An Investigation into Side Stream Technologies as a Potential Solution for Reducing Nitrogen Emissions from Municipal Waste Waters in the Irish Situation

by

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ABSTRACT

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This study explicated the requirement to substantially increase the level of nutrient removal facilities at municipal waste water treatment plants on a national scale. This requirement has resulted from recently enacted legislation. The research then considered the options for realisation of these infrastructural improvements.

Revolutionary methods of nitrogen reduction have been established and developed, which target nitrogen-rich side streams from sludge handling processes, for more sustainable nitrogen removal from the main process effluents. Dundalk WWTP was chosen as a case study site, to assess the viability of applying these new technologies in Ireland, and to provide comparison with conventional means. An evaluation of the nitrogen mass balance at Dundalk showed that 45.7% of the main plant total nitrogen load is contained within the ammonium-rich recycle effluents, currently returned untreated to the headworks. Approximately 20% Total Nitrogen reduction is possible at this facility through side stream treatment application.

Two options for side stream treatment were assessed; based on efficiency predictions, both systems would shift the operation of the B-stage treatment process at Dundalk from oxygen limited to ammonium limited, reducing the Total Nitrogen emissions to within acceptable limits. When compared against conventional biological nitrogen removal processes, applying a unitary operational cost driver, the cost of conventional treatment is significantly greater than the side stream options examined. Reduction of nitrogen in a side stream treatment process is more sustainable and energy efficient than nitrogen reduction in a conventional stream.

This study demonstrated that certain side stream technologies exist, which can provide an economically viable option for the various Irish plants requiring such reduction in emissions, whilst reducing the carbon footprint of these facilities. For this reason, the potential use of side stream technology should be afforded due consideration on a national scale.

Pilot plant installation in advance of full-scale implementation at Dundalk is recommended. An opportunity for further study also exists in determining the suitability of this technology for sustainable phosphorus removal from waste waters and for leachate pre-treatment.

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INTRODUCTION & AIMS AND OBJECTIVES

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General

On July 30th 2009, new environmental quality legislation came into effect, namely the European Communities Environmental Objectives (Surface Waters) Regulations 2009 (Irish Government 2009). This legislation established new environmental quality objectives for surfaces waters, which included strict standards for Total Ammonia concentrations (for inland waters) and Dissolved Inorganic Nitrogen concentrations (relating to coastal waters).

Article 4 of the regulations asserts that a Public Authority that has functions, which may affect the achievement of these environmental objectives, shall, *inter alia*:

> *'...ensure, in so far as its functions allow, that- ...surface water bodies comply with the relevant environmental quality standards specified in the Schedules contained in these Regulations...'*
>
> (European Communities Environmental Objectives (Surface Waters) Regulations 2009, 9)

The 2009 surface water regulations provide a vehicle for securing this function by way of a mandatory requirement for examinations and/or reviews of all waste water discharge authorisations; to be undertaken by the appropriate authorities (e.g. the Environmental Protection Agency (EPA)) before a set deadline. The purpose of the reviews is to ensure emission limit values (ELV's) attached to discharge consents support compliance with the new environmental (water) quality standards (EQS's). Indeed this has been reiterated at a recent seminar on the 2009 surface water regulations, whereby it was confirmed that ELV's would be based on such considerations as the 2009 EQS's, assimilative capacities and mass balance (Creed 2010).

The EPA, in their recently-appointed role of granting authorisations for Local Authority municipal waste water discharges, have been cognisant of this, and have attached conditions relating to emission limits for nitrogen and phosphorus to waste water discharge licences granted to date, even in situations where nutrient removal may not be a legislative requirement of the Urban Waste Water Treatment Directive (EC 1991).

The 2009 surface water regulations and the modified administrative responsibilities stem from the Water Framework Directive (EC 2000). Unfortunately EU policy does not always accord with economic reality. The literature review herein discusses the current shortfall in terms of nutrient removal facilities on a national basis. With an anticipated shortage of government funding for any newly emerging required infrastructural improvements (indirectly necessitated by the 2009 surface waters regulations), the potential to upgrade all plants requiring nutrient removal may not be realised. This is further compounded by the fact that an additional ten waterbodies have been designated *'nutrient sensitive'* this year under the Urban Waste Water Treatment (Amendment) Regulations 2010 (Irish Government 2010).

Non-compliance with the Urban Waste Water Treatment Directive relating to inadequate infrastructural provision has, to date, incurred penalties for the State (Smith *et al.* 2009). The project herein will therefore seek to clarify the issue at hand and thereafter will focus upon the potential solutions that may be applied in terms of providing nitrogen reduction facilities where these do not exist, in a cost effective and viable way.

Overall Research Aim and Individual Research Objectives

The overall aims of this research are: firstly, to determine if there are deficiencies associated with existing municipal waste water infrastructure in Ireland (in terms of Local Authority ability to comply with the most up-to-date legislation pertaining to waste water discharges); and secondly, to advance the concept of isolating nitrogen-rich recycle streams in such facilities for specialised biological treatment, with the ultimate aim of considerably reducing nitrogen emissions in primary discharges in a sustainable manner.

Specifically, the objectives of this research are to:

1. Outline the fundamental nitrogen characteristics in sewage.
2. Evaluate the potential consequences of a 'do-nothing' approach towards nitrogen emissions from municipal sources.
3. Identify the legal requirements for nitrogen removal.

4. Investigate waste water treatment infrastructural deficiencies on a national scale.
5. Review the sustainability issues concerning implementation of conventional technology to remedy deficiencies.
6. Evaluate critically the biotechnological advances in side stream nutrient removal.
7. Demonstrate the nitrogen mass balance at municipal facilities via case study (at Dundalk Waste Water Treatment Plant (WWTP)).
8. Produce predictions on effectiveness of and costings for side stream technologies.
9. Formulate recommendations on side stream treatment applicability as a possible means of offsetting upcoming difficulties with legislative compliance.

Several conventional nitrogen reduction methods exist, however new patented processes have also been developed that have already been implemented internationally. Efficient methods of nitrogen reduction have been established in mainland Europe relatively recently. Effluent streams that are both high in ammonia concentration and temperature have the potential to be applied successfully to this new technology. Unfortunately, in Ireland, these effluent streams have not been the focus of laboratory analysis; therefore little is known of their constituents or strengths.

The primary focus of this study will be to determine the presence (or otherwise) of high-strength nitrogen-rich streams in municipal waste water treatment facilities in Ireland via case study analysis. These streams would be expected to derive from anaerobic digestion of sludge. Elevated temperatures are associated with mesophilic digestion, which is a common digestion method in this country. For this reason, Dundalk WWTP has been chosen as an appropriate plant for recycle stream analysis, as mesophilic digestion forms part of the sludge handling process there.

The research herein aims to contribute towards the development of sustainable waste water treatment.

LITERATURE REVIEW

SECTION 1. LITERATURE REVIEW

EPA publications, technical guidance, EU and national legislation and various research papers and publications were drawn upon in the preparation of the literature review.

1.1 Nitrogen in Municipal Waste Water

The fundamental characteristics of nitrogen in sewage are explained hereunder, as frequent references are made to the various forms of nitrogen throughout the study.

Municipal sewage comprises typically 99.9% water with just 0.1% solids (Gray 1999). The solid portion of waste water comprises a mixture of faeces, fats, oils, greases, particles of food, detergents, sand, grit and plastics, etc. Proteins, carbohydrates and fats constitute the organic fraction of sewage, reflective of the human diet. Proteins in sewage are broken down to polypeptides, then to, *inter alia*, individual amino acids, nitrogenous compounds and sulphides (*ibid.*).

Protein and urea provide the main source of nitrogen in sewage. It has been reported that the per capita production of nitrogen in the UK is approximately 6.0g N per day, with an average concentration of ammoniacal nitrogen normally within the range of 25-50mg N/l in raw domestic sewage (IWPC 1987). Therefore, it follows that the concentration of Total Nitrogen is related to the concentration of Biochemical Oxygen Demand (BOD) for any specific domestic influent.

At a very basic level, waste water is generally characterised by the concentrations of BOD, COD, suspended solids, phosphorus and nitrogen present. Nitrogen, arriving at a waste water treatment facility, is present typically in the form of organic nitrogen and ammonium (NH_4-N), the sum of both parameters being termed "Kjeldahl Nitrogen". In conventional municipal sewage treatment, organic nitrogen is converted to ammonia, and this ammonia is then taken up by bacteria and utilised for cell growth. (It is worth noting that nitrogen can be present in activated sludge in the form of nitrite and nitrate; however this form of oxidised nitrogen would not normally be found in raw sewage. Total Nitrogen is the sum of Kjeldahl Nitrogen and oxidised nitrogen).

The negative impacts associated with uncontrolled nitrogen emissions are discussed in the section to follow, to allow the reader to appreciate the potential implications of adopting a 'do-nothing' approach towards legislative requirements.

1.2 Do-nothing Approach

Depending upon site-specific discharge limits, some sewage treatment plants may not include provision for nitrogen removal from waste waters. In the absence of nitrogen removal facilities, potential negative impacts to receiving waters as a result of effluent discharges containing high concentrations of ammonia/nitrogen include: fish mortalities; accelerated eutrophication; and human and animal health issues surrounding drinking water supplies (elaborated further below).

1.2.1 Ammonia Toxicity

Ammonia, although already present in low concentrations in all natural waters, is harmful to aquatic life at more elevated levels. Elevated concentrations of ammonia generally arise from anthropogenic sources, such as improperly treated sewage discharges and agricultural run-off. Heath (1995), reporting on fish mortalities, stated that when death occurs as a result of acute exposure to pollutants, it would often be as a result of *'respiratory homeostatis'*. Kirk and Lewis in 1993 (cited in Heath 1995) used histopathology to study the affect of ammonia on fish gills, and concluded that ammonia *'caused disorganization of lamellae and proliferation of mucus cells'*. Heath also reported on other adverse affects of ammonia on various fish species, such as increased activity on the renal and hypertension functions.

As outlined by Cole *et al.* (1999), in aqueous solution, ammonia forms an equilibrium between non-ionised ammonia (NH_3), the ammonium ion (NH_4^+) and the hydroxide ions. It is the non-ionised fraction of ammonia that is most toxic to aquatic life and to salmonids in particular; nonetheless, the bulk of ammonia encountered in waters is present in the ammonium ion form (EPA 2001).

An issue arises whereby the non-ionised fraction is difficult to measure directly. The proportions of ionised and non-ionised ammonia can be calculated from the Total Ammonia, by considering the salinity, temperature and pH of the water body in question. pH and temperature are major influential factors on the degree of dissociation of the non-ionised ammonia fraction. For example, at pH 8.5, the proportion of non-ionised ammonia in water is approximately 10 times that encountered at pH 7.5. In addition, the proportion of non-ionised ammonia in water approximately doubles for every 9ºC rise in temperature. It is therefore necessary to record the pH and temperature values to calculate the corresponding level of free ammonia (Abel 1996).

Bearing in mind the difficulty to predict free ammonia concentrations given fluctuating pH and temperature, it is frequently deemed appropriate by regulatory authorities to set ELV's and EQS's as 'Total Ammonia' values, to correspond with the safe upper limit of free ammonia.

1.2.2 <u>Nutrient Enrichment</u>

Ammonia, released into receiving waters will oxidise slowly to nitrite, then nitrate, the latter being the last oxidation product of the nitrification process. Nitrogen does not tend to be the limiting nutrient in freshwaters, however nitrate is known to be the main cause of eutrophication and enrichment of estuaries and coastal waters, thus high concentrations of nitrates in receiving waters are not desirable.

Augmented primary productivity as a result of increased nitrogen inputs will inevitably lead to increased productivity for herbivorous and detritivorous animals, hence increased overall productivity in an aquatic ecosystem. It is reported that disproportionate primary productivity would result in the following adverse outcomes (Abel 1996):

- Macrophyte and filamentous algal growth brings about a *'blanketing effect'*, and due to the significant physical changes in habitat, major faunal alterations will occur.
- Dense plant growth respiration can cause dissolved oxygen sags at night when photosynthesis ceases, but also during daytime hours if light penetration is limited due to the blanket growth.

- Certain algal species tend to *'bloom'* (i.e. rapidly reproduce and dominate other indigenous flora) under elevated nutrient conditions. Algal blooms give rise to tainting, discolouration and production of harmful toxins in surrounding waters.
- Ultimate decay of the plant biomass will lead to further enrichment, producing similar end results to the input of further large quantities of allochthonous organic matter.

1.2.3 Health Implications

Both human and animal health issues have been associated with the use of raw water supplies with high nitrogen content. Surface waters with elevated ammonia concentrations, when combined with chlorine for disinfection purposes, can lead to the formation of (mono-, di- and tri-) chloramines (IWPC 1987). Moore and Calabrese (1980) made reference to a link between mutagenicity, carcinogenicity and chlorination of public water supplies containing organics, although acknowledging that this had been a relatively new research area at that time. Following on from that, numerous epidemiological studies were undertaken concerning the carcinogenic effects of nitrate in drinking water supplies (Ward *et al.* 1996; De. Roos *et al.* 2003; Ward *et al.* 2003, etc.); however the results appear to be conflicting.

Ogur *et al.* (2005) advanced this line of research, concluding that nitrate can be reduced to nitrite in the body, which can react with amines by means of nitrosation, combining to form nitrosamines. Morales-Suarez-Varela *et al.* (cited by Zaki *et al.* 2004) demonstrated that nitrates could indeed be converted at gastric level into nitrites, before their transformation into N-nitroso compounds, which are known carcinogens to the stomach.

High nitrate levels in potable water supplies have also been implicated with acquired methaemoglobinemia cases in infants. In fact, this is reported to be the major biological effect associated with human exposure to nitrate/nitrite (WHO 2007). Nitrate conversion to nitrite in the human gastrointestinal system is associated with the oxidation of normal haemoglobin to methaemoglobin, inhibiting the transport of oxygen to the tissues. In extreme cases, high concentrations of methaemoglobin can lead to asphyxiation. Infants ingesting oxidising substances such as nitrates or nitrites can develop methaemoglobinemia (Verive and Kumar 2009). Young infants are more susceptible than adults or older children as fetal haemoglobin is more easily oxidised to methaemoglobin. Research has also suggested that the presence of gastrointestinal infections combined with high nitrate intake in infants can be a causative factor in methaemoglobinemia (WHO 2007).

1.3 Legislative Requirements for Nitrogen Removal

1.3.1 General

The previous sections included a discussion on the adverse impacts of ammonia and nitrates on receiving environments, providing insight into the fundamental importance of nitrogen removal from municipal waste water. The sections to follow identify the current legislation pertaining to nitrogen removal responsibilities of local authorities. An investigation into the existing waste water treatment infrastructure in Ireland, and the adequacy of this infrastructure to meet the legislative obligations, are then presented.

The most relevant EU and national legislation concerning water quality and emissions of nitrogenous compounds to receiving surface waters, arising from municipal effluent sources, are broadly interpreted in the sections to follow.

1.3.2 Council Directive (EC) 1991/271/EEC of 21 May 1991 concerning Urban Waste Water Treatment

The Urban Waste Water Treatment Regulations 2001 (Irish Government 2001) and 2004 amendment regulations (Irish Government 2004) give national effect to the Urban Waste Water Treatment Directive (EC 1991). The EPA is the responsible authority for the implementation and enforcement of these regulations. (On February 19th 2010, additional amendment regulations came into force, giving further effect to Directive 91/271/EEC and Directive 2000/60/EC. The particulars of these regulations will be discussed further in Section 1.3.6 below.)

The 2001 and 2004 regulations specify limits for waste water discharges of BOD_5, COD and Total Suspended Solids. Discharge limits are also set for Total Phosphorus and Total Nitrogen discharging to *'sensitive waters'* only, as outlined in the Second Schedule Part 2 of the 2004 amendment regulations. An extract from the 2004 amendment regulations is provided in Appendix A of this document. The 2001 regulations set deadlines for appropriate treatment, secondary treatment or *'more stringent than secondary treatment'* of waste waters depending on agglomeration size and receiving waters classification. Since May 2008, all deadlines outlined in the 2001 regulations have passed.

In order to achieve compliance with the regulations, sanitary authorities are obliged to provide appropriate nutrient removal from all waste water discharges to *'sensitive areas'* or to the relevant catchment areas of *'sensitive areas'* for agglomerations greater than 10,000 population equivalent (PE). *'Sensitive areas'* for the purposes of the regulations comprise certain river stretches, lakes, estuaries and bays deemed to be nutrient sensitive, that are subject to eutrophication, and which are listed in Schedule One of the 2010 amendment regulations (Appendix C). The list of sensitive areas, last updated by the 2010 amendment regulations, comprise twenty five stretches of river, six lakes and twenty estuaries and bays.

The Total Nitrogen ELV's (refer to Appendix A) for discharges to *'sensitive areas'* are 15mg N/l for agglomerations of between 10,000PE and 100,000PE and 10mg N/l for agglomerations greater than 100,000PE (These values for concentration are annual means). However, the 2004 amendment regulations specify that the requirement to remove nitrogen is also dependent on local eutrophic conditions (i.e. in assessing the legislative requirement for nitrogen reduction from any particular authorised discharge, if nitrogen is not the limiting nutrient in terms of primary production in the receiving waters relating to that discharge, this negates the requirement for nitrogen removal from that discharge).

Thus, Council Directive 1991/271/EEC (EC 1991) places an obligation on Local Authorities to provide nutrient removal facilities only for those discharges to *'sensitive areas'* (or the catchment areas of same), and the requirement to provide either phosphorus or nitrogen removal, or both, will depend on a case-by-case assessment of the limiting nutrient. Hence, at present, dedicated nutrient removal is not a requirement at many local authority sewage plants in Ireland, and is mostly confined to phosphorus removal. (As phosphorus tends to be the limiting nutrient in inland (fresh) waters, most inland treatment facilities with nutrient reduction facilities are limited to phosphorus removal.)

1.3.3 Water Framework Directive (Council Directive 2000/60/EC)

The Water Framework Directive came into force on the 22nd of December 2000 (EC 2000). EU directives in the past have focused on the achievement of physico-chemical standards in waters, calculated from toxicity testing of certain compounds on aquatic life, to ensure that a diverse fauna and flora was sustained. The Water Framework Directive (WFD) places emphasis on the actual demonstration of the presence of a healthy flora and fauna system; hence the framework has been designed to focus on biology as well as chemistry. Member States will be required to classify all surface waters in terms of quality status, determined by examining and documenting the deviation of any particular water body under examination from undisturbed reference conditions for an unpolluted water body of equal typology.

The fundamental objective of the Directive is to achieve at least *'good status'* in relation to all waters by 2015 and to prevent deterioration in all waters, and this will only be achieved through attaining a high level of biological diversity in waters. The main activities for the implementation of the WFD are currently well underway, in the context of River Basin District (RBD) Management Projects led by Local Authorities.

In accordance with the requirements of the European Communities (Water Policy) Regulations 2003 (Irish Government 2003) (transposing Directive 2000/60/EC into Irish law), work to date has included, *inter alia*, an initial characterisation and analysis of Ireland's river basin districts, which was submitted by the EPA to the European Commission in the form of a National Summary Report in March 2005, development of a National Monitoring Programme, and preparation of individual River Basin Management Plans.

A number of other regulations were enacted to give further effect to Directive 2000/60/EC. Those that are considered relevant to this study are discussed below.

1.3.4 Waste Water Discharge (Authorisation) Regulations, 2007 (S.I. 684, 2007)

The 2007 regulations (Irish Government 2007) have introduced a new system of authorisation and registration for Local Authority municipal waste water discharges. As a result of this legislation, all discharges of municipal effluent by Water Services Authorities now require a Waste Water Discharge Licence, or in the case of agglomerations of less than 500PE, a Certificate of Authorisation, to be granted by the EPA. Such licences or certificates set specific emission limits for discharges to waters in accordance with national and European legislation, to prevent and control water pollution from urban waste water treatment works (Smith *et al.* 2009). The licences also outline, where necessary, appropriate remedial actions within specified timeframes.

The license application process for pre-existing municipal discharges was undertaken on a phased basis, with a Stage 1 application deadline for receipt of applications for agglomerations in excess of 10,000PE set at December 14th 2007. In terms of the current status of this process, licenses are currently being rolled out at present for first, second and third phase applications.

Generally speaking, on examination of licences granted to date, emission limit values for phosphorus and/or nitrogen have been set, with December 2012 deadlines attached in many instances. Nutrient emission limits have been imposed on discharges to receiving waters designated *'nutrient sensitive'* or otherwise. The 2007 regulations have also empowered the EPA with additional enforcement powers; with the objective of bringing about improvements both in effluent quality and reporting practice on a national scale.

1.3.5 European Communities Environmental Objectives (Surface Waters) Regulations, 2009 (S.I. 272, 2009)

Statutory Instrument 272 of 2009 (Irish Government 2009) came into effect on July 30th 2009 and applies to all inland surface waters, transitional waters and coastal waters (extending out a distance of one nautical mile), but not including groundwater. The regulations provide, *inter alia*, for:

- A legally binding set of quality objectives for all surface waters within the State (including nutrient objectives).
- An examination and, where appropriate, a review of existing discharge authorisations by the appropriate Public Authorities (as listed in Schedule 1 of the regulations) by not later than December 22nd 2012, to ensure that the emission

limits laid down in authorisations support compliance with the new water quality objectives/standards.

Objectives of the Regulations

The primary environmental objective, as outlined in Part III of the regulations, is for the protection (and to prevent deterioration in status) of surface waters where the status is determined to be *'high'* or *'good'* (or of *'good potential'*) and restoration to at least *'good'* status by not later than 22nd December 2015 for waters determined to be of a lesser quality currently. Part I, Article 3(1) defines '*good surface water status*' as the status achieved by a water body when both the ecological status and the chemical status are determined to be at least *'good'*. Schedule 4 contains biological, hydromorphological and physico-chemical quality elements that may be used in calculating ecological status.

Schedule 5 establishes criteria in the form of EQS's for the purposes of calculating the surface water ecological status. EQS's relating to a list of substances of a persistent, bioaccumulative and/or hazardous nature are contained within Schedule 6, as a means of assigning the chemical status of surface waters. An extract from Schedule 5 of the 2009 regulations (EQS's for *'nutrient conditions'*) is provided in Appendix B.

Classification of Surface Waters

Article 24 places a duty on the EPA to classify waters according to the ecological and chemical status, with a deadline of completion of classification by June 22nd 2011. Article 25 stipulates that the classification be based on results of the Water Framework Directive Monitoring Programme (EPA 2006), established by the EPA during 2006. The findings of the status assessment going forward will aid in decision making for the programme of measures to be adopted, for each water body to ultimately achieve compliance with the main objectives of the WFD.

Environmental Quality Standards (EQS's) and Objectives

Schedules 5 and 6 set out EQS's relating to biological quality, physico-chemical conditions, specific pollutants and priority substances. These EQS's include oxygenation, thermal and nutrient criteria, previously introduced in Annex V of the Water Framework Directive as *'general conditions'*. Thus EQS's for nitrogen have been introduced, which now apply to all surface waters.

