	0.033
Benzo(b)+Benzo(k) fluoranthene	10	7.029	9.0756
Benzo(a)pyrene	10	4.789	0.014
Indeno(123cd)pyrene	10	2.545	4.31
Dibenzo(ah)anthracene	10	1.111	5
Benzo(ghi)perylene	10	2.936	7.64

**US EPA Ecological Screening Level, 1999*

11.8.3 Total Phosphate

The removal efficiencies of total phosphate ranged from 78 to 88%. This is very high and is not well documented in the literature.

11.8.4 Heavy metals

The removal of zinc was high ranging 81% to 99% this is comparable with findings from Perry and McIntyre (1986) who reported removal efficiencies of 81%.

The removal of cadmium ranged from a negative value of -52 to 76%. This will need further investigation.

The removal of lead ranged from 27 to 73% this is lower than reported findings of 83% reported by Perry and McIntyre (1986).

The removal of copper ranged from 41 to 83%. This will need further investigation.

Table 11.6: Maximum Values for some determinands

Pollutant	Maximum value , mg/L	EQS*, mg/L
TSS	10495	-
TP	4.45	0.7
NPOC	74.02	-
Cd	0.02	0.05
Cu	0.45	0.05
Pb	0.8	0.005
Zn	3.2	3
Cl-	367	250

**Surfacewater Abstraction Directive(75/440/EEC)*

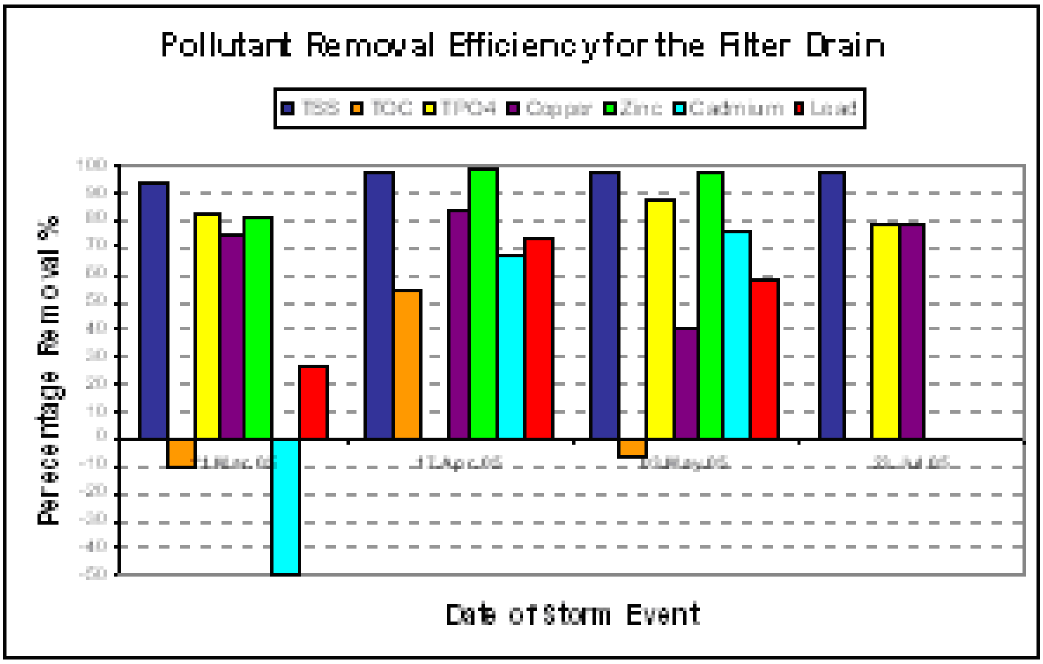


Figure 11.6: Pollutant removal efficiencies for the filter drain

11.9 Relationships between the parameters measured

A regression analysis indicated a strong linear relationship between Total Suspended Solids and many of the other parameters, particularly the heavy metals. To illustrate, Figures 11.7 to 11.13 show the correlations for the Kildare site. Similar strong correlations were found for the Maynooth filter drain site, but not for the Monasterevin (new filter drain) site. This may be because the latter has, in general, a lower suspended solids content in its runoff. This has a strong implication on the method of treatment to be employed. This means that much of the pollutants would be removed if the suspended solids were effectively removed from the runoff. There is also a strong correlation between the heavy metals. This implies that these the physical and chemical conditions that mobilize these metals are similar.

It is also important to mention that the "first flush" effect is clearly observed for suspended solids and other pollutants. The effect of the antecedent dry period (ADP) was also apparent in some of the parameters. A typical example would be a storm that occurred on the 25th of May 2004. The ADP was 20 days. The total suspended solids load on the first bottle was measured at 10,495mg/L.

11.10 Conclusions

1. The filter drain performed surprisingly well removing up to 98% of the total suspended solids (TSS), 54% for total organic carbon (TOC), 88% of the total phosphate (TP), 99% of total zinc, 76% of total cadmium, 73% of total lead and 83% of total copper. There were increases in contaminants including total organic carbon and cadmium at the outlet of the filter drain for a few storm events.

2. The runoff coefficients which are basically a water balance for the system were found to be extremely low indicating a large volume of highway runoff is going elsewhere in the system probably into the underlying subsoil. In certain locations, this may have implications for groundwater contamination and protection which needs to be investigated further.

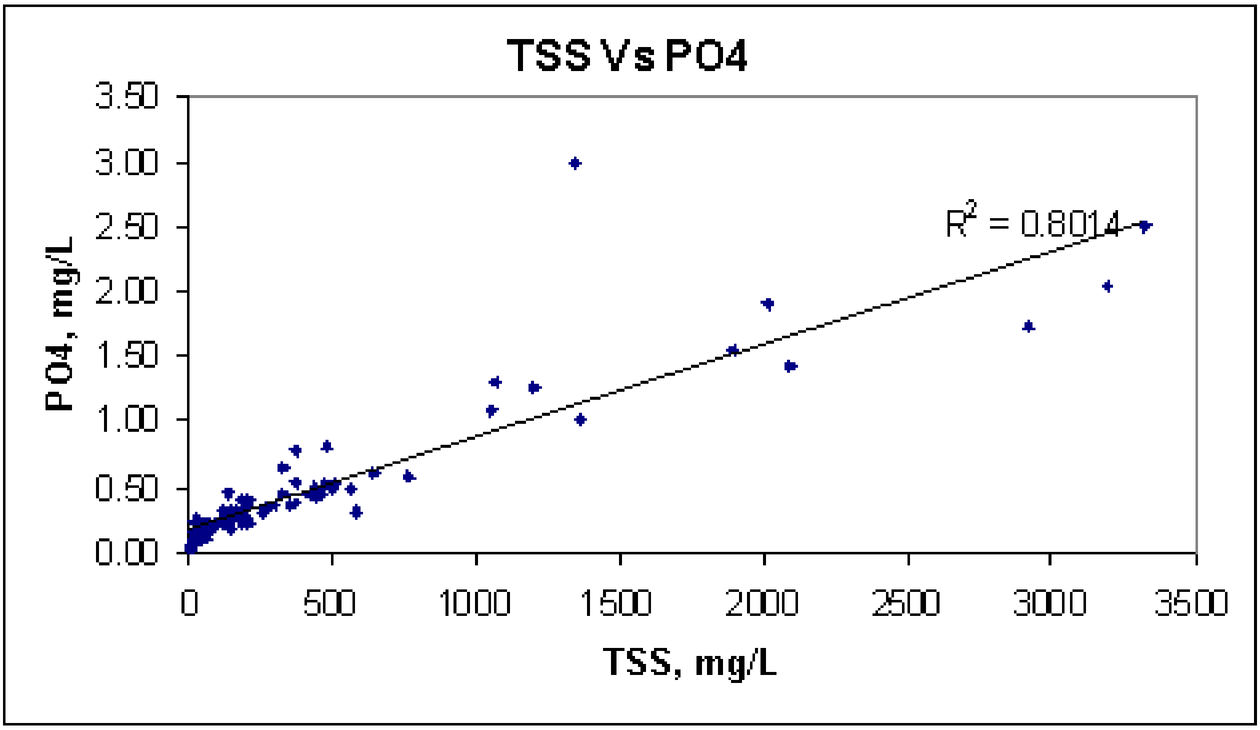


Figure 11.7: Relationship between TSS and Phosphate

11.11 Excavation of Old and New Filter Drain

11.11.1 Old Filter Drains

Filter drains (french drains) are by far the most popular type of highway drainage system found on motorways throughout Ireland. A visual survey of the M7 Dublin to Portlaoise found 72% of the linear highway drainage was made up of filter drain (FD) systems. They are frequently employed in Ireland because groundwater levels tend to be high and subsurface drainage systems such as filter drains are needed to control water levels under the sub base of the road and softening of the pavement structure.

Since the year 2000 a geotextile lining has been included in the FD design and construction, Figure 11.14. The purpose of this geotextile is twofold; it adds strength to the FD structure and also prevents silt from entering and clogging the FD material. Part of this project is to investigate the purpose of the overlapping of this geotextile at approximately 300mm in depth from the surface of the filter drain.

Two filter drains were excavated and sediment samples were extracted within the filter drains for further analysis. The first filter drain was excavated at the Maynooth Site D were the new Kilcock

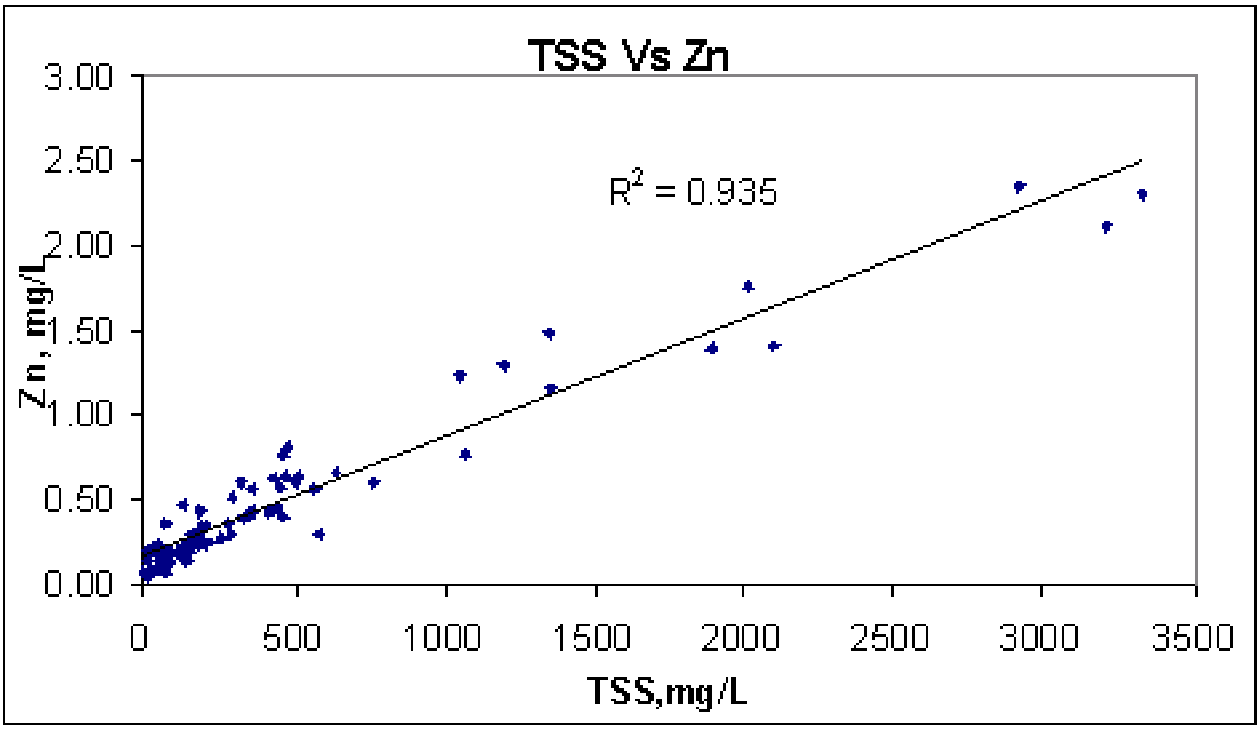


Figure 11.8: Relationship between TSS and Zinc

By-pass is tied in with the old Maynooth By-pass (M4). This FD is 12 years old and an example of the old type which has no geotextile lining. The second filter drain was excavated at the Naas Road were the existing highway is been widened into three lanes. This FD is approximately 5 years old and is an example of the new type of FD which has a geotextile lining in the structure.

Results

Runoff coefficients which indicate the water balance of the filter drain system have already been calculated for the old filter drain at the Maynooth site D and the new filter drain at Monasterevin Site C. The runoff coefficient values for the old type of FD (Site D) ranged from 0.28 to 0.62 with an average of 0.52. The runoff coefficients for the new type of FD (Site C) were notably lower ranging from 0.03 to 0.52 with an average of 0.19.

The mean runoff coefficient for the old FD at the Maynooth Site D was low compared to other research findings. This low value could indicate that there is a substantial lose of water throughout the system maybe into the underlying subsoil, this as clear implications for groundwater contamination. The mean runoff coefficient for the new FD at the Monasterevin Site C is extremely low and such values have never been reported before. One of the reasons for this low value could be a blockage in the system which as a result prevents water passing through the filter material to the carrier pipe.

The two types of filter drains were excavated and soil samples were taken to be tested for heavy metals and particle size distribution.

The soil samples which included the filter drain material (gravel) and associated sediment were extracted throughout the filter drain structure as shown in Figures 11.15 and 11.16. They were tested for metal content which included copper, cadmium, zinc and lead, this is shown in Figrure 11.21 which show the metal content of the samples from the top of the FD right through to the bottom. A particle size distribution analysis was also carried out on each of the samples and represented in Figure 11.22.

Discussion

The soil samples at the top of the filter drain show high values for all four metals which gradually decreases towards the bottom of the filter drain. The metals lead and zinc concentration in the sediment

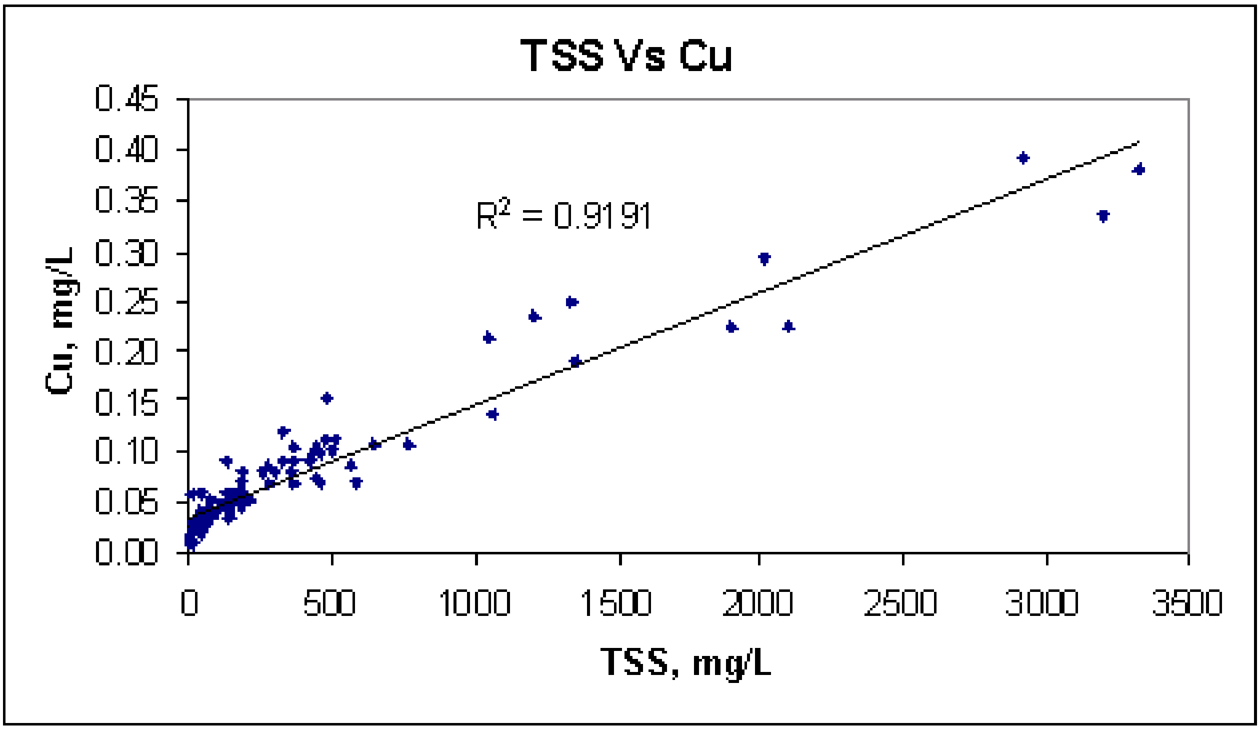


Figure 11.9: Relationship between TSS and Copper

show the greatest decrease from the top to bottom of the FD with a decrease of approximately 70% at the bottom. The metals cadmium and copper follow the trend of decreasing as the FD gets deeper but not to the same degree in fact copper is only reduced by 5% from top to bottom.

The majority of the filter material in the upper section of the FD should be retained in the 14mm sieve or higher if it were constructed properly. The particle size analysis values indicate that there is a large percentage of intruded material i.e. sediment less than 14 mm in the top section of the FD as much as 65%, with 50% in the middle section. These results indicate that either the filter drain was not built to the correct specifications or that it has become clogged with sediment from the highway surface.

Figure 11.18 shows one of the consequences of the clogging of the filter material. Highway runoff is restricted from passing through the FD to the carrier pipe at the bottom. If the highway surface is not adequately drained through deteriorated infiltraiton there could be problems with localised flooding and water entering and softening the pavement structure.

11.11.2 New Filter Drain Site

The next site to be excavated was the new FD structure located on the Naas By-pass. This FD had a non woven geotexitle incorporated into the structure which was overlapped at approximately 300 mm from the FD surface. Samples were taken at top of this overlap and at the bottom. A particle size distribution analysis was carried out on the samples and the results are shown in Figures 11.21 to 11.23.

Results

At the top of the geotextile there was 45% intruded material found but below the geotextile there were only 11% intruded material found. From a visual inspection one can clearly see that the top of the geotextile is badly clogged with sediment and below the geotextile the filter material is in excellent condition and could easily be used for other FD constructions. The geotextile is obviously doing its job of preventing sediment passing but ironically because of this it is becoming clogged at the overlap with the high sediment load from the highway surface. If this blockage is hindering the passage of runoff from the highway this has significant implications for the drainage of the road.

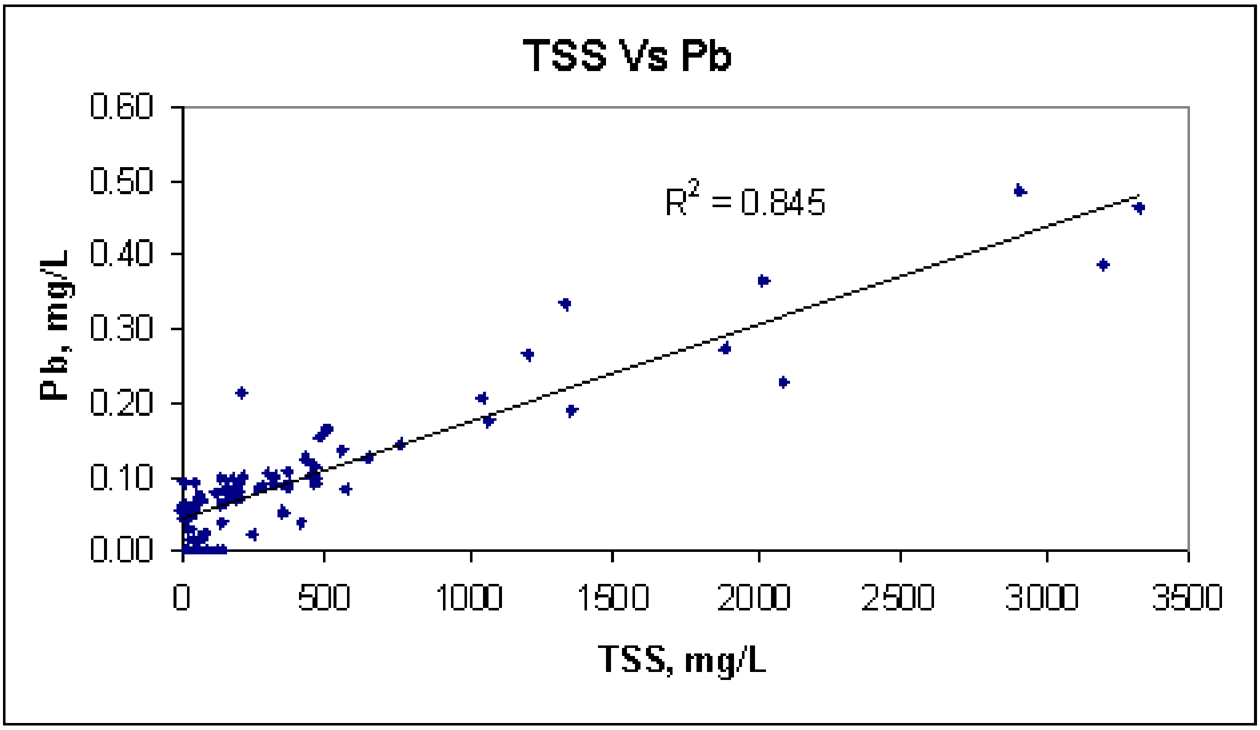


Figure 11.10: Relationship between TSS and Lead

Discussion

In Volume 2 of 'Notes for Guidance on the Specification for Road Works' (2000) it is stated that if a geotexile is to be used in the FD structure it should incorporate a margin of safety to allow for the reduction in permeability with time due to clogging. It also states that this margin should also include an allowance for the fact that the geotextile's quoted permeability is obtained from an unimpeded water flow test, whereas the filter material in a FD will block some of the geotextile. If the geotextile is to be used in the FD structure this margin of safety should be investigated especially where the overlap is which incorporates a doubling up of the geotextile material.

11.11.3 Conclusion

It is clear that the old type FD at the Maynooth Site D has become clogged with sediment over its 12 year life span. As a result a large percentage of the runoff from the highway is either remaining on the road surface or going elsewhere in the system most likely into the underlying sub soil, probably to groundwater.

It is surprising to see that the new FD which was investigated on the Naas By-pass (excavation) and at Monasterevin Site C (water balance) is becoming blocked so soon. The FD on the Naas By-pass is approximately 5 years old and already has 45% intruded material present above the overlap geotextile. The FD at the Monasterevin site is only a year old and the water balances indicate a significant water loss throughout the system. The mean average runoff coefficient indicates a loss of 80% of the runoff from the highway surface. It was found that up to 98% of the total suspended solids was removed from the highway runoff entering the filter drain.

It is clear to see that there is already a problem with this FD design in particular the overlap of the geotextile material. The blockage that already exists will only get worse as the more sediment load from the highway surface enters the FD and is impeded from passing by the geotextile material, which is acting as a filter barrier. As a result this new FD system should be investigated further and a new design, one which may exclude the overlap of the geotextile, brought into practice.

