Dissertation Title:

The Pollution Potential of Road Salt on Freshwater Environments in Ireland

Author: David Kelly BSc.

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Supervisor: Dr. Frances Lucy (I.T Sligo)

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Abstract

Road salt or rock salt as it is sometimes known, is a commonly used de-icing material and is used throughout Ireland by local authorities (i.e. county councils), private road operators and members of the public during times of freezing weather. County councils, road authorities and private road operators apply road salt as required as part of their winter road maintenance programs.
The road salt used is predominantly sodium chloride (NaCl) as it is relatively inexpensive when compared to other de-icing agents, easy to manufacture and readily available.

A number of negative environmental effects and a loss in water quality have been associated with stormwater (melt water) containing dissolved road salt entering fresh waterbodies in the vicinity of roads which are de-iced with sodium chloride.

This study uses the M3 motorway in County Meath as a case study. International findings from other studies on road salt are used to illustrate the potential pollution threat posed by spreading road salt. Recognised best practice for the mitigation of this pollution threat is reviewed and stormwater treatment methods along the M3 are evaluated with regard to reducing sodium chloride levels in stormwater run-off.

This study has found that treated stormwater from the M3 does not cause a significant elevation in chloride levels. The treatment methods applied to the stormwater may remove the chloride from road salting and the receiving waterbodies dilute the chloride in the stormwater to concentrations that are below recognised toxic limits.

A ‘Salt Management Plan’ is the key mitigation measure. Awareness of maintenance companies and staff to the pollution potential of road salt, training of employees, well maintained salt spreading equipment, pre-wetting of salt and active management of road maintenance particularly in areas where roads run in close proximity to waterbodies are essential to limit the threat of road salt to water quality and the environment.

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Finally, to my wife Marie, for all her support, not just during the completion of this study, but always. I dedicate this study to her and our two little boys, Rory and Darragh.

Table of Contents

List of Figures

List of Tables

List of Photographs

1. Introduction

Road salt or rock salt as it is sometimes known, is a commonly used de-icing material and is used throughout Ireland by local authorities (i.e. county councils), private road operators and members of the public during times of freezing weather. County councils, road authorities and private road operators apply road salt as required as part of their winter road maintenance programs.

The road salt used is predominantly sodium chloride (NaCl) as it is relatively inexpensive when compared to other de-icing agents, easy to manufacture and readily available. However, other salt compounds such as magnesium chloride (MgCl) and potassium chloride (KCl) are also used to a lesser extent and mainly in climates experiencing extremely cold weather. In Ireland, sodium chloride is generally used and therefore is referred to in this study as 'Road Salt'.

Road salt works as it increases the salinity of snow, ice and water – salt water has a much lower freezing -point, - 18°C, than fresh water. This effectively melts accumulated snow and ice and prevents refreezing above ground temperatures of - 18°C. The application of road salt prior to freezing road conditions will also prevent ice formation on areas of application below temperatures of - 18°C. Road salt is commonly mixed with sand as an abrasive, offering increased traction to vehicles travelling on roads where it has been spread (Fay et al, 2007).

Members of the public also use road salt to de-ice minor and local access roads not covered by local authority winter maintenance programs. In housing developments, residents also apply road salt and grit to provide for safe access to and from the their houses during cold spells. Local authorities and private road operators employ modified vehicles to spread the road salt at predetermined rates as the vehicle moves along the stretch of road. The rates of salt application will depend on weather conditions and application rates will increase in very severe weather with lower temperatures and thicker ice necessitating heavier road salt use (Meath County Council, 2014). A recommended limit-rate of application for road salt of 1.8 Kg of salt per $100m^2$/road, was published by the Minnesota Pollution Control Agency (Asleson, 2013). Members of the public usually apply road salt manually from salt bins using shovels at varying spreading rates.

All precipitation – snow, rain, sheet and ice will follow the principle of the hydrologic cycle. The hydrologic cycle is the continuous movement of water between the earth's atmosphere and the earth, both above and below ground. In general, all of the precipitation that falls on a watershed is returned to the atmosphere (evapotranspiration), discharged from the watershed as surface flow (runoff), or temporarily stored (surface water, subsurface water, or groundwater) – (DeBarry, 2004). Therefore, all melted snow and ice will enter surfacewaters and groundwaters at some point before re-entering the atmosphere. Road surfaces are hardstand areas and do not allow for direct percolation of melt water. In the case of road ice and snow, melt water will form surface water run-off and either flow to nearby drains and streams/rivers or percolate through the ground and enter groundwaters (US EPA, 2010).

Melt water from snow and ice that has had road salt applied to it will be saline and have elevated chloride levels. It is the environmental effects of this water containing elevated chloride levels on receiving freshwater rivers and streams that is the primary focus of this study.

Ireland in recent years has been subjected to long spells of snow and sub-freezing temperatures, particularly in the winters of 2009-2012 (interpreted from Met Eireann weather data). The lack of road grit and road salt was an issue in many counties and was the focus of media attention such as the Irish Independent article from 2nd December 2010 which showed that local authorities in many counties in Ireland had run out or were running low on road salt or grit. Road salt stocks were quickly depleted as the supply normally used over a whole winter was consumed in a matter of weeks. If such cold winters were to become more common, the issue of surfacewaters containing elevated levels of chloride entering sensitive freshwater systems may become an increasingly important environmental factor in Ireland.

There are a number of agencies and other stakeholders whose activities and outputs will be affected by any significant reduction in water quality due to road salting.

1. Local Authorities: Local authorities such as Meath County Council are responsible for both road driving conditions and water quality of rivers and stream within county boundaries. Roads must remain accessible and safe

during freezing conditions; therefore water quality should be protected by mitigation measures against road run-off water. County councils have a legal obligation and responsibility to ensure water quality is of good status under the Water Framework Directive (2000/60/EC & SI No. 722 of 2003), the 2009 Surface Water Regulations (SI No. 272 of 2009) and the 2010 Groundwater Directive (SI No. 9 of 2010).

2. Irish Water: Water users are a major group that are affected by deterioration in water quality. Rivers are a source of water for the abstraction of potable water in Ireland, including abstractions at a number of points along the River Boyne as it flows through County Meath, e.g. Staleen WTP. Water that has higher chloride levels as a result of road salt use requires more extensive treatment to be suitable for human consumption and this increase may have cost implications for Irish Water during potable water treatment.

3. Private road operators that are contracted by local authorities to maintain roads and operate tolls have a responsibility to keep roads accessible and safe during freezing conditions and also to ensure that their actions are not responsible for a loss in water quality.

4. The National Roads Authority (NRA) is responsible for the planning, construction and operating the majority of the roads in Ireland. Its environmental strategy involves four stages to limit the environmental impacts of roads. Firstly, an environmental impact assessment (EIA) is made in support of planning for the road construction and operation. Best practice is then determined, which will minimise the environmental impact of the road during construction. An environmental operating plan to ensure mitigation measures to limit negative environmental impacts is effectively implemented. Post EIA studies are also undertaken after the road project has been completed to evaluate the mitigation measures in place. (www.nra.ie)

5. An Bord Pleanála is responsible for reviewing and issuing applications for planning permission granted for roads built in Ireland. The potential environmental effects of road projects is a major factor for consideration in granting or refusing planning permission and local authorities in conjunction

with the NRA, are required to present environmental impact assessments (EIA) in support of planning applications. Studies on the potential effects of road projects on water quality will form part of the EIA and mitigation measures during construction and operation of the road should be in place to ensure that the impacts on water quality are minimal.

6. The Environmental Protection Agency of Ireland is ultimately responsible in ensuring that water quality in Ireland meets the principles set out in the Water Framework Directive (2000/60/EC) and the national legislation implementing the Water Framework Directive, WFD, (SI No. 722 of 2003). The Surface Water Regulations SI No. 272 of 2009, require that Ireland has a legally binding responsibility to ensure that freshwater bodies meet set criteria to be classified as ‘good status’. Groundwater quality is also covered under the WFD. Pollutants from road operations transported in run-off have the potential to negatively affect water quality if not mitigated against effectively.

7. The National Parks and Wildlife Service (NPWS) are responsible for the identification and designation of Special Areas of Conservation (SAC), Special Protection Areas (SPA) and National Heritage Areas (NHA). The NPWS are also responsible for the implementation and upholding the principles of various European Directives and legislation regarding the protection of habitats, flora and fauna such as the Birds Directive (2009/147/EC), the Habitats Directive (92/43/EEC), the Habitats Regulation of 2011 (SI No. 477 of 2011 and the Wildlife Act (SI No. 38 of 2000). The NPWS are responsible for the management of activities within and in the vicinity of protected areas. Roads such as the M3 motorway pass through protected sites and can if not planned and managed correctly, negatively impact on the protected site.

8. Inland Fisheries Ireland is the state agency responsible for the management of inland fisheries i.e. rivers, lakes and canals. Fisheries management includes the protection of aquatic habitats to ensure good stocks of fish are available for angling along Ireland’s waterways. The M3/N3 motorway/road crosses a number of designated salmonid waters such as the River Boyne and River Blackwater.

The Environmental Impact Assessment performed in support of planning permission granted for the construction and operation of the M3 motorway by Meath County Council is used in section 4 of this dissertation as a case study. The M3 motorway runs from Clonee to North of Kells in County Meath. Its route passes over a number of rivers and streams, most notably the famous River Boyne a Special Protected Area (SPA 004232) and a Special Area of Conservation (SAC 002299).

The M3 runs for 49 kilometres and bypasses several major towns in the county – Navan, Kells and Dunshaughlin. The winter maintenance program for the M3 is provided by a private road operator in conjunction with Meath County Council. Road salt, sodium chloride, is the de-icing agent used.

A full Environmental Impact Assessment (EIA) was performed as part of planning permission to identify potential environmental impacts caused by the construction and operation of the M3/N3 motorway/road and to propose mitigation measures that would reduce or eliminate such negative impacts. This EIA was prepared by MC O'Sullivan, Halcrow-Barry and ARUP and submitted in February 2002.

In terms of impacts to flora and fauna, it is important to note that the extent of chloride toxicity is not just dependent on the chloride concentration in the water but also very much on the tolerance of individual species or groups of species to elevated chloride levels.

The main aims and objectives of this study are to:

1. Determine if the use of road salt for de-icing in winter months poses a pollution threat to receiving surfacewaters along the M3 motorway.
2. Investigate and detail potential negative environmental effects associated with the use of road salt – primarily sodium chloride.
3. Evaluate drainage and mitigation measures in place along the M3.
4. Discuss mitigation measures currently in place along the M3 for negating the generation of surface water with increased chloride concentrations.
5. Identify international best practice for mitigating against environmental effects posed by road salt run-off.

6. Propose potential alternative mitigation measures for future road and motorway construction with regard to potential negative environmental impacts of run-off water containing increased concentrations of chloride.

2. Literature Review

2.1 Introduction

In order to establish if road salt used as a de-icing agent poses a significant pollution threat this literature review will first investigate whether or not the application of road salt has a negative environmental impact. This includes an initial investigation on how de-icers work and their environmental pathways.

Understanding the solubility of chloride derived from road salt (sodium chloride, magnesium chloride and potassium chloride) and how it reacts in freshwater environment is important and needs to be understood because this has an important bearing on the pollution potential of chloride in road salt. Salts are known to be highly soluble and the chloride introduced to water as a result of road salt application may prove to be very difficult to remove from solution. The measures in place for treating road drainage may be ineffective in removing highly soluble compounds. Mitigation methods for preventing pollution from road run-off and desalination methods for water are reviewed. Alternatives to road salt are also examined.

Studies that have investigated the toxicological effects of water containing road salt and higher levels of sodium chloride illustrate that the use of road salt as a de-icing agent is an important environmental issue that is of concern to freshwater pollution and river environments (Amundsen et al, 2012) (Environment Canada, 2001).

A review of legislation, regulation and guidance pertaining to the use of road salt use is also of importance in order to determine the extent to which potential negative environmental effects have been recognised both within Ireland and internationally. Therefore road salt regulation and relevant legislation are reviewed within this literature review.

2.2 How De-icers Work

Ice forms when water undergoes a phase change from liquid to solid at 0°C. Above this temperature the ice melts back to liquid water. This is a process known as congruent melting. Incongruent melting occurs when another substance reacts with the water to melt ice. Melting and freezing are equilibrium processes, wherein water molecules move from one phase to another along a chemical potential gradient (moving from high to low chemical potential). When another substance (termed a solute) is dissolved in water covering ice, the chemical potential of the solution is

lower than the chemical potential of the ice, thus water molecules move from the ice to the solution to restore equilibrium (Kelting & Laxson, 2010).
As temperature declines, more solute is required to melt the ice until the eutectic temperature is reached. The eutectic temperature is the lowest temperature at which the solution will solidify (American Heritage Dictionary, 2000). As the temperature of the ice goes down, the chemical potential of the ice declines, so a higher concentration of solute is needed at lower temperatures to maintain the chemical potential gradient needed to melt ice. Therefore, more de-icer is needed to melt ice at lower temperatures and some de-icers are more effective and efficient than others. For more effective de-icing, the amount of de-icer applied should be adjusted based on temperature.

Kelting & Laxon's (2010) study report also describes how the ability of solutes to depress the freezing point of water is important for anti-icing. Water is a polar molecule, and therefore the cations and anions contributed by the solute, the salt, to the solution are attracted to the positive and negative poles of water molecules. This interferes with crystal lattice formation, a transformation necessary for water to change phase from liquid to solid. The more positive and negative the charge contributed to the solution by the solute, the more water is attracted to the ions. Sodium chloride ($NaCl$) contributes 34 moles of charge (molc) per kilogram (kg) and magnesium chloride ($MgCl2$) contributes 42 molc per kg. Therefore magnesium chloride is a more effective anti-icing agent per kilogram. Magnesium chloride is often used in climates that experience very low winter temperatures. In Ireland, sodium chloride is predominantly used as our winter climate is not very severe and although the de-icing properties of sodium chloride are less than magnesium chloride, it is sufficient for our climate. According to the US EPA (2010) publication on managing highway de-icing, sodium chloride is the most economical de-icer available and this is also a significant reason for it being so widely used in Ireland. Fazio and Strell (2011) also state that sodium chloride is so widely used as a de-icer because it is relatively inexpensive when compared to other de-icing agents. Figure 2.1 below illustrates how the de-icing action of sodium chloride.

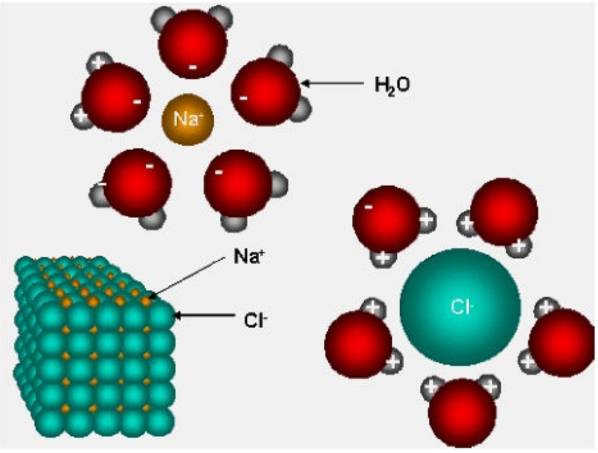


Figure 2.1: Chemical action of sodium chloride (Kelting & Laxson, 2010)

2.3 Environmental Pathways

Road salts enter the environment via a number of mechanisms. Road salts enter surface water, soil and groundwater after snowmelt. Road salts may also be dispersed through the air by splashing and spray from vehicles and as windborne powder. Road salt is applied directly to open ground and water accidentally due to poor spreading techniques and lack of controlled procedures (Environment Canada, 2001).
Kelting & Laxson (2010) state that portions of the precipitation will runoff as overland flow when soils are saturated, or the ground is impervious through freezing, and directly or indirectly enter streams, ditches or storm water systems and discharge from the watershed in a time frame of hours.

Sodium chloride is highly soluble in water. The disassociated ions Na+ and Cl- will migrate with the precipitation toward the water table. The negatively charged chloride ion does not adsorb on mineral surfaces, enter oxidation, reduction or biochemical reactions or form ion complexes. As a result chloride is highly mobile, with a migration rate identical to that of the water (Jones and Jeffery, 1992).
Chloride ions are conservative, moving with water without being retarded or lost. Accordingly, all chloride ions that enter the soil and groundwater can ultimately be expected to reach surface water; it may take from a few years to several decades or more for steady-state groundwater concentrations to be reached. This is not the case for sodium, because it is a positively charged ion that is readily adsorbed to the negatively charged surfaces of minerals and clays. Therefore with the use of sodium chloride as a de-icing agent it is the chloride ion that is of most concern and not the sodium ion.

As previously outlined, chloride is very mobile in the environment due to its negative charge and can pass from the surface, through soils and subsoils and enter groundwaters. Chloride ions will also not readily adsorb onto hardstand areas, clay or grit particles. As a result chloride concentrations in road run-off may be high where de-icing agents are in use (Environment Canada, 2001).

