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Assessment of Eutrophication Status of Two Northern Irish Loughs

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Resumo

A eutrofização das áreas costeiras é um problema global que afecta variados ecossistemas e actividades humanas em todo o mundo. O fenómeno da eutrofização tem vindo a aumentar substancialmente devido às actividades humanas. É causada pelo excesso de nutrientes e é identificada pelo surgimento de alguns sintomas. A avaliação proposta trata deste problema de uma forma específica. A metodologia "Assessment of Estuarine Trophic Status - ASSETS" será aplicada a dois estuários da Irlanda do Norte, de forma a classificar o seu estado de eutrofização e permitir uma comparação com outros métodos existentes. Os dados disponíveis para estes sistemas permitiram a implementação desta metodologia inovadora, que permite obter uma classificação baseada em pressão, estado e resposta. Assim, considerando as influências das actividades antropogénicas sobre as áreas costeiras, examinando os sintomas específicos dos sistemas aquáticos e analisando os indicadores para uma resposta futura, é possível atingir resultados consistentes relativamente à qualidade da água nos estuários e, consequentemente, identificar as medidas mais adequadas de forma a efectuar a sua gestão. Controlando o enriquecimento em nutrientes das áreas costeiras é possivel evitar problemas, como por exemplo, morte de peixes, interdição de aquacultura, perda ou degradação da vegetação dos leitos aquáticos e desaparecimento de bivalves e outros organismos bênticos. Como resultado, diversos custos sociais e económicos podem ser reduzidos. A metodologia ASSETS foi aplicada aos dois sistemas com sucesso, classificando ambos os estuários, Strangford Lough e Belfast Lough como "Moderate". Estas classificações não mudarão a classificação da sua qualidade da água, sobre a Directiva Quadro da Água, Directiva do Tratamento das Águas Residuais Urbanas ou Directiva Nitratos, no entanto, é uma ferramenta que permite guiar os decisores políticos na tomada de decisões mais eficientes em termos de gestão futura dos sistemas.

Palavras-chave: Eutrofização na Irlanda do Norte, enriquecimento em nutrientes, sintomas primários e secundários, pressão, estado e reposta, Strangford Lough, Belfast Lough

Abstract

Coastal eutrophication is a global problem which affects many natural systems and human activities throughout the world. The phenomenon of eutrophication has increased substantially due to human activities. It is caused by excess nutrients and is identified by the emergence of some symptoms. The proposed assessment will address this problem in a more specific way. The Assessment of Estuarine Trophic Status (ASSETS) methodology is going to be performed to two Northern Irish Loughs in order to rank their eutrophication status and allow a comparison with other existing methods. The data available for these systems allowed the implementation of this innovative methodology, which can provide a classification based on pressure, state and response. Thus, by considering the influences of anthropogenic activities over the coastal areas, examination of specific symptoms of the water systems and analyzing the indicators for future response, it is possible to achieve consistent results regarding the quality of the water in the “loughs” and, consequently, identify the most adequate tools to enable their proper management. By controlling the nutrient enrichment of coastal areas it is possible to avoid problems, such as, fish kills, interdiction of shellfish aquaculture, loss or degradation of sea grass beds and smothering of bivalves and other benthic organisms. As a result, many social and economical costs can be reduced. ASSETS was successfully applied to both Strangford Lough and Belfast Lough, classifying them as “Moderate”. This classification will not change their water quality status under the Water Framework Directive, Urban Wastewater Treatment Directive or Nitrates Directive, however, it is a tool to guide policy makers into better decisions in terms of future management.

Key words: Eutrophication in Northern Ireland, nutrient enrichment, primary and secondary symptoms, pressure, state and response, Strangford Lough, Belfast Lough

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1 Introduction

Coastal eutrophication is a global problem which affects many natural systems and human activities throughout the world. It is a phenomenon which has increased substantially due to human activities, it is caused by excess nutrients and is identified by the emergence of some symptoms, such as, organic matter enrichment, low water clarity, abundance of algae and to a higher extent, fish kills, interdiction of shellfish aquaculture, loss or degradation of sea grass beds and smothering of bivalves and other benthic organisms. As a result, many social and economical costs can be reduced. The proposed dissertation will address this problem in a more specific way.

The main objective of this work is to apply the Assessment of Estuarine Trophic Status (ASSETS) methodology to two Irish Loughs: Strangford Lough and Belfast Lough. They are currently subject to several monitoring campaigns due to the obligation of Northern Ireland to comply with the Urban Wastewater Treatment Directive, Nitrates Directive and Water Framework Directive. Therefore, there is data available in order to rank their eutrophication status and there are other methods which are used by these Directives, which can be equally involved in a comparison, for these specific scenarios. The most innovative aspect of this method is the classification based on pressure, state and response of the estuaries, in order to achieve an overall grade for eutrophication. Thus, by considering the influences of anthropogenic activities over the coastal areas, examination of specific symptoms of the water systems and analyzing the indicators for future response, it is possible to achieve consistent results regarding the quality of the water in the Loughs, and consequently, identify the most adequate tools to enable their proper management.

The first chapter consists of this introduction, which summarizes the objectives of the work and provides a broader understanding of the overall structure.

The second chapter provides an overview of the existing methodologies in terms of evaluation of Eutrophication and quantitative and qualitative characterization of coastal water bodies.

In the third chapter a more detailed description of the phenomenon of eutrophication is given, together with a description of the approach adopted.

In the fourth chapter there will be a description of the methodology used to conduct this assessment, together with the tools which will be useful to understand the simulation of the eutrophication for the two Loughs.

The fifth chapter describes the spatial domain which is going to be explored, particularly, the location of the two Loughs and some characteristics.

The sixth chapter is where the results of the application of the assessment are presented and it is therefore, the core of this work. Firstly, Strangford Lough will be assessed, followed by Belfast Lough. For each Lough, a description of their physical characteristics will be given, followed by the analysis of the data and the assessment of Pressure-State-Reponse, finishing with the final result.

In the final chapter, the conclusions of the application of this assessment, to both Northern Irish Loughs will be formulated.

2 State of the Art

At an international level, the United Nations Convention on Law of the Sea is the basic legal framework that governs the uses of the oceans and seas. At a national or regional level, several initiatives have been developed worldwide, such as the Oceans Policy in Australia, the Oceans Act in Canada and the United States, the National Water Act and Coastal Management Act in South Africa, several legislation addressing environmental protection in China and the Water Framework Directive and European Marine Strategy in Europe (Borja et al., 2008). All these initiatives aim to protect and restore the oceans and coastal areas, by promoting a sustainable use of the seas and conservation of marine ecosystems. Avoiding coastal eutrophication is a phenomenon which is fundamental in achieving the goals proposed by national and international regulations and its assessment is often one of the biggest challenges faced by responsible agencies.

Historically, the analysis of eutrophication in estuaries and coastal areas has been quantified by the classical freshwater approach, also known as Phase I, which adopts the following methodology (Bricker et al., 2003):

- measurement of variables (transparency, nutrients and chlorophyll a);
- establishment of a nutrient-based classification system.

This approach derives from freshwater methods, which are not necessarily appropriate to the complexity of coastal systems. Also, as more developments in this area emerged, it has been shown that high nutrient concentrations are not an obligatory indicator of eutrophication and low concentrations do not necessarily indicate absence of eutrophication (Bricker et al., 2003), because systems show widely varying responses to similar nutrient forcing (Xiao et al., 2007). This conclusion was enough to determine the fragile structure of the methodology adopted and that new methods were needed.

More robust methods have been researched, which use several parameters in order to characterize physically and biologically the estuarine and coastal systems. Currently, there are three types of methodologies most commonly used in the European Union and the United States, to assess the trophic status of coastal waters. These methodologies which are used worldwide are:

- OSPAR Common and Comprehensive Procedure;
- EPA National Coastal Assessment (NCA);
- NOAA National Estuarine Eutrophication Assessment (NEEA) / ASSETS.

These three methodologies will be described in more detailed in order to better understand the current framework in terms of methods to identify eutrophication in water bodies.

2.1 OSPAR Common and Comprehensive Procedure

OSPAR is the mechanism by which fifteen Governments of the western coasts and catchments of Europe, together with the European Community, cooperate to protect the marine environment of the North-East Atlantic (OSPAR Commission, 2009). In order to assist their members in identifying areas where nutrient inputs may cause pollution, and to periodically assess the eutrophication status of the OSPAR maritime area, OSPAR developed a common assessment framework: the OSPAR Common and Comprehensive Procedure. This is a two step assessment process which is used in the European Union. The Common Procedure is a primary step which consists of a screening process in order to enable regional comparisons of eutrophication status by characterizing a water body as a problem area, an area with potential problems or a non-problem area. The Comprehensive Procedure is a second step which is applied to all the areas classified as problem areas or potential problem areas. The assessment of eutrophication status is based on four categories of information, which are described in Table 1.

Table 1 – Categories of information used in the Comprehensive Procedure of OSPAR.

Category I	Causative Factors including sources of nutrients such as riverine loading of TN, TP, winter DIN and DIP, N/P-ratios
Category II	Direct Effects of nutrient enrichment including growing season maximum and mean chlorophyll a, phytoplankton indicator species, macrophytes, including macroalgae, microphytobenthos
Category III	Indirect Effects of nutrient enrichment including growing season degree of oxygen deficiency, changes/kills in zoobenthos and fish kills, changes of organic matter, ecosystem community structure
Category IV	Other Possible Effects of nutrient enrichment such as algal toxins DSP/PSP mussel infection events

The data obtained for each indicator is compared with background and reference levels and a classification (equal to the Common Procedure), is given. If an indicator is below or equal to a reference level, it is classified as non problem area (-). In case the value obtained by the indicator is higher or below 50% of the reference level, it is considered as a problem area (+) or potential problem area (?), respectively. When some trends are observed in the evaluation of the data, a classification might be altered and for situations which are difficult to interpret, other indicators can be added (light climate, turbidity, hydrodynamic conditions, climate, zooplankton grazing or others). In the end, the indicators of each category are classified, the scores obtained are combined and a final classification is achieved. An important fact in this final process is that, if an indicator is classified as a problem area, then the entire category to which it belongs will be classified equally. An example of the final score obtained by combining the different categories is shown in Table 2.

Table 2 – Example of a final score table for OSPAR Comprehensive Procedure.

Category I	Category II	Category III	Category IV	Classification
+	+	+	+	**Problem Area**
-	+	+	+	**Problem Area**
+	-	-	-	**Potencial Problem Area**
-	-	-	-	**Non Problem Area**

The approach adopted by this methodology, makes it that the region-specific characteristics play a role in explaining the results of the area classification and are essential for the definition of a final classification.

2.2 EPA National Coastal Assessment

The EPA NCA is used in the United States as an instrument to fulfill specific requirements of the Clean Water Act. This document requires EPA to report periodically on the condition of the nation's waters. In the first report presented, the eutrophication indicator was taken from the NOAA National Estuarine Eutrophication Assessment. In the second report the indicator used is roughly equivalent to NEEA / ASSETS eutrophication indicator. The necessary data used as input for the characterization of the indicators, is originated from a sampling campaign performed once a year in all estuaries or coastal water bodies included in the study. The indicators used are: nitrogen, phosphorous, chlorofill a, water clarity and dissolved oxygen.
The classification of each indicator is rated as poor, fair or good. The scores obtained by each indicator are then combined in order to reach a specific classification for a site, or a more global classification for a region, based on the sites related to their specific region (Table 3).

Table 3 – Final result and the criteria used in the classification for the EPA NCA methodology.

Rating	Site Criteria	Region Criteria
Good	A maximum of one indicator is fair and no indicators are poor.	Less than 10% of coastal waters are poor and less than 50% are in combined poor and fair condition.
Fair	One of the indicators is rated poor or two or more indicators are rated fair.	10 to 20% of coastal waters are in poor condition or more than 50% are in combined fair and poor condition.
Poor	Two or more of the five indicators are rated poor.	More than 20% of coastal waters are in poor condition.

Although the final criteria is region-specific and based on the sensitivity of a system to nutrient inputs, it does not include an evaluation of influencing factors.

2.3 NOAA National Estuarine Eutrophication Assessment / ASSETS

The NOAA National Estuarine Eutrophication Assessment (NEEA) is used in the United States and relies on the following diagnostic tools in order to evaluate eutrophication status:

- influencing factors;
- overall eutrophic condition;
- future outlook.

Factors influencing eutrophication are nitrogen load and the estuary's susceptibility to nitrogen, overall eutrophic condition is based in the analyses of primary and secondary symptoms (chlorophyll a, Macroalgae, Dissolved oxygen, submerged aquatic vegetation and nuisance toxic blooms) and the future scenario is calculated according to the changes in the nutrient loads and susceptibility to them.
ASSETS is an extension of the NEEA methodology which aims to combine the final results into one overall rating. The classification grades obtained for the systems evaluated are: high, good, moderate, poor or bad. It also, incorporates some significant changes, such as, the introduction of a comparison between anthropogenic nutrient loading and natural background concentrations and the refinement of the quantitative criteria for classification of system state based on different symptoms, including the combination of relational databases, geographical information systems and statistical criteria. Therefore, the combination of these two methodologies provides a consistent assessment procedure, which can harmonize the work performed in the European Union and the United States and at the same time converge to the objectives enclosed in the Clean Water Act and the European Union Water Framework Directive.
The most recent challenge has been the development of the NOAA National Estuarine Eutrophication Assessment Update Program which aims to improve monitoring and assessment efforts of the previous NEEA and ASSETS, by forming three workgroups: Typology, Monitoring, assessment and classification and Modeling and management. The typology working group intends to develop a type classification with the purpose of determining type specific indicator variables and thresholds. The monitoring, assessment and classification working group addresses the eutrophic conditions, causes and future outlook in order to introduce additional modifications and intends to develop a human use / socioeconomic index. The modeling and management working group focus on developing a better understanding of the complex system of nutrient input / water body response to ensure a successful management of the problems which arise. All these measures encompassed in the update program will result in improvements to the assessment method.

When comparing the previously described methodologies, it is possible to conclude that the OSPAR Common and Comprehensive Procedure and the EPA NCA differ from

ASSETS in the following aspects: the concentration of DIN and DIP are taken as indicators of eutrophication and there is no differential weighting across indicators. Also, the OSPAR procedure fails to set thresholds for indicators concern. In EPA NCA only acutely degraded water quality is characterized during the monitoring period. It does not identify consistently poor conditions throughout longer periods. Besides this, it has a limited set of parameters, which do not include biological indicators neither nutrient concentrations.

Therefore, NEEA / ASSETS methodology is the only process which provides a broader and sustained scenario of the eutrophication status in the water bodies. By providing an integrated approach which accommodates historical records and present facts in order to predict the future events, this methodology is an essential tool for investigators, companies and organizations with responsibilities in the control of this phenomenon. Moreover, its flexibility allows the introduction of new developments to the method and its consequent improvement.

3 Approach

3.1 Understanding Eutrophication

There are several definitions of eutrophication, however, for the purpose of this dissertation it will be defined as "a natural process by which productivity of a water body, as measured by organic matter, increases as a result of increasing nutrient inputs. These inputs are a result of natural processes but in recent decades they have been greatly supplemented by various human related activities" (ASSETS, n.d). Several nutrient sources are resulting from these activities, such as, agriculture, urban runoff, wastewater treatment plants and consumption of fossil fuels, which by one way or another, might end up in the aquatic systems accelerating eutrophication. In Figure 1, it is possible to observe a conceptual diagram which provides the comparison between a system without any signs of increased eutrophication and a similar system exhibiting eutrophic symptoms.

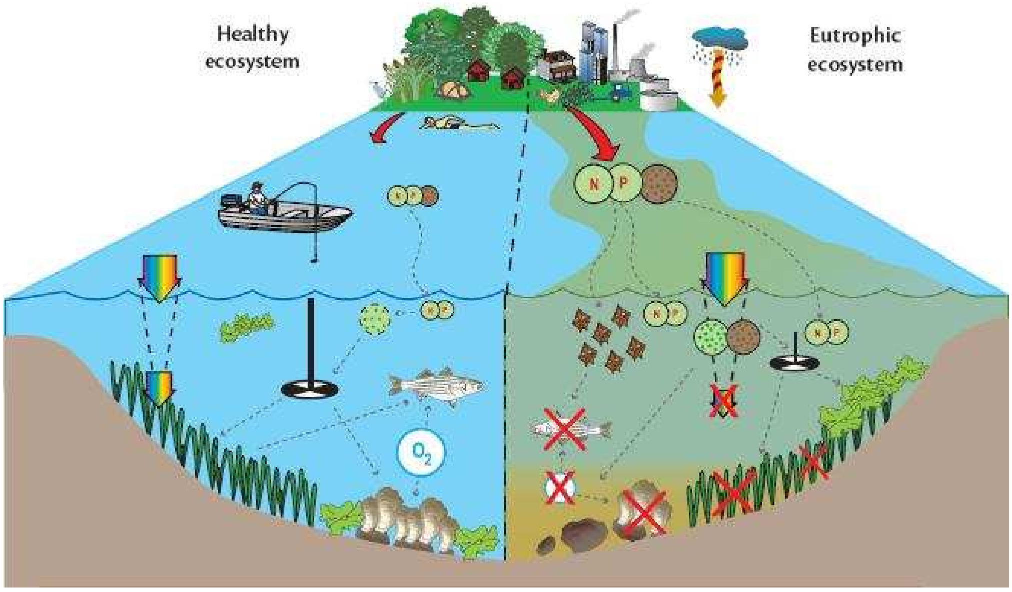


Figure 1 – Conceptual diagram comparing a healthy ecosystem without signs of increased eutrophication and another ecosystem exhibiting eutrophic symptoms (Bricker et al., 2007).

In healthy ecosystems, nutrient inputs, occur at a rate that stimulates a level of macroalgal and phytoplankton (chlorophyll a) growth in balance with grazer biota[1]. A low level of chlorophyll a in the water column helps keep water clarity high, allowing light to penetrate deep enough to reach submerged aquatic vegetation. Low levels of chlorophyll a and macroalgae result in dissolved oxygen levels most suitable for healthy fish and

[1] Refers to a predator which feeds on plants or other multicellular organisms, such as algae.

shellfish so that humans can enjoy the benefits that a coastal environment provides (Bricker et al., 2007).

In an eutrophic ecosystem, increased sediment and nutrient loads from farming, urban development, water treatment plants and industry, in combination with atmospheric nitrogen, help trigger both macroalgae and chlorophyll a blooms, exceeding the capacity of grazer control. These blooms can result in decreased water clarity, decreased light penetration, decreased dissolved oxygen, loss of submerged aquatic vegetation, nuisance and toxic algal blooms and the contamination or die off of fish and shellfish (Bricker et al., 2007).

In terms of the nutrients involved, the most commonly discussed are nitrogen and phosphorous, however, other nutrients, such as, carbon and silica, may affect the onset of symptoms, but less knowledge exist at the moment, concerning their role (Bricker et al., 2007). A way to evaluate the level of eutrophication of an aquatic system is not only by looking at its status but also considering the capacity to assimilate, or inherent ability to absorb nutrients. Each system can react differently to similar inputs of nutrients.

The more sensitive to nutrients systems are, the higher the possibilities of being adversely affected, in terms of, even a slight increase in nutrients, by common maritime related activities, such as, commercial and recreational fishing, boating, swimming and tourism.

The impacts of eutrophication are interrelated and usually viewed as having a negative effect on water quality, ecosystem health, and human uses. Management concerns should address the human, or human-related activities, portion of nutrient additions insofar as the additions are detrimental to the environment, having into consideration the characteristics of the water body which is being managed.

3.2 Current Legislation

In 1991 the European Union (EU) introduced legislation dealing with the trophic status of estuaries and coastal waters. The Urban Waste Water Treatment Directive (91/271/EEC) deals with the relationship between eutrophication and urban waste water discharges. A similar directive, the Nitrates Directive (91/676/EEC), specifically relates to eutrophication resulting from nitrate inputs. In 2000 the Water Framework Directive (2000/60/EC) was launched, which establishes a legal framework to protect and restore clean water access in Europe. In 2008 the Marine Strategy Framework Directive (2008/56/EC), which determines deadlines for countries to achieve or maintain good environmental status of their waters, was released.

3.2.1 Urban WasteWater Treatment Directive (UWWTD)

This Directive requires that waters may be identified as “sensitive” concerning urban waste water treatment, based on the application of a criteria identified in Table 4.

Table 4 – Criteria used by the UWWTD to determine sensitive areas.

Directive	Classification	Type of Water Body	Criteria
UWWTD	Sensitive areas	Freshwater lakes, other freshwater bodies, estuaries, coastal waters and marine waters	- Eutrophic conditions - System with poor water renewal - High nutrient discharge
		Surface freshwaters	- Nitrate > 50 mg.l^{-1}
	Less sensitive areas	Estuaries and coastal waters	- Good water exchange - Not subject to eutrophication - Not subject to oxygen depletion

This directive states that where a water body is found to be eutrophic or sensitive, certain management strategies must be implemented. It requires that suitable treatment must be introduced for qualifying sewage works (those with a Population Equivalent higher than 10 000) if the waters to which they discharge are classified as "sensitive". Also, Trophic Status Studies are required under this Directive.

However, the definitions of "sensitive" refer, above all, to the potential for adverse effects to occur, caused by eutrophication arising from elevated nutrient inputs. These definitions contain several aspects which are left open to interpretation by Member States. In the United Kingdom guidance was issued for identifying sensitive areas under UWWTD in March 1993. Supplementary guidance was issued in May 2002 (UK National Report, 2008). For marine waters, the guidance is aligned closely with the OSPAR Common Comprehensive Procedure, whose methodology indicators used, are outlined in Figure 2.

Category 1. Causative Parameters and Prediction of Potential Adverse Effects
(a) Nitrate (DIN) and Phosphate (DIP) Concentrations and Loadings • DIN – Dissolved Inorganic Nitrogen • DIP – Dissolved Inorganic Phosphorus
Category 2. Response Parameters
(b) Planktonic algal biomass and duration of blooms (c) The occurrence of exceptional or unusual algal blooms (d) Changes in Macrophyte / Macroalgal Growth
Category 3. Parameters for Secondary and Other Effects.
(e) Oxygen Deficiency (f) Changes in Fauna (g) Formation of Algal Scums on Beaches (h) Occurrence and Magnitude of Paralytic Shellfish Poisoning

Figure 2 – Indicators used in the methodology in the UK for definition of sensitive areas (EHS, 2003).

In order to determine whether a water body is sensitive or a problem area, the methodology formerly described for the OSPAR Procedure, is applied.

3.2.2 Nitrates Directive

The waters may be identified as "vulnerable" under this Directive, concerning pollution by nitrates from agricultural sources, if found to be eutrophic or likely to become eutrophic, in case protective action is not taken. The criteria used by the Nitrates Directive to determine whether a water body is vulnerable or not, is presented in Table 5.

Table 5 - Criteria used by the Nitrates Directive to determine vulnerable zones.

Directive	Classification	Type of Water Body	Criteria
ND	Vulnerable zones	Surface freshwaters Freshwater lakes, other freshwater bodies, estuaries, coastal waters and marine waters	- Nitrate > 50 $mg.l^{-1}$ - Eutrophic conditions

In simple terms, the Nitrates Directive requires that appropriate controls on agricultural inputs of nitrate must be put in place within the catchment area of any water body classified as "vulnerable".

Similarly, to the UWWTD, the definitions of "vulnerable" refer, mainly, to the potential for adverse effects to occur, caused by eutrophication arising from elevated nutrient inputs, which leave those definitions open to interpretation by Member States.

3.2.3 Water Framework Directive (WFD)

The WFD establishes two different quality requirements, which are: chemical and ecological status. Chemical status is based upon concentrations of metal and organic compounds and ecological status integrates physico-chemical, chemical and biological indicators. It also establishes an innovative approach for water management based on river basins districts (RBD). The delimitation of these districts in Northern Ireland can be seen in Figure 3.

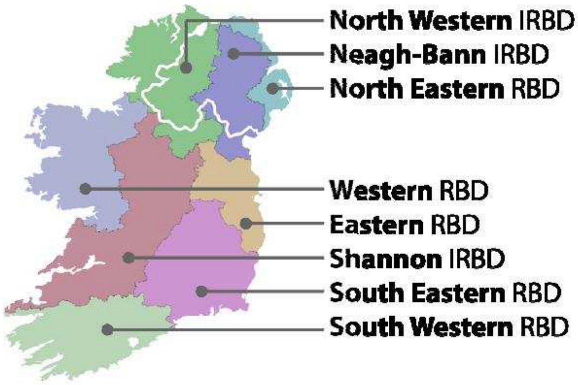


Figure 3 – Definition of the River Basin Districts in Ireland (NIEA, 2008a).

The WFD also establishes specific deadlines for the protection of aquatic ecosystems. The most important objective within the European Water Framework Directive is to achieve a “good ecological status” (GES) for all surface waters and groundwaters, by 2015. A surface water body is a section of a river, a lake, transitional or coastal waters. Transitional waters connect freshwaters and marine waters. Some methodologies have been developed for assessing GES within natural water bodies, in which the ecological status is a perceived or measured deviation from a reference condition (Borja et al., 2008).

The WFD also considers “Heavily modified water bodies” (HMWB), which are water bodies resulting from physical alterations by human activities, which substantially change its hydrogeomorphological character, such as harbours or weirs. In implementing the WFD, environmental managers are required to assess the status of HMWB in terms of achieving “Good Ecological Potential” (GEP). Ecological Potential means that it is expected the water body to achieve the biology that can be achieved given its changed conditions. Separate and less stringent goals are set for these situations.

The final result of the systems classifies the systems into five grades: High, Good, Moderate, Poor and Bad. This classification can then be added the ecological status or potential. The requirements for achieving the ecological status or potential are defined in an Annex to the Directive.

3.2.4 Marine Strategy Framework Directive

This Directive establishes a framework within which Member States shall take the necessary measures to achieve or maintain good environmental status in the marine environment by the year 2020 at the latest. This is achieved by a two stage approach, which consists of:

- preparation phase;
- programme of measures.

The preparation phase establishes deadlines for the delivery of current status of the water bodies, as well as, targets expected. The programme of measures relate to adequate actions to be taken in order to achieve or maintain good environmental status and the entry into operation of the programme.

The determination of a set of characteristics for good environmental status is conducted on the basis of the qualitative descriptors, indicative lists of elements and pressures or impacts of human activities in each marine region or sub region, listed in the Annexes of the Directive. In Annex I, eutrophication is addressed specifically, as a qualitative descriptor, when it is mentioned “Human-induced eutrophication is minimised, especially adverse effects thereof, such as losses in biodiversity, ecosystem degradation, harmful algae blooms and oxygen deficiency in bottom waters”, which is a different approach than the ones adopted by the other Directives.

3.3 Eutrophication in Northern Ireland

Northern Ireland has a widespread problem of eutrophication of surface waters and a large proportion of this nutrient enrichment is attributable to agriculture (NIEA, 2008a). A very simplified graphical image representing the water quality status in the North Eastern River Basin District of Northern Ireland can be seen in Figure 4.

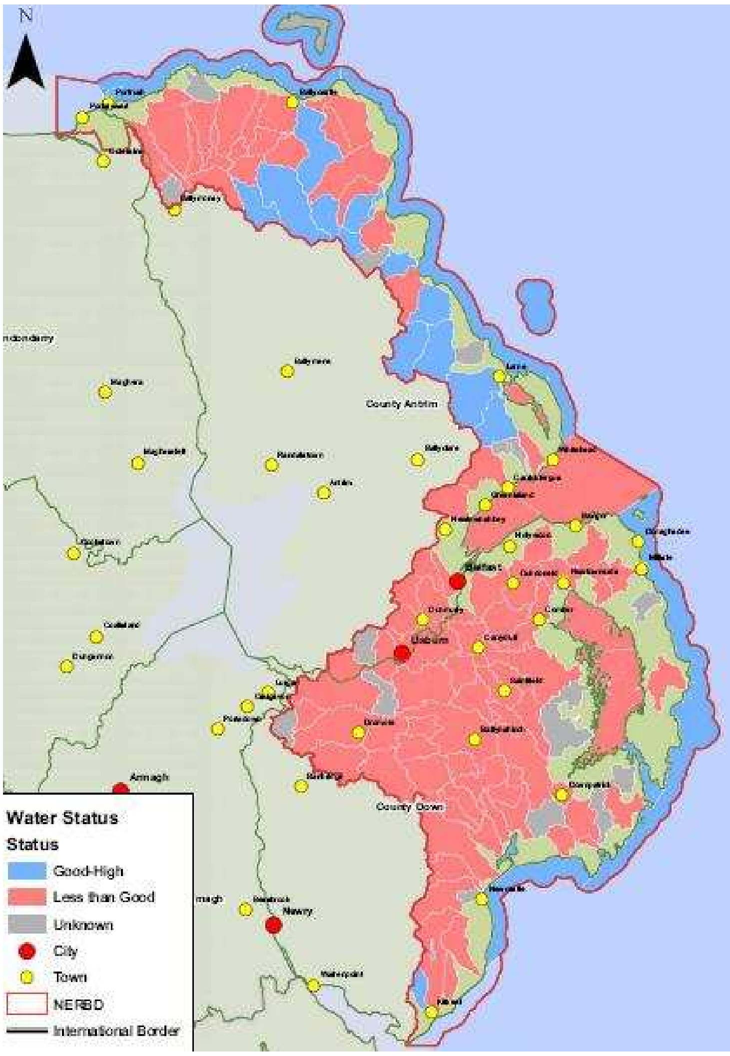


Figure 4 – Overall simplified classification of the status of water quality in the North Eastern River Basin District of Northern Ireland (NIEA, 2008j).