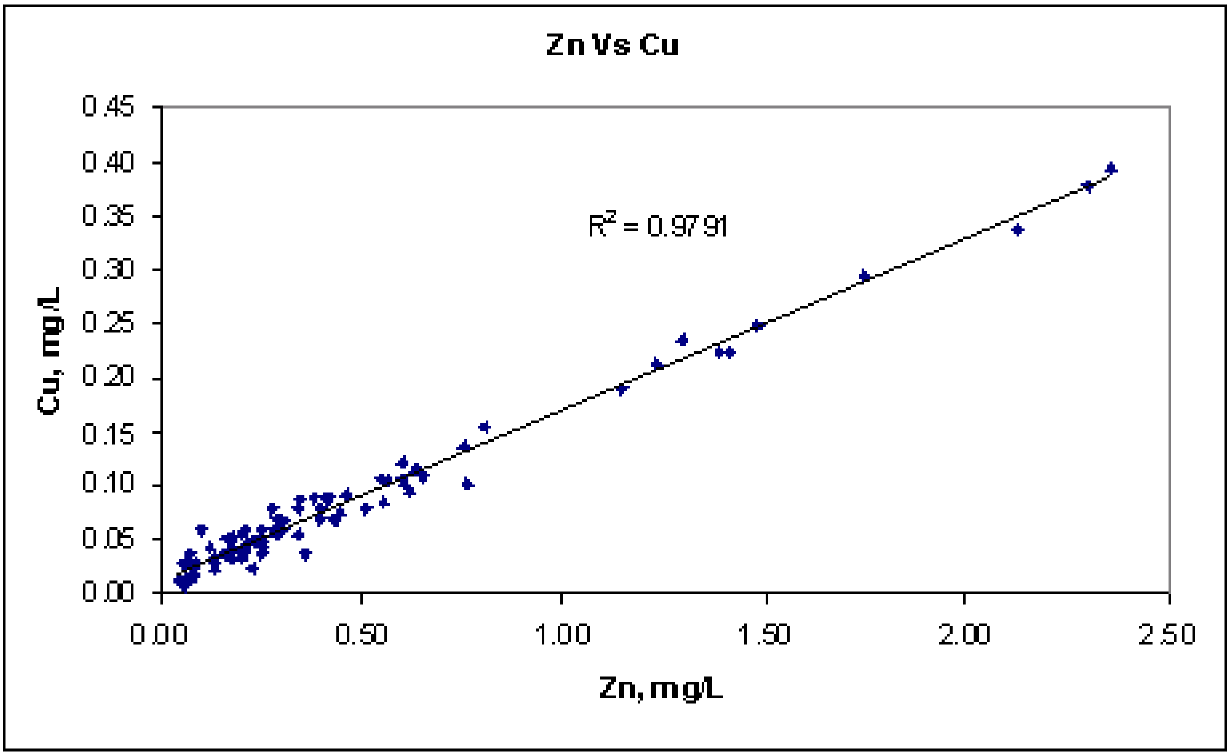


Figure 11.11: Relationship between Zinc and Copper

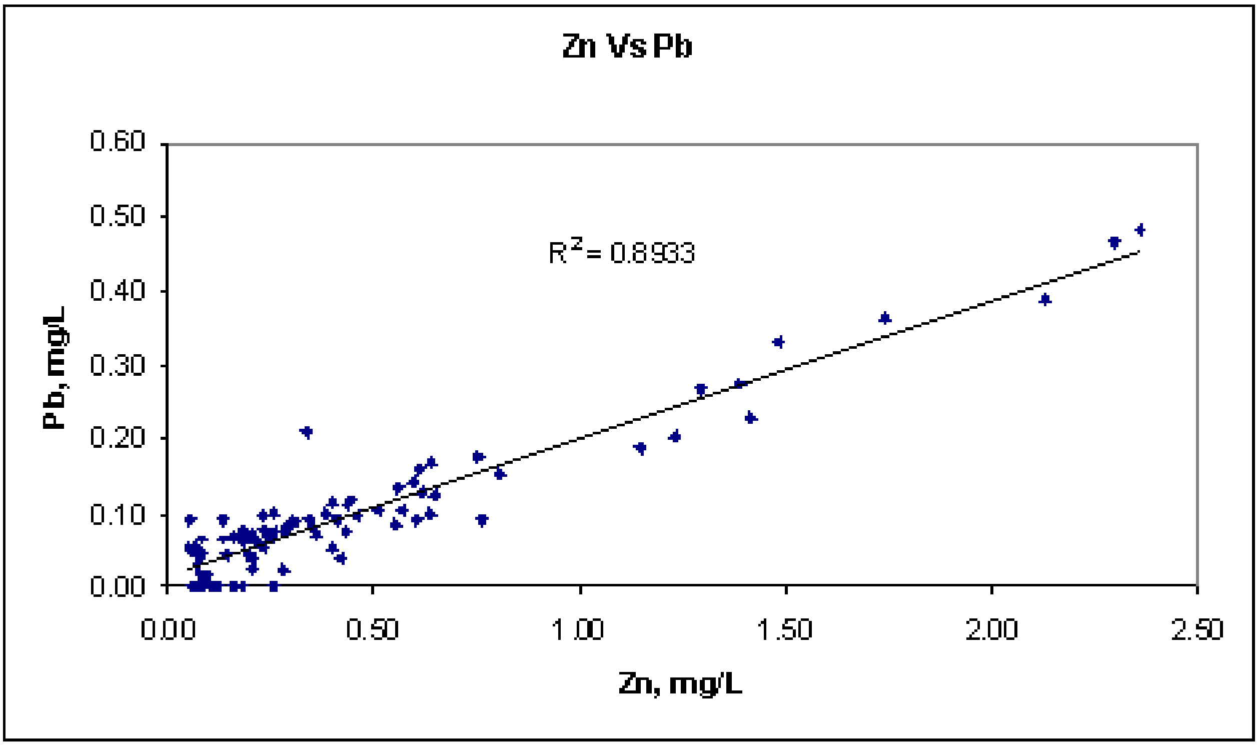


Figure 11.12: Relationship between Zinc and Lead

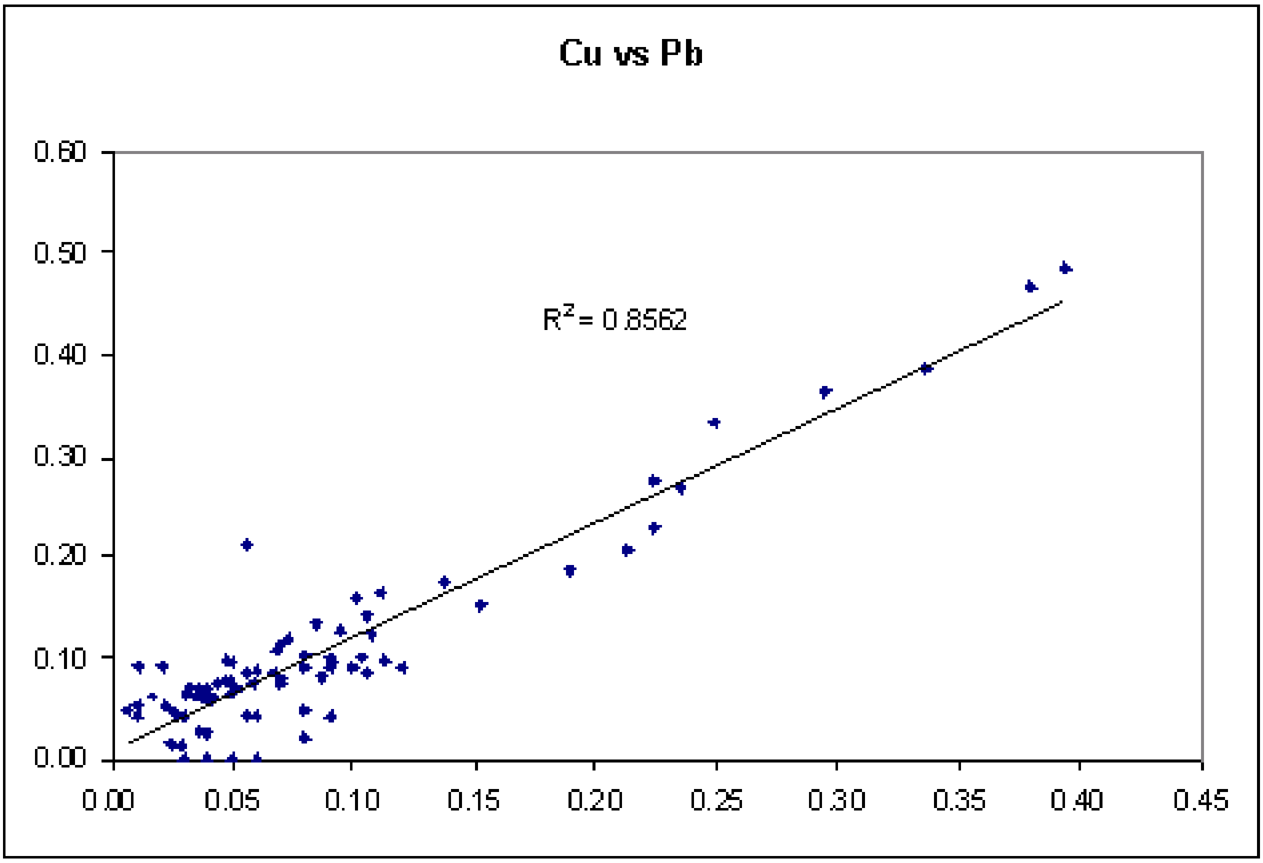


Figure 11.13: Relationship between Copper and Lead

Figure 11.14: Diagram of the old and new filter drain systems

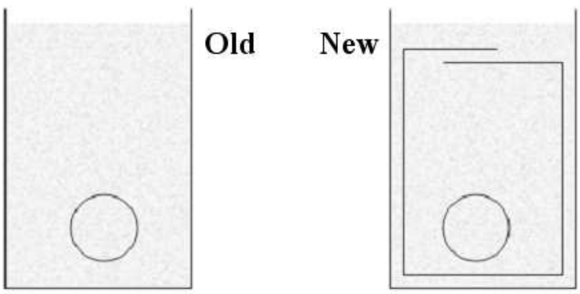


Figure 11.15: Excavation of the old filter drain at the Maynooth Site D

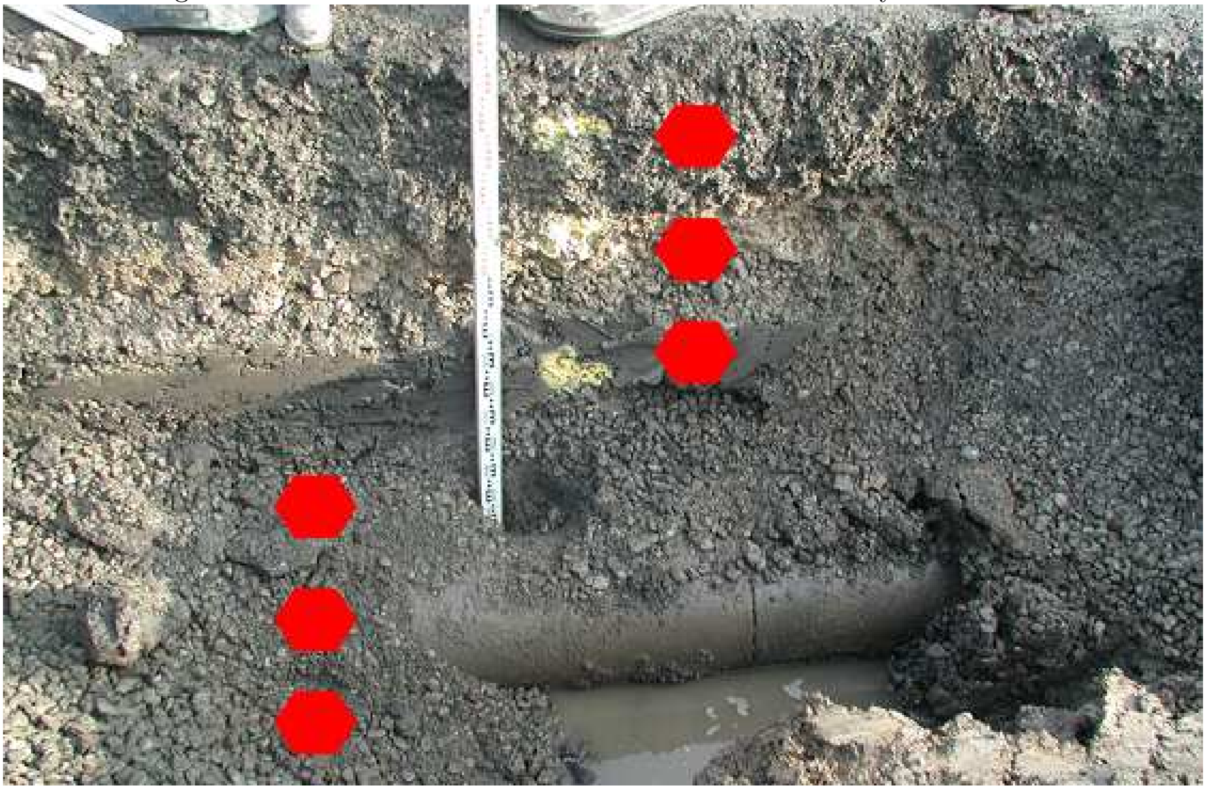


Figure 11.16: Locations of sampling points

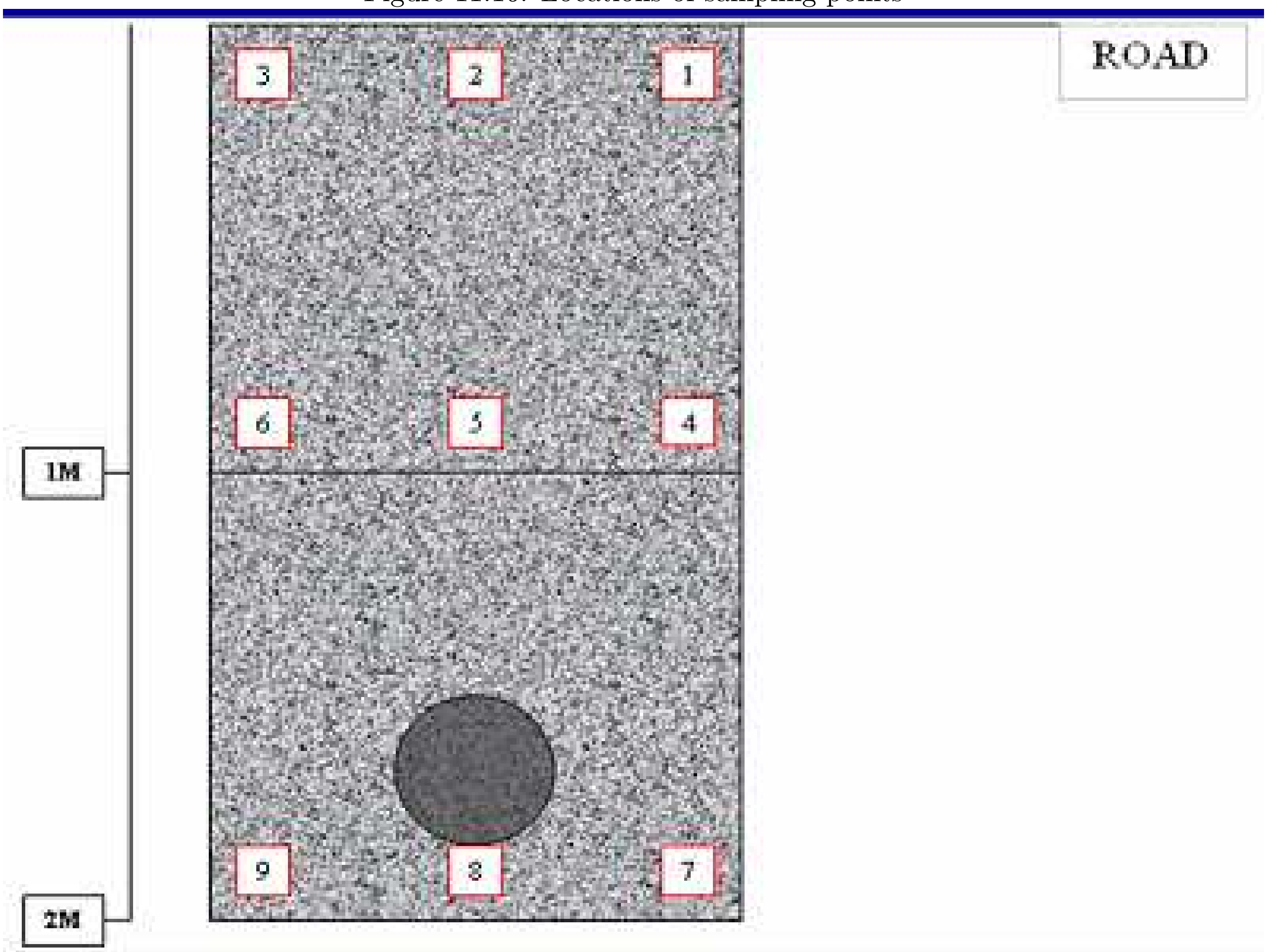
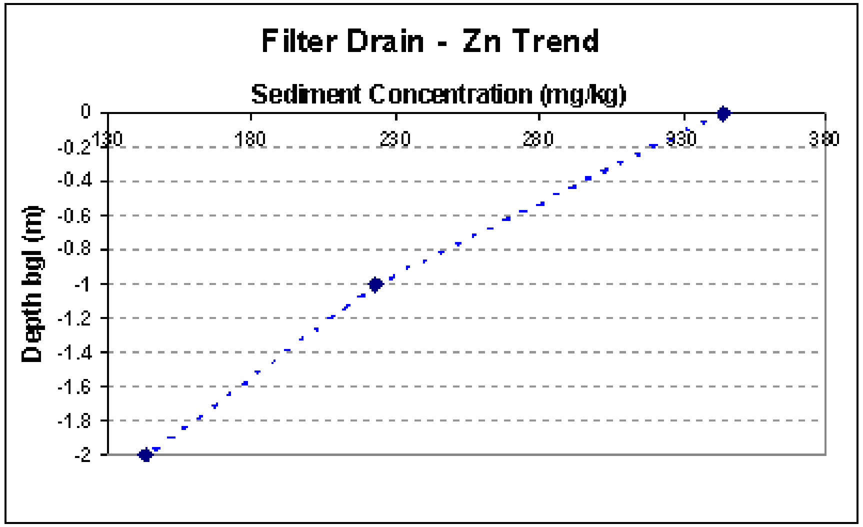


Figure 11.17: The concrete pipe at the bottom of the old FD (Maynooth)

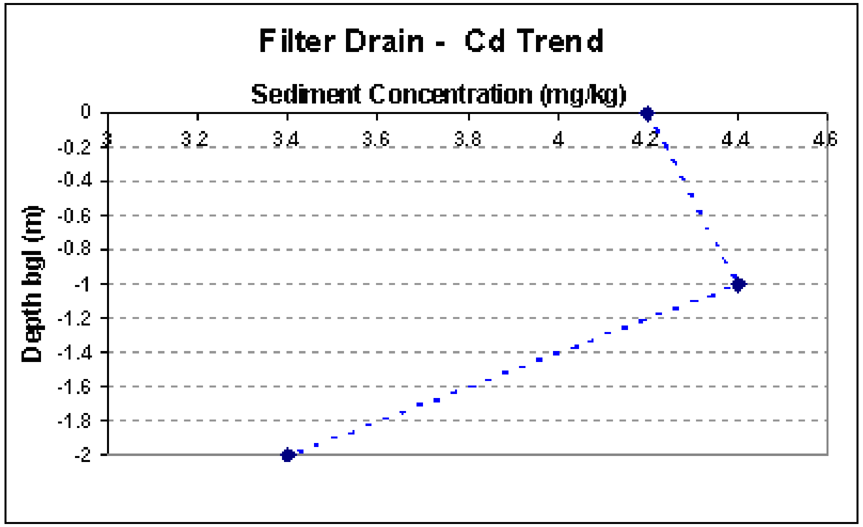
Figure 11.18: Water is ponding on the surface of the filter as a result of the filter material clogging

Figure 11.19: The concrete pipe at the bottom of the new FD (Naas By-pass)

Figure 11.20: The geotexile overlap (woven geotextile)



(a)



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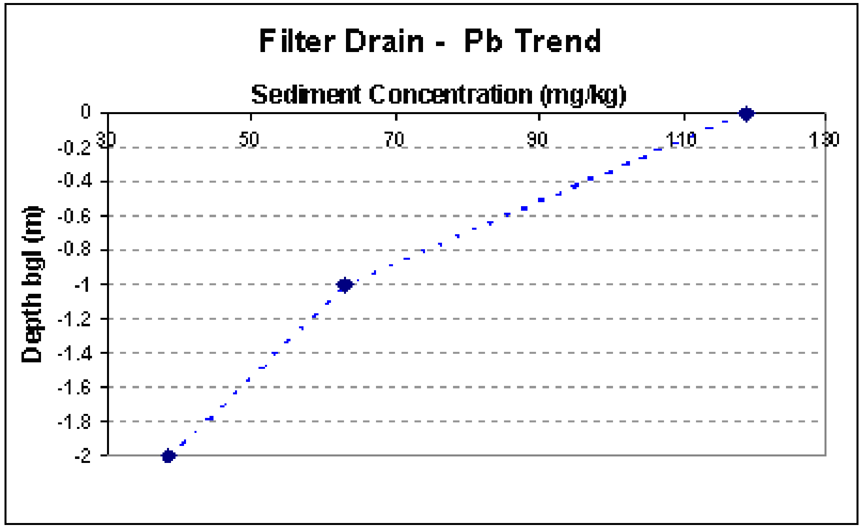
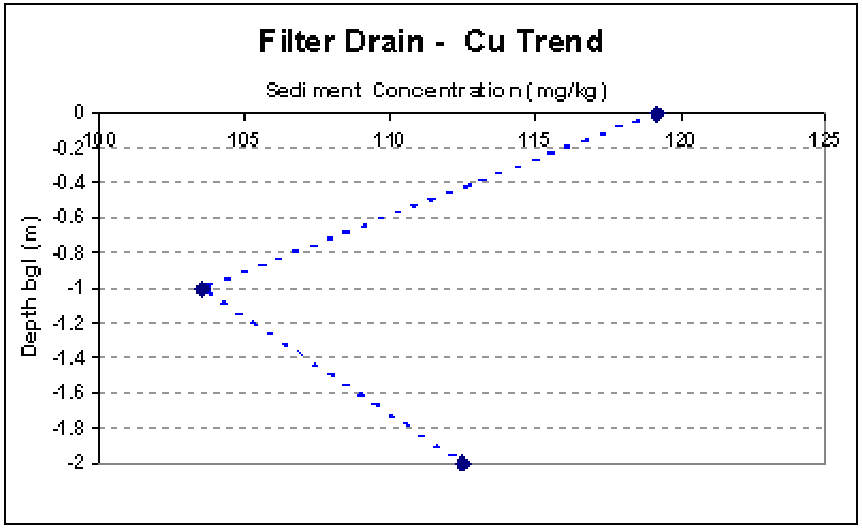
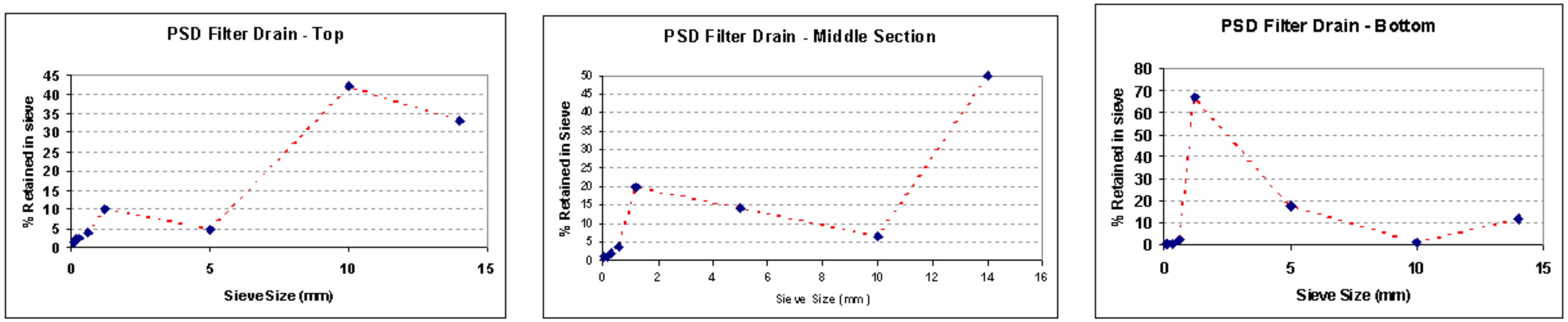


(c)



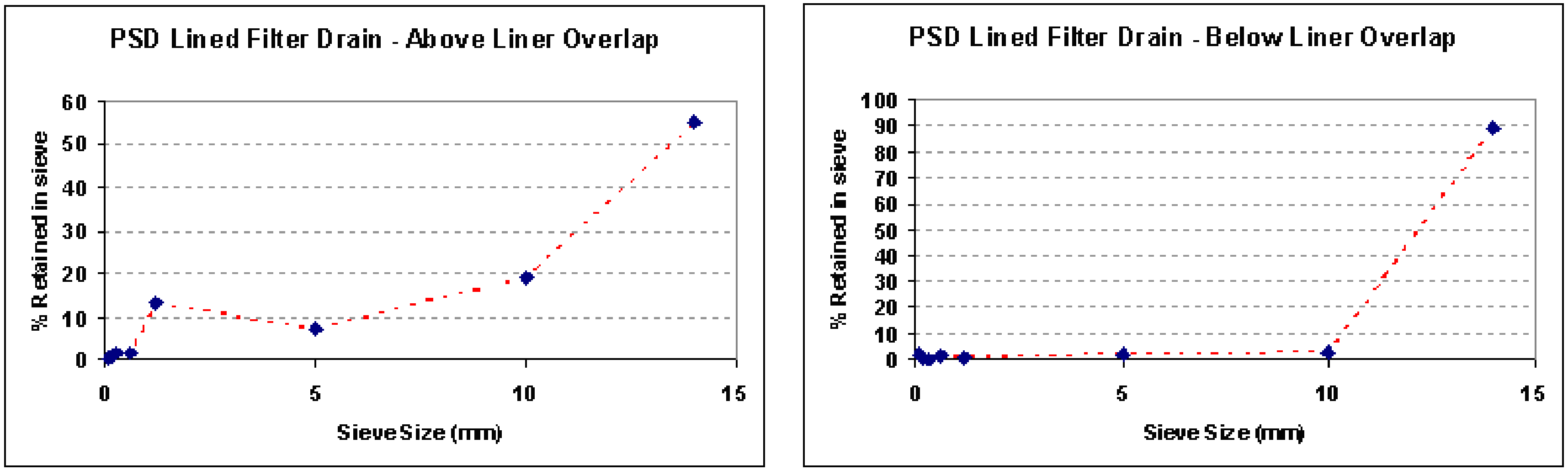
(d)

Figure 11.21: Concentration of heavy metals in sediment throughout filter drain (old FD)



(a) (b) (c)

Figure 11.22: Particle size distributions at filter drain (old FD)



(a) (b)

Figure 11.23: Particle size distributions at new filter drain

Chapter 12

Assessment and comparison of treatment options

12.1 Introduction

The construction of impervious highway surfaces is on the increase in Ireland, with an estimated 850 Km of highway scheduled to be built by 2014 (National Roads Authority, Ireland, 2005). With this increase in paved areas comes an extensive modification to the existing hydrological cycle with increased flow rates to adjacent surface and ground waters. The runoff associated with these discharges is characterised by fast flowing events which can lead to both a hydraulic and water quality impact on existing waters.

The current highway drainage design in Ireland is to provide rapid removal of the water from the highway surface. The methods used are either through direct and positive drainage e.g. kerb and gully to the nearby water course or by indirect drainage involving an infiltration system e.g. filter drain which may include integrated collection.

It is now widely acknowledged after numerous research that runoff from the highway surface particularly heavily trafficked surfaces can contain a range of pollutants which if discharged to adjacent waters can have detrimental impacts on both the ground and surface water quality. As a result there needs to be a new approach on how to manage highway runoff and the way it is discharged to receiving waters so that the environment is not impacted on. Pollutants carried from highway surfaces in the runoff can now be controlled by a set of controls commonly called Best Management Practices.

12.2 Review of Best Management Practices

Highway runoff Best Management Practices (BMPs) are defined as schedules of activities, prohibitions of practices, maintenance procedures, the use of pollution control devices and management procedures to prevent or reduce the amount of pollution introduced to receiving waters from highway runoff.

The most economical and effective time to address potential impacts of highways is during the initial planning and design stage. It is much more costly to correct any problems after the highway has been constructed. During the planning phase, the way to reduce a highways impact is often as simple as choosing the route which avoids flood plain areas, environmentally sensitive areas, and minimises water crossings. During the design phase, after a highways location and layout have been determined, the impact of highway runoff can be addressed and suitable best management practices can be integrated into the design. Best Management Practices can be divided into two main groups:

1. Non-Structural Best Management Practice - which deal with source management such as transportation and land use planning.

2. Structural Best Management Practices - which include the physical construction of a system such as a swale or a detention pond.