The Norwegian Public Roads Administration published a technical report (No. 2587) (Amundsen et al, 2012), titled 'Environmental Damages caused by Road Salt – a literature review'. From this report we may gain an understanding of how road salt is transported through the environment from road applications. The positive sodium ions, Na^+, will be delayed more than the negative ions because the soil has a greater cation exchange capacity than an anion exchange capacity. The negative Cl^- ions will therefore be transported at a rate nearly equal to that of water meaning that the chloride ions are highly soluble in water and will move rapidly through a terrestrial environment into groundwaters and will subsequently infiltrate surfacewater. Figure 2.2 illustrates the transport pathways from roadside application to the environment (Blomqvist, 2001).

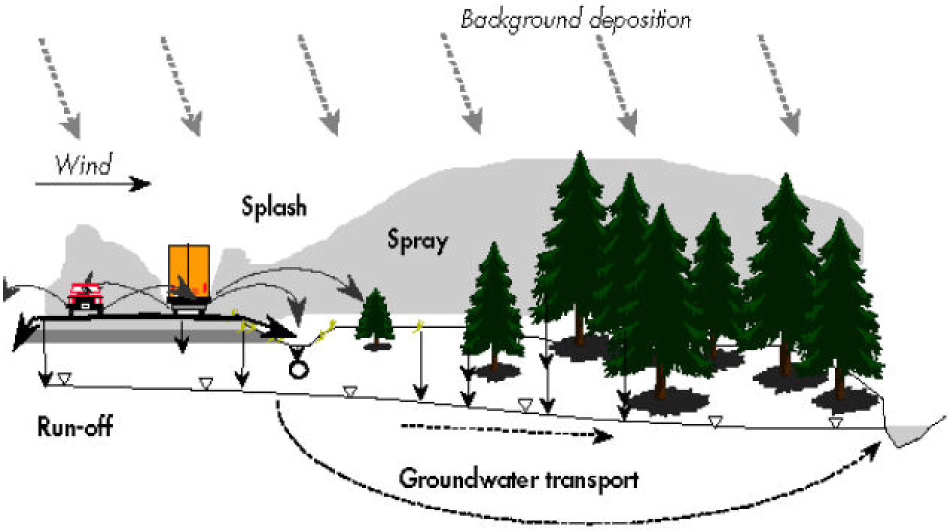


Figure 2.2: Road salt transport pathways (Blomqvist, 2001)

This diagram shows that road salt may be dispersed to the environment from application by the wind carrying some salt to the land adjacent to the road, it may be transported to the land adjacent to the road as a result of vehicular and snow plough movement and it will be transported to the environment from run-off.

The aquifer vulnerability map shown below from the Geological Society of Ireland illustrates the vulnerability of groundwater aquifers in County Meath and in the vicinity of the M3/N3 motorway – the case study considered by this dissertation. The M3/N3 can be clearly seen in the map passing through areas containing aquifers considered to have extreme to high vulnerability due to the subsoil composition. These aquifers are more 'vulnerable' to contamination from the surface as the subsoil composition will allow such contaminants to be transported to the groundwater held in the aquifer below. Contaminants may include sodium chloride contained in run-off from the road network in the county during winter months.

Canadian studies have found that the mass balance modelling and field measurements indicate that regional-scale groundwater chloride concentrations greater than 250 mg/L will likely result under high-density road networks subject to annual loadings above 20 tonnes sodium chloride per two lane-kilometre. Groundwater will eventually well up into the surface water or emerge as seeps and springs. Research has shown that 10–60% of the salt applied enters shallow subsurface waters and accumulates (Environment Canada, 2001).

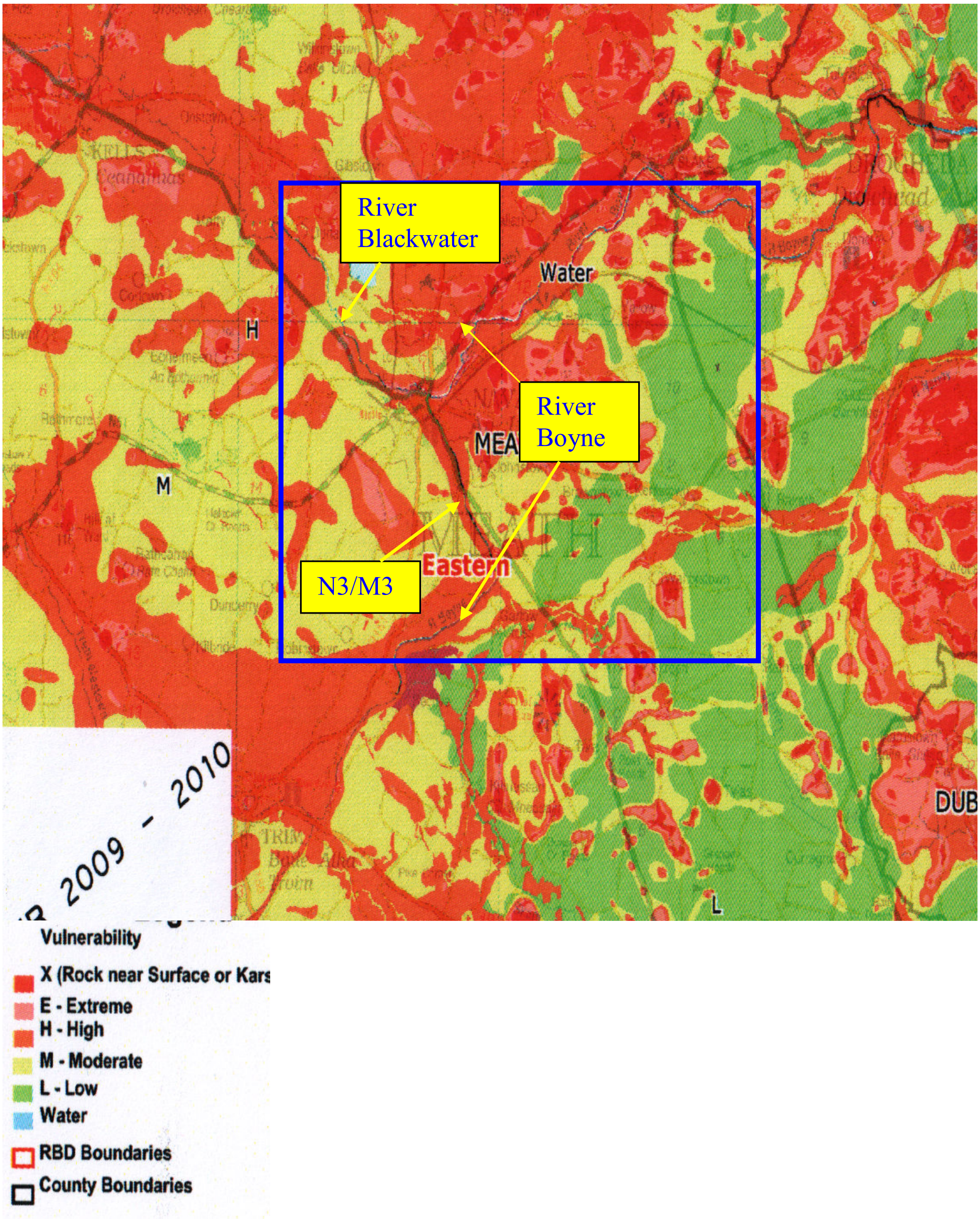


Figure 2.3: County Meath aquifer vulnerability (www.gsi.ie)

The ordinance survey map of County Meath indicates the proximity of the M3/N3 road route to the River Boyne (south of Navan) and the River Blackwater (running parallel to the N3 south of Kells). The close proximity of rivers to major roads that are de-iced using road salt increases the potential for negative environmental effects as a result of the road salt – the closer the river is to the area of road salt application the more likely and more significant the negative environmental effects are likely to be (Karraker et al , 2008).

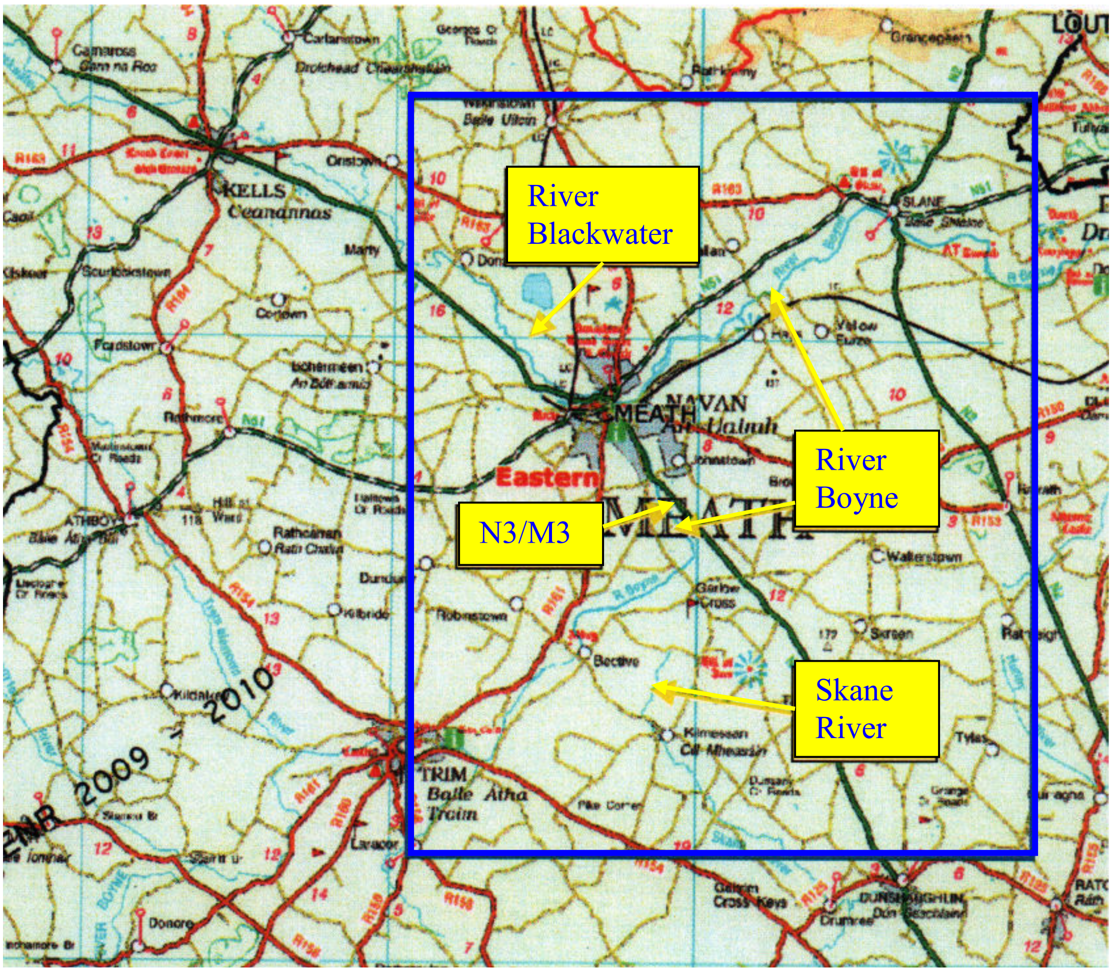


Figure 2.4: County Meath Map and M3/N3 route (www.osi.ie)

2.4 Alternatives to Road Salt

There are many alternatives to road salt available for de-icing and the main other de-icers used are detailed in brief below. Generally speaking there are environmental pros and cons for the use of all de-icing agents.

2.4.1 Calcium Chloride (CaCl), Potassium chloride (KCl) and Magnesium Chloride (MgCl)

This is a widely used de-icing agent and it is available in flake, pellet or liquid. It is effective at lower temperatures with a practical melting temperature of -29°C. In liquid form it can be used to pre-wet salt or applied directly as an anti-icing technique which can help in preventing snow and ice from bonding to the pavement and reduce the application amount needed. The environmental impact of CaCl use is similar to Road Salt (NaCl) due to chloride release to aquatic environments. Economically it is more extensive than road salt and is associated with corrosion to metal. KCl is a naturally occurring material (muriate of potash) that also is used as fertilizer. It is available in liquid or crystal with a practical melting temperature of -6.7°C. It can be damaging to concrete, has environmental impacts due to chloride release to waters. KCl is also associated with inhibiting plant growth and burn foliage.

MgCl is available in liquid or crystal form that melts faster than rock salt; it has a practical melting temperature of -15°C. It is corrosive and contributes to the chloride load in receiving waters. (Kelting & Laxson, 2010)

2.4.2 *Urea*

Urea is used primarily as fertilizer with a practical melting temperature of -4°C. It releases nitrogen into the soil and can lead to a chemical imbalance in water systems due to nutrient loading. Amundsen et al (2012) review that urea is corrosive and breaks down rapidly into ammonia, which is released into the environment and can cause eutrophication. Urea also poses a risk of oxygen depletion in receiving waters due to its high biochemical oxygen demand when compared to chloride based de-icers.

2.4.3 Acetates

Acetate based de-icers have a practical melting temperature of -26°C and are generally biodegradable and non-corrosive. It can lower oxygen levels in the waterbody due to its relatively high biochemical oxygen demand. This is a commonly used de-icer in the airline industry and is relatively non corrosive. Degradation of acetate and other organic based de-icing agents can result in lack of oxygen in soil because oxygen is used during degradation. This can lead to increase in transport of iron and manganese because precipitated oxidised binding of iron and manganese is reduced, released and becomes more mobile. This can also result in an increase in release of heavy metals from soil (Amundsen et al, 2012).

2.4.4 Ethylene Glycol

Ethylene glycol was historically widely used in the air travel industry. Pure ethylene glycol freezes at about −12 °C but when mixed with water the mixture does not readily crystallize and therefore the freezing point of the mixture is depressed. A mixture of 60% ethylene glycol and 40% water freezes at −45 °C. Today its use is not widespread in road spreading, due to its high oxygen demand on receiving waters (Kelting & Laxson, 2010).

2.4.5 Agricultural by-products

These can be derived from sources such as corn, beet, grain, alcohol, or molasses. These products are not good at melting snow and ice; however, they do slow down the formation of ice crystals by having a lower freezing point. They are less corrosive than conventional de-icers. These attributes make the product good for anti-icing and pre-treating salt. They have environmental impacts in aquatic systems due to their organic nature and can lead to biological oxygen demand, heavy metals, and nutrient enrichment by nitrogen and phosphorus in receiving waters. (New Hampshire Department of Environment, 2011)

2.5 Road Salt - Associated Environmental Effects

There have been a number of studies conducted and papers/articles published concerned with the negative or pollution effects that road salt poses on the environment.

The New York Law Journal published at article regarding the environmental effect of road salt and de-icers (Fazio & Strell, 2011). The publication of this article was very timely and followed record snow levels in New York. This article states that sodium chloride is the primary de-icing agent used in the USA. Fazio and Strell (2011) go on to highlight the negative environmental impacts posed by the use of sodium chloride as a de-icing agent.

Road salt run-off is recognised as a major contributor to elevated chloride levels in soils, groundwaters and surfacewater as melting ice and snow carry sodium and chloride ions onto open land and into receiving waters. It is stated that according to the United States Geological Survey, many streams now have chloride levels that are toxic to aquatic life and exceed the chronic water quality criteria recommended by the US EPA for chloride. Exposure to high levels of chloride in water, especially for an extended term, affects abundance, diversity and reproduction of fish and other aquatic organisms. In addition to the direct effects of chloride, salty water is denser than fresh water, so it sinks to the bottom of water bodies, impairing complete circulation of water, which in turn can deplete oxygen levels and affect the survival of fish and invertebrates (Fazio & Strell, 2011).

Studies on the toxicity of sodium chloride and chloride to freshwater aquatic macrophytes such as phytoplankton have also been conducted. Toxicity studies by Evans and Frick (2001) present critical toxicity values of 2,430 mg/L and 1,475 mg/L for sodium chloride and chloride respectively. Blinn, et al (1981) in Environment Canada (2001) concluded from field studies that that continuous exposure to chloride concentrations as low as 1000 mg/L (1653 mg sodium chloride/L) for time periods as short as 1 week, can result in a decrease in phytoplankton density.

Scher and Thiery (2005) studied the relationship between dragonfly and amphibian populations and water quality in motorway stormwater retention ponds included the effects of chloride from de-icing of road surfaces as a pollutant. The spreading of sodium chloride as road de-icing agent usually lasts less than 7 days per year in southern France. However the salt inflow induces an increase in conductivity which may last several months when no rain occurs as observed in 2003 with a very long drought until autumn.