The Urban Waste Water Treatment Directive put in place a requirement for nitrogen removal from point source municipal discharges, which focused only on discharges to *'nutrient-sensitive'* water bodies. With the establishment of the 2009 Surface Waters Regulations however, Total Ammonia standards will apply to all river and lake bodies, whilst Dissolved Inorganic Nitrogen standards will apply to all coastal water bodies. As discussed previously, ELV's going forward will be based on a combination of EQS's and assimilative capacities, thus in all likelihood warranting treatment plant upgrades for a substantial number of agglomerations. The nitrogen EQS's, detailed in Appendix B of this study, could be considered relatively stringent in comparison with existing legislation.

In considering nitrogen EQS's, the 2009 regulations appear to be quite rigid, in that they do not allow a deviation from the limits on a percentile (or other statistical) basis. Article 39 of the regulations attempts to rectify this deficiency by allowing the EPA to establish a

> *'...permitted statistically based range within which the general physico-chemical quality elements may deviate from the values specified in Schedule 5...'*
>
> (European Communities Environmental Objectives (Surface Waters) Regulations 2009, 21)

during the classification stage.

<u>Duties on Public Authorities</u>

Article 4 asserts that a Public Authority that has functions, which may affect the achievement of the environmental objectives established by the regulations, shall, *inter alia*:

> *'...ensure, in so far as its functions allow, that- ...surface water bodies comply with the relevant environmental quality standards specified in the Schedules...'*
>
> (European Communities Environmental Objectives (Surface Waters) Regulations 2009, 9)

Article 7 requires that point and diffuse sources liable to cause water pollution will be prohibited except where subject to prior authorisation or registration. A Public Authority that authorises a discharge is required under legislation to lay down emission limits in such authorisation, for all new discharges to surface waters and for reviews of existing authorisations, granted under various Acts.

Such existing discharge authorisations will include the many Local Authority-operated municipal sewage treatment facilities of varying capacity throughout the country, having recently undergone/currently undergoing waste water discharge authorisation by the EPA. Such authorisation, as previously discussed, is warranted under the Waste Water Discharge (Authorisation) Regulations, 2007.

Article 7(a) states emission limits shall be based, *inter alia*, on the calculated maximum concentration and the maximum quantity of a substance permissible in a discharge with the aim of achieving the environmental objectives of the regulations, including the EQS's established in Schedules 5 and 6 of the regulations. Article 8 includes a requirement for persons, Public Authorities or corporate bodies, so authorised under Article 7, to comply with the emission limits set within a specified timeframe.

<u>Review of Existing Authorisations</u>

Article 11(1) places a December 2012 deadline on Public Authorities for the examination of all existing discharge authorisations to which the legislation applies. Upon examination, if it is determined that a review of the authorisation is required for the purposes of compliance with Article 7, this must be completed by said deadline.

Local Authority waste water discharge authorisations issued to date by the EPA have included ELV's for Total Nitrogen and/or Total Ammonia. The Agency have therefore been cognisant of the recently-introduced nitrogen EQS's. The capability of existing nutrient removal infrastructure to meet these demands is discussed later in this literature review.

<u>Prosecution of Offences and Performance of Statutory Functions by Public Authorities</u>

Provisions are included under Articles 13 to 17 (inclusive) for prosecution for offences of non-compliance with the requirements of the regulations. Prosecution may be taken by a Minister of the Government, the EPA, the co-ordinating Local Authority for the river basin district affected, and the relevant Public Authority. Article 14 details maximum fine amounts and prison sentences relating to summary and indictment convictions.

1.3.6 Urban Waste Water Treatment (Amendment) Regulations, 2010 (S.I. 48 of 2010)

These regulations (Irish Government 2010) were introduced on February 11th 2010 with the purpose of giving further effect to Directive 91/271/EEC and Directive 2000/60/EC. The regulations amend the Urban Waste Water Treatment Regulations 2001 (S.I. 254 of 2001), *viz.*:

1. Replacing the Third Schedule of the 2001 regulations (designating *'sensitive areas'*) with Schedule 1 of the 2010 amendment regulations, and;
2. Amending Regulation 4 of the 2001 regulations, such that the EPA will determine whether a nitrogen emission limit or phosphorus emission limit (or both) shall be applicable to each authorised waste water discharge. (This determination is to be dependent on the local situation.) The EPA shall take this into account when authorising a waste water discharge for the purpose of the Waste Water Discharge (Authorisation) Regulations 2007 (S.I. 684 of 2007).

The 2010 (amendment) regulations include the previously-designated *'sensitive areas'* as listed in the 2001 and 2004 (amendment) regulations. (The description of five of the estuaries/bays have been somewhat amended by the new legislation). The deadlines previously imposed, relating to the *'nutrient sensitive'* areas, have not been revised.

Ten additional areas have been designated as *'sensitive areas'* (including sections of the River Boyne, Liffey, Barrow, Shannon, Fergus, Brosna and the Tullamore River, the Boyne Estuary, Clonakilty Harbour and Wexford Harbour). The deadline for implementing nutrient removal at facilities discharging to the relevant section of the River Fergus is December 22nd 2012. In the case of Clonakilty Harbour and the Boyne Estuary, a deadline of December 22nd 2016 has been set.

Appendix C of this study contains Schedule 1 of the 2010 regulations, providing up-to-date mapping of all *'nutrient sensitive'* waterbodies on a national scale. A non-exhaustive list of waste water treatment facilities, which could potentially be impacted upon by these new regulations, has been drawn up for the purposes of this study; also included in Appendix C.

1.4 Review of Existing Waste Water Treatment Infrastructure

1.4.1 Current Infrastructural Deficiencies

A recent report published by the EPA (Monaghan *et al.* 2009) presents the findings of a investigation conducted by the Agency during 2006/2007 into the level of treatment of municipal waste water at 482 agglomerations (including villages, towns and cities) throughout Ireland. The report also examined effluent quality at 370 such treatment facilities, which provided at least secondary treatment from agglomerations in excess of 500PE. The main objective of the study was to assess the level of compliance with the Urban Waste Water Treatment Directive (1991/271/EEC).

Directive 1991/271/EEC requires that *'appropriate treatment'* be provided for agglomerations of less than 2,000PE discharging to freshwaters and estuaries, and for agglomerations of less than 10,000PE discharging to coastal waters. Secondary treatment must be provided for all discharges from agglomerations of 2,000PE or greater to freshwaters or estuaries, and similarly for all agglomerations of 10,000PE or greater for discharges to coastal waters. Nutrient reduction is an additional requirement for discharges to *'sensitive areas'* or the catchment of *'sensitive areas'* where the agglomeration size is greater than 10,000PE.

'Appropriate treatment' is defined in the Urban Waste Water Treatment Regulations 2001 as the level of treatment deemed necessary to satisfy receiving water quality standards. Thus, it is worth considering, that for agglomerations of less than 2,000PE discharging to *'sensitive'* freshwaters or estuaries, water quality standards may in certain circumstances dictate that nutrient removal is a necessary component of the treatment process for such agglomeration. An anomaly therefore exists in the Directive, in that more stringent than secondary treatment may form a legislative requirement for effluents from agglomerations of less than 2,000PE discharging to sensitive waters in order to satisfy the requirement for *'appropriate treatment'*, whereas agglomerations of between 2,000 and 10,000PE would require secondary treatment only for compliance with the Directive.

Monaghan *et al.* (2009) reported that a total of €2.7 billion was invested in improving waste water infrastructure in Ireland between the years 2000 to 2007, based on data obtained from the Department of Environment, Heritage and Local Government, and that this investment had led to significant reductions in the volume of waste water being discharged without secondary or appropriate treatment. However, Figures 1-1 and 1-2 below summarise the position at the beginning of 2008 in terms of the level of implementation in Ireland for the secondary treatment requirement of the Urban Waste Water Treatment Directive (bearing in mind the deadline for provision of secondary treatment was December 31st 2005 in most circumstances).

Figure 1-1 and Figure 1-2 were compiled by the writer, based on data abstraction and manipulation from the 2009 report (*ibid.*). The charts represent all reported discharges to freshwaters and estuaries with an agglomeration size of 2,000PE or greater and all discharges to coastal waters with an agglomeration size of 10,000PE or greater. The charts do not include for smaller catchments requiring *'appropriate treatment'* as the treatment level required would be case specific. A database of existing infrastructure corresponding to these charts has been provided in Appendix D.

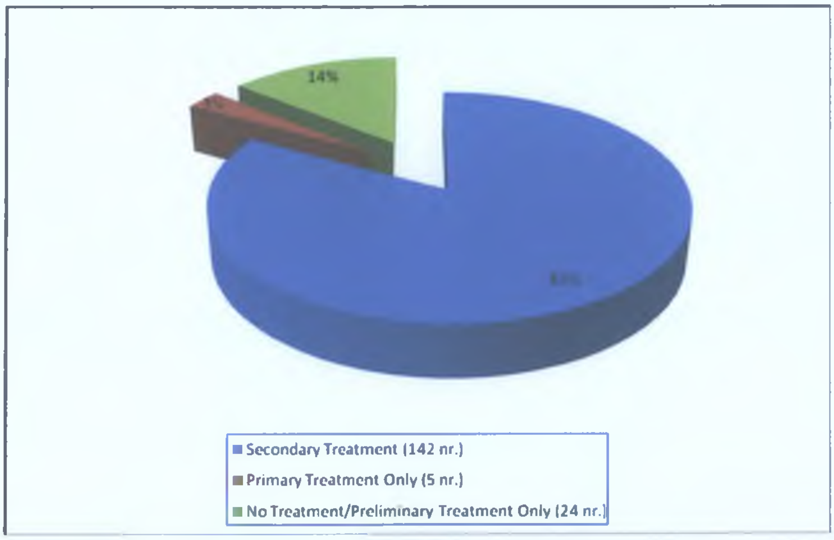

Figure 1-1 **Level of compliance with Directive 1991/271/EEC concerning the statutory provision of secondary treatment facilities at municipal waste water treatment plants, by number of plants /agglomerations.**

(modified data from Monaghan *et al.* 2009)

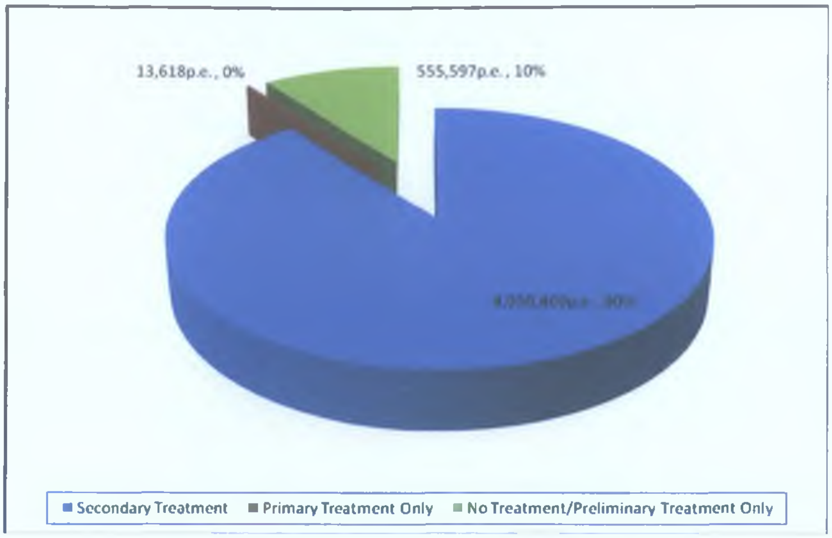

Figure 1-2 **Level of compliance with Directive 1991/271/EEC concerning the statutory provision of secondary treatment facilities at municipal waste water treatment plants, by population equivalent.**

(modified data from Monaghan *et al.* 2009)

The above figures illustrate the deficiencies with regard to secondary treatment implementation in Ireland at the end of the reporting period (December 31st 2007). By this date, 29 (17%) of the 171 agglomerations requiring secondary treatment facilities were not provided with such. In terms of corresponding organic loads, just over 10% of waste waters were being discharged without secondary treatment. However, due consideration must be given to the fact that over two years have elapsed since the last reporting period, and in that time, vital infrastructure has been put in place at a number of large population centers. Table 1-1 provides a summary of recent developments and commitments concerning water services investments.

Plant Status	Nr. of Plants	Corresponding Population Equivalent requiring Secondary Treatment
2008 Commissioning Date	5	109,400 PE
2009 Commissioning Date	7	188,500 PE
2010 Commissioning Date	1	65,700 PE
2009 Construction Start Date	4	45,555 PE
2010 Construction Start Date	3	15,563 PE
2011 Construction Start Date	1	2,000 PE
2012 Construction Start Date	2	94,500 PE
2013 Construction Start Date	5	31,000 PE
Subject to Review Proceedings	1	16,997 PE
Total	**29**	**569,215 PE**

Table 1-1 Summary of Investment Programme (treatment facilities for agglomerations of at least 500PE)

(modified data from Monaghan *et al.* 2009)

Table 1-1 illustrates the recent local authority commitment to deal with the all of the deficiencies identified on Figure 1-1 and Figure 1-2. This investment programme will be rolled out over the coming five years, albeit approximately a decade or more since the deadlines (as outlined in Directive 1991/271/EEC) for secondary treatment provision have passed.

Non-compliance with the Directive has, to date, incurred penalties for the State. On September 11th 2008, the European Court of Justice ruled against Ireland for the State's failure to comply with Directive 91/271/EEC in respect of the Sligo, Bray, Tramore, Howth and Shanganagh agglomerations. The case (C-316/06) related to the State's failure to provide collection systems and secondary treatment by the required deadline of December 31st 2000 at those locations. The case also concerned the inadequacies of Letterkenny Waste Water Treatment Plant in dealing with incoming loadings throughout the year. Under Article 69(2) of the Rules of Procedure, Ireland was ordered to pay the costs applied for by the European Commission (Smith *et al.* 2009).

Of the 482 agglomerations assessed by the EPA during the 2006/2007 reporting period, the findings showed that 120 of these agglomerations discharge to *'sensitive areas'* (Monaghan *et al.* 2009). 112 of the 370 secondary treatment facilities throughout the country included nutrient removal; however these do not always coincide with the discharges to *'sensitive areas'*. The 112 nutrient reduction facilities account for some 840,788PE, and in terms of organic loading, this translates to 14% of the total (482 agglomerations) assessed. Unfortunately, the report does not distinguish between phosphorus and nitrogen removal facilities. Figure 1-3 below illustrates the position with regards to the levels of nutrient removal put in place by the State at the end of the reporting period (December 2007).

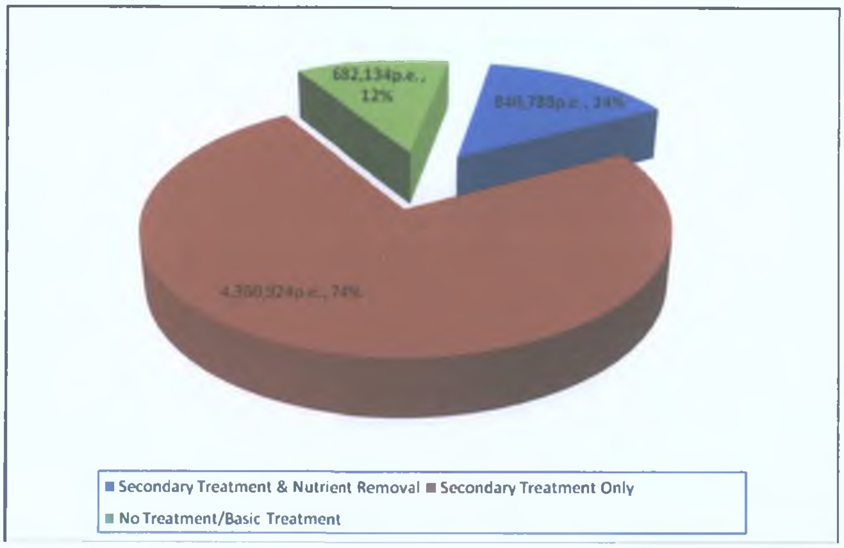

Figure 1-3 **Level of nutrient reduction facilities in Ireland at December 31st 2007, based on population equivalent.**

(modified data from Monaghan *et al.* 2009)

To reiterate, nutrient reduction is a legislative requirement for discharges to *'sensitive areas'* or the catchment of *'sensitive areas'* where the agglomeration size is greater than 10,000PE. Assessing the data provided in the report (*ibid.*), only 56 of the 112 treatment plants providing nutrient reduction were discharging to *'sensitive areas'*. As stated previously, the findings of the report indicate that 120 agglomerations discharge to *'sensitive* areas'. This implies that waste water discharges from 64 plants were being released to receiving waters designated as *'sensitive'* without nutrient reduction (at the end of 2007). Nonetheless, nutrient reduction is only required for those discharges greater than 10,000PE; hence legislation at present only calls for nutrient removal at the larger plants. Figure 1-4 below illustrates the position at December 2007 with regards to the statutory provision of nutrient removal at waste water treatment plants catering for agglomerations greater than 10,000PE.

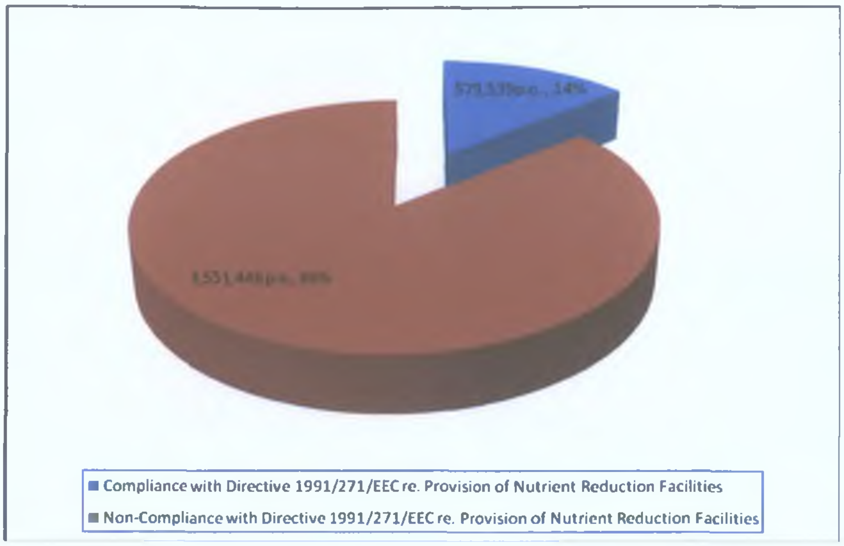

Figure 1-4 **Level of compliance with Directive 1991/271/EEC regarding the statutory provision of nutrient reduction facilities at municipal waste water treatment plants.**

(modified data from Monaghan *et al.* 2009)

Figure 1-4 reveals that 86% of waste waters discharged to receiving waters designated as *'sensitive'*, from agglomerations of greater than 10,000PE do not undergo nutrient removal, and therefore are not compliant with Directive 1991/271/EEC. The above figures do not take into account small agglomerations requiring *'appropriate treatment'*, which as site-specific quality standards would dictate, may also imply nutrient removal requirements.

The two largest agglomerations – Dublin City (Ringsend) and Cork City Waste Water Treatment Plants, which collectively represented 54% of Ireland's total waste water discharges for 2007, both discharge to sensitive areas; however nutrient removal facilities are not provided. In terms of the other significant discharges, Killybegs Waste Water Treatment Plant accounts for an estimated 92,000PE (due to a concentrated influent loading from a fish processing plant); however this discharge receives no form of treatment at all. A significant lack of nutrient removal infrastructure is apparent from the above data, which may lead to further prosecution at a European level. No literature could be sourced to decipher between the scale of the nitrogen reduction deficiencies and the phosphorus reduction deficiencies in Ireland. A reasonable assumption can be made however, given the coastal locations of the more significant discharges mentioned above, that nitrogen reduction deficiencies would represent a considerable proportion of the issue at hand.

In terms of the other reported deficiencies in waste water treatment in Ireland, following EPA auditing of 29 facilities between 2006 and 2007, Monaghan *et al.* (2009) declared that a number of recurring problems were evident, *viz.* inadequate collection systems, frequent storm overflows, insufficient capacity at the plant, poor final effluent quality, insufficient sampling, lack of training for Plant Caretakers, poor receiving water assimilative capacity and poor sludge management.

As a result of all of the above factors, receiving waters have been impacted upon, and are therefore at risk of not achieving the objectives of the EU Water Framework Directive. In *'Water Quality in Ireland 2004-2006'* (Clabby *et al.* 2008) it was reported that of 2,985 river sampling locations examined during 2004-2006, 1,011 locations were classified as polluted, mainly resulting from nutrient enrichment/eutrophication, with municipal effluent discharges implicated as the main source of nutrient loss (369 locations), followed by agriculture (330 locations) along with some other minor sources. Stabilisation in the condition of surface waters had been acknowledged in the report, attributed to a number of new measures taken to reduce nutrient losses to waters in recent years, albeit not at a sufficient rate to guarantee the objectives of the Water Framework Directive by 2015. The report goes on to conclude the following:

> *'This Report indicates that discharges from municipal waste water treatment works and from agricultural activities are the principal suspected causes of less than satisfactory water in the State. Industrial discharges and discharges from several other activities have also been identified as contributing to a lesser extent. It is clear, therefore, that in order to achieve the objectives of the WFD within the given timeframe, that priority must be given to reducing the polluting impact of these discharges and in particular to reduce their nutrient content.'*
>
> (Clabby *et al.* 2008)

The EPA published *'Focus on Environmental Enforcement in Ireland – A Report for the years 2006-2008'* during 2009 (Smith *et al.* 2009). Although Monaghan *et al.* (2009) had focused on 482 agglomerations discharging municipal waste water within the State, Smith *et al.* (2009) suggest that the number of licensed treatment facilities will be well in excess of that figure, thus perhaps further exacerbating the inadequate treatment issue. Table 1-2 below provides a summary of figures sourced from Smith *et al.* (2009), detailing the number of waste water discharge license applications received by the EPA up to June 2009. It must be borne in mind that a large number of agglomerations of less than 500PE will also contribute to the figures below.

Agglomeration Size	Number of Applications	Prescribed Date for Receipt of Applications
>10,000	63	December 14th 2007
2,001-10,000	144	September 22nd 2008
1,001-2,000	138	February 28th 2009
500-1,000	157	June 22nd 2009
Total	**502**	

Table 1-2 **Summary of waste water discharge license applications received by EPA at June '09.**

(modified table from Smith et al. 2009)

1.4.2 Future Enforcement

Prior to the full implementation of the Waste Water Discharge (Authorisation) Regulations, 2007, during the period 2006 to 2008, the EPA issued 104 notices under Section 63 of the Environmental Protection Agency Act, 1992 (EPA 1992) relating to local authority poor statutory performance in relation to water quality issues, in order to improve compliance (*ibid.*). With their newly appointed statutory powers under the authorisation regulations, the Agency will employ a new type of enforcement policy in the future which will be risk-based and outcome driven, and plants with inadequate provisions to meet relevant standards will be targeted. Finalised River Basin Management Plans will contain Programmes of Measures, as drivers to deliver good water quality.

Local authorities must prepare Water Services Strategic Plans aimed at achieving the measures contained in the River Basin Management Plans. For example, the Draft River Basin Management Plan for the Neagh Bann International River Basin District (NBIRBD 2008) outlines that the Environmental Objectives Regulations are to provide a basis for determining waste water treatment appropriate to the objectives contained therein, which will enable necessary infrastructural and operational improvement to be prioritised. These improvements are to be included in future Water Services Investment Programmes.