Considering that in recent years the phenomenon of eutrophication has become more serious, mainly due to agriculture and development pressures, in Northern Ireland six tidal waters and sea Loughs were identified, where marine eutrophication may justify the designation of their catchment as Nitrate Vulnerable Zones. These were (Foy & Girvan, 2004):

- Quoile Pondage;
- Strangford Lough;
- Newry River;
- Lower Bann;
- River Lagan;
- Belfast Lough;
- River Foyle;
- Lough Foyle.

The two areas discussed in this assessment are Strangford and Belfast Lough. Both of them are represented in this list, as well as their transitional water bodies: Quoile Pondage and Tidal Lagan, respectively.

The requirement for designation depends on the vulnerability of these waters to eutrophication and that a significant proportion of the nitrate input originates from agricultural sources. To date this significant proportion has been taken to be 20% of the annual input of nitrate (Foy & Girvan, 2004). It should be noted that all the inflowing rivers to the tidal waters in Northern Ireland were in compliance with the standards for concentration of nitrate in surface waters as set by the Nitrates Directive (Foy & Girvan, 2004).

In relation to the UWWTD application, the last report performed in 2005 recommended eleven new Sensitive Area identifications: eight freshwater areas and three coastal waters. These new identifications will mean that over 80% of the total land area of Northern Ireland drains into water bodies that are sensitive. This correlates closely with the land area draining to polluted waters under the Nitrates Directive (EHS, 2005b).

When analysing the areas involved in this assessment, in Strangford Lough, only the North part was subject to this classification and the same for the inner part of Belfast Lough.

In terms of the WFD, the objectives defined are being prepared throughout the whole country by the several River Basin Districts. The analysis of the surface water overall status has been already performed and is illustrated in Figure 5.

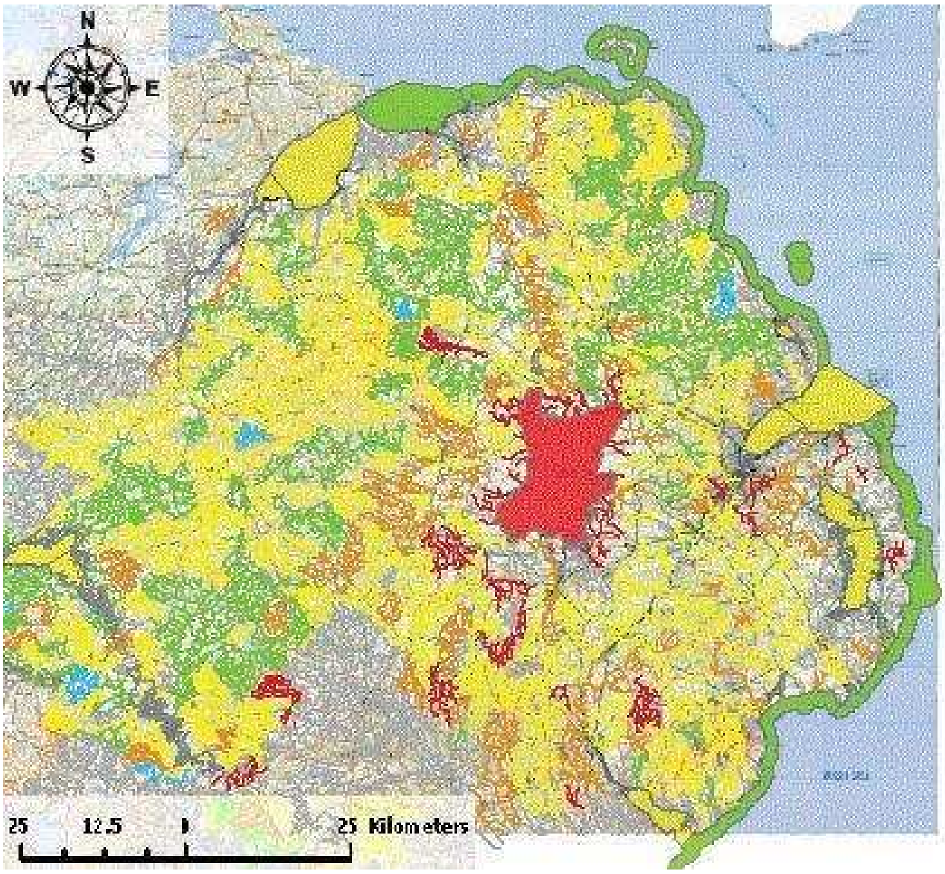


Figure 5 – Surface water body overall status under the WFD, for Northern Ireland, where dark blue color is high, light blue is good, yellow is moderate, orange is poor and red is bad ecological status (Water Framework Directive Map in Northern Ireland, 2009).

It is possible to infer that the majority of the areas are moderate or good, although almost all the systems have been downgraded in some way. In the North Eastern River Basin District, Quoile Pondage and Tidal Lagan are classified as a Heavily Modified Water Bodies, however their classification under the WFD was conducted as transitional water bodies. The classification obtained for Quoile was Moderate Ecological Status (NIEA, 2008f) and for Tidal Lagan was Bad Ecological Status (NIEA, 2008g). For Strangford Lough, an updated WFD assessment has not been completed yet, and therefore the UWWTD assessment is the most up to date assessment of this water body. Based on this, the current status has been downgraded to Moderate Ecological Status (NIEA, 2008e). For Belfast Lough, the results fell into the Moderate Ecological Status (NIEA, 2008h).

4 Methodology

The methodology used was the Assessment of Estuarine Trophic Status (ASSETS), which can be applied to estuaries and coastal areas in order to rank their status and address management options. Most of the concepts have derived from the United States National Estuarine Eutrophication Assessment (NEEA), as described in previous chapters.

This methodology has been applied to several estuaries and coastal areas around the world and it is based on a logical stepwise process which combines three indices, calculated from the datasets available, in order to assess the eutrophication status.

The first step is to perform a physical classification of the system, with the objective of dividing it into zones with similar characteristics. For this method there is a maximum of three homogeneous zones based on salinity. These are:

- Tidal freshwater (zone with less than 0,5 psu[2]);
- Mixing (zone with values between 0,5 and 25 psu);
- Seawater (zone with more than 25 psu).

Each salinity zone is calculated supported on the measured salinity values representative of that area and on the results obtained from the sampling stations.

The second step is to validate the data available in terms of completeness and reliability, with the objective of interconnecting the spatial and temporal quality of the datasets (completeness) and the confidence in the results (reliability).

The data used in this method was obtained from the sampling campaigns performed in former Trophic Status Studies, meteorological data and in situ monitoring stations. The high amount of data available is mainly extracted using the BarcaWin2000 software. This tool uses databases and combines them in an organised and structured way, so that the final output can be exported to Excel and transformed into valuable information.

The third step is to calculate the eutrophication indices, based on the validated data and according to each homogeneous zone found in the system. The schematic representation of the three indices used in the ASSETS methodology, is presented in Figure 6.

[2] psu = practical salinity unit, which is a concentration unit practically similar to parts per thousand

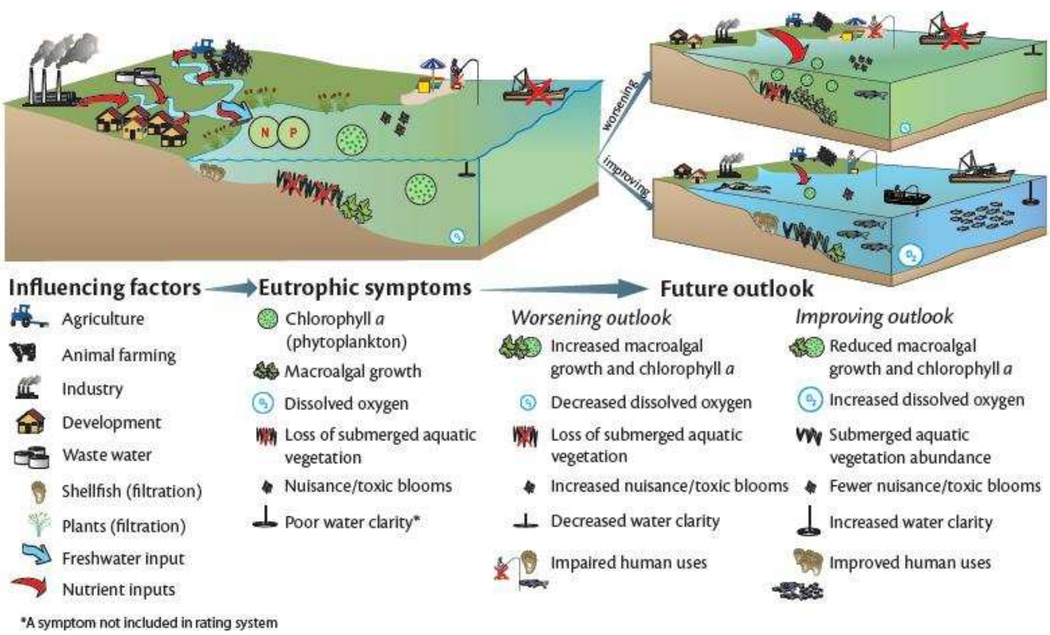


Figure 6 – Scheme of the pressure-state-response approach adopted by the ASSETS methodology (Bricker et al., 2007).

The three indicators used by this methodology are based on influencing factors, eutrophic symptoms and future outlook which depend on quantitative components, field data, models and expert knowledge in order to define them. The influencing factors are the physical, hydrologic and anthropogenic factors which influence water quality and are defined in this method as Overall Human Influence (OHI). The eutrophic symptoms are a subset of five parameters whose concentration, spatial coverage and frequency of occurrence are representative of the eutrophic condition of the estuary or coastal system. This diagnostic tool is characterized in ASSETS as Overall Eutrophic Condition (OEC). Finally, the future outlook tries to forecast the behaviour of the system in terms of eutrophic conditions, by combining its susceptibility with the predicted future nutrient loads, to determine whether these conditions will improve or worsen.

The final step is to combine the three components described above in order to obtain a single overall score for each system, which may fall into one of five categories: High, Good, Moderate, Poor or Bad. This combination is performed through a matrix which is described in Appendix I. The categories are colour coded following international convention and provide a scale for setting reference conditions for different types of systems. The high grade will not be assigned if the expected future outlook is for worsening conditions, but a system may be rated as good based on high or good eutrophic condition and influencing factors, even if the expectation is that it will worsen in the future. Poor and bad grades reflect a range of undesirable pressure and state conditions, even if there are management plans for recovery (Bricker et al., 2007).

In the end and based on the results obtained throughout the methodology, it is possible to determine recommendations for potential management responses to eutrophic conditions in the systems assessed. A more detailed description of the three core diagnostic tools used in the ASSETS methodology is performed hereafter.

4.1 Overall Human Influence (OHI)

In order to better understand the factors that influence eutrophic symptoms in a coastal area, a link between a system's natural sensitivity to eutrophication and the nutrient loading must be establish. Therefore, the OHI in the ASSETS methodology is determined by calculating two factors, which are:

- Susceptibility of the system;
- Nitrogen loads to the system.

Susceptibility is a measure of a system's nutrient retention based upon dilution and flushing potential. In terms of dilution potential, an assumption is made that a larger portion of the water column is potentially available to dilute nutrient loads in a vertically homogeneous water body than in a vertically stratified system. Thus, determination of dilution potential can be performed according to the decision rules illustrated in Figure 7.

Type	IF: Vertical Stratification	THEN: Dilution Volume	IF: Dilution Value	Dilution Potential
A	Vertically Homogenous •all year •throughout estuary	$1 / VOL_{estuary}$	10^{-13} 10^{-12}	HIGH
B	Minor Vertical Stratification •navigation channels •upper estuary	$1 / VOL_{estuary}$	10^{-11}	MODERATE
C	Vertically Stratified •most of year •most of estuary	$1 / VOL_{fwf}$ (fwf = freshwater fraction)	10^{-10} 10^{-09}	LOW

Figure 7 – Decision rules for the determination of dilution potential (Bricker et al., 1999).

In terms of flushing potential, the flushing capability of a system is determined by tidal action and the amount of freshwater flowing in from its catchment. Therefore, it is assumed that water bodies with large tide and freshwater influences have a greater capacity to flush nutrient loads. The determination of flushing potential can be performed according to the decision rules depicted in Figure 8.

Type	Tide Range (ft)		Freshwater Inflow / Estuary Volume	Flushing Potential
1	macro (>6)	and	large or moderate (10^{00} to 10^{-02})	HIGH
2	macro (>6)	and	small (10^{-03}, 10^{-04})	MODERATE
3	meso (>2.5)	and	large (10^{00}, 10^{-01})	HIGH
4	meso (>2.5)	and	moderate (10^{-02})	MODERATE
5	meso (>2.5)	and	small (10^{-03}, 10^{-04})	LOW
6	micro (<2.5)	and	large (10^{00}, 10^{-01})	HIGH
7	micro (<2.5)	and	moderate (10^{-02})	MODERATE
8	micro (<2.5)	and	small (10^{-03}, 10^{-04})	LOW

Figure 8 - Decision rules for the determination of flushing potential (Bricker et al., 1999).

In both of the scenarios mentioned above, the higher the rating, the greater the capacity to dilute or flush nutrient loads. By combining both components, a rating of susceptibility of the water body to retain or flush nutrient loads is obtained. The matrix used for this combination is shown in Figure 9.

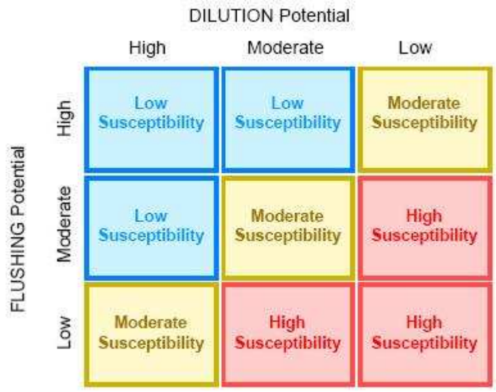


Figure 9 – Matrix used in the determination of the susceptibility of the water body to retain or flush nutrient loads (Bricker et al., 1999).

Regarding the nutrient loads to the systems, this is the critical component for determining an OHI score. The ASSETS methodology uses nitrogen loads, because, although it is recognised that phosphorous may be the limiting nutrient in some systems or seasons, it is nitrogen the typical limiting nutrient in the majority of the estuaries and coastal waters. A new simple model which combines human pressure and system susceptibility was developed and integrated in ASSETS. The loading component is then estimated as the ratio of nitrogen coming from the land to that coming from the ocean and a rating is given. The equations used for the determination of the nitrogen loading to the water body can be better understood in Bricker et al., 2003, however, for the purpose of this assessment, they are written as shown in Equations 1, 2 and 3:

$$\textbf{(1)}\ m_h = \frac{m_{in}(S_0 - S_e)}{S_0}\ ; \qquad \textbf{(2)}\ m_b = \frac{m_{sea} S_e}{S_0}\ \text{and} \qquad \textbf{(3)}\ m_c = m_h + m_b$$

In the first equation, m_h is the human derived concentration of nitrogen (kg.m^{-3}), m_{in} is the nitrogen concentration in the inflow (kg.m^{-3}), S_0 is the offshore salinity and S_e is the estuarine salinity. In the second equation, m_b is the background concentration of nitrogen (kg.m^{-3}) and m_{sea} is the nitrogen concentration in the ocean (kg.m^{-3}). In the third equation, m_c is the total expected concentration of nitrogen (kg.m^{-3}). In order to achieve a final rating for nutrient loading, one more formula is used (Equation 4), which is:

$$\textbf{(4)}\ OHI = \frac{m_h}{m_c}$$

With this equation it is possible to determine a value which allows the final classification for OHI parameter to be defined by using the decision process outlined in Table 6.

Table 6 – Thresholds and categories used to rate the nutrient loads to the system (Bricker et al., 2003).

Class	Thresholds
Low	0 to 0,2
Moderate Low	> 0,2 to 0,4
Moderate	> 0,4 to 0,6
Moderate High	> 0,6 to 0,8
High	> 0,8

The higher the rating obtained, the greater the influence of anthropogenic pressures to the system. In these calculations it should be noted that the concept of mean salinity used, only makes sense in systems where there is some regularity in the river discharge. In torrential areas, where rainfall is concentrated in a short period of the year, it is more appropriate to use the median salinity. Also, in coastal lagoons, where river inputs are not important, the approach mentioned above will not work, since it considers freshwater discharge as the main nutrient vector to the system. For all other areas the loading from the perimeter may easily be combined with the river-borne loading as a summation (Bricker et al., 2003).

Although the thresholds obtained from the application of the equations, can be a strong indication of the final OHI score, since that it accounts for the susceptibility components, (mainly, in terms of difference in the salinity of the ocean and the estuary), it is necessary to combine nitrogen loads and susceptibility of the water body, in order to obtain this final rating. Thus, the OHI score for the systems, when using the ASSETS methodology is obtained from the matrix shown in Figure 10.

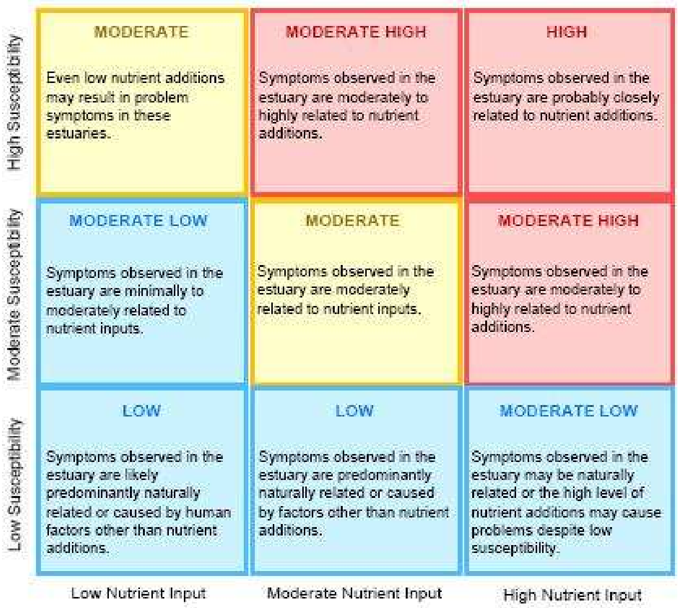
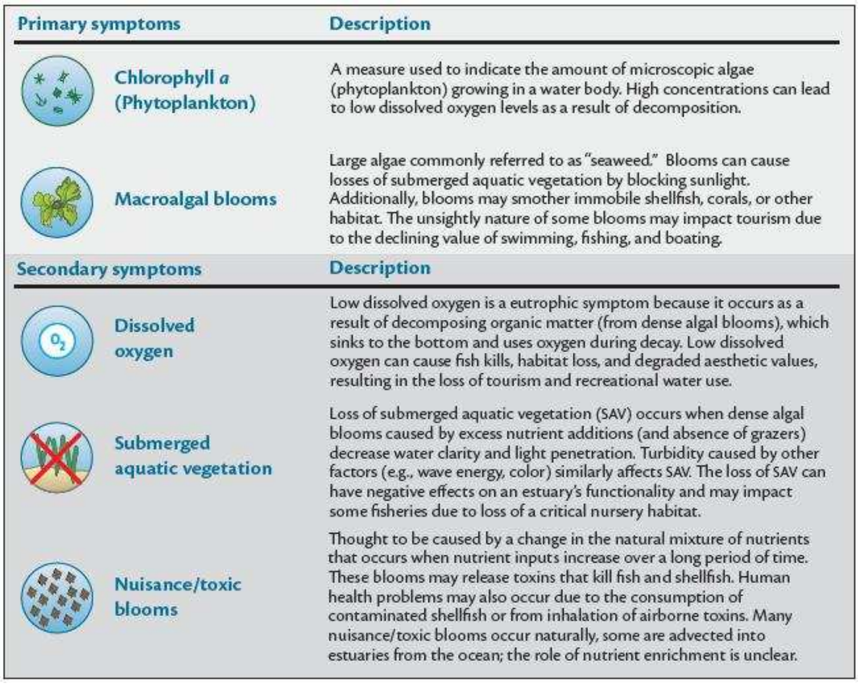


Figure 10 - Matrix used for the determination of the OHI score of the water body in the ASSETS methodology (Bricker et al., 1999).

4.2 Overall Eutrophic Condition (OEC)

In general, there are several nutrient related water quality parameters which can be used in order to assess the eutrophication status of a system. However, only a subset of five parameters was chosen to provide an index of state, expressed as overall eutrophic condition. These parameters are divided into primary and secondary symptoms of eutrophication. The primary symptoms are chlorophyll a and macroalgae, whereas the secondary symptoms are dissolved oxygen, submerged aquatic vegetation (SAV) and nuisance and toxic algal blooms. A summarised description of the way these symptoms are disclosed in the systems and an explanation for their importance in the definition of OEC, are presented in Figure 11.



Primary symptoms	Description
Chlorophyll *a* (Phytoplankton)	A measure used to indicate the amount of microscopic algae (phytoplankton) growing in a water body. High concentrations can lead to low dissolved oxygen levels as a result of decomposition.
Macroalgal blooms	Large algae commonly referred to as "seaweed." Blooms can cause losses of submerged aquatic vegetation by blocking sunlight. Additionally, blooms may smother immobile shellfish, corals, or other habitat. The unsightly nature of some blooms may impact tourism due to the declining value of swimming, fishing, and boating.
Secondary symptoms	**Description**
Dissolved oxygen	Low dissolved oxygen is a eutrophic symptom because it occurs as a result of decomposing organic matter (from dense algal blooms), which sinks to the bottom and uses oxygen during decay. Low dissolved oxygen can cause fish kills, habitat loss, and degraded aesthetic values, resulting in the loss of tourism and recreational water use.
Submerged aquatic vegetation	Loss of submerged aquatic vegetation (SAV) occurs when dense algal blooms caused by excess nutrient additions (and absence of grazers) decrease water clarity and light penetration. Turbidity caused by other factors (e.g., wave energy, color) similarly affects SAV. The loss of SAV can have negative effects on an estuary's functionality and may impact some fisheries due to loss of a critical nursery habitat.
Nuisance/toxic blooms	Thought to be caused by a change in the natural mixture of nutrients that occurs when nutrient inputs increase over a long period of time. These blooms may release toxins that kill fish and shellfish. Human health problems may also occur due to the consumption of contaminated shellfish or from inhalation of airborne toxins. Many nuisance/toxic blooms occur naturally, some are advected into estuaries from the ocean; the role of nutrient enrichment is unclear.

Figure 11 – Description of the primary and secondary symptoms used for the determination of OEC in ASSETS (Bricker et al., 2007).

In ASSETS, a logic stepwise decision method is used in order to combine all these symptoms into one final indicator of the overall eutrophic condition of the water body. This method is described in Appendix II, through the schematic example of the calculation of OEC. In here, a brief description is provided according to Bricker et al., 2003. Firstly, for each primary symptom an area weighted expression value for each zone is determined according to Figure 12. The symptom expression value is a combination of the concentration, frequency of occurrence and spatial coverage of problem levels of each indicator.

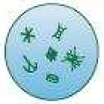
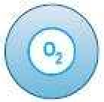
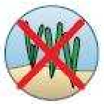
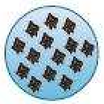
Symptom	Parameters	Expression: Low	Expression: Moderate	Expression: High
 Chlorophyll *a* (phytoplankton) Typical high concentration (µg L^{-1}) in an annual cycle determined as the 90th percentile value.	*Spatial coverage:* High >50%; Moderate 25–50%; Low 10–25%; Very low 0–10% *Frequency:* Episodic; Periodic; Persistent *Concentration:* High >20 µg L^{-1}; Medium 5–20 µg L^{-1}; Low 0–5 µg L^{-1}	*Low symptom expression:* *Conc. / Coverage / Frequency* low / any / any medium / mod. - v. low / episodic high / low - v. low / episodic	*Moderate symptom expression:* *Conc. / Coverage / Frequency* medium / high / episodic medium / moderate / periodic high / low - v. low / periodic high / moderate / episodic	*High symptom expression:* *Conc. / Coverage / Frequency* medium / high / periodic high / mod. - high / periodic high / high / episodic
 Macroalgae Causes a detrimental impact on any natural resource.	*Frequency of problem:* Episodic (occasional/random) Periodic (seasonal, annual, predictable) Persistent (always/continuous)	No macroalgal bloom problems have been observed.	Episodic macroalgal bloom problems have been observed.	Periodic or persistent macroalgal bloom problems have been observed.
 Dissolved oxygen Typical low concentration (determined as the 10th percentile value) in an annual cycle.	*Spatial coverage:* High >50%; Moderate 25–50%; Low 10–25%; Very low 0–10% *Frequency:* Episodic; Periodic; Persistent *State:* Anoxia 0 mg L^{-1}; Hypoxia 0–2 mg L^{-1}; Biol. stress 2–5 mg L^{-1}	*Low symptom expression:* *State / Coverage / Frequency* anoxia / mod. - low / episodic anoxia / very low / periodic hypoxia / low - v. low / periodic hypoxia / moderate / episodic stress / any / episodic stress / mod. - v. low / periodic	*Moderate symptom expression:* *State / Coverage / Frequency* anoxia / high / episodic anoxia / low / periodic hypoxia / moderate / periodic hypoxia / high / episodic stress / high / periodic	*High symptom expression:* *State / Coverage / Frequency* anoxia / moderate - high / periodic hypoxia / high / periodic
 Submerged aquatic vegetation A change in SAV spatial area observed since 1990.	*Magnitude of change:* High >50%; Moderate 25–50%; Low 10–25%; Very low 0–10%	The magnitude of SAV loss is low to very low.	The magnitude of SAV loss is moderate.	The magnitude of SAV loss is high.
 Nuisance/toxic blooms Causes detrimental impact on any natural resources.	*Duration:* Persistent, seasonal, months, variable, weeks, days, weeks to seasonal, weeks to months, or days to weeks *Frequency:* Episodic, periodic, or persistent	Blooms are either a) short in duration (days) and periodic in frequency; or b) moderate in duration (days to weeks) and episodic in frequency.	Blooms are either a) moderate in duration (days to weeks) and periodic in frequency; or b) long in duration (weeks to months) and episodic in frequency.	Blooms are long in duration (weeks, months, seasonal) and periodic in frequency.

Figure 12 – Description of the ratings used in ASSETS, in order to determine the expression value of each symptom by homogeneous zone (Bricker et al., 2007).

After obtaining the expression value for each symptom by zone, the symptom level of expression for the whole system, is obtained by summation (Equation 5).

$$\textbf{(5)}\ SLE = \sum_{1}^{n}\left(\frac{A_z}{A_e}E_1\right)$$

In Equation 5, SLE is the symptom level of expression of each symptom, A_z is the surface area of each zone, A_e is the total system surface area, E_l is the expression value at each zone and n is the number of system zones.

Afterwards, the level of expression of the primary symptoms for the system is determined by calculating the average of the two level of expression values, according to Equation 6.

$$\textbf{(6)}\ P_1 = \frac{1}{p}\sum_{1}^{p}\left[\sum_{1}^{n}\left(\frac{A_z}{A_e}E_1\right)\right]$$

In Equation 6, P_1 is the level of expression of the primary symptoms for the system and p is the number of primary symptoms used. This step is followed by the determination of the same level of expression, but for secondary symptoms. Thus, for each secondary symptom, an area weighted expression value for each zone is determined as described in Equation 5 above. However, the level of expression of secondary symptoms for the estuary is determined by choosing the highest of the three estuary level symptom expression values instead of following the same process as for primary symptoms. This is due to the fact that secondary symptoms are considered to be a clear indicator of problems, and the application of the precautionary principle means that the highest (worst-case) value dictates the classification. This way, it is recognized that these symptoms are indicative of more advanced nutrient-related impacts.