2.5.1 Aquatic Toxicity

A study on the effects of road salt on aquatic toxicity and water quality by Corsi et al was published in 2010. The study was conducted primarily in Wisconsin in the USA and involved long and short term monitoring studies. Corsi et al (2010) found that increased salt levels from road salt run-off had negative environmental impacts and that those high concentrations may have immediate or long-term ecosystem population effects. Lower levels of increased chloride concentrations may affect community structure, diversity, and productivity. Studies also indicated that levels of chloride in streams were common for extended periods of time, even through the summer months when no road salt was being spread. The Corsi et al (2010) study of groundwater influence on stream chemistry concluded that chloride from road de-icing applications persisted throughout the year as a source of contamination in groundwater and that groundwaters contaminated with road salt can be a source of excessive chloride to freshwater streams with throughout the year.

This may have significant implications with regard to road salt use in Ireland where our winter weather is not as adverse as in countries such as Canada or Norway and de-icing of roads may be performed for relatively short duration. Salt contamination of groundwaters may result in higher chloride levels in rivers and streams for periods that are longer than expected. This may be of increasing significance in areas with high aquifer vulnerability ratings – those areas in which the M3/N3 pass through in county Meath.

It is fair to say that the majority of research and publications regarding the environmental effects of road salt from de-icing are from North America – Canada and the northern states of the USA. One Irish study by Bruen et al (2006) looked at the effects of road run-off on surfacewater quality. All identified polluting constituents in the run-off were analysed and chloride in road salt was not the main focus of this study. However, during this study a chloride concentration of 367 mg/L was measured from a sample taken from the filter drain at the Maynooth bypass in county Kildare during a period of ice and snow. The corresponding conductivity value was 7,592 µS/cm and chloride levels from the same site ranged from 15-40 mg/L, during the summer months.

Research into environmental effects of road salting has also been conducted in Scandinavian countries where extreme cold weather is regularly experienced such as Canada and Norway. Environment Canada, the Canadian Environmental Protection Agency, published a priority substance assessment report in 2001 for Road Salt. The final conclusion of the Environment Canada assessment was that road salt containing inorganic chlorides such as sodium chloride should be considered a toxic substance due to "tangible threats of serious or irreversible environmental damage". The Environment Canada report also states while many of the negative environmental effects of sodium chloride from road salt run-off cannot be quantified; there is a good probability that it causes immediate or long-term harmful effect on some surface water organisms and terrestrial vegetation that are susceptible to elevated levels of chloride (Environment Canada, 2001).

If the receiving water is a moving lotic waterbody such as a stream or lake, chloride entering the water may quickly become diluted to low levels depending on the size and flow of the waterbody and the initial concentration of chloride in the run-off entering the water. However, in lentic waterbodies such as lakes and ponds, there is a greater potential to develop higher concentrations of chloride in the water. Salty water is denser than fresh water, so it sinks to the bottom of water bodies, impairing complete circulation of water, which in turn can deplete oxygen levels and affect the survival of fish and invertebrates (Kelting & Laxson, 2010). Increased salt concentrations in lakes can lead to stratification, which retards or prevents the seasonal mixing of waters, thereby affecting the distribution of oxygen and nutrients (Environment Canada, 2001). Anoxic conditions in lakes are unsupportive of most aquatic life and can lead to the generation of toxic gases such as hydrogen sulphide.

In larger lakes natural stratification may occur as a result in temperature differences from the lake bottom to the surface. Seasonal changes cause fluctuations in lake temperatures and the movement of water within the lake. Saline stratification in these lakes can inhibit this natural movement of water (Boehrer & Schultze, 2008). If a lake is to maintain good oxygen conditions and stable nutrient content in water, vertical circulation is important. Therefore if a lake regularly receives added salts from the use of road salt, this could potentially lead to a more permanent chemical layering in the lake. Streams and rivers will not develop chemical layers such as a lake and rivers will have a significant rapid change in water quality. However, rivers and streams will upon entering a lake, transport salty water to lakes where it may accumulate and causing chemical layering. This will not be a consideration for rivers or streams that flow directly to the sea and do not pass through lakes. Larger rivers will generally have lower concentrations and relatively less variation in chloride concentrations due to a greater dilution effect of applied salt (Amundsen et al, 2012). Thermal stratification in roadside surface water retention ponds may be more likely due to their proximity to the area of road salt application and due to accidental direct contact with road salt during spreading. The formation of anoxic conditions within these retention ponds is a potential environmental problem.

Research by Hunt et al (2012), reported that high chloride concentrations in freshwater can harm aquatic organisms by interfering with osmoregulation, the biological process by which they maintain the proper concentration of salt and other solutes in their bodily fluids. Difficulty with osmoregulation can hinder survival, growth, and reproduction. In Rhode Island, USA, the Department of Environmental Management (DEM) has set acceptable chloride concentration exposure limits for freshwater organisms at 860 ppm to prevent acute (immediate) exposure effects and at 230 ppm to prevent chronic (long-term) exposure effects (Hunt et al, 2012).

Amundsen et al (2012) report that that the toxicity of road runoff to aquatic flora and fauna is not only explained by increased concentrations of chloride but is also due to mobilization, increased bioavailability and increased toxicity of other traffic caused pollution components. Very high concentrations have been measured in streams and rivers after high runoff of melting snow in the winter, and chloride concentrations over 1,000 mg/L have been measured. It is reported that runoff from road salt deposits in the USA have been shown to contain extremely high concentrations of more than 10,000 mg/L of chloride have been measured (Evans and Frick, 2001).

The US EPA established limits in 1988 for the chronic toxicity of chloride of 230 mg/L and acute toxicity of 860 mg/L of chloride. Chloride levels reported by Evans and Frick (2001) in stream and rivers following the application of road salt greatly exceed these EPA limits.

Freshwater species are adapted to coastal areas are also likely to tolerate the effects road salting better. The spring smolting process of anadromous salmonids, will probably also overlap in time with the snowmelt period of some rivers' catchment area. Salmonids in the smolting stage are essentially more sensitive to changes in water chemistry than at the parr stage (Amundsen et al, 2012). Experiments by Evans and Frick (2001) in Canada with fish species similar to those present in Norway, indicates critical levels of over 500 mg/L of chloride with more than a week of exposure. Salmon and trout (Salmonidae) appear to be more sensitive than coarse fish such as perch and carp (Cyprinidae) and there is likely to be considerable variation in tolerance within the various fish families (Evans and Frick, 2001).

Environment Canada's priority substances assessment report on road salt (2001), reported that high concentrations of chloride have been measured in run-off from roads that have had road salt applied with concentrations of chloride over 18,000 mg/L in runoff from roadways. This report also details the chloride concentrations in snow cleared from city streets in Canada and this can be quite variable – for example in Montréal it was 3,000 mg/L (secondary streets) and 5,000 mg/L (primary streets).In the environment, resulting chloride concentrations have been measured as high as 2,800 mg/L in groundwater in areas adjacent to road salt storage yards, 4,000 mg/L in ponds and wetlands, 4,300 mg/L in watercourses, 2,000–5,000 mg/L in urban impoundment lakes and 150–300 mg/L in rural lakes.

The Environment Canada report compares these chloride concentration levels to known toxic effect concentrations on freshwater fish with exposures to chloride concentrations as low as 870, 990 and 1,070 mg/L for median lethal effects (fathead minnow embryos (*Pimephales promelas*), rainbow trout eggs/embryos (*Oncorhynchus mykiss*) and also to water fleas (*Daphnia magna* and *Daphnia pulex*, respectively). The NOEC (No Observed Effect Concentration) for the 33-day early life stage test for survival of fathead minnow was 252 mg/L chloride. This is the concentration limit of chloride in water that no toxicological effects on fathead minnow are known. Fathead minnow does not occur in Ireland, the equivalent minnow species (also Family Cyprinidae) in Ireland is the common minnow (*Phoxinus phoxinus*).

Environment Canada estimated that 5% of aquatic species would be affected (median lethal concentration) at chloride concentrations of about 210 mg/L, and 10% of species would be affected at chloride concentrations of about 240 mg/L. It is not specified if these estimates concern just fish species or fish and freshwater invertebrates. However, toxicity studies focused on fish and invertebrate species such as the Water Flea *(Ceriodaphnia dubia)*. It is therefore taken that these values refer to aquatic species as a whole.

The US EPA report ‘Ambient Water Quality Criteria for Chloride’ Benoit (1988). This report suggested that sodium chloride is less toxic than other salts such as calcium, potassium and magnesium chlorides and laboratory studies showed than these salts have lower concentration LC50 (Lethal Concentration) and EC50 (Effective Concentration) values than sodium chloride when tested on the same organism. Freshwater flea species *Daphnia magna* had an LC50 of 2,024 mg/L and *Daphnia pulex* had an LC50 of 1,470 mg/L to sodium chloride. Both organisms are types of freshwater flea. Results from tests with a variety of species show that if freshwater animals do not die within the first 24 hr of the test, they probably will not die during periods ranging from 48 hr to 11 days. A life-cycle test with *Daphnia pulex* and early life-stage tests with the rainbow trout (*Oncorhynchus mykiss*) and fathead minnow (*Pimephales promelas*) produced chronic values of 372.1, 922.7, and 433.1 mg/L respectively.

The US EPA established chronic toxicity limits for of chloride of 230 mg/L and acute toxicity of 860 mg/L. Chloride levels reported by Evans and Frick in stream and rivers following the application of road salt greatly exceed these EPA limits.

A number of studies have also found that the toxicity of ammonia and nitrites in water, from sources such as agricultural run-off, is highly dependent on the chloride concentration in the water. For freshwater bodies, increased levels of chloride have been found to inhibit the toxicity of ammonia and nitrite to freshwater fish including salmon *(Salmo salar)* (Kroupova et al, 2005).Therefore, it may be the case that there is some potential benefit from road salt run-off entering freshwater rivers and lakes, subject to agricultural pressures.

2.5.2 Effects on Terrestrial Animals

The effects of road salt run-off on pool breeding amphibians were researched by Karraker et al (2008). Adult and larval amphibians are particularly sensitive to osmolar environments or waters that have a relatively high solute concentration. The study was focused on two vernal-pond-breeding amphibian species, the spotted salamander (*Ambystoma maculatum*) and the wood frog (*Rana sylvatica*). Neither of these species are present in Ireland; amphibians commonly found in Ireland are the common frog (*Rana temporaria*) and smooth newt (*Lissotriton vulgaris*). Karraker et al (2008) concluded that embryonic and larval survival rates were reduced in ponds in the vicinity of roads where road salt run-off had increased electric conductivity to levels in the region of 3,000 uS/cm. The study also found that the closer the pond was to roads subjected to road salt, the greater the effect on amphibian survival and that in the case of the spotted salamander, road salt entering ponds had the potential to cause total extinction in some ponds. Karraker et al (2008) recommended reducing application of road salt near wetlands with high conductivity levels, to reduce effects on pool breeding amphibians.

Amphibians in general, may be especially sensitive to increased salinity due to their highly permeable skin, which functions critically for osmoregulation (the process by which organisms maintain internal solute concentrations) and respiration, and because their life history typically includes both aquatic and terrestrial stages (Duellman and Trueb, 1986 in Kelting & Laxson, 2010). They also report that, in amphibian embryos, normal development is dependant on a slow exchange of water through the vitelline chamber where the embryo is contained.

However, a study on the relationship between amphibian populations and water quality of motorway stormwater retention ponds in France by Scher and Thiery (2005) produced data that did not show any relationship between amphibian richness and water contamination.

A study on the effects of increased salt concentrations on soil dwelling invertebrates – earthworms (Oligochaeta) and springtails (Collembola) was published by Addison (2002). A 50% reduction in the reproduction rate of one springtail species were recorded, at concentrations from 480mg to 940mg of sodium chloride per kilogram. In earthworms, (*Eisenia fetida*) for example, a 50% reduction in cocoon production was measured at concentrations of approximately 1800mg sodium per kg soil. Tests showed that noted effects are dependent on soil type and effects decrease with increased soil organic content. Pure sodium chloride is more toxic than road salt. Environment Canada (2001) reference studies show that chronic effects of sodium chloride are detected at concentrations as low as 480mg of sodium chloride (or 280mg

Cl/kg) in springtails, while earthworms have been shown to be somewhat less sensitive.

Due to their herbivorous or grain based diet, many species of birds and mammals may be sodium deficient, and attracted to salted roadways from great distances to satisfy a "salt hunger" (Schulkin, 1991). Road salt negatively impacts terrestrial wildlife primarily through two mechanisms; increased vehicular collision and poisoning. Road salt application has also been linked with negative implications for terrestrial mammals and birds. Research by Environmental Canada (2001) showed a significant increase with road collisions between animals and vehicles at times following road salt application. Animals were attracted to surface waters along road sides containing elevated salt levels. Toxicology studies for direct salt intake in brown rats (*Rattus norvegicus*) and house sparrows (*Passer domesticus)* have also been conducted. The lethal oral dose for the tree sparrow (*Passer montanus*) was found to be 3 - 3.5 g/kg body weight and a possible no-effect level was estimated at 2 g/kg body weight. For brown rats an LD50 of 3750 mg/kg was reported (Fischel, 2001 in Environmental Canada, 2001).

Road mortality in birds is primarily caused by vehicle strikes however, new evidence is mounting that suggests salt toxicity is contributing to the vulnerability of small songbirds to road traffic, and in some cases is a direct cause of mortality (Environment Canada, 2001).

2.5.3 Effects on Terrestrial Plants

Forest Research issued a Pathology Advisory Note (No. 11) (Rose & Webber, 2011), concerning de-icing salt damage to trees. This study informs that there are two pathways in which road salt may damage trees – by direct impact of salt spray and by salt contamination of the soil in which the tree is growing. Salt taken up in the roots of deciduous trees accumulates in the dormant buds and twigs. The buds either fail to open resulting in leafless branches or open and soon die (Rose & Webber, 2011). Direct impact of salt spray is less detrimental to the tree, however localised damage to the tree may occur as salt enters through scars and openings in tree bark. The effects on coniferous trees in similar with regard to direct impact and soil uptake of salt on already existing needles and buds – a browning and dying off of needles.

As with road salt toxicity to amphibian studies, the proximity to roads subjected to road salt is a major factor on the negative effects on tree populations.
This is further outlined by Amundsen et al (2012). The extent of salt damage generally decreases with increasing distance from the road; however significant damage can still be expected at distances more than fifty metres. The extent of damage and its symptoms are dependent of a number of other factors apart from distance. Environmental conditions at the site such as soil type and the slope or terrain and other factors such as the species of plant and tree have direct relationships with extent of damage. It is recommended that in areas adjacent to roadsides, tree and plant species that show a higher tolerance to increase salt concentrations in soil and water are planted. Amundsen et al (2012) not only look at the effects of road salting on road side trees and plants, but also the effects of domesticated crop plants and knock-on economic considerations such as crop yields. From research performed by Colorado State University, crops such as carrot, peas, strawberry and onion are sensitive to salt concentrations in soil with low levels of tolerance. Crops including asparagus, olives and beet showed the highest salt tolerance.

County Meath is one of the main counties in Ireland for the growing or protected or covered crops. These are crops that are grown in glasshouses and polytunnel type structures. The main crops grown under protection in the county are tomatoes, strawberries and lettuce (Bord Glas, 2001). Crops under protection may also include filed based crops covered in plastic based sheeting. On visual evidence there are also large crops of other vegetables grown in the immediate vicinity of the M3 such as potato, carrot and cabbage. If uncontrolled, storm water containing high levels of salt may pose a threat to such crops. Carrot and strawberries were noted as being salt sensitive during growth by Amundsen et al (2012).

Although not the main focus of this study, road margins themselves may be seen as important habitats for many species and contribute to general biodiversity in an important way. It has been reported that 35 of Great Britain's 257 nationally rare plants are found in roadsides and roadsides may from an increasing important habitat for some rare plant species (Way, 1977). A study in the Netherlands found that perennial grass and herb species that remain physiologically active throughout the colder winter months can suffer negative effects due to osmotic shocks in the cells of their roots as a result of exposure to road salt (Liem et al, 1984).

2.6 Road Salt Regulations

There are currently no regulations regarding the application of road salt in Ireland and no permit is required by the EPA or local authorities for the use of road salt as a de-icing agent. In the USA, the EPA has set a water quality standard for chloride as 230 mg/L, based on toxicity to aquatic life – yet for the most the use of salt as a de-icing agent is not regulated in the USA. The question of regulation road salt application has been discussed in several countries.

According to Fazio & Strell (2011), although road salt use is popular throughout the USA because it is relatively cheap, readily available, and effective, its use also causes environmental harm and much of its use is unregulated and unmonitored. Within New York City, road salt use is not restricted, does not require a permit for application and because road salt is applied to land surfaces and is washed away by snowmelt and rain, it generally is treated as non-point source pollution. Only in the circumstance of road salt run off entering treatment systems and being discharged from a treatment plant is the discharge of road run-off included within a discharge permit and this does not specifically regulate the road salt run-off.