1.4.3 Conclusion

In concluding the 2006/2007 assessment, recommendations by Monaghan *et al.* (2009) included, *inter alia*, a review of the operation of all urban waste water treatment facilities, and the development and implementation of corrective action programmes for plants failing to meet effluent quality standards set out in the legislation. The Agency also recommended that Local Authorities should improve their management and operation of plants by investing in the re-training of plant operators in order to improve the operation and functioning of the plants. The report goes on to recommend the liaison and follow up procedure between those responsible for environmental monitoring and those in charge of the operation of the plant.

While the Sanitary Authorities appear to be actively tackling the issue of insufficient secondary treatment facilities, the distinct lack of nutrient removal facilities at the locations deemed necessary by Directive 1991/271/EEC will present a considerable challenge. The stringent nitrogen standards recently introduced with the European Communities Environmental Objectives (Surface Waters) Regulations 2009, combined with ensuing Programmes of Measures will serve to bring these treatment deficiencies into further focus. The scale and urgency of the task at hand is therefore considerable.

In concluding the Literature Review thus far, it is clear that certain commitments will be required from the State arising from impending legislative obligations, considering the apparent deficiencies in existing nitrogen removal infrastructure. The engineering consequences of this emerging problem are now discussed.

1.5 Review of Conventional Method for Nitrogen Removal from Municipal Waste Water

1.5.1 Introduction

The rationale for removal of ammonia and nitrate from discharges to receiving waters, having regard to the issues surrounding both downstream abstraction and the environmental impact on aquatic life and on human health, was established in Section 1.2. Section 1.3 ascertained the legal requirements for nitrogen removal from municipal waste waters, which appear to be continually evolving in line with the objectives of the Water

Framework Directive. The state of existing infrastructure has been investigated in Section 1.4, demonstrating the pressing need to significantly increase the scale of nutrient removal infrastructure in the State. Thus, having clarified the issue, the literature review herein examines two options for rectifying the problem at hand:

1. Conventional nitrogen removal.
2. An alternative method of nitrogen removal via Side Stream Technology.

1.5.2 Conventional Nutrient Removal - Nitrification and Denitrification

Nitrogen removal from municipal waste waters by conventional biological means involves the hydrolysis of organic nitrogen, ammonia oxidation followed by nitrite oxidation to nitrate and finally denitrification to gaseous nitrogen. The following sections provide information on the fundamentals of conventional nitrogen removal from waste water.

Nitrification Process

Incoming ammonia in raw sewage influent can be oxidised in a secondary waste water treatment process via the nitrification process. Nitrification takes place in a reactor, (usually a shared reactor for carbonaceous and ammonia oxidation), carried out by autotrophic bacteria under aerobic conditions. In some cases, carbonaceous and ammonia oxidation will take place in separate reactors (Gray 1999).

Nitrification is a two-step process, utilising natural bacteriological reactions with a high oxygen requirement to allow the metabolism of nitrogen.

Step 1:

Ammonia is oxidised to nitrite by the bacteria *Nitrosomonas*, as shown in the equation below:

$$2\ NH_4 + 3\ O_2 \longrightarrow 2\ NO_2^- + 4\ H^+ + 2\ H_2O + \text{energy}$$

(Gray 1999, 335)

Step 2:

Nitrite is further oxidised to nitrate by the bacteria *Nitrobacter*, as shown below:

$$2NO_2^- + O_2 \longrightarrow 2NO_3 + \text{energy}$$

(Gray 1999, 335)

As heterotrophic bacteria (which oxidise carbonaceous matter during secondary treatment) exhibit a much faster growth rate than autotrophic bacteria, they will be present in greater numbers in the sludge floc when treating municipal sewage with organic compositions within the typical range. Because of this, sludge-wasting rates have a considerable effect on the ability of the system to achieve nitrification. In other words, in order to ensure the nitrification step occurs, sludge wastage rates must be sufficiently low such that nitrifying (autotrophic) bacteria are allowed to accumulate within the floc, and the specific wastage rate should be less than the autotrophic specific growth rate.

To achieve nitrification under steady-state conditions, the following equation must apply:

$$\frac{Cm - Cmo}{Cmo} > \frac{\Delta S}{S}$$

(IWPC 1987, 81)

Where:

Cm is the concentration of *Nitrosomonas* leaving the aeration section in the effluent mixed liquor.

Cmo is the concentration of *Nitrosomonas* entering the aeration section of the inlet mixed liquor.

ΔS is the increase in sludge concentration, which is produced in the mixed liquor from inlet to outlet during aeration.

S is the MLSS concentration entering the aeration section.

$\Delta S/S$, under steady-state conditions is the specific sludge wastage rate. The wastage rate is also the reciprocal of sludge age. Typically in the UK and Ireland when treating municipal waste water, with temperatures and pH values within the normal range, and in maintaining dissolved oxygen levels in the activated sludge at around 2.0mg/l, nitrification can be achieved by operating under the following design constraints:

Max. allowable sludge loading rate (F/M ratio):0.15 kg BOD/kg Sludge D.S. per day
Minimum sludge age (nitrification only): 4 days

Denitrification Process

Nitrate can be converted to nitrogen gas under extremely low oxygenation conditions, in a process known as denitrification. The nitrification and denitrification processes must be space (separate reactor) or time (batch system) separated as a necessary component of this treatment process, as is the requirement to maintain dissolved oxygen levels close to 0mg/l in the anoxic zone. In the absence of such dedicated anoxic zones, denitrification would only tend to occur in the settled sludge present in the secondary clarifier. An energy (carbon) source is also a necessity for denitrifiers.

In terms of an energy source, denitrifying bacteria metabolise carbonaceous material (BOD) in the waste water, however; if insufficient concentrations of BOD are available to aid the denitrification process, an external carbon source can be added to the process, such as methanol. The facultative anaerobes are commonly *Pseudomonas spp.* and to a lesser extent *Achromobacterium spp.*, *Denitrobacillus spp.* and *Spirillum spp.*, etc. The fundamental principle of the process is that nitrate will be utilised by these bacteria in lieu of oxygen as a terminal electron acceptor (Gray 1999).

In summary, in a denitrification process undertaken by facultative anaerobic bacteria (that require a carbon source), nitrate is converted to nitrogen gas (N_2), which diffuses to the atmosphere, as shown in the equation below:

$$NO_3^- + 1.08CH_3OH + H^+ \rightarrow 0.065C_5H_7O_2N + 0.47N_2 + 0.76CO_2 + 2.44H_2O$$

(IWPC 1987, 128)

It is commonplace for anoxic zones to be installed upstream of the aeration basins in an activated sludge plant, where incoming raw (or primary treated) waste water mixes with return activated sludge. It has been found that the denitrification process is fairly robust in terms of variations in pH, inhibiters and sludge wastage, and experience has shown that denitrification will occur consistently in anoxic zones where at least 0.5 hours retention has been provided (IWPC 1987).

As can be seen from the above stoichiometric equation, considerable amounts of oxygen are liberated in the denitification process. In placing an anoxic zone upstream of the main aeration basins, this oxygen can be beneficially used in nitrifying the effluent in the downstream aeration zone, thus minimising the oxygen requirement from external sources. Denitrification, producing nitrogen gas, which is driven off to the atmosphere, is obviously beneficial as the nitrate concentrations in the final effluent are reduced.

Proper and consistent denitrification of waste water has another advantage, in that it prevents accidental denitrification of settled sludge in the final clarifiers, which would otherwise lead to carry over of solids in the final effluent.

1.5.3 Engineering Consequences of Conventional Nitrogen Removal

Conventional biological treatment for the removal of nitrogen from waste water via nitrification and denitrification is generally quite successful; however this method tends to be expensive. Jetten *et al.* (1997) identified the problems and costs associated with conventional nitrogen removal, *viz.*

- Conventional oxidation of ammonium requires a large amount of energy in supplying oxygen to the process.
- As COD is required for denitrification, and the amount of COD available may be limiting, it is often necessary to purchase an external source (e.g. methanol).
- Due to the long sludge age required for nitrification, large reactors are necessary.

The capital costs associated with providing conventional extended aeration systems for the purposes of nitrogen reduction are significant. This is due to the large reactors and associated extensive mechanical and electrical works required. Conventional biological nitrogen removal is effective; however, because the growth rate of the microorganisms responsible for nitrogen removal is relatively slow, the conventional treatment process is also slow (Khin and Annachhatre 2004). Typical sludge age in extended aeration plants, incorporating nitrification and denitrification, range from 8.3 to 20 days (ATV-DVWK-A 131E), thus necessitating large reactor volumes.

Operating costs of conventional systems are also significant. The nitrification reaction consumes a large amount of energy in producing oxygen at a rate of 4.2g per gram of ammonium nitrified. Furthermore, operational control of the nitrification/denitrification conditions can be problematic. Despite much research into optimising main stream reactors, many process issues remain, including difficulty in stabilising the desired biomass populations, not achieving sufficient rates of nitrification/denitrification and inadequate carbon quantities in waste waters to allow optimum conversion of NO_3^- and NO_2^- to N_2 (Khin and Annachhatre 2004).

Janus and Van der Roest (1997) asserted the optimal use of existing process units combined with complementary treatment systems to be a more advantageous method of increasing the nutrient removal capacity at many plants. They contend that such systems circumvent the requirement for conventional biological extensions, thus avoiding unnecessary capital expenditure, and also are more operationally efficient.

The complementary systems, which form the focus of this study, involve the separate side stream treatment, typically of liquor from sludge dewatering and sludge drying, with the aim of nitrogen removal. For example, Notenboom *et al.* (2002), conducting research on the treatment of digestate from solid waste digestion, discovered that a particular side stream technology (i.e. the 'SHARON' Process) combined with post treatment in a conventional activated sludge plant resulted in high overall ammonia conversion rates and low effluent concentrations. The research recognised that approximately 15% of the total nitrogen loading of a typical sewage treatment plant could be contained within the recirculating water from sludge digestion. Because of the strength of this liquid, it must be taken into account as a major contributor to the organic loading to the plant.

1.6 Side Stream Technology

1.6.1 Introduction

A review of recently developed side stream technologies was undertaken with specific emphasis on operational aspects and performance capabilities. All of the technologies included in the review were originally developed to treat recycle waste waters from biosolids handling, by employing novel microbial technologies. During the review of the literature, no evidence could be found to suggest that this treatment technology is already employed in Ireland.

Several relatively new processes have been developed aimed at efficient nitrogen removal from nutrient-rich side streams, with the ultimate objective of achieving substantial nitrogen reduction from main process final effluents. High strength nitrogen streams usually derive from industrial effluents, sludge liquor return from anaerobic digesters and from landfill leachates (Wett *et al.* 2009). To date, advances in side stream technologies have included the treatment of nutrient-rich streams in simple reactors, with the use of high temperatures (30 to 40°C) to incorporate a different metabolic pathway than is usually implemented in waste water treatment. The aim of the new technology is to achieve nitrification and denitrification in a shorter than normal retention time. These processes operate on the principle of partial nitrification of ammonium to nitrite followed by ammonium oxidation under anaerobic conditions. Some of the more established processes include: the 'SHARON', 'ANAMMOX', 'CANON', 'In-Nitri' and 'BABE' processes.

Prior to exploring the technical merits of the technologies, background research into recycle flows is presented below.

1.6.2 Reject Streams - Typical Characteristics

As a fundamental design function of conventional biological sewage treatment, sludge is separated to varying degrees from incoming waste water and is typically pumped to primary and waste-activated sludge thickeners. Primary and waste-activated sludges are then blended prior to discharge to sludge digestion units. Wett *et al.* (2009) cite a figure of 40% of the influent nitrogen load typically being transferred in this manner to the thickening units. Hydraulically, this flow to the thickeners accounts for approximately 2 to 5% of the total inlet flow; approximately 3% of this flow usually being returned to the main stream as supernatant draw-off. Ammonia concentrations in the thickener supernatant would tend to be broadly similar to concentrations in the influent to the treatment works. Thickened sludge draw-off from the thickeners is normally sent on to the digesters, and in hydraulic terms this flow stream would be in the order of 1% of the main flow to the plant (*ibid.*).

Stabilised sludge is drawn from the digesters after a number of days (usually 13 to 15 for mesophilic digestion) and is dewatered. Two end products result from dewatering, *viz.* sludge cake and centrate (reject water).

Hence, in considering the major recycle flows within a waste water treatment plant, these would comprise:

1. Sludge Thickener Supernatant;
2. Centrate (discharged as a by-product of dewatering via a belt press or centrifuge).

Wett *et al.* (2009) indicated that centrate would generally contain 12 to 25% of the influent ammonia load. Notenboom *et al.* (2002) quote typical nitrogen loadings in the order of 15% in recycle streams following digestion. Other minor recycle streams also exist and these will be discussed later in this study.

In 2005, Jardin *et al.* (cited in Cervantes 2009) analysed ammonia return loads from 204 German waste water treatment plants where anaerobic mesophilic digestion took place. On average these plants yielded a specific return load in the order of 1.5g N/PE, which equates to approximately 15% of a typical influent concentration. The research also established that two stage activated sludge plants produce approximately 20% higher nitrogen return loads than single stage activated sludge plants. Figure 1-5 below shows the ammonia return load at 204 waste water treatment plants, as reported by Jardin *et al.* (2005).

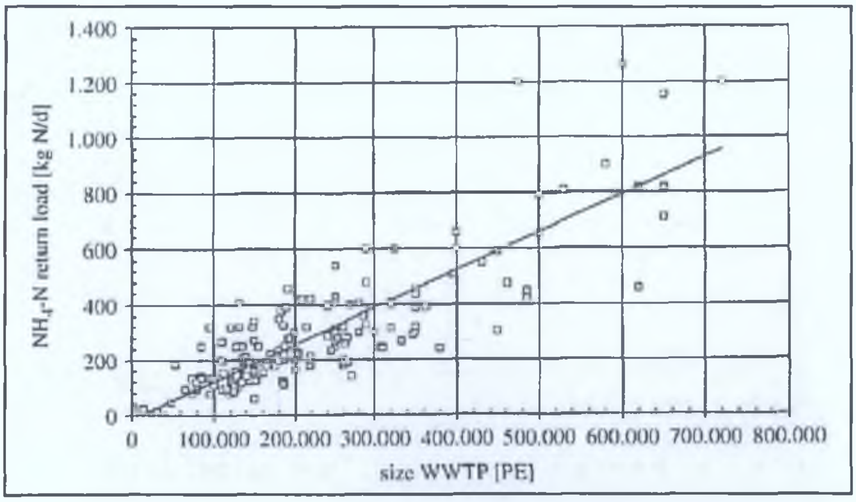

Figure 1-5 **Ammonia return load at 204 WWTPs with anaerobic mesophilic digestion (Jardin *et al.* 2005)**

(Source: Cervantes, 2009, 119)

1.6.3 Side Stream Technology - Introduction

Side stream treatment technologies for nitrogen reduction can be divided into two broad categories, namely:

1. Physical-Chemical Side Stream Treatment;
2. Biological Side Stream Treatment.

Figure 1-6 broadly summarises the various options available for nitrogen removal from centrate (modified from Constantine *et al.* 2005, cited in Cervantes 2009).

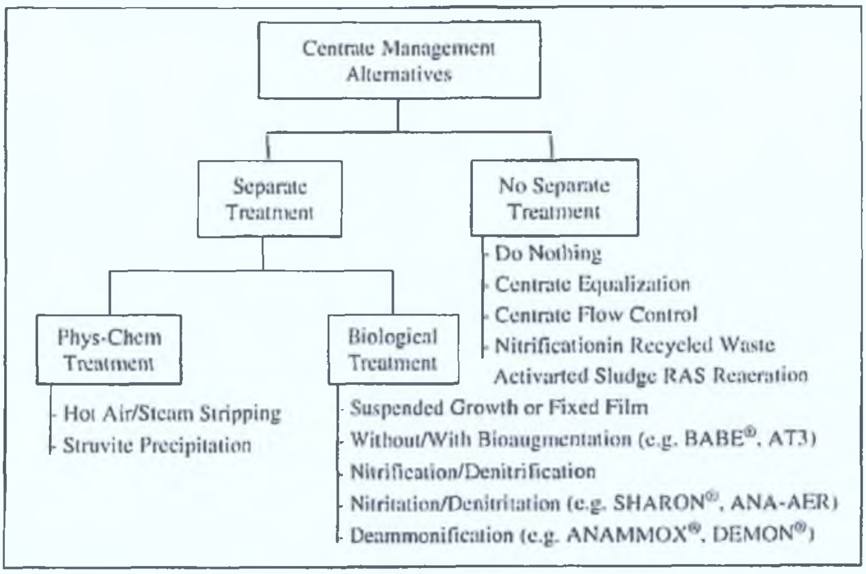

Figure 1-6 **Overview of the centrate treatment processes (modified from Constantine *et al.* 2005)**

(Source: Cervantes 2009)

1.6.4 Physical-Chemical Side Stream Treatment

The current study is focused upon investigating the feasibility of side stream treatment application to recycle waters in municipal waste water treatment facilities, utilising available resources arising from anaerobic digestion of sludge, in the Irish situation. For this reason, physical-chemical side stream treatment will not form the focus of this research as these technologies do not tend to take full advantage of these resources, and tend to be more focused upon nitrogen recovery.

1.6.5 Biological Side Stream Treatment

Biological treatment can be sub-categorised into three main methodologies, which have a common goal of inhibiting the growth of nitrite oxidisers, accomplished by limiting the aerobic Sludge Retention Time (SRT).

Table 1-3 below summarises biological side stream treatment methodologies.

Option	Method	Description
1	Nitritation/Denitritation	Repression of nitrite oxidisers, with complete nitrogen reduction directly via the nitrite step.
2	Deammonification	Involves the partial conversion of ammonium to nitrite, followed by nitrite conversion to dinitrogen gas under anaerobic conditions with ammonium as an electron donor.
3	Bioaugmentation	Applying Option 1 technology to side streams for the purposes of bio-augmentation of the main treatment process to improve efficiency there.

Table 1-3 Broad categorisation of biological side stream nitrogen removal processes

The section to follow provides a description of the first attempts at separate treatment of side streams, prior to more sophisticated technological developments. It must be borne in mind that the methodology employed as described hereunder provided nitrification of side streams only.

1.6.6 Side Stream Treatment using Conventional Biological Treatment Methods

A side stream system was implemented at Roundhill Waste Water Treatment Facility, West Midlands in 1994 for the separate treatment of digested sludge liquor from the dewatering process. The side stream plant was designed to operate for approximately 6 months during the colder seasons of the year and comprised primary clarification, a biological treatment step and final clarification. The aeration tank was sized for 50 hours hydraulic retention with a Sludge Retention Time (SRT) of 14 days (Water Environment Federation (WEF) 2005).

The Water Environment Federation (*ibid.*) provide more detailed information on the Minworth facility, which is reported to have operated at a reduced retention time of 15 hours. As per the Roundhill facility, Minworth only operated for 6 months of the year, as ammonia emission limits tended to be attainable via the main treatment process alone during the warmer months. Research has indicated that the side stream processes at both facilities achieved almost complete nitrification, resulting in relatively large quantities of oxidised nitrogen. Hence, in the case of Minworth, an anoxic zone was incorporated into the main process to reduce effluent nitrate levels. The WEF Report indicated an ammonium oxidation rate of greater than 95% at this facility. An interesting feature of these sites was that waste sludge from the side stream activated sludge reactor was sent to the main plant activated sludge reactor as a method of bioaugmentation.

Advances in waste water biotechnology led to the development of specifically-designed side stream technologies, whereby both nitrification and denitrification (i.e. Total Nitrogen removal) could be efficiently achieved in a single reactor. These advances are broadly categorised in Table 1-3 (and Figure 1-6) above. The scope of this literature review does not facilitate a detailed examination of all technologies available, therefore a proven technology from each category was selected for review, *viz.*

1. Option 1 (Nitritation/Denitritation): 'SHARON' Process;
2. Option 2 (Deammonification): Combined 'SHARON/ANAMMOX' Process;
3. Option 3 (Bioaugmentation): 'In-Nitri' Process.

1.6.7 Option 1 – The 'SHARON' Process (Nitritation/Denitritation)

'SHARON' (an acronym for '*stable high-rate ammonia removal over nitrite*') is a relatively new treatment process for the biological removal of nitrogen from waste waters. This process is suitable for treatment of ammonia-rich waste waters, in particular, reject waters from dewatering of digested sewage sludge and from sludge drying and incineration plants (Mulder *et al.* 2006). Other applications include treatment of landfill leachate and treatment of reject water from the digestion of organic waste and manure (Notenboom *et al.* 2002).

The process, which was originally developed in the 1990s at the Technical University Delft, the Netherlands (Hellinga *et al.* 1998), can be operated in a single reactor, at high temperatures (30°C - 40°C) and at high pH values (7-8), without the requirement of biomass retention (Hellinga *et al.* 1997). The 'SHARON' process employs a modified metabolic pathway to achieve high-rate nitrification/denitrification for the removal of Total Nitrogen from nutrient-rich waste streams (Bartholomew 2002).

The core concept behind the 'SHARON' process is that denitrifying bacteria have the ability to anoxically convert nitrite directly to nitrogen gas, effectively bypassing the nitrate step (Bartholomew 2002). Mulder *et al.* (2006) maintained that in bypassing the nitrate step by applying this type of side stream treatment at various full-scale waste water treatment plants located in the Netherlands, resultant savings towards energy and consumables have been realised. However, the key to ensuring stable partial nitrification appears to be grounded in the availability of an ammonium-rich influent, maintained at relatively high temperatures (between 30 - 40°C), combined with appropriate process control.

Typically, in conventional activated sludge treatment, the temperature of waste water would be expected to be in the approximate range of 10°C to 12°C (ATV-DVWK-A 131E). Within this temperature range, the growth rate of nitrite oxidisers is greater than for ammonium oxidisers, thus ammonium under such conditions is fully oxidised to nitrate. The opposite, however, is true at temperatures greater than 15°C, whereby it was demonstrated by Hunik in 1993 (cited in Hellinga *et al.* 1998) that ammonium oxidisers have a higher growth rate than the nitrite oxidisers, as seen on Figure 1-7 below:

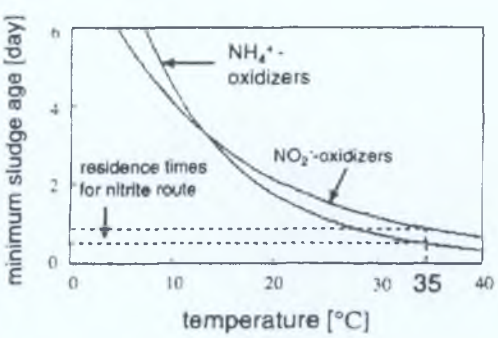

Figure 1-7 **Minimum residence time for ammonium and nitrite oxidisers as a function of temperature**

(Source: Hellinga *et al*, 1998)

The high temperatures of digested sludge centrate enable high specific microbial growth rates, so that sludge retention is not required, and more specifically, the high temperatures enable the wash out of nitrite oxidisers *Nitrobacter* and retention of ammonium oxidisers *Nitrosomonas* along with the denitrifiers (Hellinga *et al.* 1998). Hence, as the sludge residence time (SRT) equates to the hydraulic residence time (HRT), selecting a low HRT will allow the wash out of *Nitrobacter* as illustrated in Figure 1-7 above. Indeed, Mulder *et al.* (2006) validated that by restricting the aeration retention time in the reactor to approximately one day, nitrite oxidisers would be washed out, and the nitrification will be limited to nitrite formation.