The system is then assigned a category for primary and secondary symptoms based on the level of expression calculated for each one of them, according to Table 7.

Table 7 – Categories for primary and secondary symptoms according to their expression value in the system (Bricker et al., 2003).

System Expression Value	Category
0 to ≤ 0,3	Low
0,3 to ≤ 0,6	Moderate
0,6 to ≤ 1	High

Finally, the primary and secondary symptoms are compared in a matrix (Figure 13), to determine the overall eutrophic condition for the system. Generally, with this methodology, it is assumed that primary symptoms are the indicators of early stages of eutrophication and secondary symptoms describe a more developed stage in this process. However, in some cases secondary symptoms can exist without the presence of primary symptoms. The causative reasons for this event to happen are well described in Bricker et al., 2007, and should be taken into account when calculating the OEC score, which by default already considers this factor, so that the results are not compromised.

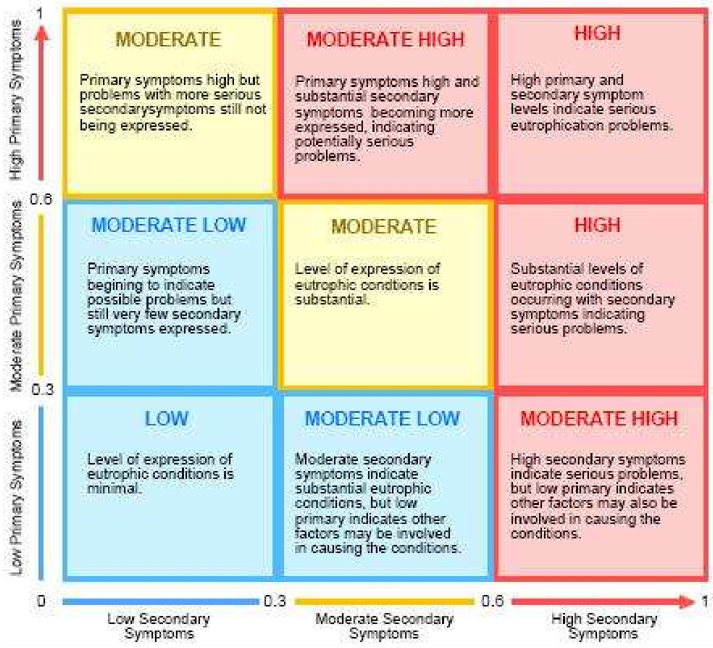


Figure 13 - Matrix used for the determination of the OEC score of the water body in the ASSETS methodology (Bricker et al., 1999).

4.3 Determination of Future Outlook (DFO)

For the determination of the future outlook, two factors are combined in order to estimate future changes in terms of eutrophication conditions, based on expected modifications in nutrients inputs to a system. These are:

- Susceptibility;
- Predicted future loads.

In terms of the susceptibility of the system to nutrient loads, the analysis is the same as performed for OHI and described previously. The determination of the predicted future loads is based on predicted population increase, planned and/or recently implemented management actions and expected changes in watershed uses. In quantitative terms, it is carried out by ASSETS using the changes in demographic, wastewater treatment and agriculture trends.

Similarly to the other two components, the future outlook is ultimately determined by a matrix, which is depicted in Figure 14.

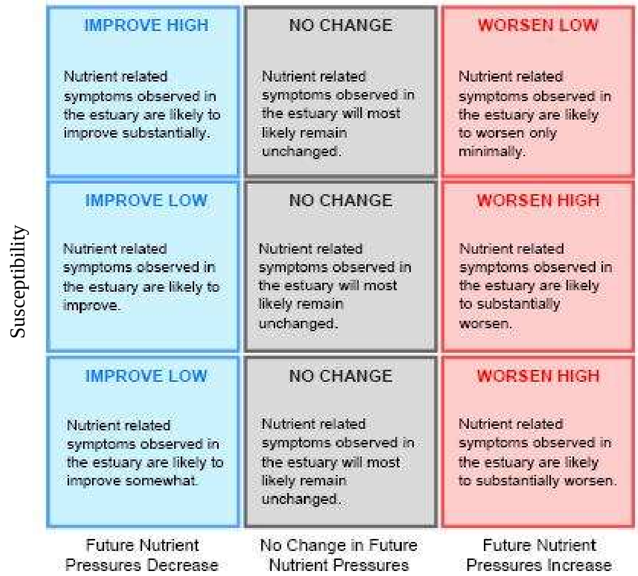


Figure 14 - Matrix used for the determination of the DFO score of the water body in the ASSETS methodology (Bricker et al., 1999).

5 Spatial Domain

The focus of this work is to conduct an assessment to specific coastal water bodies which are designated as estuaries. An estuary is an area where fresh water and salt water come together. The mixing of fresh and salt water creates a different environment, but estuaries are still home to a lot of plants, animals and bacteria. They are also extremely nutrient-rich because of sediment deposit of rivers, creeks or streams feeding into the salt water environment. There are five sea estuaries in Northern Ireland, being two of them transboundary systems, which form an international border with the Irish Republic. These estuaries are locally called loughs and can be seen in Figure 15.

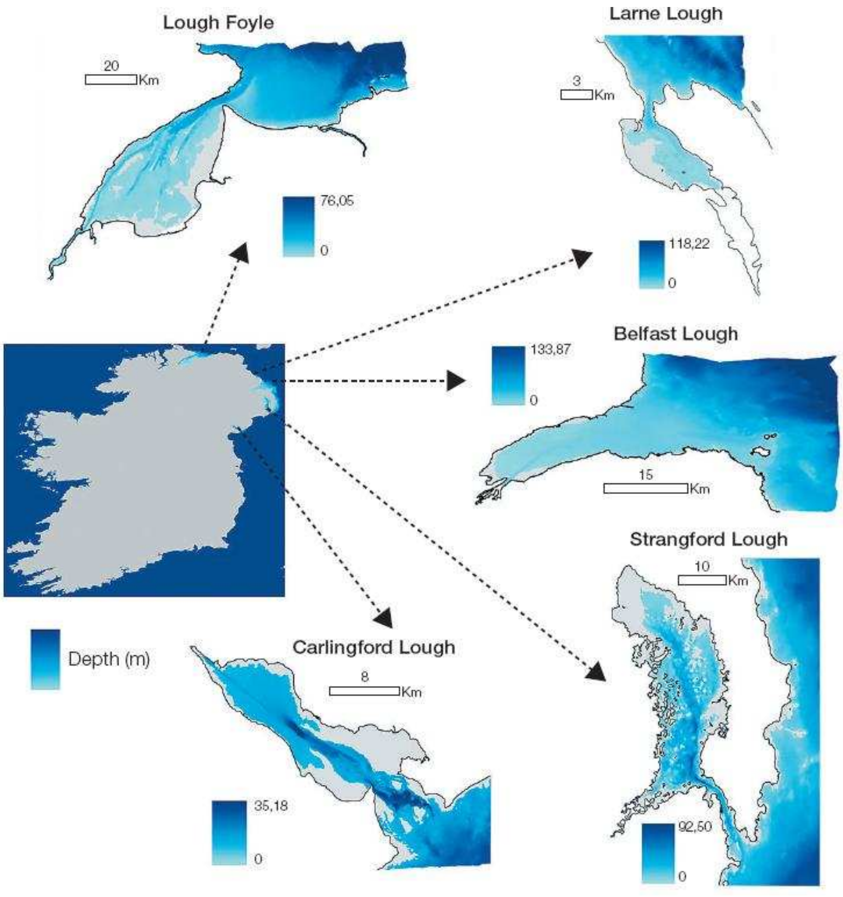


Figure 15 - The five loughs of Northern Ireland (Ferreira et al., 2007).

Together, the five loughs have an area of 522 km^2 and drain a combined catchment of about 6000 km^2 (Ferreira et al., 2007). The two Loughs which are going to be studied are: Strngford Lough and Belfast Lough. They are located in the North Eastern River Basin District, as mentioned before. This is the smallest District in the island of Ireland, lying entirely within Northern Ireland. It has a land area of just over 3 000 km^2 and a further

1 000 km^2 of marine waters, accounting for most of Northern Ireland’s coastline. Belfast Lough and Strangford Lough are the largest sea inlets in the district (NIEA, 2008j).

Due to the natural conservation of the main sea Loughs in Northern Ireland, all of them are subject to a range of conservation designations. Besides this, there are several activities being developed, directly or indirectly related to the Loughs, such as, recreational and commercial fishing, tourism, harbour developments and shipping. The Loughs are also used as receiving bodies for wastewater discharges.

The expansion in the shellfish aquaculture industry in Northern Ireland (Ferreira et al., 2007) adds an increasing pressure towards the adequate use of the water bodies. The more activities are developed within the Loughs, the more legislative measures apply to it and constraints arise. Therefore, more conscientious decisions are necessary towards, a more sustainable management and environmental compliances.

6 Results

6.1 Strangford Lough

6.1.1 Description of the Lough

Strangford Lough is a large marine Lough which lies on the eastern County Down coast of Northern Ireland and is placed between the Ards Peninsula and the mainland. It has an area of approximately 150 km^2 and it is connected to the Irish Sea via an 8 km long channel called the 'Narrows' which is as little as 800m wide in places. Although depths of more than 60 metres have been recorded in this channel, the majority of the Lough is less than 10 metres in depth (EHS, 2005a). A more detailed perspective of the Lough's depths and the sampling stations used in this assessment, can be observed in Figure 16.

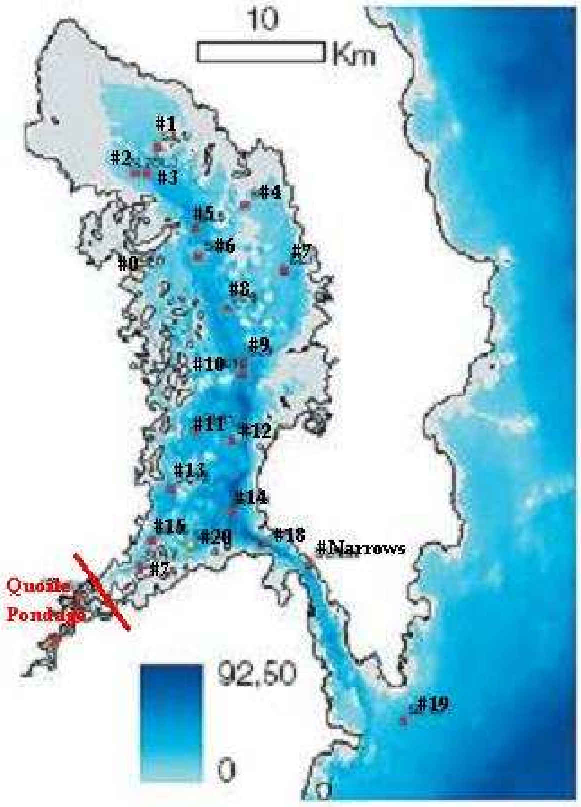


Figure 16 – Location of the sampling stations and surface depths of Strangford Lough (Ferreira et al., 2007).

The rising tides from the Northern Irish Sea affect significantly the characteristics of the Lough, specially in terms of salinity, although it is somehow moderated by the strategic position of the ‘Narrows’. Due to this fact, 30% of the Lough’s surface is intertidal (EHS, 2005a). There are two main freshwater flows into Strangford Lough: the Comber (Enler) River, which enters the Lough in its north western corner and the Quoile River, in the south western corner. The main characteristics of Strangford Lough are presented in Table 8.

Table 8 - Physical Properties of Strangford Lough (Ferreira et al., 2007 and Service et al., 1996).

Physical Properties	Strangford Lough
Volume (x 10^6 m^3)	1537
Area (km^2)	149
Maximum Depth (m)	60
Catchment (km^2)	772
Temperature (ºC)	2-19
Mean Salinity	33
River Flow (m^3 s^{-1})	16
Water Residence Time (d)	4-28
Population in Catchment	144 000

Strangford Lough is classified as an Area of Special Scientific Interest (ASSI) and a Special Protection Area (SPA). Also, from all of the sea loughs analyzed, Strangford Lough is the only system on the UK list for designation as a Special Area of Conservation (SAC) under the EC Habitats Directive (Ferreira et al., 2007). This means that there is a special interest for nature conservation in this Lough.

The Lough can be divided geographically into three different areas which are influenced by different factors. The southern area, which is deeper and receives the direct inflows of seawater, the northern area which is shallower and is somewhat more affected by the intertidal effects and the Quoile Pondage which is directly affected by the discharge of the Wastewater Treatment Works and agriculture practices, therefore subject to higher loadings of nutrients.

6.1.2 Homogeneous Areas

The salinity of the Lough as a whole is virtually identical to that of the open sea (Brown, 1990). However, in the areas where streams and rivers flow in there are local effects due to the run of fresh water which makes it possible to see the division between the waters of any farmland stream and the true sea water of the Lough (Brown, 1990).

The western Irish Sea has a salinity that ranges between 34 and 35 psu (EHS, 2005a). For this study it was considered the median value of sampling station #19, which was 34 psu.

Regarding the physical classification of the Lough, two homogeneous zones were defined. This classification was made using the thresholds defined by ASSETS and the median salinity values of the sampling stations. There is a mixing zone which corresponds to the south area, where the Quoile Pondage is located (0,6 km^2) and the seawater zone is the remaining area of the Lough (148,4 km^2). The salinity value defined as representative of the mixing zone of the estuary was 2 psu and the seawater zone was 33 psu.

6.1.3 Data Completeness and Reliability

The amount of sampling stations used for this assessment cover almost the complete area of the Lough. This data is provided by the Estuarine and Coastal Waters Monitoring Programme (ECWMP), which has permanent monitoring sites in the whole area of the Lough and Trophic Status Studies performed during the periods between July of 1993 and December of 1995 and January of 2004 and March of 2006. The number of stations sampled, dates and water quality parameters for Strangford Lough are shown in Table 9.

Table 9 – Results of the data completeness and reliability for Strangford Lough

Number of Stations	Parameters	Date	Area
4*	Dissolved Oxygen	October 1990 to January 2004 (winter)	Seawater
12 11	Salinity Chlorophyll a	July 1993 to April 1994 (monthly)	Seawater (all area)
15 19	Salinity Chlorophyll a	May 1994 to May 1995 (monthly)	All estuary
15 15	Salinity Chlorophyll a	July to September 1995 (monthly)	Seawater (all area)
13	Chlorophyll a	October to December 1995 (monthly)	Seawater (all area)
5*	Dissolved Oxygen	January 1998 to May 2003 (winter)	Mixing
1	Salinity	January to November 2004 (monthly)	Mixing
1	Chlorophyll a	July to October 2004 (monthly)	Seawater
5	Chlorophyll a	January 2004 to November 2005 (monthly)	Mixing Seawater
16	Salinity	March 2004 to September 2005 (winter and summer)	Seawater (all area) Irish Sea
1 2	Salinity Chlorophyll a	December 2004 to March 2006 (monthly)	Seawater
3	Chlorophyll a	January to November 2005 (monthly)	Seawater

* metadata was used from the ECWMP Monitoring Stations (mean)

Due to the difficulty in analysing the data, some sampling campaigns performed in isolated days in stations scattered all over the Lough, were not included in the figure above. These campaigns were mainly performed after January 2004 and are not representative of large temporal periods, however, they were considered in the assessment. The remaining campaigns shown were performed monthly, which provides a good temporal perspective, even though the timeframe between the campaigns conducted in the two homogeneous zones do not overlap on occasions. Thus, the data used in the assessment is considered to be reliable on account of the spatial and temporal representativeness of sampling and the analytical quality of the analyses. However, in terms of data completeness there is some inconsistency observed between the two homogeneous zones, in the period of sampling after January 2004, although the sampling campaigns are performed monthly.

6.1.4 Overall Human Influence

6.1.4.1 Susceptibility

6.1.4.1.1 Dilution Potencial

Due to the low depth of most of the Lough and high tidal amplitudes, the whole system is considered to be well mixed.

When wind and current are running in approximately the same direction, the waters tend to be relatively calm. A few hours later, when the tide turns, and current and wind are in opposition, a fierce sea can develop with standing waves breaking against each other as they fight against the current (Brown, 1990). In Figure 17, it is possible to observe the directions of tidal currents and waves in Strangford Lough.

When moving away from the Narrows, and away from the main thrust of the currents in the central channel, the water flow becomes much reduced, which makes it that, the more an area is enclosed, the less the energy from water movement (Brown, 1990). Because of this constriction, it takes almost one hour and a half for each rising tide to flow into Strangford Lough, from one end to the other, and so high tides within the Lough lag behind those in the open sea (Brown, 1990).

Figure 17 - Tidal currents (left), wave direction (right) (Brown, 1990).

Strangford Lough is subject to essentially the same weather regime as the rest of the Province, but the rainfall is considerably reduced by the presence of the Mountains of Mourne, some 35 Km to the south-west. This rain shadow as it is called, gives the south-western parts of the Lough the distinction of being one of the driest parts of Ireland (Brown, 1990). This fact can explain the low freshwater flows into the Lough (NIEA, 2008b).

Another difference between the Lough and the Irish Sea is that the tidal range (difference between high and low water levels) is around four metres compared with about five on much of the open coast (Brown, 1990). Again, it is the Narrows creating this effect by hindering the tide levels in the Lough from reaching their maximum potential.

Most sea areas have some degree of layering, or stratification, which is usually identified by brightly lit surface layers stirred by the wind and heated by the sun, one or more intermediate layers, and a zone of dim or dark water intimately linked with the sea bottom. Each may differ from the others in its composition, and they may vary considerably in the degree to which they mix with each other (Brown, 1990). In Strangford Lough, with each tide, the turbulence of the water in the Narrows breaks up these layers, and mixes them thoroughly. This results in even temperatures and a remarkably equable distribution of dissolved nutrients throughout most of the Lough. Because of this, the Lough never gets particularly cold in winter, nor especially hot in summer, and there is an ample supply of basic nutrients to all levels throughout most of the year. The situation found in the open sea, where surface nutrients are heavily depleted by microscopic algae in early summer, does not occur as there is always a fresh supply being churned up from below (Brown, 1990).

One major area that seems to operate in a slightly different way to the rest of the Lough is the shallow area lying to the north. To some extent this is due to the fact that the rate of water exchange with the other areas is slightly less - possibly because of the narrowing of the Lough and the long distance from the Narrows. With the tide rising over vast stretches of open mudflats the effects of summer sun and winter frost are much greater, and as a result water temperatures in this area vary considerably. Water from the rivers and canals running into it, can take somewhat longer to disperse. The combination of all these factors increases the likelihood of layering, or stratification, in this part of the Lough, which would reduce the amount of nutrient exchange in the water with considerable implications for wildlife, and for the effects of sewerage effluents (Brown, 1990). The differences in the northern and southern areas in terms of temperature of the waters, identifying possible layers of stratification can be seen in Figure 18.

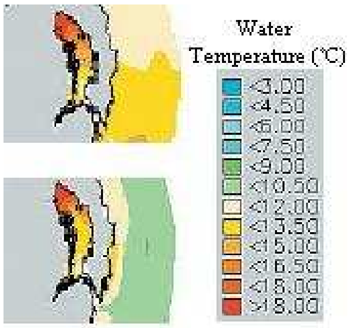


Figure 18 – Differences in water temperature in Strangford Lough, near the surface (up) and near the bottom (down) (Ferreira et al., 2007).

It may be possible that the one redeeming feature preventing major stratification of this area is the influence of wind and wave action which must help to stir up those shallow waters (Brown, 1990). On the other side, some symptoms of stratification have been observed in the lower reaches of the Quoile Pondage, particularly, oxygen depletion and anoxia (Roberts et al., 2004).

Due to these diverse characteristics and physical differences between the northern and southern parts of the Lough, to the low freshwater inflow and after applying the formula described in previous chapters, the results obtained for the dilution potential fall within the "Moderate category".

6.1.4.1.2 Flushing potential

It has been calculated that the total yearly freshwater input to the Lough from rivers and streams (mainly the Comber and Quoile Rivers) is exceeded by the amount of sea water entering over a mere three tides (Brown, 1990). It has also been calculated that the Lough's tidal exchange[3] is about 350 million cubic meters and results in a wide range of

[3] volume of seawater that enters and exits the estuary on each tidal cycle

current strengths and tidal variations, which results from its diversified characteristics. As an example, the Narrows are subjected to strong tidal currents, where the influence from tidal exchange is more noticeable. Conversely, some sheltered inlets on the western shores have virtually still water and are less influenced by this exchange (EHS, 2005a). By knowing the tidal exchange, the freshwater input rate (river flow) and the total volume of the Lough, it is possible to determine the water residence time. The water residence times from the surface and bottom of Strangford Lough can be seen in Figure 19.

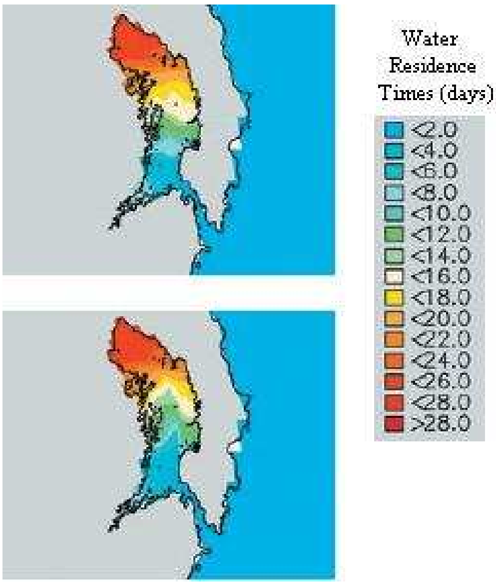


Figure 19 - Water residence times in Strangford Lough, near the surface (up) and near the bottom (down) (Ferreira et al., 2007).

By analysing the figure above, it is possible to identify major differences between the areas located to the north and to the south. In the Northern area of the Lough there is less exchange of water due to the specific details described in the chapters above.

Another different zone is the Quoile Pondage. Although its location is a favourable one, close to the entrance of seawater in The Narrows, the flushing potential is controlled by the Quoile barrage and therefore is not subject to the natural tidal exchange as the remaining water body. This Pondage drains twice daily at low tide, which increases the susceptibility to eutrophication of this particular zone (EHS, 2005a).

Domains with long residence times are vulnerable to nutrient losses if the main supply flux is from the coast and to eutrophication if the land based flux is much larger than the advection/dispersion rates (Ferreira et al., 2007). Although these data do not allow to determine, exactly the amount of freshwater and seawater which are mixed together, the fact that this Lough is major influenced by seawater, supports the idea that the most important supply flux comes from the coast.

However, since there are considerable differences, once more, between the northern and southern areas of the Lough and the Quoile Pondage, supported by the application of the decision rules for flushing potential, the classification will fall within the "Moderate" category.

6.1.4.2 Nutrient Inputs

Strangford Lough is not classified as a sensitive or vulnerable water body under the definitions of the UWWT and Nitrates Directives (Roberts et al., 2004), however, its northern part is subject to this classification. Its catchment area is approximately 772 km^2 (Ferreira et al., 2007). It is estimated that approximately 65% of the land in the catchment is predominantly agricultural with a relatively greater importance of crop culture in the north and of livestock grazing in the south of the region (Roberts et al., 2004). Besides agricultural waste, there are also discharges from septic tanks and Waste Water Treatment Works (WWTW) entering the rivers and the direct catchment of the Lough.

In a yearly basis, further source apportionment throughout the catchment, demonstrated that the majority of sources of Dissolved Inorganic Nitrogen (DIN) and a significant part of the sources of Dissolved Inorganic Phosphorous (DIP), to Strangford Lough were from agricultural sources. (EHS, 2005a). The soil uses in the catchment of Strangford Lough is described in Figure 20.

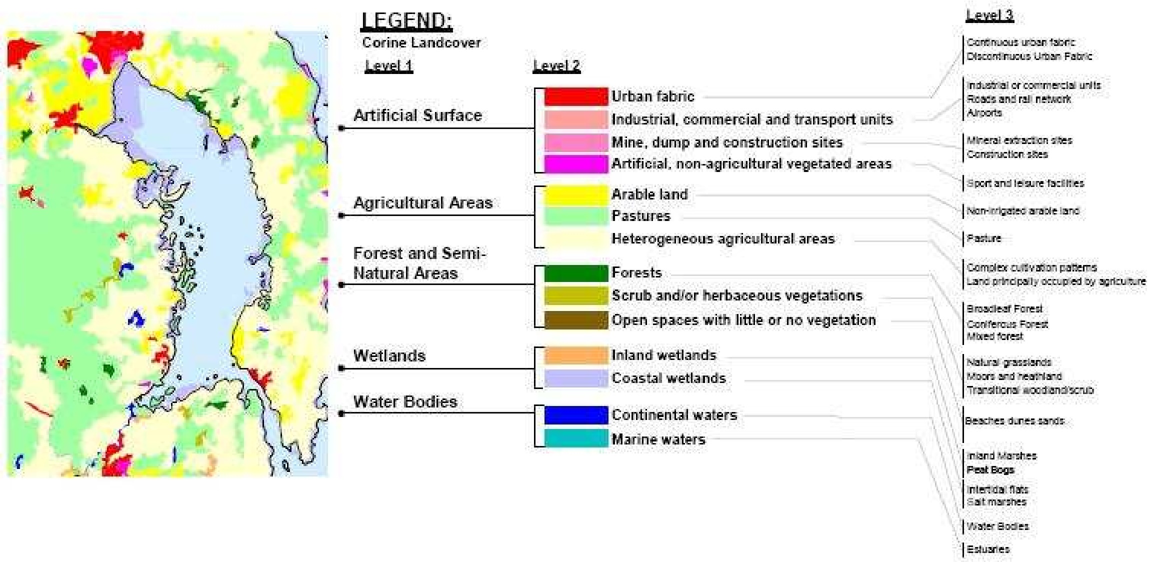


Figure 20 – Soil uses in the catchment of Strangford Lough (NIEA, 2008j)

In the land cover map shown above, it is possible to define the contribution of each agricultural activity in terms of discharge of nutrients into the Lough. A more detailed calculation regarding this contribution can be seen in Appendix III.

There are 26 WWTW in the Strangford Lough catchment, serving a population of approximately 101 740 (Foy & Girvan, 2004). The major works are those at Ballyrickard, Killyleagh and Downpatrick, the three of them together accounting for 81% of the total population equivalent of the catchment (EHS, 2005a). The detailed list of characteristics of the more important WWTW systems can be seen in Table 10.

Table 10 – Characteristics of the Wastewater Treatment Works which discharge in Strangford Lough, until the year of 2004.

WWTW	Type of Treatment in 2004	Population Equivalent	Responsible
Ballyrickard	Secondary	59 400	Glen Water
Killyleagh	Secondary	13 025	Northern Ireland Water
Downpatrick	Secondary	8 415	Northern Ireland Water
Kircubbin	Primary	2 000	DRD Water Service
Portaferry	Coarse Screening	3 000	Northern Ireland Water
Greyabbey	Secondary	1 000	DRD Water Service
Others		14 900	
Total		101 740	

Because of the fragile status of the northern part of the Lough and considering that Ballyrickard WWTW contributes 15% of the total nitrogen loading to Strangford Lough (excluding the loadings for the Quoile Pondage.), it was recommended nitrogen reduction to be installed in Ballyrickard WWTW to meet the requirements of Article 5 of the UWWTD (EHS, 2005a). This is expected to happen by 2013.

Estimates point out that the nitrogen loading from Downpatrick WWTW makes up only 2,7% of the total nitrogen loading to the Quoile Pondage, which is a low value. However, due to the location of the discharge from the works entering an enclosed, heavily modified waterbody with minimal dilution, in this instance nitrogen removal was recommended and has been accounted for, with the construction works expected to end during the year of 2009. This WWTW contributes 15% of the total P loading to the Quoile Pondage and P removal is therefore also contemplated for this works (EHS, 2005a).

In Northern Ireland more than 110 000 households (20% of the total) are currently without public sewerage provision, representing around 0,3 million people (a fifth of Northern Ireland's population), and generating around 65 million litres of wastewater a day (NIEA, 2008j). Strangford Lough is not an exception to this, with many isolated houses situated in its catchment, draining directly or through septic tanks, to the coastal waters. Based on the data from the total population living in the districts surrounding Strangford Lough, an estimation was made of around 42 260 people in this conditions in the catchment. This result was obtained by subtracting the total population to the population served with public sewerage network (Appendix III).