Road salt run-off from a specific road location is not seen as being pollution from a point source, which would require permitting and Fazio and Strell (2011) put forward the point that this should maybe be the case. The application of road salt has similarities with the spraying of mosquito repellents by US government bodies and there have been several challenges to this by environmental groups. The US EPA have taken the position that once the repellent spraying was done in accordance to the manufacturers instructions, this is not a discharge of a pollutant even though the repellent spray finds its way into waterbodies.

In a recent case, the US Court of Appeals disagreed with a district court’s conclusion that spraying pesticides from applicators attached to trucks or aircraft were not “point sources” because the spray went directly into the air, not the water. The court held that “the spray apparatus was attached to trucks and helicopters, and was the source of the discharge. The pesticides were discharged ‘from’ the source, and not from the air (Fazio & Strell, 2011).

The decision of the US Court of Appeals in this case can be related to the application of road salt and it could be interpreted that if the case related to road salt and not mosquito repellent, the decision would have been that road salt application is point source pollution and should therefore be regulated and permitted.

A bill was recently proposed by the New York state senate, NY S02020 2012, which would require the commissioner of transportation to use salt substitutes near environmentally sensitive highways (Fazio & Strell, 2011). This bill was referred to the New York Department of Transport pending its introduction into New York state legislation.

In 2011, the New Hampshire legislature introduced HB202 – FN, 2011, which requires anyone who applies salt to public and private roads and parking lots, as a means to limit the amount of de-icing salt spread in New Hampshire to apply for state certification and to enforce best management practices in the application of road salt. These codes of practice were published in document WD-WMB-4 and include measures such as ensuring application equipment is calibrated and to wet ground areas before application with the overall aim to reduce the amount of salt applied therefore lowering environmental impacts (New Hampshire Dept. of Environmental Services, 2011).

Environment Canada classify Road Salt as being a toxic substance and should be “considered for possible risk management measures, such as regulations, guidelines, pollution prevention plans or codes of practice to control any aspect of their life cycle, from the research and development stage through manufacture, use, storage, transport and ultimate disposal”. The need for regulation of road salt is highlighted however to date road salt use in Canada is not regulated.

2.7 Mitigation measures

Fazio & Strell (2011), inform us in their article that due to the high solubility of chloride in water it is very difficult to remove and that the introduction best management strategies for the reduction of road salt use is the most effective way of reducing negative environmental impacts.

Pre-wetting of areas reduces the volume of salt applied as the salt dissolves more quickly and dissolved salt brine is more effective at melting snow and ice – reportedly reducing salt application by 20%.
The practice of “anti-icing” involves applying a chemical to areas prior to snowfalls that lowers the freezing point of the ground before snow falls on it and reduces the amount of salt needed to melt accumulated snow.

Kelting & Laxson (2010) outline a ‘Salt Management Plan’ that includes the identification of salt sensitive areas and the use on alternative de-icers in these areas. The practice of anti-icing and pre-wetting are also highlighted as cost effective methods of reducing the volume of salt required for de-icing and therefore reducing negative environmental impacts.

From an Irish study on the surfacewater quality impacts of highway drainage by Bruen et al (2006) we are informed that “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”.
Chapter 4 of this dissertation presents a case study on the M3 motorway; where the drainage and surfacewater treatment system in place is a ‘French’ drain system with retention ponds, reed beds, interceptors and grit traps before the road run-off waters discharge to rivers and streams. Treatment of drained surfacewater using retention/detention ponds, natural and artificial wetlands is also common practice in Ireland and other European countries. This system is as outlined by Bruen et al (2006).

The Bruen et al (2006) study is focused on assessing road-run off and does not look exclusively at the impact of high chloride in road run-off from spreading of road salt during winter months. Road run-off may contain many pollutants – nutrients, heavy metals, volatile organic carbons (VOCs) and poly aromatic hydrocarbons (PAHs). This study does not look into the effects of chloride to any great extent. However from the Bruen et al study we learn that the business of a road measured in Annual Average Daily Traffic (AADT) has a direct relationship with the surface water treatment required for road run-off. In the US if a road has an AADT of more than

60,000, run-off treatment is required – in Ireland the AADT of the M50 is greater than this. However, for most other national routes such as the M3, the AADT is less than 30,000 according to 2006 data implying that no treatment is required using the US AADT cut-off point. (Bruen et al, 2006).

Bruen et al (2006) present chloride results for samples taken in March 2005; samples passing from a French drains at a study site in Co. Kildare were 10 mg/L and at the same site results for water entering a stream from a road drainage gully with gully pots for sediment removal was 1 mg/L.

The Norwegian Public Roads Administration published a technical report on environmental damages caused by road salt, in which there are several mitigation measures aimed at reducing environmental effects. Measures such as: (1) the dilution of chloride concentrations by utilising stormwater ponds, (2) directing runoff to less vulnerable watercourses and where possible discharges to the sea, (3) optimization procedures for dispersal and (4) good maintenance of spreading equipment, are suggested for mitigation of environmental effects from road salt applications. The physical removal and disposal of salt-rich ploughed snow to landfill or less vulnerable areas and milling snow in to areas with increased distance from the road and road ditches to increase local infiltration are also potential mitigation options. Prevention rather than mitigation by considering the use of alternative de-icing agents on stretches of road within vulnerable areas is recommended, e.g. calcium magnesium acetate.

To reduce high chloride levels in road run-off, water methods used for the desalination of water or what Amundsen et al (2012) called technical treatment methods are required. These methods generally require an energy input, some require a high energy per m^3 of water treated, and are expensive to operate when considering desalination of large volumes or road run-off water. This in effect makes these desalination methods impractical for road run-off treatment. Methods used for desalination of drinking water include distillation, reverse osmosis, electro dialysis, and membrane distillation (Amundsen et al, 2012) (Kelting & Laxson, 2011).

The US EPA has also published a ‘Source Water Protection Bulletin’ to protect water used for potable supplies against road salt contamination (USEPA, 2010). Again measures such as equipment maintenance, pre-wetting of snow/ice, application of salt in solution (brine) and pre ploughing are outlined as mitigation measures. A focus on road maintenance staff awareness to sensitive waters is also discussed.

2.8 Relevant Legislation

2.8.1 Water Framework Directive

The Water Framework Directive (WFD), 2000/60/EC, is a key initiative aimed at improving water quality throughout the EU and was transposed into Irish legislation under the European Communities (Water Policy) Regulations, 2003 (S.I. No. 722 of 2003). Under the WFD, Ireland is divided into eight separate river basin districts (RBDs). The Eastern RBD is shown in Figure 2.5. The WFD requires an integrated approach to managing water quality on a river basin basis with the aim of maintaining and improving water quality. The Directive, due to its wide-reaching nature, will eventually replace a number of the other water quality directives (for example, that on Surface Water Abstraction, Freshwater Fisheries and Shellfish Waters).

Specifically the WFD aims to:

- protect/enhance all waters (surface, ground and coastal waters)
- achieve "good status" for all waters by December 2015
- manage water bodies based on river basins (or catchments)
- involve the public streamline legislation

Figure 2.5: Eastern River Basin District Map

The seven river basin districts in the Republic of Ireland cover approximately 800 groundwater bodies and 5,000 surface water bodies (canals, rivers, lakes, transitional and coastal waters. The RBD plans aim for significant improvements in water quality but they also recognise that in some cases soils and waters will take time to recover even where measures to address pollution have been put in place. The plans aim to improve the proportion of rivers and canals at good or high status from 54% currently to 68% by 2015, and the proportion of lakes at good or high status from 65% currently to 84% by 2015. The river basin plans are supplemented by Water Management Unit Action Plans which provide more detail on measures at a sub river basin level (WFD Ireland, 2008).

RBD Plans recognise that the two most significant impacts on water quality in Ireland are discharges from wastewater treatment plants and pollution arising from agricultural activities. However, the impacts of non-point and point pollution from our road network has the potential to also pose a significant threat to water quality if not collected and treated effectively.

The M3/N3 lies within the Eastern River Basin District incorporates all or part of twelve Local Authority areas: Dublin City, Meath, Kildare, Wicklow, Cavan, Dun Laoghaire-Rathdown, Fingal, Offaly, South Dublin, Westmeath, Louth and a small portion of Wexford; the main river catchments in the area are the Boyne (Hydrometric Area 07), the Nanny/Delvin (HA 08), the Liffey (HA 09), and the Avoca/Vartry (HA 10).

Two of the main pieces of legislation aimed at implementing and supporting the Water Framework Directive are the 2009 Surfacewater Regulations (SI No. 272 of 2009) and the 2010 Ground Water Regulations (SI No. 9 of 2010).

2.8.2 Surface and Ground water Regulations

The Water Policy Regulations (S.I. No. 722 of 2003), Surface Waters Regulations (S.I. No. 272 of 2009) and Groundwater Regulations (S.I. No. 9 of 2010) govern the shape of the WFD characterisation, monitoring and status assessment programmes in terms of assigning responsibilities for the monitoring of different water categories, determining the quality elements and undertaking the characterisation and classification assessments.

The Surface Water Regulations institute a wide-ranging set of environmental standards for Irish surface waters. The Groundwater Regulations establish environmental objectives to be achieved in groundwater bodies and include groundwater quality standards and threshold values for the classification of groundwater and the protection of groundwater against pollution and deterioration in groundwater quality.

The Water Framework Directive requires that for surface waters

"Member States shall implement the necessary measures to prevent deterioration of the status of all bodies of surface water"

and that

"Member States shall protect, enhance and restore all bodies of surface water, subject to the application of subparagraph (iii) for artificial and heavily modified

bodies of water, with the aim of achieving good surface water status at the latest 15 years after the date of entry into force of this Directive"

Under the Surfacewater Regulations, maximum allowable concentrations values (MAC) are given for specific physico-chemical parameters. No MAC values are specified for chloride or sodium chloride. However, if road run off with elevated levels of chloride are discharged to receiving surfacewaters (streams, rivers and lakes) the biological quality based an benthic invertebrate fauna populations may be negatively effected unless species in-situ are saline tolerant. Biological quality elements such as Q rating scores for benthic invertebrate communities also have a significant bearing on the achievement of 'good' water quality status as required under the Surface Water Regulations and the Water Framework Directive.

One of the main aims of the Groundwater Regulations (SI No. 9 of 2010) measures to prevent or limit the input of pollutants into groundwater and to prevent the deterioration of the status of all bodies of groundwater, in accordance with the requirements of Article 4 of Water Framework Directive (2000/60/EC):

"Member States shall implement the measures necessary to prevent or limit the input of pollutants into groundwater and to prevent the deterioration of the status of all bodies of groundwater"

and that

"Member States shall protect, enhance and restore all bodies of groundwater, ensure a balance between abstraction and recharge of groundwater, with the aim of achieving good groundwater status at the latest 15 years after the date of entry into force of this Directive"

The regulations set 'Groundwater Threshold Values' (GTV) for testing of groundwater for specific chemical parameters. The GTV for chloride under the regulations is 187.5 mg/L. This GTV is effectively a limit for chloride concentrations in groundwater to illustrate if the groundwater has been subjected to pollutants that will inhibit its use for human consumption and uses.

2.8.3 Habitats Directive and Birds Directives

The Habitats and Birds Directives are the main bodies of legislation that form Europe's nature conservation policy. These directives formed and implemented the Natura 2000 network of protected sites and its system of species protection. The Habitats Directive alone (92/43/EEC) protects over 1,000 animals and plant species and over 220 habitat types (e.g. special types of forests, meadows, wetlands, etc.), which are of European importance. Annex II species under the Habitats Directive requires the designation of Special Areas of Conservation, Annex IV lists those species in need of strict protection.

The Habitats Directive led to the setting up of a network of Special Areas of Conservation, which together with the existing Special Protection Areas form a network of protected sites across the European Union called Natura 2000. Such sites are protected by national legislation introduced to support Natura 2000 – the Habitats Regulation of 2011 (SI No. 477 of 2011) and the Wildlife Act 2000 (SI No. 38 of 2000).

The M3/N3 motorway runs adjacent to and crosses over the River Boyne and Blackwater SAC (SAC No. 002299). Fish species Atlantic salmon *(Salmo salar*) and European river lamprey *(Lampetra fluviatilis)* are protected species found in the Boyne and Blackwater rivers. The European Otter (*Lutra lutra*) is another protected species found within this SAC (National Parks and Wildlife Services, www.npws.ie). The otter is dependent on good populations of freshwater fish such as brown trout (*Salmo trutta*) for its survival. Therefore water of good quality status is essential to the otter population within the Boyne/Blackwater SAC.

The otter is a legally protected species under the EU Habitats Directive (listed in Annex II) and is found throughout Ireland (Hayden and Harrington, 2000). In a survey of otters in the east of Ireland, Hayden and Hamilton, 2000, report that 75% of sites visited in the Boyne catchment were classed as positive for otter presence. This includes most of the sampling points on the Boyne and Skane Rivers that are close to the proposed route alignment. These sampling points coincide with the EPA water quality sampling sites and include Ballinter Bridge on the Boyne, and Dowdstown and Ambrose bridges on the Skane. In the course of the field surveys, otter spraints were observed at one location on the banks of the Lismullin River at chainage 26700.

Otters are rarely found far away from water and tend to occupy long linear territories. They also require suitable bankside vegetation as cover for their holts. Otters are sensitive to disturbance and deterioration of water quality. Any negative impacts on fisheries as a result of the proposed development could have knock-on effects for otters. The passage of otters can be restricted by inappropriate culvert design. (www.NPWS.ie)

The Birds Directive (2009/147/EC) created a comprehensive scheme for the protection for all wild bird species naturally occurring in the EU. It was adopted as a response to increasing concern about the declines in Europe's wild bird populations resulting from pollution, loss of habitats as well as unsustainable use. It was also in recognition that wild birds, many of which are migratory, are a shared heritage within the EU Member States and that their effective conservation required international co-operation.

The directive recognises that habitat loss and degradation are the most serious threats to the conservation of wild birds. It therefore places great emphasis on the protection of habitats for endangered as well as migratory species (listed in Annex I), especially through the establishment of a coherent network of Special Protection Areas (SPAs) comprising all the most suitable territories for these species. Since 1994 all SPAs form an integral part of the NATURA 2000 ecological network.The River Boyne and Blackwater is also a designated Special Protected Area under the Birds Directive (SPA No. 004232). It includes the river sections along the River Boyne crossed by the M3 Motorway and the River Blackwater crossed by the N3 along with Boyne tributary rivers and streams. The SPA site includes the river channel itself and marginal vegetation along river banks. The River Boyne and River Blackwater Special Protection Area is of high ornithological importance as it supports a nationally important population of Kingfisher (Alcedo atthis), a species that is listed on Annex I of the E.U. Birds Directive.

2.8.4 Road Legislation

The Road Act 1993 (SI No. 14 of 1993) requires a road authority to prepare a statement of the likely effects on the environment, an EIA or environmental impact statement, of any proposed road development. The EIA should consider not just the construction of the motorway but also the ongoing use and maintenance of the road.

An environmental impact statement shall contain sufficient and appropriate information on the likely significant effects, direct and indirect, on the environment of the proposed road development, explained by reference to its possible impacts on soil, water, air, climate and the fauna and flora that depend on the environment through which the road passes. Where significant adverse effects are identified a description of the measures envisaged in order to avoid, reduce and, if possible, remedy those effects should be detailed in the EIA and where appropriate, an outline of the main alternatives (if any) studied and an indication of the main reasons for choosing the proposed alternative, taking into account the environmental effects.

Under the Roads Act of 1993, an EIA should include estimates of the type and quantity of expected emissions resulting from the proposed road development when in operation and the likely short and long term effects of these emissions.

3. Methodology

The subject of high salt level road run-of posing an environmental threat to receiving freshwater rivers and lakes was researched to establish its relevance and whether or not the subject is important in an Irish context. Initial research was performed using the internet to source and review relevant papers and publications on this subject.

This initial research established that the potential environmental effect associated with the use of road salt to de-ice roads has been recognised internationally. Several key publications on the matter were sourced and Email contact with representatives of relevant government bodies and authorities in Ireland, Denmark and Norway was made.
The analysis of test data from international studies on the toxicology of road salt was also performed to illustrate the potential negative effects of sodium chloride on fresh waterbodies.

Phone interviews with An Bord Pleanála, Meath County Council, Irish National Road Authority and the Irish Environmental Protection Agency were conducted to establish if a potential environmental threat from the use of road salt has been considered in Ireland and if any mitigating actions or recommendations have been put in place to deal with this issue. With regard to mitigation measures, international best practice for the spreading and management of road salt (sodium chloride) was also established through the review of relevant publications.

This study uses de-icing along the M3 motorway in County Meath as a case study. River monitoring data from the environmental section of Meath County Council was obtained and chloride levels in the rivers that cross the M3 were reviewed for any noted changes in chloride during winter months.

An on site review of stormwater drainage and treatment systems along the M3 were performed with the cooperation of Eurolink M3, the company responsible for the maintenance, including de-icing, of the motorway.