It is acknowledged that although the ammonium oxidisers are fast growing, they do however have a low affinity for substrate (20 – 40mg NH_4^+-N/l), hence in practice the 'SHARON' process will lead to relatively high effluent ammonium concentrations (in the order of 10 – 100mg N/l) (Jetten *et al.* 1997; van Dongen *et al.* 2001*b*). Thus the 'SHARON' treatment system is only appropriate for ammonium-rich streams, i.e. greater than 500mg N/l where effluent quality from the process itself is not critical (van Dongen *et al.* 2001*b*).

In avoiding the nitrate step, research has verified that this metabolic approach allows for savings in aeration energy and carbon addition by up to 25% and 40% respectively (Bartholomew 2002; Mulder *et al.* 2006). However, it is worth noting that carbon addition does not constitute normal practice at conventional activated sludge treatment plants in this country, therefore it would be more likely that carbon addition would constitute an additional operational cost as opposed to a saving in Ireland. Nonetheless, the reductions in energy and carbon addition by application of the 'SHARON' process when compared with conventional nitrification/denitrification can be further clarified by way of the following equations:

<u>Nitrification Step:</u>

$$NH_4^+ + 1.5O_2 \rightarrow NO_2 + H_2O + 2H^+ \quad \{SHARON\}$$

$$NH_4^+ + 2O_2 \rightarrow NO_3^- + H_2O + 2H^+ \quad \{conventional\}$$

(Grontmij Nederland BV 2008, 3)

Denitrification Step:

$$6NO_2^- + 3CH_3OH + 3CO_2 \rightarrow 3N_2 + 6HCO_3^- + 3H_2O \quad \{SHARON\}$$

$$6NO_3^- + 5CH_3OH + CO_2 \rightarrow 3N_2 + 6HCO_3^- + 7H_2O \quad \{conventional\}$$

(Grontmij Nederland BV 2008, 3)

Oxidation of NH_4^+ is an acidifying process. pH control is therefore a vital element with this system, as low pH values can inhibit the microbial conversion rates (van Kempen *et al.* 2001). pH will decrease substantially during the nitrification stage due to the highly concentrated influent and it is reported that ammonium oxidation will cease at pH values of approximately 6.4 (Jetten *et al.* 1997). This is due to the pH-dependant equilibrium between the ammonium ion and ammonia. For every mole of NH_4^+ present, two moles of H^+ are produced. Approximately 50% of this acid can be neutralised by carbon dioxide stripping, which occurs in the reactor (utilising the bicarbonate present in the waste water from the digestion process).

In the absence of a denitrification step, the remaining 50% would require neutralisation via base addition (Hellinga *et al.* 1998). However, the Water Environment Federation (2005) suggest that if a denitrification step is included, this will produce alkalinity, thus the requirement for supplementary alkalinity addition (such as caustic) can be minimal or unnecessary depending on the influent COD/N ratio.

Nonetheless, it is also important to realise that carbon addition (such as methanol dosing) is required to allow the denitrification process to proceed effectively. In this regard, Hellinga *et al.* (1998) have advised a cost saving on methanol dosing of 40-50% over NaOH (caustic) addition.

The process can be accomplished in a simple single continuously stirred reactor, with alternating aerobic and anoxic cycles for nitrification and denitrification or as a two stage continuous system utilising two reactors (aerated and anoxic reactors). A simple schematic of the 'SHARON' process is presented in Figure 1-8 below. The relatively short aeration retention time ensures that 'SHARON' reactors are modest in size, negating construction of larger main stream reactors associated with conventional nitrogen removal with resultant capital cost savings (refer to Section 1.5.3 above).

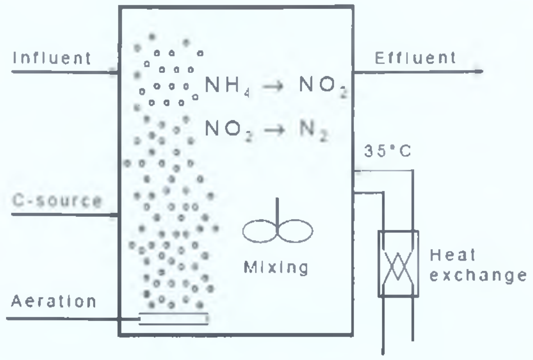

Figure 1-8 **Schematic representation of SHARON Reactor**

(Source: Grontmij Nederland BV. 2008)

The SHARON process was initially developed for the treatment of ammonium-rich centrifuged sludge digestion effluent (Hellinga *et al.* 1998). As part of the study undertaken by Hellinga *et al.*, influent (centrate) with an annual average ammonium concentration of approximately 1,000mg NH_4^+-N/l and with a corresponding average temperature of 30°C and a pH in the range of 8.1-8.4 was fed into a laboratory scale 'SHARON' treatment unit. The process was operated at laboratory scale (1.5 litre reactor) for 2 years, in a continuously stirred reactor. The hydraulic residence time was set to 1.5 days and the required process temperature was set at 35°C. An average ammonium conversion rate of 80-85% was achieved in this experimental unit. Using molecular ecological techniques on liquor taken from this unit, Logemann *et al.* (1998) demonstrated the presence of approximately 50 to 70% ammonia oxidising bacteria (*Nitrosomonas* species) in 'SHARON' biomass.

As part of the study undertaken by Hellinga *et al.*, a computer model was generated in 'MATLAB/SIMULINK' for simulating the full scale process and evaluating variable operational costs. The model included:

> '*13 non-linear differential equations for gas and liquid phase expressing the accumulation of the involved compounds as a function of the influent load and the microbial conversion rates*'.
>
> (Hellinga *et al.* 1998, 139)

Arising from the model, optimised reactor design and process cost estimates were enabled, leading eventually to full scale (1,800 cubic meter capacity) 'SHARON' construction at the Dokhaven Waste Water Treatment Plant in Rotterdam.

Following on from this, 'SHARON' technology has been applied to the treatment of reject water from the dewatering of pre-digested sludge at various waste water treatment plants for several years (van Kempen *et al.* 2001). It has been asserted that this process was the first successful commercial technology for nitrogen removal via nitrification/denitrification with nitrite as an intermediate under stable process conditions (van Kempen *et al.* 2001; Notenboom *et al.* 2002).

Operational experience indicates that the 'SHARON' process can be applied to successfully improve nitrogen emissions from the main stream effluent at waste water treatment plants, constituting a cost effective alternative to expansion of aeration basins and anoxic zones in a conventional manner (Mulder *et al.* 2006). Mulder *et al.* demonstrated up to 95% Total Nitrogen removal efficiency from side streams, however in reviewing this research it is apparent that fluctuations tend to occur from time to time during extended commissioning. Nonetheless, Total Nitrogen effluent concentrations tend to be less than 100mg N/l regardless of feed concentrations.

Figure 1-9 presents the nitrogen removal efficiencies achieved at the 'SHARON' treatment plant located at Beverwijk Waste water Treatment Plant. The graph shows an average Total Nitrogen reduction efficiency of 88%.

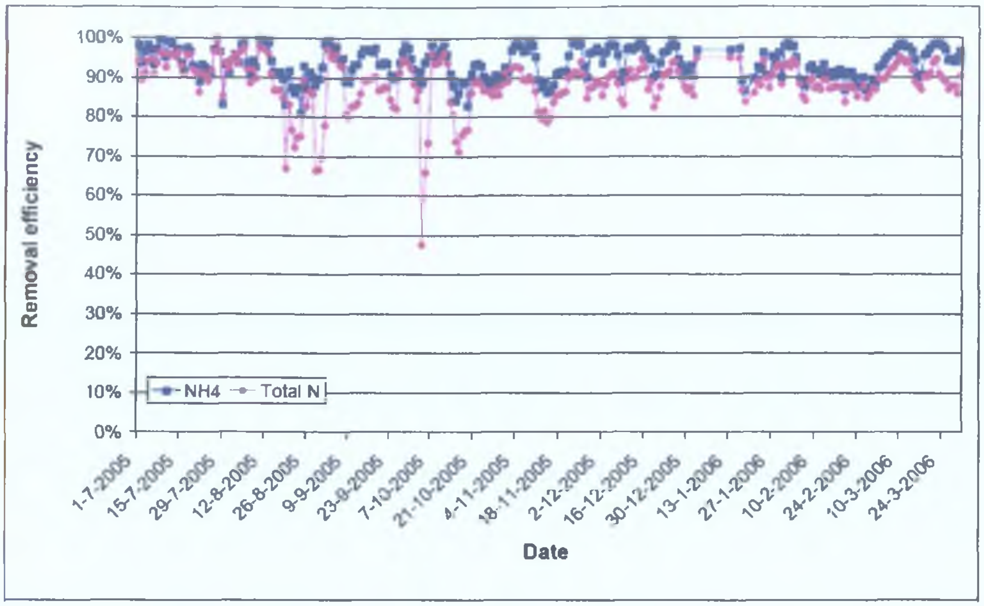

Figure 1-9 **Nitrogen and ammonium removal efficiencies achieved at the 'SHARON' Plant in Beverwijk WWTP for 2005/2006.**

(Source: Mulder *et al.* 2006)

Mulder *et al.* (*ibid.*) report that the process has also been applied in co-treating centrate and condensate from sludge drying plants, as the latter would tend to be COD-rich, thus eliminating the requirement for an external carbon source.

1.6.8 Option 2 – The Combined 'SHARON/ANAMMOX' Process (Deammonification)

'ANAMMOX' Process

The 'ANAMMOX' (or *'anaerobic ammonium oxidation'*) process is a nitrogen reduction technology whereby nitrite is converted to dinitrogen gas under anaerobic conditions with ammonium as an electron donor. It is a variation of the 'SHARON' process. The bacteria involved in this process are autotrophic, thus eliminating the requirement for an external COD source (Jetten *et al.* 1997).

The existence of chemolitoautotrophic bacteria, capable of oxidising ammonium using nitrite as an electron acceptor was first predicted by Broda in 1977 by using thermodynamic calculations (Vázquez-Padin *et al.* 2009). The prediction was subsequently experimentally confirmed by Mulder in 1992 in a denitrifying pilot plant at Gist-brocades (Mulder 1992; Mulder *et al.* 1995). The process involves providing partial nitrification of waste water, producing an ammonium/nitrite mixture, then conversion of the nitrite to nitrogen gas under anoxic conditions using the remaining ammonium as the electron donor (van Dongen *et al.* 2001*b*).

'SHARON/ANAMMOX' Combined Process

The 'SHARON/ANAMMOX' Combined Process is a form of deammonification, i.e. a two-stage reaction involving two distinct biomass populations, developed by the Delft University of Technology (van Loosdrecht and Jetten 1998).

As outlined above, the 'SHARON' process allows for the complete oxidation of ammonium to nitrite. For the combined 'SHARON/ANAMMOX' process however, the goal is to produce a 45:55 ammonium-nitrite mixture. The oxidation of 55% to 60% of ammonium to nitrite is undertaken in a 'SHARON' reactor (chemostat). Oxygen supply is limited in the reactor in order to limit the oxidation (STOWA 2006; USEPA 2007).

Jetten *et al.* (1997) claim that controlling the process such that only 50% conversion of ammonium is achieved is a straightforward task. Jetten *et al.* suggest that (provided no pH control is applied to the 'SHARON' reactor) the bicarbonate (from the anaerobic digester effluent), acting as a counter ion for ammonium, will be fully used at approximately 50% ammonium conversion, after which, due to a rapid drop in pH, nitrification will cease. Thus, according to this research, the requirement for recycling between nitrification and denitrification zones for pH control is negated, which would otherwise be the case for conventional nitrogen reduction processes.

However, although theoretically this is shown to be the case, Volcke *et al.* (2003) argue that the actual ratio of nitrite to ammonium obtained in the 'SHARON' process may deviate significantly from the ideal ratio if pH control is excluded. This was concluded following a simulation study inputting a year of actual influent data from the Dokhaven 'SHARON' plant. Volcke *et al.* made strong recommendations going forward for pH control (acid/base addition) at the 'SHARON' treatment stage to avoid inhibition of the 'ANAMMOX' process from toxic nitrite concentrations.

Following stage one of the process, whereby a suitable ammonium/nitrate mixture has been obtained, the second step of the treatment process then involves feeding this mixture to the 'ANAMMOX' reactor, which is essentially a Sequencing Batch Reactor. The ammonium in the mixture acts as an electron donor for the conversion of nitrite to nitrogen gas under anoxic conditions. The bacteria contained in the 'ANAMMOX' reactor are anaerobic ammonia oxidising microorganisms that work autotrophically to convert the incoming mixture to nitrogen gas (Wett *et al.* 2009). 16S RNA analysis of the biomass contained in such systems has shown that it is the organism *Brocadia anammoxidans* (Order *Planctomycete*) that is primarily responsible for 'ANAMMOX' reactions, which have a very high affinity for ammonium and nitrite (maximum specific nitrogen consumption rate at 0.82g N/gVSS.day) (van Dongen *et al.* 2001*b*). Due to the autotrophic nature of the bacteria involved in this reaction, there is no requirement for external carbon addition and it is this particular design aspect that appears to provide an advantage over the 'SHARON' process alone.

The biological reactions of the 'SHARON' reactor followed by the anoxic ammonium oxidation 'ANAMMOX' process are summarised in the following simplified equations:

$$NH_4^+ + HCO_3^- + 0.75O_2 \rightarrow 0.5NH_4^+ + 0.5NO_2^- + CO_2 + 1.5H_2O$$
$$NH_4^+ + NO_2^- \rightarrow N_2 + 2H_2O$$

(STOWA 2006, 1)

The 'ANAMMOX' bacteria exhibit slow growth (doubling time in the order of 10 days at 30°C); therefore SBRs must be of sufficient volume to ensure that wash out of the bacteria does not occur. When operated in a Sequencing Batch Reactor, a HRT of approximately 0.5 days and an SRT of 15 to 20 days is advised (Water Environment Federation 2005). Nonetheless, it is worth noting that the bacterial seeding of the 'ANAMMOX' reactor can be sourced from most common sludge outlets (STOWA 2006). Another obvious advantage of the system is minimal surplus sludge production, given the low growth yield of the organism responsible for the 'ANAMMOX' process (Jetten *et al.* 1997). Caution is advised however, as van Graaf *et al.* (1996) (cited in Khin and Annachhatre 2004) reported acute inhibitory effects of phosphate, oxygen and acetylene on 'ANAMMOX' activity.

Analysing the above stoichiometric equations, it can be concluded that the 'SHARON' process combined with the 'ANAMMOX' process operates with reduced running costs, i.e. the energy requirements arising from aeration are reduced by 60% when compared with conventional nitrogen removal methods. When compared to the 'SHARON' process (operating alone), further savings can be seen, as an external carbon source is not required for the combined process, due to its autotrophic nature. In addition, it is reported that sludge production and CO_2 emissions are minimal (van Dongen *et al* 2001*b*).

The ability to produce a 50:50 mixture of ammonium and nitrite in a stable manner was evaluated by van Dongen *et al.* (2001*b*), whereby sludge liquor from the Rotterdam WWTP was fed to a laboratory scale 'SHARON' reactor for a period of just under 250 days. The findings of this experiment are presented in Figure 1-10 and summarised in Table 1-4 below.

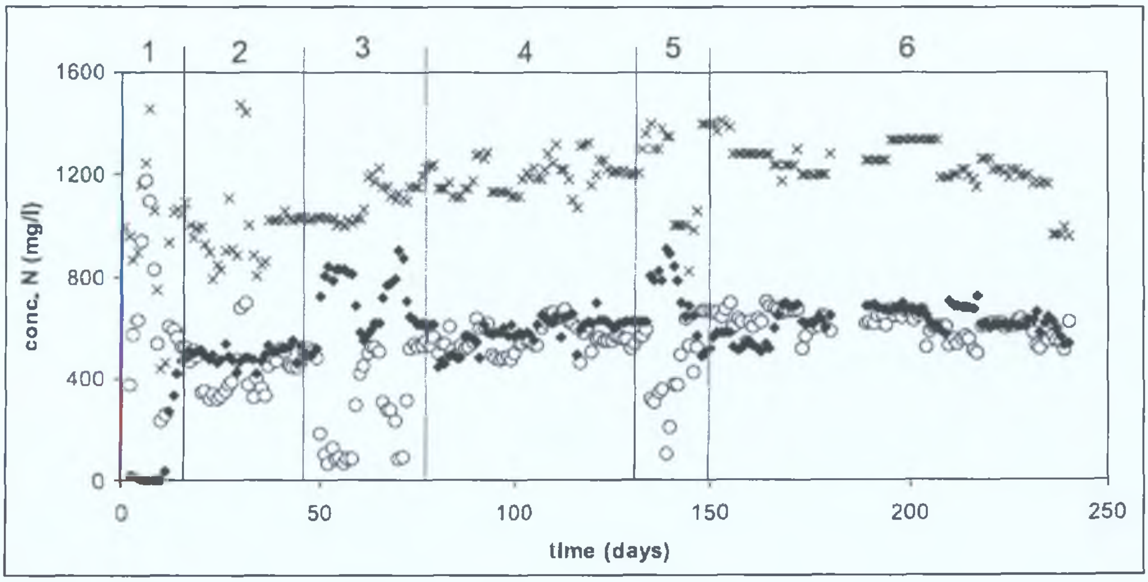

Figure 1-10 **Ammonium conversion in a 'SHARON' reactor with continuous operation**

HRT and SRT were both one day. Period 1: start up period, Period 2, 4 and 6: steady state operation without pH control, Period 3 and 5: test period to evaluate effect of reactor pH on conversion [x: NH_4-N in; o:NH_4-N out; ♦: NO_2-N out]

(Source: van Dongen *et al.* 2001b, 155)

Parameter	Unit	Steady state operation	Total period (240 d)
Influent NH_4-N	kg/m^3	1.18±0.14	1.17±0.25
Influent NO_x	kg/m^3	0	0
Effluent NH_4-N	kg/m^3	0.55±0.10	0.60±0.20
Effluent NO_2-N	kg/m^3	0.60±0.10	0.55±0.20
Effluent NO_3-N	kg/m^3	0	0
pH		6.7±0.3	6.8±1.2
NH_4-N conversion	%	53	49
N-conversion	$kg/m^3/d$	0.63±0.10	0.52±0.20

Table 1-4 **Conversion in a 'SHARON' reactor during the test period.**

Influent used was the centrate of digested sludge from the Rotterdam Dokhaven WWTP [HRT = SRT = 1 day].

(Source: van Dongen *et al.* 2001b, 155)

Under laboratory-controlled conditions, the research concluded that a stable conversion of approximately 53% of ammonium to nitrite was achievable at a load of 1.2kg N/m^3 without pH control. The analysis also proved that ammonium oxidising bacteria had the ability to perform adequately and displayed a tolerance for elevated concentrations of nitrite (>0.5g NO_2-N/l at pH 7).

Following on from this, a combination of the 'ANAMMOX' and the 'SHARON' processes was tested by feeding the 'ANAMMOX' SBR reactor with the effluent from Stage 1 experiments (see Table 1-4 above, effluent from 'SHARON' reactor). Results of these tests, proved to be successful, and are provided in Table 1-5 below. Nitrite was found to be the limiting substrate in this case, with 100% of NO_2^- being removed, but with some residual ammonium present in the reactor effluent.

Parameter	Unit	Steady state operation
Test period	day	110
Influent NH_4-N	kg/m^3	0.55±0.10
Influent NO_2-N	kg/m^3	0.60±0.10
NH_4-N conversion	kg/m^3/d	0.35±0.08
NO_2-N conversion	kg/m^3/d	0.36±0.01
Effluent NO_2-N	kg/m^3	0
Volumetric conv.	kg N_{tot}/m^3/d	0.75±0.20
Sludge conversion	kg N_{tot}/kg SS/d	0.18±0.03

Table 1-5 **Conversion in a granular sludge SBR 'ANAMMOX' reactor fed with a nitrified effluent from a 'SHARON' reactor.**

(Source: van Dongen *et al.* 2001b, 158)

During laboratory analysis of this combined process, the possible influence of biomass in the 'SHARON' effluent on 'ANAMMOX' process efficiency was investigated. A potential for negative impact was initially recognised given the low growth rate of the 'ANAMMOX' cells combined with possible dilution of the SBR liquor with incoming ammonium oxidisers from the 'SHARON' process. FISH analysis indicated the dominance of *B. Anammoxidans* in the mixed liquor with washout of the ammonium oxidisers originating from the 'SHARON', when the process was operated in a granular sludge reactor.

Jetten *et al.* (1997) also reported on the successful pilot plant testing of a combination of the 'ANAMMOX' and 'SHARON' process. A Total Nitrogen load of 0.8kg N/m^3 per day of sludge digester effluent was fed to the (step 1) 'SHARON' reactor, which was operated without pH control. During this treatment step 53% of ammonium was oxidised. The resulting ammonium-nitrite mixture was then fed to the (step 2) 'ANAMMOX' (fluidised bed) reactor. The resultant nitrogen balance is shown as in Table 1-6 below, with nitrite and ammonium removal efficiencies averaging 100% and 83% respectively.

	Influent	Sharon Effluent/Anammox Influent (mg N / liter)	Anammox Effluent
NH_4^+	584	267	29
NO_2^-	<1	227	1.4
NO_3^-	<1	64	83
N_2O^a	<1	4	<1
N_2^a	<1	<1	476^b

Table 1-6 **Nitrogen balances in the combined 'SHARON/ANAMMOX' process, results obtained from a preliminary laboratory test with sludge digester effluent**

(a = concentration relative to the influent flow, b = determined as the difference between the dissolved and gaseous nitrogen compounds).

(Source: Jetten *et al.* 1997, 176)

Jetten *et al.* (1997) summarised and compared the main process parameters for low loaded conventional activated sludge plants as compared with the combined 'SHARON/ANAMMOX' process, as shown in Table 1-7 below:

	Conventional System	Proposed System
Oxygen demand		
kg O_2 per kg N removed	4.65	1.7
kg O_2 per kg COD removed	0.6	0.2
COD demand		
kg COD per kg N verwijderd	4-5	0
Methane production		
kg CH_4-COD per kg COD removed	0	0.5
Sludge production		
kg sludge-COD per kg COD removed	0.4	0.3

Table 1-7 **Main differences (in global values) between a conventional low loaded (0.05kg BOD/kg VSS per day) activated sludge system and the combined 'SHARON/ANAMMOX' process.**

(Source: Jetten *et al.* 1997, 179)

The savings in energy requirements are clearly evident from the above table.

The first full-scale 'ANAMMOX' reactor was commissioned in Dokhaven WWTP, Rotterdam during June 2002, as a retrofit to an existing 'SHARON' plant that had been installed previously. It is reported (STOWA 2006) that the 'SHARON' process was successfully operational at Dokhaven from 1998 up until commissioning of the 'ANAMMOX' system there.

1.6.9 Option 3 – The 'In-Nitri' Process (Bioaugmentation)

In-Nitri is an American patented process, which operates on the principle of bioaugmentation. The process is reported to shorten required SRT values, thus reducing the size of reactors required, and has been designed for colder climatic conditions (USEPA 2007). Waste activated sludge (WAS) (containing nitrifiers) is fed from the side stream nitrification reactor to augment the main activated sludge process, thus improving the nutrient removal efficiency of the main plant. Hence, the purpose of the side stream reactor in this case is for the establishment of a reserve of supplemental nitrifiers utilising ammonia-rich liquors, usually readily available on site as a byproduct of sludge treatment.