The two main freshwater discharges are the Comber (Enler) and Quoile Rivers, which, drain 11% and 31%, respectively, of the total catchment area of the Lough (EHS, 2005a). These two rivers together with the North Strangford catchments have been designated as sensitive under the Urban Wastewater Treatment Directive in relation to nutrients (NIEA, 2008b). There is one more river which drains into the Lough, which is the Blackwater river, although its catchment area is much smaller than the remaining two.

Although phosphate enrichment of the upper basin of the Lough occurs in association with the freshwater inputs, nitrogen limitation seems to be the most likely factor controlling phytoplankton growth during the late summer and autumn blooms (AFBI, 3/08/2009). In order to be able to define the correct amount of DIN discharged into the Lough, the contribution of each anthropogenic source was determined and can be observed in Figure 21.

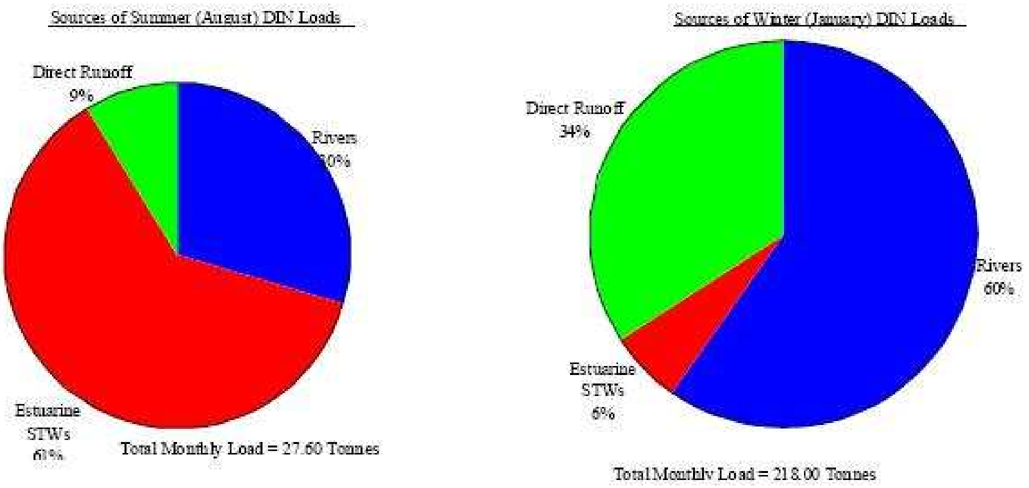


Figure 21 – Sources of Dissolved Inorganic Nitrogen into Strangford Lough between 1993 and 1995, in summer, right and winter, left (Roberts et al., 2004).

In the summer when freshwater flows are low, directly discharging WWTW (which in the figure are described as Estuarine STWs) contribute 61% of the total load. However during winter months directly discharging WWTW contribute 6%. The load of DIP shows less seasonal variation as it is dominated by loads from WWTW which are not seasonal and contribute 77 and 34% of the summer and winter loads respectively. Therefore, the loads of DIN into Strangford Lough are seasonal and vary between a mean of 27,6 tones per month in the summer to a mean of 218 tones per month during winter (AFBI, 3/08/2009). The total amount of nitrogen discharged into Strangford Lough due to the several anthropogenic sources in its catchment, was calculated based on the Export Coefficient Model (ECM), which uses the following equation:

$$L_N = \sum_{i=1}^{M} [E_i \times A_i] + S + W + P$$

Where L_N is the basin nutrient load ($kg.yr^{-1}$), E_i is the export coefficient ($kg.ha^{-1}.yr^{-1}$) for land class i, A_i is the area of the watershed in land class i (ha), S is the Septic Load ($kg.yr^{-}$

^{1}), W is the wastewater load (kg.yr^{-1}) and P is the precipitation load (kg.yr^{-1}) (Xiao et al., 2007). The detailed calculation of the loads and concentration of DIN discharged into Strangford Lough are presented in Appendix III. The summary of the results obtained are show in Table 11.

Table 11 – Nitrogen Loads from the main anthropogenic sources to Strangford Lough

Sources		**DIN (ton N year^{-1})**
WWTW		206
Drainage to the Rivers	**Quoile**	396
	Enler	111
	Blackwater	97
Direct Drainage		425
Not served by WWTW		78
Total		**1313**

These results show that the major yearly contribution of DIN to the Lough is from agricultural sources, whether it is by arriving through the rivers or by the direct drainage from its catchment.

Although the amount of nutrients discharged into the Lough is high, regarding the spatial distribution of the nutrients within the water body, the levels vary both temporarily and spatially, with DIN and DIP concentrations being highest in the north of the Lough during the winter. Concentrations of DIN approached limiting concentrations in the summer and the ratio of N:P fell below the Redfield ratio[4] of 16. These improved towards the mouth of the Lough (EHS, 2005a). In order to better understand the temporal change in nutrient concentration in the northern and southern parts of the Lough, throughout the most problematic period, which is during winter months, Figure 22 and Figure 23 are presented below.

[4] Redfield Ratio is the molecular ratio of carbon, nitrogen and phosphorus in phytoplankton

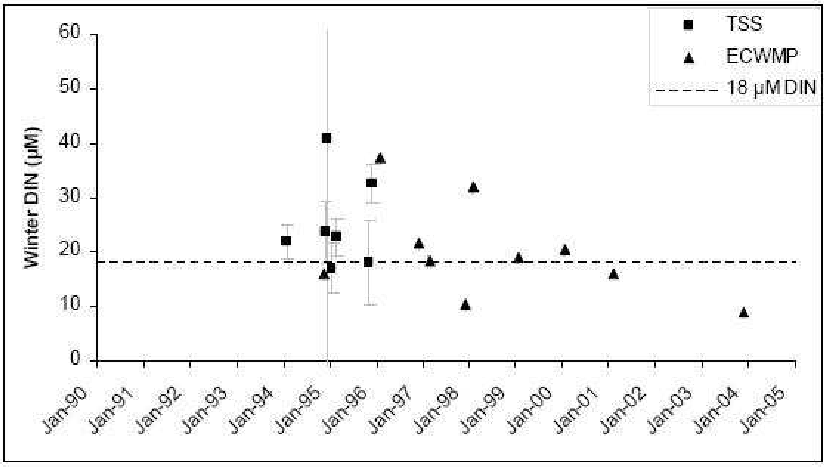


Figure 22 – Winter DIN for the north of Strangford Lough. Points are the mean of all samples in each sampling station (TSS stands for the Trophic Status Study and ECWMP is the Estuarine and Coastal Waters Monitoring Programme). For TSS data, error bars are presented and for ECWMP no error bars exist due to one single station present in the water body (EHS, 2005a).

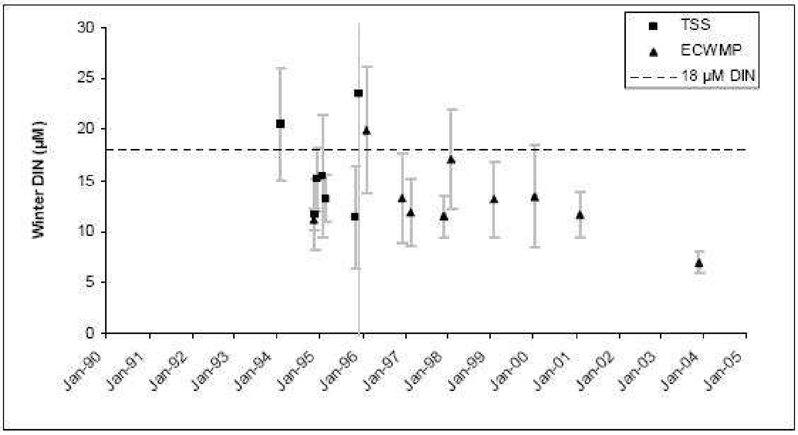


Figure 23 - Winter DIN for the south of Strangford Lough. Points are the mean of all samples in each sampling station. Error bars are presented for both situations (EHS, 2005a).

In these figures it is possible to observe that, in the north part of the Lough, the UK criteria for the Irish Sea, of 18 µmol.l^{-1} (EHS, 2005a), is frequently surpassed, while in the south, this limit is only exceeded on three occasions.

A similar situation is represented in Figure 24, regarding the concentration of DIN, during the winter months, in the Quoile Pondage.

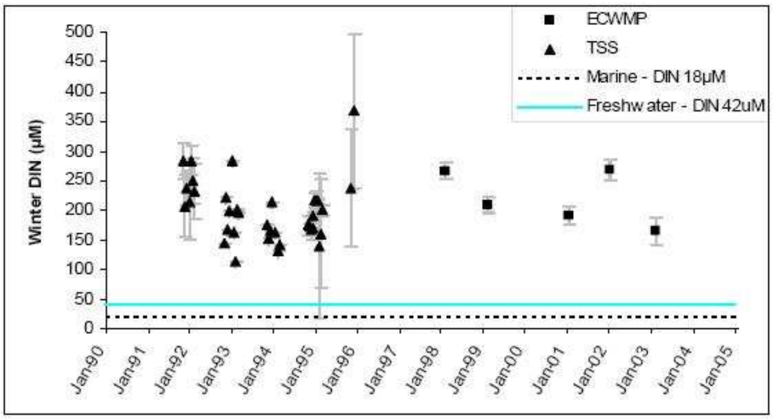


Figure 24 - Winter DIN for the Quoile Pondage. Points are the mean of all samples in each sampling station. For both situations error bars are presented (Taken from EHS, 2005a).

In this transitional water body, all of the values observed are high above the values defined in the UK marine nutrient criteria, although this threshold is inappropriate, due to the fact that the Quoile pondage is not completely saline. Besides that, they also exceed by far the value proposed in the WFD, of 42 µmol.l^{-1}, as a background concentration of DIN in freshwater. In 2001 the Quoile Pondage was also, designated as a sensitive area under the Urban Waste Water Treatment Directive (EHS, 2005a).

Based on the nitrogen loads and the flows which drain into the Lough, described in Service et al. (1996), the concentrations of DIN flowing into the Lough are 180 µmol.l^{-1}. The mean values considered to be representative of the closest area of the Irish Sea are those taken from sampling station #19, the data provided by the European Environment Agency and the values provided by Kennington et al. (2002), which is 8,9 µmol.l^{-1}. Therefore, the value for nutrient input is 0,39, which is then considered as “Moderate”.

6.1.5 Overall Eutrophic Condition

6.1.5.1 Primary Symptoms

6.1.5.1.1 Chlorophyll a

It is recognized that the calculation of chlorophyll a concentrations must be based on commonly observed peaks, rather than a single exceptional one, and must reflect a significant event in space and/or time (Bricker et al., 2003). This has been defined in the present work using a percentile system. The criteria used has been the percentile 90 value for chlorophyll a. In Figure 25 and Figure 26, it is possible to observe the frequency distribution for chlorophyll a in the mixing and seawater zones, respectively, of Strangford Lough.

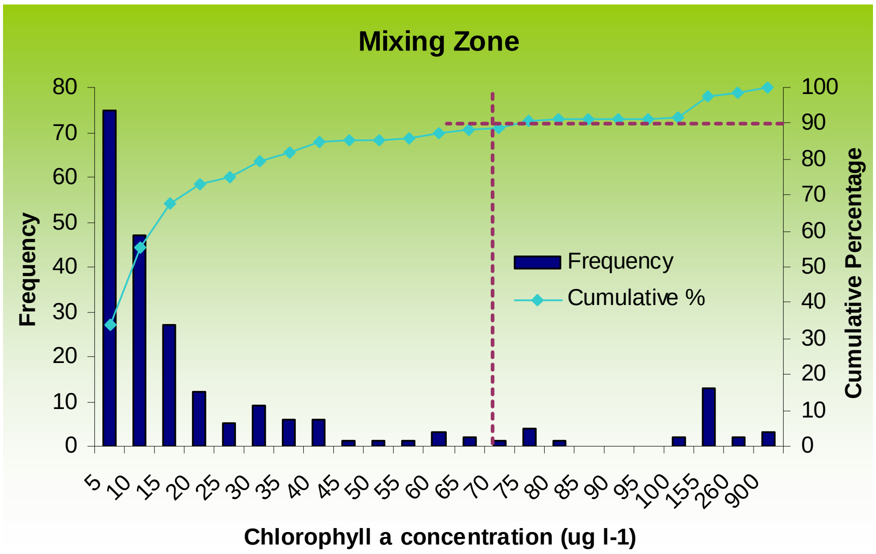


Figure 25 – Frequency distribution for Chlorophyll in the mixing zone in Strangford Lough.

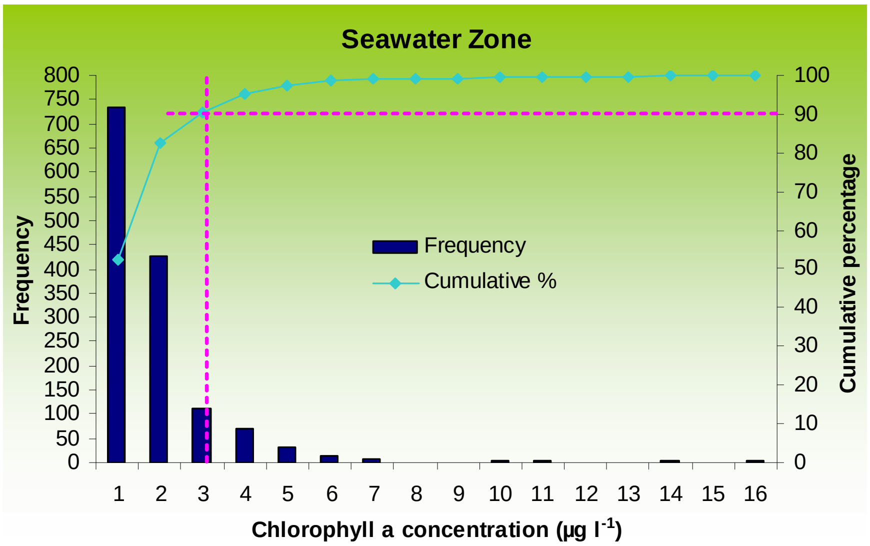


Figure 26 - Frequency distribution for Chlorophyll in the seawater zone in Strangford Lough.

According to the ASSETS thresholds, the value obtained for the seawater zone of 3,6 $\mu g.l^{-1}$, is within the "Low" category. However, for the mixing zone the percentile 90 value obtained of 74,5 $\mu g.l^{-1}$, falls within the "Hypereutrophic" zone.

In order to evaluate the frequency of occurrence of the problematic situations in the mixing zone, the annual cycle of chlorophyll a in the Lough for the two salinity zones is represented in Figure 27.

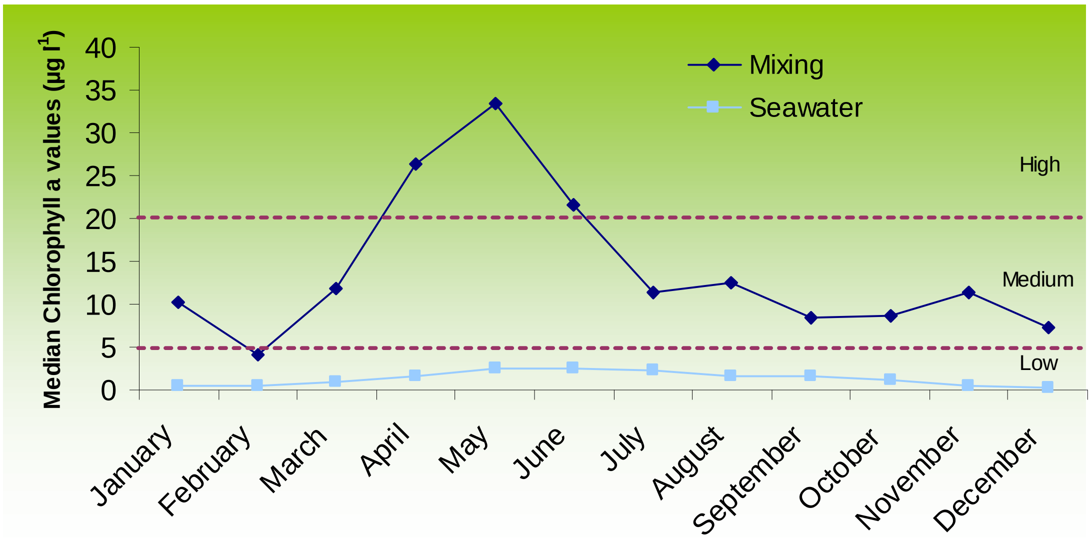


Figure 27 – Annual cycle of chlorophyll a in the two zones of Strangford Lough.

The analysis of this cycle shows that there is one clear peak observed in the mixing zone, where only the values of percentile 90 where used, in the end of Spring and beginning of Summer. The occurrence of this phenomenon during this period is predictable and takes place annually. Thus, the frequency of occurrence of chlorophyll a in the mixing zone is considered to be periodic.

In order to calculate the spatial coverage of the high values of chlorophyll a observed in the mixing zone, the Thiessen Polygons Method was used. With this method, the spatial weight of each sampling station in that zone is calculated by using the sum of those weights where maximum values were observed. The zones of influence of each sampling station in the mixing zone of Strangford Lough can be observed in Figure 28.

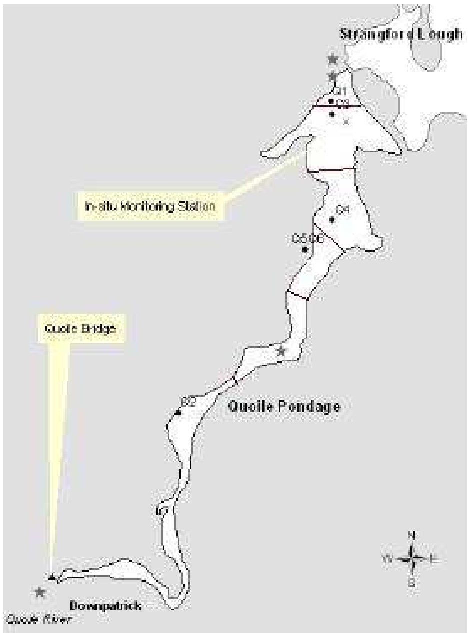


Figure 28 - Zones of influence of each sampling station in the mixing zone, calculated with the Thiessen Polygons Method.

After analysing the zones of influence of the sampling stations with the highest values of chlorophyll a in the mixing zone, it is considered that the percentage covered by them is around 50 %. Therefore the spatial coverage of the values will fall within the “Moderate” category. The results of the ASSETS index application for chlorophyll a in Strangford Lough, is represented in Table 12.

Table 12 – Results of the ASSETS index application for chlorophyll a in Strangford Lough.

ZONE	IF Concentration	AND Spatial coverage	AND Frequency	THEN		Area	SLE
				Expression	Value		
Mixing	Hypereutrophic	Moderate	Periodic	High	1	0,60	0,004
Seawater	Low	-	-	Low	0,25	148,4	0,250
					Total	**149**	**0,254**

6.1.5.1.2 Macroalgae

The distribution of macroalgae species between the northern and southern parts of the Lough reveals a clear difference. Because the north end of Strangford Lough is characterised by a predominantly sandy/muddy intertidal zone, with little hard substrate, this type of shore, will generally be devoid of attached algae with the dominant species consisting of opportunists, which can cope with less favourable conditions (EHS, 2005a). A study of macroalgae completed by the Environment and Heritage Service (EHS) in 2002, recorded a total of 83 species throughout Strangford Lough. However, species richness is depleted in the north of the Lough ranging from between 13 and 41. In the South End, on the other side, variable species richness were recorded at different sites, indicating that this water body clearly supports a high diversity of macroalgal species (EHS, 2005a).

Other surveys performed at the Lough in 1988 and 2003 revealed that the major changes observed, are related with the increase in Sargassum muticum and Enteromorpha spp. and the decrease in Ascophyllum nodosum. Sargassum muticum is an invasive introduced specie whose wide distribution throughout the water body can impoverish the biodiversity and constitute a problem for submerged aquatic vegetation in comparison with native macroalgae (Roberts et al., 2004). Enteromorpha spp. is an invasive intertidal green algae which has a very successful reproductive stage and is considered very problematic regarding the smothering of submerged aquatic vegetation, due to its quick settling in available substrates. Ascophlyllum nodosum is a long lived macroalgae with a slow growth, which has been present in Strangford Lough for more than 100 years. However, the recent surveys have identified loss of this specie, which can take years to recover (Roberts et al., 2004).

There is a significant change in the species of macroalgae throughout a consistent period of time, particularly in the northern part of the Lough. During this period, enteromorpha has been the cause of many problems related with loss of submerged aquatic vegetation. However, there is no complete link between these events and anthropogenic actions and no recent data has confirmed this increase. Thus, it was considered that some problems with macroalgae have been episodically occurring in the seawater zone. The results of the ASSETS index application for primary symptoms in Strangford Lough, are presented in Table 13.

Table 13 – Results of the ASSETS index application for primary symptoms in Strangford Lough.

Zone	**Area (km^2) (A_Z)**	**Value (v_{ij})**		**$A_Z/A_t \times v_{ij}$**	
		Chlorophyll a	**Macroalgae**	**Chlorophyll a**	**Macroalgae**
Seawater	148,4	0,25	0,5	0,250	0,498
Mixing	0,60	1	0	0,004	0
Sum	149	-	-	0,254	0,498
Primary symptoms level of expression value for the estuary: 0,38 Moderate					

6.1.5.2 Secondary Symptoms

6.1.5.2.1 Dissolved Oxygen

Low values of dissolved oxygen should be representative of system conditions, and not a single minimum value (Bricker et al., 2003). Because of this fact, the percentile 10 value for dissolved oxygen was used. The frequency distribution for dissolved oxygen values in the two salinity zones can be observed in Figure 29 and Figure 30, respectively.

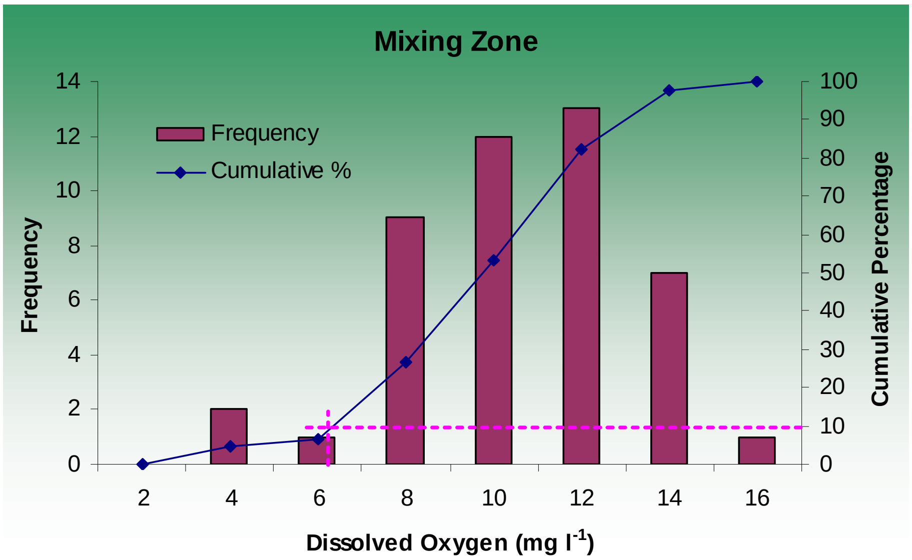


Figure 29 - Frequency distribution for dissolved oxygen in the mixing zone in Strangford Lough.

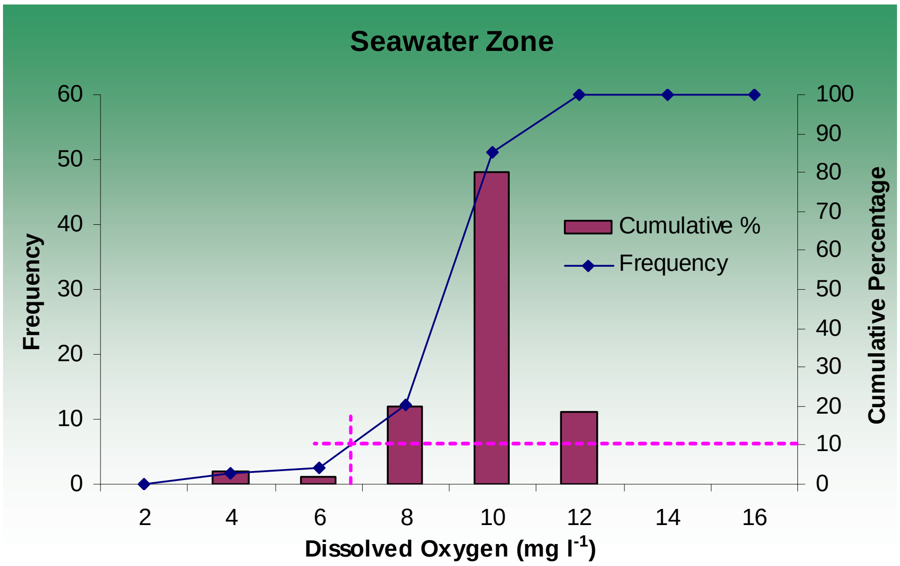


Figure 30 - Frequency distribution for dissolved oxygen in the Seawater zone in Strangford Lough.

According to the thresholds used in ASSETS, the minimum values of dissolved oxygen in terms of percentile 10 considered to indicate biological stress, for the different salinity zones, should be 5 $mg.l^{-1}$. The values obtained in these two zones, are above this threshold. However, due to the fact that some complaints have been recorded regarding hypoxia and fish kills in the mixing zone (EHS, 2005a), an analysis of the yearly distribution of dissolved oxygen in the three distinctive parts of the Lough (Figure 31, Figure 32 and Figure 33), have been performed.

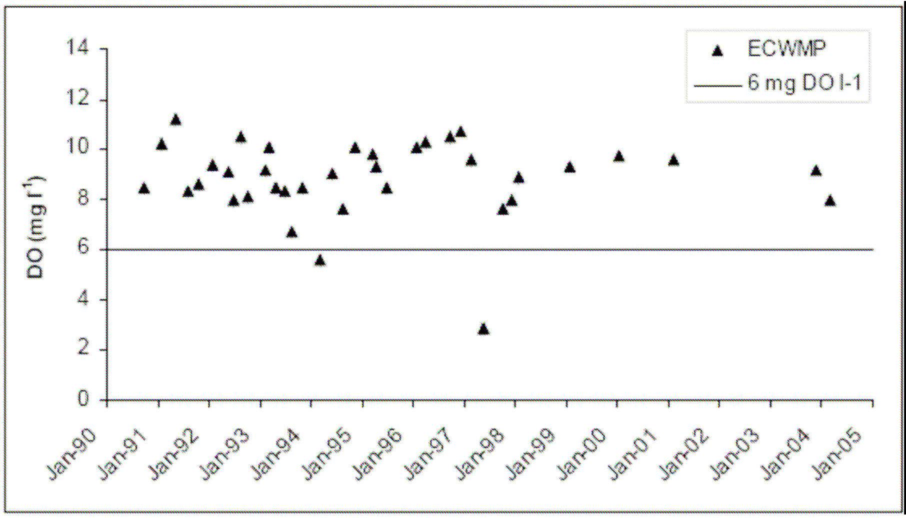


Figure 31 – Dissolved oxygen for the north of Strangford Lough. Data refers to samples from the ECWMP sampling station (EHS, 2005a).

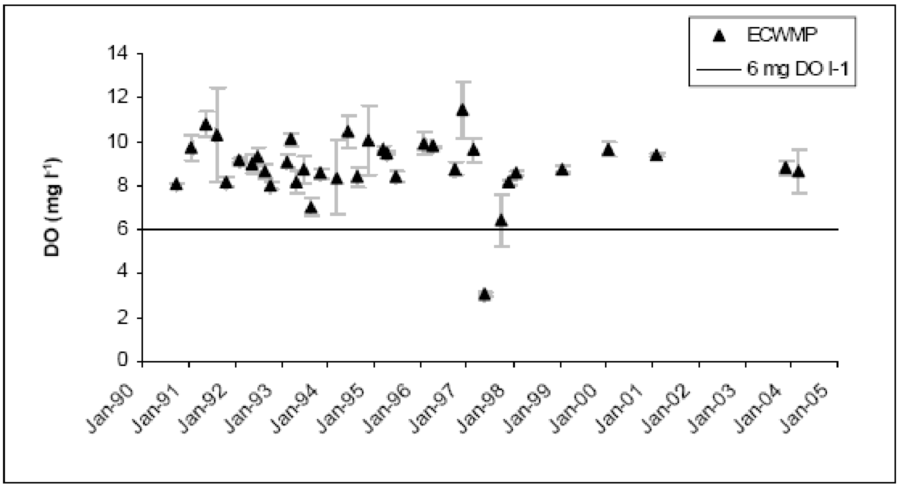


Figure 32 - Dissolved oxygen for the south of Strangford Lough. Points are the mean of all samples in the ECWMP sampling stations. Error bars are presented (EHS, 2005a).