An evaluation of mitigation measures proposed and accepted as part of the EIA for the M3 motorway and the storm water treatment system was made from:

(1) research of international best practice;
(2) literature reviews on how sodium chloride reacts in the environment.

4. The M3 Motorway – A Case Study

4.1 M3 Motorway - Background

An Environmental Impact Assessment (EIA) for the construction and Operation of the M3 Motorway from Clonee to North of Kells, Co. Meath was prepared in support of planning permission in February 2002. An application for planning permission was lodged by Meath County Council to An Bord Pleanála in March 2002.
Planning permission was granted in 2003.

"Having regard to the provisions of the current County Meath Development Plan, the National Development Plan 2000 –2006 and the Strategic Planning Guidelines for the Greater Dublin Area, the existing and predicted traffic flows and to the mitigation measures proposed in the environmental impact statement, it is considered that, subject to the modifications set out in the Schedule to this order, the proposed road development would be in accordance with the proper planning and sustainable development of the area and would not have significant adverse effects on the Environment" – An Bord Pleanála.

At the time the construction, the motorway planning was contested because the route passes near the Hill of Tara and through the archaeologically rich Tara-Skryne valley (Simpson, 1994). The M3 Scheme was designed, constructed and is maintained as part of a Public-Private Partnership (PPP) contract between the NRA and Eurolink Motorway Operations M3 Ltd. (www.eurolink-m3.ie). Eurolink is also responsible for the design and everyday maintenance of the drainage on the main project road or the M3 including de-icing during winter months.

The M3 has been fully operational since June 2010 following approximately 3 years of construction. The M3 begins at the end of the Clonee By-Pass, on the N3/R147 and runs adjacent to the N3/R147 for approximately 51Km before joining the N3 again approx. 8Km north of the Kells exit. The N3 then forms a dual carriageway for approx. 15Km before it reduces to single carriageway at the Meath/Cavan county boundary. The main towns bypassed by the M3 motorway are Dunshaughlin, Navan and Kells. The map below details the route the M3 takes, the crossing of the River Boyne is shown on the map south of Navan.

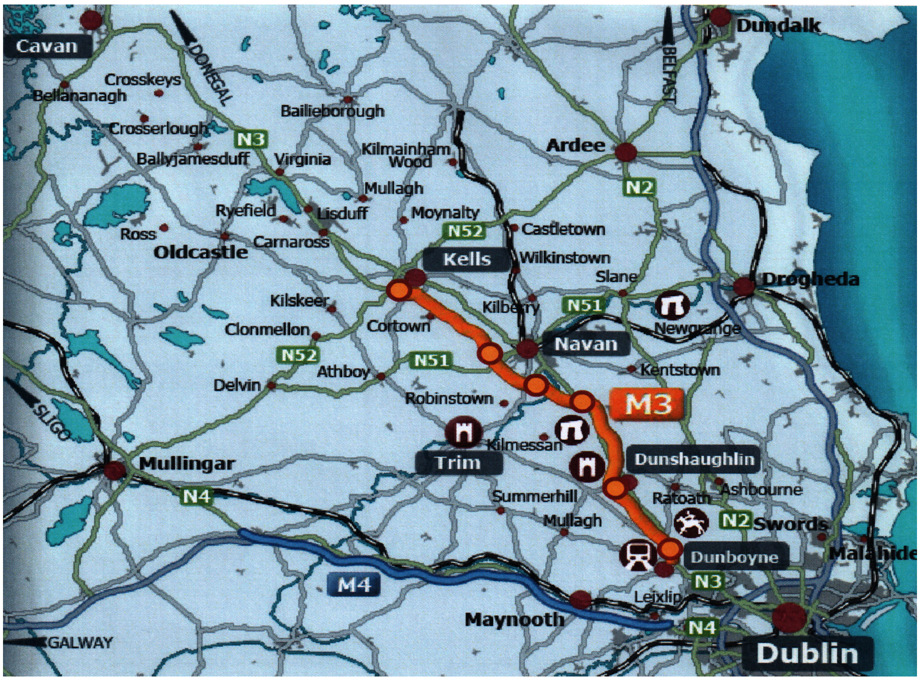


Figure 4.1: Eurolink Operations M3 Motorway Map (www.eurolinkm3.ie)

According to the EIA submitted for the M3, traffic volumes in 2002 on the N3 before the M3 was completed exceeded 22,000 vehicles per day between Clonee and Blackbull – North of Dunboyne; 15,000 vehicles per day between Blackbull and Dunshaughlin; 16,000 vehicles per day between Dunshaughlin and Navan; and 11,000 vehicles per day between Navan and Kells. A 2002 study predicted that volumes of traffic were expected to double by 2022. As detailed in Section 2.7, from the Bruen et al (2006) study we learn that the annual average daily traffic (AADT) has a direct relationship with the surface water treatment required for road run-off. The UK Design Manual for Roads and Bridges (DMRB-UK, 1998) expects pollution impacts on receiving waters mainly from roads 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 point is used to determine whether a given road requires a certain type of run-off treatment system before discharging to receiving streams. Applying AADT or the 'limit' used in the United States suggests that the predicted road data for most of the route along the M3 is less than the 30,000 cut off point below which no treatment is deemed appropriate in the USA.

4.2 De-icing Programs

The M3 was constructed as a Public-Private Partnership between the National Roads Authority (NRA) and Eurolink M3 Ltd. Eurolink are responsible for the operation and maintenance of the M3 including winter de-icing programs. Eurolink's jurisdiction is along the M3 from Clonee to north of Kells, a distance of just over 50Km (Fig 4.1).

Meath County Council is responsible for the de-icing of the other roads in County Meath and the local authority spreads road salt along 577km of roadways covering 10 main routes in the county Meath, each time icy roads are predicted, using National Road Authority (NRA) methods. The NRA has implemented an ice monitoring system for national roads and motorways that allows local authorities and road operators to predict, to a certain degree, whether specific sections of the roads network are likely to encounter snow or ice conditions during the colder months. The road surface is monitored by a series of ice monitoring stations called 'Icecast'. These stations are strategically positioned throughout the National Road network. Each station is monitored remotely by a central system. The data collected can provide a reasonable assessment of the current road condition.

The data is collected centrally and, through the services of Met Eireann, future weather and road condition is forecast. Based upon this information, local authorities are able to make sound judgements, on a day-to-day basis, as to when pre-emptive action is necessary to treat the road (i.e. gritting) in order to prevent ice forming. (www.nra.ie)

Meath County Council de-ices National Primary (Priority 1), National Secondary (Priority 1) and approx. 80% of all Regional Routes (Priority 1/2) in the county. In exceptional circumstances other stretches may be salted when assessed on a case by case basis – these are listed as priority 3 routes.

Approximately 15% (by length) of all roads in county Meath are treated with road salt prior to and during icy weather. Other roads that may not be treated as a priority are minor or local roads and these may be 'salted' by local residents on a voluntary basis.

There are also four motorways that pass through County Meath are considered primary routes. They are the M1 motorway (Dublin-Belfast), M2 motorway (Ashbourne Bypass), M3 motorway (Clonee-Kells) and M4 motorway (Dublin-

Sligo/Galway). De-icing and road maintenance on these motorways is provided by private road operators who are in turn responsible to the National Roads Authority.

According to the transport section of Meath County Council, prior to 2009 the average number of callouts per winter season was in the region of 40 to 45 treatments. With the exception of 2011/12, there has been a large rise in the required number of Meath County Council de-icing callouts. This illustrates the increased use of road salt in recent years due to colder winters with prolonged icy weather. Should this trend continue, the issue of controlling road salt run-off becomes increasingly important and a greater environmental threat to receiving surface waters.

Table 4.1: Meath County Council Road Salting Callouts (Meath County Council, 2014)

Year	**No. of Callouts**
Gritting Season 2009/2010	85
Gritting Season 2010/2011	91
Gritting Season 2011/2012	38
Gritting Season 2012/2013	94

For each callout Meath County Council will use approx. 22 tonnes of road salt to de-ice priority 1 routes and 48 tonnes of road salt to cover priority 2 routes. This equates to 6,580 tonnes of road salt used by Meath County Council alone in the winter of 2012/2013.

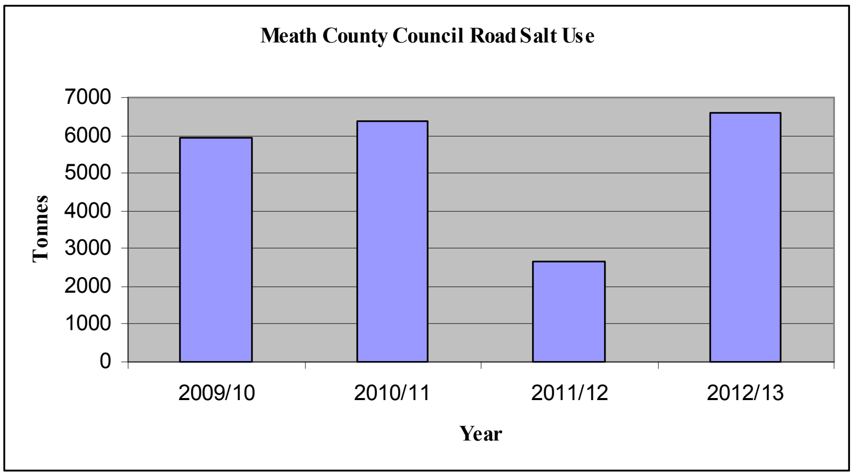


Figure 4.2: Meath County Council Road Salt Use (Original)

The main focus of this case study is the potential effects de-icing on the M3 motorway has on surface waters. Eurolink M3 Ltd. applies pre-wetted salt along the 50Km of M3 motorway. Eurolink apply a standard spreading rate of 10g/m^2 during light frost and snow, 20 to 30 g/m^2 during moderate ice and snow and 30 to 40 g/m^2 during heavy continuous snow. Prior to the winter of 2011-2012 Eurolink changed from using dry rock salt to treat the motorway to Pre-wet salt. Pre wet is where the rock salt is dampened down with fresh water, giving rise to a 23% mix of salt called brine. It works much more effective than dry salt as it clings to the pavement instead of bouncing off or being swept away by traffic and also salt requires moisture to work and with freezing dry temperatures dry salt is not effective until its trafficked and breaks down. Salt brine can work immediately as it has already been moistened. During snowfall, the spreading of salt is always accompanied by ploughing the snow.

Table 4.2: Eurolink M3 Road Salting (Eurolink M3, 2014)

Season 2010 – 2011	Monthly Tonnes	Season 2011 – 2012	Monthly Tonnes	Season 2012 – 2013	Monthly Tonnes	Season	Monthly Tonnes
Oct-10	43	Oct-11	0	Oct-12	9	Oct-13	0
Nov-10	542	Nov-11	19	Nov-12	111	Nov-13	85
Dec-10	1134	Dec-11	276	Dec-12	180	Dec-13	195
Jan-11	397	Jan-12	52	Jan-13	209	Jan-14	161
Feb-11	47	Feb-12	63	Feb-13	108	Feb-14	107
Mar-11	38	Mar-12	4	Mar-13	237	Mar-14	75
Apr-11	0	Apr-12	4	Apr-13	12	Apr-14	0
May-11	0	May-12	0	May-13	0	May-14	0
Total	**2201**		**418**		**866**		**623**

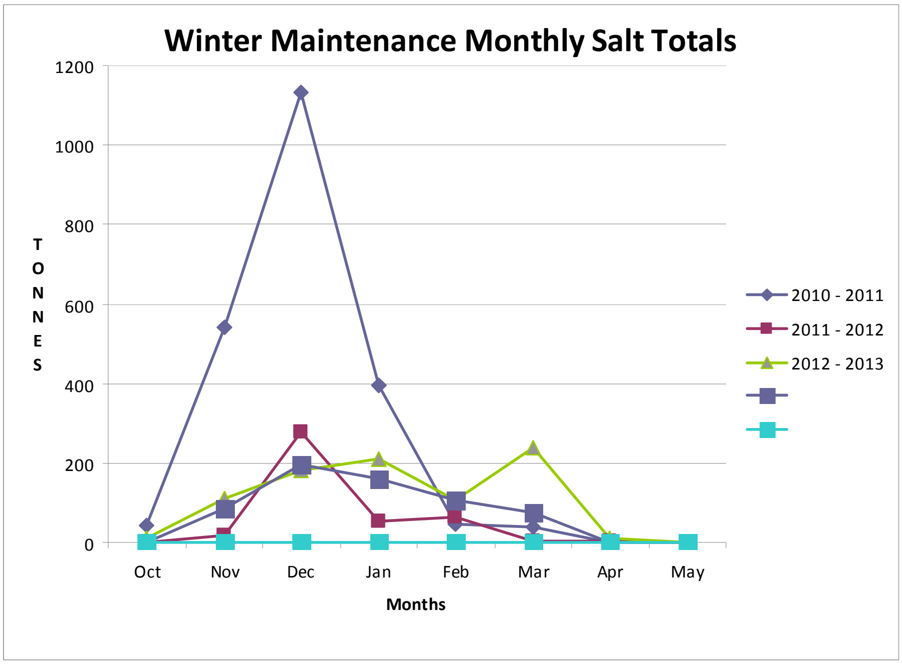


Figure 4.3: Eurolink M3 Road Salting Trends (Eurolink M3, 2014)

In Ireland there are a high proportion of marginal nights when temperatures are very close to zero. This makes it more difficult to accurately predict frost than in colder countries such as Canada or Norway. Met Eireann only guarantee 80% accuracy in their forecasts. It can take up to three hours to salt a route therefore any journey may start or end on an untreated section of the route.

In heavy rain, salt can be washed away and the wet surface may subsequently freeze if the temperature falls below zero. In cases of extended severe weather events, the network salted may have to be reduced to Priority 1 routes due to restrictions in road salt availability.

4.3 River Boyne and River Blackwater Protected Areas

The River Boyne and River Blackwater are a designated Special Area of Conservation (SAC No. 002299) under the EC Habitats Directive (92/43/EEC). The main conservation objectives for this SAC is to maintain and restore favourable habitat conditions within environments designated to be important to rare and protected species of flora and fauna. There are a number of aquatic species that an afforded protection within the Boyne and Blackwater SAC. Fish species *Salmo salar* (Atlantic salmon) and *Lampetra fluviatilis* (European river lamprey) are protected species found in the Boyne and Blackwater rivers. The European Otter (*Lutra lutra*) is another protected species found within this SAC and it is dependent on good populations of freshwater fish such as brown trout for its survival. Therefore water of good quality status is essential to the otter population within the Boyne/Blackwater SAC.

Both salmon and river lamprey are associated with both freshwater and saltwater at different life cycle stages. The European otter (*Lutra lutra*) is primarily found by freshwater rivers and lakes but can also be found in coastal waters. It does however require freshwater in order to clean its fur. Although it has a tolerance to saline waters, it is dependent on good populations of fish and amphibians for its survival (www.npws.ie).

The Natura 2000 data form for this SAC gives further information on the site characteristics and on the sites quality, importance and vulnerabilities.

Inland freshwater bodies make up 30% of the SAC. This site comprises most of its freshwater element from upriver of the Boyne Aqueduct at Drogheda, the Blackwater

River as far as Lough Ramor and also from three principal tributaries of the River Boyne - the Deel, Stoneyford and Tremblestown Rivers. This system provides drainage for considerable areas of counties Meath and Westmeath and to a lesser extent for counties Cavan and Louth.

The rivers of this Boyne/Lagan catchment flow through a landscape dominated by intensive agriculture, mostly of improved grassland but also of cereals and other tillage cops in counties Louth and Meath. Much of the river channels were subjected to arterial drainage schemes in the past. Natural flood-plains now exist along only limited stretches of river, however it is noted that there is often a fringe of reed swamp (Habitat Code FS1), freshwater marsh (Habitat Code GM1), wet grassland (Habitat Code GS4) or deciduous wet woodland (WN4/WN6) immediately at or along river banks and riparian zones. Habitat Codes are taken from Fossitt (2000).

The Boyne and its tributaries are one of Ireland's premier game fisheries (www.fisheriesireland.ie) and offer a wide range of angling, from fishing for spring salmon to sea trout fishing. Good stocks of brown trout (*Salmo trutta*) provide for excellent fishing on some river stretches.

This SAC site is one of the most important in eastern Ireland for Atlantic salmon (*Salmo salar*) and has very extensive salmonid spawning grounds. Salmon counts on the Boyne and its tributary rivers are shown in Table 4.2. No salmon count could be recorded in the main Boyne and Blackwater rivers this due to consistent high water levels. The River Boyne is a designated Salmonid Water under the EU Freshwater Fish Directive. Although this species is still fished in Ireland at a low level, it is considered to be endangered or locally threatened elsewhere in Europe and is listed on Annex II of the Habitats Directive.