In practice, the installation of such a system would entail the construction of a modest aeration tank and clarifier for the production of nitrifiers. The presence of a high strength liquor (with an ammonia content in the range of approximately 300mg/l to 900mg/l and a temperature range of 30 to 35°C) is a requisite of this system. The Water Environment Federation (2005) report that bioaugmentation of the main activated sludge system with a readily-available on-site nitrifier seed source can lead to a reduction in required SRT at the main reactor and can counteract inefficiencies resulting from shock loadings leading to year-round nitrification. Figure 1-11 shows a typical schematic for the 'InNitri' process, employed in combination with conventional treatment.

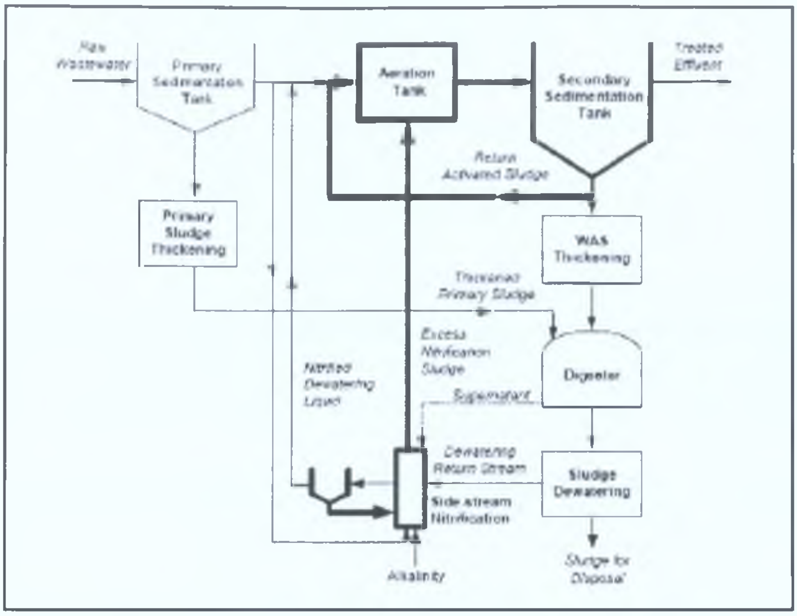

Figure 1-11 **Typical Schematic of 'InNitri' Process combined with Conventional Waste water Treatment**

(Source: USEPA 2007, 4)

Mathematical modeling was conducted by Kos in 1998 (cited in Warakomski 2001), for both conventional nitrification and for the 'In-Nitri' theory. Kos firstly proved that for conventional nitrification at 10°C, the concentration of nitrifiers decrease with SRT, causing increased ammonical nitrogen concentration in final effluent. Kos' model then validated the presence of nitrifiers at all SRTs examined when considering the 'InNitri' approach.

Effluent temperatures modeled ranged between 7.5 to 20°C. Model results concluded that the 'In-Nitri' process allows for significantly lower SRT values than conventional systems in achieving any chosen target final effluent ammonium concentration, with considerable cost reductions over conventional systems for lower temperature waste waters. However, the Water Environment Federation (2005) reported on research conducted at the University of Manitoba on a laboratory scale unit. The research argued that nitrification capacity is somewhat compromised by temperature correction.

A feasibility study was undertaken in 2000 at Harrisburg City Waste Water Treatment Facility located in the colder region of north-eastern United States (Pennsylvania) to determine the potential viability of retrofitting the 'In-Nitri' process to the existing conventional process (Brinjac, Kambic and Associates 2000; cited in Warakomski 2001) with the aim of reducing nitrogen in main process emissions. Final effluent from Harrisburg City WWTP is discharged to the Susquehanna River, which ultimately discharges to Chesapeake Bay, a location that is the focus of nutrient reduction efforts. The facility was restricted in terms of available expansion area. The recommendation of the study was for the implementation of the 'In-Nitri' system at the facility. However, at present (March 2010), subsequent research could not be found to suggest that any full-scale 'In-Nitri' installations exist.

1.7 Literature Review Summary

The Literature Review was initiated by providing the reader with a fundamental outline of nitrogen characteristics in waste water with the intention of allowing the reader to become familiar, at an early stage, with the various forms of inorganic nitrogen referenced throughout this study.

The rationale for nitrogen removal from waste water emissions is reinforced based on the findings of the literature review concerning a 'do-nothing' approach. Research has proven that uncontrolled nitrogen emissions to receiving waters can in some instances lead to, *inter alia*, ammonia toxicity of aquatic life, eutrophication and enrichment of estuaries and coastal waters, algal blooms and compromised diversity in aquatic ecosystems. In addition, elevated nitrate levels have been implicated in contributing to human health issues such as mutagenicity, carcinogenicity and methaemoglobinemia, in terms of potable water supply.

Relevant EU and national legislation was reviewed to ascertain the current position on legal nitrogen reduction requirements of the State. The Water Framework Directive is seen as the driver behind all recent water quality legislative requirements, which are becoming increasing challenging for those responsible for municipal waste water treatment and disposal. Legal requirements for nitrogen removal from municipal waste water arise from two sources:

1. The requirement to comply with the Urban Waste Water Treatment Directive (91/271/EEC), where the receiving water has been designated *'nutrient sensitive'*.
2. The requirement to comply with ELV's set by the EPA in Waste Water Discharge Consents (in cases where a nitrogen ELV has been set).

Recently enacted (2009/2010) legislation, relevant to both sources, is set to dramatically increase the statutory requirement for nitrogen reduction on a national basis. However, a review of an EPA study on municipal waste water, undertaken during 2006/2007 (Monaghan *et al.* 2009), indicated that while Ireland was gaining ground on compliance with the secondary treatment requirement, there was still 86% non-compliance with the statutory provision of nutrient reduction facilities at December 2007. This shortfall is further exacerbated by the recent legislation.

Finalised versions of River Basin Management Plans will contain Programmes of Measures designed to address these shortcomings, which are likely to include recommendations for municipal treatment plant upgrades to incorporate nitrogen reduction in certain areas. The literature review examined the technical merits of two options for implementing nitrogen reduction, *viz.*:

1. Conventional upgrade of treatment works to incorporate nitrogen removal;
2. Side Stream Treatment Technology as an alternative for nitrogen removal.

The latter option concerns isolation of side streams for specialised treatment. Biotechnological advances have enabled the successful side stream treatment of ammonium-rich streams, resulting in considerable nitrogen reduction from main stream final effluent; however no research could be sourced to suggest that this has been employed in Ireland to date.

Every technology examined shared a common pre-requisite, i.e. a nitrogen-rich feed source. Research on side stream constituents from treatment plants in Germany and the Netherlands demonstrated that typically 12 to 25% of the total plant nitrogen load is being recycled in anaerobic sludge digestion effluents. Unfortunately, little is known of side stream constituents or strengths in Irish municipal plants, as this type of analysis has not been the focus for operators. Research is necessary to establish the presence and constituents of nitrogen-rich recycle streams in Ireland.

Various sources of detailed research verified that both Option 1 and 2 (above) can be effective at nitrogen removal in their own right. Capital and operational costs will vary with each method; however impartial research was not available to provide sufficient evidence of the cost savings of side stream nitrogen removal over conventional. This requires further unbiased examination.

The study going forward will establish the presence of nitrogen-rich streams choosing a subject municipal waste water treatment site in Ireland. If nitrogen-rich streams are successfully identified, the research will proceed on the basis of a feasibility study.

AIMS OF THE RESEARCH

SECTION 2. AIMS OF THE RESEARCH

The main aim of the research is to determine whether established side stream technologies could be applied at municipal waste water treatment plants in Ireland as a successful alternative to conventional means of Total Nitrogen reduction.

This determination will be realised through choosing a suitable Irish waste water treatment site case-study and completing a Feasibility Study relating to same. Dundalk Waste Water Treatment Plant became the chosen site due to a number of factors:

- Anaerobic digestion and sludge drying forms part of the treatment process there (hence high-temperature ammonium-rich recycle streams are likely to be present);
- The scale of the plant is relatively large (designed to 179,535PE);
- The plant does not already provide dedicated nitrogen removal.
- The receiving water (Castletown Estuary) was designated *'nutrient sensitive'* under the Urban Waste Water Treatment Regulations 2001 and in subsequent amendments thereof.

More specifically, the question then to be answered in assessing Dundalk WWTP is: whether the addition of a side stream treatment process can deliver an increased nutrient reduction capacity that would allow the main stream final effluent to lie within acceptable ranges of Total Nitrogen, negating the requirement for a more expensive conventional upgrade. The likelihood for successful application of side stream technology at other similar waste water treatment plants in Ireland will become more apparent following the conclusion of this study.

In achieving the research objective, the individual research tasks will be:

1. Obtain a clear understanding of all aspects of the treatment process at Dundalk, including technologies, flow characteristics, current performance in terms of treatment efficiencies and effluent quality, side stream data - via site monitoring and interviews with Operators;
2. Identify target recycle streams;
3. Prepare a mass balance of the nitrogen within the site by undertaking sampling and analysis of side streams;

4. Assuming a nitrogen ELV (as this has not yet been established by the EPA), undertake engineering design for a conventional upgrade of existing units to meet assumed standard – calibrate design for existing conditions encountered;
5. Produce a cost estimate for the conventional upgrade;
6. Utilising literature review findings, produce predictions of effectiveness of side streams considering mass balance results;
7. Undertake a preliminary engineering design of side stream technologies (choosing two options for treatment);
8. Produce cost estimates for side stream retrofit;
9. Formulate recommendations on side stream treatment applicability as a possible means of offsetting upcoming difficulties with legislative compliance.

The ultimate aim of the research is to provide a cost effective solution for Local Authorities to allow compliance with nitrogen reduction legislation concerning municipal discharges, where feasible.

MATERIALS AND METHODS

SECTION 3. MATERIALS AND METHODS

3.1 Introduction

This section details the methods and strategies for primary and secondary data collection alluding to the objectives of Section 2.0 above. The primary empirical data collected relates to establishing the existence of highly concentrated nutrient streams in Irish municipal waste water treatment plants, undertaken by way of site investigation, sampling and constituent analysis. The absence of previous research in this specific area renders this study necessary and worthwhile.

The Materials and Methods Section is sub-divided into data collection methodologies and data analysis techniques. Limitations to the study have been included at the end of this chapter.

3.2 Research Strategy

One of the tried and tested research strategies for empirical data gathering is through case-study analysis (Biggam 2008). The primary and secondary data collection phase of the research (herein) has been enabled through a case study at Dundalk WWTP; encompassing a comprehensive desk study, interviews with treatment plant staff, observations, surveys and through grounded theory, all undertaken with an unbiased approach. The research is therefore positivist in nature.

Choosing a case study as the primary research strategy (as opposed to theoretical methods) was seen as the only reliable means of achieving a definitive answer to the primary research question.

3.3 Data Collection Methodology

For this study, data collection was undertaken on a progressive basis, i.e. the completion of each stage of data collection led logically to each subsequent stage. Hence research strategies relating to each stage are presented hereunder in progressive order.

3.3.1 *Preliminary Selection of Case-Study Site*

The EPA web-based archive system allowed the easy access to countrywide Waste Water Discharge Consent Application files, which provided detailed mapping of plant locations, final effluent discharge locations and a basic overview of treatment processes and sludge handling facilities. Dundalk WWTP was then selected for the reasons provided in Section 2.0.

A literature review of environmental quality data and legislation provided background on the receiving water status and the nitrogen reduction requirements pertaining to the treatment plant. This enabled a determination of whether nitrogen is likely to be an issue at the case study facility.

Permission was then sought from Operators of the plant (EPS Ireland Ltd.), the relevant Local Authority (Louth County Council) and the Consultant Engineer (TOBIN Consulting Engineers) to proceed with the research proposal. The purpose of this step was to obtain the co-operation of all parties at an early stage in terms of data availability and permission to include findings in a dissertation document for third party examination.

3.3.2 *Secondary Data Collection*

An initial desk study assessment of contract documentation (tender specifications), as constructed drawings and original design documentation was undertaken to establish the design process flows and treatment capabilities (design discharge standards) of the existing treatment plant. These documents were made available by TOBIN Consulting Engineers.

Site visits, interviews and (telephone and email) correspondence with Dundalk WWTP personnel, including the Regional Plant Manager, Site Manager, plant operatives and scientific staff were conducted. An accurate outline of operational characteristics of the facility was obtained via this interview approach and through on-site observations.

A list of the research questions formulated at desk study and interview stage can be found in Appendix E.

A comprehensive dataset of process flows, influent and effluent chemical analysis and records of sludge and leachate imports (tonnages and dry solids content) for Year 2009 was made available by EPS Ireland Ltd. from digital site record keeping. Limited records were available relating to recycle streams, providing only aggregate flow-rates of all streams returned to the headworks.

3.3.3 Primary Data Collection

Recycle stream mapping was enabled by means of a manhole (dye) survey. Researcher witnessing of this survey was imperative to the study to avoid data misinterpretation. The manhole survey was undertaken by plant operatives under the instruction of the researcher.

A preliminary sampling and analysis programme for side streams encountered was formulated by the researcher while on site, following recycle stream mapping. Further site observation was necessary to finalise the logistics of isolating streams, sampling and flow-rate/liquid level recording. All recycle streams encountered were included in the sampling programme, however at this stage the literature review findings were drawn upon in terms of recognising the potentially concentrated streams, which were earmarked for greater focus.

Sampling frequency was dependent upon each particular stream. Grab samples were abstracted on a daily basis between the 17th and 24th of February 2010. Sampling techniques employed were as per the recommendations of independent laboratory Euro Environmental Ltd. The parameters for analysis were selected to include those listed as common analytes *'used to characterise waste water entering and leaving a plant'* by the EPA (1997).

Figure 3-1 shows the sampling locations in schematic form. Table 3-1 details the recycle stream sampling regime.

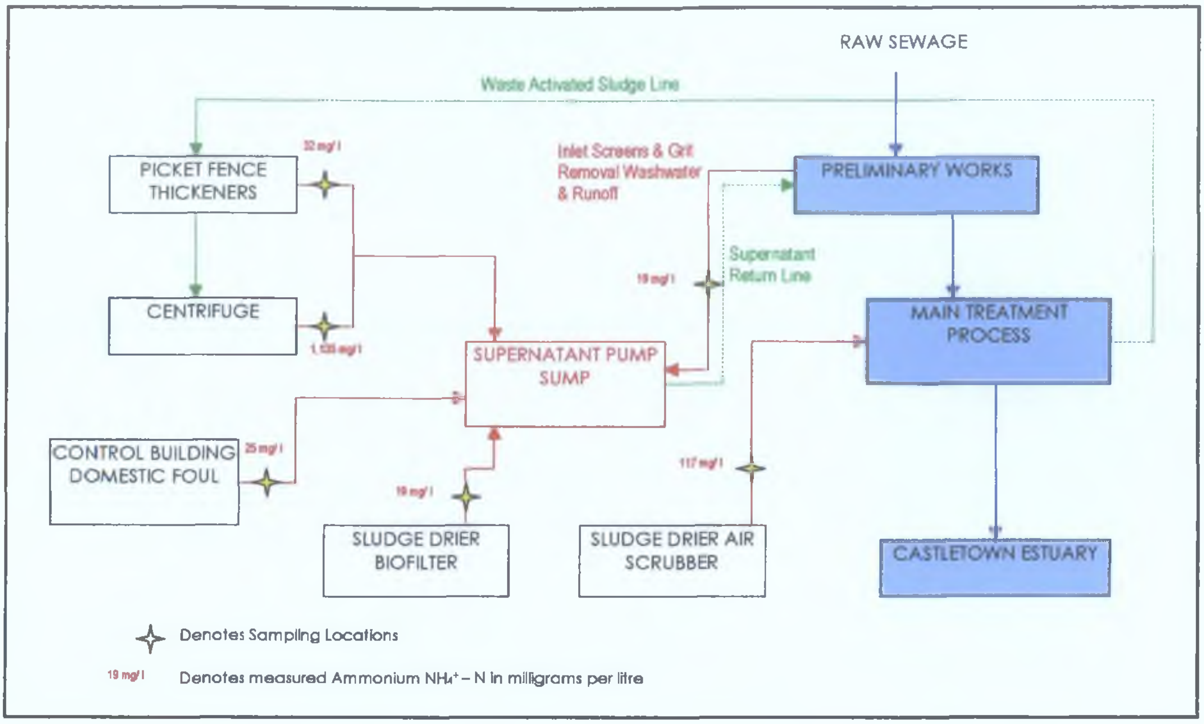

Figure 3-1 **Schematic of Recycle Stream Sampling Locations at Dundalk Waste Water Treatment Plant (Sampling undertaken 17/02/2010 – 24/02/2010).**

Sample Ref.	Sample Description	Location for abstraction	Min. Nr. Of Samples Reqd.	Parameters for Analysis
DK1	Centrate from Centrifuge Units	Manhole after Centrifuge process but upstream of Supernatant sump	5	Temperature pH Total Nitrogen (as N) Ammonium (as NH_4-N) Nitrate (NO_3 as N) Nitrite (NO_2 as N) Suspended Solids BOD_5 COD
DK2	Supernatant from Picket Fence Thickeners	Supernatant Return Sump (isolate by obtaining sample prior to centrifuge start-up)	5	
DK3	Sludge Drier Condensate	From Washwater Tank immediately downstream of Air Scrubber	2	
DK4	Biofilter Return Effluent	Sample directly from return pipe in sump adjacent to biofilter unit venting Drier Building	2	
DK5	Preliminary Treatment Units Washwater	From manhole in drain immediately upstream of Drier Building	3	
DK6	Control Building Foul	Isolate at Supernatant Return Sump	1	

Table 3-1 **Recycle Stream Sampling Regime at Dundalk Waste Water Treatment Plant (Sampling undertaken 17/02/2010 – 24/02/2010).**

The temperature and pH of the samples were recorded in the field using a "Eutech pH 300" combined pH and temperature probe. (This unit is calibrated weekly). Analysis for suspended solids, COD and ammonium (as NH_4-N) was conducted at Dundalk WWTP on-site laboratory via a "Hach Lang" spectrophotometer. Analysis for COD was undertaken via the 'Reactor Digestion Method' using medium range (0-1,500mg/l) and high range (0-15,000mg/l) vials as appropriate. The 'Salicylate Method' was selected for ammonia analysis using high range (0-50mg/l) vials.

Samples were then sent to Euro Environmental Ltd. in Drogheda for analysis of BOD, Total Nitrogen, Total Phosphorus, nitrate and nitrite. This laboratory is INAB accredited. Sample abstraction and delivery to Drogheda occurred on the same day during each sampling event.

Daily flows from the recycle streams were calculated/estimated from flow meter records, tank water level readings, sludge dry solid analysis and best estimates of water usage of certain plant.

On determination of the volumes and concentrations of all side streams, a nitrogen mass balance was prepared for the site, as detailed below. Further data was sought to validate the mass balance findings by way of a second questionnaire, forwarded to the Site Manager, on-site Laboratory Technician and Environmental Manager for the plant. A copy of the questionnaire is included as Appendix F.

3.4 Framework for Data Analysis

This section describes the methodologies for analysis of the raw data collected. Evaluation of existing plant performance and required improvements were conducted via statistical analysis of raw data sourced from site records. Mass balance preparation was necessary to identify target streams potentially suitable for side stream treatment, but firstly to allow the prediction of final effluent quality assuming side stream treatment implementation (in order to determine the technical viability of such a process at Dundalk).

3.4.1 System Selection

As a means of determining the economical viability of side stream treatment at Dundalk, preliminary engineering designs for two different side stream treatment options and (for comparison purposes) for a conventional upgrade were completed. This enabled accurate cost estimates of each system to be generated.

In considering the preferred option for side stream treatment, reference was made to Table 3-2 (below), which provides a comparison of the merits of various side stream nitrogen removal methods by Grontmij BV and (operational) cost estimates relating to same, produced by STOWA (The Dutch Foundation for Applied Water Research) in 1996.

General comparison of different techniques for N-removal from rejection water

	Production chemical sludge	Production biological sludge	Dosage chemicals	Energy requirements	Operation	Cost* estimate Euro/kg N
Air stripping	yes	no	yes	average	average	6.0
Steam stripping	yes	no	yes	high	complex	8.0
MAP/CAFR process	yes	no	yes	low	complex	6.0
Membrane bioreactor	no	yes	yes	high	average	2.8
Biofilm airlift reactor	no	low	yes	average	average	5.7
SHARON process	no	low	yes	average	average	1.5

*Cost estimate base on STOWA[1] (1996) for WWTP capacity of 500.000 p.e.

Table 3-2 Comparison of Side Stream Nitrogen Removal Methods by STOWA

(Source: Grontmij Nederlands BV 2008)

As seen on the above table, STOWA reported that of the six methods assessed, the 'SHARON' process incurred the least operational costs per kilogram of nitrogen removed, (based on a 500,000 P.E. capacity plant). The combined 'SHARON/ANAMMOX' process, developed after this assessment, does not appear on this table, however research suggests that this process is also successful and holds certain advantages over the 'SHARON' process, hence it was included as part of the feasibility study.

The options examined were therefore as follows:

Option A: Conventional upgrade of the main biological treatment process.

Option B: Upgrade by retrofitting 'SHARON' side stream treatment system.

Option C: Upgrade by retrofitting combined 'SHARON/ANAMMOX' side stream treatment system.

3.4.2 Mass Balance Preparation

Primary data collection provided concentrations and daily volumes of individual recycle streams. A nitrogen load in kg per day was calculated for each side stream using the following formula:

$$\frac{[\text{mg N/l}] \times [\text{m}^3/\text{d}]}{1{,}000} = [\text{kg N/d}]$$

The result was then expressed as a percentage of the Total Nitrogen load entering the main treatment works.

3.4.3 Side Stream Prediction and Preliminary Design

The literature review findings were drawn upon to prepare predictions concerning final effluent improvements at Dundalk assuming side stream retrofitting. The predictions were based upon past operational experience at other facilities (refer to Section 1.0).

Process parameters such as HRT, SRT and process control requirements were catalogued from existing and established facilities in the Netherlands. This catalogue was then used to establish likely reactor volumes and associated mechanical and electrical plant requirements for Dundalk.

The main considerations in designing the side stream treatment systems (Options B and C) were:

- Minimum Sludge Retention Time
- Volume requirements for the reactor
- Oxygen requirements (& energy demand)
- Chemical usage.

Hellinga *et al.* (1998) reported the following with regards to 'SHARON' reactor design;

> *'The important scale-up aspect is the height to diameter ratio of the reactor. The higher the reactor, the higher the average pressure in the gas phase. As CO_2 must be transferred from the liquid to the gas phase for pH control, a higher gas pressure counteracts this transport which is reflected by higher costs for denitrification, or even additional costs for base addition.'*
>
> (Hellinga *et al.* 1998, 140)

The reactor design as part of this study (for Options B and C) has incorporated a height to diameter ratio of approximately 1:4.5 to avoid elevated gas pressure in the reactor.