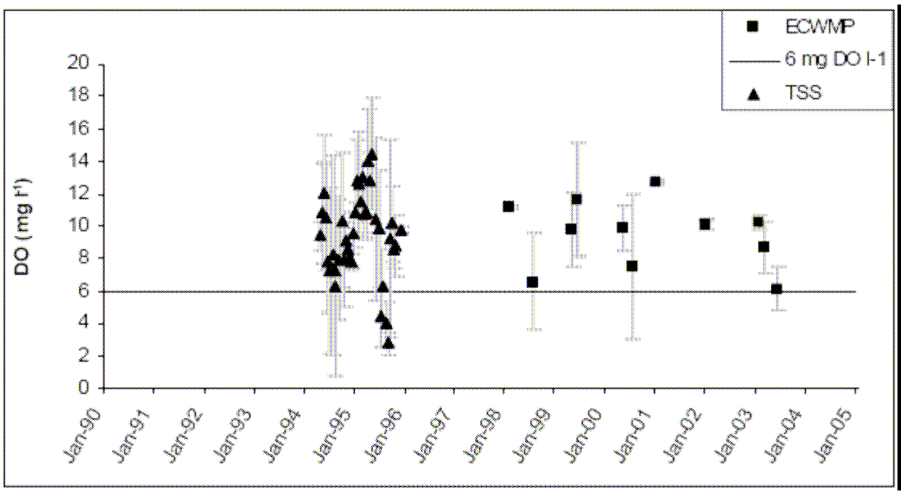


Figure 33 - Dissolved oxygen for the Quoile Pondage. Points are the mean of all samples in each sampling station (TSS and ECWMP). For each station, error bars are presented (Taken from EHS, 2005a).

In both salinity zones the values obtained are above the UK criteria of 6 $mg.l^{-1}$ (EHS, 2005a) and the threshold adopted as indicative of biological stress in the ASSETS method, which is 5 $mg.l^{-1}$. However, the higher concentrations registered in the mixing zone, added to the observations of fish kills events during hot summers suggests that there are problems occurring. These problems are, most likely, due to the stratification of the Quoile Pondage, causing the lower layers to be low in dissolved oxygen, which is not reflected in the sampling campaigns made. The frequency of occurrence is periodic and the spatial coverage falls within the High category (more than 50 % of the total mixing zone). The results of the ASSETS index application for dissolved oxygen in Strangford Lough, are presented in Table 14.

Table 14 - Results of the ASSETS index application for dissolved oxygen in Strangford Lough.

ZONE	IF Oxygen Demand	AND Spatial coverage	AND Frequency	THEN Expression	THEN Value	Area	SLE
Mixing	Biological stress	High	Periodic	Moderate	0,5	0,60	0,002
Seawater	Not observed	-	-	-	0	148,4	0
					Total	**149**	**0,002**

6.1.5.2.2 Nuisance and Toxic Blooms

Regarding the observation of algal blooms, some monitoring campaigns were performed in Strangford Lough for the periods of 1996 to 2005. The tables containing the sampling records and analysis performed during those events can be found in Appendix IV.

Although not all marine algal blooms are toxic, some species, such as Alexandrium spp. and Dinophysis spp. can produce toxins potentially harmful to humans and marine life and the presence of these species were recorded in these tables. Their potential impacts for humans and marine life are, mainly, fish poisoning and resulting hypoxic conditions, which can be supported by other previous studies (Roberts et al., 2004). It is, however, unknown what are the thresholds regarding the real impact of this phenomenon. This is the case of peaks of abundance of Dictyocha speculum and Gymnodinium spp. which were both recorded in Strangford Lough and are known to be toxic to fish. However, without known bloom thresholds for fish poisoning, it is impossible to establish whether this type of event has happened in Strangford Lough. Only a large and widespread event causing fish kills could support this evidence and none have been reported (EHS, 2005a).

There are, however, records of algal blooms and the resultant toxic poisoning of the shellfish stock identified in the past, according to the Agri-food and Bioscience Institute of Northern Ireland (AFBINI, 2009a).

In 2004, there were records of concentrations of Dinophysis spp slightly in excess of the OSPAR guideline for over a period of 1 week at Marlfield Bay. This resulted in a temporary shellfish bed closure for a one week period, because of an increased risk in consumers getting diarrhoetic shellfish poisoning (EHS, 2005a). Although, the nuisance algal species were not recorded for longer than this period, the occurrence of such event is registered as episodic.

6.1.5.2.3 Submerged Aquatic Vegetation

In the Northern end of the Lough, the natural physical conditions which do not favour macroalgae, do however favour some submerged aquatic vegetation (SAV), particularly, Zostera spp., or eel grass. The north end of Strangford Lough has extensive intertidal Zostera beds covering some 924 ha and constituting 80% of the total Zostera beds found in Northern Ireland. It is also a priority habitat of the Northern Ireland Biodiversity Strategy (EHS, 2005a).

EHS completed a Northern Ireland Zostera survey in 2003, which concluded that some of the Zostera beds in the north end of the Lough are under threat of eutrophication and excessive nutrient inputs were causing growth of the opportunistic green algae, Enteromorpha spp which causes the smothering of Zostera spp. Subsequent studies recorded a 30% reduction in Zostera spp distribution in the north end of the Lough (EHS, 2005a). Because of this fact, the magnitude of loss of SAV is considered to be Moderate. The results of the ASSETS index application for secondary symptoms in Strangford Lough, are presented in Table 15.

Table 15 - Results of the ASSETS index application for secondary symptoms in Strangford Lough.

Zone	Area (km^2) (A_Z)	Value (v_{ij})			$A_Z/A_t \times v_{ij}$		
		Dissolved O_2	SAV	Blooms	Dissolved O_2	SAV	Blooms
Seawater	148,4	0	0,5	0,25	0	0,498	0,249
Mixing	0,60	0,5	0	0	0,008	0	0
Sum	149	-	-	-	0,008	0,498	0,249
Secondary symptoms level of expression value for the estuary: 0.50 Moderate							

6.1.6 Determination of Future Outlook

In order to achieve a sustainable management and an increase in the quality of water bodies in Northern Ireland, a Management Plan has been prepared according to the WFD, by dividing areas of intervention in the water bodies by districts. Strangford Lough will be addressed in the North Eastern River Basin District.

Ten planning topics have been identified as significant for the North Eastern River Basin District. These are: land use planning, agriculture, water supply and treatment, waste management, natural heritage, forestry, fisheries, coastal, flooding and climate change planning. All the measures to be taken are integrated in a Management Plan set out under these topics, to be implemented at national, regional and local levels by a range of statutory bodies and organizations (NIEA, 2008c).

Within this plan, many objectives regarding the improvement of the quality of river and coastal water bodies in Northern Ireland, have been agreed. The current status and the proposed objectives for improving the quality of the river water bodies in Strangford Lough, is shown in Figure 34.

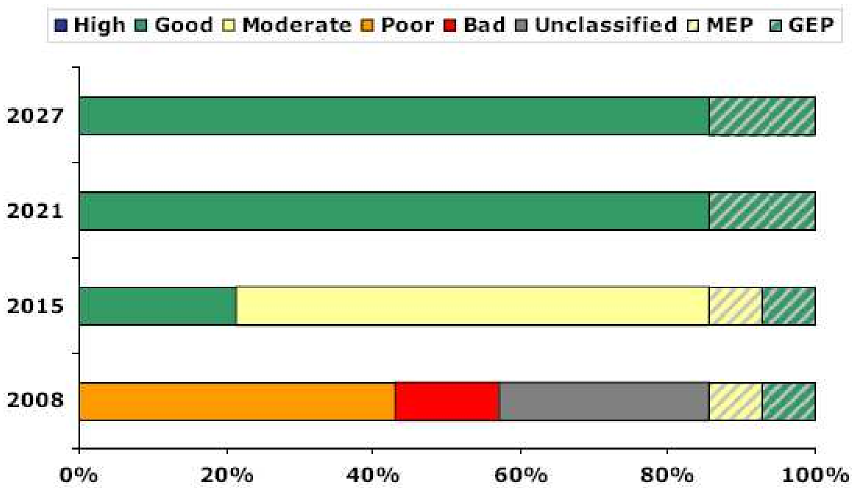


Figure 34 - Current Status and Proposed Objectives for River Water Bodies in the Strangford Management Area 2008-2027 (MEP and GEP are Moderate and Good Ecological Potential, respectively) (NIEA, 2008b).

The Plan proposes to achieve good status in 29% of river water bodies by 2015. Regarding the Enler River, which has been designated as heavily modified by human activities, it is proposed that it should achieve good ecological potential by 2021. The Quoile pondage, is designated as a heavily modified transitional water body and it is proposed that it should achieve good ecological potential by 2015 (NIEA, 2008b).

The current status and the proposed objectives for improving the quality of the coastal water bodies in Northern Ireland, within the North Eastern River Basin Management Plan, is shown in Figure 35.

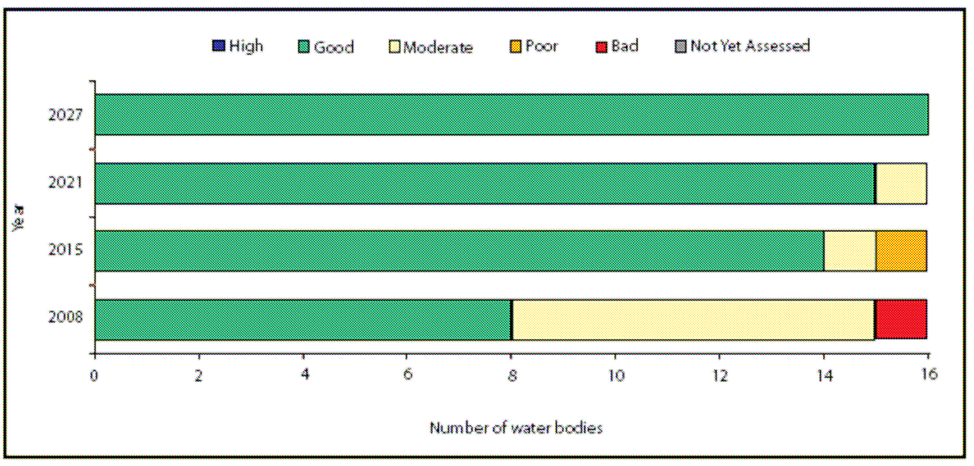


Figure 35 - Current Status and Proposed Objectives for Coastal Water Bodies in the North Eastern River Basin District 2008-2027 (NIEA, 2008b).

Although this analysis is performed at a nationwide perspective, it is proposed that by 2015, 100% of coastal water bodies in Strangford Lough Management Area will achieve good status (NIEA, 2008b).

At the same time that the management plan and its proposed measures are being taken, a number of projects and initiatives run, by local communities, angling groups and voluntary environmental organisations will contribute to achieving the objectives for the increase in the quality of water (NIEA, 2008b).

The proposed measures to improve the quality of the waters in the North Eastern Basin, where Strangford Lough is located, take into account the three most important pressures, considered in ASSETS:

- Agriculture;
- Population;
- Wastewater Treatment Works.

In the agricultural sector, which is recognised as a significant contributor to nutrient concentrations in the waterways of Northern Ireland, a single action programme, supported by the implementation of the Nitrates Directive in Northern Ireland, is currently being negotiated, that will be applicable to all farmers across the country (EHS, 2005b). This programme includes the following most significant measures (EHS, 2005b):

- requirements for farmers to provide adequate storage for animal slurries (between at least 22 and 26 weeks storage depending on sector);
- introduction of closed periods for the spreading of organic and inorganic fertilisers to land;
- limitation of the amount of nitrogen that can be applied to the land to 170kg N/ha/year in livestock manures;
- indicating where land-use or development change should take place;
- providing agri-environment grant schemes, such as the Department of Agriculture and Rural Development's Northern Ireland Countryside Management Scheme and the Northern Ireland Environment Agency (NIEA) Management of Sensitive Sites (MOSS) Scheme, to encourage environmentally friendly farming practice (NIEA, 2008c).

Adding to the expected improvement achieved with these measures, in Northern Ireland over the last 10 years, farm numbers have been declining at an annual average rate of 1,9 % and the size of the agricultural labour force has been reducing at an annual average rate of 2,1% (NIEA, 2008a).

The authorities responsible for the sustainable management of the Loughs in Northern Ireland intended to develop catchment management plans by 2015 which identify those parts of the catchment which are the most important sources of pollution where advice and regulatory action will be focused (NIEA, 2008a).

Due to this expected improvements in the agricultural practices and considering the predominant decrease in this area throughout the last years, a value of 50% was set for overall improvement in terms of agricultural pressures to the Lough in the future. Adding to this, it was also considered that agriculture will still have the most relevant contribution in terms of nutrient pressures to Strangford Lough.

In terms of population pressures to Strangford Lough, the results of the Census for the last years for the District Council Areas of Northern Ireland are described in Table 16.

Table 16 - Census Populations 1991, 2001 and 2008 estimate for District Council Areas, part or all of which lie within NERBD (NISRA, 2009).

Local Government District	1991	2001	% increase 1991 - 2001	2008 estimate	% increase 2001 - 2008
Antrim	44.516	48.366	8,6	53.243	10,1
Ards	64.764	73.244	13,1	77.614	6,0
Belfast	279.237	277.391	-0,7	268.323	-3,3
Carrickfergus	32.750	37.659	15,0	40.031	6,3
Castlereagh	60.799	66.488	9,4	66.205	-0,4
Derry	95.371	105.066	10,2	109.097	3,8
Down	58.008	63.828	10,0	69.816	9,4
North Down	71.832	76.323	6,3	78.889	3,4
Larne	29.419	30.823	4,8	31.292	1,5
Lisburn	99.458	108.694	9,3	114.766	5,6
Moyle	14.789	15.933	7,7	16.876	5,9
Newtownabbey	74.035	79.995	8,1	82.744	3,4

The analysis of the population trends between the years of 1991, 2001 and 2008 show that, for the District Council Areas in the North Eastern River Basin District of Northern Ireland, there as been increases of population in almost all of them. However, the percentage increase between these periods has been decreasing.

The data for the Down District County which represents most of the population in the catchment of Strangford Lough, follows the same trends as the remaining districts with population increasing between all the periods but, with a reduction in the percentage increase between the last years. Due to this fact, a value of 25 % was set, for overall increase in pressure in terms of population, in the future.

Regarding wastewater treatment plants in the catchment of Strangford Lough, they will benefict, mainly, from two programmes, which are (NIEA, 2008c):

- Northern Ireland Water Capital Works Programme;
- Small Works Programme.

The Northern Ireland Water Capital Works Programme sets out priorities for sewerage infrastructure to be upgraded and has the objective of increasing the amount of population equivalent served by the wastewater treatment works from 77% to 94%. The Small Works Programme establishes a priority list for small wastewater treatment works to be built or upgraded by Northern Ireland Water in conjunction with NIEA (NIEA, 2008c).

The modifications to the major Wastewater Treatment Works discharging in the rivers in the catchment area of Strangford Lough are described in Table 17.

Table 17 - Modifications to the major Wastewater Treatment Works discharging in the rivers of the catchment area of Strangford Lough.

WWTW	New Population Equivalent	Modification in Treatment
Ballyrickard	-	Upgraded to tertiary treatment by 2013
Killyleagh	-	Upgraded
Downpatrick	-	Upgraded to tertiary treatment, with works completed in end of 2009
Kircubbin	3500	Upgraded to Membrane Bioreactor Treatment after 2004
Portaferry	5300	Upgraded to secondary treatment, with works completed in end of 2009
Greyabbey	2500	Upgraded to Membrane Bioreactor Treatment after 2004

The most important WWTW in terms of Nitrogen discharge into the Lough, are in Ballyrickard and Downpatrick. Because one of them has been already upgraded and the other has plans to incorporate tertiary treatment, it can be considered that an improvement has been made. All the other WWTW have also been upgraded in some way.

Adding to these improvements to the existing WWTW, there are several plans to build other small plants in substitution of former septic tanks or even in places where there was no treatment (NIEA, 2008a). Because of this significant improvements in the WWTW in Northern Ireland and Strangford Lough, a value of 75% was set for overall improvement in terms of wastewater treatment pressures to the Lough in the future.

6.1.6.1 Climate change

Although the exact effects of climate change in the atmosphere, water and earth processes is still under intense investigation, some potential constrictions and measures to be adopted are being already defined beforehand. However, some research projects, such has the MarClim Project, have provided strong evidence that recent rapid climate change has resulted in changes in the abundance, population structure and biogeographic ranges of a number of intertidal indicator species and these changes are occurring quicker in marine systems (plankton, fish as well as intertidal species) than terrestrial systems (MarClim, n.d.).

In terms of the unpredictability of weather related events, such as, heavy rain, the increase in the flow and consequent discharge of nutrients to the Lough and increase of stratification, can be balanced by the measures which are being planned.

However, regarding the expected increase in temperatures, the shallow waters of Strangford Lough may be expected to respond to elevated temperatures due to climate change (Roberts et al., 2004).

It is clear that, more research is needed regarding sea-surface temperature changes over the last 25 years in order to determine recent climate change (Roberts et al., 2004), but this phenomenon might create some unpredictability in the processes developing in Strangford Lough, including eutrophication, due to the fact that:

- enhanced algal and plant growth because of the high temperatures and its association with the increase in nutrient run-off might exacerbate its effects on the water environment;
- non native species might be favoured, creating an unbalance in the ecosystem of the Lough;
- higher temperatures will reduce the dissolved oxygen present;
- changes in land use because of the adaptation of new cultures have to be accounted for, in terms of its potential effects.

The proposed plan and measures to adapt the marine ecosystems in Norhern Ireland to climate change have considered these aspects. Some of the effects of climate change on the marine environment in Northern Ireland and the necessary measures to reduce its effects, can be found in Appendix V.

6.1.7 Final Score

Table 18 summarizes the results obtained for the ASSETS methodology application in Strangford Lough. The application of the final calculation matrix, provides an overall classification of the estuary as “Moderate”.

Table 18 – Summary of the results obtained by the application of ASSETS methodology to Strangford Lough. EAR: Estuary Aggregation Rules; PSM: Primary Symptoms Method; SSM: Secondary Symptoms Method.

<table>
<tr><th>Indices</th><th>Methods</th><th colspan="3">Parameters/Value/EAR</th><th>Index category</th></tr>
<tr><td rowspan="4">Overall Eutrophic Condition (OEC)</td><td rowspan="1">PSM</td><td>Chlorophyll a
Macroalgae</td><td>0,254
0,498</td><td>0,38 Moderate</td><td rowspan="4">Moderate</td></tr>
<tr><td rowspan="3">SSM</td><td>Dissolved oxygen</td><td>0,008</td><td rowspan="3">0,498 Moderate</td></tr>
<tr><td>Submerged aquatic vegetation</td><td>0,498</td></tr>
<tr><td>Nuisance and toxic blooms</td><td>0,249</td></tr>
<tr><td rowspan="2">Overall Human Influence (OHI)</td><td>Susceptibility</td><td>Dilution potential
Flushing potential</td><td>Moderate
Moderate</td><td>Moderate Susceptibility</td><td rowspan="2">Moderate</td></tr>
<tr><td>Nutrient inputs</td><td colspan="3">Moderate nutrient input</td></tr>
<tr><td>Future Outlook for future conditions (DFO)</td><td>Future nutrient pressures</td><td colspan="3">Future nutrient pressures decrease</td><td>Improve Low</td></tr>
</table>

6.1.8 Conclusions

Strangford Lough is a system which is very much influenced by the presence of The Narrows. This physical characteristic determines much of the rate of water exchange and controls many mechanisms inside the estuary. Adding to this, it has a low depth and very low freshwater flow, which reduces stratification, however, it is possible that climate change events might alter this fact.

Agriculture is, by far, the main source of nutrients to the Lough, although its waters do not appear to have high concentration of nutrients. It is demonstrated that it can flush nutrients efficiently. However, although the catchment of Strangford Lough is very homogeneous, there is a considerable difference, in terms of the status of eutrophication between the northern and southern parts of the Lough and also, the Quoile Pondage. The main problems with the northern part of the Lough refer to the change in macroalgae and submerged aquatic vegetation composition. In Quoile Pondage, the most problematic factors are chlorophyll a and dissolved oxygen. These should be the parameters of concern for the adoption of corrective measures, particularly, the loss of SAV.

For the future, an extension of the routine sampling campaigns conducted currently, should be addressed and the parameters should be enlarged, in order to effectively correct the harmful eutrophic processes that might occur in the Lough. This type of centralised data management is the adequate one for this particular Lough, because of its environmental and economical importance. Also, given the multiple uses of the Lough, appropriate levels of activity and zonation of such activities must be planned and regulated.

The planned management activities for the Lough in terms of reducing nitrate inputs from agricultural activities and a stricter control of those activities, are fundamental for the improvement in the classification. Also, the higher quality treatment performed in the WWTW and the enlargement of the amount of population served by sewerage networks are the right management decisions. If the Management Plan outlined is put into place, a significant improvement in the status of the coastal waters in Strangford Lough is expected.

Because of its several natural classifications, Strangford Lough needs additional protection and its eutrophication risks should be avoided. Future Management must be aware of the economical aspects related with the degradation of the water quality. Also, several regulations apply to the Lough, due to its special area classifications and they are becoming stricter. The penalties involved in the non-compliances are also to be considered. Important activities for the whole Northern Ireland, performed in the site, might be most affected, such as aquaculture, for example, the modiolus reefs which might continue threatened if nothing is done. Tourism is also an important component of social and economic benefits of this region and if severe eutrophication events are prolonged, it may be compromised. This can be due to the loss in ecosystem diversity, obstacles for navigation and gastronomic constraints.

Regarding the methodology used, some improvements have to be made regarding the thresholds of dissolved oxygen, because of the facts occurred in this assessment, where by analyzing the results of the mixing zone there were no evidence of biological stressful conditions. However, a more detailed analysis revealed some poor conditions and even situations of hypoxia. A vertical dispersion coefficient which would account for stratification or an indicator of fish kills, could improve this analysis.

The classification obtained with ASSETS was “Moderate”, which is the same as the value obtained for the WFD. Therefore, the proposed measures should be immediately put in place, the classification as a sensitive area must be maintained and the designation as a vulnerable zone should be reinforced.

6.2 Belfast Lough

6.2.1 Description of the Lough

Belfast Lough is a shallow semi-enclosed bay located on the north-eastern coast of Northern Ireland. It has an area of 130 km^2 and the sea bed of the Lough slopes gradually from the city of Belfast, to a depth of approximately 22 m at the outer limit (EHS, 2003). According to its physical characteristics it can be divided into inner and outer Belfast Lough. The Inner Lough comprises a series of mudflats and lagoons whilst the Outer Lough is composed of mainly rocky shores with some small sandy bays. A more detailed perspective of the Lough and the sampling stations used in the analysis performed in this report can be seen in Figure 36.

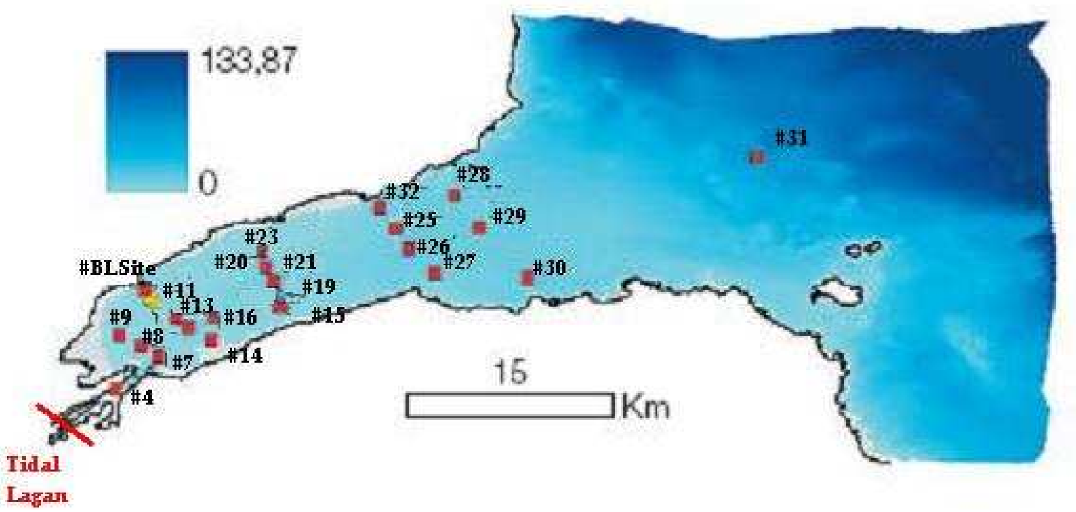


Figure 36 - Location of the sampling stations and surface depths of Belfast Lough (Ferreira et al., 2007).

Due to its exposure to the Irish sea and frequent water exchange, almost 96 % of the area is subtidal (Ferreira et al., 2007). The main freshwater source is River Lagan, which enters from the south-western shore. An intermediate area between the river and the inner Belfast Lough is the Tidal Lagan, which is an impounded stretch from the river, located to the north-east and separated from the harbour area by a weir in 1997 (NIEA, 2008j). The main characteristics of Belfast Lough are presented in Table 19.

Table 19 - Physical Properties of Belfast Lough (Ferreira et al., 2007).

Physical Properties	Belfast Lough
Volume (x 10^6 m^3)	1548
Area (km^2)	130
Maximum Depth (m)	22
Catchment (km^2)	900
Temperature (ºC)	2-21
Mean Salinity	28
River Flow (m^3 s^{-1})	32
Water Residence Time (d)	10-20
Population in Catchment	646 000

The Lough has been designated in terms of the level of nature conservation and protection as an ASSI, SPA and a RAMSAR site. On its shores, industry is now light, but the lough has a long history of heavy industry and it still is a major commercial port with heavy passenger and freight traffic in addition to a booming leisure industry (AFBINI, 2009b).

6.2.2 Homogeneus Areas

The physical classification of the Lough into homogeneus zones was made using the thresholds defined by ASSETS and the median salinity values of the sampling stations. Two areas were determined. A mixing zone, which corresponds to the Tidal Lagan, with a total area of 0,32 km^2 and the seawater zone is the remaining area of the Lough (129,68 km^2). The salinity value defined as representative of the mixing zone of the estuary was 19 psu and the seawater zone was 28 psu.

For the Irish Sea it was considered the median value of sampling station #31, which coincides with the value used for Strangford Lough which was 34 psu.

6.2.3 Data Completeness and Reliability

The percentage of area of Belfast Lough covered by the sampling stations used in this assessment is almost complete and the source of this data is very reliable on account of the spatial and temporal representativeness of sampling and the analytical quality of the analyses. This data is provided by Trophic Status Studies performed during the periods between November of 1991 and January of 1998 and December of 2003 and April of 2006. However, in terms of data completeness there are some significant differences between two homogeneous zones. The mixing zone has a high coverage for the period of time from November 1991 to January 1998, since that, all the parameters are sampled at consistent timeframes. However, in the seawater zone there is a high inconsistency observed between the periods of sampling. The number of stations sampled, dates and water quality parameters for Strangford Lough are shown in Table 20.

Table 20 – Results of the data completeness and reliability for Belfast Lough

Number of Stations	Parameters	Date	Area
2 2 2	Salinity Chlorophyll a Dissolved Oxygen	November 91 to January 1998	Mixing (all area)
11	Salinity	September and October 1992 (monthly)	Seawater
26	Salinity	October to November 1992 and January 1993 to May 1994 (monthly)	Seawater (all area)
2 2 2	Salinity Chlorophyll a Dissolved Oxygen	June 1994 to January 1998	Mixing (all area)
19	Salinity	March 1995 to June 1996 (monthly)	Seawater (inner lough)
8	Chlorophyll a	December 2003	Seawater
23 15	Salinity Chlorophyll a	March 2004 to April 2006	Seawater (all area) Irish Sea
19	Dissolved Oxygen	August 2004	Seawater (all area)

After a close analysis to the figure shown above, it is possible to infer that the temporal data available for the seawater zone is wider for one parameter than for others. Also the values obtained for dissolved oxygen in this area, derive only from one sampling campaign conducted in August of 2004. For the mixing zone a good completeness is achieved for the period mentioned before, however, no data was found for more recent years.