12.3 Non-Structural Best Management Practices

The first consideration in Best Management Practice evaluation is whether non-structural BMPs (source controls) can be used effectively to prevent pollutants from entering highway runoff by eliminating the source of the pollution, or by preventing contact of pollutants with the rainfall and runoff (Washington State Department of Transportation, 1995). Non-structural BMPs are by far the most cost-effective means for reducing pollutant constituents in highway runoff; however they seldom replace structural controls as an option. If they are properly deployed they can reduce the pollutant removal requirements for a structural BMP as well as provide some aesthetic appeal that may not be included in the selected structural BMP.

Non-structural Best Management Practices are basically practical activities that can be carried out to reduce the source of the contaminants that are available to be carried in the highway runoff to nearby water courses. They involve a good understanding of the highway and the pollutants that may be associated with it. A number of non-structural practices exist including, transport management, control of de-icing agents, and street and gully pot cleaning.

12.3.1 Transport Management

Providing alternative modes of transportation or encouraging car pooling can reduce the traffic congestion and also lower the fuel consumption and total vehicle miles travelled. Burch et al., (1985) reported the success of several such programs at reducing the total load of pollutants deposited on the highway surface. Gupta et al., (1984) suggested that traffic factors such as vehicular mix (percentage trucks/cars), congestion factors (stop and start conditions), number of highway lanes and the vehicle speed all contributed to the pollutant load in highway runoff. Therefore these factors should be investigated and controlled to reduce the pollutant build-up on the highway surface. Barrett et al., (1995) reported that the goal of land use and transport planning for mitigation of highway runoff is to protect the environmental balance of an area in terms of runoff volume, rate and water quality by restricting developments that generate high traffic volumes in sensitive areas.

The actual design of the highway can also have implications for the reduction of runoff pollution. The elimination of barriers such as kerbs prevents many types of sediment and other particulates being trapped on the highway. With the exclusion of these kerbs, wind and turbulence will remove much of the fine material from the highway surface reducing the sediment load in the runoff (Burch et al., 1985a)

The application of fertilisers, herbicides and pesticides, particularly in areas with direct runoff to natural receiving waters should be managed to prevent unnecessary release. Pesticides and herbicides which are used to control weeds in highway medians can cause significant acute and chronic toxic responses in terrestrial and aquatic ecosystems (Barrett et al., 1995).

12.3.2 Control of De-icing Agents

The benefits from the use of de-icing salt on highway surfaces should be weighed against the associated environmental costs. Concerns have been raised about the high levels of chloride in surface and ground waters adjacent to highways in the US. As a consequence most States in the US now require salt applications to be used wisely so as not to create excessive waste. Amrhein and Mosher (1993) reported that calcium magnesium acetate which is less toxic to aquatic live and is less mobile in road side soils than sodium chloride could be used as an alternative although it is more expensive. Marsalek et al. (1999) reported that through the careful use de-icers and the adoption of BMPs to allow for chloride dilution the environmental impact can be significantly reduced.

Vegetative management such as grass cutting should also be carefully managed. Such operations can leave cuttings and other debris along highway shoulders, which in time can form thatch layers which can hinder the passage of water and cause flooding (Barrett et al., 1995).

12.3.3 Street and Gully Pot Cleaning

Street cleaning processes have often been considered as a possible means of reducing the pollutant loads on highway surfaces. Several studies have reported findings from studies on highway and urban streets with the majority of research conducted on urban streets.

Maestri et al, (1985) reports that street cleaning is effective only for large solids and as most pollutants are associated with fine material there is little reduction in pollutant load. Sartor and Boyd, (1972) concluded that street cleaning processes were essential for aesthetic purposes but that their efficiency in the removal of the dust and dirt fraction of street surface contaminants was low.

Highway gully pot emptying should be undertaken at least once every six months with the removed material disposed to landfill. There is currently limited research that has been conducted on gully pot emptying and associated pollutant removal efficiency, although Young et al. (1996) have reported that unless frequently maintained, gully pots can become a source of pollutants through resuspension.

12.4 Structural Best Management Practices

Many researches including Barrett et al., (1995) have concluded that pollution associated with highway runoff is usually transported by storm water runoff along the kerbside, pavement and hard shoulder. They have also found that the associated pollutant load is either suspended particulate matter or contaminant material adsorbed to the suspended solids; therefore the most effective control measure will reduce the amount of particulates available for transport or will settle and/or filter the particulate matter in the runoff.

Structural Best Management Practices are used to treat the highway runoff either at the point of generation or the point of discharge to receiving waters. The selection and successful design of selected structural BMPs for highway runoff is dependant on where it's to be sited and what's going to be treated. Structural BMPs can be grouped into 5 different categories each with similar and some different roles to play in treating highway runoff.

- Vegetated Controls;
- Ponds;
- Wetlands;
- Infiltration Devices;
- Water Quality Inlets.

12.4.1 Vegetated Controls

Vegetated controls which include swales and filter strips can provide conveyance, storage and infiltration facilities for highway discharge (DMRB-UK, 1998). With careful design they can reduce peak flows and allow runoff volumes to be attenuated long enough for solids and associated pollutants to be removed through sedimentation, biofiltration and chemical adsorption. They usually require a sizeable amount of land and should be located adjacent to the highway surface so that they receive sheet flow either across the filter strip or along the swale. Research suggests that although vegetated controls represent a practical and potentially effective technique for controlling highway runoff quality, there is still considerable variability in their performance (Schueler et al., 1992).

It is evident that swales provide good removal rates for the sediment and associated contaminants however there is little removal rates achieved for soluble metals and nutrients (Barrett et al., 1995). Schueler et al., (1992) reported pollutant removal efficiency for well-designed, well maintained grassed swales as 70% for total suspended solids (TSS), 30% for total phosphate (TP), and 50% to 90% for various trace metals.

Under low to moderate velocity, filter strips can effectively reduce particulate pollutant levels such as sediment, organic materials, and trace metals. Schueler, (1987) reported removal efficiency for a 6 metre width filter strip as 20% to 40% for total suspended solids (TSS), 20% for total phosphate (TP), and 20% to 40% for various trace metals.

The design of the vegetated control is crucial to the overall performance and it is well documented that gentle slopes, check dams, permeable soils, dense grass cover and increased contact time all contribute to successful pollutant removal in the system. It has also been noted that the factors decreasing the effectiveness of the vegetated control include compacted soils, frozen ground, short grass height, steep slopes and high runoff velocities and discharge rates. Dorman et al., (1988) reported that vegetative controls are effective first flush controls and should be used as first flush treatment prior to the use of a further treatment system such as a detention pond.

Figure 12.1: Swale located adjacent to a highway in Scotland

12.4.2 Ponds

The use of ponds to store and attenuate highway runoff is well-documented although there are limited reports on their treatment efficiency. Two types of pond exist - detention pond and retention pond. Detention ponds are primarily flood control devices. They are specifically designed to reduce the peak flow associated with large storm events. In between storms they are usually dry but during a storm event, surface water runoff is routed through the detention pond and the outlet is restricted so that the pond fills with runoff. They are usually designed to detain runoff for up to minimum of 1 hour. In general, the pollutant efficiency of a detention pond is minimal (Pope and Hess, 1989) so their main purpose is to protect stream ecosystems from excessive erosion by reducing the peak rate of runoff during a storm event by storing the flow and releasing it at a lower rate.

Extended detention ponds are similar to detention ponds but water is detained in them for much longer durations. The detention times are increased through the use of adjustable drainage orifices, or by using vertical riser pipes. This increase in detention time allows the suspended particles time to settle out; therefore the pollutant removal capacity is increased and so they are more suitable for improving runoff water quality. Stahre and Urbonas, (1990) have reported efficiencies for extended detention basins having 48 hour detention times of 50% to 70% for total suspended solids and hydrocarbons, 75% to 90% for lead and 30% to 60% for zinc respectively. They reported that the removal efficiency was greatly enhanced by longer detention times.

The retention pond is similar to a dry detention pond except that a permanent volume of water is incorporated into the design. The retention pond is a facility which removes sediment, BOD, nutrients and trace metals from the highway runoff. This is accomplished by slowing down of the highway runoff using an in-line permanent pond which allows the settling out of the pollutants. Mudge and Ellis, (2001) have reported removal efficiencies of 40% to 80% for total suspended solids (TSS), 30% to 60% for hydrocarbons and 30% to 60% for various trace metals.

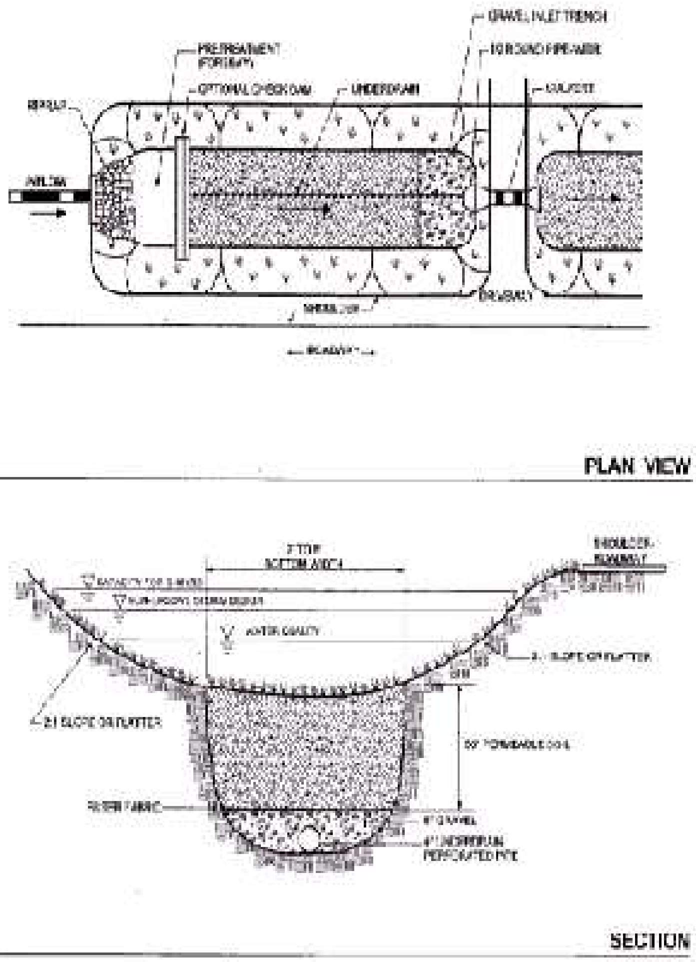


Figure 12.2: A schematic of a dry swale (FHWA, 1996)

Research suggests that properly designed, constructed and maintained retention ponds can be a very effective best management practice. They can also provide substantial aesthetic/recreational value and wildlife habitat. It has been clearly identified that the longer the highway runoff is retained in the pond the greater the pollutant removal efficiency. The presence of a permanent pool as in the retention system provides significant water quality improvement across a broad spectrum of constituents, including dissolved nutrients and heavy metals. Ponds can also provide a considerable reduction in flow rate and energy of highway runoff discharging into receiving water.

Figure 12.3: Extended detention pond located adjacent to a highway in Scotland

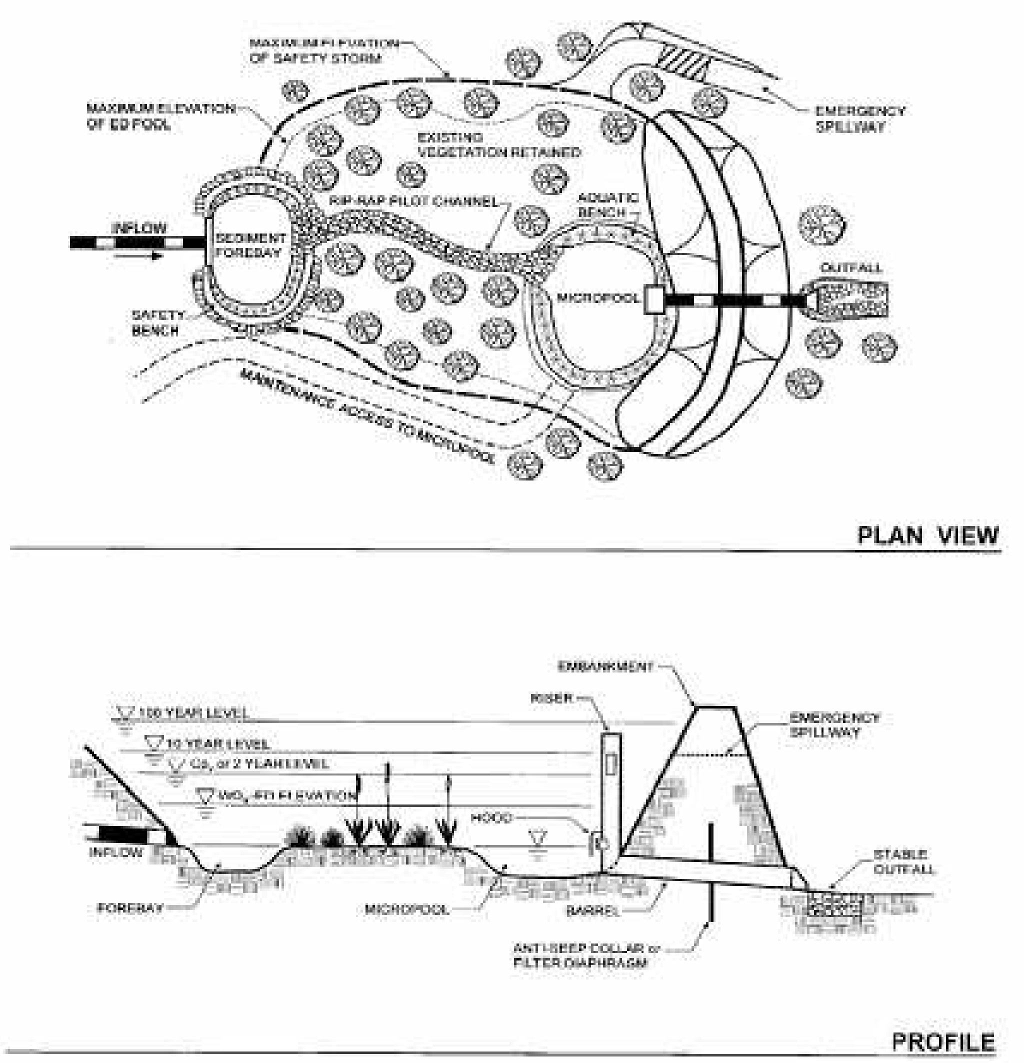


Figure 12.4: Extended Detention Basin (FHWA, 1996)

12.4.3 Constructed Wetland

Constructed wetland basins have normally non-soil substrates and a permanent (but usually shallow) volume of water that can be almost entirely covered in aquatic vegetation. Constructed wetlands provide physical, chemical, and biological water quality treatment of highway runoff. The physical treatment occurs as a result of decreasing flow velocities in the wetland, and is present in the form of sedimentation, evaporation, adsorption, and filtration. Biological processes include decomposition, plant uptake and removal of nutrients, plus biological transformation and degradation. The overall performance of the constructed wetland is largely influenced by the way it is designed and constructed. Factors such as: local climate, topography and geology; traffic loadings (present and future); road drainage area; land availability; cost size/extent and type of receiving water body; water quality classification and objective; and environmental enhancement value will all dictate whether a constructed wetland is suitable for a site.

Wetlands (both natural and constructed) have been widely used and examined for the treatment of sewage and for urban and agricultural runoff but experience in their use for highway runoff is relatively limited (Mudge and Ellis, 2001). Of the known research reported constructed wetlands seem to be one of the most efficient best management practices for flood attenuation, reduction of peak discharges and overall water quality improvement but much more investigation is needed. With the added vegetation there is significant removal of soluble constituents such as nutrients and dissolved metals. Mudge and Ellis, (2001) reported pollutant removal efficiency of 70% to 95% for total suspended solids (TSS), 50% to 85% for hydrocarbons, 40% to 75% for various metals and up to 40% for the dissolved metal fraction.

Figure 12.5: Constructed Wetland adjacent to the Monasterevin By-pass (part of M7) in Ireland (designed and built by project team)

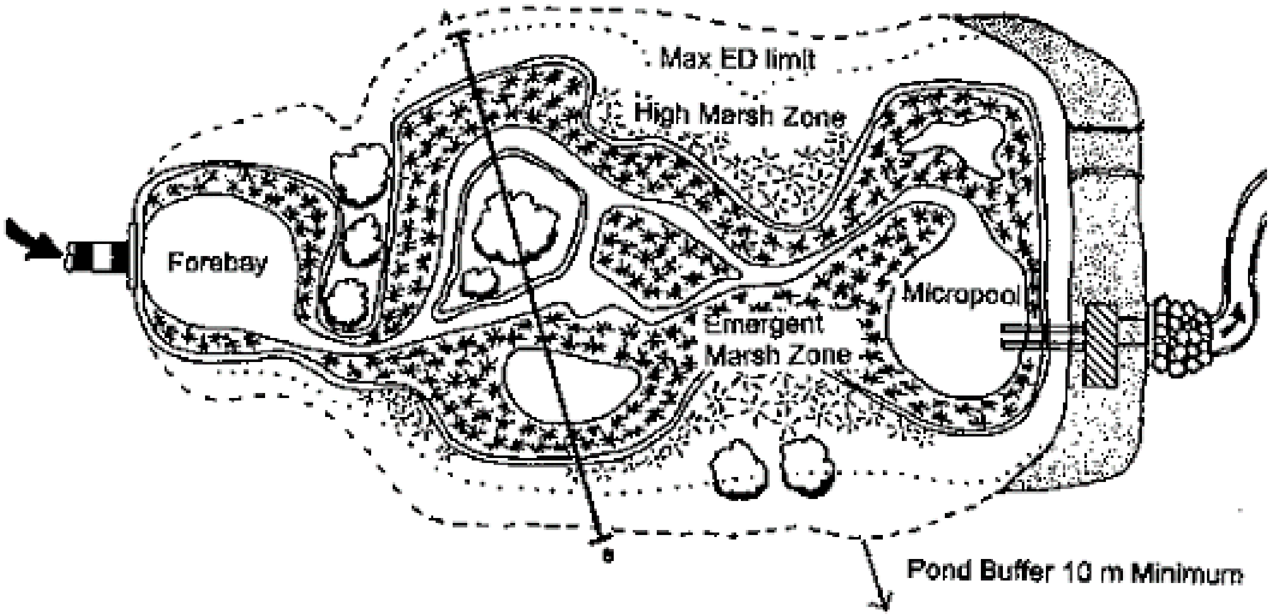


Figure 12.6: Constructed Wetland (Schueler, 1992)

12.4.4 Infiltration Systems

Infiltration systems include infiltration trenches, soak ways and porous paving. An infiltration system is a runoff management structure in which runoff water from the highway surface is collected and then allowed to infiltrate into the groundwater. The main form of treatment is by sorption, precipitation, trapping, straining and bacterial degradation upon infiltrating through the soil. They are usually only appropriate where the soil is of high/moderate permeability; the groundwater is at least 3 m below the infiltration point: there is sufficient storage capacity to allow infiltration and the suspended solids concentration of the highway runoff is low so to prevent blockages of the systems.

Despite the extensive use that has been made of infiltration systems there has been limited examination of their performance (Pratt, 2001). The minimal research that has been conducted found that pollutant removal rates vary with the type of infiltration system used. There has also been widespread concern regarding the hydraulic performance of the systems, with the general expectation that failure through blockage by sediment and debris would necessitate reconstruction within a limited time span (Pratt, 2001). In recent years there has been growing concern about the impact on groundwater the water passing through the infiltration system may have (Pratt, 2001).

Mudge and Ellis, 2001 reported removal efficiencies of 60% to 90% for total suspended solids (TSS), 70% to 90% for hydrocarbons, and 70% to 90% for various metals and up to 35% for the dissolved metal fraction.

Figure 12.7: Infiltration trench adjacent to a major highway in America

12.4.5 Water Quality Inlets

Water quality inlet structures include trapping catch basins, oil/grit separators, oil/water separators and grit chambers. They consist of at least one or more chambers that promote sedimentation of coarse materials and separation of free oil (as opposed to dissolved or emulsified oil) from highway runoff. Some water quality inlets also include a set of screens that help to retain larger or floatable debris. The newer designs will include a coalescing screen that helps promote the separation of oil and water.

Research has found that water quality inlets such as oil/water separators are effective for collecting oil from spills and also provide some removal of coarse sediment. Due to their limited storage they generally provide minimal flood attenuation and reduction of peak discharge. Even ideally designed water quality inlets cannot remove pollutants as well as other best management practices therefore it is recommended they are integrated with another practice such as a constructed wetland.

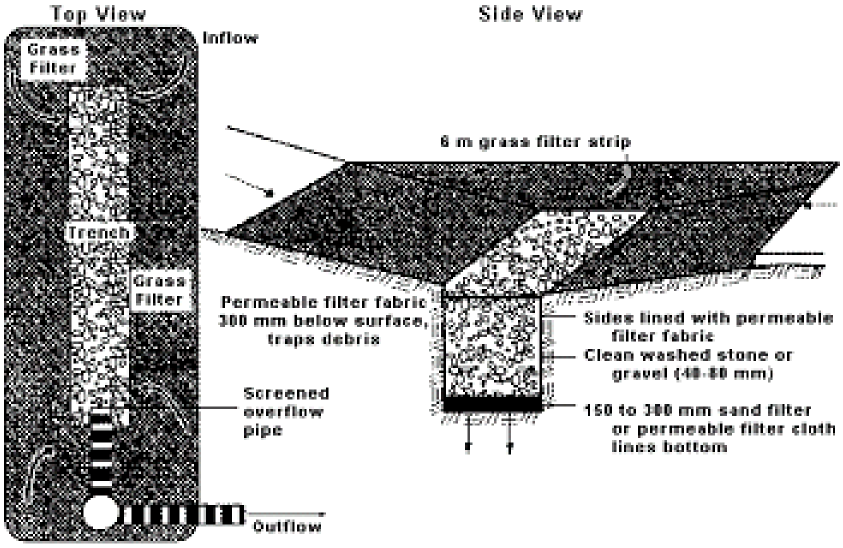


Figure 12.8: Infiltration system (Schueler, 1987)

12.5 International Approach to the Use of Best Management Practice's

A wide number and variety of best management practices both structural and non-structural are used throughout highways in the UK. The most common structural practices found include filter drains, gully pots, oil interceptors, and detention and retention ponds. The most common non-structural practices include street cleaning and routine management practices.

Throughout other European countries such as Germany swales and infiltration systems are frequently used. In France constructed wetlands and porous paving with in built reservoir structures are common. In colder climate countries such as Sweden and Denmark, retention ponds are frequently used to reduce peak flows and retain pollutants. In the more southern European countries such as Spain, Portugal, Greece and Italy the use of Best Management Practices is limited but due to an increase in public awareness of environmental issues there is a growing interest in Best Management Practices and their benefits.

12.6 Conclusions

Each of the Best Management Practices outlined have individual advantages in the removal of pollutants from highway runoff. Therefore, a combination of these systems should be used for enhanced and more uniform overall pollutant removal performance. In fact a combination of runoff management and control measures is recommended whenever it is feasible (Burch et al., 1985b).

Vegetative controls are the measures best suited to treat runoff as it is conveyed. Therefore, they are recommended wherever possible as collection and conveyance links between treatment systems (Burch et al., 1985b). Barrett et al. (1995) conclude that when combining treatment systems two restrictions should be considered. Firstly infiltration systems should be the last structures in the treatment train since they are adversely affected by high sediment loads. The preceding structures should remove as much of the suspended sediment as possible so as to increase the overall effectiveness and life span of the infiltration system. Secondly, constructed wetlands alone should not be used in conjunction with infiltration devices the as wetlands have the potential to discharge large sediment loads and decaying matter which can clog infiltration systems. Barrett et al. (1995) conclude that wetlands are best positioned in the middle of treatment systems and should discharge to ponds or vegetated control structures.

The selection of a particular control option or a combination of systems for the management and treatment of highway runoff very much depends on the local and site characteristics. The final design criteria of the system will include consideration of the highway carrying capacity, the size and character of the site drainage, the sensitivity of the receiving surface and/or groundwater (in terms of flow volumes and quality), landscaping and planning concerns in addition to normal safety, operational and maintenance requirements (Mudge and Ellis, 2001). A detailed evaluation of these characteristics will indicate which type of system or technique and what level of expenditure can be justified for the particular site. A combination wetland incorporating an upstream sedimentation pond is a good precursor to a downstream vegetated infiltration structure

Under current EU legislation, the Water Framework Directive will dictate the likely measures to be employed so as to minimise risk to receiving waters under prevailing local conditions. Particular consideration for choice of treatment system in Ireland should relate to relatively high water tables and rainfall.