In terms of 'ANAMMOX' reactors, van Dongen *et al.* (2001*a*) emphasised the importance of reactor configuration. A study undertaken by van Dongen *et al.* concluded that biofilm reactors or granular sludge reactors were best suited to the 'ANAMMOX' process. Advantages and disadvantages are associated with each reactor type, i.e. the biofilm reactor allows a relatively easy start up and operation, however the granular sludge reactor allows reactor volume savings over the former. A disadvantage of the granular sludge type reactor is that, due to the lower sludge retention time, start up of such a system is slower. The granular sludge reactor type was chosen for the Option C design at Dundalk. Despite documented disadvantages with start-up times, it was considered that the reactor size would be more efficient over the biofilm-type, leading to savings in capital and longer-term operational costs.

3.4.4 Conventional Upgrade Design

The conventional upgrade design was based upon the original Phase 1 hydraulic and organic design loadings. The function of the design was to estimate additional sludge mass required to incorporate nitrification/denitrification at the B-Stage process.

The conventional upgrade design was initially undertaken by revising the original design calculations for Dundalk WWTP (which were stated to be partially based upon STOWA Directives) to include nitrification and denitrification. However, on evaluating the design output, the upgrade design of the activated sludge basins was subsequently recalculated in accordance with the German Design Standard ATV-DVWK-A 131E method.

The type of process currently in place at Dundalk WWTP is a two-stage activated sludge system, selected specifically to buffer wide variabilities in incoming load. The German standard, although relating to single-stage activated sludge plant design, was deemed a more appropriate design methodology as it takes greater account of important process parameters such as sludge age, F/M ratio and Mixed Liquor Suspended Solids (MLSS) than the former design method. The design model was calibrated to reflect realistic process efficiencies from Stage 1 of the biological treatment process as an input to Stage 2 design.

3.4.5 Cost Estimates

In preparing cost estimates both for conventional and side stream technologies, capital costs have been estimated bearing in mind the 'brownfield' site project and the more-than-adequate availability of footprint at the site for conventional expansion of the treatment process (which was an influential factor in cost estimates from previous research due to inavailability of land (Mulder *et al.* 2006)). For this study, capital costs included total construction costs associated with the upgrade, planning and supervision costs, employer overheads and plant replacement costs. Rates used in estimating construction costs were based on current construction rates from similar civil engineering projects (April 2009).

The cost estimate was based upon an assumed construction duration of 5 months for conventional and side stream upgrade, commencing in May 2011.

Estimates on operating costs have been projected based on 10-year operation within the existing Operation and Maintenance (O&M) Contract. Fixed operational charges include labour, O&M Contractor overheads and administration, whilst variable operational charges include materials, electricity supply and miscellaneous costs. Costs were comparable by means of applying a unitary cost driver, i.e. cost per kg of Nitrogen removed.

The cost estimates were generated for an entire 10 year operation and maintenance period, with annual inflation added at assumed rates. A Net Present Value (NPV) was calculated for the stream of cashflows. The discount rate assumed in calculating the NPV was 5%. Assumptions used in constructing the estimate are provided in Appendix G.

3.5 Limitations and Problems

Although a great deal of new information was generated as a result of this study, certain limitations are associated with this data. Grab samples on a limited number of sampling events provided just a 'snap shot' of side stream constituents at this plant. Therefore, an assumption must be made for the purposes of continuing this study, that laboratory results and flow data obtained are representative of the year round scenario. Nonetheless, it was confirmed by the Site Manager that sludge handling practices, which tend to influence side stream characteristics, would not differ to any considerable degree throughout the year at this facility.

Side stream efficiency predictions are based on the previous performance of other such plants located throughout the Netherlands. As each facility will differ considerably in terms of side stream characteristics, as will the proportion and nature of industrial effluent contributing to each facility, it would be prudent to install a pilot plant in advance of full-scale implementation at Dundalk.

RESULTS

SECTION 4. RESULTS

4.1 Introduction

This chapter reveals the results of the case study described in Chapter 3.0 – Materials and Methods. The findings are divided into existing plant data, recycle stream analysis and the options for plant upgrade to incorporate a nitrogen reduction facility.

4.2 Existing Facility

4.2.1 Process Description

Dundalk Waste Water Treatment Plant was procured as a traditional contract, and is now operated under a 20-year O&M Contract held between Louth County Council and EPS Ireland Ltd. The existing works were commissioned in 2000, designed to treat waste water from a contribution population equivalent of 179,535. Loads to the plant are variable due to the industrial nature of the catchment.

The existing treatment facility has been constructed to Phase 1 design parameters. The operation and maintenance of the plant, under this load, is being performed under defined contract conditions and defined final effluent standards and performance metrics. The existing design parameters and target final effluent emission limits for Dundalk are provided in Table 4-1 below.

Existing Design Parameters	Design Value
Design Dry Weather Flow (DWF)	18,088 m^3/d
Maximum design flow to treatment	2.7DWF: 48,838 m^3/d
Design BOD load	10,772 kg/d
Design Population Equivalent	179,535PE
Design Discharge Standards	**Target Emission Limit**
BOD	25 mg/l
COD	125 mg/l
Suspended Solids	35 mg/l
Total Nitrogen	(Phase 2 requirement only)

Table 4-1 Dundalk Waste Water Treatment Plant – existing design parameters and target effluent emission limits.

The treatment process is a two stage A/B process. The main treatment process incorporates preliminary screening, grit removal, stormwater holding, A-Stage aeration basins and clarifiers and B-Stage aeration basins and clarifiers for secondary treatment of waste water prior to discharge to the Castletown Estuary.

Phase 1 design requirements did not include a design discharge standard for nitrogen, therefore the existing plant does not currently incorporate dedicated nitrogen removal. In attempting to implement nitrogen removal at the existing plant, one would find that the B-stage would tend to be overloaded. More specifically, the desired sludge age could not be reached due to insufficient volumetric aerobic capacity and the absence of an anoxic capacity at the aeration stage.

In terms of sludge handling, sludge wasted from the A-Stage and B-Stage clarifiers is pumped to a 1st Stage picket fence thickener and 2nd Stage thickener respectively. Thickened sludge is sent to two anaerobic digestion units, where it is held for a minimum of 12 days at 33+/- 3°C. Digested sludge is sent to one of two holding tanks prior to dewatering via centrifuge. The moisture content of dewatered sludge cake is then further reduced by sludge drying; however an option to lime-dose the sludge is also available to the Contractor. Biogas is produced as a byproduct of mesophilic digestion, which is fully utilised for powering the facility, supplemented by natural gas. Power from biogas production equates to approximately 200kWh.

A layout plan of the existing facility together with a map illustrating the facility and agglomeration location have been provided in Appendix H.

The two stage activated sludge system was selected specifically to buffer wide variabilities in incoming load. The existing Phase 1 plant was designed to take into account eventual Phase 2 expansion. There is sufficient footprint available on site for eventual expansion to Phase 2 of capacity 220,000PE. The preliminary units, first stage aeration basins, digesters, sludge holding and dewatering systems have included provisions in design for Phase 2 loadings. A conventional upgrade to incorporate dedicated Total Nitrogen reduction would entail increasing the sludge age in the B-Stage aeration tanks, but as the design may dictate, may also necessitate the construction of an anoxic tank.

Applying nitrification/denitrification without expansion of the plant would result in negative effects in the B-Stage clarifiers during wet weather, which would be determined by the actual settleability of the sludge, when the plant is operated under reduced organic load in a nitrification/denitrification process.

4.2.2 Effluent Loadings

Prior to proceeding to design stage, a detailed consideration of the current effluent loading to the plant was afforded, based on monitored organic data (BOD and Total Nitrogen) in the influent for Year 2009. Table 4-2 includes a summary of daily averages for hydraulic and organic loads on a monthly basis, for the monitoring duration 1st January 2009 to 31st December 2009.

Month	Influent Load to Dundalk WWTP				Supernatant Return
	Avg Daily Flow	Avg. Daily BOD Load	Avg. Daily TN Load	Avg. PE	
Jan-09	25,881 m^3/d	5,626 kg/d	nm	93,772 PE	997 m^3/d
Feb-09	26,170 m^3/d	5,682 kg/d	nm	94,702 PE	1,231 m^3/d
Mar-09	20,661 m^3/d	5,593 kg/d	nm	93,211 PE	1,282 m^3/d
Apr-09	23,520 m^3/d	4,878 kg/d	nm	81,293 PE	1,504 m^3/d
May-09	26,225 m^3/d	3,769 kg/d	nm	62,811 PE	1,327 m^3/d
June-09	21,676 m^3/d	4,298 kg/d	nm	71,627 PE	1,242 m^3/d
Jul-09	29,942 m^3/d	4,701 kg/d	nm	78,350 PE	1,155 m^3/d
Aug-09	26,692 m^3/d	5,515 kg/d	738 kg/d	91,920 PE	1,300 m^3/d
Sept-09	26,141 m^3/d	4,078 kg/d	725 kg/d	67,975 PE	1,009 m^3/d
Oct-09	23,458 m^3/d	5,521 kg/d	700 kg/d	92,020 PE	1,181 m^3/d
Nov-09	39,715 m^3/d	4,387 kg/d	800 kg/d	73,119 PE	854 m^3/d
Dec-09	27,796 m^3/d	4,551 kg/d	721 kg/d	75,848 PE	1,081 m^3/d

Table 4-2 Average hydraulic and organic loads received at Dundalk WWTP.
('nm' denotes not measured at the time).

Table 4-2 shows the average 2009 loadings to the plant. Supernatant return flows arising from sludge handling are also included. External sludges are imported to site and introduced to the process downstream of the influent monitoring point, but supernatant flows are returned upstream of the monitoring point. This table therefore allows the inclusion of loadings arising from external sludge supernatant. Appendix I provides a copy of the full daily dataset available relating to both influent and final effluent for 2009.

Because of the hydraulic and organic variability of incoming flows to Dundalk (particularly from the brewing and food processing industries), the maximum, 95 percentile, 90 percentile and average statistical loadings have been calculated. These statistics have been based on daily flow monitoring and approximate bi-weekly BOD sampling over a 12-month period (2009). Table 4-3 summarises this data.

Maximum	95%-ile	90%-ile	Average	Standard Deviation
305,954 PE	152,099 PE	125,797 PE	81,106 PE	40,410 PE

Table 4-3 Statistical analysis of incoming loads (PE) to Dundalk WWTP.

The standard deviation of loading to the plant is 40,410PE, reflective of the highly variable inputs, which are attributable to the industrial nature of the waste water accepted at Dundalk. Last year (2009), a mean load of 81,106PE was encountered at the treatment works, which is designed for a loading of 179,535PE. Considering the calculated standard deviation of 40,410PE, there is a significant possibility that a load on a given day could exceed 121,516PE (i.e. mean plus 1SD).

Table 4-1 shows a design BOD loading for Phase 1 of 10,772 kg BOD. Table 4-4 summarises the existing position with regards to incoming BOD loadings.

Maximum	95%-ile	90%-ile	Average	Standard Deviation
18,357 kg/d	9,126 kg/d	7,548 kg/d	4,866 kg/d	2,425 kg/d

Table 4-4 Statistical analysis of incoming loads (BOD) to Dundalk WWTP (Jan. – Dec '09).

Last year (2009), a mean load of 4,866 kg BOD/d was encountered at the treatment works. Considering the calculated standard deviation of 2,425 kg BOD/d, there is a significant possibility that a load on a given day could exceed 7,291 kg BOD/d (i.e. mean plus 1SD).

The plant is currently operating below design capacity; therefore it is not necessary that the upgrade design should incorporate an expansion in terms of increasing population equivalent. Hence, the design will proceed on the basis that the current plant capacity of 179,535PE will be adequate to cater for existing and projected incoming loads for at least 5 years (2016). This capacity will deal with incoming biological and hydraulic loads. An assumption has been made that no significant additional industrial loadings will arise during the 5-year design life, which would otherwise push the organic loading above the design capacity.

4.2.3 Current Final Effluent Quality

Table 4-1 lists the design discharge limits for BOD, suspended solids and COD, which the O&M Contractor must endeavour to meet. Figure 4-1 illustrates the 2009 position at Dundalk with regards to influent and effluent BOD concentrations.

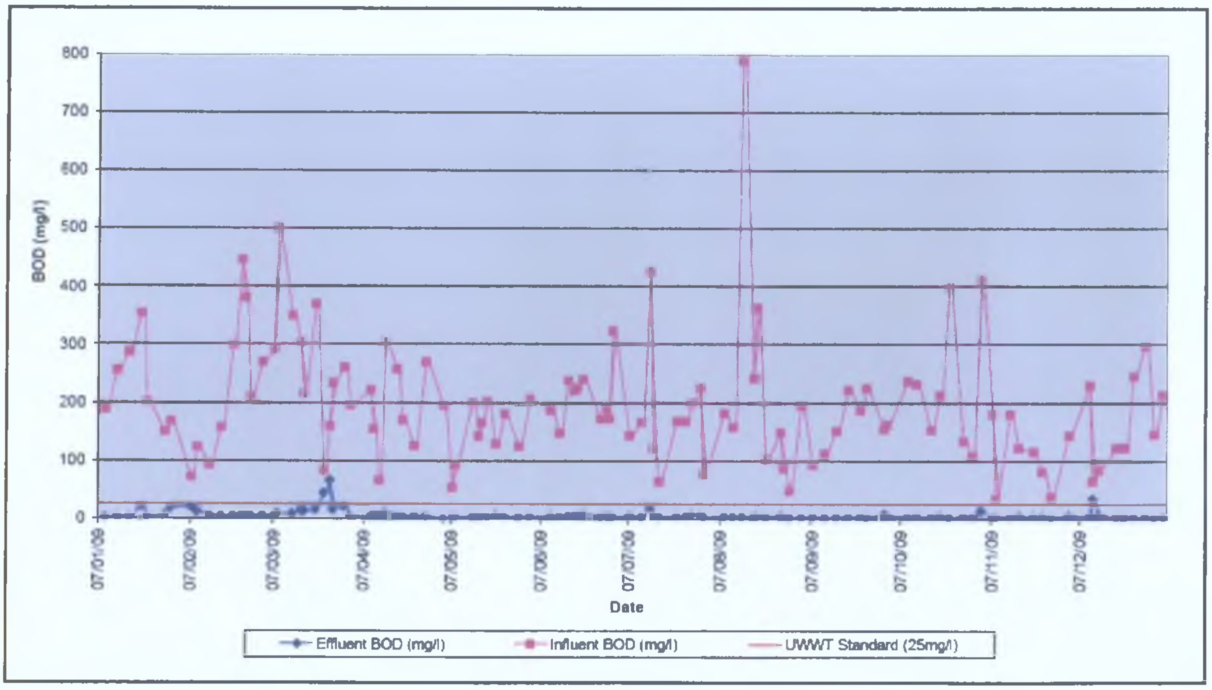

Figure 4-1 **Influent and effluent BOD concentrations at Dundalk WWTP.**

Since June 2001, the Castletown River from the weir 130m downstream of St. John's Bridge to the Pile Light has been designated a *'sensitive area'* under the Urban Waste Water Treatment Regulations (S.I. 254 of 2001) and accordingly, by May 31st 2008 there has been a requirement to achieve a Nitrogen Standard. The standard to be achieved is likely to be 10mg/l Total Nitrogen, but the final outcome of this may be based upon authorisation of the discharge by the EPA (which is pending).

Figure 4-2 illustrates the 2009 position at Dundalk with regards to influent and effluent Total Nitrogen concentrations. Influent monitoring for Total Nitrogen commenced in August 2009.

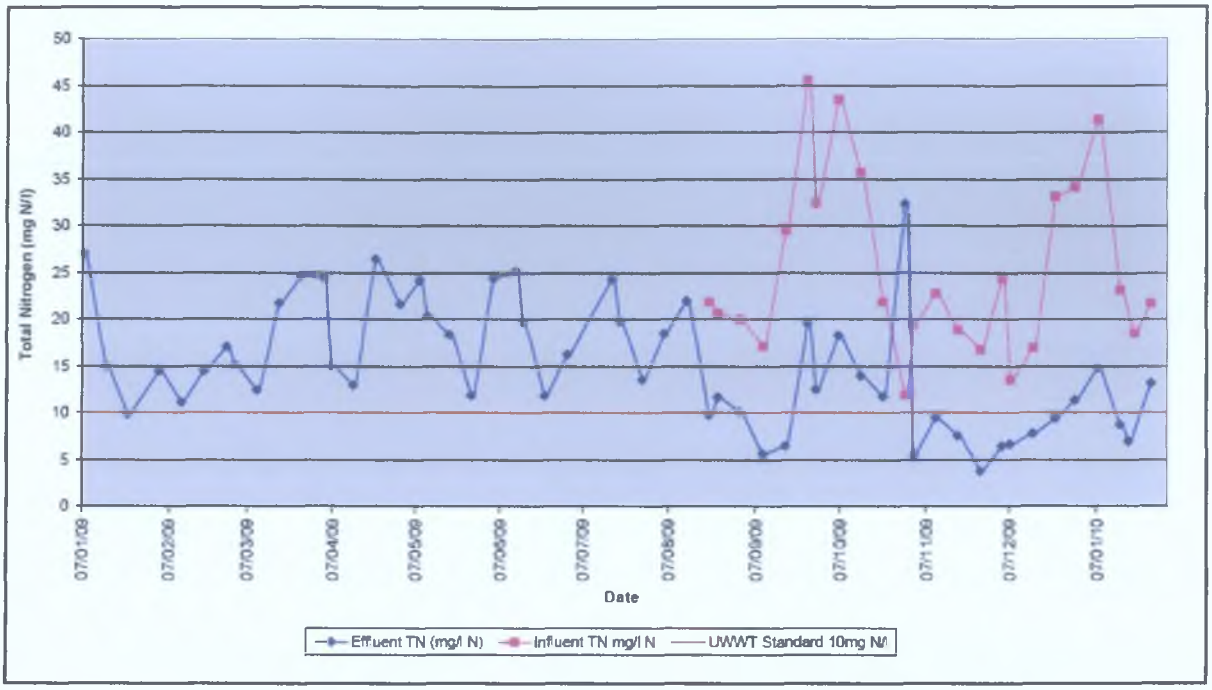

Figure 4-2 **Influent and effluent Total Nitrogen concentrations at Dundalk WWTP.**

Figure 4-1 shows that although dedicated nitrogen removal has not been incorporated into the current plant design features, considerable Total Nitrogen reduction occurs within the secondary treatment process both as a result of sludge wasting and biological processes occurring within the activated sludge basins. Analysis of the raw data indicates that the average percentage reduction for Total Nitrogen for 2009 was 61%. (Similarly, considerable Total Phosphorus reduction occurs during the existing treatment process, averaging 67% for 2009). However, Figure 4-2 shows that the final effluent Total Nitrogen concentrations frequently exceed the Urban Waste Water Treatment Directive requirement of 10mg N/l.

The design undertaken as part of this study will therefore assume a design loading of 179,535PE, with a requirement for further upgrade to allow final effluent Total Nitrogen values to meet a 10mg N/l limit as an annual means.

4.3 Recycle Stream Analysis

The treatment process at Dundalk includes a supernatant return pump station, into which the majority of reject flows arising from sludge management and from preliminary sewage treatment are diverted. The combined reject steams are pumped from this location back to the inlet of the main treatment process without pre-treatment. A manhole (dye) survey was undertaken with the aim of identifying the source of each individual reject stream. The following reject streams were identified to be discharging to the supernatant return sump:

- Centrate from the dewatering of digested sludge (centrifuge process);
- Supernatant decanting from the 1st and 2nd Stage picket fence sludge thickeners;
- Washwater from the inlet screens, launder unit and grit removal process (runoff from a concrete hardstand area also combines with this flow in wet weather);
- Foul sewage from the Control Building.

Initially, it was understood that all reject flows were diverted to the supernatant return sump, however, following closer examination of the sludge drying process, a further two reject streams were identified:

- Sludge drier condensate (currently pumped directly from the drier building to the A-Stage aeration basins);
- Biofilter effluent (final effluent is used for moisture control of the biofilter unit, which when spent, is normally pumped directly back to the A-Stage treatment process).

Samples were extracted from each of the above reject streams, and sent for analysis as detailed in Table 4-1 above. The frequency of sampling was dependant upon the particular stream, with priority given to those streams of greatest potential.

The literature review findings indicate that ammonium-rich high temperature streams are particularly suitable for side stream treatment. Table 4-5 provides a summary of the analysis carried out on reject streams encountered at Dundalk, in terms of average ammonium concentrations, average temperatures and estimated average daily flows. A full copy of reject stream analytical results is provided in Appendix J.

Sample Ref.	Sample Description	Ammonia as NH_4-N (average)	Temperature (average)	Estimated Average Daily Flow
DK1	Centrate from Centrifuge Units	1,135.2 mg/l	20.3 °C	94.8 m^3/d
DK2	Supernatant from Picket Fence Thickeners	31.5 mg/l	9.6 °C	550.0 m^3/d
DK3	Sludge Drier Condensate	117.0 mg/l	32.1 °C	275.1 m^3/d
DK4	Biofilter Return Effluent	19.4 mg/l	10.0 °C	17.3 m^3/d
DK5	Preliminary Treatment Units Washwater	19.0 mg/l	8.7 °C	37.0 m^3/d
DK6	Control Building Foul	25.0 mg/l	7.0 °C	0.5 m^3/d

Table 4-5 **Recycle stream ammonium concentrations, temperature and estimated average daily flows (Sampling undertaken 17/02/2010 – 24/02/2010).**

At Dundalk WWTP, the estimated Total Nitrogen load in the combined reject flows (DK1 to DK6 inclusive) was found to average 335.9kg N per day. This accounts for some 45.7% of the average Total Nitrogen load entering the treatment works.

The corresponding Total Nitrogen mass balance is included in Appendix J.

Samples DK1 and DK3 (centrate and sludge drier condensate) were found to be ammonium-rich. The temperatures of both streams were recorded above 20°C. Some 24% of the Total Nitrogen load was estimated to be contained within these two streams. A significant nitrogen loading appears to be contained within the picket fence thickener supernatant (DK2). This stream was found to have ammonia concentrations similar to the main process influent. The average temperature recorded on this stream was 9.6°C. Other streams examined were found to be insignificant in terms of nitrogen return loads.

4.4 Options for Implementing Nitrogen Reduction

4.4.1 Option A: Conventional Upgrade of the Main Biological Treatment System

Design

A conventional upgrade (termed 'Phase 1A' upgrade) was designed based on German Design Standard ATV-DVWK-A 131E. Completed design spreadsheets are provided in Appendix K. Based on the findings of Section 4.2, the upgrade design was prepared for a Phase 1 Design population equivalent of 179,535 and a DWF of 18,088m^3/d with a new design requirement to achieve an emission limit of 10mg N/l Total Nitrogen in the final effluent.

The as-constructed dimensions of the existing A-Stage and B-Stage clarifiers were inputted to the design and a check was undertaken to determine the adequacy of these units to deal with the Phase 1A upgrade (incorporating nitrogen removal via extended aeration).

The A-Stage clarifiers comprise 2 nr. 30m diameter tanks with 1.6m side wall depths. The hydraulic retention time, upward flowrate and hydraulic capacity of the peripheral channels were checked and were found to be adequate to deal with the Phase 1A upgrade.