6.2.4 Overal Human Influence

6.2.4.1 Susceptibility

6.2.4.1.1 Dilution Potential

Tidal currents are weak and oscillatory in the Inner Lough resulting in a predominantly sheltered area where the currents are dominated by tides. In the Outer Lough, a clockwise rotatory current has been documented as well as the rapid exchange of water with the ocean. These physical conditions result in less potential for eutrophication (EHS, 2003).

The large mixing capacity of the Inner Lough allows effluent to be dispersed quickly between the Inner and Middle Loughs. Phytoplankton growth in Belfast Harbour and the Inner Lough is rarely limited by nutrients (AFBINI, 2009b). The differences between the surface and bottom temperature of the waters, identifying possible layers of stratification can be seen in Figure 37.

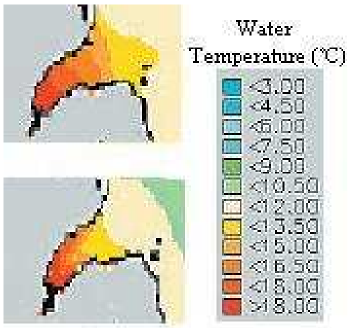


Figure 37 - Differences in water temperature in Strangford Lough, near the surface (up) and near the bottom (down) (Ferreira et al., 2007).

Although the Lough has a horizontal temperature gradient between the head and the mouth, they remain vertically well mixed (Ferreira et al., 2007). With stratification being rare and considering the favourable conditions for dilution of freshwater but accounting for the weak currents and the high river flow and also, when applying the decision rules for dilution potential, Belfast Lough is classified in the “Moderate” category.

6.2.4.1.2 Flushing Potential

Belfast Lough is a subtidal estuary with a tidal range of around 3 m (River Lagan Wildlife, 2008). The total area of the Lough has residence times characterised by intermediate and short-intermediate periods (Ferreira et al., 2007), with rapid water exchange with the North Channel, and, consequently, higher flushing rates in the Outer Lough (EHS, 2003). The water residence times from the surface and bottom of Belfast Lough can be seen in Figure 38.

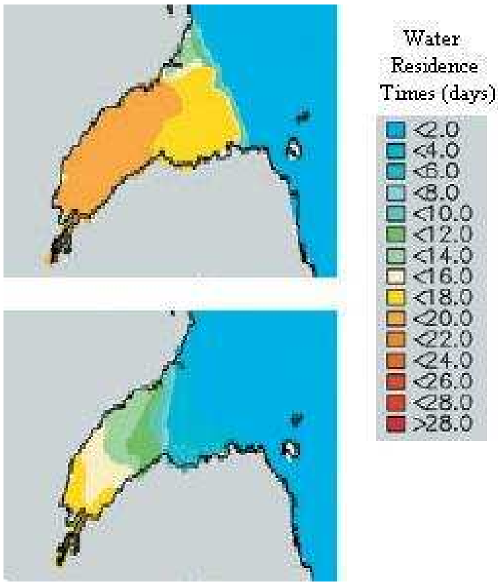


Figure 38 - Water residence times in Belfast Lough, near the surface (up) and near the bottom (down) (Ferreira et al., 2007).

By analysing the figure above, it is possible to identify major differences between the outer and inner areas, particularly, regarding the surface and bottom temperatures for each one of them. The flushing potential of the outer area is much higher than the more enclosed areas of the Lough. Due to these differences and after applying the decision rules for flushing potential this parameter will fall within the "Moderate" category

6.2.4.2 Nutrient Inputs

Belfast Lough has a catchment area of approximately 900 km^2 (Ferreira et al., 2007), with heavily urbanised regions. Historically, the major input of nitrogen into the Lough has been the Irish Fertilizer Industries factory, which discharged (almost 75 % of the total input) into the Tidal Lagan, contributing, thus, to the loading to Inner and Outer Belfast Lough (almost 58 % of the total input) (Foy & Girvan, 2004). Besides this, the remaining sources of nutrients have been: urban areas, with most of the discharges coming from WWTW and septic tanks, agriculture activities and rivers. In 2001, the Inner Lough and tidal Lagan were designated as sensitive areas under UWWT Directive (EHS, 2005b). Due to this, a number of changes have occurred in Inner Belfast Lough, resulting in a reduction of nutrient inputs, concentrations and an overall improvement in trophic status. These included (EHS, 2003):

- The introduction of full secondary treatment with nutrient (N) removal at Belfast WWTW, from December 1998;
- Secondary treatment at Kinnegar WWTW was operational from December 2000 with nitrogen reduction operational, from June 2001;
- A progressive tightening of the discharge consent of the major industrial discharger (fertilizer plant) and its closure in December 2002;

- The rapid development of a shellfishery in Inner Belfast Lough since 2000;
- The WWTW at Whitehouse which had secondary treatment only, was upgraded by the end of 2008.

The closure of the fertilizer plant was expected to significantly decrease nutrient concentrations throughout the Lough. The influence of the contribution of each source in the input of nutrients in Belfast Lough, can be seen in Figure 39 and Figure 40.

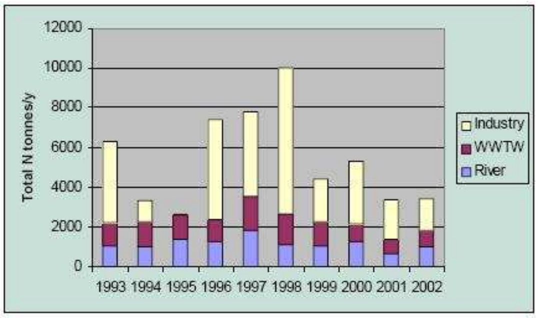


Figure 39 – Total DIN loadings to Belfast Lough by source (EHS, 2003).

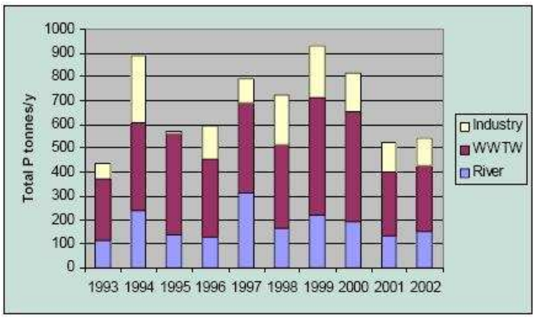


Figure 40 - Total DIP loadings to Belfast Lough by source (EHS, 2003).

The total contribution of each source in the nutrient enrichment of the Lough is variable according to the type of nutrient. For DIN, the major source, until the year of 2002 has been industry. In terms of DIP, the major source is primarily from WWTW. In order to provide the quantitative contribution of nutrients, of the fertilizer plant into the Lough, Figure 41 is presented below, revealing the loading of ammonium, nitrate and phosphate from the Irish Fertilizer Industries factory.

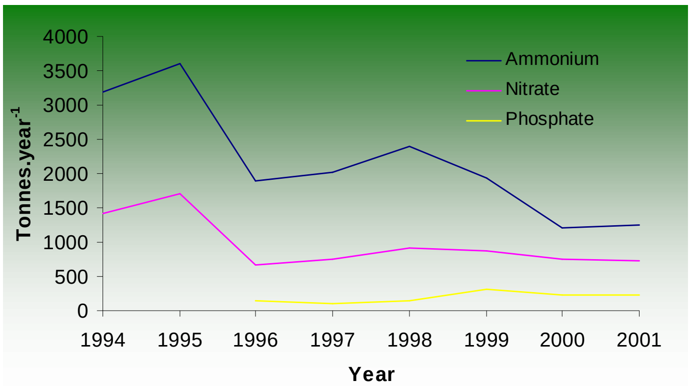


Figure 41 – Loading of ammonium, nitrate and phosphate from the fertilizer plant into Belfast Lough, before its closure (Foy & Girvan, 2004).

This data is very useful to better understand the evolution of the characteristics and symptoms in terms of eutrophication in this Lough, although it will not be used for the calculations of the inputs of nitrogen into the Lough referred in this chapter, once it is no longer active.

In terms of agricultural contribution, this activity has been estimated to account for 75, 57 and 51 % of the loadings of DIN to tidal Lagan, Inner and Outer Belfast Lough, respectively (Foy & Girvan, 2004). These estimations are relatively small, when compared with other Loughs in Northern Ireland, because this Lough has a significant contribution from urban areas. Without the contribution of the fertilizer plant, the percentages increased significantly. The soil uses in the catchment of Belfast Lough is described in Figure 42.

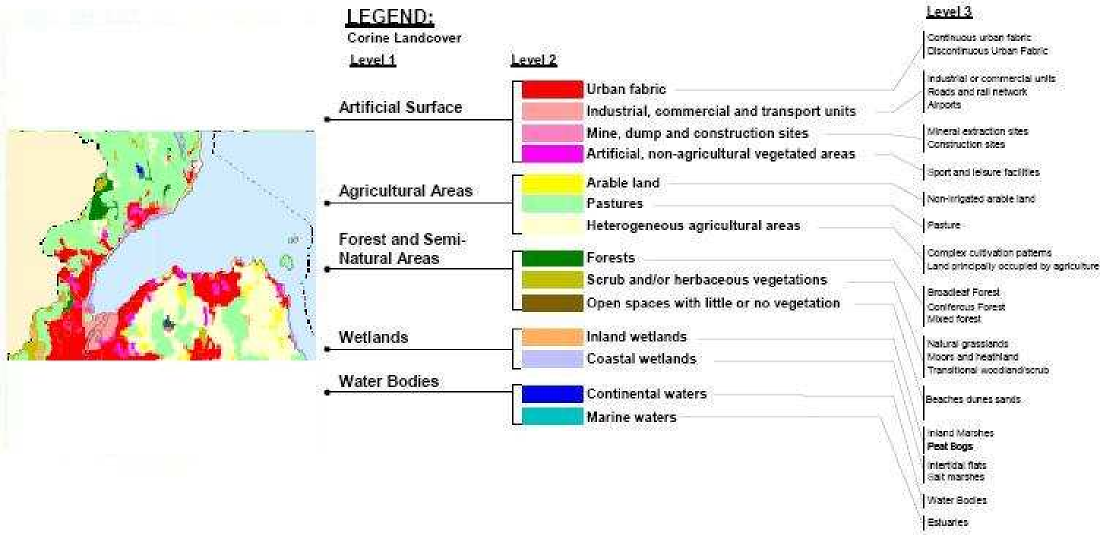


Figure 42 – Soil uses in the catchment of Belfast Lough (NIEA, 2008j).

Analysing the map of soil uses, it is possible to observe the high contribution of urban areas, particularly in the southern and eastern parts and agricultural activities in the north-western and remaining eastern part of the Lough. It would be expected that urban pressures would be felt considerably in the tidal Lagan, however, these account only for 21 % of the DIN loading in this area. This is due to much of the sewage being derived from the urban areas directly to the Inner and Outer Belfast Lough, which account for loadings in excess of 40 % (Foy & Girvan, 2004).

There are 39 WWTW in the Belfast Lough catchment, serving a population of approximately 535 638 (Foy & Girvan, 2004) and contributing approximately 30 % of the DIN load (AFBINI, 2009b). However, the most important contributions in terms of nutrients are those at Belfast and Kinnegar, discharging directly into the Inner Lough and exceeding 100 000 population equivalent served. A detailed list of the characteristics of the most important WWTW in the catchment of the whole Lough, can be seen in Table 21.

Table 21 – Characteristics of the Wastewater Treatment Works which discharge into Belfast Lough.

WWTW	Catchment	Type of Treatment	Population Equivalent	Responsible
Belfast	Inner Lough	Tertiary (P removal)	117 500	Northern Ireland Water
Kinnegar		Tertiary (P removal)	108 130	Northern Ireland Water
Whitehouse		Tertiary (P removal)	65 010	Northern Ireland Water
Briggs Rock	Outer Lough	Secondary	75 160	
Dunmurry	Tidal Lagan	Tertiary (P removal)	44 518	Northern Ireland Water
New Holland		Tertiary (P removal)	38 004	Northern Ireland Water
Others			87 361	
Total			535 683	

A problematic situation has been described in Briggs Rock, where raw wastewater has been discharging directly into the Lough (Friends of the Earth, 2009). Although, this WWTW is currently equipped with secondary treatment, this is still insufficient according to the requirements of the UWWTD. Also, some smaller works are still without any treatment, such as, Bangor and Whitehead and others are equipped only with primary treatment, such as Seahill. The remaining level of treatment and the percentage of the population served from the majority of the WWTW is acceptable, however, there are still some households without public sewerage provision in the catchment, which, as previously described for Strangford Lough, account for 20 % of the total population of Northern Ireland. In order to estimate these missing data, the census of the population living in Northern Ireland was used. This data is obtained by subtracting the total population living in the districts surrounding Belfast Lough and the population which is currently served with a public sewerage network in the same districts (Appendix III). An estimation of 110 317 people which are currently in these conditions was made.

In terms of the main freshwater discharges, River Lagan is the main river from the drainage basin of Belfast Lough and its major nutrient input source is agriculture, with urban discharges to a lesser extent. It is considered to be sensitive to nutrients according to the UWWTD (EHS, 2005b).

The differences between relative nutrient loadings to Inner and Outer Belfast Lough, are depicted in Figure 43 and Figure 44.

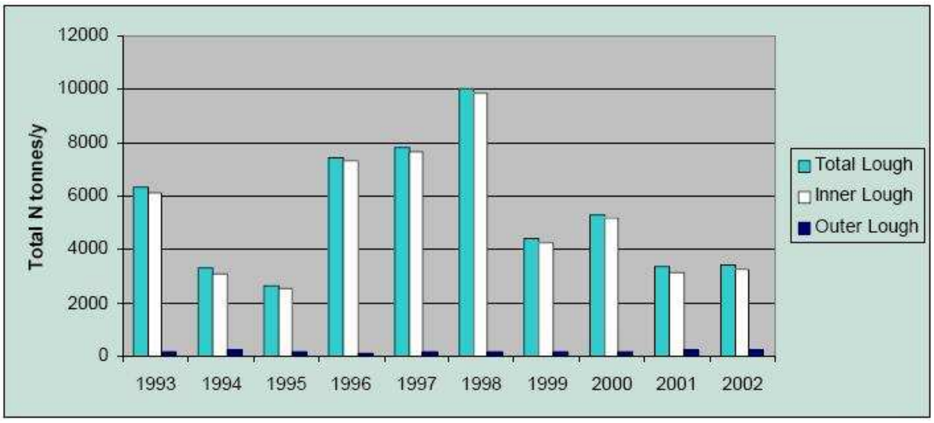


Figure 43 – Total DIN loadings to Inner and Outer Belfast Lough (EHS, 2003).

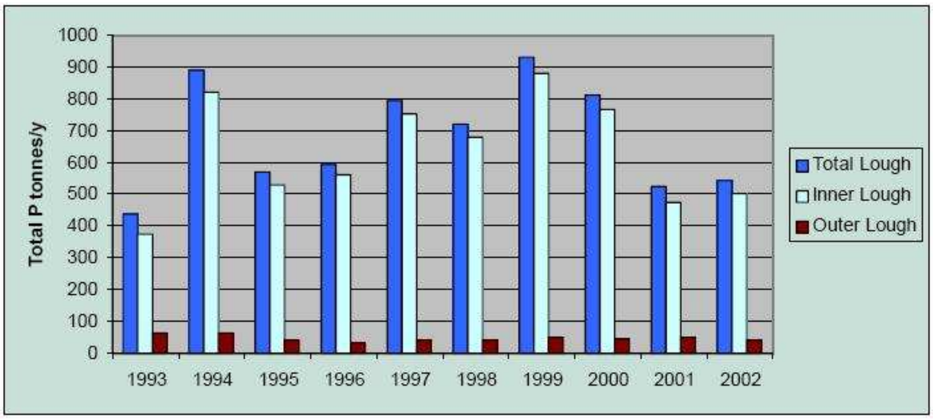


Figure 44 - Total DIP loadings to Inner and Outer Belfast Lough (EHS, 2003).

These figures demonstrate that the largest proportion of the total loading of nutrient inputs to Belfast Lough, are located in the Inner Lough. However, this fact is not determinant because the major source of nutrients to the Outer Lough is the Inner Lough (EHS, 2003), mainly due to the high water exchange between the two areas. It should be noted that these results account for the contributions of the industrial source, which is already inactive. This is justified by the need to observe the patterns in terms of total nutrient loadings.

In order to estimate the nutrient load to Belfast Lough, the Export Coefficient Model, described previously for Strangford Lough, was used. The detailed calculation of the loads and concentrations of DIN discharged into Belfast Lough are presented in Appendix III. The summary of the results obtained are shown in Table 22.

Table 22 - Nitrogen Loads from the main anthropogenic sources to Belfast Lough.

Sources		DIN (ton N $year^{-1}$)
WWTW		878
Drainage to the River		1134
Direct Drainage	**Tidal Lagan**	39
	Inner Lough	539
	Outer Lough	505
Not served by WWTW		204
Total		**3229**

The major contribution of nutrients discharged into the tidal and river Lagan are agricultural sources. In terms of Inner and Outer Belfast Lough, these contributions are relatively in balance with the urban sources. It is possible to conclude that the yearly nutrient inputs to the Lough in more recent years are still high, even though, the closure of the fertilizer plant was conducted effectively in 2002.

There are some evidences that winter nutrient concentrations are decreasing in both the Inner and Outer Lough, however, there is still evidence of enrichment in the Inner Lough (EHS, 2003). In this Lough the UK criteria for the Irish Sea, of 18 $\mu mol.l^{-1}$ (EHS, 2005a), is frequently surpassed. This situation is not the same for the Outer Lough, where the concentrations are typically bellow this threshold (AFBINI, 2009b). A similar situation has been occurring regarding DIP concentrations, which is supported by the fact that the redfield ratio is consistently above 25 in the Inner Lough, although decreasing, and it is constantly between 13 and 15 in the Outer Lough.

Using the estimations and data relevant for the nitrogen loads and the several flows which drain into the Lough, demonstrated in Appendix III, the concentrations of DIN flowing into the Lough are 230 $\mu mol.l^{-1}$. The mean values considered to be representative of the closest area of the Irish Sea are those taken from sampling station #31 and the data provided by the European Environment Agency and Kennington et al., 2002, which is 8,9 $\mu mol.l^{-1}$. Therefore, the value for nutrient input is 0,82, which is then considered as "High".

6.2.5 Overal Eutrophic Condition

6.2.5.1 Primary Symptoms

6.2.5.1.1 Chlorophyll a

The same method was used as in Strangford Lough, which is the percentile 90 values for detecting chlorophyll a excessive blooms. The frequency distribution for chlorophyll a in the mixing and seawater zones of Belfast Lough, are represented in Figure 45 and Figure 46.

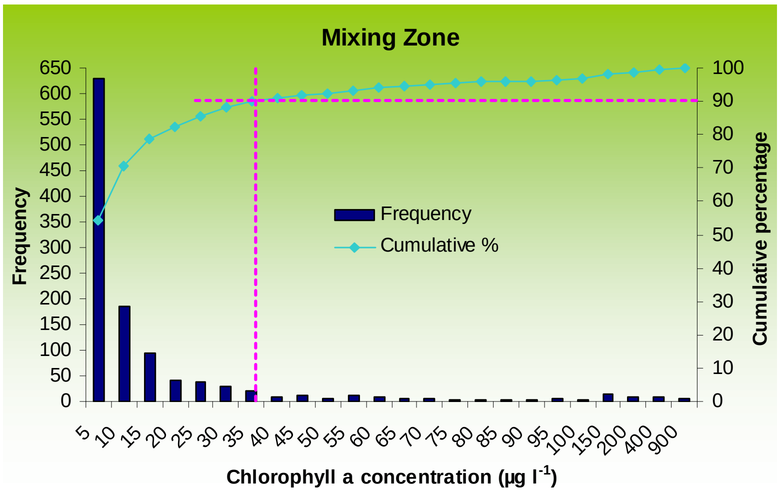


Figure 45 - Frequency distribution for Chlorophyll in the mixing zone in Belfast Lough.

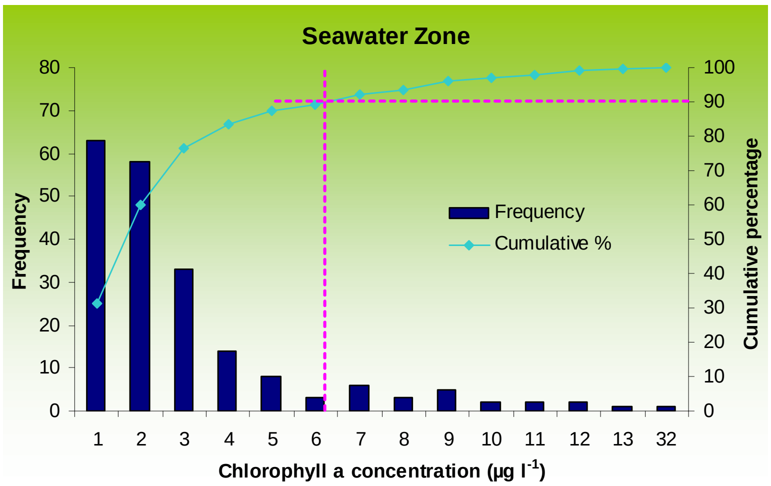


Figure 46 – Frequency distribution for Chlorophyll in the seawater zone in Belfast Lough.

The percentile 90 values obtained for the seawater and mixing zones were 6,5 and 35 $\mu g.l^{-1}$, respectively. The values for the seawater zone fall within the “Medium” category and for the mixing zone they are placed in the “High” category. However, the results observed in the mixing zone refer to the years before the deactivation of the industrial discharges and the values from the sampling stations in the remaining areas of the Lough refer to the period of time after this event. This is relevant because chlorophyll concentrations have been decreasing throughout the Lough in the last years sampled, with more influence in the Inner Lough and less significant in the Outer Lough. Thus, the spring and summer chlorophyll a concentrations in inner Belfast Lough throughout several years, from 1990 to 2002, is presented in Figure 47.

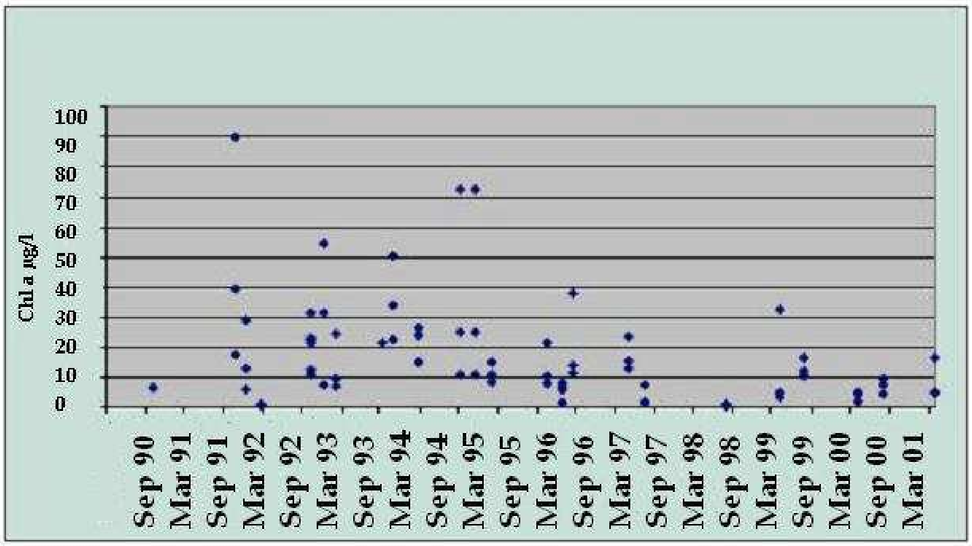


Figure 47 - Spring and summer chlorophyll a concentrations in inner Belfast Lough, taken from the ECWMP Routine Monitoring Station (EHS, 2003).

Although progressive decrease of concentrations of chlorophyll a in the Lough is confirmed by this figure, there is still some evidence of elevated chlorophyll concentrations in the Inner Lough. However, these levels do not appear to be directly related to DIN levels, but more to other factors, such as, other key nutrients or light availability (Service et al., 1996). Due to this fact, it is presented the spatial and frequency of occurrence of unusual events, for both homogeneous zones. In order to evaluate the frequency of occurrence of blooms of chlorophyll a, its annual cycle in Belfast Lough is shown in Figure 48.

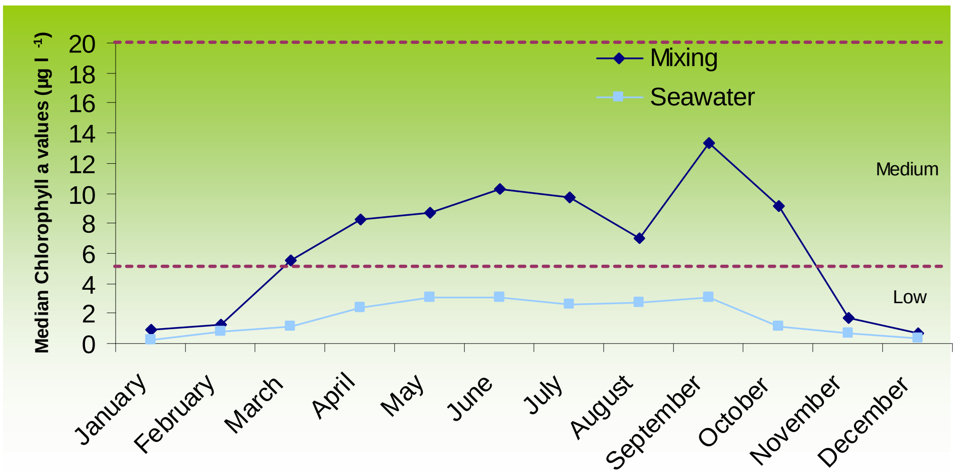


Figure 48 – Annual cycle of chlorophyll a values for the two zones of Belfast Lough.

In both homogeneous zones, throughout the year there is a consistent increase in chlorophyll values in the beginning of spring. However, in the seawater zone, there is a small decrease during the summer months with a smaller peak in the beginning of autumn, which is consistent with other analysis performed previously in the Lough (Service et al., 1996). In Tidal Lagan there is a significant difference, with a maximum peak reached in September. This is due, mainly, to the values recorded in sampling station #3TL, for the years of 1994 and 1995 and strengthens the idea that point source discharges of nitrogen might have a fundamental influence on the events occurring in the Lough. For both areas the frequency of occurrence is then considered as periodic, once these conditions occur annually.

Regarding the spatial coverage of the high values of chlorophyll a, Figure 49 and Figure **50** represent the distribution of concentration levels of chlorophyll for the year of 1995 in Belfast Lough and the coarser grid used for ecological modelling of Belfast Lough, respectively.

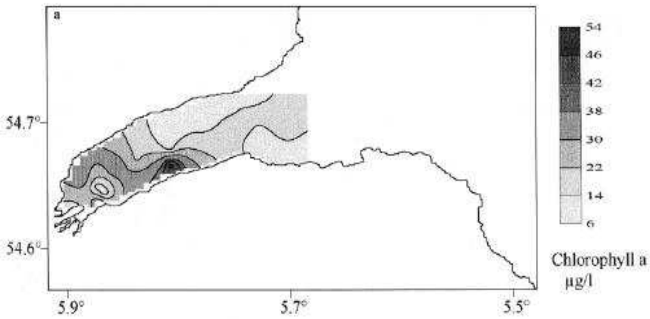


Figure 49 – Distribution of concentration levels of chlorophyll for the year of 1995 in Belfast Lough (Service et al., 1996).

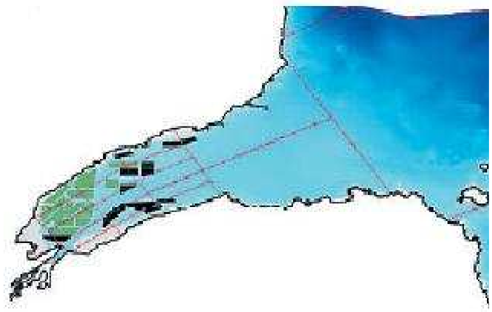


Figure 50 - Coarser grid used for ecological modelling of Belfast Lough (Ferreira et al., 2007).