BMP TYPE			VCF	CF	OF	RF
Structural BMPs		Filter strips/Grass Swales			X	
		Filter (french) drains	X			
	Infiltration Systems	Soakaways		X		
		Infiltration Trenches		X		
		Infiltration Basins				X
	Above ground storage Facilities	Storage Tanks/Chambers			X	
		Lagoons			X	
		Detention & Extended Detention Basins	X			
		Retention (Balancing) Ponds	X			
		Constructed Wetlands		X		
	Road Surfacing	Porous Paving			X	
		Porous Asphalt			X	
		Rainwater Harvesting				X
		Gully Pots (Oil Interceptors)	X			
Non-Structural BMPs		Street Cleaning	X			
		Reduction in Pollutant Usage			X	
		Snow Management Practices		X		
		Educational Practices			X	
		Routine Management Practices	X			
		Control of Impervious Area		X		

KEY: **VCF:** Very Commonly Found (tending to standard or "normal" practice)
CF: Commonly Found (and quite frequently practiced)
OF: Occasionally Found (but of only local and limited interest)
RF: Rarely Found (only a few examples/sites)

Table 12.1: Summary of Best Management Practices found in the UK (Day Water Report, 2003)

Table 12.2: : Removal efficiency of current drainage practices and a number of BMPs (Mudge and Ellis, 2001)

Treatment	Hydraulic	Removal Efficiency (%)				
					Metals	
System	Robustness	TSS	TN	Hydrocarbons	Total	Dissolved
Gully/Pipe System	High	10 - 30	-	5 - 10	10 - 20	0
French Drain	Low - Moderate	60 - 90	20 - 30	70 - 90	70 - 90	10 - 20
Infiltration Trench	Low - High	60 - 90	20 - 50	70 - 90	70 - 90	20 - 35
Swale	High	10 - 40	10 - 35	60 - 75	70 - 90	15 - 25
Sedimentation Tank	Low - Moderate	50 - 85	10 - 20	60 - 90	60 - 90	20 - 30
Oil Separator	Low - Moderate	30 - 70	10 - 15	40 - 80	30 - 60	0 - 5
Extended Detention Basin	High	30 - 60	5 - 20	30 - 50	20 - 50	0 - 5
Retention Basin	High	40 - 80	20 - 40	30 - 60	30 - 60	5 - 10
Wetland Moderate	High	70 - 95	30 - 50	50 - 85	40 - 75	15 - 40

Table 12.3: Summary of a review on a number of treatment options used for highway runoff in the UK (Mudge and Ellis, 2001)

Treatment Facility	Water Quality	Flow Rate Control	Reduction Runoff Volume	Operation Maintenance	Sensitivity to Site Conditions	Potential for groundwater Pollution	Overall Failure Potential	Design Robustness		Average Rating	Rank Order
								Hydraulic	Water Quality		
Wetland	5	4.5	2	-3	-4	-1	-1	4	4	1.17	1
Retention Basin	4	5	1.5	-3.5	-3	-1	-1	4	4	1.11	2
Extended Detention Basin	3	5	1	-2	-2	-2	-2	4	3	0.89	3
Porous Pavement	3.5	4.5	3	-4	-2	-2	-2	4	3	0.89	3
Sedimentation Lagoon	4	4	1	-4	-4	-1	-3	3	3	0.33	5
Oil/Grit Interceptor	4.5	2	0	-4	-2	0	-3	2	2	0.17	6
Gully/Carrier Pipe System	1	4.5	0	-5	-1	-1	-2	3	1	0.06	7
Grass Swale	2	3	1.5	-3	-3	-2	-2	3	1	0.06	7
Infiltration Trench	2	2	2	-3	-3	-2	-2	2	1	-0.11	9
Soak way	4	4	4	-4.5	-4	-5	-5	2	2	-2.5	10

Chapter 13

Conclusions and Recommendations

13.1 Conclusions

13.1.1 Contamination from road runoff

Traffic and road surfaces are significant sources of various types of contamination which form part of the runoff as it leaves the road pavement along highways in Ireland.

13.1.2 Contaminants

Analyses of the runoff waters showed that contaminants include suspended solids, heavy metals, hydrocarbons including PAHs, chlorides, nitrates and phosphorus. However, no MTBE was detected in the samples analyzed.

13.1.3 Comparability

The nature and concentrations of contaminants measured were broadly comparable with those reported from similar site conditions in other European countries. Although contaminant concentrations show considerable variation, the common influencing factors are traffic flow, rainfall (amount, duration and antecedent conditions) and, possibly, the age of the fleet.

13.1.4 Origin

Most of the contaminants detected are consistent with a road-traffic source. However, some, particularly nitrates and phosphorus, may have upstream sources in receiving waters or originate in soils or associated road infrastructure (eg embankments, median strips etc.). Other potential water-related sources of contaminants associated with roads are airborne (eg aerosols, spray), which may fall on or beyond road margins, but these were not explicitly measured in this study. For instance, PAHs may have a number of origins and the composition of individual PAHs in the mixture would reflect this.

13.1.5 Contaminant pathways

Drainage from most major roadway pavements in Ireland has surface water as the designated receptor. However, on the sites studied, significant proportions of the flow and the associated contaminant load from the road surface do not reach the intended receptor.

13.1.6 Runoff coefficients

Careful water balance calculations on four intensively investigated sites on the N4 and N8 suggest that there are alternative, undocumented pathways taken by part of the runoff. Runoff coefficients as low as 25% were recorded. Investigation indicated that there are subsurface pathways which bypass the designed drainage route to surface water. These bypass pathways have the potential to cause contamination of adjacent soils and subsurface waters.

13.1.7 Surface water receptors : sediment

The contaminants as measured have been found in river sediments near road drainage outfalls. However, away from the outfalls, no consistent pattern of statistically significant changes between sediments upstream and downstream of the outfall was observed in most cases. However in one location, the downstream concentrations of PAHs and heavy metals were significantly higher than upstream.

13.1.8 Surface water receptors : vegetation

Heavy metals have been found in the tissue of vegetation near road drainage outfalls. However, away from the outfalls, no consistent pattern of statistically significant changes between vegetation upstream and downstream of the outfall was observed.

13.1.9 Surface water receptors : macroinvertebrates

No adverse effects from the road drainage could be detected in the macroinvertebrate fauna. Where differences existed they were probably more related to limitations in the physical habitat or impacts from other sources.

13.1.10 Surface water receptors : fish

The analyses of the fish did not reveal a negative impact of road runoff on these biota. One of the major difficulties in the present study was that most sites were already impacted by upstream nutrient/organic pollution making it extremely difficult to isolate any possible effects of the road runoff from other pollution effects.

13.1.11 Surface water receptors : other contaminant sources

A large number of the rivers at the road crossing sites in eastern Ireland were already impaired from upstream sources. An extensive search of the region revealed very few un-impacted sites. More un-impacted sites were found in the west of Ireland.

13.1.12 Subsurface receptors : soil and groundwater

On sites where runoff was removed by 'French Drain' systems, there was a significant risk of the contamination in road runoff being trapped by adjacent soils. Investigation of 12-year old sites on the N4 near Maynooth showed heavy contamination (PAHs and heavy metals) of soil adjacent to the road. Furthermore some of the water balance calculations indicated an unexplained loss of water from the filter drain system, which might reach groundwater. Although a major aquifer was located near one of our sites, groundwater impacts were not investigated directly as part of this study. The European experience as reported by TRL (chapter 5) showed that it is a potential receptor of significance in vulnerable conditions.

13.1.13 Treatment options : French drains

French drains are commonly incorporated in Irish road drainage design to remove excess water from the road infrastructure. They are not expressly designed to perform a runoff treatment function, although they usually do play such a role. However, investigation showed that, as typically designed, their drainage functions appears to deteriorate relatively rapidly with age, mainly through clogging of surrounding soil and geotextiles. Frequent maintenance is required for efficient functioning as a drainage system. Moreover, this drainage system requires redesign if it is to perform a treatment role. At present, the deteriorating drainage function appears to enhance the treatment role.

13.1.14 Treatment options : Constructed wetlands/swales

A review of worldwide experience with alternative forms of treatment which can be incorporated into road drainage design showed that constructed wetlands would be the best all-round option for treatment, although it is clear they should not be used alone. Combinations of systems to suit local conditions should be used. The combination of a swale and wetland showed promise for Irish conditions. A wetland was constructed adjacent to the N8 at Monasterevin and the treatment efficiencies so far measured and reported for the typical road runoff contaminants are uniformly high.

13.1.15 Treatment options : efficiency

No treatment options are maintenance free. Choice of treatment option should include maintenance as a factor, in terms of cost and efficiency, in the light of local conditions.

13.1.16 Traffic flow rates

Although our sites were on some of the busiest Irish roads (except for the M50), traffic flow rates were low compared with major UK and European roads. In addition, the variation in traffic flow between our sites was small. For these reasons we were not able to reliably establish the relationship between contamination levels and traffic flows.

13.2 Recommendations

13.2.1 Surface water : sediments

As this study reflects the position in receiving surface waters at a particular point in time, the accumulation and distribution of sediments over time in the river and their potential long term impacts on aquatic biota should be monitored. Longer term evaluation would be worthwhile to substantiate current conclusions.

13.2.2 Groundwater

The unexplained losses of water from filter drain systems should be investigated further, with a view to determining if there are any implications for groundwater contamination.

13.2.3 Treatment options

The study has revealed the complexity of drainage and treatment pathways currently occurring in Irish road runoff drainage. At present the lack of impact on surface water receptors may, in part, be due to the (inadvertent) trapping of contaminants along the pathway between the road pavement and the receiving water. A specific design protocol, for both drainage and treatment, should be developed for help in decision making on the best options for particular site conditions in Ireland. The options will depend on traffic densities, climate, hydrological and other site conditions. Under the EU Water Framework Directive, both surface water and groundwater receptors need consideration in any such protocol.

13.2.4 Monitoring of current treatment sites

To fully validate the treatment options of a constructed wetland and swale in Irish conditions, monitoring and evaluation should be continued on the sites constructed under this study.

13.2.5 Other treatment options

The role of oil interceptors was not examined in this study but the development of any protocol for the selection of treatment options should include the role of such devices. If the French drain is to continue in use, a re-design is required to improve its efficiency in terms of drainage as well as treatment if it is specifically to assume that role. In particular, it is recommended that the role of the geotextile be re-examined.

13.2.6 PAHs

A detailed examination of the various PAH species in stream sediments could be used to identify their origin.

Chapter 14

Acknowledgements

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Appendix A

Project team

A.1 Personnel

UCD Dublin Two Schools were involved in the project. The hydrological and chemical water quality work was done in the Centre for Water Resources Research (www.ucd.ie/cwrr) of the School of Architecture, Landscape and Civil Engineering. The Biological aspects of the work were done in the School of Biology and Environmental Science. The UCD Dublin personnel involved were:

1. Dr. Michael Bruen
2. Dr. Mary Kelly-Quinn
3. Dr. Peter O'Connor
4. Mr. Mesfin Berhanu
5. Mr. Patrick Kearney
6. Mr. Derek Holmes
7. Ms. Suzanne Burns
8. Ms. Catherine Bradley
9. Mr. James Lynch
10. Mr. Eoin Burke
11. Mr. Frank Dillon

TCD The work on treatment options was done in the School of Engineering. The TCD personnel involved were

1. Mr. Paul Johnston
2. Mr. Neil Higgins
3. Mr. Laurence Gill

Atkins A number of the proposing group, Atkins contributed to the survey of Irish Road Drainage practice and advised on site selection. the person most involved was;

1. Mr. Geoffrey Clarke

TRL Dr. Aideen Hird

Appendix B

Practice with Design Build and PPP contracts

The following information was supplied by Atkins (Mr. Geoffrey Clarke)

Contractors and designers under Design & Build and Public Provate Partnership contracts are in general required to conform with the following requirements in regard to drainage design and drainage works :-

1. The Contractor shall, prior to the commencement of the Works, notify in writing the Environment Protection Agency, the Office of Public Works and the Regional Fisheries Board of the intended date for commencement of the Works.
2. The contractor shall consult and comply with the requirements of the Environmental Protection Agency, the Office of Public Works and the Regional Fisheries Board in respect of the drainage design and the drainage Works.
3. The specified minimum pipe sizes shall be adhered to and drainage systems shall be accessible for inspection and testing. All drainage runs shall end with a catchpit or manhole the maximum distance between access chambers on a pipeline shall be 90 metres.
4. Manholes and catchpits shall have a minimum internal diameter of 1,050 mm and all gully ,manhole and catchpit gratings, covers and frames shall comply with IS EN 124.
5. In the interest of pollution control and containment, road drainage shall be kept separate from other catchment drainage where possible.
6. The design shall ensure that drainage shall be installed to intercept water from adjoining land towards the road at the top of cuttings and the base of embankments. Side slopes shall be drained where egress of groundwater is encountered.
7. The design shall ensure that severed land drains, ditches and private outfalls shall be diverted into the road drainage system after liaison and agreement with landowners.
8. Access for livestock to streams shall be maintained or replaced where required.
9. The contractor shall ensure that there is no silting up, erosion of beds or pollution of any stream or watercourse, and shall not interfere with the supply or quality of any groundwater resource. Where necessary, settling ponds shall be provided to remove mud from water before it joins the stream. Waste products associated with the Works shall not be permitted to enter watercourses and all precautions necessary shall be taken to prevent the spillage of diesel fuel or other solvents.
10. The design shall ensure that any well or spring to be capped conforms to the recommendations of CIRIA Report 137 "Monitoring, Maintenance and Rehabilitation of Water Supply Boreholes". The Contractor shall not cap any well or spring without consulting and complying with the requirements of EPA and OPW.

11. The capacity of the natural drainage network shall be assessed and measures to mitigate against flooding shall be adopted where necessary. The discharge of the road drainage system shall be controlled or attenuated to ensure that the runoff shall not adversely affect downstream pipes, culverts, watercourses, or static water bodies. Attenuation and holding ponds shall be designed to accommodate a 1 in 50 year storm condition.

12. Grit traps shall be incorporated as part of the drainage system.

13. A water level monitoring programme shall be undertaken in the vicinity of earthwork cuts whose base is below the natural water table and shall be carried out on a three weekly basis, prior to, during and for one year after the Completion Date or such later date as shall be necessary.

14. Where practicable, the lowest invert level of the drainage of the road scheme in the vicinity of wetlands shall be at a level greater than the existing water level in the wetland areas. Where this is not possible, a sealed drainage system shall be provided.

15. The Contractor shall carry out a groundwater quality monitoring programme to ensure that the Construction Requirements are met.

16. Wells which have been affected to the extent that they can no longer provide a water supply to the owners shall be replaced or deepened or the owners shall be connected to a mains water supply.

17. The Contractor shall prepare and operate an emergency plan to deal with accidental spillages.

18. The design shall ensure that all gullies are trapped with connections to drains formed with junction pipes.

19. The Contractor shall maintain all existing foul and surface water drainage until the permanent drainage for the Works is constructed and functioning satisfactorily. Ground profiles shall at all times be maintained to shed surface water efficiently and directly into the nearest drain and to prevent penetration of water into or below existing pavements.

20. The design shall ensure that sub surface water drainage shall be constructed to drain: (a) the road formation (b) the road sub-formation where a capping layer is adopted in the road design; (c) water percolating through the verges

21. The design shall ensure that in areas of cut the residual runoff from the lowered ground water table shall be intercepted and incorporated into the drainage system.

22. The design shall ensure that where a drain run crosses the cut-fill line a chamber shall be constructed 5 metres from the cut-fill line in original ground.

23. The Contractor shall ensure that discharge of the design drainage system shall be controlled or attenuated and shall not increase the run-off to any downstream watercourses, pipes or culverts which receive water from an outfall to the extent that the return period for flooding is affected. The Contractor shall ensure that discharge of the design drainage system shall not make the present situation, in terms of flooding, any worse for any watercourse.

24. The design of any outfall shall cause minimum disruption to the end user and shall meet the requirements of the Relevant Authorities. The Contractor shall not discharge water from the site and off site areas on either a temporary or permanent basis until: a. It has consulted with the relevant interested parties and relevant persons; b. It has consulted and complied with the requirements of Relevant Authorities; and c. The Authority's Representative has acknowledged receipt of Consultation Certificates in accordance with the Certification Procedure.

25. The Contractor shall take cognisance in the Design and Construction for the areas throughout the site, off site areas and adjacent areas which are susceptible to flooding to ensure the drainage design does not increase the frequency or extent of flooding.

26. A specific assessment of the potential impact of route run-off on the receiving aquifer in areas of high to extreme aquifer vulnerability shall be undertaken by the Contractor and the drainage system shall be designed to avoid significant adverse impacts to the aquifer.

27. Each outfall discharge location shall have a surface water treatment system comprising of either lagoons, swales, petrol/oil interceptors or any combination thereof subject to consulting and complying with the requirements of the Relevant Authorities. Design of interceptors shall conform to the recommendations of CIRIA Report 142, Control of Pollution from Highway Drainage Discharges.

28. All watercourses whether flowing or dry shall, where the Environmental Impact Statement requires, continue on their existing line and be taken under the new roads in culverts with headwalls at both ends. These culverts shall be designed for the 1 in 100 year design flood flow of the watercourse.

29. Effective measures shall be taken where watercourses are culverted to prevent livestock entering the culvert.

30. The invert of all watercourses shall be stone pitched for a minimum of 2 metres both upstream and downstream of the culvert ends.

31. The minimum culvert size shall be 900mm diameter or as otherwise required.

32. The Contractor shall consult and comply with the Relevant Authorities requirements in respect of culverts which shall permit the free passage of fish, amphibians or mammals.

33. Provision shall be made to facilitate the safe access to each culvert inlet and outlet for inspection and maintenance provision.

34. Culverts shall be designed to operate under sub-critical, free flow conditions for the design flow conditions.

35. Drainage systems shall be designed to reduce the risk of accidental spillages causing pollution and to provide for significant removal of suspended solids and other contaminants.

36. The combined risk of a spillage outfalling from any discharge and leading to pollution of a receiving water shall be no greater than 1 in 100 years (plus or minus 10 percent).

37. All spillage control or containment facilities shall include provision to completely isolate the carriageway drainage system from the watercourse to which it discharges and shall include adequate facilities for access, maintenance and emptying using standard suction tankers or suitable pumping arrangements. Irrespective of the calculated spillage risk, no outfall shall be made to any watercourse in such a way that pollution incident control contingency plans cannot reasonably be expected to be effective in containing the spread of accidental spillage of hydrocarbons to other watercourses.

38. The design of any proposed spillage containment or control facilities shall meet the requirements of the Relevant Authorities. The Contractor shall consult and comply with the requirements of the Relevant Authorities regarding the timescale if any of its activities in and around controlled waters.

39. The Contractor shall design the drainage system and locate discharge outfalls to ensure that run-off from the road (in the absence of accidental spillages) does not cause unacceptable pollution of the receiving waters and particularly, but not exclusively, having due regard to the effect of road run off on soluble (e.g. dissolved copper) and insoluble (e.g. suspended solids and oils) pollutants.

Appendix C

Questionnaire Form

Questionnaire

Review of Current Road Drainage Experience and Practice in Ireland

The objective of this questionnaire is to find out what types of road drainage systems and maintenance practices are used in rural dual carriageways and motorways (national primary roads) in Ireland. This is part of an ongoing EPA/NRA research project in the Departments of Civil Engineering, UCD and TCD.

County/Office____

1. Road Drainage Design

1.1 What is the total length of roads in your county?

Motorways…………………………………………__________km
National primary (Dual Carriageway) ……………..__________ km
National Primary (Single Carriage way)……………__________km
National Secondary (Dual Carriageway)………….___________ km
National Secondary (Single Carriageway)…………..__________ km

1.2 Does your county have a road drainage design guideline (manual)?
____

1.3 If you answered yes to (1.2), please mention what it is and give information as to where to get a copy?
____

1.4 What year was the guideline in (1.2) last updated?
____

1.5 Are there any important issues not covered in this guideline?
____
____
____

1.6 What standard methods or commercially available softwares do you use for road drainage design?
____
____

1.7 Please include comments for this section below, if you have any.
____
____
____

2 Current Drainage System

2.1 Please identify the types of road drainage systems used in motorways and dual carriageways in your county. Estimate the length, to the nearest kilometre, of road drained by each type.

Drainage system	Use ✓/✗	Length of road drained, km
Kerb and Gully		
Surface water channel		
Filter Drain		
Over the edge drainage		
Combined Kerb and drainage block		
Open ditch		
Other (specify)		

3 Runoff Treatment Systems

3.1 Which types of runoff treatment systems do you use in motorways and dual carriageways in your county?

Runoff Treatment System	Use ✓/✗	Location (or Name of Road) if used
Silt traps		
Soakaways		
Oil interceptors		
Filter strips		
Swales		
Ponds		
Infiltration basins		
Constructed wetlands		
Other (specify)		

3.2 Does your county have any design guidelines for the treatment systems used in your area? If so, please give its name and include information for obtaining a copy.

____

____

____

3.3 Are there any studies already done or in progress funded by your county on highway drainage and its impacts on receiving waters? If so please provide information for contacting or obtaining a copy.

____

____

____

3.4 What are your most important future research needs in highway drainage? List in order of priority if possible.

____
____
____
____
____

4 Road Drainage Maintenance Practice:

4.1 Does your county have a programmed inspection and cleaning frequency for drainage systems? If so, please fill in the following table accordingly.

Drainage system	Inspection Frequency (per year or months)	Common problems with the drainage structure	Maintenance method (manual/ machinery), If machine is used, please give its name)
Surface drainage			
Pipes			
Gullies			
Over the edge drainage			
Ditches			
Filter Drains			
Oil separators			
Balancing Ponds			
Other (specify)			

4.2 Are these (4.1) programs a requirement by the National Roads Authority or any other regulatory body?

____

4.3 When inspection and maintenance is done, does your county keep a record of the drainage system or any other information? If yes, please state what information is recorded.

____
____

4.4 What stormwater management measures do your county use during construction of roads?

____
____

4.5 When drainage problems occur, has knowing the exactly what feeds the drain and where the water discharges into ever been a problem? If yes, how have you addressed such problem?

____
____
____

4.6 How do you react to the following hazards caused by road drainage problems? Please give value 1 for immediate (up to 24 hr) and 2 for delayed (programmed work) action.

- Flooding of highway_______
- Flooding of buildings, houses, etc.)____
- Flooding of land, etc____
- Health hazard due to water contamination____
- Disruption of traffic___
- Accidental spills____

Include comments if necessary.

____
____
____

4.7 What do you consider the most important and recurrent problem the current road drainage systems in your county have if any?

____
____
____

4.8 What are the main limitations with respect to inspection and maintenance of highway drainage?

____
____
____

5 Legal Aspects of Drainage Discharge

5.1 In your opinion, should highway runoff be allowed to discharge into inland waters (natural or artificial), or any tidal waters without of treatment? Why?

____
____
____
____

5.2 What water quality regulations should apply in this area?

5.3 Who should be responsible for controlling the quality of the discharge?

6 Are there any issues or comments you wish to include? If so, please include them below.

END
THANK YOU

Appendix D

Questionnaire Survey

D.1 Overall Summary of Responses

The lengths of motorways and dual carriageways reported by each local authority are listed in Table D.1.

D.2 Analysis of responses

This section outlines a summary information on the responses of County Councils under each section of the questionnaire.

D.3 Road Drainage Design

Respondents listed the documents cited in Chapter 3, Section 3.5 in the main report above as those consulted during road drainage design.

D.3.1 Issues not covered in design manuals used

They identified some issues not covered in the guideline

- One respondent pointed out that the Guideline for Road Drainage (DoEHLG) publication is primarily concerned with removing surface runoff. He/She said that there is not much emphasis on impact of road drainage on the receiving water.
- Another respondent mentioned about the lack of sufficient information from the NRA DMRB on maintenance of drainage systems.
- A third one wants the DMRB to include guideline for design and analysis of drainage networks.

D.3.2 Standard Methods or Software Packages used in the design

The following software packages or design methods are mentioned
DOER Drainage Program Microdrainage Program (WinDes) Hydraulic Tables (Colebrook-White) as give in DoEHLG publication Wallingford Procedure

D.4 Current Drainage Systems

Five County Councils gave the types of the drainage systems and estimated lengths of roads drained by each type as summarised in Table D.2.

Table D.1: Summary of the responses from county councils

County	Total Length of Motorways and Dual Carriageways	Responded
Carlow	0	NMDCW*
Cavan	0	NMDCW*
Clare	26	yes
Cork	39	No
Donegal	6	No
Dun Laoghaire/Rathdown	18	No
Fingal	47	yes
Galway	3	NMDCW*
Kerry	0	yes
Kildare	73	No
Kilkenny	0	NMDCW*
Laois	20	No
Leitrim	0	NMDCW*
Limerick	20	yes
Longford	0	NMDCW*
Louth	33	yes
Mayo	0	yes
Meath	16	No
Monaghan	0	yes
Offaly	0	yes
Roscommon	0	yes
Sligo	10	yes
South Dublin	36	No
Tipperary North	0	NMDCW*
Tipperary South		yes
Waterford	0	NMDCW*
Westmeath	16	No
Wexford	0	NMDCW*
Wicklow	27	No

**NMDRW = no motorways or dual carriageways*

Table D.2: Length of each type of drainage system in Local Authority Responses

Drainage system	Length (km) in each Local Authority area					
	Kerry	S. Tipp.	Carlow	Sligo	Louth	Total
Filter Drain	25	5.8	13	3.5	23	70.3
Kerb and Gully	10		12	0.2	6	28.2
Open Ditch	40	1.6	45			86.6
Surface water Channel				1.0		1.0
Over-the-edge Drainage	25	0.5		13		38.5
Combined kerb and Drainage Block					4	4.0

D.5 Runoff Treatment Systems

D.5.1 Highway runoff treatment systems used in county councils

Runoff Treatment System Number Counties 7. Oil Interceptors 6 S.Tipp., Fingal, Mayo, Kerry, Louth, Clare 8. Silt traps 5 Mayo, Sligo, Louth, 9. Ponds 5 S.Tipp.,Louth, Clare 10. Filter Strips 4 Sligo, Louth 11. Swales 2 Mayo, Louth 12. Soakaways 2 Mayo, Sligo,

D.5.2 Design Guidelines for Treatment Systems

There is no other specific design guideline for runoff treatment systems than mentioned under section 1.

D.5.3 Studies done (or in progress) on highway drainage impacts on receiving waters.

Respondents emphasised that the impacts are considered in the Environmental Impact Statement. No local authority reported sponsoring a research.

D.5.4 Future Research Needs

County councils listed the following as their most important future research needs:

1. Long term maintenance needs for Swales, French Drains, Petrol Interceptors, etc. 2. Effect of salting Motorways and Dual Carriageways on receiving water quality 3. Effect on water quality of major oil spillages and response times for clean up 4. Effect of runoff from adjacent land on highway drainage 5. Flow data of receiving watercourses 6.Sustainable Urban Drainage Systems 7.Characteristics of highway runoff 8. Short duration rainfall statistics to aid in the selection of design of rainfall intensity

D.6 Road Drainage Maintenance Practice

D.6.1

Drainage systems are maintained mostly on reactive basis (when problems occur). Inspections are mostly done once or twice per year as part of good practice. There are no standard maintenance procedures other than those developed locally.

D.6.2 Records kept

Five out of the 10 respondents of this section reported that they don't keep record of the maintenance work done or any other details.

D.6.3 Stormwater management during construction

A number of measures are taken during construction to prevent pollution of receiving waters. County councils mentioned the use of retention pond (holding tanks), silt traps, or open drains. Some also mentioned that the contractor must ensure the suspended solids content of the receiving waters do not increase through adequately designed drainage system.

D.6.4 The need for local knowledge

Two respondents stressed the need for local knowledge when drainage problems occur. It is possible that the complete picture of the drainage network may not be visible on the actual ground. This is particularly true in old road schemes. Dying the line or use of CCTV solved such problems.

D.6.5 Priority problems

Only flooding of land was seen as a less important problem. It was seen by all but one respondent as a secondary problem to be done on a programmed basis. Respondents emphasised that it is the responsibility of the land owner. Two (out of 11) respondents were hesitant to consider accidental spill as a problem that require immediate action.