The B-Stage clarifiers comprise 2 nr. 43.2m diameter tanks with 1.5m side wall depths. The sludge volume flowrate, thickening time, hydraulic retention time and hydraulic capacity of the peripheral channels were checked and were found to be adequate to deal with the Phase 1A upgrade. However, the adequacy of these parameters was based on achieving a low sludge volume index (SVI) in the secondary sludge (close to 100ml/g). Modification of baffles may be necessary to ensure this SVI.

The as-constructed features of the B-Stage aeration basins were inputted to the Phase 1A upgrade design, with an assumption that BOD and suspended solids removal rates of 30% and 60% (respectively) were being achieved through the A-Stage treatment process. This assumption was based on estimations of process efficiencies received from the Regional Site Manager.

The existing 3 nr. aeration tanks have a combined liquid volume of 5,259m^3. Inputting the existing parameters into the model showed that attempting to apply nitrification/denitrification without expansion of the aeration basins would result in an overloaded B-Stage. A conventional upgrade to incorporate dedicated Total Nitrogen reduction will entail increasing the sludge age in the B-Stage aeration tanks.

In providing extended aeration at Dundalk, to bring Total Nitrogen concentrations in final effluent to a level of 10mg N/l, the design output shows that an additional 5,943m^3 of aeration tank volume will be required. To allow for nitrate removal, an additional denitrification stage will also be required in the form of a 2,800m^3 capacity anoxic zone. These estimates were based on increasing the Sludge Age (SRT) to a minimum of 10 days with a corresponding F/M ratio of 0.15kg BOD/kg Sludge Dry Solids. Given the configuration of the existing aeration basins, the cost estimate was based on:

- Additional aeration basins required: 3nr. x 55.2m x 7.18m x 5m(d) = 5,945 m^3
- New anoxic tanks (to be installed upstream of aeration basins): 6nr. x 13m x 7.18m x 5m(d) = 2,800 m^3.

Additional air blowers (2 nr. 180kW units) and sludge mixers will also be required.

Cost Estimate

A cost estimate was prepared to include the capital and 10-year operational costs associated with the above design. The full details of the estimate, together with a list of assumptions in arriving at the estimate, have been presented in Appendix G.

The cost of land purchase was not factored into the estimate, as sufficient footprint has been set aside at the existing treatment plant site for extended aeration. The capital costs assumed a 5-month construction programme and insitu reinforced concrete structures supported by pile foundations given the poor ground conditions at the site. Table 4-6 provides a summary of estimated capital costs entered into the Cashflow Chart (provided in Appendix G). The cost estimate included a Schedule of Plant Replacement for the lifetime of the project.

Capital Cost Element	Estimated Cost € (excl. VAT)
Construction costs (including preliminaries & tests on completion)	€1,443,516.00
Planning and supervision costs (including site investigation)	€180,008.00
Employer overheads	€28,870.00
TOTAL	€1,652,394.00

Table 4-6 **Summary of Capital Cost Estimate for Option A: Conventional Upgrade at Dundalk WWTP.**

Table 4-7 provides a summary of the estimated operational costs entered into the Cashflow Chart (also included in Appendix G) relating to Year 1 (2011) operation only.

Operational Cost Element	Estimated Cost € (excl. VAT)
Fixed costs (labour, O&M overheads & Procedure Monthly Status Reporting)	€40,000.00
Variable costs (materials, energy & miscellaneous)	€188,743.00
TOTAL	€228,743.00

Table 4-7 **Summary of Operational Cost Estimate (Year 1 only) for Option A: Conventional Upgrade at Dundalk WWTP.**

The Net Present Value (NPV) of the upgrade has been estimated based on a discount rate of 5% and assumed inflation rates ranging from 1% to 3% over a 10-year period. The capital cost NPV includes estimated plant replacement costs. Table 4-8 presents the NPV for a 10-year contract.

Net Present Value Element	Estimated NPV € (excl. VAT)
Capital Costs NPV	€1,615,587.00
10-year Operation Costs NPV	€1,907,942.00
TOTAL NPV – OPTION A	€3,523,529.00

Table 4-8 **Summary of Net Present Values for Option A: Conventional Upgrade at Dundalk WWTP.**

Construction and operation of Option A upgrade for nitrogen reduction results in an estimated NPV of €3,523,529.00.

4.4.2 Option B: Upgrade by Retrofitting 'SHARON' Side Stream Treatment

Efficiency Predictions

Mulder *et al.* (2006) demonstrated an average of 88% Total Nitrogen removal efficiency from side streams at Beverwijk Waste Water Treatment Plant treating a combination of centrate and sludge drying condensate. This is the lowest reported efficiency for Total Nitrogen reduction for the six Dutch plants reviewed. This research also indicated that, regardless of feed concentrations, Total Nitrogen effluent concentrations tended to be less than 100mg N/l.

Based on the mass balance exercise, centrate and sludge drier condensate streams at Dundalk were found to be ammonium-rich with a high temperature. The combined average daily nitrogen load from these two streams was found to be 176.1kg N/d. The calculated concentration of the combined stream average 476mg N/l. By conservatively assuming that the effluent Total Nitrogen concentration, following side stream treatment, would be in the order of 100mg N/l, an assumed efficiency of 79% is arrived at.

Applying this reduction, the Total Nitrogen Load being returned to the headworks would reduce from an average of 24% to 5%, resulting in a 19% overall reduction in Total Nitrogen emissions.

Design

A preliminary design for the 'SHARON' system was based on publications and findings of previous experience, outlined in the literature review and methodology section above. The upgrade was based on a design flowrate of 370m^3/d, an average Total Nitrogen concentration of 476mg N/l and an average influent Total Nitrogen loading of 176.1kg/d. These design parameters correspond with the findings of the nitrogen mass balance in relation to centrate and sludge drier condensate.

Two separate reactors were conservatively assumed for the design, as is the case at Zwolle WWTP, where design input parameters are broadly similar (refer to Appendix L). The design assumed hydraulic retentions times in the aerated and anoxic reactors of 1.6 days and 0.8 days respectively, leading to the following optimised reactor designs:

Aerated Reactor : 15.038m diameter tank x 3.35m liquid depth = 595m^3

Anoxic Reactor : 11.190m diameter tank x 3.00m liquid depth = 295m^3

Additional air blowers (2nr. 50kW duty/standby units), sludge mixers, a methanol dosing unit and heat exchanger will be required as part of the retrofit.

Cost Estimate

A cost estimate was prepared to include the capital and 10-year operational costs associated with the above design. The full details of the estimate, together with a list of assumptions in arriving at the estimate, have been presented in Appendix G.

The capital costs again assumed a 5 month construction programme and insitu reinforced concrete structures supported by pile foundations. A patent holders fee has been included in the estimate at an assumed value to cover the cost of use of the intellectual property. Table 4-9 provides a summary of estimated capital costs entered into the Cashflow Chart.

Capital Cost Element – 'SHARON'	**Estimated Cost € (excl. VAT)**
Construction costs (including preliminaries & tests on completion)	€512,910.00
Planning and supervision costs (including site investigation)	€128,495.00
Employer overheads	€10,258.00
TOTAL	**€651,663.00**

Table 4-9 **Summary of Capital Cost Estimate for Option B: Upgrade by retrofitting 'SHARON' side stream system at Dundalk WWTP.**

Table 4-10 provides a summary of the estimated operational costs entered into the Cashflow Chart (also included in Appendix G) relating to Year 1 (2011) operation only.

Operational Cost Element	Estimated Cost € (excl. VAT)
Fixed costs (labour, O&M overheads & Procedure Monthly Status Reporting)	€45,000.00
Variable costs (materials, energy & miscellaneous)	€39,970.00
TOTAL	**€84,970.00**

Table 4-10 **Summary of Operational Cost Estimate (Year 1 only) for Option B: Upgrade by retrofitting 'SHARON' side stream system at Dundalk WWTP.**

The Net Present Value (NPV) of the upgrade has been estimated based on a discount rate of 5% and assumed inflation rates. The capital cost NPV includes estimated plant replacement costs. Table 4-11 presents the NPV for a 10-year contract.

Net Present Value Element	Estimated NPV € (excl. VAT)
Capital Costs NPV	€653,118.00
10-year Operation Costs NPV	€708,734.00
TOTAL NPV – OPTION B	**€1,361,852.00**

Table 4-11 **Summary of Net Present Values for Option B: Upgrade by retrofitting 'SHARON' side stream system at Dundalk WWTP.**

Construction and operation of an Option B upgrade for nitrogen reduction results in an estimated NPV of €1,361,852.00.

4.4.3 Option C: Upgrade by Retrofitting Combined 'SHARON/ANAMMOX' Side Stream Treatment

Efficiency Predictions

van Dongen *et al.* (2001*b*) stated that greater than 85% Total Nitrogen removal was achievable with the combined system, with nitrite being the limiting factor.

The calculated concentration of the candidate side streams average 476mg N/l. Assuming a Total Nitrogen removal efficiency of 85%, the Total Nitrogen Load being returned to the headworks would reduce from an average of 24% to 3.6%, resulting in a 20.4% overall reduction in Total Nitrogen emissions.

Design

A preliminary design for the combined 'SHARON/ANAMMOX' system was again based on publications and findings from previous experience, outlined in the literature review and methodology section above. The upgrade was based on a design flowrate of $370m^3/d$, an average Total Nitrogen concentration of 476mg N/l and an average influent Total Nitrogen loading of 176.1kg/d, as per the design parameters pertaining to Option B.

Two separate reactors are required for this treatment technology, i.e. an aerated reactor is required to allow the 'SHARON' process to occur and a much reduced anoxic reactor is necessary for the 'ANAMMOX' step. The reactor design for the 'SHARON' stage was identical to the aerated reactor design of Option B. Based on experience at Rotterdam, an 'ANAMMOX' reactor must be sized at $0.15m^3$/kg N/d. Based on this design criteria, the anoxic reactor was designed to the following dimensions:

Anoxic Reactor : 4.0m diameter tank x 2.2m liquid depth = $27.6m^3$

Additional air blowers (2nr. 50kW duty/standby units), sludge mixers, ammonium-nitrite monitoring systems (2nr.), a pH dosing system and a heat exchanger will be required as part of the retrofit.

Cost Estimate

A cost estimate was prepared to include the capital and 10-year operational costs associated with the above design. The full details of the estimate, together with a list of assumptions in arriving at the estimate, have been presented in Appendix G.

The capital costs again assumed a 5 month construction programme, an insitu reinforced concrete aerated reactor and a proprietary anoxic reactor supported by pile foundations. A patent holders fee has been included in the estimate at an assumed value to cover the cost of use of the intellectual property. Table 4-12 provides a summary of estimated capital costs entered into the Cashflow Chart.

Capital Cost Element – 'SHARON/ANAMMOX'	Estimated Cost € (excl. VAT)
Construction costs (including preliminaries & tests on completion)	€569,265.00
Planning and supervision costs (including site investigation)	€151,530.00
Employer overheads	€11,385.00
TOTAL	**€732,180.00**

Table 4-12 **Summary of Capital Cost Estimate for Option C: Upgrade by retrofitting combined 'SHARON/ANAMMOX' side stream system at Dundalk WWTP.**

Table 4-13 provides a summary of the estimated operational costs entered into the Cashflow Chart (also included in Appendix G) relating to Year 1 (2011) operation only.

Operational Cost Element	Estimated Cost € (excl. VAT)
Fixed costs (labour, O&M overheads & Procedure Monthly Status Reporting)	€45,000.00
Variable costs (materials, energy & miscellaneous)	€35,846.00
TOTAL	**€80,846.00**

Table 4-13 **Summary of Operational Cost Estimate (Year 1 only) for Option C: Upgrade by retrofitting combined 'SHARON/ANAMMOX' side stream system at Dundalk WWTP.**

The Net Present Value (NPV) of the upgrade has been estimated based on a discount rate of 5% and assumed inflation rates. The capital cost NPV includes estimated plant replacement costs. Table 4-14 presents the NPV for a 10-year contract.

Net Present Value Element	Estimated NPV € (excl. VAT)
Capital Costs NPV	€733,312.00
10-year Operation Costs NPV	€674,341.00
TOTAL NPV – OPTION C	**€1,407,653.00**

Table 4-14 **Summary of Net Present Values for Option C: Upgrade by retrofitting combined 'SHARON/ANAMMOX' side stream system at Dundalk WWTP.**

Construction and operation of the Option C upgrade for nitrogen reduction results in an estimated NPV of €1,407,653.00.

DISCUSSION

SECTION 5. DISCUSSION

5.1 Introduction

This section forms a discussion of the findings of the empirical research. The findings are then compared with other published works on the subject of side stream treatment.

5.2 Existing Facility

Table 4-1 above shows the Phase 1 design DWF at 18,088 m^3/day. In terms of the existing hydraulic loading, 2009 data is indicative of a DWF slightly above the Phase 1 design value. Both the minimum and 5 percentile values for inflow to the plant were examined and were found to be 15,562m^3/d and 18,906m^3/d respectively. The five percentile value would generally reflect the dry weather condition above the minimum (with due allowance for non-productive days for industry). The plant is however capable of accepting 48,838 m^3/day (2.7DWF) for full treatment. In analysing organic loads to the plant, it can be concluded that the facility is currently operating below capacity. Hence, the upgrade design proceeded on the basis of a Phase 1 design capacity of 179,535PE.

Figure 4-1 illustrates that the plant performs well in terms of final effluent BOD concentrations. Given the *'nutrient sensitive'* designation of the receiving waters for the plant, it was anticipated that a 10mg/l Total Nitrogen standard would be likely to be applicable to the discharge in the near future, but the final outcome of this may be based upon authorisation of the discharge by the EPA (which is pending).

The plant does not already include dedicated nitrogen removal facilities. Figure 4-2 illustrates that although considerable Total Nitrogen reduction occurs within the secondary treatment process both as a result of sludge wasting and biological processes (average percentage reduction for Total Nitrogen for 2009 was 61%), final effluent Total Nitrogen concentrations frequently exceed the Urban Waste Water Treatment Directive requirement of 10mg N/l.

5.3 Recycle Stream Analysis

The nitrogen balance at Dundalk WWTP was studied. The balances include the external and internal nitrogen loads relating to the existing situation at the plant. An evaluation of the mass balance shows that 45.7% of the main plant influent total nitrogen load is contained within reject effluents returned to the headworks. This compares well with a corresponding figure of 40% cited by Wett *et al.* (2009), especially when considering that substantial sludge imports occur at Dundalk, thus increasing the recycle load.

Wett *et al.* indicated that centrate would generally contain 12 to 25% of the influent ammonia load. Notenboom *et al.* (2002) quote typical nitrogen loadings in the order of 15% in recycle streams following digestion. The empirical data collected at Dundalk concurs with this research, which demonstrates 13.8% nitrogen loadings in centrate.

Some 24% of Dundalk's recycle effluent (centrate and sludge drier condensate) would appear to be suitable for side stream treatment application. This conclusion is arrived at in light of the ammonium rich and high temperature characteristics of both streams. A substantial nitrogen loading was found to be recycled through picket fence thickener supernatant (21.5%), however due to the low temperature and relatively low concentrations of ammonium contained within this liquor, this stream was deemed unsuitable for side stream treatment application. Wett *et al.* (*ibid.*) also reported on ammonium-weak thickener supernatant streams.

Finally, in 2005, Jardin *et al.* (cited in Cervantes 2009), reporting on ammonia return loads from 204 German facilities with anaerobic mesophilic digestion, demonstrated an average specific return load in the order of 1.5g N/PE. The research also established that two stage activated sludge plants produce approximately 20% higher nitrogen return loads than single-stage activated sludge plants (i.e. 1.8g N/PE). Considering the mean population equivalent recorded at Dundalk during 2009 of 81,106, and based on the mass balance findings, the average specific return load for Dundalk would be 1.72g N/PE, thus validating the mass balance study.

5.4 Conventional Upgrade to incorporate Nitrogen Reduction

An engineering design was undertaken for a conventional upgrade of the existing treatment works to meet an assumed Total Nitrogen standard of 10mg/l. Based on certain reasonable assumptions, the design determined that a nitrification/denitrification step could be incorporated by increasing the capacity of the aeration basins by 5,943m^3 and introducing anoxic zones with a combined volume of 2,800m^3. This would be necessary to increase the sludge age in the process. Certain civil and mechanical/electrical modifications would also be necessary for the upgrade.

If implemented, substantial capital and operational costs will be associated with this upgrade. The capital cost associated with a conventional upgrade was estimated at €1,652,394.00, whilst the yearly operation and maintenance costs were estimated at €228,743.00. Variable costs such as energy and materials account for the majority of the operational costs. In terms of the net present value of this work (over a 10 year operating period) this equates to €3,523,529.00 exclusive of VAT.

5.5 Potential for Side Stream Treatment Application at Dundalk

5.5.1 Efficiency Predictions

Two side stream options have been selected for further evaluation for potential suitability at Dundalk. The main operational features of each system are described briefly below.

- Option B – The 'SHARON' Process – ammonium is oxidized to nitrite in a single aerated reactor without sludge retention. The nitrite is then anoxically reduced to nitrogen gas with the aid of an external carbon source. It has been reported (see Section 1.6.7) that when compared with conventional processes, an energy saving of 25% can be realised, with reduced sludge production and reduced CO_2 emissions.
- Option C – The combined 'SHARON/ANAMMOX' process – approximately 50% of ammonium is firstly converted to nitrite. The ammonium/nitrite mixture is then converted to nitrogen gas autotrophically under anaerobic conditions (i.e. external carbon source addition is not required) in a second reactor with sludge retention. Compared with conventional nitrogen reduction processes, it is reported (van

Dongen *et al.* 2001*a*) that this process leads to an energy saving of 40%, sludge production is negligible and CO_2 emissions are much reduced.

Mulder *et al.* (2006) reported on six full-scale 'SHARON' plants located throughout the Netherlands, the first of which was commissioned in 1997. Reference was also made in that report to a proposed 5,000 kg N/day capacity plant at Wards Island, New York, under construction during 2008 (Grontmij Nederland BV 2008). Appendix L provides in summary form the design parameters of the full-scale Dutch plants.

Mulder *et al.* described in detail the operational experience at the Utrecht and Rotterdam-Dokhaven plants, summarised hereunder.

Rotterdam-Dokhaven: Prior to implementation of the 'SHARON' system at this facility, aeration basin capacity was the limiting factor. The sludge recycle water at Dokhaven contains typically 15% of the total plant nitrogen load with a corresponding volume of 1% of the hydraulic load (van Dongen *et al.* 2001*b*). Retrofitting the side stream process at this plant brought about a 66% reduction in effluent ammonia emissions of the main plant (average of 6.2mg/l to 2.1mg/l for the period 1999 through 2000) and a 48% reduction in effluent Total Nitrogen emissions (average of 7.5mg/l to 3.9mg/l for the period 1999 through 2000).

Utrecht: Insufficient denitrification capacity was the limiting factor at the Utrecht WWTP. Following side stream application ('SHARON') the Total Nitrogen concentrations in the main plant effluent decreased by 30% (16mg/l to 11mg/l decrease for 1998), despite increases to nitrogen loadings over time (Grontmij 2008).

Table 5-1 compares Dundalk recycle stream data (established as part of this study) with Rotterdam centrate.

Parameter	Unit	Rotterdam WWTP[1]	Dundalk WWTP[2]	Dundalk WWTP[2]
		Centrifuged Sludge Digestion Effluent	Centrifuged Sludge Digestion Effluent	Sludge Drier Condensate
COD	mg/l	810	385	4,275
BOD	mg/l	230	36	430
N-Kj	mg/l	1,053		
Total Nitrogen	mg/l		1,071	271
NH_4^+ -N	mg/l	1,000	1,135	117
Total Phosphorus	mg/l	27	109	112
Suspended Solids	mg/l	56	139	4694
pH		8.1-8.4	7.8	7.2
Temperature	°C	30	20	32

[1] Average composition of centrate at Dokhaven WWTP, Rotterdam from 1994: Hellinga *et al.* 1998.

[2] Average composition of stated recycle streams at Dundalk, sampling period 17/02/2010 to 24/02/2010, undertaken as part of the current study.

Table 5-1 **Comparison of Recycle Streams for Rotterdam and Dundalk WWTPs.**

As can be seen from Table 5-1, ammonium concentrations in centrate from both facilities are broadly similar, while condensate from Dundalk tends to be less concentrated.

Research has shown that the combined 'SHARON/ANAMMOX' process is capable of achieving greater than 85% Total Nitrogen removal. An 85% reduction in the Total Nitrogen from the recycle flow of centrate and sludge dryer condensate at Dundalk would shift the operation of the B-stage from oxygen limited to ammonium limited, reducing the Total Nitrogen emissions from the plant by 20.4% to 8.8mg N/l (presently at an average of 11.03mg N/l – average from analysis for Total Nitrogen from July to December 2009). An assumed efficiency of 79% was applied to effluent predictions for the 'SHARON' process operating alone, which would reduce Total Nitrogen emissions from the plant by 19% to 8.9mg N/l. Both systems would therefore be capable of achieving required nitrogen emission concentrations in the final effluent.

5.5.2 *Design & Cost Considerations*

Reactor Design

Option B – retrofitting the 'SHARON' system was designed based on optimum hydraulic retention times. Based on the side stream analysis at Dundalk, design calculations suggest that an aerated reactor of $595m^3$ capacity and an anoxic reactor of $295m^3$ capacity would be sufficient. The 'SHARON' system incorporates a chemostat, whereby the basic principle of the process, as stated in previous chapters, is to allow sufficient hydraulic retention time (HRT) to establish a stable population of ammonium oxidising bacteria (AOB), however at the same time restrict the HRT such that the growth of nitrite oxidising bacteria (NOB) is limited (van Kempen *et al.* 2001). Chemostats operate on the basis of a flow through system, whereby HRT is equal to sludge retention time (SRT). The typical HRT of SHARON reactors is 2 to 3 days (Wett *et al.* 2009).

The Aerated Retention Time (ART) is a very important design parameter, and at a temperature of approximately 30°C, an ART of 1 to 2 days is required to produce greater than 98% nitrite. The Dundalk 'SHARON' reactor has been designed for a 1.6 day ART.

Temperature

Heating and/or cooling equipment must form a design consideration, as research has shown that a temperature increase of 10°C would tend to occur in an insulated reactor with an ammonia concentration at 1000mg N/l and a COD/N ratio of approximately 1, as a result of exothermic activity (Wett *et al.* 2009). However, in reality, due to temperature losses (through the reactor structure and through pipework and aeration) the USEPA report (2007) that this temperature increase may be more in the order of 5 to 8°C. Mulder *et al.* (2006) states that for successful operation of the 'SHARON' process, liquid temperature must be maintained between 30 and 40°C. A mixture of centrate and sludge drier condensate at Dundalk would be expected to average approximately 25°C. Conservatively, assuming a 5 degree exothermic increase in temperature would imply that sufficient temperatures would be reached, thus negating supplemental heat supply.

Carbon Addition

With the 'SHARON' system an external COD source is required, e.g. methanol due to the low carbon content of the centrate. At Dundalk this could potentially be counteracted by treating drier condensate in combination with centrate, which is discussed in greater detail below.

pH Control

Research has shown that a high pH is preferable to outcompete nitrite oxidisers and to achieve a low ammonium concentration in the effluent from the 'SHARON' process (Hellinga *et al.* 1998). pH control may be required at Dundalk, as samples of condensate show relatively low pH values. As stated in Section 1.6.7, denitrification could be included for Total Nitrogen removal, but also would have the advantage of counteracting the predicted pH decrease resulting from the nitrification stage. Recycle liquor from sludge digestion usually provides sufficient alkalinity for almost complete removal efficiency while leachates typically contain a surplus of alkalinity from sources other than ammonia release (Wett *et al.* 2009).