Table 4.3: Salmon Counts on the Boyne Tributaries (Inland Fisheries Ireland)

RIVER	***2000***	***2001***	***2002***	**2003**	**2004**	**2005**	**2006**
Athboy-Trimblestown	172	87*	89*	91*	82*	283	145*
Boycestown	17	5*	45	19*	10*	5	28
Clady	20	8*	10*	9*	18	19	17
Deel	50	70*	*	*	40*	91	0*
Enfield Blackwater.	29	45*	*	*	*	56	0*
Fair English	10	12*	10*	*	6*	0*	0*
Kinnegad	22	25*	11*	*	*	0*	19*
Knightsbrook	82	59*	59*	67*	74*	165	101*
Luenstown	19	15*	17	*	38*	30	0*
Mattock	6	30*	56*	36*	25*	22	109*
Milltownpass	20	14*	14	*	*	14*	13
Moynalty	96	125*	112*	60*	86*	90	129*
Riverstown	19	16*	*	28*	*	42	0*
Skane	79	50*	43*	61*	20*	46	79*
Stonyford	92	41*	46*	70*	202	176	193*
Total	**733**	**602**	**502**	**441**	**601**	**1039**	**833**

Atlantic salmon run the Boyne almost every month of the year. The Boyne is most important as it represents an eastern river which holds large three-sea-winter fish from 20 –30lb. Both salmon and brown trout spawn in the winter months – usually between November and January and the time of spawning may vary from river to river (www.fisheriesireland.ie).

The spawning season in winter months coincides with the greatest use of road salt during cold weather. Atlantic Salmon use the tributaries and headwaters of the River Boyne as spawning grounds (www.npws.ie).
These tributaries receive storm water from the road network throughout County Meath. Therefore spawning sites will be subjected to any polluting matter not removed by treatment methods in storm water including road salt from de-icing the roads. Salmon counts do not significantly decrease after the construction of the M3 motorway and in some tributaries salmon counts were significantly higher during years of M3 construction, most notably in 2006.

The upstream of Navan and the M3 is generally deep and slow flowing but holds extensive stocks of wild brown trout. The majority of fishing in this area is controlled by Angling Associations with some being maintained by private fishery owners. There is excellent wild brown trout fishing on the river Boyne and the average weight of trout is three quarters of a pound, however a number of fish to 5lbs and 6lbs are taken annually. Downstream of the M3 motorway, there are a number of popular fishing locations in the Navan area and these are located at Kilcarn, Blackcastle and Dunmoe. There is also good trout fishing in the Stackallen area and downstream of Slane at the Scabby Arch, Crewbawn, Johnsons, Rossnaree and Staleen. The River Blackwater holds good stocks of wild brown trout up to two pounds and over and most of the stretches provide good angling. In 2004 the Blackwater produced a new record brown trout for the river which weighed in at over 9lbs 11ozs. In 2004 the Kells Blackwater produced several wild brown trout that weighed 3lbs to 5lbs (www.fisheriesireland.ie).

The River Boyne also has an important population of *Lampetra fluviatilis*, a listed species under Annex II of the Habitats Directive (92/43/EEC). A survey of juvenile lamprey populations throughout the River Boyne catchment was conducted by Ecofact Environmental Consultants Ltd. in 2005 (O'Connor, 2006). This survey found that significant populations of river/brook lampreys occur throughout the River Boyne catchment and that the main lamprey populations in the River Boyne are currently protected within the existing SAC.

Lutra lutra is widespread throughout the site according to the River Boyne and Blackwater SAC site synopsis (www.npws.ie). An otter survey of Ireland was conducted in 2004/2005 by Bailey, M. and Rochford J. (2006). This survey found that the Eastern River Basin District (ERBD), including the River Boyne, had the lowest percentage occurrence of otters at 59.50% positive site recordings. The higher rate of urbanisation within the Eastern RBD was given as the main reason for a lower otter population in the ERBD (Bailey and Rochford, 2006).

The Blackwater is described as a medium sized limestone river which is still recovering from the effects of the arterial drainage scheme of the 1970's which involved extensive dredging. It is reported that salmon stocks have not recovered to the numbers recorded pre drainage.

The SAC site conservation objectives identify the main threats to the ecological interest of the site. These are threats from drainage schemes and from pollution sources which affect water quality. Pollution from domestic, agricultural, industrial and infrastructural sources threatens water quality. The conservation objectives also state that a reduction in the inputs of pollution into the Boyne and Blackwater catchment area is required to preserve 'the important aquatic interests of the site'. Surfacewater run-off from the M3 and N3 are infrastructural sources and should be sufficiently mitigated against in order to preserve water quality.

The River Boyne and Blackwater is also a designated Special Protected Area under the Birds Directive (SPA No. 004232). It includes the river sections along the River Boyne crossed by the M3 Motorway and the River Blackwater crossed by the N3 along with Boyne tributary rivers and streams. The SPA site includes the river channel itself and marginal vegetation along river banks. The River Boyne and River Blackwater Special Protection Area is of high ornithological importance as it supports a nationally important population of Kingfisher (*Alcedo atthis*), a species that is listed on Annex I of the E.U. Birds Directive.
Kingfishers are dependent on small species of freshwater fish and the fry of trout and salmon as a source of food. If water quality deteriorates as a result of pollutant inputs to the Boyne catchment, the Kingfisher population may decline as a result of reduced fish stocks. Kingfisher are a protected bird species found throughout the River Boyne and River Blackwater Special Area of Protection (SPA) and although primarily associated with freshwater, often are found in Winter along the coast as their normal freshwater lakes/streams can freeze over (www.birdwatchireland.ie).

4.4 Water Framework Directive (WFD)

The Water Framework Directive, 2000/60/EC, (WFD) requires specific waterbody identification codes to be allocated to these rivers and their tributaries. The Boyne (WFD WB Code EA_07_1517) and the Blackwater (WFD WB Code EA_07_1035) are listed under the Eastern River Basin District characterisation report as being protected waterbodies. The Boyne has protection status under the Water Framework Directive as it is a Special Area of Conservation under the Habitats Directive, a Special Area of Conservation under the Birds Directive, it is a designated salmonoid waterbody and recognised as a nutrient sensitive waterbody. The Blackwater River is a listed Special Area of Conservation (SAC) under the Habitats Directive.

The Boyne, The Blackwater and the River Skane (WFD WB Code EA_07_1629) all form part of the Boyne Catchment area (Hydrometric Area 07)

The main environmental risk and potential threat to water quality in the Boyne catchment is considered to be agricultural production. The catchment area contains 2560 km^2 of agricultural land (95% of the total catchment). Pastures comprise 74% of the catchment. Waterbodies in the vicinity of grazing land may be subject to organic pollution from livestock and agricultural practices.

Water quality monitoring and biological monitoring at over 100 stations indicate that about 30% of the river water bodies are "unpolluted" and 1% are considered "seriously polluted". However, 42% of the monitored channels are considered "slightly polluted" (Phillips, 2005). The risk categorisation of waterbodies in the Boyne Catchment is summarised in figure 4.4.

Risk Category	Assessment Categories (number of water bodies)				Overall	River Length	% of Length
	Morpho-logical	Hydrology	Diffuse	Point Source			
Not at risk (2b)	18	105	1	57	0	0	0
Probably not at risk (2a)	2	0	5	38	0	0	0
Probably at risk (1b)	97	5	85	16	52	225.6	29%
At risk (1a)	2	9	28	8	77	546.3	71%
TOTAL	119	119	119	119	119	771.9	100%

Figure 4.4: Boyne waterbody risk categorisation (Phillips, 2005)

The Boyne (main channel), the Blackwater (main at Kells) and the Skane (Lower) rivers are categorised as being 1a – at risk by the Easter River Basin District characterisation report. At risk status means that waterbodies are at risk of not meeting the WFD target of "good ecological status" by the end of 2015 if the identified risks to water quality are not adequately addressed. The use of road salt to de-ice the M3 motorway and other roads in County Meath may have a detrimental effect on water quality and impact on the achievement of good water quality status.

4.5 M3 Surface Water Drainage, Analysis & Treatment

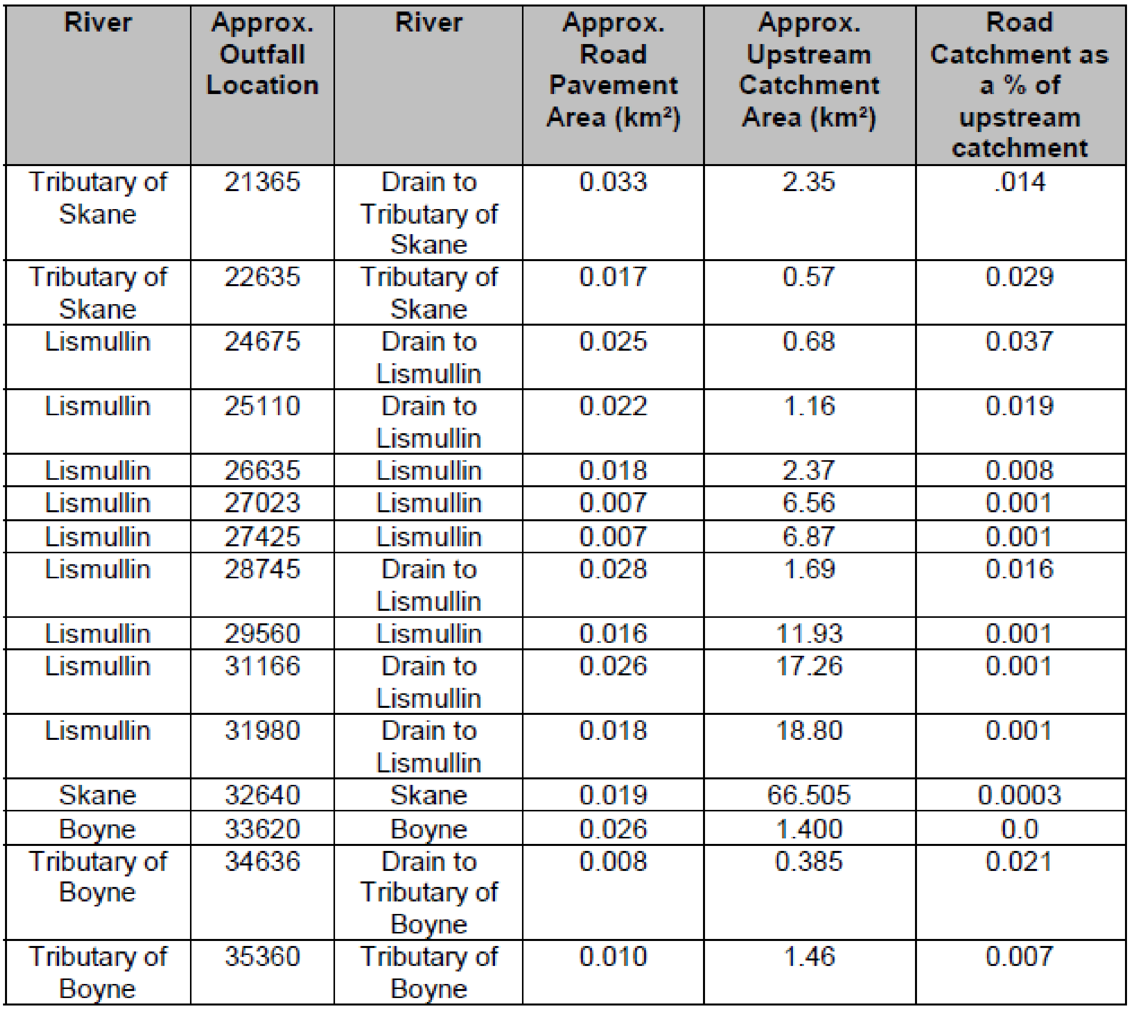
4.5.1 Drainage Catchments Areas and Outfalls

The impact of the M3/N3 road development scheme on drainage was been considered in two ways by the Environmental Impact Assessment (EIA) accepted by An Bord Pleanála for the scheme. Firstly the quality of run off and the ameliorative measures to minimise adverse impacts from surfacewater constituents were considered. Secondly the quantity of run off and the capacity of the individual watercourses to accommodate the additional run off were considered.

In the EIA for the main M3 section between Dunshaughlin and Navan, sixteen outfall locations were identified from which the surface run off discharges to nearby watercourses - all outfalls are either directly into or into tributaries of the River Boyne. The site is one of the most important in eastern Ireland for *Salmo salar* and has very extensive spawning grounds. Atlantic Salmon use the tributaries and headwaters as spawning grounds (www.npws.ie).

Table 4.4 details the location and drainage catchment areas of these sixteen stormwater outfalls.

Table 4.4: M3 Storm water Outfalls and Drainage Catchment Area (Meath County Council, 2014)



River	Approx. Outfall Location	River	Approx. Road Pavement Area (km²)	Approx. Upstream Catchment Area (km²)	Road Catchment as a % of upstream catchment
Tributary of Skane	21365	Drain to Tributary of Skane	0.033	2.35	.014
Tributary of Skane	22635	Tributary of Skane	0.017	0.57	0.029
Lismullin	24675	Drain to Lismullin	0.025	0.68	0.037
Lismullin	25110	Drain to Lismullin	0.022	1.16	0.019
Lismullin	26635	Lismullin	0.018	2.37	0.008
Lismullin	27023	Lismullin	0.007	6.56	0.001
Lismullin	27425	Lismullin	0.007	6.87	0.001
Lismullin	28745	Drain to Lismullin	0.028	1.69	0.016
Lismullin	29560	Lismullin	0.016	11.93	0.001
Lismullin	31166	Drain to Lismullin	0.026	17.26	0.001
Lismullin	31980	Drain to Lismullin	0.018	18.80	0.001
Skane	32640	Skane	0.019	66.505	0.0003
Boyne	33620	Boyne	0.026	1.400	0.0
Tributary of Boyne	34636	Drain to Tributary of Boyne	0.008	0.385	0.021
Tributary of Boyne	35360	Tributary of Boyne	0.010	1.46	0.007

4.5.2 Natural Land Drainage

The M3 route is dominated by the presence of the River Boyne and its tributaries. The Boyne therefore controls the drainage patterns of the road catchment. The Boyne has a lowland catchment covering the fertile plains of County Meath, a large area of County Westmeath and parts of Counties Kildare, Louth, Cavan and Offaly. The total catchment area is estimated at 2,694 square kilometres with a main channel length of 113km. The main M3 section between Dunshaughlin and Navan crosses the River Boyne just East of Ballinter Bridge. The majority of the route lies to the south of the River Boyne and is drained by its tributary, the Skane River, and its tributaries including the Lismullin River. The Skane River rises close to Dunshaughlin and flows northwards through Kilmessan to join the Boyne downstream of Ballinter Bridge at Dowdstown. The Lismullin River flows close to the proposed route for most of its length, crossing it at a number of locations until its confluence with the Skane at Dowdstown Bridge.

4.5.3 Considered Effects on Surfacewater Quality

The EIA for the M3 considered stormwater containing contaminants from various sources. The principal sources that were identified are:

- Degradation of Road Surface and vehicles producing small discrete particles
- The products of combustion from vehicle exhausts
- **Salts used for de-icing**
- Accidental spillages of transported goods
- Soil erosion
- Aerial deposition

Discoloration and an increase in the turbidity of receiving waters mainly from grit and clay carried in stormwater were considered in the EIA for the M3. Other pollutants carried on these suspended solids were also considered.

“The most significant role of sediments is not their direct effect on water quality but their capacity for absorbing, transporting and releasing other contaminants such as organic chemicals, lubricating oil, heavy metals and de-icing salts. The amount of contaminants in road runoff depends on the time elapsed between rainfall events, the volume of traffic during that period, the intensity of the rainfall and the total volume discharged. The greatest amounts of contaminants are washed off the road surface during periods of heavy rainfall when the level of dilution is greatest. However the peak run-off from a road will not coincide with the peak from the upstream catchment. This may mean that in unfavourable circumstances a short period could exist during which the level of dilution is limited. This situation would be rectified as soon as the watercourse flood waters reach the point of confluence. It is not possible to be precise about the levels of dilution available at each outfall. The only meaningful comparison that can be made is to quote the relative areas of the contributing motorway and upstream catchments” – Meath County Council EIA (2002).

The EIA recognised that existing water quality in river systems could be potentially impacted by discharges of road drainage carrying hydrocarbons, metals and other pollutants. Deterioration in the water quality of receiving waters by sodium chloride from road salting was not considered to any great extent by the EIA for the M3.

The EIA for the M3 concluded that there would be a slight increase in surface water flow at each of the outfall locations and that the road catchment area is negligible in comparison with the total catchment area of the outfall. It was therefore not anticipated that there will be any increase in peak flow or any significant deterioration in the water quality downstream of the M3 and its stormwater outfalls.

4.5.4 Pre M3 Surface Water Chloride Concentrations

Prior to the construction of the M3, analysis results of a range of environmental parameters were collated from data provided by the Environmental Section of Meath County Council in order to present baseline concentrations. Chloride analysis results for locations on the River Boyne and one of its main tributaries, the River Shane, is presented in Table 4.4. The highest chloride result recorded at the monitoring location on the River Boyne was in May 1999. The lowest result recorded on the Boyne pre-M3 construction was in August 1999. On the River Skane, the highest chloride concentration was recorded in January 1998 and the lowest result was recorded in January 1999. Chloride results are discussed further in Chapter 5.