D.6.6 Major drainage problems

The major problems mentioned by respondents include Constant encroachment of grass verge Blockage of road gullies Flooding in flat or sagged sections Lack of regular maintenance Oil spills Land owners diverting land drainage onto carriageways or maintenance of drains not carried out by land owners. Culverts not capable of coping with blockages and not self cleansing

D.6.7 Limitations to frequent inspection and maintenance

The three most important limitations of inspection and maintenance of drainage systems are listed by respondents in order of priority are:

Limitation of technical staff(6/11) Absence of dedicated funding for maintenance(4/11) Limitation of resource (3/11)

D.7 Legal Aspects of Road Drainage

D.7.1 Should untreated road runoff allowed to be discharged into receiving waters?

All respondents but one (1/12) want to see some form treatment (silt trap or oil interceptor) done before it is discharged into the receiving water.

D.7.2 Water quality regulations

Most respondents were reluctant to answer this question. A few have mentioned Fisheries guidelines Salmonid water Directive Requirements of Dept of Marine and Fisheries board Surfacewater Abstraction Directive (75/440/EEC)

D.7.3 Regulatory Authority

Eight out of the nine respondents believe that Local Authorities should be responsible for regulation of discharge.

Appendix E

Protocols for Sampling, Transportation, Storage and Analysis of Water and Sediment Samples

E.1 Introduction

Appropriate sampling, transportation, storage and analysis techniques are important to produce reliable results. Accurate and representative data from a variety of drainage systems and receiving waters collected from adequate number of sites over a given period can be achieved if acceptable and convenient guidelines are established and strictly followed. Such guidelines set criteria for selection of appropriate sites, frequency and duration of data collection, and sampling and analysis techniques that yield as accurate data as possible over the entire sampling period. Road runoff quality is known to vary relatively rapidly over a short period of time as a response to rainstorms. More than 50% of the pollutants are washed of the road and transported during the first few minutes of the initiation of runoff, a phenomena known as the first flush effect. The sampling program has to be designed to efficiently capture this important period of a storm event. In such circumstances, automatic samplers provide the advantage of timely sampling of runoff over the full period of the storm event. Automatic samplers are triggered following a storm event, expected water level rise or volume of water passing a section in a given time in the drainpipe. Pacing (transition form one bottle to the next) is based either on volume of runoff, rate of water level rise at section or uniform time interval after the sampler is triggered. Volume paced sampling is advantageous over uniform time paced sampling in that the former allows collection of more representative samples in terms of the number and spacing of samples that better reflect the storm pattern. The intensity of the storm capable of generating sufficient runoff for sampling has to be determined beforehand. An estimated value may be assigned and later improved through experience.

The samples collected should be transported as soon as possible to the respective laboratories for analysis under the necessary preservation and transportation guidelines to minimise changes in concentration. To facilitate immediate recovery of the samples, automatic samplers are quipped with modems that allow data communication and transmission using existing mobile phone network. Analysis of samples should be done upon arrival to the laboratory. This is however not always possible. It is therefore necessary to store the samples following the necessary guidelines appropriate to the parameters to be tested. The objective of this protocol is to outline the procedures and techniques that will be adopted for sampling, transportation, storage and analysis of highway drainage samples in this project.

E.2 Selection of Parameters

Highway runoff contains a number of pollutants at different levels depending on site characteristics such as rainfall, nature and intensity of traffic, and the drainage system. An extensive literature review has been carried out to identify pollutants reported in major studies and known for their deleterious effects on biota in the receiving waters. Polycyclic Aromatic Hydrocarbons (PAHs) and heavy metals have

Table E.1: List of parameters analysed

Parameter	Method of Analysis (APHA, 1998)	Units
BOD5	5210B	mg/L
Chloride	4500-Cl- B	mg/L
Metals (Total and Filtered Cd, Cu, Cr, Pb, Zn)	3111B/3030E	mg/L
Nitrate + Nitrite	4500-NO3-E	mg/L
Phosphorous	4500-P-D	mg/L
Total Alkalinity	2320-B	mg/L
Total Hardness	2340-C	mg/L
Total Suspended Solids	2540D	mg/L
Total Organic Carbon (NPOC)	5310B	Mg/L
US EPA PAHs (list of 16)acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, Benzo(a)anthracene, Chrysene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Benzo(a)pyrene, Indeno(123cd)pyrene, Dibenzo(ah)anthracene, Benzo(ghi)perylene	6440C	ng/L
VOCs (MTBE, Xylene, Ethylbenzene, Tolune, Benzene, Petrol Range Organics C10-12, Petrol Range Organics C5-C9	US EPA 8260B	mg/L

been identified as the most important pollutants in a number of literatures. These pollutants are highly associated with the solid matter contained in the runoff. This solid matter deposits in receiving stream sediments causing toxic effects to freshwater organisms. It is therefore necessary to determine if these pollutants have reached contamination level in the receiving stream sediments. Table 2 summarises these and other parameters of interest and recommended methods of analysis in this study.

E.3 Physical Parameters for Field Measurement

Physical parameters measured in field are pH, dissolved oxygen (DO), specific conductance and temperature. These are continuously monitored using Multi-parameter Probes. The probe to be used is model 600R Sonde supplied by YSI Incorporated.

E.4 Laboratories for Analysis

Much of the chemical analysis of the water samples was carried out in UCD's Water and Effluents Laboratory. ALcontrol Laboratories (Dublin) analysed the PAHs (16) and VOCs such as MTBE.

E.5 Sampling and Storage

E.5.1 Sampling

Samples from road runoff monitoring sites were collected using automatic samplers. The automatic samplers were ISCO 6712 full-size portable samplers with 24 glass bottles of Teflon-lined caps. In addition, the instrument is used as a data logger for the Multi-parameter Probe, the Rain Gauge and the Area Velocity Flow Module. An example of sampler program is given in the Appendix. A telephone modem is used for data downloading (in addition to direct downloading) and for checking sample collection from a remote location (office). The glass bottles were wrapped with foil (to minimise photolytic decomposition) to comply with the requirements for PAHs sampling.

Samples from the receiving streams were collected manually at suitable times to best represent the changing nature of their water quality conditions. The collected samples were stored in "cooler boxes" for transport to the laboratory. Since sediment samples reflect the long-term changes in water quality more accurately than water samples (which are known to vary in a relatively short period of time) stream sediment samples were also be collected and analysed for heavy metals.

E.5.2 Storage

Samples are collected to meet the specific requirements of the sampling program and the parameter to be tested. The policy was to analyse samples as soon as possible after collection. If it was not possible to analyse all the samples at a reasonable time, they were preserved properly to minimise deterioration or contamination before analysis. A potential disadvantage of automatic samplers is that if samples are not retrieved promptly they may undergo physical, chemical and biological changes. The analyst must therefore continually check for sampling events and consider visiting the site frequently in the absence of control systems from a remote location such as a telephone modem.

Preservation methods available are pH control, chemical addition, refrigeration, and/or freezing depending on the parameter to be tested. There are several, if not different, recommendations in the literature for holding samples for different water quality parameters. Those given in the Standard Methods are outlined in the following sections and are summarised in Table—E.2 (APHA, 1998).

In addition to the information given in Table—E.2, samples for analysis of PAHs and VOCs required special treatment, as described below.

PAHs

PAHs are sensitive to light. They were collected with amber glass bottles or foil wrapped bottles to minimise photolytic decomposition (APHA, 1998). Samples were also protected from light during compositing. The minimum volume required for this analysis was 300ml. The samples are refrigerated at 4^oC from time of collection (compositing) until extraction.

VOCs

Traditional automatic samplers can not be used for Volatile Organic Compounds (VOCs) because the pumping system may strip off the VOCs from the samples during pumping. Moreover, the sample containers in these samplers are not sealed after collection allowing volatile compounds to escape. For this reason, manual sampling was used in this project for VOCs.

New 40-ml VOC vials were supplied from the commercial laboratory for use in this project. Duplicate samples and reagent blanks were collected with each set of samples. The bottles were filled excluding air bubbles. The bottles were cooled at 4^oC until shipping for analysis.

E.5.3 Sample Transportation

Bottle labelling

Prior to transporting, each sampling bottle and bag was assigned a unique label. The information entered on the label included the following:

- Project code (2000-MS-13-M2)
- Sample ID (four digit number)
- Location (Station ID), date and time of collection
- Analysis requested (PAHs, MTBE or others)
- Preservative/filtered (HNO3 or H2SO4)

Table E.2: Sample handling and preservation requirements

Measurement	Container	Min Vol of Sample, ml	Preservation	Maximum Holding Time
Alkalinity	P,G	200	Cool @4^{o}C	24 hours
BOD5	P,G	1000	Cool @ 4^{o}C	With in 6 hrs in no case $<$ 24 hrs
Chloride	P,G	100	No preservative necessary	–
Hardness	P,G	100	Add HNO3 to pH<2	28 days
Metals Dissolved	P,G rinsed with acid	100	Filter on site, 2HNO3 pH below 2	6 months
Metals Total	P,G rinsed with acid	100	2HNO3 pH below 2	6 months
Nitrogen Nitrate + Nitrite	P,G	20	Add H2SO4 to pH <2, Cool @ 4oC	48 hrs
PAHs	G (amber)	300	Cool @ 4^{o}C Extract within 7 days	Analyse within 40 days of extraction
Phosphorous Total	G acid rinsed	50	H2SO4 or HCl- pH < 2, cool @ 4^{o}C	28 days
Phosphorous Dissolved	G acid rinsed	50	Filter sample on site and Freeze @ or below 10^{o}C	24 hrs
Suspended Solids	P,G	100	Cool @4^{o}C	With in 24 hrs. In no case > 7days
TOC***	P,G	100*	Cool @2-5^{o}C	7** days
TOC***	P,G	100*	Freeze 15 to -20^{o}C	Several weeks
VOCs (MTBE and others)	G (VOC vials)	40	Cool @ 4^{o}C	7 days

** Fill the sample bottle completely ** If volatile organic compounds are suspected, carry out the measurement without acidification and within 8 h of sampling *** The sample has to be homogenised by shaking or even using a magnetic stirrer*

Transportation

Samples are transported to the laboratory at 4^oC covered with ice in sealed coolers. Composites for PAHs shall be made in UCDs Water and Effluents Lab and shipped to Alcontrol Laboratories in a cooler box.

Site Visit Frequency

Sampling sites were visited regularly for sample collection and routine maintenance. Maintenance activities include changing batteries, cleaning of sensors from debris, cleaning of rain gauges, and correcting programming problems in the sampler.

E.6 Quality Assurance and Quality Control

Errors introduced during sample collection and analysis affect the interpretation of the water-quality data. Establishment of quality-assurance plans ensured that the data collected are compatible and of sufficient quality to meet the project objectives. The following quality assurance and quality controls were followed throughout the project period.

E.6.1 Quality control/quality assurance measures

1. the work was done by experienced and trained laboratory technicians and supervisors from UCDs Water and Effluents Lab.
2. An externally supplied standard was analysed at least once for each target parameter as a calibration check.
3. In addition to standard samples, analysis of duplicate samples, laboratory blanks and field blanks were used for checking.
4. Overall care was exercised with respect to equipment handling, container handling/storage, decontamination, and record keeping.
5. Lab equipment and sensors were calibrated as per manufacturer recommendations.
6. If protective gloves were clean, new and disposable. These were changed upon arrival at a new sampling point.

E.6.2 Method detection limits

As part of the quality control/assurance measures, Method Detection Limits (MDL) were determined for each parameters. MDL is defined as the smallest amount of an analyte that can be detected within 99% confidence limit above zero in a given procedure. It is calculated as the standard deviation (s) times the students "t" value. The number of replicate runs determines the students "t" value, the minimum number of duplicates was seven. MDL is important to ensure the methods and techniques used in each lab are reasonably accurate and the reported results are meaningful.

E.7 Methods Summary

E.7.1 Total Alkalinity

Method: Titration Method, (APHA, 1998)

Definition: Alkalinity is a measure of the capacity of water to neutralise acids. The main buffering materials that contribute to total alkalinity are bicarbonates (HCO3-) and carbonates (CO3–).

Principle: Total alkalinity is determined by an autotitrator (Mettler DL 25) 0.01M H_2SO_4 to the carbonic acid equivalence point.

Sampling and preservation: Samples are collected in polypropylene or glass bottles and stored at low temperature. The bottles are filled completely and capped tightly. Analysis is done without delay preferably within one day.

Apparatus: Autotitrator (Mettler Titrator, model DL 25)

Reagents: Standard sulphuric acid, 0.01mol/ L (0.02N) H_2SO_4.

Procedure: Place 50m/100ml of sample in to a titrator cup. Rinse the mixer and sensor with distilled water before placing the sample. Set the titrator to determine volume of acid to be added. The titrator automatically runs producing the results.

Calculation: The result is displayed (printed) in mmol/L and is recorded as mg/L $CaCO_3$.

E.7.2 5-Day BOD

Method: (APHA, 1998) 5210 B

Principle: A bottle of 250 to 300 ml is filled with sample to overflowing, capped airtight and incubated at 20^oC for 5 days. Dissolved oxygen is measured initially and after incubation, and the BOD is computed from the difference between initial and final DO.

Sample holding and preservation: Samples for BOD analysis may degrade significantly during storage between collection and analysis. Minimise reduction of BOD by analysing sample promptly or by cooling it to near freezing temperature during freezing. Even at low temperature, keep holding time to a minimum. Start analysis with in 6 h of collection, in no case after 24-h. Warm chilled samples to 20^oC.

Apparatus:
1. Incubation bottles 250 to 300 ml capacities with stoppers. Clean bottles with a detergent, rinse thoroughly, and drain before use.
2. Air incubator or water bath, thermostatically controlled at 2010C. Exclude all light to prevent possibility of photosynthetic production of DO.
3. Magnetic stirrer

Procedure:
1. Place about 300 ml of carefully mixed water sample in a 1L graduated cylinder.
2. Mix well with a plunger-type mixing rod
3. Add the water in to the BOD bottles to the flared mouth.
4. Calibrate the DO meter
5. Determine initial DO immediately after filling the BOD bottle with sample
6. Stopper the bottle tightly to avoid drawing air into the bottle and incubate for 5 day at 200C.
7. Determine the final DO in samples after 5-d incubation.

Calculation: BOD5 = (DO1-DO5)/P, where P is the dilution factor

Control: Run a blank and duplicates of each sample.

E.7.3 Total Suspended Solids

Method: (APHA, 1998) 2540D

Principle: A well-mixed sample is filtered through a dried and weighed standard glass fibre filter (934 AH) and the residue on the filter is dried to a constant weight at 103 to 105^oC. The increase in weight of the filter represents the total suspended solids.

Apparatus:
1. Glass-fibre filter disks (934 AH)

2. Filtration Apparatus
3. Drying oven, for operation at 103 to105^oC
4. Analytical balance capable of weighing 0.1mg.
5. Desiccator
6. Planchet, aluminium or stainless steel

Procedure: 1. Preparation of glass-fibre filter: - Insert the glass-fibre filter into the infiltration apparatus with its wrinkled side up. Apply vacuum and wash disk in three successive 20ml portions of reagent grade water. Continue to suction to remove all traces of water. Remove filter from apparatus and transfer into an inert planchet. Dry in oven at $103 - 105^oC$ for at least 1 hour. Cool in desiccator to balance temperature and weigh. Repeat cycle of drying and weighing until a constant weight is obtained or until weight change is less than of the previous weighing or 0.5mg, whichever is less. Store in desiccator until needed.

2. Selection of volume of sample: - Because excessive residue on the filter may form a water entrapping crust, limit the sample size that yields no more than 200mg residue.
3. Sample analysis: - Place the filter in the filtering apparatus and wet it with small amount of reagent grade water to seat it. Add a known volume of a well-mixed sample (use magnetic stirrer to mix if necessary) into the seated glass fibre filter. Wash with three successive 10ml volumes of distilled water, following a complete drainage of the previous, and continue suction for about three minutes. Carefully remove the filter from the filtration apparatus and place it into the planchet. Dry for at least 1 hour at $103 - 105^oC$ in an oven, cool in a desiccator to balance temperature, and weigh. Repeat cycle of drying, cooling, and weighing until a constant weight is obtained or until the weight change is less than 4% of the previous weight or 0.5mg whichever is less.

Calculation:

(E.1)

where: A = weight of filter + dried residue, mg, and B = weight of filter, mg.

E.7.4 Chloride, Cl-

Method: Argentometric Method ((APHA, 1998) 4500-Cl-)

Principle: In a neutral or slightly alkaline solution, potassium chromate can indicate the end point of the silver nitrate titration of chloride. Silver chloride is precipitated quantitatively before red silver chromate is formed.

Interference: Substances in amounts normally found in potable waters will not interfere. Sulfide, thiosulfate, and sulfite ions can interfere but can be removed with treatment with hydrogen peroxide.

Apparatus: Erlenmeyer flask, 250ml and Buret, 50ml.

Reagents: 1. Potassium dichromate indicator solution: Dissolve 50g K2CrO4 in a little distilled water. Add AgNO3 solution until a definite red precipitate is formed. Let it stand for 12 h, filter, and dilute to 1L with distilled water.

2. Standard silver nitrate solution, 0.0141 M: Dissolve 2.395g AgNO3 in distilled water and dilute to 1000ml. Standardise against NaCl. 1.00ml=500μg Cl-. Store in a brown bottle.
3. Standard Sodium Chloride, 0.0141M: Dissolve 824.0 mg NaCl (dried at 140 ^oC) in distilled water and dilute to 1000ml; 1.00ml=500ug Cl-.

Procedure: 1. Sample preparation: use a 100ml sample or a suitable portion diluted to 100ml.

2. Titration: Directly titrate samples in the pH range 7 to 10. Adjust sample pH to 7 to 10 with H_2SO_4 or NaOH if it is not in this range. Add 1.0 ml K_2CrO_4 indicator solution. Titrate with standard AgNO3 titrant to a pinkish yellow end point. Be consistent in end point recognition.
3. Standardise $AgNO_3$ titrant and establish reagent blank value by the method outlined above.

Calculation:

(E.2)

where: A = ml titration for sample, B = ml titration for blank, and N = normality of $AgNO_3$.(note: mg/L NaCl/L = (mg Cl-/L) * 1.65)

E.7.5 Total Hardness

Method: EDTA Titrimetric Method ((APHA, 1998), 2340C)

Principle: Total hardness is defined as the sum of calcium and magnesium concentrations both expressed as calcium carbonate in milligram per litre. If a small amount of Eriochrome Black T is added is added to an aqueous solution containing calcium and magnesium ions at pH of 10 0.1, the solution becomes turns wine red. If EDTA (Ethylenediaminetetraaceetic acid) is added as a titrant, the calcium and magnesium will be complexed, and when all of the calcium and magnesium has been complexed, the solution turns from wine red to blue, marking the end point of the titration.

Apparatus: Buret, 50ml

Interference: Some metal ions may interfere by causing fading or indistinct end point or stoichiometric consumption of EDTA. Suspended or colloidal organic matter may also interfere with the end point.

Sample holding and preservation: Preserve sample with HNO_3 to pH less than 2. Hold sample for a maximum of six months.

Reagents:

1. Ammonia buffer Dissolve 16.9g ammonium chloride (NH4Cl) in 143ml conc ammonium hydroxide (NH4OH). Add 1.25g magnesium salt of EDTA and dilute to 250 ml with distilled water.
2. Indicator (Eriochrome Black T)
3. Standard EDTA titrant 0.01M Weigh 3.723 g analytical reagent-grade EDTA in distilled water and dilute to 1000ml. Standardise against standard calcium solution.

Procedure:

1. Select a sample volume that requires less than 15ml EDTA titrant and complete titration with in 5minutes, measured from time of buffer addition.
2. Add 1 to 2 ml of buffer solution to the sample to bring the pH to 100.1.
3. Add appropriate amount of dry powder indicator formulation.
4. Add EDTA titrant slowly, with continuous stirring, until the last reddish tinge disappears. Add the last few drops 3 to 5 second intervals. At the end point the solution is pure blue.

Calculation:

(E.3)

where: A = ml titration for sample, and B = mg CaCO3 equivalent to 1.00ml EDTA titrant.

E.7.6 Nitrate (NO3-)

Method Cadmium Reduction Method ((APHA, 1998) 4500- NO3- E)

Principle NO_3- is reduced almost quantitatively to nitrite (NO_2-) in the presence of cadmium (Cd). The NO_2- produced thus is determined by diazotizing with sulphanilamide and coupling with N-(1-naphthyl)-ethylebediamine dihydrochloride to form a highly coloured azo dye that is measured colourimetrically. A correction is made for any NO_2- present in the sample by analysing without the reduction step.

Scope and Application This method is applicable in the measurement of Nitrate in potable, surface and saline waters and domestic and industrial wastewaters. The applicable range of this method is 0.01 to 1.0mg/L NO_3- N/L.

Interferences Suspended matter in the column may restrict sample flow. Reduction column may reduce efficiency due to higher concentrations of iron, copper, other metals, residual chlorine, oil or grease in the sample.

Sample holding and preservation Cool samples at 40C if not analysed immediately and hold for no more than 48 hours.

Apparatus

1. Reduction column
2. Spectrophotometer (set to read at 543nm)

Reagents

1. Distilled water (the absorbence of a blank prepared with this water should not exceed 0.01)
2. Colour reagent: To 800-ml water add 100ml 85% phosphoric acid and 10g Sulfanilamide. After dissolvong sulfanilamide completely, add 1g N-(1-naphthyl)-ethylenediamine dihydrochloride. Mix to dissolve, then dilute to 1L with water.
3. Ammonium Chloride-EDTA solution: Dissolve 13g NH_4Cl and 1.7 g disodium ethylenediamine tetraacetate in 900 ml distilled water. Adjust to pH 8.5 with conc. NH_4OH and dilute to 1L.
4. Prepare Nitrate stock solution: dry KNO_3 in oven at 105^oC for 24 h. Weigh 0.7218g dried KNO_3 and dissolve in 900ml distilled water. Dilute to 1L and add 2ml $CHCl_3$ for preservation. 1.00ml = 100ug NO_3- -N

Procedure

1. Prepare a series of standard solutions in the range 0.05 to 1.0 mg/L by diluting the stock solution.
2. To 25.0 ml of each standard, blank and sample, add 75ml of NH4Cl- EDTA solution and mix.
3. Pour into column and collect at a rate of 7 to 10ml/min. Discard the first 25 ml. Collect the remainder in a 50-ml flask.
4. As soon as possible, and not more than 15 min after reduction, add 2.0ml-colour reagent to the collected 50-ml and mix. If NO3- concentration exceeds about 1mg/L, make an appropriate dilution.
5. Between 10 min and 2h afterward, measure absorbance at 543 nm against a distilled water reagent blank

Calculation Obtain a standard curve by plotting absorbance of standards against nitrate concentration. Compute sample concentrations directly from standard curve. Report as milligrams oxidised N per litre (the sum of NO_3- - N plus NO_2- - N) unless the concentration of NO_2- - N is separately determined and subtracted.

E.7.7 Nitrogen (Nitrite) (NO_2-)

Method Colourimetric Method ((APHA, 1998) 4500- NO2- A)

Principle Nitrite NO_2- is determined through formation of reddish purple azo dye produced at pH 2.0 to 2.5 by coupling diazotized sulphanilamide with N-(1-naphthyl) ethylebediamine dihydrochloride (NED dihydrochloride).

Scope and Application This method is applicable in the measurement of Nitrite in potable, surface and saline waters and domestic and industrial wastewaters. The applicable range of this method is 0.01 to 1.0mg/L NO_2- N/L.

Interferences Suspended solids should be removed by filtration. The following ions interfere because of precipitation under test conditions and should be absent: Sb_3+, Au_3+, Bi_3+, Pb_2+, Hg_2+, Ag_+, Chloroplatinate(PtCl62-), and metavandate (VO32).

Sample holding and preservation Never use acid preservation for samples to be analysed for NO_2-. Make the determination promptly on fresh samples to prevent bacterial conversion of NO_2- to NO_3- or NH_3. For short-term preservation of 1 to 2 days, freeze samples at 20^{o}C or cool at 40^{o}C.

Apparatus Spectrophotometer (set to read at 543nm)

Reagents

1. Distilled water (nitrate-free water)
2. Colour reagent
3. Prepare Nitrite stock solution: Dissolve 1.232 g $NaNO_2$ in water and dilute to 1000ml; 1.00ml = 250mg. Preserve with 1 ml CHCl3.

Procedure

1. Prepare a series of standard solutions in the range 0.05 to 1.0 mg/L by diluting the stock solution.
2. If sample contains suspended solids, filter through a 0.45 mm pore diameter membrane filter
3. If sample pH is not between 5 and 9, adjust to the range with 1N HCl or NH_4OH as required.
4. To 50.0-ml sample, or to a portion diluted to 50.0 ml, add 2ml-colour reagent and mix.
5. Between 10 min and 2 h after adding colour reagent to sample and standards, measure absorbance at 543nm

Calculation Obtain a standard curve by plotting absorbance of standards against nitrite concentration. Compute sample concentrations directly from standard curve.

E.7.8 Total and Reactive Phosphorous (PO43-)

Method Stannous Chloride Method ((APHA, 1998) 4500- P D)

Principle Phosphate reacts with ammonium molybdate to form molubdophosphoric acid. Molubdophosphoric acid is then reduced by stannous chloride to form intensely coloured molybdenum blue. The intensity of the colour is measured at 690 nm. Results are expressed as ppm (mg/l) PO_4.

Scope and Application The minimum detectable concentration is about 3mg/l. The applicable range of this method is 0.01 to 6.0mg/l P/l.

Interferences Silica and arsenate cause positive interference only if the sample is heated. Arsenate, fluoride, thorium, bismuth, sulphide, thiosulphate, thiocyanate, or excess molybdate cause negative interferences.

Sample holding and preservation If total phosphorous alone is to be determined, add 1ml HCl/L or freeze without any additions. Dont store samples containing low concentrations of phosphorous in plastic bottles unless kept in a frozen state because phosphate may be adsorbed on to the walls of plastic bottles. Never use commercial detergents containing phosphate for cleaning glassware used in phosphate analysis. Use acid washed glassware for determining low concentrations of phosphorous. Phosphorous contamination is common because of its absorption on glass surfaces. Preferably, reserve the glassware only for phosphate determination, and after use, wash and keep filled with water until needed. If this is done, acid treatment is required only occasionally.