The first figure reflects the predominance of point source discharges into the Lough, mainly from industrial activities. The second figure is used for simulation of processes at the ecosystem scale, by defining each grid according to homogeneous physical conditions, morphology, currents and vertical stratification (Ferreira et al., 2007). Using this tool, a more complete analysis of the influence of each sampling station contained in each grid, can be obtained. Because most of the high values were observed in the sampling stations located in the middle of the inner Lough, the percentage of coverage for the seawater zone was around 21%, which places it in the "Low" category.

For the mixing zone, in order to calculate the spatial coverage of the high values of chlorophyll a observed, the Thiessen Polygons Method was used. The zones of each sampling station in the Tidal Laghan, can be observed in Figure 51.

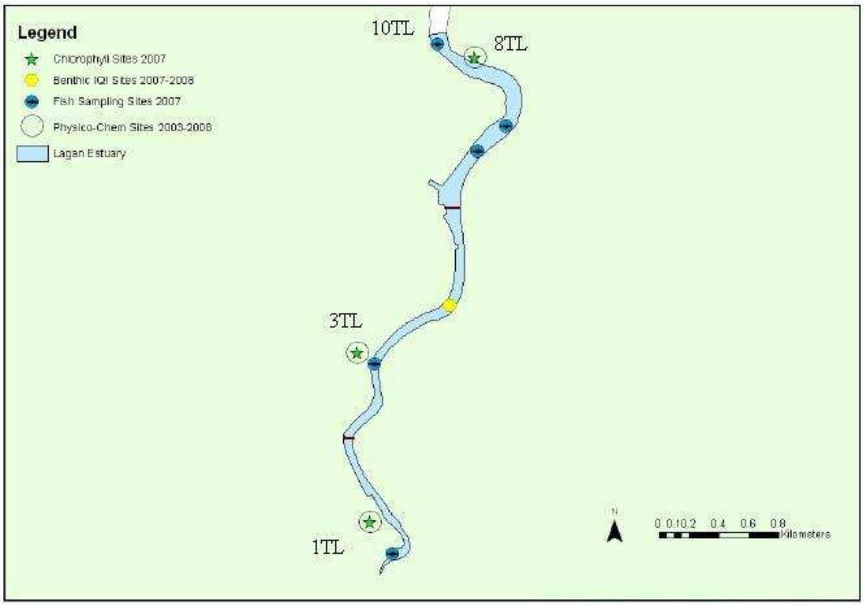


Figure 51 – Zones of influence of each sampling station in the mixing zone of Belfast Lough, calculated with the Thiessen Polygons Method.

When comparing the zones of influence of each sampling station with the highest values recorded, a clear pattern is observed between the concentration of chlorophyll a and the distance to the mouth of the river, as it is shown in Figure 52.

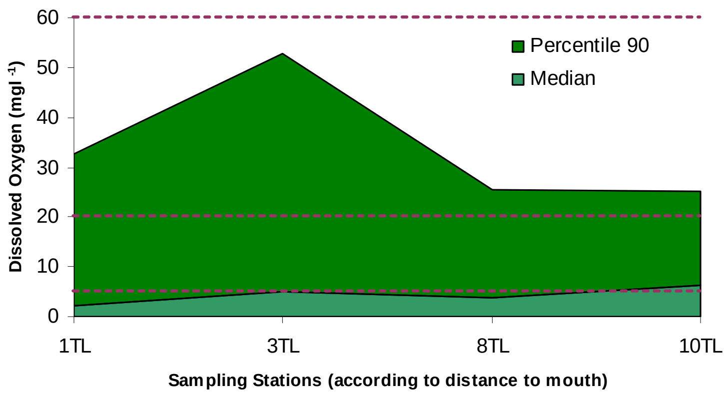


Figure 52 - Longitudinal profile of chlorophyll a in the mixing zone of Belfast Lough.

The median values of chlorophyll a decrease according to the increase in the distance to the mouth of the river. However, there is a clear peak of chlorophyll a concentrations in the analysis of the percentile 90 values for sampling station #3TL. Although it is taken into consideration that the values of concentration of chlorophyll a in the mixing zone refer to a period of time before the deactivation of the major source of nitrogen into the Lough and the quality of the water may have been improved in the last years due to that, the location of this pollution source, far away from this area, associated to the fact that no pattern of decrease in chlorophyll was recorded in Tidal Laghan throughout the years, determines that the data should be considered in this evaluation. Therefore, considering the influence of sampling station #3TL on the results obtained, it was calculated a 32% spatial coverage, which means that the mixing zone falls within the “Medium” category. The results of the ASSETS index application for chlorophyll a in Belfast Lough, is presented in Table 23.

Table 23 – Results of the ASSETS index application for chlorophyll a in Belfast Lough.

ZONE	IF Concentration	AND Spatial coverage	AND Frequency	THEN Expression	THEN Value	Area	SLE
Mixing	High	Medium	Periodic	High	1	0,32	0,002
Seawater	Medium	Low	Periodic	Low	0,25	129,68	0,250
					Total	**130**	**0,252**

6.2.5.1.2 Macroalgae

In Belfast Lough macroalgae surveys have been completed at three sites on the right bank, in the years of 2002 and 2003 (EHS, 2003). Ballymacormick Point and Swineley Point are representative of the Outer Belfast Lough and Helen’s Bay, which was only sampled in 2003, represents the characteristics of Inner Belfast Lough.
Although macroalgae mats are scarce, which may be due to the lack of a suitable substratum for their attachment (Service et al., 1996), the species data indicates good species richness at all these sites, with species totals ranging from 51 to 89. This difference may be attributed to the macrophytes which make from Ballymacormick Point one of the most rich and diverse sites in Northern Ireland. There is a large turnover of species due to natural variation with species richness remaining relatively constant at both Swineley Point and Ballymacormick Point over the last 15 years (EHS, 2003).

The 2002 and 2003 investigation of these sites also indicated no dominant species, particularly with regard to opportunist species like Enteromorpha sp. and Ulva sp. At this time the abundance of these nuisance algae was considered at acceptable levels with a composition typical of a moderately exposed rocky shore (EHS, 2003). However, surveys performed in 2007 showed evidence of Sargassum muticum (NIEA, 2008i), which is an invasive specie, at both sites in Outer Lough. Also, in former years the green algae Ulva latissima has been detected and the potential for its appearance during summer periods is significant (Service et al., 1996).

As a result of these combinations of events, it was considered that problems with macroalgae, due to invasive species which can influence light penetration, have been occurring in the seawater zone of Belfast Lough and their frequency is episodic. For the mixing zone, there is evidence of disturbance to the balance of macrophyte assemblages in 100% of the river length surveyed in 2002 where nutrient concentrations are elevated, with the presence of pollution tolerant species being significant. However, no problems in the downstream of the river, encompassing the tidal Lagan area, were observed. The results of the ASSETS index application for primary symptoms in Belfast Lough, are presented in Table 24.

Table 24 - Results of the ASSETS index application for primary symptoms in Belfast Lough.

Zone	Area (km^2) (A_Z)	Value (v_{ij})		$A_Z/A_t \times v_{ij}$	
		Chlorophyll a	Macroalgae	Chlorophyll a	Macroalgae
Seawater	129,68	0,25	0,5	0,250	0,50
Mixing	0,32	1	0	0,002	0
Sum	130	-	-	0,252	0,50
Primary symptoms level of expression value for the estuary: 0,38 Moderate					

6.2.5.2 Secondary Symptoms

6.2.5.2.1 Dissolved Oxygen

Using the data obtained from the sampling campaigns, the percentile 10 value was used to investigate the high or low concentrations of dissolved oxygen in Belfast Lough. The frequency distribution for dissolved oxygen values in the two salinity zones can be observed in Figure 53 and Figure 54, respectively.

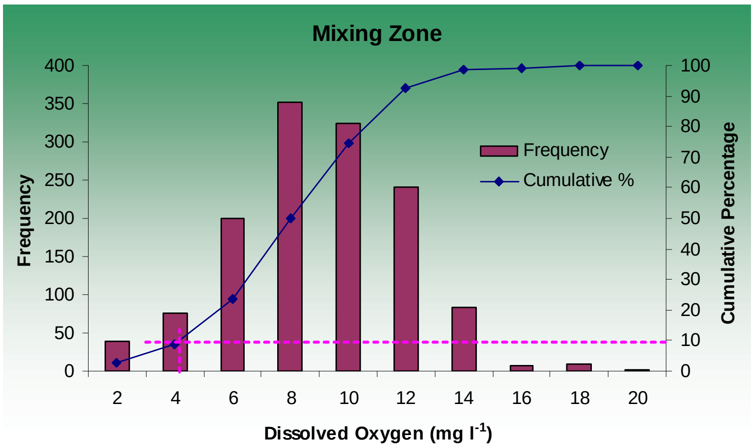


Figure 53 - Frequency distribution for dissolved oxygen in the mixing zone in Belfast Lough.

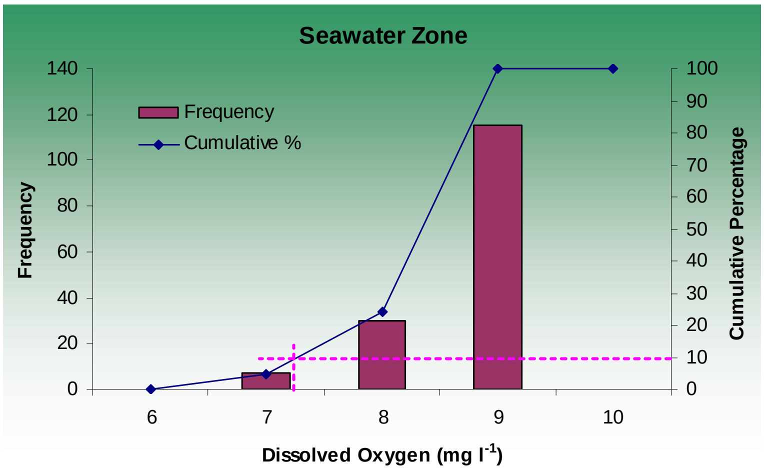


Figure 54 – Frequency distribution for dissolved oxygen in the seawater zone in Belfast Lough.

The percentile 10 value obtained for the seawater zone was 7,3 mg.l^{-1} which does not reveal any biological stress occurring within the water body. In the mixing zone this value attained was 4,2 mg.l^{-1} which is placed under the threshold value for biologically stressful conditions. However, the values observed in the mixing zone refer to the years before the deactivation of the industrial discharges and the values from the sampling stations in the remaining areas of the Lough refer to the period of time after this event. Adding to this, the values for the seawater zone, derive solely from one campaign, performed in 2004. In order to confirm the reliability of the results obtained, the dissolved oxygen concentrations for the Inner Belfast Lough are shown in Figure 55.

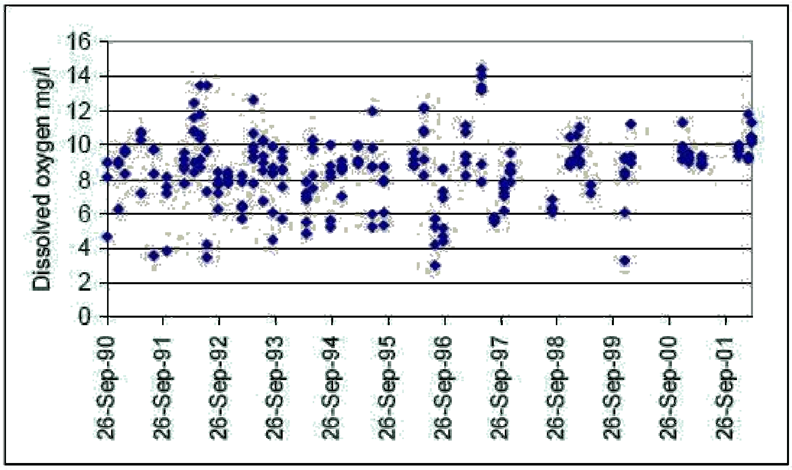


Figure 55 – Dissolved oxygen concentrations in inner Belfast Lough, taken from the ECWMP Routine Monitoring Station (EHS, 2003).

Throughout the years, it is clear that the amount of dissolved oxygen in the inner Lough has been increasing. As the concentrations of nitrogen from industry, have reduced progressively, the conditions were more favourable for the presence of oxygen and biotic life in the Lough. Therefore it is considered that there are no biologically stressful conditions in the seawater zone of Belfast Lough.

As mentioned previously for chlorophyll a, the values obtained for the mixing zone will be considered in this assessment, although there is a possibility of some improvement of the quality of the water in recent years. Therefore, the spatial coverage and frequency of occurrence were determined for the available data. In Figure 56, the frequency of occurrence of low values of dissolved oxygen throughout the year for the mixing zone in Belfast Lough, is presented.

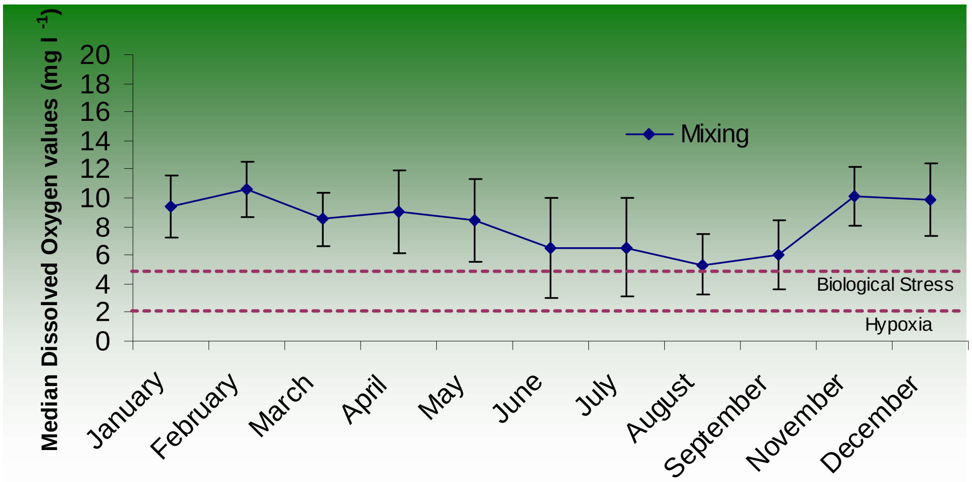


Figure 56 – Annual median values of dissolved oxygen in the mixing zone of Belfast Lough, with error bars representing standard deviation.

It is considered that the frequency of occurrence in this homogeneous area is periodic, due to the clear problems with the concentrations of dissolved oxygen during the summer months. There is also a specific pattern between the concentration of dissolved oxygen observed and the distance to the mouth of the river, as it is shown in Figure 57.

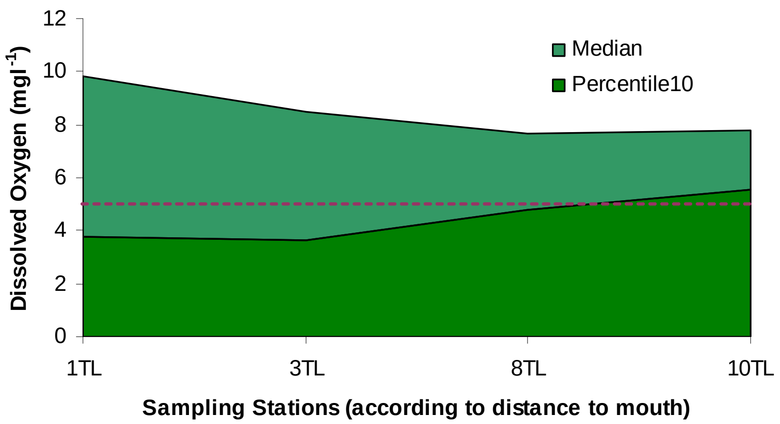


Figure 57 – Longitudinal profile of dissolved oxygen in the mixing zone of Belfast Lough.

Values of Dissolved oxygen recorded in Tidal Lagan, reveal that the higher the distance to the mouth of the river, the more the influence of point source discharges is felt in this zone. This is clearly observed by the difference between the median and percentile 10 values which is somewhat higher according to this distance. Therefore, considering the area of coverage of each station, determined before, the mixing zone of Belfast Lough is classified as “High” in terms of spatial coverage, which corresponds to 58% of the total area.

6.2.5.2.2 Nuissance and Toxic Blooms

Some monitoring campaigns for occurrence of exceptional or unusual algal blooms have been performed in Belfast Lough. A more detailed description of the data gathered can be seen in Appendix IV.

Two exceptional toxic blooms have occurred in Inner Belfast Lough during the years sampled: Dinophysis spp and Alexandrium spp. Dinophysis spp are found regularly in the Inner Lough, however, its toxins have only been detected in 2001 on 2 isolated occasions, in March and August of 2001, and on these occasions, the bloom period has been less than 1 month (EHS, 2003). Excessive amount of cells of Alexandrium sp. have been detected in water samples from early April to mid May in 2000, 2001 and 2002, however, tissue samples were collected and no toxicity was detected, at that time. Another event was recorded on one occasion in 10 May 2001, due to a small amount of toxicity from Alexandrium tamarense cysts (EHS, 2003).

Besides these two events, some blooms of Phaeocystis spec., a specie which causes algal scums, are regularly observed in early summer (Service et al., 1996), with no significant impact.

Although the two nuisance species which reside in the Inner Lough, are constantly present, no significant outbreaks of toxicity have occurred in the Lough since July 1996 when toxins were recorded in mussels in excessive values (EHS, 2003). Therefore, no problems with significant impact upon biological resources, for this parameter, are considered in the seawater zone. As for the mixing zone, extensive and sustained blooms of dinoflagellates were found (Charlesworth et al., 2003), without any problems being recorded.

6.2.5.2.3 Submerged Aquatic Vegetation

No information was identified in the literature about the occurrence of problems with submerged aquatic vegetation in any of the homogeneous zones of Belfast Lough. The results of the ASSETS index application for secondary symptoms in Belfast Lough, are presented in Table 25.

Table 25 - Results of the ASSETS index application for secondary symptoms in Belfast Lough.

Zone	Area (km^2) (A_Z)	Value (v_{ij})			$A_Z/A_t \times v_{ij}$		
		Dissolved O_2	SAV	Blooms	Dissolved O_2	SAV	Blooms
Seawater	1129,68	0	0	0	0	0	0
Mixing	0,32	0,5	0	0	0,001	0	0
Sum	130	-	-	-	0,001	0	0
Secondary symptoms level of expression value for the estuary: 0.001 Low							

6.2.6 Determination of Future Outlook

The requirements for sustainable management of the water bodies demanded by the WFD, make it essential for a closer surveillance and accompaniment to be performed in Belfast Lough and its catchment. Similarly to Strangford Lough, this is addressed by the North Eastern River Basin District Management Plan.

The current status and proposed objectives for improving the quality of the river water bodies in Belfast Lough Management Area, is shown in Figure 58.

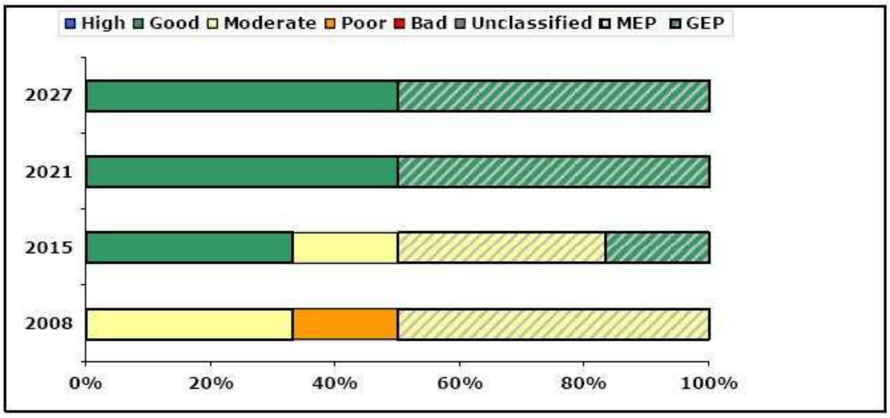


Figure 58 - Current status and proposed objectives for river water bodies in the Belfast Lough Management Area 2008-2027 (MEP and GEP are Moderate and Good Ecological Potential, respectively) (taken from NIEA, 2008d).

All the river water bodies in the Belfast Lough area have been classified as less than good status and, therefore, some actions need to be taken globally in order to invert the situation. It is proposed that some small rivers should achieve good ecological status by 2015, with all other water bodies, particularly, river Lagan, achieving good status by 2021 (NIEA, 2008d).

Regarding coastal water bodies in the Belfast Lough Management Area, two areas are defined: Belfast Inner Lough (designated as Heavily Modified) and Outer Lough. The current status and proposed objectives for improving the quality of these two coastal water bodies in Belfast Lough Management Area, is shown in Figure 59.

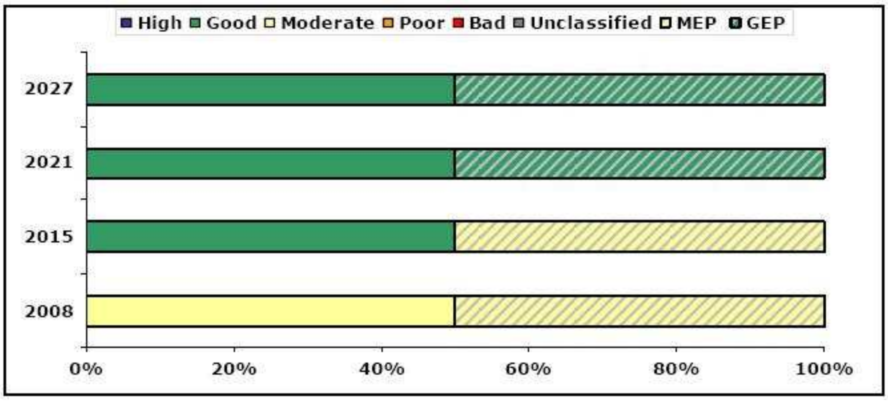


Figure 59 - Current status and proposed objectives for Inner and Belfast Lough (MEP and GEP are Moderate and Good Ecological Potential, respectively) (taken from NIEA, 2008d).

Both of them are currently classified as moderate (ecological potential for Inner and status for Outer), but it is proposed these will both achieve good status by 2021 (NIEA, 2008d).

The most important future pressures in terms of nutrient inputs to the Lough are agriculture, population and wastewater treatment works. All of them are considerably accounted for in the North Eastern River Basin Management Plan and in terms of agriculture pressures it applies the same measures described in this same chapter for Strangford Lough. Thus, a value of 50 % was considered for overall improvement in terms of agricultural pressures to Belfast Lough in the future.

In terms of population pressures, the results of the census mentioned before for Strangford Lough, show that, similarly to the whole country, the population in most of the District Council areas located in the Belfast Lough catchment, experience a population increase, although with a reduction in the percentage increase between the last years. Therefore, for Carrickfergus, North Down, Lisburn and Newtownabbey, the population is expected to increase for the next years, although with a slower pace.

The exceptions to this growth are the Belfast and Castlereagh District Councils, whose population in the last years have been decreasing and therefore, is expected to continue this slight decrease for the next years. In the case of Belfast, this is the district with highest amount of population, by far, and its decrease is more significant. Due to this scenario, a value of 25% increase was set, in terms of future pressures for Belfast Lough. This is meant to take into consideration the general increase of population and, at the same time, accounting for the expected decrease in the most populated district of Northern Ireland.

Regarding wastewater treatment works, in Belfast Lough, they are also, in general, subject to the same effective measures proposed by the North Eastern River Basin District Plan, like it was mentioned before for Strangford Lough. More specifically, the modifications to the major WWTW discharging in the rivers and in the catchment area of Belfast Lough, are described in Table 26.

Table 26 – Modifications to the major Wastewater Treatment Works discharging in the rivers and catchment area of Belfast Lough.

WWTW	New Population Equivalent	Modification in Treatment
Belfast	319 000	Upgraded to tertiary treatment in 2005
Kinnegar	-	Upgraded to tertiary treatment in 2001
Whitehouse	-	Upgraded to tertiary treatment in 2008
Briggs Rock	-	No tertiary treatment performed or scheduled
Dunmurry	-	Upgraded to tertiary treatment (phosphorous removal), with works completed in 2009 and currently being proposed for nitrate removal
New Holland	-	Upgraded to tertiary treatment (phosphorous removal), with works completed in 2009 and currently being proposed for nitrate removal

The majority of the works throughout the catchment are well equipped and prepared, however, some problems still exist. The most problematic situations have been referred to in Briggs Rock, because of lack of nitrogen removal, in Seahill, where only primary treatment is performed and in Bangor and Whitehead where raw wastewater is discharged directly into the Lough and no immediate measures have been found to solve this issue (Friends of the Earth, 2009). Also, due to its size, the WWTW in Dunmurry and New Holland, should immediately be equipped with nitrate removal, which is at the moment in the planning phase. The fact that this Lough has numerous WWTW in its catchment is a problem which has to be always addressed in any management decision.

In terms of industrial pressures, which could, hypothetically, be applied to Belfast Lough in case the industrial fertilizer plant would be kept in production, this does not apply anymore since this factory was closed in 2002. There are some small industrial activities present in the catchment, whose inputs are accounted for in the WWTW effluents.

When considering the general improvements planned at a global scale in Northern Ireland, concerning wastewater treatment facilities and septic tanks, the expected scenario is a favourable one. Also, the effective improvements in the major works and, particularly, in the industrial sources, have delineated good future prospects for Belfast Lough. However, the significant problematic situations found in some WWTW without any solution for improvement in the near future, make it that a value of only 50% improvement in terms of wastewater treatment pressures, should be defined in this situation.

6.2.6.1 Climate Change

The expected problems derived from climate change in the future, will affect all the Loughs in Northern Ireland in a similar way. Some of the major concerns were previously addressed in the assessment for Strangford Lough, however, the more detailed effects of climate change on the marine environment in Northern Ireland and the necessary measures to reduce its effects, can be found in Appendix V.

Some considerations can be made, concerning Belfast Lough, in comparison with the other Loughs. Because, if the increase in temperatures might accelerate the problems due to chlorophyll a growth, the increase in precipitation will not affect so seriously the inputs of nutrients, as in other Loughs, because of the less predominant rural characteristics of the catchment.

6.2.7 Final Score

Table 27 summarizes the results obtained for the ASSETS methodology application in Belfast Lough. The application of the final calculation matrix, provides an overall classification of the estuary as “Moderate”.

Table 27 - Summary of the results obtained by the application of ASSETS methodology to Belfast Lough. EAR: Estuary Aggregation Rules; PSM: Primary Symptoms Method; SSM: Secondary Symptoms Method.

<table>
<tr><th>Indices</th><th>Methods</th><th colspan="3">Parameters/Value/EAR</th><th>Index category</th></tr>
<tr><td rowspan="3">Overall Eutrophic Condition (OEC)</td><td>PSM</td><td>Chlorophyll a
Macroalgae</td><td>0,252
0,501</td><td>0,38 Moderate</td><td rowspan="3">Moderate Low</td></tr>
<tr><td rowspan="2">SSM</td><td>Dissolved oxygen
Submerged aquatic vegetation</td><td>0,001
0</td><td rowspan="2">0,001 Low</td></tr>
<tr><td>Nuisance and toxic blooms</td><td>0</td></tr>
<tr><td rowspan="2">Overall Human Influence (OHI)</td><td>Susceptibility</td><td>Dilution potential
Flushing potential</td><td>Moderate
Moderate</td><td>Moderate Susceptibility</td><td rowspan="2">Moderate High</td></tr>
<tr><td>Nutrient inputs</td><td colspan="3">High nutrient input</td></tr>
<tr><td>Future Outlook for future conditions (DFO)</td><td>Future nutrient pressures</td><td colspan="3">Future nutrient pressures decrease</td><td>Improve Low</td></tr>
</table>

6.2.8 Conclusions

Belfast Lough is a relatively open system with low average depths, low freshwater flow, which reduces stratification, and moderate flushing rates. However, it is possible that climate change events might alter this fact in the future, especially, because of the shallow waters.

The nutrient inputs draining into the Lough are mainly from urban areas, once this water body is the one with a highest percentage of urban occupation in its catchment. Agriculture has also a significant presence. Although, the nutrient concentrations in its waters do not surpass the thresholds defined in the UWWTD, there are still several sources and amount of nutrients being transported to the Lough, which have to be addressed. The most affected area is the Inner Lough, followed closely by the Tidal Lagan and Outer Lough to a lesser extent. Most of the problems are due to macroalgae and chlorophyll a. These should be the parameters of concern for the adoption of corrective measures.