Table 4.5: Pre-M3 River Chloride Concentrations

River Boyne at Ballinter Bridge		**River Skane at Dowdstown Bridge**	
Date	**Chloride as Cl^- (mg/L)**	**Date**	**Chloride as Cl^- (mg/L)**
Jan-98	20.6	Jan-98	29.1
Feb-98	21.6	Jun-98	25.3
Mar-98	19.1	Jul-98	24.4
Apr-98	18.1	Dec-98	21.6
May-98	19	Jan-99	20.5
Jun-98	18.09	Apr-99	22.8
Jul-98	21.2	Jun-99	24.7
Aug-98	22.3	Jul-99	21.6
Sep-98	19.53	Oct-99	21.2
Oct-98	16.4	Nov-99	25.5
Nov-98	21.2	01/00	22.8
Dec-98	16.42	03/00	23.4
Jan-99	23.42	05/00	25.5
Feb-99	18.2	09/00	27.1
Mar-99	17.99	*	*
Apr-99	18	*	*
May-99	24.6	*	*
Jun-99	19.1	*	*
Jul-99	21.2	*	*
Aug-99	14.7	*	*
Sep-99	20.2	*	*
Oct-99	22.6	*	*
Nov-99	20.2	*	*
Dec-99	20.5	*	*
Jan-00	20.8	*	*
Feb-00	22.6	*	*
Mar-00	20.9	*	*
Apr-00	18.7	*	*
May-00	22.9	*	*
Jun-00	21	*	*
Jul-00	21.7	*	*
Sep-00	21.4	*	*
Sep-00	35	*	*
Oct-00	21.4	*	*
Nov-00	19.7	*	*
Dec-00	20.5	*	*

***** *indicates no sample taken***

4.5.5 Post M3 Surface Water Chloride Concentrations

Meath County Council monitors water quality on the River Boyne and the River Skane, into which stormwater from the M3 motorway is discharged. Results for the nearest downstream points on both rivers are given in Table 4.5. Chloride levels do not increase significantly after the construction of the M3 motorway. The highest chloride result recorded at the monitoring location on the River Boyne was in March 2013. The lowest result recorded on the Boyne post-M3 construction was in November 2009. On the River Skane, the highest chloride concentration was recorded in March 2103 and the lowest result was recorded in November 2009.

Table 4.6: Post-M3 River Chloride Concentrations

River Boyne at Ballinter Bridge		River Skane at Dowdstown Bridge	
Date	**Chloride as Cl-**	**Date**	**Chloride as Cl-**
21/03/2007	19.5	13/03/2007	20.1
21/05/2007	20.2	15/05/2007	24.2
29/08/2007	17.7	21/08/2007	17.9
29/11/2007	19.1	20/11/2007	21.9
26/02/2008	19.4	20/02/2008	22.3
27/05/2008	19.7	20/05/2008	22.1
19/08/2008	14.7	21/08/2008	20.8
19/11/2008	15.5	25/11/2008	19
12/02/2009	18.4	18/02/2009	21.7
27/05/2009	16.8	28/05/2009	20.3
26/08/2009	15.2	25/08/2009	18
18/11/2009	14.3	19/11/2009	13.3
17/02/2010	18.2	18/02/2010	20.6
26/05/2010	20.8	19/05/2010	22
31/08/2010	21.7	25/08/2010	21.8
24/11/2010	16.9	17/11/2010	21.9
24/02/2011	16.5	16/02/2011	24.4
26/05/2011	19	01/06/2011	23.7
17/08/2011	21.1	10/08/2011	25.1
06/12/2011	15.7	24/11/2011	20.1
07/03/2012	17.1	28/02/2012	22.1
23/05/2012	18.6	24/05/2012	21.6
21/08/2012	14.7	09/08/2012	21.2
06/12/2012	17	04/12/2012	23.6
21/03/2013	24.5	22/03/2013	28.1
13/08/2013	19.7	09/08/2013	25
20/11/2013	17.2	21/11/2013	24.5

4.5.6 Statistical Analysis of Chloride results

A student t-test using chloride analysis results before and after the construction of the M3 motorway is conducted to determine if the construction and operation of the M3 has caused a significant increase in chloride levels in the Boyne and Skane rivers that receive the M3 stormwater discharges.

River Boyne at Ballinter Bridge

t= 3.31 ($p > 0.05$)

Standard deviation = 2.92

Degrees of freedom = 61

Mean = 20.6

95% confidence interval for Mean: 19.61 thru 21.55

Standard Deviation = 3.24

River Skane Chloride Results at Dowdstown Bridge

t= 0.560 ($p > 0.05$)

Standard deviation = 4.25

Degrees of freedom = 39

Mean = 22.5

95% confidence interval for Mean: 20.24 thru 24.83

Standard Deviation = 6.17

The relatively low t-test and standard deviation values for the River Boyne chloride results before and after the construction of the M3 illustrate that there is no significant difference ($p > 0.05$) between the pre and post M3 chloride analysis results. This is also the case for chloride analysis of water from the River Skane at Dowdstown Bridge ($p > 0.05$).

This is also shown in Figures 4.5 and 4.6 with no real difference in chloride levels noted.

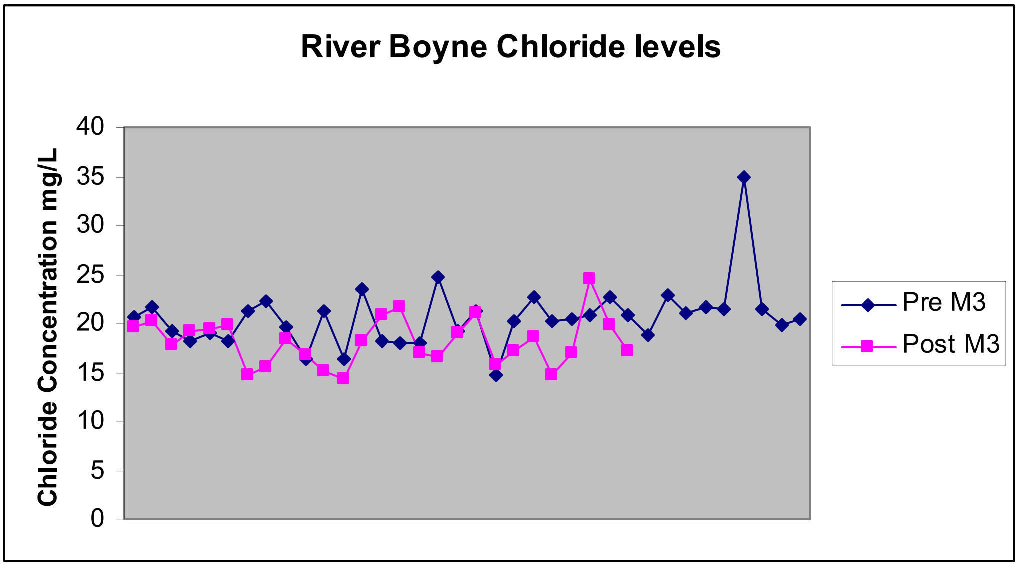


Figure 4.5: River Boyne Chloride analysis (Original)

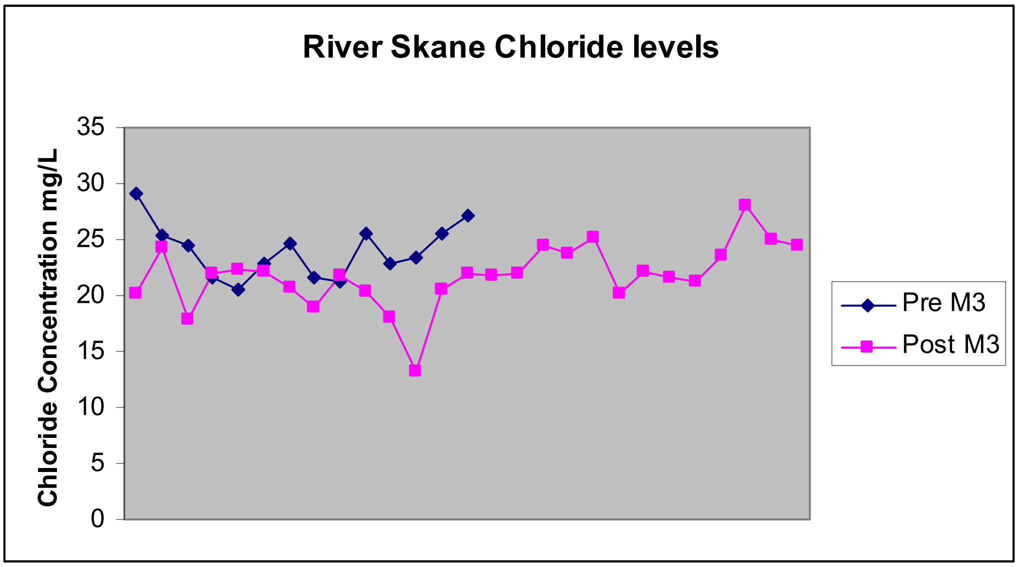


Figure 4.6: River Skane Chloride analysis (Original)

4.5.7 Stormwater Flow and Treatment

The M3 motorway was constructed as a Public-Private Partnership scheme. The maintenance and operation of the M3, including de-icing, is performed by Eurolink Motorway Operations Ltd. on behalf of the National Roads Authority (NRA). The flow chart below summarises the M3 stormwater drainage and treatment. (***Note: All photos are original***)

1. Precipitation (rain, snow, ice) including road salt run-off from the road surface and enter the drainage system

↓

2. Run-off stormwater passes enters drains at the side of the motorway. Drains are mainly French drains (Photo 4.1), but there are also kerb drains (Photo 4.2) and gully drains (Photo 4.3) along some stretches of motorway where the angle of the road drains surfacewater to the central median strip.

↓

3. Stormwater runs through drains and into of Girt Pots or Sumps which entrap larger suspended articles in the surfacewater

↓

4. Stormwater passes from French drains to Holding/Settling Ponds (Photos 4.4 & 4.5) where settling of smaller suspended solids in the water takes place. There has been some natural colonisation of reed beds in these ponds (Photo 4.7), which will also provide for the breakdown and treatment of organic material in the surfacewater

↓

5. Settled stormwater leaves the pond and enters an interceptor (Photo 4.6) – usually a twin chamber interceptor. Here oils and petroleum based pollutants are removed by the interceptor.

↓

6. Stormwater enters 'Clean' drains before discharge to receiving river or stream

Figure 4.7: Stormwater flowchart (Original)

Photo 4.1: French Drain

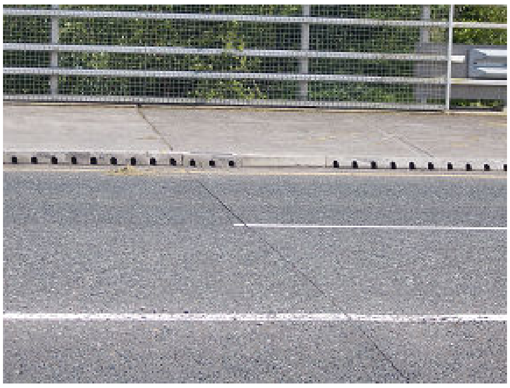


Photo 4.2: Kerb Drain

Photo 4.3: Gully Drain

Photo 4.4: Inlet to Settlement Pond

Photo 4.5 Settlement Pond Outlet

Photo 4.6: Interceptor Chamber

Photo 4.7: Reed Beds in Settling Pond

Photo 4.8: River Boyne at Ballinter Bridge

5. Evaluation of Mitigation Measures for the M3 Motorway

In the EIA submitted by Meath County Council to An Bord Pleanála measures proposed to minimise permanent impact from the M3 motorway scheme included:

- Incorporation of holding ponds and petrol interceptors to attenuate the impact of road drainage on flooding and water quality;
- The use of 'French Drains' (Figure 5.1) - filter drains with porous stone backfill, geotextile surround and silt trap manholes, to collect surface water run-off.
- Planting on side slopes and verges will minimise the amount of suspended matter in run off.

The planting of side slopes and verges was noted during site visits along the M3 motorway. Planting of slopes and verges is not viewed as a stormwater treatment method but rather as a measure to reduce suspended solids in storm water. Planting vegetation is not expected to have an impact on chloride levels in the storm water.

The use of French drains reportedly results in a considerable improvement in water quality of motorway run-off. French drains act not only in the collection of stormwater; they act as an initial filter for the water. Contaminants are removed from the stormwater as it percolates through the gravel bed that surrounds the perforated drain pipe. This is particularly effective in removing larger particulates and petroleum based products that adhere to the gravel (Meath County Council EIA, 2002).

Along the M3, the majority of collected stormwater passes initially through a 'French' drainage system. French drains remove suspended particles from stormwater through absorption, filtration and sedimentation. Other constituents of the motorway stormwater run-off, such as petroleum based materials, may adhere to these suspended materials. The materials that are absorbed on to suspended particles will also be removed. If designed to allow for a slow filtration through the drain, natural biological processes also have more time to carry out the attenuation of pollutions.

French drains are known to be effective at removing suspended solids including solid lead and zinc from stormwater. French drains also provide for a significant reduction in chemical oxygen demand ranges if slower filtration rates are slowed by drain design and weather conditions. However, chloride is highly soluble in water as concluded by various studies. The disassociated ions Na+ and Cl- will migrate with the precipitation toward the water table. The negatively charged chloride ion does not adsorb on mineral surfaces, enter oxidation, reduction or biochemical reactions or form ion complexes. As a result chloride is highly mobile, with a migration rate identical to that of the water (Jones and Jeffery, 1992). Therefore, chloride ions will remain in solution as the stormwater passes through the French drainage system. Sodium ions that are positively charge will absorb onto the French drain media and other suspended particles and will be removed from the stormwater.

Therefore 'French' drains are viewed as being ineffective for the removal of chloride from solution in stormwater from the M3 motorway.

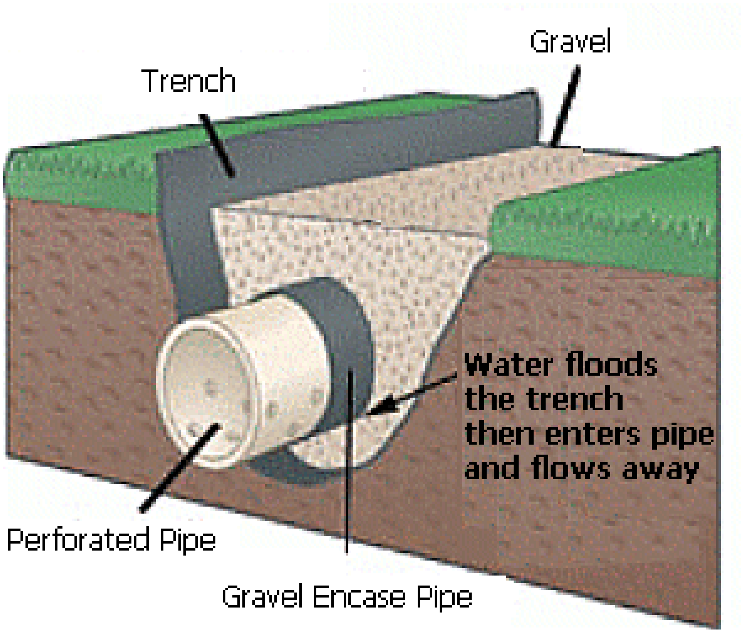


Figure 5.1: Typical 'French' drain design (www.greenboylawns.com) No scale specified

Collected stormwater passes from 'French' drains into grit traps.

Grit traps (Fig. 5.2) allow for larger particles to fall out of suspension as the stormwater passes into and out of the trap. This action is illustrated below. As chloride is so soluble in water, chloride present in stormwater from the application of road salt will pass through the grit trap and enter the next treatment phase – the settlement pond.

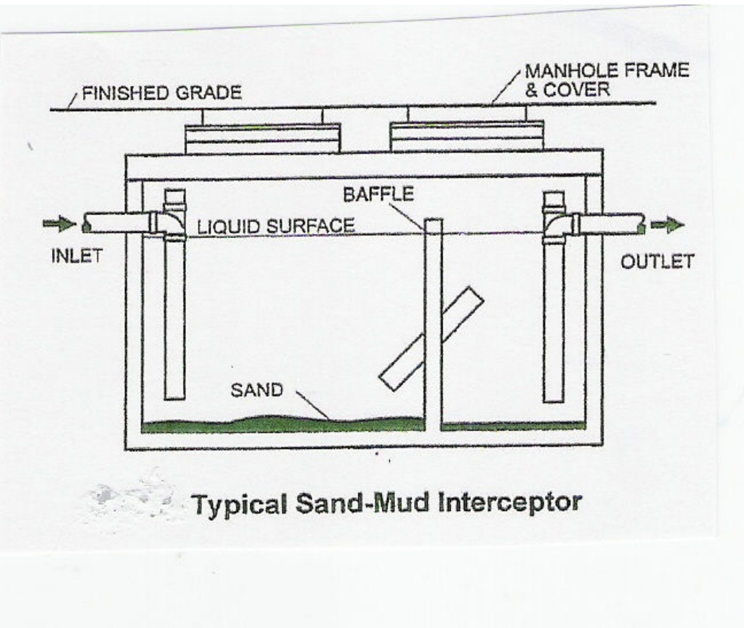


Figure 5.2: Grit trap (www.pumptruckhouston.com) No scale specified.