Apparatus

1. Spectrophotometer (set to read at 690nm)
2. Autoclave or pressure cooker

Reagents

1. Distilled water (phosphate-free water).
2. Phenolphthalein indicator aqueous solution
3. Sulphuric acid solution: Carefully add 300ml conc. H_2SO_4 to approximately 600ml distilled water and dilute to 1L with distilled water.
4. Ammonium persulphate, (NH4)2S2O8, solid, or potassium persulphate, $K_2S_2O_8$, solid.
5. Sodium hydroxide, NaOH, 1N.
6. Ammonium molybdate reagent I: Dissolve 25g $(NH_4)6Mo_7O_{24}.4H_2O$ in 175ml distilled water. Cautiously add 280ml conc. H_2SO_4 to 400 ml-distilled water. Cool, add molybdate solution, and dilute to 1L.
7. Stannous Chloride reagent I: Dissolve 2.5g fresh $SnCl_2.2H_2O$ in 100-ml glycerol. Heat in water bath and stir with a glass rod to hasten dissolution. This reagent is stable and requires neither preservatives nor special storage.
8. Phosphate stock solution: Dissolve in distilled water 219.5 mg anhydrous KH_2PO_4 and dilute to 1000ml; 1.00ml = 50mg PO_43- - P.

Procedure

1. Prepare a series of standard solutions in the range 0.05 to 1.0 mg/L by diluting the stock solution.
2. Use 50 ml or a suitable portion of thoroughly mixed sample containing not more than 200 mg of P and free from colour and turbidity. Add 0.05-ml (1-drop) phenolphthalein indicator solution. If a red colour develops, add H_2SO_4 solution drop by drop to just discharge the colour.
3. Go to step 6 if only reactive phosphorous is required to be determined.
4. Then, add 1-ml H2SO4 solution and either 0.4 g solid $(NH_4)2S_2O_8$ or 0.5 g solid $K_2S_2O_8$.
5. Heat for 30 min in an autoclave. Cool, add 0.05ml (1-drop) phenolphthalein indicator solution, and neutralise to a faint pink colour with NaOH. Make up to 100ml with distilled water. Shake well to redissolve what might have precipitated.

   Add, with thorough mixing after each addition, 4.0ml molybdate reagent I and 0.5 ml stannous chloride reagent I. Rate of colour development and intensity of colour depend on temperature of the final solution, each 1^oC increase producing about an 1% increase in colour. Hence, hold samples, standards and reagents with in 2^oC of one another and in the temperature range between 20 and 30^oC.
6. After 10 min, but before 12 min, using the sample specific interval for all determinations, measure absorbance at 690nm and compare with calibration curve, using a distilled water blank
7. Always run a blank on reagents and distilled water. Because the colour at first develops progressively and later fades, maintain equal timing conditions for samples and standards. Prepare at least one standard with each set of samples or once each day that tests are made. The calibration curve may deviate from a straight line at the upper concentrations the 0.3 to 2.0-mg/L range.

Calculation Obtain a standard curve by plotting absorbance of standards against phosphorous concentration. Compute sample concentrations directly from standard curve.

E.7.9 Metals (Cd, Cr, Cu, Pb, Zn)

Method Flame Atomic Absorption Spectrometry (FAAS) ((APHA, 1998) 3111B, 3030E)

Principle The sample is aspirated into a flame (2100-2800oC) and atomised. The atoms absorb light at characteristic wavelengths. Because each metal has its own characteristic absorption wavelength, a source lamp composed of the element of interest is used. The amount of energy at the characteristic wavelength absorbed in the flame is proportional to the concentration of the analyte over a limited concentration range. A photonmultiplier detects the amount of reduction of the light intensity due to absorption by the analyte.

Interferences For the metals of interest, no major chemical interferences have been reported in the air-acetylene flame.

Sample Holding and Preservation Samples are immediately acidified with concentrated nitric acid (HNO_3) to pH ¡ 2 (1.5-ml HNO_3/L sample) and preferably stored in a refrigerator at approximately 4oC to prevent change in volume due to evaporation. Samples with metal concentrations of several milligrams per litre care stable for up to six months. For microgram per litre metal levels, analyse samples as soon as possible after collection.

Apparatus

1. Atomic Absorption Spectrometer (AAS).
2. Hot plate/Steam bath
3. 100ml Pyrex Glass Bottles

Reagents

1. Metal-free water
2. Concentrated Nitric Acid
3. Standard metal solutions

Procedure

1. The procedure depends on what fraction of the total metal contained in the sample is to be determined. To determine dissolved metals filter the sample immediately after collection through a 0.45mm membrane filter. After filtration acidify filtrate to pH ¡2 with conc HNO_3 and analyse directly.
2. For acid extractable metals, acidify entire sample with 5ml conc HNO_3/l sample. To prepare sample, mix well, transfer 100ml to a beaker or flask, and add 5ml 1 + 1 high purity HCl. Heat 15 min on a steam bath. Filter through a membrane filter, adjust filtrate volume to 100ml with water, and analyse.
3. For total metals, mix sample and transfer a suitable volume (50 to 100ml) to a 100ml pyrex bottle. Add 5ml conc HNO_3 and a few boiling chips or glass beads. Bring to a slow boil and evaporate on a hot plate to the lowest volume possible (10 to 20ml) before precipitation occurs. Continue heating and adding conc HNO_3 as necessary until digestion is complete as shown by a light-coloured, clear solution. Do not let samples dry during digestion. Wash down bottles wall with water and then filter if necessary. Transfer filtrate to a 100ml volumetric flask and dilute to mark. Take portions of this solution for metal determination.
4. For metals in sediment, oven-dry samples at 103-105^{o}C for 24 hours and cool in a desiccator. Crush and sieve to a fraction size of ¡= 250mm. Take a known weight (2g) of the sieved sample and transfer into a beaker. Add 5ml of conc. HNO3 (69%, w/w). Evaporate the sample on a hot plate to dryness. Dissolve the residue in 1% nitric acid. Filter through Whatman 934-AH Glass Microfibre Filter. Make it up to a final volume of 100ml and store in acid-rinsed plastic containers until analysis. Concentration of metals in sediment are calculated as follows:

5. Select at least three concentrations of each standard metal solution to bracket the expected metal concentration of the samples and a blank. The instrument reads out the concentrations based on this calibration curve.
6. Set the instrument to reslope the calibration curve by one of the standards. Reslope after five samples run through. If the instrument reports reslope out of range, it has to be calibrated again. If this happens, then samples run before resloping have to be reanalysed. Concentrations can be read directly from the instrument.

E.7.10 Total Organic Carbon (TOC)

Method High-Temperature Combustion Method ((APHA, 1998) 5310 B)

Principle There are basically two types of TOC measurement methods: differential and direct. In the differential method both TC (Total Carbon) and IC (Inorganic Carbon) are determined separately and TOC (Total Organic Carbon) is calculated by subtracting IC from TC. In the direct method, the IC is removed from acidified sample by purging with a purified gas, and then TOC is determined by measuring TC as TC equals TOC. TC left after purging with gas is also known to as Non-purgeable Organic Carbon (NPOC) because Purgeable Organic Carbon (POC) such as benzene, toluene, cyclohexane and chloroform are partly removed from the sample by gas stripping. The direct method is suitable for surface, ground and drinking waters, as POC is negligible as compared to TOC in such samples.

In TC by Combustion-Infrared Method, the sample is homogenised and diluted as necessary and a microportion is injected into a heated reaction chamber packed with an oxidative catalyst such as cobalt oxide. The water is vaporised and the organic carbon is oxidised to CO2 and H2O. The CO2 from oxidation of organic and inorganic carbon is transported in the carrier-gas streams and is measured by means of a non-dispersive infrared analyser.

Apparatus Total Organic Carbon (TOC) Analyzer

Reagents
1. Reagent water
2. Sulphuric acid.
3. Organic Carbon Stock Solution: Dissolve 2.1254k anhydrous potassium biphthalate, $C_8H_5KO_4$, in carbon-free water and dilute to 1000ml; 1.00ml = 1.00mg carbon. Preserve by acidifying with H_2SO_4 to pH¡2.
4. Carrier gas: Purified oxygen or air, CO_2-free and containing less than 1 ppm hydrocarbon (methane).
5. Purging gas: Any gas free of CO_2 and hydrocarbons.

Procedure
1. Follow manufacturers instructions for operation. Adjust to optimum combustion temperature (680oC) before using instrument.
2. If sample contains gross solids or insoluble matter, homogenise until satisfactory replication is obtained.

E.7.11 Polycyclic Aromatic Hydrocarbons (PAHs)

Method Gas Chromatographic/Mass Spectrometric Method (GC-MS) ((APHA, 1998) 6440C)

Principle Prior to this method, appropriate sample solvent extraction techniques must be used e.g. Acetone/Hexane extraction for soils/sediments and solid phase extraction (SPE) or liquid/liquid extraction is carried out on problem samples i.e. layers of oil on samples for waters/leachates/slurries. A known volume of the sample extract is injected into a Gas Chromatograph (GC) and is analysed by temperature programmed capillary chromatography and Mass Selective Detection (MSD). Identification is performed using Selective Ion Monitoring (SIM) and quantification of the components is carried out by means of the Internal Standard technique, using 5 deuterated Internal

Standards. The relative response of the detector to the various components is taken into consideration in the calculations together with any dilution factors (D) required.

Scope and Application Polycyclic aromatic hydrocarbons (PAHs) are prevalent in the environment. They can either occur naturally in fossil fuel products e.g. coal and oil, or as a result of incomplete combustion of organic material. PAHs are classified as carcinogenic compounds and are monitored in a wide range of environmental matrices. This method describes a procedure for the detection, identification and quantification of 16 PAHs. This method is applicable to the analysis of samples of soil, water, leachate, slurry and sediment, with analysis being conducted on a Hewlett Packard 6890 Gas Chromatograph system using a Hewlett Packard 5973 Mass Selective Detector (MSD). Detection limits are set at 1μg/kg based on 15gms of extracted wet soil/sediment and 10ng/l based on 1 litre of extracted water/leachate/slurry, however, the detection limits quoted will vary if less sample is available for extraction.

Interferences Solvents, reagent glassware and other sample processing hardware may yield artefacts and/or interferences to sample analysis. All these materials must be demonstrated to be free from interferences under the conditions of the analysis. This is undertaken by analysis of method blanks.

Interferences co-extracted from the sample will vary considerably from source to source. If analysis of an extracted sample is prevented due to interferences, it may be necessary to clean up by column chromatography.

Raw GC-MS datafrom all blank samples and spikes, where applicable, must be evaluated for interferences, all samples must be blank corrected. It must be determined if the source of interference is in the preparation and/or clean up of the samples. Corrective action must be taken to eliminate the problem.

Contamination by carry over can occur whenever high-level and low-level samples are sequentially analysed. As part of the auto-sampling sequence of the GC-MS, the syringe must be rinsed out between samples with solvent. Whenever an unusually concentrated sample is encountered (dilute if necessary and record) wherever possible the next analysis should be that of a solvent blank to ensure that no cross contamination occurs. Where the sample has been analysed as part of a batch using the auto-sampler, the sample itself and any of the following samples, which may contain carryover, must be repeated.

Reagents Custom Stock PAH Standard containing 19 PAHs, each at a concentration of 100ug/L. Semi-volatiles Internal Standard mixture, in a 1 ml glass vial, comprising:

Compound	amount	Compound	amount
Acenaphthene-d10	2000μg/ml	1,4-Dichlorobenzene-d4	2000μg/ml
Chrysene-d12	2000μg/ml	Naphthalene-d8	2000μg/ml
Perylene-d12	2000μg/ml	Phenanthrene-d10	2000μg/ml

System Suitability Check Each peak in each standard must be individually checked for correct assignment and correct integration. This procedure is then repeated for every sample and blank that is subsequently ran. The initial calibration graphs must be examined at the point of calibration checking that the linearity is =/¿ 0.995 before any samples can be processed.

The MSD 5973 system must be tuned according to manufacturers recommendations and specifications, typically once a week or after a major overhaul. Acceptance criteria need to be put in place for the autotune each week. Background subtraction, if required, is used to eliminate column bleed, electrical spikes or instrument background ions. If poor chromatography is noted this may indicate one of the following: the deactivated glass liner may need to be cleaned or replaced, alternatively the whole injection port may require cleaning, including the inlet base seal (gold plated seal). It may also be necessary to perform a column chop which involves the removal of a minimum of 5 inches maximum 12 inches of capillary column adjacent to the injector. The above procedure is an integral part of routine maintenance of the GC-MS system. If poor chromatography persists after the remedial actions noted above, it may be necessary to perform a complete column change or source clean. Instructions for column change and source clean are outlined in the HP computer support help pages and CD-ROM, provided by HP for the MSD 5973 system. All maintenance on the instruments is logged in a logbook, which can be found beside the instrument.

Peak areas of the internal standards are monitored with each run and should be within the stated acceptance criteria.

Procedure Prepare the sample for analysis as follows: Using the 10μl precision syringe, add 10μl of the working Internal Standard solution to the sample extract as received from the extraction laboratory, mix thoroughly, the sample is now ready for analysis.

Quality control Standards must be stored in a refrigerator at 4^{o}C +/- 5^{o}C. The temperature of the fridge is recorded daily. The thermometers used to check the fridges are calibrated annually using a certified reference temperature probe.

Daily AQC check standards, normally 5 μg/ml, should be analysed after every 20 samples. If the result of the QC check standard falls outside the acceptable limits, i.e. between 2 and 3 standard deviations of the expected value, the system should be re-calibrated and the samples before the AQC standard must be re-analysed.

NOTE: If the AQC is prepared from the same stock as the calibration solution then the AQC must be prepared by another analyst.

A contaminated CRM, LGC 6140, is analysed every 50 samples every second day and the results plotted on an AQC chart based on 2 and 3 standard deviations. As the CRM is a dry sample 20% water is added and it is ran as a wet sample, the moisture content is then taken into account when calculating the concentration of the CRM. If there are two consecutive points outside the warning limits a third AQC should be ran straight away and if that is outside the warning limits then the analysis must be repeated. If one point is outside the control limit then the analysis must be repeated immediately.

Compound Identification The qualitative identification of compounds determined by this method is based on retention time and on comparison of the sample analyte selected ion ratios with the same ions in the standards run with the samples. The characteristic ions are chosen as the ions of greatest relative intensity that occur in the reference mass spectrum. Or more particularly have characteristic structural significance. Ions present in the reference spectrum must be present in the sample spectrum at the same ratio if more than one ion is monitored (within 20%). When analytes co-elute (i.e. only one chromatographic peak is apparent for more than one analyte), the identification criteria must be met, but each analyte spectrum may contain extraneous ions contributed by the co-eluting compound. This is acceptable provided the target ions are present and within the correct ratio.

E.7.12 Volatile Organic Compounds (VOCs)

Method: Headspace GC-MS (US EPA 8260B)

Summary of method: The vials, containing the samples, are first heated to $80^{o}C$ and shaken for 15 minutes using a Hewlett Packard HP7694 Headspace Sampler, during this time any volatile organic compounds present are partitioned into the headspace in the vial. After this time, a known volume of the headspace (1ml) is sampled and injected into a Gas Chromatograph (GC) and is analysed by temperature programmed capillary chromatography and Mass Selective Detection (MSD). Identification is, generally, performed using the Scan Mode, however, Selective Ion Monitoring (SIM) can be used as an alternative. Quantification of the components present is carried out by means of the Internal Standard technique, using 4 Internal Standards, 3 surrogate standards are, also, used as system monitoring compounds. The relative response of the detector to the various components is taken into consideration in the calculations together with any dilution factor (D), which may be required.

In the case of uncalibrated compounds being identified within the sample, a response factor of 1 will be assumed relative to the nearest Internal Standard.

Scope and Application: Volatile organic hydrocarbons such as BTEX components (Benzene, Toluene, Ethylbenzene, Xylenes), Dichloromethane and Haloforms are known carcinogens and are highly toxic. This method describes a procedure for the detection, identification and quantitation of 60 volatile organic compounds that have boiling points typically below 200?C. A full list of the compounds detected by this method is shown in Table 1. This method can, also, be used to detect, identify and semi-quantitate any other organic compounds, that have boiling points below 200^oC, and which elute from the GC chromatography column providing they elute as sharp peaks and give an acceptable response on the detector used.

This method, also, describes a procedure the preparation and analysis of samples of soil, sediment, water, slurry and gas for volatile hydrocarbons, with the analysis being conducted on a Hewlett Packard 5890 or 6890 Gas Chromatograph system using a Hewlett Packard 5971A, 5972 or 5973 Mass Selective Detector (MSD).

Detection limits are set at 1μg/kg based on 5gm of soil/sediment, 1μg/l based on 10 mls of water/slurry.

Reagents: Stock Volatile Organic Compounds Mixture containing 60 components, each at a concentration of 100 μg/ml in Methanol. Stock Volatiles Internal Standard mixture comprising:

Compound	Amount	Compound	Amount
Pentafluorobenzene	2000μg/ml	1,4-Difluorobenzene	2000 μg/ml
Chlorobenzene-d5	2000μg/ml	1,4-Dichlorobenzene-d4	2000 μg/ml

Stock Volatiles Surrogate Standard mixture comprising:

Compount	Amount
Dibromofluorobenzene	2000μg/ml
Toluene-d8	2000μg/ml
4-Bromofluorobenzene	2000μg/ml
Carbon disulphide	99% min, BAKER ANALYSED ACS
tert-Butyl methyl ether (MTBE)	99% min

Sample storage and preservation: All standards and sample vials, prior to analysis must be stored in a refrigerator at 4^oC +/- 5^oC.

Samples Preparation: soil/sediment Into a clean 20ml clear glass, crimp topped headspace sample vial, accurately weigh 5 gm, to the nearest 0.1gm, of soil or sediment sample. Record the weight of sample used. Top up the vial, to the 10 ml mark, with Water. Using a precision syringe, add 5μl of the Stock Volatiles Surrogate Standard Mixture and 5μl of the Stock Volatiles Internal Standard Mixture. Crimp on the septum top securely and mix thoroughly, the sample is now ready for analysis.

Samples preparation: water/slurry Using the 10ml gas tight syringe, transfer 10mls of the water or slurry sample into a clean 20ml clear glass, crimp topped headspace sample vial. Using a precision syringe, add 5μl of the Stock Volatiles Surrogate Standard Mixture and 5μl of the Stock Volatiles Internal Standard Mixture. Crimp on the septum top securely and mix thoroughly, the sample is now ready for analysis.

Samples preparation: spiked blanks Using the 10ml gas tight syringe, transfer 10mls of the Water into a clean 20ml clear glass, crimp topped headspace sample vial. Using a precision syringe, add 5μl of the Stock Volatiles Surrogate Standard Mixture and 5μl of the Stock Volatiles Internal Standard Mixture. Crimp on the septum top securely and mix thoroughly, the Spiked blank is now ready for analysis.

System Suitability Check: Each peak in each standard must be individually checked for correct assignment and correct integration. This procedure is then repeated for every sample and blank that is subsequently ran. The initial calibration and the daily continuing calibration graphs must be examined at the point of calibration checking that the linearity is +/¿0.995.

The MSD 5973 system must be tuned according to manufactures recommendations and specifications, typically once a week or after a major overhaul. Acceptance criteria for the tune report is detailed below. Maximum sensitivity tune programme is suitable. Background subtraction, if required, is used to eliminate column bleed, electrical spikes or instrument background ions. If poor chromatography is noted this may indicate one of the following: the deactivated glass liner may need to be cleaned or replaced, alternatively the whole injection port may require cleaning, including the inlet base seal (gold plated seal). It may also be necessary to perform a column chop which involves the removal of 6-12 inches of capillary column adjacent to the injector. The above procedure is an integral part of routine maintenance of the GC-MS system. If poor chromatography persists after the remedial actions noted above, it may be necessary to perform a complete column change or source clean. Instructions for column change and source clean are outlined in the HP computer support help pages and CD-ROM, provided by HP for the MSD 5973 system. A log book is kept beside each instrument recording all maintenance carried out. The Surrogate standard is plotted on an AQC chart. The limits of which are based on 2 and 3 standard deviations.

Acceptance criteria for tune report are as follows:

- Ratio of mass 70 to 69 (0.5-1.6%) typical value 1.14%
- Ratio of mass 220 to 219 (3.2-5.4%) typical value 4.43%
- Ratio of mass 501 to 502 (7.9-12.3%) typical value 10.24%

Testing for air leaks:

- Ratio of 18 to 69 ¡20% typical value 1.20%
- Ratio 28 to 69 ¡10% typical value 3.22%

Electron multiplier voltage typical value should be between 1800 to 2500, replace if greater than 2600. It will operate up to 2600 ok. Peak widths should be between 0.45 0.65.

Procedure: Analyse the Calibration Standards, Spiked blanks and samples according to the typical GC-MSD and HP7694 Headspace sampler conditions. For details on how to load the Headspace sampler carousel and prepare a sequence, refer to the Hewlett Packard Operators Manual or refer to the respective HELP page within the software.

Interferences: Some solvents, such as Dichloromethane can penetrate the lids of sample vials, standard vials and water bottles. Any interference by such compounds or any external contamination of water, standards or glassware can be detected by analysis of water blanks and spiked blanks. Raw GC-MS data from all water blanks and spiked blanks must be evaluated for interferences. Any contamination in spiked blank must be subtracted from samples. Any source of interference should be determined and corrective action taken to eliminate the problem.

Contamination by carry over can occur whenever high-level and low-level samples are analysed sequentially. Spiked water blanks are analysed frequently and any suspected highly concentrated samples (e.g. pungent aroma or visible petrol/oil layer) should be diluted accordingly, with the dilution factor being recorded and, preferably, analysed at the end of the sequence in order to prevent cross-contamination of other samples.

Solvents, reagent glassware and other sample processing hardware may yield artefacts and/or interferences to sample analysis. All these materials must be demonstrated to be free from interferences under the conditions of the analysis. This is undertaken by analysis of method blanks.

Interferences co-extracted from the sample will vary considerably from source to source. If analysis of an extracted sample is prevented due to interferences, it may be necessary to clean up by column chromatography. Raw GC-MS data from all blanks samples and spikes, where applicable, must be evaluated for interferences. It must be determined if the source of interference is in the preparation and/or clean up of the samples. Corrective action must be taken to eliminate the problem.

Contamination by carry over can occur whenever high-level and low-level samples are sequentially analysed. As part of the auto-sampling sequence of the GC-MS, the syringe must be rinsed out between samples using an air purge. Whenever an unusually concentrated sample is encountered (dilute if necessary and record) wherever possible the next analysis should be that of a spiked water blank to ensure that no cross-contamination occurs. Where the sample has been analysed as part of a batch using the auto-sampler, the sample itself and any of the following samples, which may contain carryover, must be repeated.

Quality Control Checks A spiked blank was analysed after every 10 samples. A daily quality control check standard, 500 μg/l, was also analysed. If the result of the check standard falls outside the acceptable limits,i.e. 2 and 3 standard deviations the system must be re-calibrated and the samples analysed before the check standard must be re-prepared and re-analysed.

Compound Identification The qualitative identification of compounds determined by this method is based on retention time and on comparison of the sample mass spectrum with characteristic ions in a reference mass spectrum. The characteristic ions, from the reference mass spectrum, are defined as the ions of greatest relative intensity that occur in the reference spectrum. Molecular ions present in the reference spectrum should be present in the sample spectrum. Ions present in the sample spectrum but not in the reference spectrum should be reviewed for possible background contamination or presence of co-eluting compounds. Ions present in the reference spectrum but not in the sample spectrum should be reviewed for possible subtraction from the sample spectrum because of background contamination or co-eluting peaks. Identification is hampered when sample components are not resolved chromatographically and produce mass spectra containing ions contributed by more than one analyte. When gas chromatographic peaks obviously represent more than one sample component (i.e. a broadened peak with shoulder(s) or a valley between two or more maxima), appropriate selection of analyte spectra and background spectra is important.