For Belfast Lough more consistent sampling campaigns are needed, since that, in the last campaigns conducted in recent years, the temporal data was slightly distorced and there was much inconsistency between the sampling campaigns for Tidal Lagan. For the future, an extension of the routine sampling campaigns, should be addressed and the parameters should be enlarged, in order to effectively address macroalgae and submerged aquatic vegetation, once no data was found concerning this parameter. A centralised data management is useful for this particular Lough, because of its environmental and economical importance. Also, given the multiple uses of the Lough, appropriate levels of activity and zonation of such activities must be planned and regulated.

The planned management activities for the Lough in terms of reducing nitrate inputs from agricultural activities and a stricter control of those activities, are fundamental for the improvement in the classification. Also, the higher quality treatment performed in the WWTW and the enlargement of the amount of population served by sewerage networks, are the right management decisions. If the Management Plan outlined is put into place, a significant improvement in the status of the coastal water in Belfast Lough is expected. However, according to the information gathered, there are some WWTW which are discharging raw sewerage directly into the Lough and others which do not have proper treatment, particularly, nitrogen removal. These situations get worse when are qualifying plants, which discharge into sensitive zones. These are the highest priority measures to perform in the estuary.

The closure of the industrial fertilizer plant, was a very adequate measure and it is expected that, in time, the system will improve significantly. Until this moment, the nitrogen reductions are visible, but the direct effects are not yet completely clear, particularly, at the Inner Lough. For the future, the plant should remain closed, as well as other industrial activities, should be better detailed and controlled. Particularly, more details are needed concerning the heavily modified Belfast Harbour, in the Inner Lough.

In terms of socio-economical activities, Belfast Lough is currently, home to several leisure and industrial practices which might be affected with reduced water quality. Leisure activities such as, fishing, boating and tourism can be affected by the impoverishment of natural characteristics of the Lough and physical manoeuvrability. The small industries of the harbour may also suffer the consequences of stricter regulations applied to the Lough. Aquaculture is also an activity which is growing in Belfast Lough and has to be followed with close attention, since that, if performed in a sustainable way, it can influence positively the overall status of water quality.

Regarding the methodology used, some improvements could be performed, particularly what refers to the fact that SAV might not exist and therefore, the weight considered for macroalgae and this parameter, which are interrelated, should be better evaluated.

The classification obtained with ASSETS was “Moderate”, which is the same as for the WFD. Therefore, the proposed measures should be put in place and the classification as a sensitive area must be maintained and the designation as a vulnerable zone should be reinforced.

7 Conclusion

Before the start of this assessment, some signs of alert were felt, concerning the status of the Northern Irish Loughs, in terms of eutrophication. After the assessment, it is possible to conclude that, at least in these two water bodies, human-related activities have been highly influential, in the current status of the Loughs, mainly, due to the inputs of nitrogen from their catchments.

Although the two Loughs are, geographically, very close to each other, they are physically very different and are affected by different sources of nutrient inputs. Strangford Lough is a more natural system, influenced almost completely by the agriculture activities in the catchment and therefore, the management options should focus on this aspect. Belfast Lough is a more polluted system, affected almost equally by urban and agriculture occupations of its catchment, which should focus the managerial attention on the reduction of nutrient inputs from these areas.

Belfast Lough status appears to have improved from the last 20 years and Strangford Lough, in opposition has worsened its condition. This is particularly serious because of the specific and intrinsic natural environmental conditions of this water body. In Belfast Lough the most problematic indicators are chlorophyll a and macroalgae and in Strangford Lough it are macroalgae and submerged aquatic vegetation. It is expected that the programme of measures defined under the siege of the WFD, should improve significantly both Loughs.

Besides this, more consistent and wider sampling campaigns should be conducted, under a centralized management, which can have access to resources, such as, remote sensing data and web access. The ECWMP is a good tool and should be maintained and enlarged to more parameters, such as, macroalgae and submerged aquatic vegetation monitoring. In Belfast Lough more information on SAV is needed, in order to establish a better assessment. The most available data was from chlorophyll a and salinity. Dissolved oxygen data was also found to a certain extent and these sampling campaigns should be continued and sustained.

Climate change may also be a significant influence on the development of future eutrophic symptoms, because of the following main reasons: warmer waters hold less oxygen; flushing times and exchange rates may increase with rising sea levels and increased rainfall. With changing hydrology, there is also a possibility of the exacerbation or novel occurrence of stratification.

In terms of socio-economic activities, both Loughs might be affected with the continuation of the scenario achieved, particularly, in terms of leisure activities and aquaculture. Belfast Lough will, hypothetically, also be affected significantly by the reduction in navigation conditions and stricter regulations for its harbour activities and Strangford Lough will, probably suffer from reduction in tourism.

The ASSETS model proved to be very effective when comparing with other models previously described, because of its adaptability to several scenarios and its consistent approach to eutrophication. This is particularly noticeable in what concerns to the attribution of different weighting across indicators which is not performed by the OSPAR Common and Comprehensive Procedure and also by considering the water body as a whole. By adopting this method, it was possible to analyse the weighed influence of submerged aquatic vegetation and macroalgae in Strangford Lough, which was determinant for the evaluation of the main parameters to focus on.

Also, it is a very useful tool for comparing ecosystems using a standardized approach, which is fundamental for shaping the management decisions at both regional, national and international level.

During the application of ASSETS, some difficulties were found, which could be considered limitative to the good performance of the work. These were: the determination of biological stressful conditions for the mixing zone of Strangford Lough, whose high values were reported in literature to be equally valuable as sign of problems with dissolved oxygen in the system; the determination of future nutrient pressures; and relation with missing parameters. The first case can be, possibly, solved by the introduction of a vertical dispersion coefficient, the second case would benefit from the introduction of more options in terms of data to be introduced for the three future pressure indicators and the last situation can be improved by adopting options for systems where no SAV is found.

Finally, it should be mentioned that in order to provide managers and decision-makers with simple and scientific options for their work, a socio-economical tool could be added to this methodology.

Because the classification achieved for both Loughs did not improve or achieved good status, their classification defined in the Directives involved should be maintained.

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9 Appendixes

Appendix I – Matrix used in the Definition of the Final Classification of ASSETS

Grade	5	4	3	2	1
Pressure (OHI)	Low	Moderate low	Moderate	Moderate high	High
State (OEC)	Low	Moderate low	Moderate	Moderate high	High
Response (DFO)	Improve high	Improve low	No change	Worsen low	Worsen high

Metric	Combination matrix	Class
P	5 5 5 4 4 4	High
S	5 5 5 5 5 5	
R	5 4 3 5 4 3	
P	5 5 5 5 5 5 5 4 4 4 4 4 3 3 3 3 3 3	Good
S	5 5 4 4 4 4 4 5 5 4 4 4 5 5 5 4 4 4	
R	2 1 5 4 3 2 1 2 1 5 4 3 5 4 3 5 4 3	
P	5 5 5 5 5 4 4 4 4 4 4 4 3 3 3 3 3 3 3 2 2 2 2 2 2 2 2 2 1 1	Moderate
S	3 3 3 3 3 4 4 3 3 3 3 3 5 5 4 4 3 3 3 4 4 4 4 4 3 3 3 2 3 3	
R	2 1 5 4 3 2 1 5 4 3 2 1 2 1 2 1 5 4 3 5 4 3 2 1 5 4 3 5 5 4	
P	4 4 4 4 4 3 3 3 3 3 3 3 2 2 2 2 2 2 1 1 1 1 1	Poor
S	2 2 2 2 2 3 3 2 2 2 2 2 3 3 2 2 2 2 3 3 3 2 2	
R	5 4 3 2 1 2 1 5 4 3 2 1 2 1 4 3 2 1 3 2 1 5 4	
P	3 3 3 3 3 2 2 2 2 2 1 1 1 1 1 1 1 1	Bad
S	1 1 1 1 1 1 1 1 1 1 2 2 2 1 1 1 1 1	
R	5 4 3 2 1 5 4 3 2 1 3 2 1 5 4 3 2 1	

Figure 60 - Combination of pressure (OHI), state (OEC) and response (DFO) components to provide the final classification grade of the ASSETS methodology (Bricker et al., 2003)

Appendix II – Schematic Representation of the Calculation of Overall Eutrophic Condition

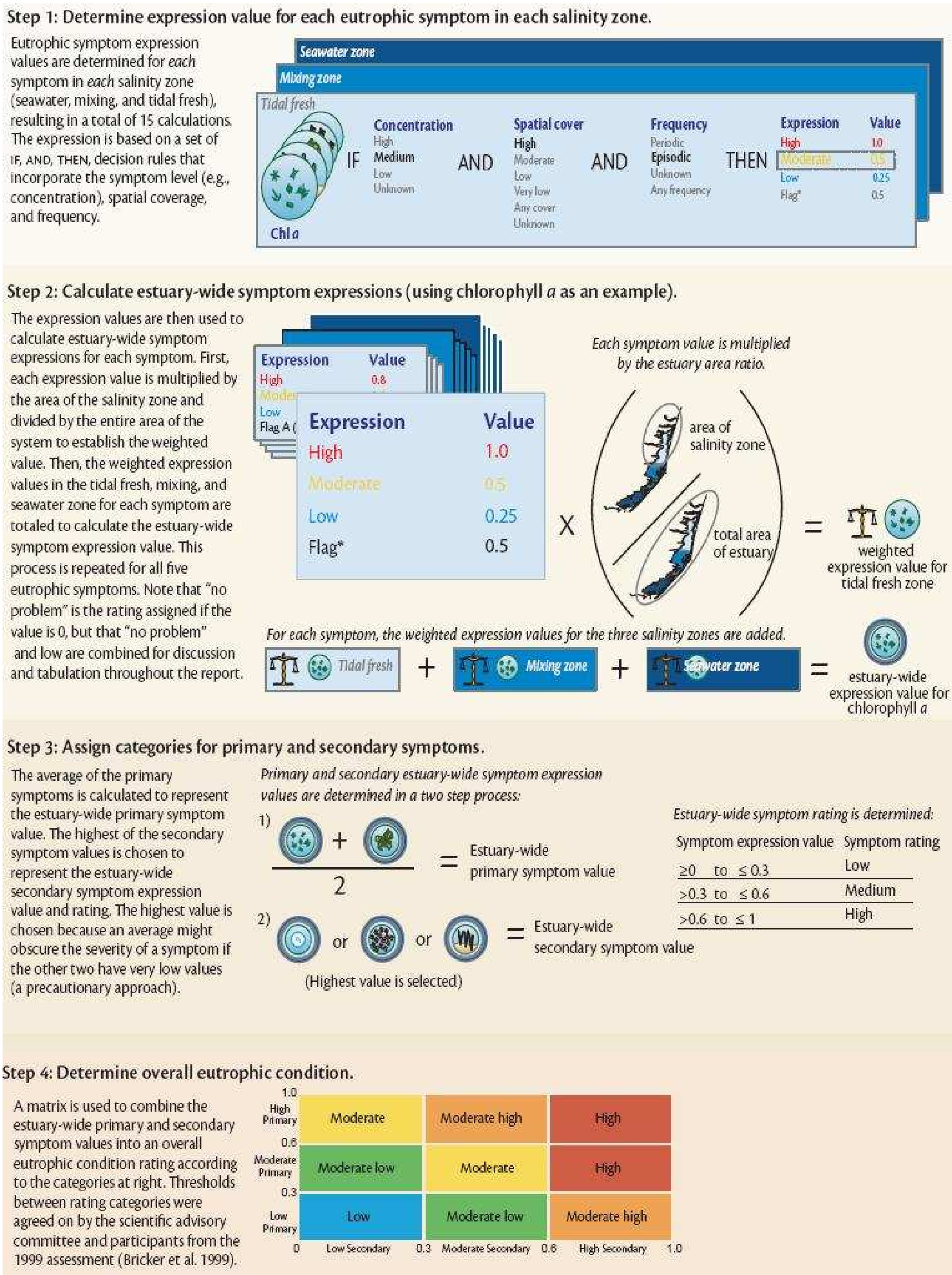

Figure 61 – Schematic example of the calculation of OEC in ASSETS (Bricker et al., 2007).

Appendix III – Calculation of the Nutrient Pressures to the Loughs

Strangford Lough

Nitrogen due to WWTW

Population = 101 740 (Foy & Girvan, 2004)

Nitrogen per capita = 2,03 kg N PE^{-1} yr^{-1} (Foy & Girvan, 2004)

Load = 101 740 x 2,03 = 206 tones / year

Nitrogen due to the Catchment of Rivers

By using the Nitrate Export Coefficients from agricultural land use types provided by Foy & Girvan (2004) and after the calculation of the agricultural area in the catchment, it is possible to achieve a value for N inputs due to agricultural activities in the catchment of rivers.

- Quoile

A = 233 800 000 m^2

Total N = 385,2 + 10,8 = 396 tones / year

- Enler

A = 62 700 000 m^2

Total N = 108 + 2,8 = 110,8 tones / year

- Blackwater

A = 50 100 000 m^2

Total N = 94,4 + 2,4 = 96,8 tones / year

Nitrogen due to the Direct Drainage

- Quoile

Area = 33,7 Km^2

Loads = 58 + 1,6 = 59,6 tones / year

- Strangford Total

Area = 207,4 Km^2

Loads = 355,9 + 9,4 = 365,3 tones / year

<u>Nitrogen due to Septic Tanks</u>

- If an analysis is performed in a very simple way, just regarding the amount of people in Northern Ireland, whose wastewater is treated, then:

300 000 People in NI without Sewerage Treatment (NIEA, 2008j)

1 742 000 People in NI total (Northern Ireland Statistics and Research Agency: Census Population for Northern Ireland 1996 and 2001)

144 000 People in Strangford Lough (according to the Census – 2006 estimate for Administrative areas of Down and Ards)

X = 24 799 People in Strangford Lough without Wastewater Treatment

- Or just a simple calculation between people served with wastewater treatment and total population in Strangford Lough catchment:

144 000 People in Strangford Lough (according to the Census – 2006 estimate for Administrative areas of Down and Ards)

101 740 served with wastewater treatment in Strangford Lough (Foy & Girvan, 2004)

X = 42 260 People in Strangford Lough without Wastewater Treatment

The second option was chosen because it was considered ot be more representative of the people in the catchment of Strangford Lough served with septic tanks.

Average Value of N Kg PE^{-1} yr^{-1} = 1,85 (Foy & Girvan, 2004)

Loads = 42 260 x 1,85 = 78 tones / year

Total Loads in Strangford Lough = 1313 tones / year

Flow into Strangford Lough = 510 x 10^6 m^3/year (Service et al., 1996)

Concentration = 1 313 000 000 000 / 510 000 000 000 = 2,6 mg/l = 0,0026 kg/m^3

When using the Equation for Conservative Processes used in Bricker et al. (2003), the final result is achieved:

Estuary

Salinity in the Lough = 33
Salinity in the ocean = 34
Concentration = 0,0026 kg/m^3

mh (N concentration in estuary) = 0,0026 x (34 – 33) / 34 = 0,000076

Ocean

Salinity in the Lough = 33
Salinity in the ocean = 34
Concentration = 0,000125 kg/m^3

mb (N concentration in ocean) = 0,000125 x 33 / 34 = 0,00012

Total

mc = 0,000076 + 0,00012 = 0,000196

mh / mc = 0,39 (Moderate Nutrient Input)

Belfast

Nitrogen due to WWTW

Population Lagan = 138 488 (Foy & Girvan, 2004)
Nitrogen per capita = 1,81 kg N PE^{-1} yr^{-1} (Foy & Girvan, 2004)

Loads = 138 488 x 1,81 = 251 tones / year

Population Inner Lough = 290 640 (Foy & Girvan, 2004)
Nitrogen per capita = 1,44 kg N PE^{-1} yr^{-1} (Foy & Girvan, 2004)

Loads = 290 640 x 1,44 = 419 tones / year

Population Outer Lough = 106 555 (Foy & Girvan, 2004)
Nitrogen per capita = 1,95 kg N PE^{-1} yr^{-1} (Foy & Girvan, 2004)

Loads = 106 555 x 1,95 = 208 tones / year

Nitrogen due to the Catchment of River Lagan

By using the Nitrate Export Coefficients from agricultural and urban land use types provided by Foy & Girvan (2004) and after the calculation of the agricultural and urban area in the catchment, it is possible to achieve a value for N inputs due to agricultural activities in the catchment of river Lagan.

A = 499 600 000 m^2

Total N = 1070 + 63,7 1134 tones / year

Nitrogen due to the Direct Drainage

- Tidal Lagan

Area = (20,2 % + 77,3 %) x 591,9 = 577 km^2

Loads = 38 + 1 = 39 tones / year

- Inner Lough

Area = (30,3 % + 58,5 %) x 103,7 = 92 km^2

Loads = 76 + 116 +344 + 3 = 539 tones / year

- Outer Lough

Area = (34,3 % + 63,3 %) x 108,9 = 106 km^2

Loads = 5 + 131 + 366 + 3 = 505 tones / year

<u>Nitrogen due to Septic Tanks</u>

- If an analysis is performed in a very simple way, just regarding the amount of people in Northern Ireland, whose wastewater is treated, then:

300 000 People in NI without Sewerage Treatment (NIEA, 2008j)

1 742 000 People in NI total (Northern Ireland Statistics and Research Agency: Census Population for Northern Ireland 1996 and 2001)

646 000 People in Belfast Lough (according to the Census – 2006 estimate for Administrative areas of Belfast, Lisburn, North Down, Carrickfergus, NewtownAbey and Castlereagh)

X = 111 251 People in Belfast Lough without Wastewater Treatment

- Or just a simple calculation between people served with wastewater treatment and total population in Belfast Lough catchment:

646 000 People in Belfast Lough (according to the Census – 2006 estimate for Administrative areas of Belfast, Lisburn, North Down, Carrickfergus, NewtownAbey and Castlereagh)

535 683 people served with wastewater treatment in Belfast Lough (Foy & Girvan, 2004)

X = 110 317 People in Belfast Lough without Wastewater Treatment

The second option was chosen because it was considered to be more representative of the people in the catchment of Belfast Lough served with septic tanks.

Average Value of N Kg PE^{-1} yr^{-1} = 1,85 (Foy & Girvan, 2004)

Loads = 110 317 x 1,85 = 204 tones / year

Total Loads in Belfast Lough = 3229 tones / year

Flow into Belfast Lough = 1022 x 10^6 m^3/year (Service et al., 1996)

Concentration = 3 229 000 000 000 / 1 022 000 000 000 = 3,16 mg/l = 0,00316 kg/m^3

When using the Equation for Conservative Processes used in Bricker et al. (2003), the final result is achieved:

Estuary

Salinity in the Lough = 28
Salinity in the ocean = 34
Concentration = 0,00316 kg/m^3

mh (N concentration in estuary) = 0,00316 x (34 – 28) / 34 = 0,00056

Ocean

Salinity in the Lough = 28
Salinity in the ocean = 34
Concentration = 0,000125 kg/m^3

mb (N concentration in ocean) = 0,000125 x 33 / 34 = 0,00012

Total

mc = 0,00056 + 0,00012 = 0,00068

mh / mc = 0,82 (High Nutrient Input)

Appendix IV - Harmful and Toxic Blooms: Results of monitoring campaigns

Table 28 – Results of the monitoring campaigns, regarding harmful and toxic blooms, performed in the northern part of Strangford Lough (EHS, 2005a).

Phytoplankton species & OSPAR Guideline	**Detected by**	**Concentration**	**Guideline Exceedence**
Nuisance Species			
Phaeocystis spp >10^6 cells/l for extended periods	DARDNI	620 cells/l (Reagh Bay 27/05/2003) 8860 cells/l (Paddy's Point 27/05/2003)	No No
Noctiluca scintillans 10^3 cells/l	DARDNI	Absent or not recorded	No
Potentially Toxic Species			
Chrysochromulina polylepis >10^6 cells/l	DARDNI	Absent or not recorded	
Karenia mikimotoi (Previously ***Gyrodinium auroleum***) >10^6 cells/l	DARDNI	Absent or not recorded	No
Alexandrium spp >10^2 cells/l	DARDN	Absent or not recorded	No
Dinophysis spp >10^2 cells/	DARDNI	Absent or not recorded	No
Prorocentrum spp >10^4 cells/l	DARDNI	Absent or not recorded	No

Table 29 - Results of the monitoring campaigns, regarding harmful and toxic blooms, performed in the southern part of Strangford Lough (EHS, 2005a).

Phytoplankton species & OSPAR Guideline	Detected by	Concentration	Guideline Exceedence
Nuisance Species			
Phaeocystis spp $>10^6$ cells/l for extended periods	DARDNI	10000 cells/l (The Dorn 13/05/2003) 4960 cells/l (Marlfield Bay 27/05/2003) 2480 cells/l (The Dorn 27/05/2003) 560 cells/l (Skate Rock 27/05/2003) 3020 cells/l (Skate Rock 02/06/2003)	No No No No No
Noctiluca scintillans 10^3 cells/l	DARDNI	20 cells/l (Marlfield Bay 21/07/2003)	No
Potentially Toxic Species			
Chrysochromulina polylepis $>10^6$ cells/l	DARDNI	Absent or not recorded	
Karenia mikimotoi (Previously *Gyrodinium auroleum*) $>10^6$ cells/l	DARDNI	20 cells/l (Marlfield Bay 12/02/2003) 20 cells/l (Skate Rock 21/07/2003) 20 cells/l (Marlfield Bay 16/08/2004) 20 cells/l (Skate Rock 25/07/2005) 20 cells/l (MarlfieldBay 08/08/2005)	No No No No No
Alexandrium spp $>10^2$ cells/l	DARDNI	(Marlfield Bay 21/06/2004)	No
Dinophysis spp $>10^2$ cells/	DARDNI	D.acuminata 260 cells/l (Marlfield Bay 21/06/2004) D.acuminata 220 cells/l (Skate Rock 21/06/2004) D.acumiata 520 cells/l	Yes Yes Yes
		(Marlfield Bay 24/06/2004) D.acuminata 720 cells/l (Skate Rock 24/06/2004) D.acuminata 260 cells/l (Marlfield Bay 28/06/2004) D.acuminata 460 cells/l (Skate Rock 28/06/2004)	Yes Yes Yes
Prorocentrum spp $>10^4$ cells/l	DARDNI	Absent or not recorded	

Table 30 – Analysis of the toxic effects and the threshold value according to the UK and OSPAR Procedure, regarding toxic species which are ikely to be present in Strangfrod Lough (Roberts et al., 2004).

Species	**Toxin/Effects**	**Threshold value**
Alexandrium minutum	Paralytic shellfish toxin	Presence
Alexandrium tamarense	Paralytic shellfish toxin	Presence
Chrysochromulina polylepis	Toxic to fish	None
Dinophysis acuminata	Diarrheic shellfish toxin	> 100 cells L^{-1}
Dinophysis acuta	Diarrheic shellfish toxin	> 100 cells L^{-1}
Dinophysis norvegica	Diarrheic shellfish toxin	> 100 cells L^{-1}
Dinophysis rotundata	Diarrheic shellfish toxin	> 100 cells L^{-1}
Dictyocha speculum	Harmful to fish	None
Gymnodinium mikimotoi	Toxic to fish	None
Gymnodinium catenatum	Paralytic shellfish toxin	Presence
Gymnodinium spp.	Some species toxic to fish	None
Heterosigma akashiwo	Toxic to fish	None
Lingulodinium polyedrum	Yessotoxin (DSP like)	> 100 cells L^{-1}
Noctiluca scintillans	Toxic to fish	None
Prorocentrum lima	Diarrheic shellfish toxin	> 100 cells L^{-1}
Prorocentrum minimum	Venerupin shellfish poisoning	None
Pseudo-nitzschia spp.	Amnesic shellfish poisoning	> 150,000 cells L^{-1}
Prymnesium parvum	Toxic to fish	None
Phaeocystis sp.	Not known	None
Protoperidinium spp.	DSP like	Presence

Table 31 - Results of the monitoring campaigns, regarding harmful and toxic blooms, performed in the Inner Belfast Lough (EHS, 2003).

Phytoplankton species & OSPAR Guideline	Detected by	Concentration	Guideline Exceedence
Nuisance Species			
Phaeocystis spp $>10^6$ cells/l for extended periods	DARD 2000 2001 2002	 Low numbers Low numbers Low numbers	 No No No
Noctiluca scintillans 10^3 cells/l	DARD 1998	 Present	 No
Potentially Toxic Species			
Chrysochromulina polylepis $>10^6$ cells/l	None found		
Gymnodinium mikimotoi $>10^6$ cells/l	EHS May 1994 Sept 1996 June 1998 DARD 2000 2001 2002	 4200 cells/l 1400 cells/l 1400 cells/l Present Present Present	 No No No No No No
Alexandrium spp $>10^2$ cells/l	DARD April 1998 Sept 1999 May 2000 May 2001 May 2002	 4900 cells/l 20 cells/ 320 cells/ 180 cells/ 7800 cells/	 Yes No Yes Yes Yes
Dinophysis spp $>10^2$ cells/l	EHS Sept 1994 Sept 1996 Oct 1997 June 1999 Aug 2001 DARD May 1998 2000 Aug 2001 Aug 2002	 1400 cells/l 1400 cells/l 1400 cells/l 4200 cells/l 32200 cells/l 680 cells/l Present 520 cells/l 400 cells/l	 Yes Yes Yes Yes Yes Yes Yes Yes
Prorocentrum spp $>10^4$ cells/l	EHS Aug 1995 Sept 1996 Oct 1997 Feb 1998 Sept 1999 Aug 2001 2002	 19600 cells/l 1400 cells/l 1400 cells/l 1400 cells/l 23800 cells/l 63000 cells/l Present	 Yes No No No Yes Yes

Appendix V – Implications and Measures for Adaptation to Climate Change

Table 32 - Summary of the implications of Climate change on the water environment (NIEA, 2008a).

Pressure type	Potential implications of climate change
Diffuse & point source pollution	• higher river flows will reduce the impact of pollution in rivers, but may increase loading of pollutants to the sea. This could increase the risk of the failure of microbiological standards in bathing waters and shellfish waters • higher rainfall with more intense episodes may increase loads of diffuse pollutants from both urban and rural areas • during periods of lower summer flow, some point source discharges may no longer be adequately diluted • lower summer flows can also cause reduction in sewer base flows , leading to blockages and potential flooding risks • higher intensity rainfall in summer following dry periods will increase combined sewer overflow discharges and consequent damage to aquatic life • lower summer river flows, along with higher temperatures reducing the dissolved oxygen in water bodies, will provide less dilution for discharges, leading to increased sewage treatment costs and energy usage • enhanced algal and plant growth due to increased temperature and increased nutrient run-off will exacerbate the effects of eutrophication. Increased temperature may also cause problems through dissolved oxygen depletion.

Morphology	• the possibility of more frequent and severe river flooding will increase requirements for flood defence schemes and sustainable flood management • more intense rainfall and higher flows will result in higher rates of river erosion • higher rainfall will lead to an increased risk of slope failure causing local hazards and the input of sediments into water courses • increased erosion from land can lead to siltation of fish spawning gravels and increased nutrient loading to loughs and marine waters • rising sea levels will impact on low-lying coast and transitional waters, and may be exacerbated by larger and more frequent storm surges. This will cause increased coastal flooding in vulnerable areas and more coastal erosion.
Alien Species	• higher temperatures, changing hydrological conditions and water quality may provide more favourable conditions for invasive non-native species and allow the spread of rare or non-native diseases including those of aquatic species • changes in seasonal cycles may have impact on the interactions between species for example, reduced pollination, changes in migration timing leading to competition between species and earlier or delayed fish spawning • there will be changes in the abundance and distribution of native species and the length of growing season • higher temperatures will be less favourable for some native species • habitats may be affected by changes in land use for example the introduction of new crops to suit new climates, or increased production of biofuels • increased riparian and coastal erosion may adversely affect key native species.

Table 33 - Summary of measures to address the implications of Climate (NIEA, 2008a).

Action Required	Mechanism	Key responsible organisations/ sectors
Take account of changes in flow regimes	- Ensure that licences take account of projected new low-flow regimes - Ensure that flood management plans are adequate for projected new higher-flow regimes - Assess impact of new rainfall patterns on combined storm overflow inputs to water bodies.	Northern Ireland Environment Agency Rivers Agency Northern Ireland Environment Agency /Northern Ireland Water
Assess impact of new climate on flooding	Review historical hydrology data for climate driven trends	Rivers Agency
Ensure groundwater abstractions are sustainable	Review groundwater abstraction licences to assess likely future water requirement and groundwater levels.	Northern Ireland Environment Agency
Understand existing and future trends in run-off of pollutants	Assess existing data for long term trends Assess factors which influence whether pollutant concentration are likely to increase or decrease as a result of increased run-off.	Northern Ireland Environment Agency