The Environmental Impact Assessment for the construction and operation of the M3 motorway performed by M.C. O'Sullivan et al (2002), stated that these silt traps will reduce the volume of sediment being carried into the watercourses. Silt traps act by their design allowing for suspended particles to fall out of suspension in the stormwater and settle in the bottom of the silt trap gravimetrically. Silt traps are most effective on larger particle with heavier mass. However, again the high solubility of chloride from road salt will mean that chloride ions remain in solution and pass into the next stormwater treatment step – stormwater retention ponds.

Grit traps are viewed as being ineffective for the removal of chloride from solution in stormwater from the M3 motorway.

Stormwater from the M3 exits the grit traps/sumps and flows through gravity to settlement ponds such as that shown in Figure 5.3. Settlement ponds act by retaining the stormwater for a sufficient time to allow for suspended solids not removed by the French drains and grit trap to settle out. The stormwater retention ponds along the M3 very often have reeds *(Phragmites australis)* growing there. Eurolink M3 employees informed that these have not been deliberately planted for water treatment purposes but have colonised stormwater settling ponds. Reed beds offer further treatment of stormwater and are efficient in the removal of biodegradable organic material from stormwater but are unlikely to remove soluble chloride in stormwater.

Stormwater retention ponds are designed to control the flow of stormwater to receiving waters and to further remove suspended solids from stormwater and act by retaining the stormwater for a sufficient time to allow for suspended solids to settle out gravimetrically. Saline water has a higher density than freshwater. It is expected that stormwater with a high chloride content due to the application of road salt will, after an initial mixing duration, begin to settle into the lower depths of the retention pond. Studies by Kelting & Laxson (2010) inform that in lentic waterbodies such as lakes and ponds, there is a greater potential to develop higher concentrations of chloride in the water. Salty water is denser than fresh water and it sinks to the bottom of fresh waterbodies. This saline stratification of water within stormwater retention ponds offers a mechanism for the retention of chloride from road salt and prevents the discharge of stormwater with elevated chloride levels to saline sensitive fresh waterbodies. It is proposed that the effectiveness of this natural saline stratification in road side retention ponds is dependent on a number of factors which may be manipulated to increase the extent of saline stratification. The manipulation of these factors will be discussed further in section 6.

Photo 5.1: Stormwater Settlement Pond (www.planningontario.com) No scale specified

The stormwater from the M3 motorway passes through the settling pond and enters an oil-water separator or interceptor, in most cases along the M3 a twin chamber interceptor. Interceptors are widely used and efficient at removing oils, grease and petroleum based products. Petroleum based pollutants float at the surface of water as they are less dense. These pollutants can then be removed from the water by taking water from the bottom of the chamber and passing this 'oil free' water into the next chamber as illustrated in Figure 5.3.

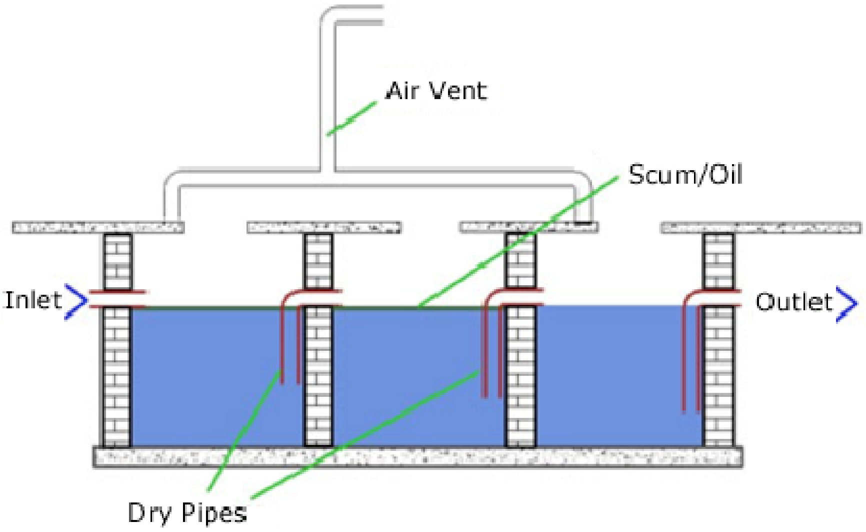


Figure 5.3: Typical Oil Interceptor Design (www.draindomain.com) No Scale Specified

The Environmental Impact Assessment for the M3 prepared by M.C O'Sullivan et al, (2002) details that 'Bypass interceptors' were used along the M3 as they receive stormwater from low risk areas such as roadways and because the majority of containments will be washed from the surface in the early stages of rainfall. These 'Bypass' interceptors allow for up to 10% of peak flows to be retained in the separation chamber for long enough to promote quiescent conditions, so that lighter than water pollutants such as oils and petrol can rise to the surface of the water. The pollutants are stored in a separator and the separated water discharges from the unit by gravity. This is the principal by which all oil interceptors operate.

Oil interceptors are viewed as being ineffective for the removal of chloride from solution in stormwater from the M3 motorway. Chloride will remain in solution and will not rise to surface layers in the interceptor chambers for removal.

6. Discussion & Recommendations

In performing a literature review for this study it was established that there is a recognised potential threat posed by the use of sodium chloride (road salt) in the de-icing of roads and motorways. This pollution potential has been investigated by a number of field based studies focused on the effects of increased water salinity on freshwater fish and fauna. Studies such as Karraker et al (2008) investigated the effects of road salt run-off on amphibian species and Evan and Frick (2001) looked at the effects of elevated sodium chloride levels on salmon and trout smolts. Studies such as these have verified the negative toxic effect of elevated sodium chloride levels from road salt application on aquatic freshwater fauna. The Environment Canada (2001) toxicity assessment of road salt concluded that there is a good probability that road salt causes immediate or long-term harmful effects on some surface water organisms and terrestrial vegetation that are susceptible to elevated levels of chloride. The US EPA established limits in 1988 for the chronic toxicity of chloride of 230 mg/L and acute toxicity of 860 mg/L of chloride.

The majority of studies on the environmental effect of road salt were performed in countries and regions that experience prolonged cold winters. Icy roads and heavy falls of snow are usual in certain states with the USA, Canada and Norway. This was as expected. However, there is a surprising lack of research work conducted on this subject in other ‘colder’ European countries such as Denmark and Sweden. Very little if any research has been conducted in the UK or Ireland. In Ireland prolonged cold spells are unusual however on review of the number of road salt ‘callouts’ and on the amount of road salt used by Meath County Council and Eurolink M3, relatively prolonged cold spells with low temperatures and icy conditions, have been experienced in recent years. The effects of road salt run-off on water quality may therefore be of increasing importance in an Irish context.

Meath County Council routinely sample and analyse river water samples at a number of locations along the rivers and streams that cross the M3 motorway. These rivers and streams are tributaries of the River Boyne and form part of the greater Boyne Catchment Area (Irish Hydrometric Area 07). The River Boyne and Skane River (a tributary of the Boyne) are sampled downstream of the stormwater discharge points from the M3 motorway. Comparing chloride results to the US EPA recommended chronic toxicity limit for chloride of 230 mg/L, no result before or after the construction of the M3 breached this limit. The highest chloride result for the River Boyne at Ballinter Bridge and the Skane River at Dowdstown Bridge after the construction of the M3 was 24.5mg/L and 28.1mg/L respectively in March 2013. Chloride analysis results show that there is no elevation of chloride concentrations at these downstream sampling locations during winter months. There is no notable difference between chloride concentrations at the sampling point on the River Boyne and its tributary, the River Skane, before and after the construction of the M3 motorway. Results are very similar pre and post M3.

Although chloride analysis results seem low, it is important to note that the monitoring locations where samples are taken by Meath County Council may be some distance downstream from the M3 motorway stormwater discharge points. The River Boyne is a large river and a large dilution factor of any stormwater discharge would be applied by the river. The River Skane is a tributary of the Boyne and a much smaller water body, yet a large dilution factor would still apply to stormwater discharges entering the Skane. In order to determine if the stormwater run-off from the M3 motorway contains chloride from de-icing in high enough concentrations to have a significant detrimental effect on water quality in these rivers, sampling and monitoring would need to be performed immediately downstream from stormwater discharges following the application of road salt.

Ireland is legally required to ensure that rivers, streams and lakes are of ‘good’ water quality status by end 2015 under the Water Framework Directive, 2000/60/EC, and the 2009 Surfacewater Regulations, SI No. 272 of 2009. Maximum Allowable Concentration values (MAC) are set for key environmental parameters. Waters must be below these MAC values to be of good quality status. There is no MAC value for chloride or sodium under the 2009 Surfacewater Regulations. However, road salt use can still have a direct bearing on compliance with the 2009 Surfacewater Regulations and the Water Framework Directive. Oxygen conditions and ecological status of water bodies are key elements to water being of ‘good’ status. If it is the case that the practice of road salting causes saline stratification in lakes resulting in anoxic conditions, the lake will not meet ‘good’ water quality criteria.

Chloride analysis results from monitoring by Meath County Council on the River Boyne and Skane River may be compared to the 1989 Surfacewater (intended for the Abstraction of Drinking Water) Regulations, 1989 – SI No. 294 of 1989. A limit of 250mg/L for Chloride is given for untreated surfacewaters intended for extraction as drinking water. This limit applies to all three classes of water A1, A2 and A3 with A1 being the highest water quality and A3 being water of the lowest quality.
Analysis results for chloride on the River Boyne and River Skane are well below this value of 250 mg/L.

Stormwater run-off collected by the drainage system on the M3 motorway receives treatment using a number of mechanical methods based on adsorption and settling. The high solubility and negative charge of chloride render it difficult to remove from stormwater. Chloride ions will not readily attach to solid particles that can be removed through filtration or by small scale gravimetric means such as grit traps. Interceptors designed for the removal of petroleum based products are not expected to effectively remove chloride – saline water containing a high concentration of chloride will not rise to surface layers in interceptor chamber where it could be removed by mechanical means. However, saline water has a higher density that fresh water and will form a saline bottom layer if conditions such as settling time and retention capacity allow. Factors that affect the extent of saline stratification may be manipulated to increase the extent to which saline stratification occurs and to increase the reduction in chloride concentration of the stormwater inflow against the final stormwater outflow. These factors are discussed below.

1. Design of pond outlets

Stormwater retention ponds outlets may be designed to ensure that stormwater is not discharged from lower levels within settling ponds. Lower bottom water in ponds is likely to contain higher concentrations of chloride. Stormwater outlets from settling ponds along the M3 motorway were noted as being located relatively high up on the walls of the ponds, ensuring that the stormwater is discharged by gravimetric flow from the top layer of water only. Stormwater settling ponds should be designed with sufficient depth to allow for saline stratification to occur. Shallow ponds will not enhance saline stratification and the outlet points on the ponds may be from bottom layers if the ponds are too shallow.

2. Size of Stormwater Retention Ponds

Stormwater retention ponds should be deeper and smaller in area rather than shallow with a large footprint. Deeper ponds will tend to form more definitive saline layers. The overall capacity of stormwater ponds should be large enough to allow for sufficient retention time of the stormwater. Longer stormwater retention times in ponds will lead to a greater reduction in suspended solids and increase saline layering within settling ponds.

3. Flow rates of inlets

The flow rate of the stormwater pond inlet and outlet is dependent primarily on weather conditions. If the flow rate of the inlet is too high, this may lead to a mixing effect in the pond and reduce the extent of saline layering. A mixing effect will also prevent the settling other polluting matter in the pond. The flow rate of the inlet can be controlled using holding chambers and V notch weirs prior to the inlet to the retention pond.

A potential negative effect of saline stratification in stormwater retention ponds is the impairment of complete circulation of water, which in turn can deplete oxygen levels and affect the survival of fish and invertebrates within retention ponds (Kelting & Laxson, 2010). Stormwater retention ponds, although primarily designed as a treatment for road stormwater, will over time develop into aquatic habitats. The types of ecosystems that develop within these retention ponds will depend on water quality and other environmental conditions. If saline stratification prevents the circulation of dissolved oxygen throughout these ponds, anoxic conditions may develop which are unsupportive of most aquatic life and can lead to the generation of toxic gases such as hydrogen sulphide (Boehrer & Schultze, 2008).

Road salt, could potentially lead to a more permanent chemical layering in the stormwater ponds. Streams and rivers will not develop chemical layers due to the mixing of water layers.

A considered measure to mitigate the build up of road salt in road side stormwater retention ponds is the physical removal of saline bottom layers from ponds using mechanical means. The bottom layer can then be treated before discharge or discharged to the sea. This however is not seen as a viable option. The removal of the lower water levels from retention ponds is likely to effect the settling within the pond and poses the risk of discharging other pollutants to receiving waters during and immediately after water removal. Stormwater retention ponds over become habitats and over time ecosystems dependent on stormwater ponds will develop. The removal of such lower layers in stormwater ponds may adversely affect these habitats and ecosystems. The discharge of the removed ‘treated’ saline layers to the sea or to tidal waters also poses a disturbance to habitats and ecosystems in receiving waters. Performing such operations would also not be cost effective and local authorities or the National Roads Authority would be subject to the costs.

A method considered for reducing the chloride content in final stormwater discharges to receiving rivers and streams is based on standard interceptor design.
Interceptors operate by allowing oils/petroleum products to float to the surface layer and water is removed from lower layers and enters the next interceptor chamber while the oily top layer is retained in the first chamber. This is illustrated in Figure 5.3. If an additional chamber is used following the same design as oil separator chambers but with the outlet from the top layer instead of from the bottom of the chamber, the heavier saline water could be retained in the chamber while the top layer retaining lower chloride levels would be discharged.
This is not viewed as a viable for a number of reasons. Chambers would need to be very large to allow for saline stratification within the chamber to occur. If saline layering did occur, the salty water in the bottom of the chambers would need to be removed by mechanical means and treated before disposal – this is likely to be economically unviable.

A more effective and proactive mitigation measure is to reduce the amount of road salt entering stormwater in the first instance through controlled work practices. Controlled de-icing working practices have been adopted by Eurolink M3 Ltd. – the company that de-ices the M3 motorway. Prior to the winter of 2011-2012, Eurolink changed from using dry rock salt to treat the motorway to Pre-wet. Pre wet is where the rock salt is dampened down with fresh water and a 23% mix of salt called brine. It works much more effective than dry salt as it clings to the pavement instead of bouncing off or being swept away by traffic. Unwetted salt requires moisture to work and with freezing dry temperatures dry salt is not effective until its trafficked and breaks down. Salt brine can work immediately as it has already been moistened. During snowfall, the spreading of salt is always accompanied by ploughing the snow.

Pre-wetting of areas reduces the volume of salt applied as the salt dissolves more quickly and dissolved salt brine is more effective at melting snow and ice – reportedly reducing salt application by 20% (Fazio & Strell, 2011).
Kelting & Laxson (2010) outline a 'Salt Management Plan' that includes the identification of salt sensitive areas and the use on alternative de-icers in these areas. The practice of anti-icing and pre-wetting are also highlighted as cost effective methods of reducing the volume of salt required for de-icing and therefore reducing negative environmental impacts.

A 'Salt Management Plan' is the key mitigation measure. Awareness of maintenance companies and staff to the pollution potential of road salt, training of employees, well maintained salt spreading equipment, pre-wetting of salt and active management of road maintenance particularly in areas where roads run in close proximity to waterbodies are essential to limit the threat of road salt to water quality and the environment.

7. Conclusions

De-icing practices on the M3 motorway does not appear to have any detrimental effects on water quality in receiving rivers and streams.

De-icing practices on the M3 motorway does not appear to pose a risk to surface water quality meeting the requirements of the Water Framework Directive (2000/60/EC).

Chloride levels in the receiving waters are below the well below the US EPA published chromic and acute toxicity limits for chloride. Chloride in the M3 stormwater may be removed in stormwater retention/settling ponds. The effectiveness of these stormwater retention/settling ponds could be further investigated by sampling and analysis of the stormwater inlets and outlets of the ponds.
The receiving rivers and streams will also apply large dilution factors to chloride concentrations in the stormwater discharges from the M3.

Eurolink M3, the company that is responsible for the maintenance of the M3 motorway, including it’s de-icing, follows internationally recognised best practices including the pre-wetting of road salt and the application of salt brine as opposed to the direct application of rock salt.

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