Examination of extracted ion current profiles of appropriate ions can aid in the selection of spectra and in qualitative identification of compounds. When analytes co-elute (i.e. only one chromatographic peak is apparent), the identification criteria may be met, but each analyte spectrum will contain extraneous ions contributed by the co-eluting compound

Appendix F

Hydrographs of individual storm events

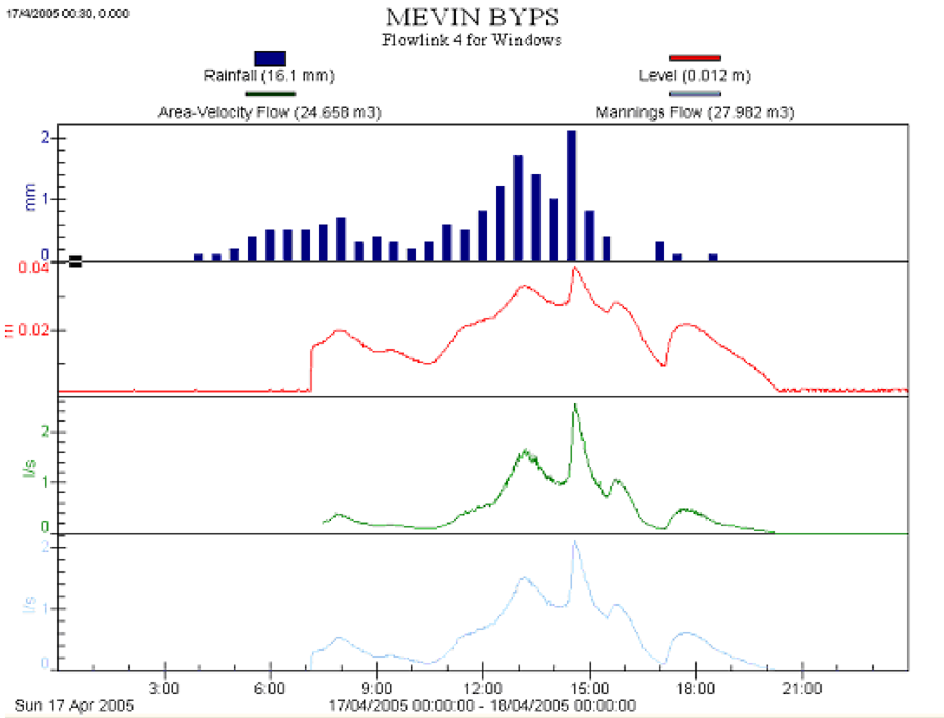

Figure F.1: Hydrograph: Monasterevin 17/Apr/2005

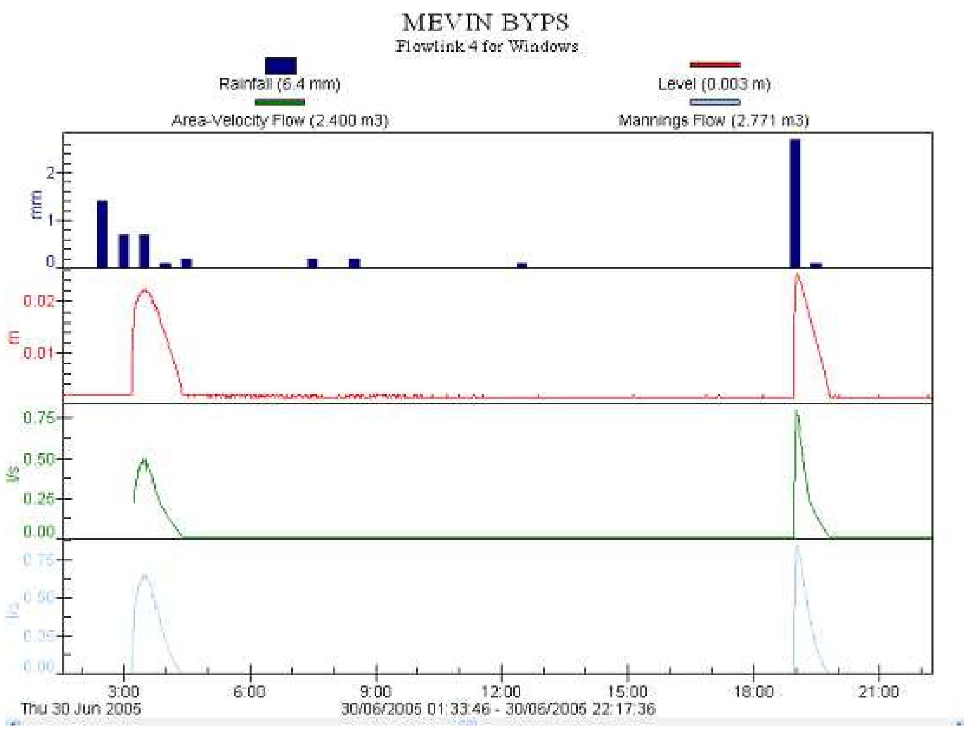

Figure F.2: Hydrograph: Monasterevin 30/Jun/2005

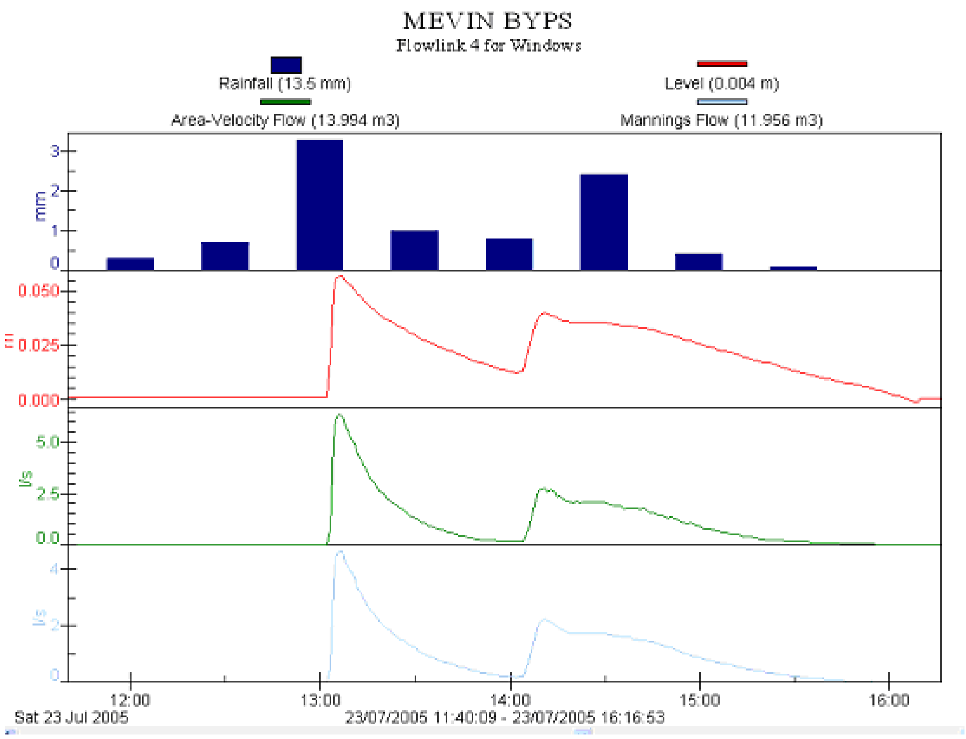

Figure F.3: Hydrograph: Monasterevin 23/Jul/2005

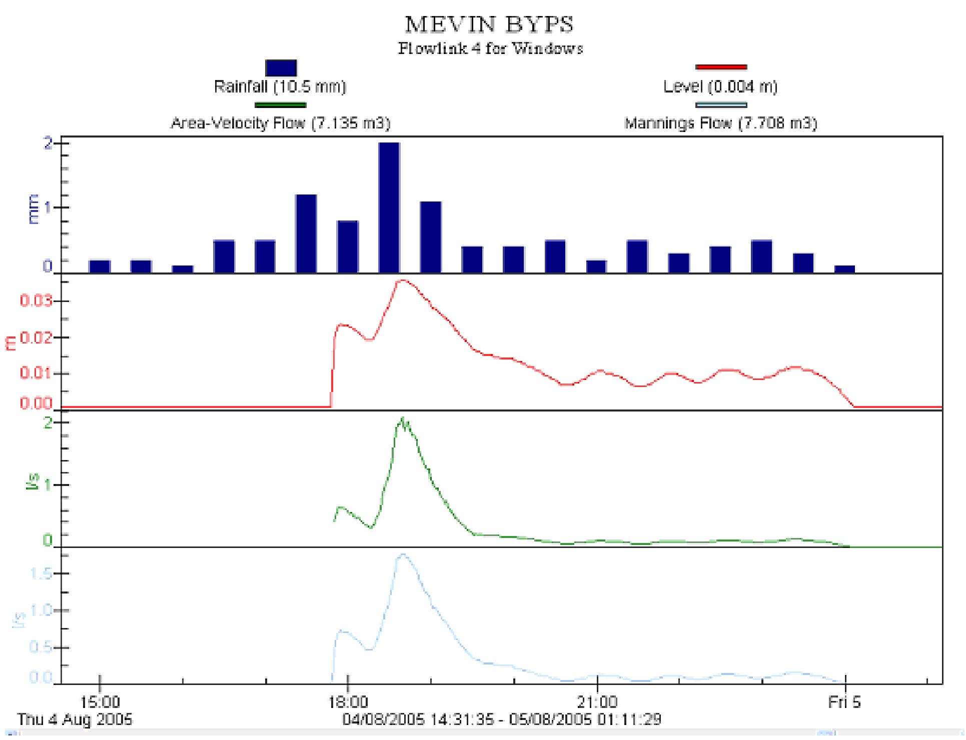

Figure F.4: Hydrograph: Monasterevin 4/Aug/2005

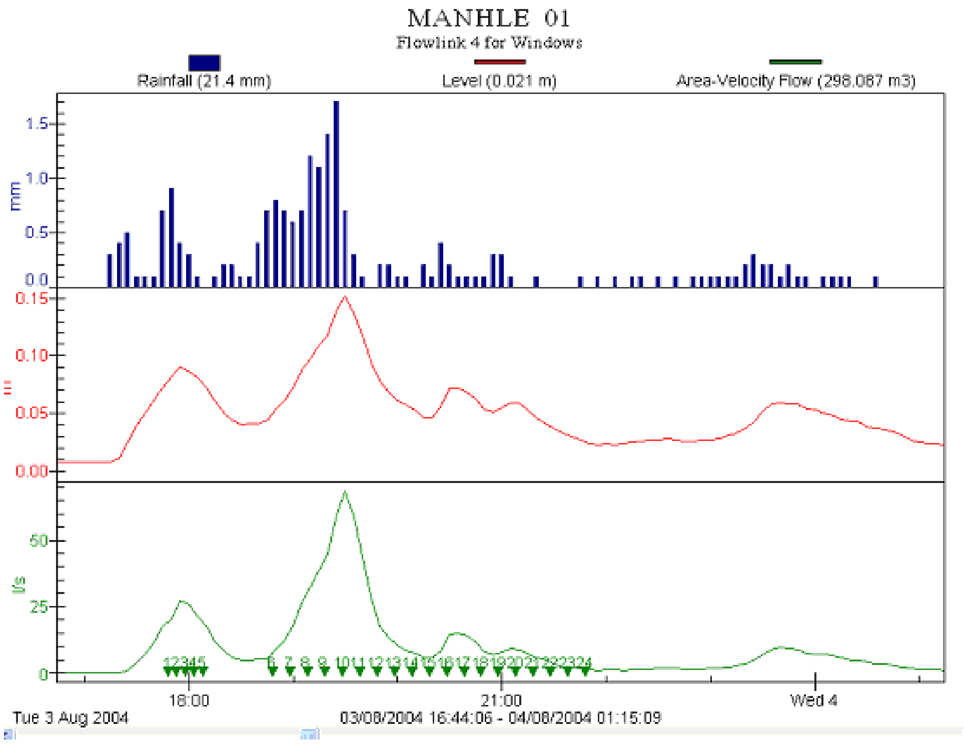

Figure F.5: Hydrograph: Kildare bypass 3/Aug/2004

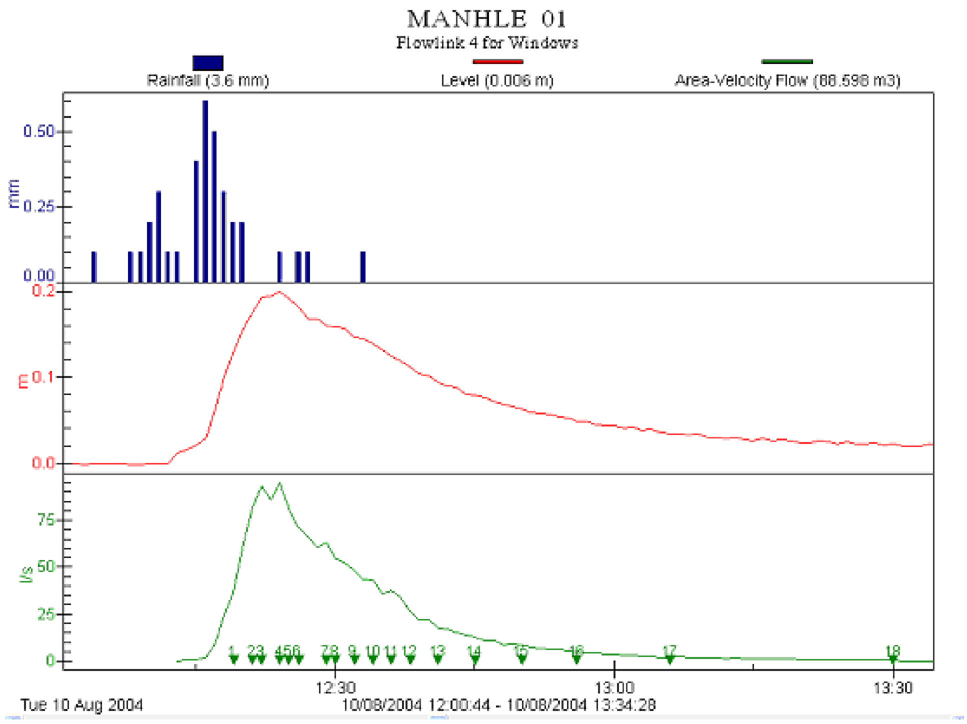

Figure F.6: Hydrograph: Kildare bypass 10/Aug/2004

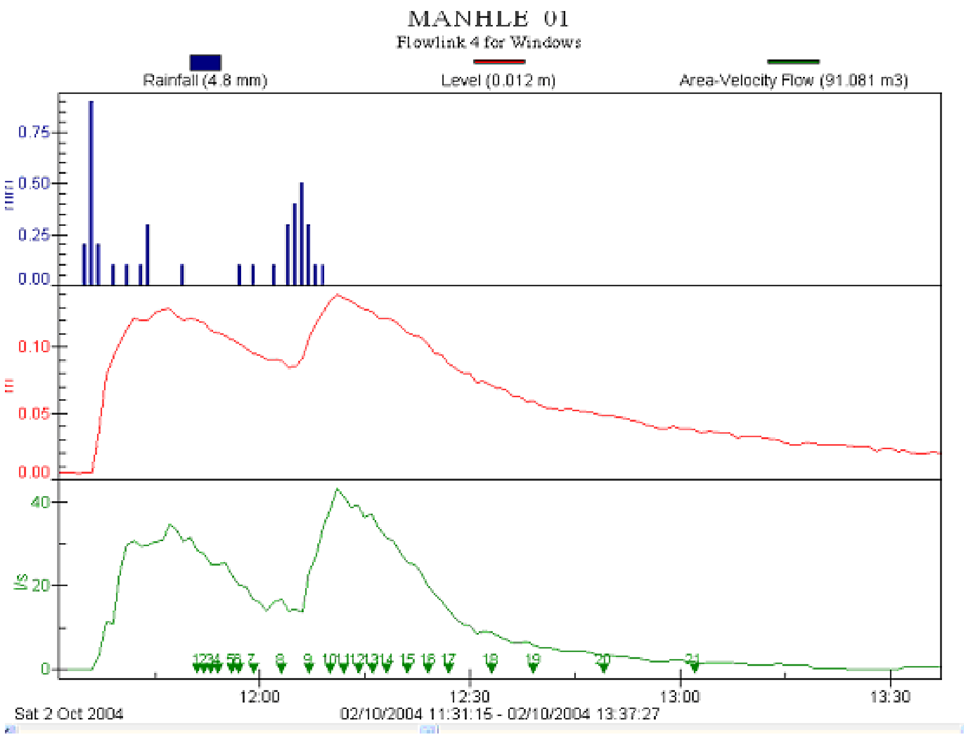

Figure F.7: Hydrograph: Kildare bypass 2/Oct/2004

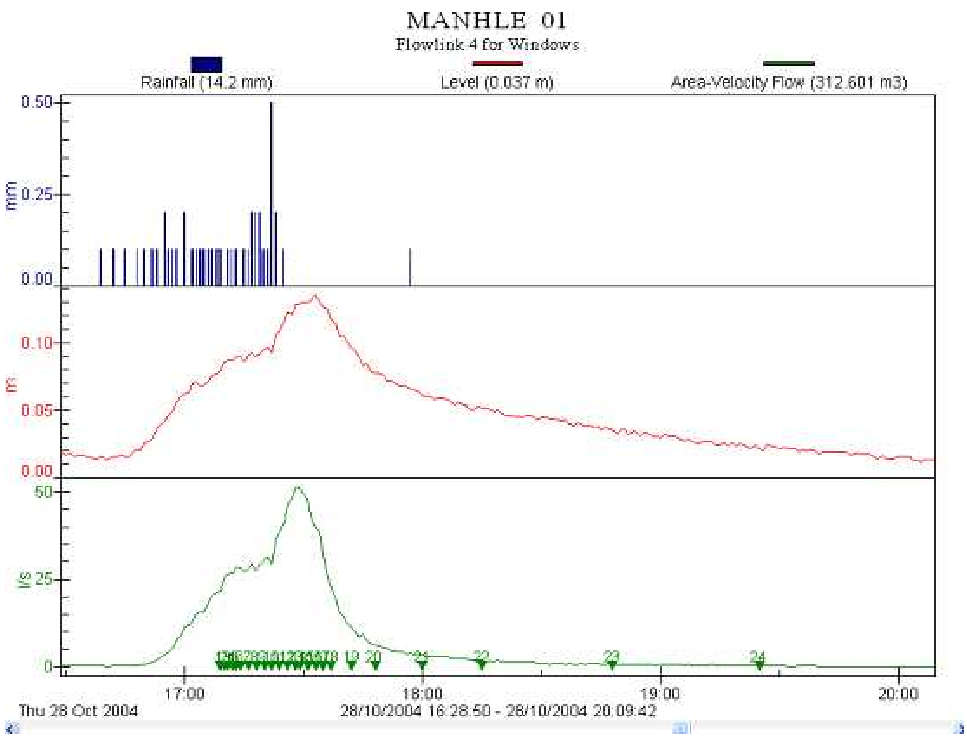

Figure F.8: Hydrograph: Kildare bypass 28/Oct/2004

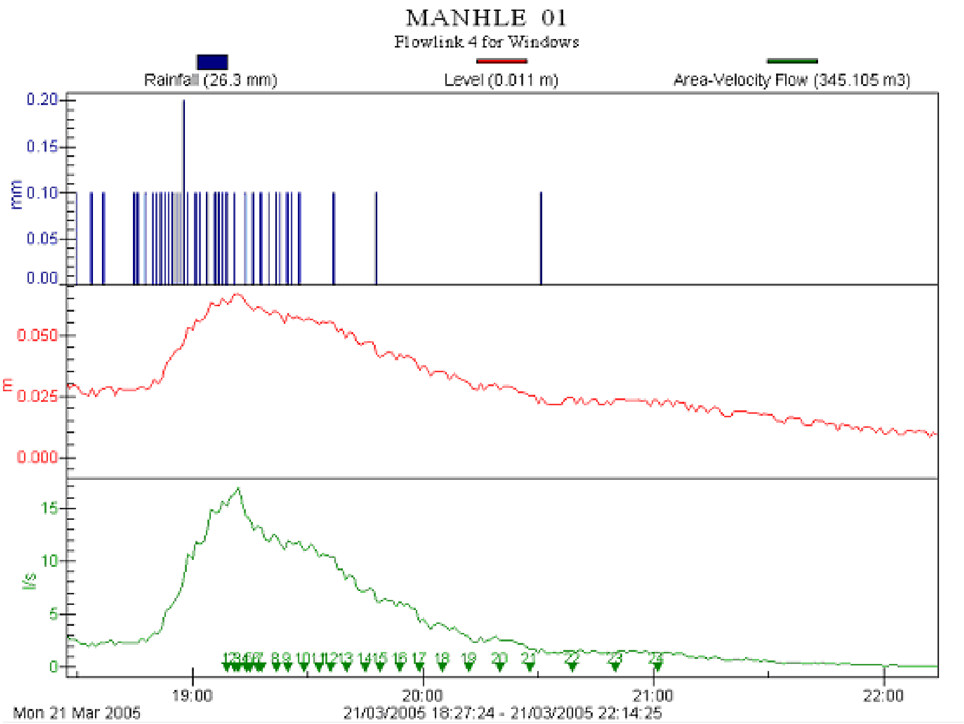

Figure F.9: Hydrograph: Kildare bypass 21/Mar/2005

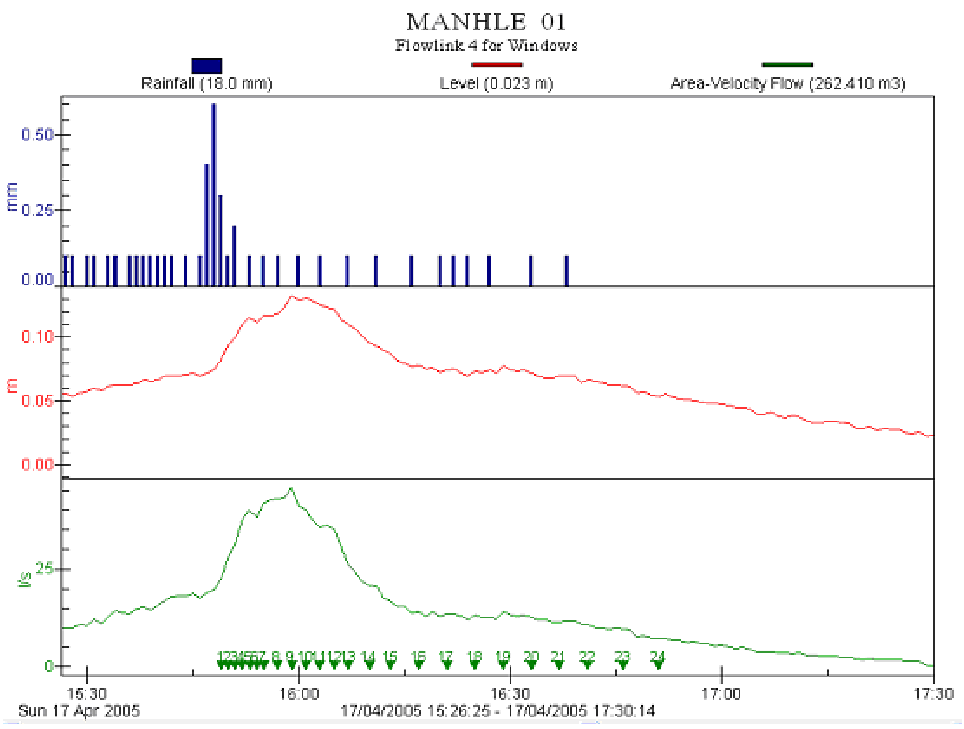

Figure F.10: Hydrograph: Kildare bypass 17/Apr/2005

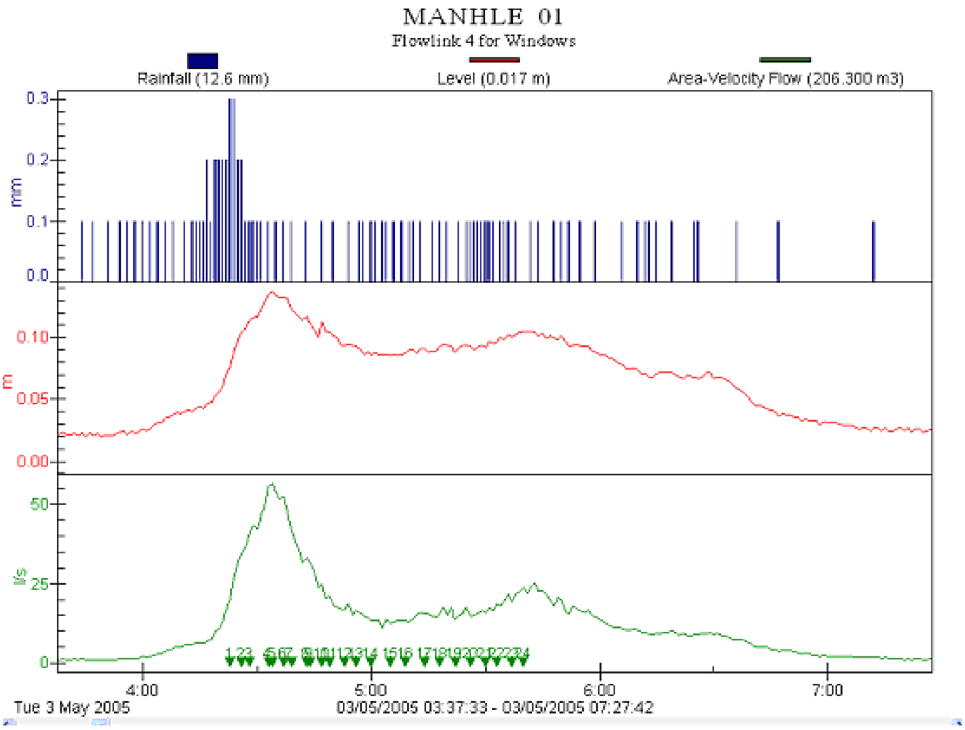

Figure F.11: hydrograph: Kildare bypass 3/May/2005

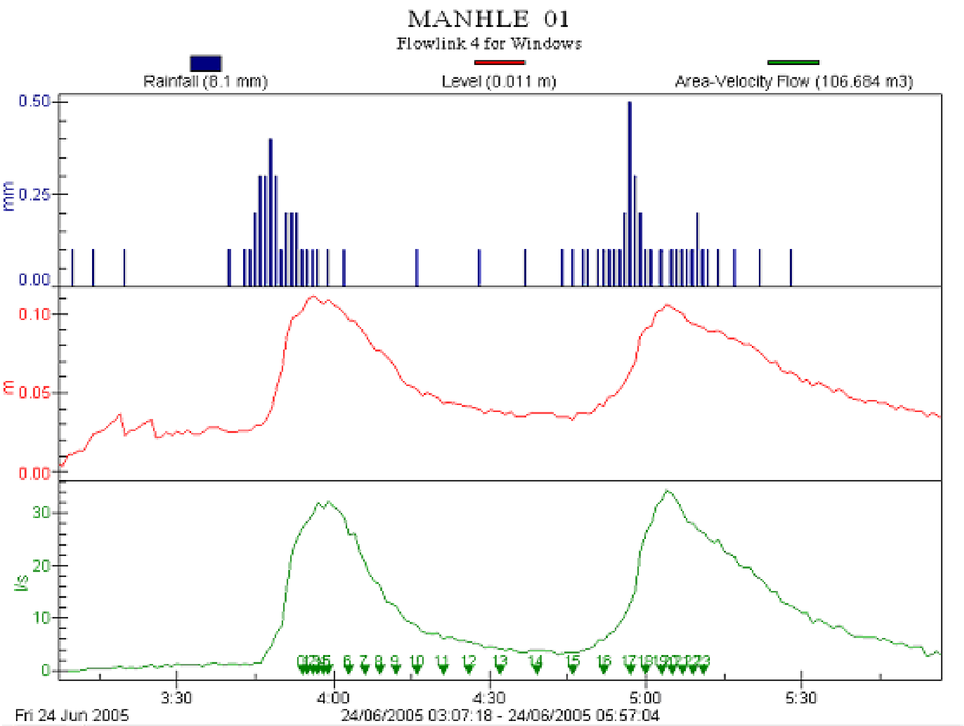

Figure F.12: hydrograph: Kildare bypass 24/Jun/2005

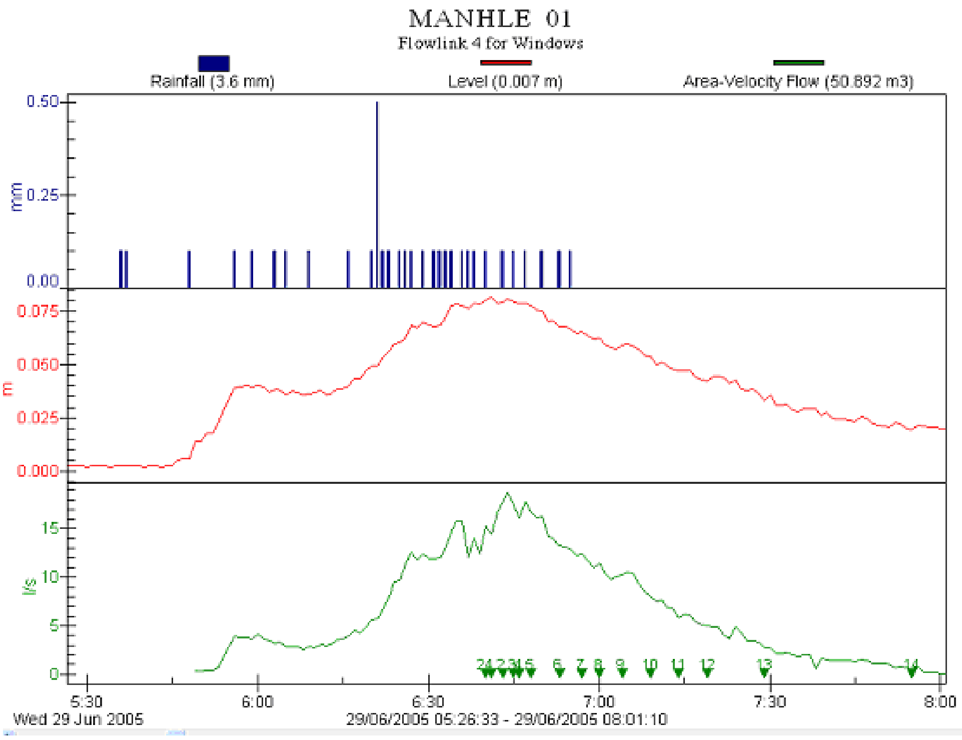

Figure F.13: hydrograph: Kildare bypass 29/Jun/2005

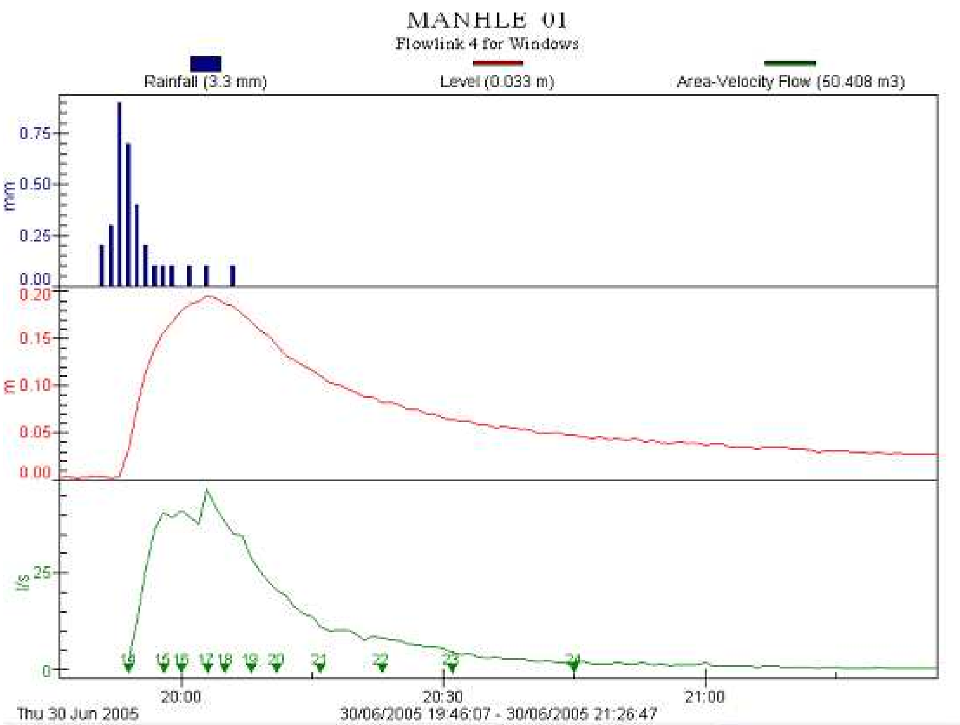

Figure F.14: hydrograph: Kildare bypass 30/Jun/2005

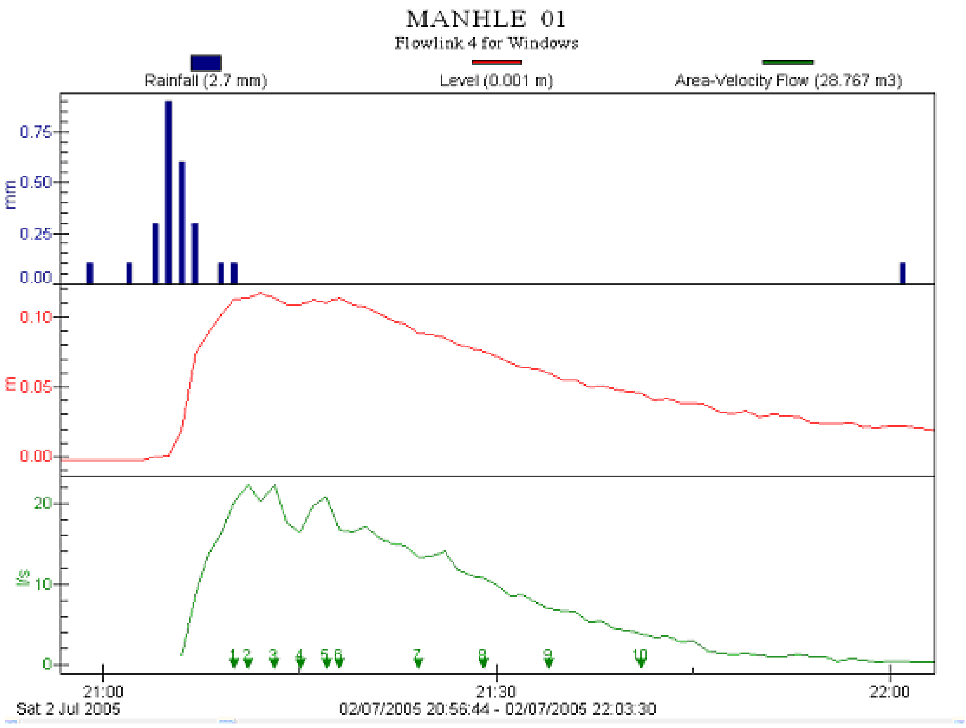

Figure F.15: hydrograph: Kildare bypass 2/Jul/2005

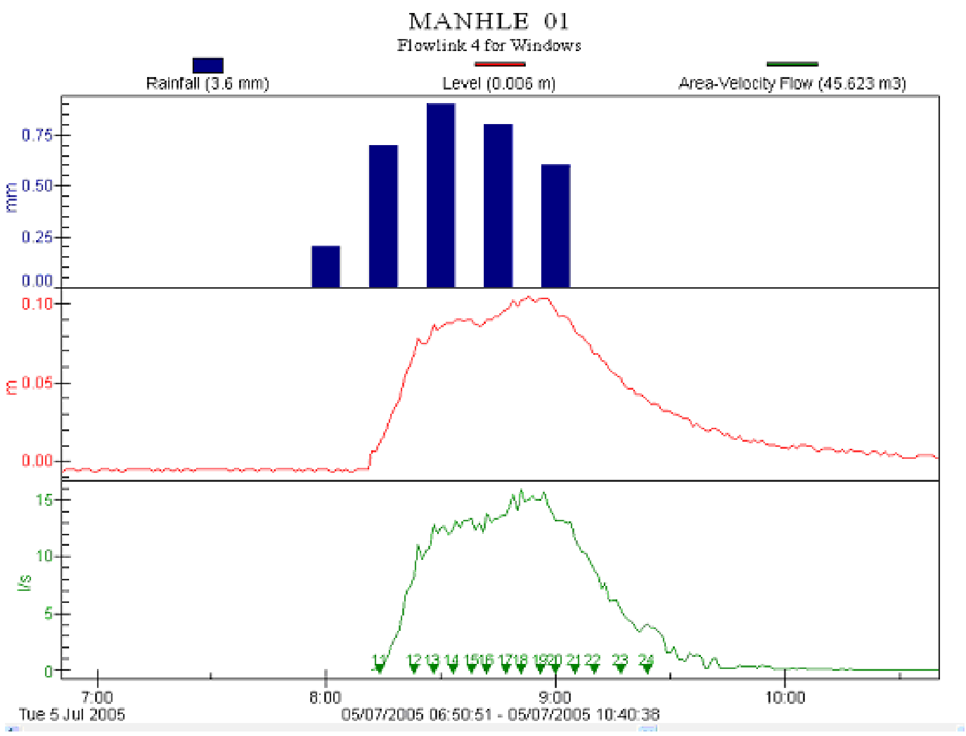

Figure F.16: hydrograph: Kildare bypass 5/Jul/2005

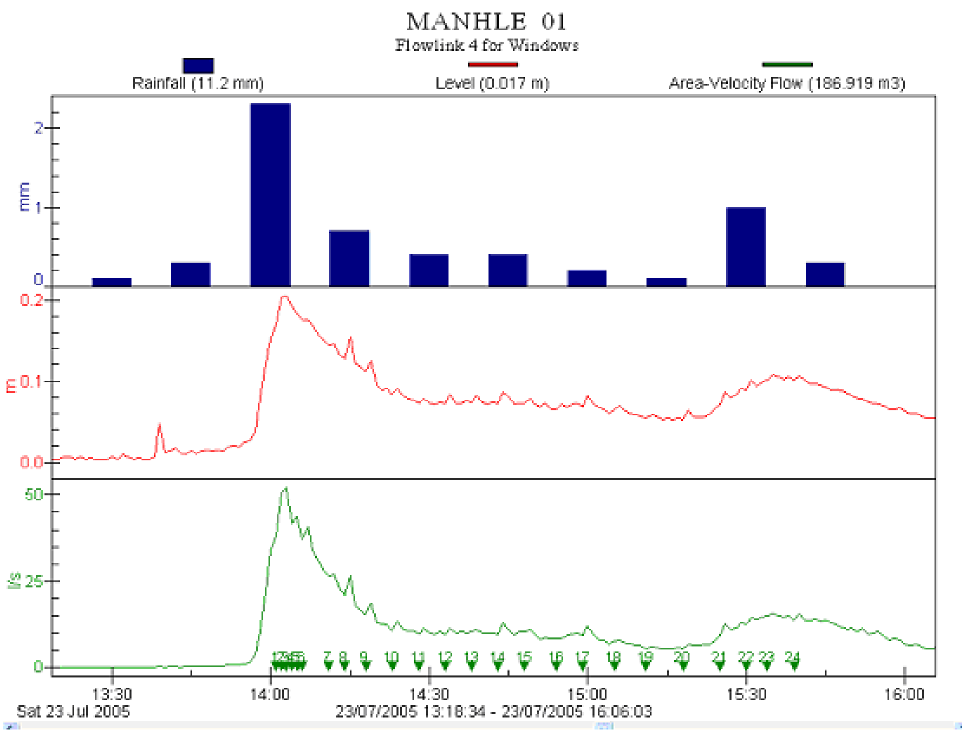

Figure F.17: hydrograph: Kildare bypass 23/Jul/2005

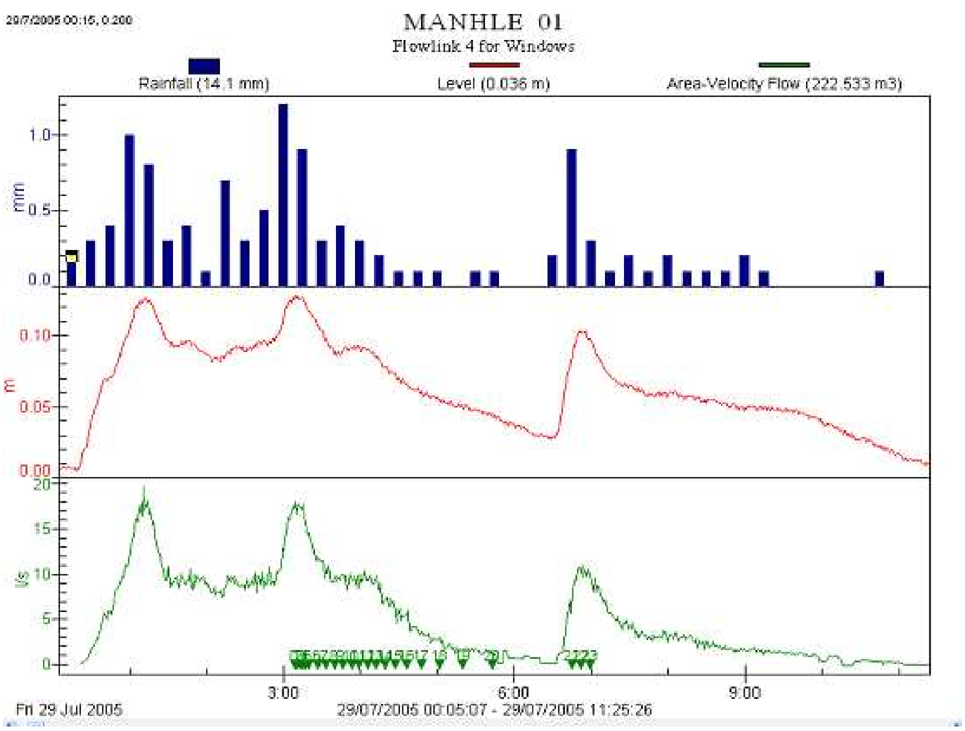

Figure F.18: hydrograph: Kildare bypass 29/Jul/2005

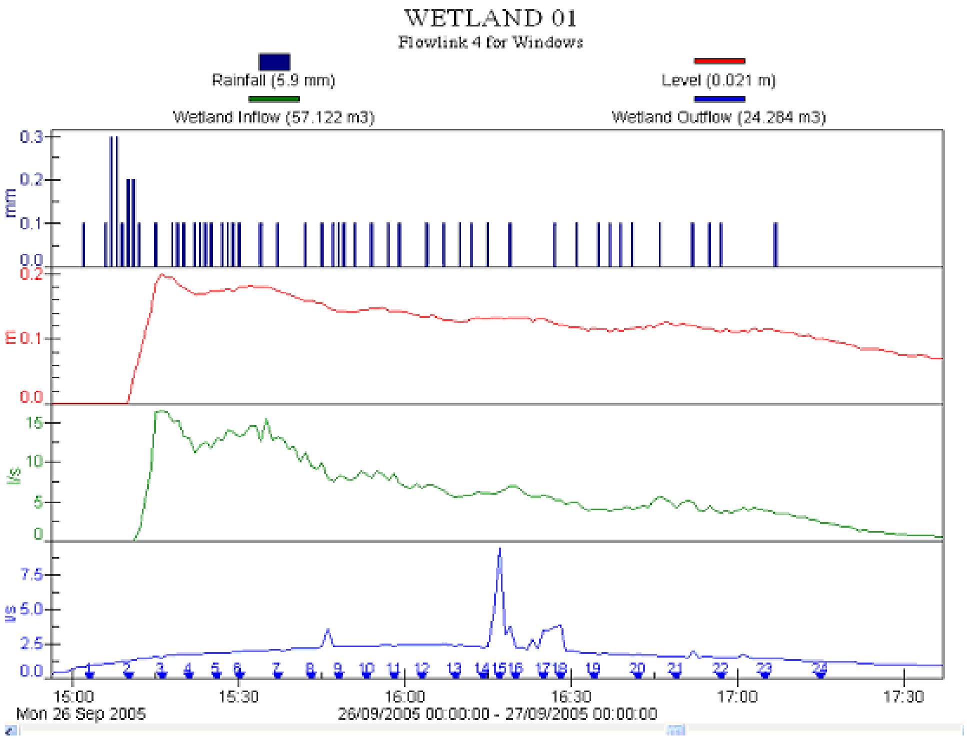

Figure F.19: hydrograph: Wetland 26/Sep/2005

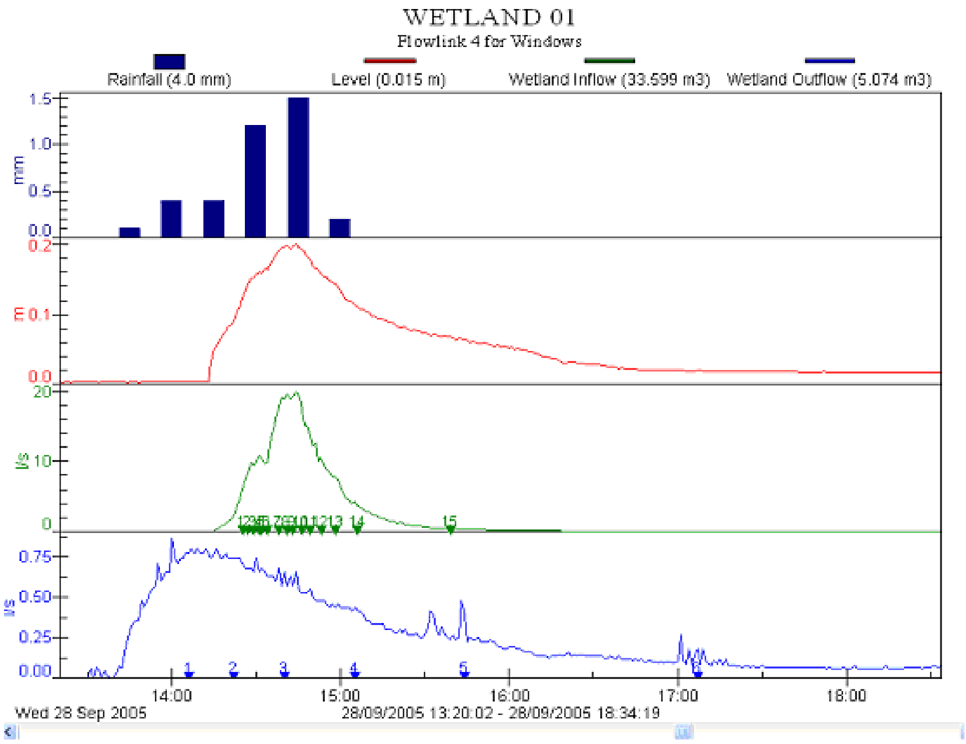

Figure F.20: hydrograph:Wetland 28/Sep/2005

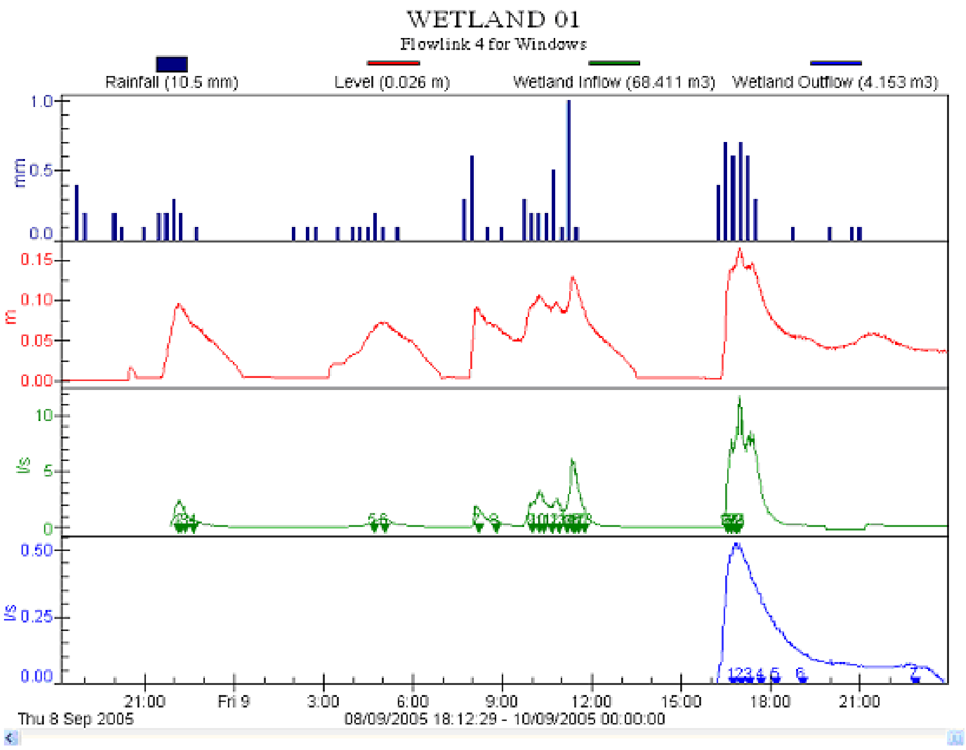

Figure F.21: hydrograph: Wetland 8/Sep/2005

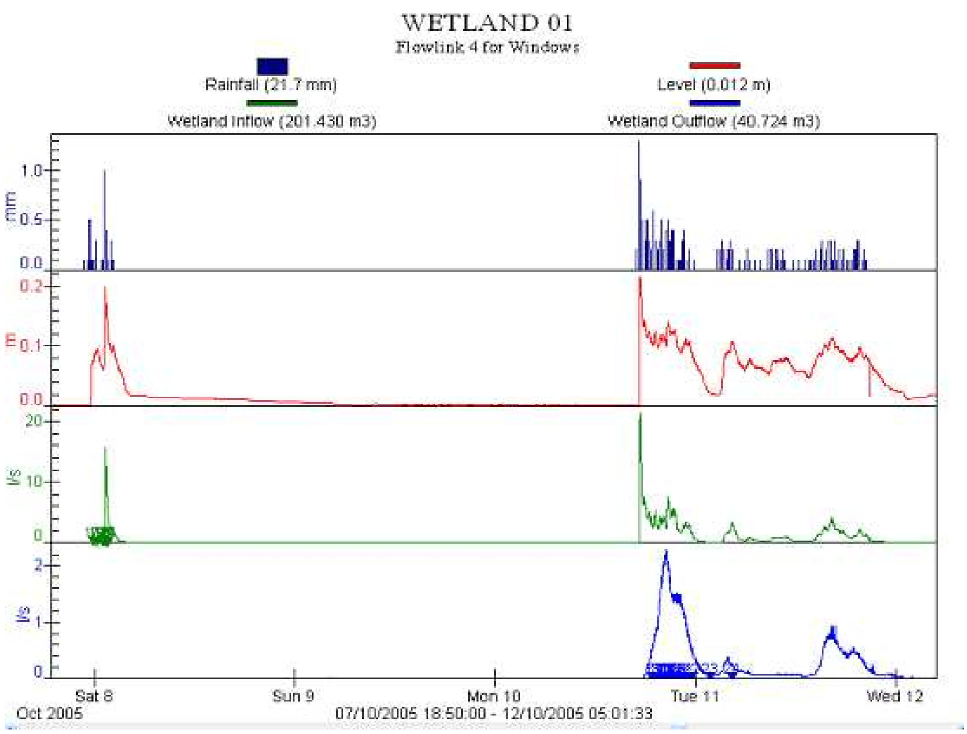

Figure F.22: hydrograph: Wetland 7/Oct/2005

Appendix G

List of deliverables

G.1 Deliverables

1.1 Review of experience and practice in Ireland and Europe.

This deliverable is addressed by two reports.

- Report-1: A review of current road drainage design practices in Ireland. This is based on a questionnaire survey of all local authorities in the Republic of Ireland. The analysis of the responses is summarised in Chapter 3 of this main report. Starting from an initial contribution from Atkins, the questionnaire results and analysis was done by UCD.
- Report -2 : Review of road drainage design in Europe: This is a report produced by TRL as one of their contributions to an EU COST action. We originally expected to have to purchase it directly from TRL, however it was not purchased as it is freely downloadable from the web-site:

  `http://europa.eu.int`

  Its contents are summarised, by TCD, in Chapter 4 of this main report.
- Report -3: This is an additional report, not part of the original list of deliverables. It is a comprehensive review, by UCD, of the international research literature concerning road runoff, its constituents and impacts. It is summarised in Chapter 2 of this main report.

1.2 Identification of suitable monitoring sites

Report-4 : Monitoring Specification.This report describes the three stage process of selecting appropriate sites for specific studies. It contains a brief description of the shortlisted sites and the selection criteria. For each of the 3 sites selected for detailed, automated, monitoring sites a detailed monitoring specification is given. Its contents are summarised in Chapter 5

1.3 Protocols for laboratory analyses.

Report -5 : Protocols are specified for collection, storage, transportation and chemical analysis of water samples. These follow accepted international practice. These are also described in Appendix E of this main report.

1.4 Coordination of Phase 1 of project. Report-6 : Phase-1 completion report. The project produced individual management reports covering each 6 month period. The Phase 1 coordination report is essentially a description of the management of the first 18 months of the project and is based on the individual 6 monthly reports.

2.1 Hydrobiological study This is a multi-faceted and complex part of the study and has been divided into two separate reports;

- Report-7 : Baseline hydrobiological status of subcatchments. See also Chapter 7 of this main report.

- Report-8 : Changes in hydrobiological status and relationship with road runoff. (analysis of temporal behaviour of catchments and of comparison between road-runoff and "control" catchments) See also Chapters 7 and 6 of this main report.

2.2 Set up and operate 2 representative road drainage sub-catchments.

Three functioning detailed monitoring stations were operated, producing a quality controlled data-set. Effectively 5 different stations were monitored in detail and 2 different treatment options investigated, Maynooth-filter-drain; Maynooth-direct runoff; Kildare kerb & gully; Monasterevin-filter-drain; Monasterevin-wetland, see Chapters 10 to 11.

2.3 Analysis of data

Report 9 - Analysis of rainfall/ runoff and water quality from major Irish Roads, see Chapters 11 and 12.

2.4 Management of Phase 2 Completed project.

Report-10 : Project completion (final) report.

G.2 Other outputs from project

Masters theses

1. Ms. Suzanne Burns
2. Mr. Eoin Burke
3. Mr. James Lynch

Ph.D. theses

1. Mr. Mesfin Berhanu (in preparation)
2. Mr. Niall Higgins (in preparation)