In the case of Dundalk, due to the requirement for maximum nitrogen removal, it would be desirable that denitrification would be optimised, therefore methanol, supplemental to the COD source in the drier condensate feed may be deemed necessary.

Solids Interference

Chemostats are not sensitive to a break-through of solids arising from dewatering operations, however Wett *et al.* (2009) report that the lack of sludge retention renders the biological system particularly susceptible to shock loadings of toxic compounds.

Inflow Fluctuations due to Intermittent Dewatering Operations

At Dundalk, inlet flow to a proposed side stream treatment unit would tend to fluctuate considerably due to discontinuous operation of the sludge dryer and dewatering facilities, with scheduled downtime at weekends. This issue can be counteracted, as research (Mulder *et al.* 2006) has shown that by restricting the aeration during these idle periods the ammonia removal capacity is reserved. In the absence of oxygen, nitrite oxidising activity ceases to occur and full capacity remains on standby. In terms of process issues associated with the interrupted flow regime, Mulder *et al.* (2006) report that the high temperatures and high ammonia oxidiser growth rate enables good process stability.

5.5.3 Option B – Estimated Costs

Option B – 'SHARON' System

Capital Costs

Option B, if implemented, would result in an estimated capital cost of €651,663.00. This assumes two separate reactors for nitrification and denitrification, additional air blowers, sludge mixers, pumps, a methanol dosing system and a heat exchanger.

Operational Costs

The main operational costs associated with the 'SHARON' treatment are for energy and carbon addition. At Dundalk it is proposed to treat centrate in combination with condensate from the sludge drying process in a side stream reactor. As stated above, an external COD source may be required, e.g. methanol due to the low carbon content of the centrate. In the case of Dundalk, the average concentration of COD measured in the centrate was found to be in the region of just 385mg/l. The average COD concentration of the sludge dryer condensate was found to be 4,275mg/l, or based on estimated average condensate flowrates, the average COD loading to the side stream reactor from this source would be in the order of 1,176kg COD per day. Hence, the potential exists for an on-site carbon source, which would be available without cost to the operators, thus eliminating significant operational costs associated with carbon addition.

Furthermore, the potential to import COD-rich industrial waste streams exists and may even provide a source of income, however, prior to the acceptance of these effluents comprehensive investigations would be required to ensure that other pollutants of a conservative/persistent nature would not be present. As shown in Appendix L, byproducts from biofuel production has been utilised at the Utrecht and Zwolle plants.

Hellinga *et al.* (1998) estimated capital, maintenance and operational costs for ammonium conversion, concluding that power input accounts for 35% of the total costs (of which 90% relates to aeration) and 25% of total costs accounting for methanol dosage. Figure 5-1 provides estimates of costs in US dollars per kg of ammonium removed, based on influent ammonium content and removal efficiency required.

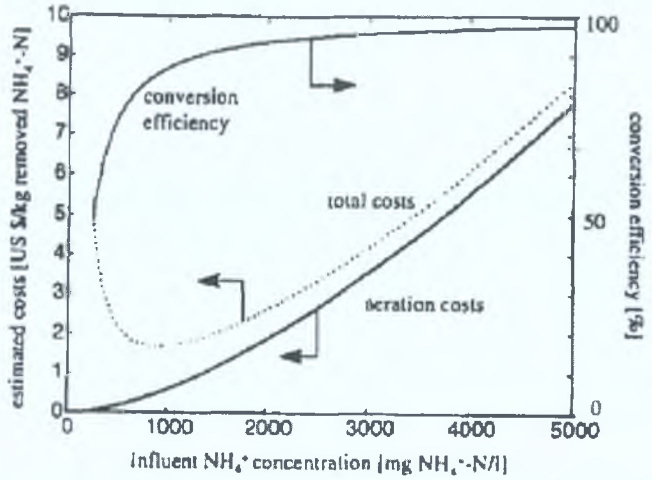

Figure 5-1 Cost estimates in US dollars per kg ammonium removed.

Assuming centrate and sludge dryer condensate would be treated at Dundalk, and based on analysis of the recycle streams undertaken as part of this study, the influent ammonium concentration of the influent would be expected to be in the region of 378mg NH_4^+- N/l. At an ammonia concentration of 378mg NH_4^+- N/l, the estimated cost per kg of ammonium removed would be just under $3 US per kg of NH_4^+ removed, or approximately $120,966.60 US per annum at 1998 levels (ca. €99,000.00 at today's rates), corresponding with an ammonium conversion efficiency of 79%. However, caution is advised in considering this evaluation, as details regarding the initial calculation of capital costs were not detailed in this research. The cost estimate undertaken as part of this study indicates an annual operational cost of €84,970.00.

Hellinga *et al.* concluded that at low influent concentrations (as is the case at Dundalk), total costs are mainly determined by fixed costs, whereas at high influent concentrations variable costs are more significant.

Option C - Combined 'SHARON/ANAMMOX' System

Capital Costs

Option C, if implemented, would result in an estimated capital cost of €732,180.00. This assumes two separate reactors for nitrification and denitrification, additional air blowers, sludge mixers, pumps, a pH control system and a heat exchanger.

Based on 2001 rates, van Dongen *et al.* (2001*b*) estimated capital costs in the range of €1.81M and €2.26M (dependant on influent ammonium concentrations) for the provision of combined 'SHARON/ANAMMOX' systems treating a nitrogen loading of 1,200 kgN/d. In a 176kg N/d unit, the pro-rata capital costs would translate to €265,467.00 to €331,467.00. The estimated capital costs for Dundalk amount to over double this figure, however van Dongen *et al.* do not provide details on costings for modifications of existing plant, siteworks, planning and supervision costs and employers overheads, which add substantially to the capital costs. Furthermore, smaller units would attract a larger proportion of capital costs, when considering the total costs of these systems.

Operational Costs

van Dongen *et al.* (2001*a*) estimated operating costs for treating digester supernatant at €0.70 to €1.10 per kg N removed. The corresponding treatment cost with the SHARON process (using methanol for pH adjustment) was estimated at €0.90 to €1.40 per kg N removed. Other biological nitrogen removal technologies for treating digester supernatant were found to have associated operational costs in the order of €2.30 to €4.50 per kg N removed, whilst physical-chemical techniques have associated costs ranging from €4.50 to €11.30 per kg nitrogen.

Based on the above research, the annual operating cost of treating centrate and drier condensate at Dundalk using the combined 'SHARON/ANAMMOX' process would be in the order of €38,245.00 to €60,099.00, corresponding with an ammonium conversion efficiency of 85%. The cost estimate undertaken as part of this study indicates an operational cost of €80,847.00 per annum, making due allowance for inflation in the intervening period.

5.6 Conclusion

Option A – conventional upgrade was examined and was found to be prohibitively expensive and unsustainable in terms of energy usage. Based on efficiency predictions for both side stream processes examined, this study indicates that both systems would be adequate to bring final effluent nitrogen levels down to acceptable levels. During the beginning of 2009, operational improvements at Dundalk have brought Total Nitrogen emissions down to an average of 11.03 mgN/l, still above the annual mean requirement of

10mg N/l of the Urban Waste Water Treatment Directive. The implementation of Option B (the 'SHARON' process) at Dundalk, based on conservative assumptions, would bring about an estimated 19% reduction in Total Nitrogen (TN) emissions from the plant (resulting in an annual mean of 8.9mg TN/l). Implementation of Option C (the combined 'SHARON/ANAMMOX' process) at Dundalk, again based on conservative assumptions, will bring about an estimated 20.4% reduction in Total Nitrogen emissions from the plant (resulting in an annual mean of 8.8mg TN/l). The difference in Total Nitrogen reductions is therefore negligible in considering which Option to choose.

Based on the capital and 10-year operational and maintenance costs associated with Options A, B and C, the following net present values result:

Net Present Value Element	Estimated NPV € (excl. VAT)
Option A – Conventional Upgrade	€3,523,529.00
Option B – 'SHARON'	€1,361,852.00
Option C – 'SHARON/ANAMMOX'	€1,407,653.00

Table 5-2 **Net Present Values for Options A, B and C for Total Nitrogen Reduction at Dundalk WWTP.**

In terms of the operating cost, the unit costs of Option A, B and C are €4.45 /kg N, €1.65 /kg N and €1.57 /kg N removed respectively. Option B presents a 10 year saving of €2,161,677.00 over Option A. Option B presents a smaller saving over Option C in the amount of €45,801.00. In consideration of the costs savings and efficiencies of each system, Option B – 'SHARON' System appears to be the most viable option for implementing dedicated Total Nitrogen reduction at Dundalk Waste Water Treatment Plant.

However, in considering a longer life cycle assessment, of say, 20 years, Option C would tend to become the most favoured Option. Nonetheless, a 10 year life cycle was chosen to reflect the remaining life span of the existing O&M Contract.

SUMMARY & CONCLUSIONS

SECTION 6. SUMMARY & CONCLUSIONS

Recently enacted (2009/2010) legislation is set to dramatically increase the statutory requirement for nitrogen reduction on a national basis in municipal waste water discharges. The Water Framework Directive is seen as the driver behind all recent water quality legislation, which is becoming increasing challenging for those responsible for municipal waste water treatment and disposal.

With this in mind, the overall aims of this research was:

- Firstly, to determine if there were nitrogen reduction deficiencies associated with existing municipal waste water infrastructure in Ireland; and
- secondly to advance the concept of isolating nitrogen-rich recycle streams in such facilities for specialised biological treatment, with the ultimate aim of considerably reducing nitrogen emissions in primary discharges in a sustainable manner.

Revolutionary methods of nitrogen reduction have been established and developed in mainland Europe in the past decade, and effluent recycle streams that are both high in ammonia and temperature have the potential to be applied successfully to this new technology. Unfortunately, in Ireland, these effluent streams have not been the focus of laboratory analysis; therefore little is known of their constituents or strengths. The primary focus of this study was therefore to determine the presence (or otherwise) of high-strength nitrogen-rich streams in municipal waste water treatment facilities in Ireland via case study analysis. These streams were expected to derive from anaerobic digestion of sludge.

Dundalk WWTP was chosen as an appropriate case study facility for recycle stream analysis, as mesophilic digestion forms part of the sludge handling process there. If nitrogen-rich streams were successfully identified, the research would then proceed on the basis of a feasibility study. The ultimate aim of the research was to provide a cost effective solution for Local Authorities to achieve compliance with nitrogen reduction legislation in municipal discharges, where feasible.

The research herein aims to contribute towards the development of sustainable waste water treatment in Ireland.

6.1 Research Objective 1: Identify the legal requirements for nitrogen removal

6.1.1 Summary

Relevant EU and national legislation was reviewed to ascertain the current legal position on nitrogen reduction requirements of the State. Legal requirements for nitrogen removal from municipal waste water arise from two sources:

1. The requirement to comply with the Urban Waste Water Treatment Directive (91/271/EEC), where the receiving water has been designated *'nutrient sensitive'*.
2. The requirement to comply with ELVs set by the EPA in Waste Water Discharge Consents (in cases where a nitrogen ELV has been set).

6.1.2 Conclusion

Recently enacted (2009/2010) legislation, relevant to both sources, is set to dramatically increase the statutory requirement for nitrogen reduction on a national basis, through nitrogen ELV's attached to recent discharge consents, and due to a series of additional nutrient sensitive areas, designated in February 2010.

6.2 Research Objective 2: Investigate the current infrastructural deficiencies

6.2.1 Summary

In a review of municipal waste water undertaken during 2006/2007, Monaghan *et al.* (2009) indicated that while Ireland were gaining progress (albeit delayed) on compliance with the secondary treatment requirements of the Urban Waste Water Treatment Directive, there was still 86% non-compliance with the statutory provision of nutrient reduction facilities at December 2007. This shortfall is further exacerbated by the recent legislation.

6.2.2 Conclusion

While the Sanitary Authorities appear to be actively tackling the issue of insufficient secondary treatment facilities, the distinct lack of nutrient removal facilities at the locations deemed necessary by Directive 1991/271/EEC will present a considerable challenge. The stringent nitrogen standards recently introduced with the European Communities Environmental Objectives (Surface Waters) Regulations, 2009 combined with ensuing

Programmes of Measures in River Basin Management Plans will serve to bring these treatment deficiencies into further focus.

It is clear that certain commitments will be required from the State arising from impending legislative obligations, considering the apparent deficiencies in existing nitrogen removal infrastructure. This will present a difficult task bearing in mind the current funding issues.

6.3 Research Objective 3: Review the sustainability issues concerning implementation of conventional technology to remedy deficiencies

6.3.1 Summary

Conventional biological treatment for the removal of nitrogen from waste water via nitrification and denitrification is generally quite successful. However when applying a unitary operational cost driver, the cost of treatment is significantly greater than the side stream options examined. Operating costs of conventional systems are also significant. The nitrification reaction consumes a large amount of energy in producing oxygen at a rate of 4.2g per gram of ammonium nitrified. The capital costs associated with providing conventional extended aeration systems for the purposes of nitrogen reduction are also significant, due to the large reactors involved.

Furthermore, operational control of the nitrification/denitrification conditions can be problematic. Issues include difficulty in stabilising the desired biomass populations; not achieving sufficient rates of nitrification/denitrification; and inadequate carbon quantities in waste waters to allow optimum conversion of NO_3^- and NO_2^- to N_2 (Khin and Annachhatre, 2004).

6.3.2 Conclusion

Janus and van der Roest (1997) asserted the optimal use of existing process units combined with complementary treatment systems to be a more advantageous method of increasing the nutrient removal capacity at many plants. They contend that such systems circumvent the requirement for conventional biological extensions, thus avoiding unnecessary capital expenditure, and also are more operationally efficient.

6.4 Research Objective 4: Demonstrate nitrogen mass balance via case study analysis (as a means of determining the potential presence of nutrient-rich streams at Irish plants in general)

6.4.1 Summary

The Nitrogen balance at Dundalk Waste Water Treatment Plant was studied with a view to side stream nitrogen treatment application. An evaluation of the mass balance shows that 45.7% of the main plant influent total nitrogen load is contained within the recycle effluents within the plant.

Some 24% of Dundalk's reject effluent (centrate and sludge drier condensate) would appear to be suitable for side stream treatment application. This is because both streams are ammonium rich and have high temperatures. A substantial nitrogen loading was found to be recycled through picket fence thickener supernatant (21.5%), however due to the low temperature and relatively low concentrations of ammonium contained within this liquor, this stream was deemed unsuitable for side stream treatment application.

6.4.2 Conclusion

24% of Dundalk WWTP's Total Nitrogen load could be targeted for side stream treatment.

6.5 Research Objective 5: Formulate recommendations on side stream applicability (as a possible means of offsetting upcoming difficulties with legislative compliance)

6.5.1 Summary

Three side stream options were selected for evaluation as a potential means of nitrogen removal at Dundalk.

- Option A – Conventional Extended Aeration
- Option B – The 'SHARON' Side Stream Process
- Option C – The combined 'SHARON/ANAMMOX' Side Stream Process

An engineering design was undertaken for Option A, however costings showed this option to be prohibitively expensive. The evaluation determined that Option C - the combined 'SHARON/ANAMMOX' process would shift the operation of the B-stage treatment process at Dundalk from oxygen limited to ammonium limited, reducing the Total Nitrogen emissions from the plant by 20.4% to 8.8mg N/l (presently at an average of 11.03mg N/l). Efficiency calculations determined that Option B - the 'SHARON' process would reduce Total Nitrogen emissions from the plant by 19% to 8.9mg N/l. Both systems would therefore be capable of achieving required nitrogen emission concentrations in the final effluent.

In estimating the capital and 10-year operational and maintenance costs associated with Options A, B and C, net present values were arrived at. Option B presents a 10-year saving of €2,161,677.00 over Option A. Option B presents a smaller saving over Option C in the amount of €45,801.00.

6.6 Conclusion

Based on efficiency predictions for Option B and C (side stream processes), this study indicates that both systems would be adequate to bring final effluent nitrogen levels down to acceptable levels. The difference in Total Nitrogen reductions is negligible in considering which Option to choose.

In considering Option B, research from various sources (as discussed in the preceding chapters) has indicated that the 'SHARON' process is proven in significantly reducing nitrogen emissions from internal recycle streams arising from sludge digestion, dewatering and drying operations. Based on existing established full-scale 'SHARON' facilities located in the Netherlands, and using data obtained in preparing a nitrogen mass balance for Dundalk WWTP, a reactor design and corresponding cost estimate was prepared for retrofitting this process at Dundalk.

Capital costs are comparatively low when assessing against the costs of conventional extended aeration on the main plant, due to the modest dimensions of the reactor and relative simplicity of the process. A significant proportion of the operational costs associated with the unit would involve aerating the unit. Considerable savings have resulted from the much reduced volume of liquor to be aerated as compared with the conventional plant. Further savings to aeration, estimated in the order of 25%, will result from limiting the nitrification stage to nitrite formation. Using denitrification for pH control has been shown to eliminate the requirement for pH control via caustic dosing.

Furthermore, it is hoped that by including the COD rich sludge dryer condensate stream, the requirement for methanol usage will be negated, however it would be prudent to install methanol dosing facilities when constructing a 'SHARON' facility as a fall back position. For this reason, the capital cost of methanol dosing facilities has been incorporated into the capital cost estimate.

Based on existing Urban Waste Water Treatment emission standards, it is anticipated that Dundalk WWTP will be required to undertake complete nitrogen removal, i.e. a Total Nitrogen Standard as opposed to an ammonia standard. The requirement to denitrify renders the 'SHARON' system particularly suitable for application at Dundalk, as the process itself requires denitrification in order to maintain pH control (negating the requirement for caustic dosing). Any remaining nitrite exiting the process is likely to be denitrified in the A-stage of the A/B process.

In consideration of the costs savings and efficiencies of each system, Option B – 'SHARON' system appears to be the most viable option for implementing dedicated Total Nitrogen reduction at Dundalk Waste Water Treatment Plant.

Research to date on side stream technology indicates associated savings in energy and chemical consumption, thus a reduction in the carbon footprint of waste water treatment plants occur where this technology has been employed. For this reason, the potential use of side stream technology should be afforded due consideration on a national scale.

RECOMMENDATIONS

SECTION 7. RECOMMENDATIONS

7.1 General

Deficits in funding continue to be an issue, especially when considering the level of capital investment that will be required in the provision of conventional nitrogen removal plant upgrades nationally. The need to practice sustainable and cost effective waste water treatment is therefore great.

At present and for the past number of years, commercial industries have been focused upon greener technologies and attaining increasing levels of sustainability in their work practices/processes. This is also reflected in their waste water management practices, as per the policy objectives of IPPC licensing, e.g. minimisation of resource use.

Developments to date in terms of alternative technologies for sustainable nitrogen removal have enabled a similar approach to be adopted in municipal situations. Conventional biological nitrogen removal processes, commonly employed at Irish municipal treatment facilities, cannot objectively be considered sustainable due to the significant energy requirements and substantial reactor volumes involved.

Hence, the potential to adopt sustainable nitrogen reduction technologies in implementing the required infrastructural improvements arising from recent EPA authorisation of waste water treatment facilities should, at this point, be recognised.

The research herein has shown that certain side stream technologies exist which are capable of reducing nitrogen emissions from final effluent streams to such an extent as will render the technology an economically viable option at the various Irish plants requiring such reduction in emissions. Unit processes for nitrogen removal from low-volume highly concentrated streams tend to be compact systems, and this aspect is seen as increasingly important where land availability is minimal.

The study herein has shown the 'SHARON' process to be the most efficient and cost effective means of nitrogen reduction at Dundalk. Centrate volumes are currently relatively low. Should ELV's become more stringent in years to come, increasing the volume of sludge to be dewatered per day can further enhance nitrogen removal capacity at Dundalk. It is interesting to note that in conventional treatment systems COD is generally oxidised from waste water by way of endogenous respiration at a rate of 0.6kg O_2/kg COD (Jetten *et al.* 1997). This is obviously energy intensive. However, by maximising sludge production, energy (aeration) demand can be minimised.

Jetten *et al.* (1997) indicated that by dosing relatively small amounts of flocculant to a waste water, solid and colloidal COD can be captured effectively, thus increasing the sludge production sent on for methanogenic digestion, while minimising the organic load going on to the main treatment process.

Taking into account the MRP environmental quality standard (relating to rivers and estuaries), introduced with the European Communities Environmental Objectives (Surface Waters) Regulations (S.I. 272 of 2009), flocculation to increase sludge production can be effectively combined with phosphorus removal (however suggestions by van Graaf *et al.* (1996) should be duly considered in terms of the inhibitory effect of phosphate on 'ANAMMOX' activity if this option were to be selected). A secondary advantage can be gained in increasing the sludge production, i.e. the volume of biogas will increase (0.5kg methane/kg COD digested – Jetten *et al.* 1997), thus increasing self-sufficiency of the plant.

Hence it is recommended that the potential to apply minimal doses of flocculant be additionally considered at Dundalk, which would have the effect of increasing the nitrogen and phosphorus loads to side stream treatment. This study has shown that reduction of nitrogen in a side stream treatment process is more sustainable and energy efficient than nitrogen reduction in a conventional stream.

7.2 Potential for Phosphorus Reduction

Total Phosphorus (TP) analysis was included in the sampling suite at Dundalk. Elevated TP concentrations were encountered in the centrate, the supernatant from the sludge thickeners and the condensate from the sludge drier (averaging 108.8mg P/l, 69.3mg P/l and 112.4mg P/l respectively). In considering the candidate streams for side stream application alone (i.e. centrate and sludge drier condensate), the Total Phosphorus loading currently being recycled back to the headworks represents some 30% of the Total

Phosphorus loading to the main plant. This equates to 41.2 kg P/day on average based on results of the sampling. A proportion of the phosphorus could potentially fall out of the system during the biological side stream nitrogen removal process, but given the lack of research in this area, the extent of this would be difficult to predict at this stage.

If phosphorus emissions become an issue at Dundalk, the potential to dose the 'SHARON' reactor using ferric could also be investigated in order to enhance phosphorus removal. Should this be found to be successful, dosing at the side stream stage would be likely to significantly reduce the volumes of chemical dosing otherwise used to reduce emissions in the main process. Indeed, research has been successfully undertaken previously, involving the dosing of Ferro(III)chloride to a pilot plant 'SHARON' reactor treating digestate from a combined manure and organic slurry digestion plant in Belgium (Notenboom *et al.* 2002).

7.3 Potential for Leachate Treatment

Landfill leachates are essentially filtrates from large fermenter deposits. Deposited waste undergoes two stages of degradation, producing acetogenic and methanogenic leachates from these phases. An EPA publication on landfill design (EPA 2000) indicates mean concentrations of ammoniacal nitrogen in leachates, from large landfills with relatively dry high waste input rates, at 922mg/l and 889mg/l respectively for acetogenic and methanogenic leachates. Cervantes (2009) on the other hand quotes higher values for acetogenic leachate ammonia concentrations at 3,000 to 4,000 mg NH_4-N /l and 500 to 1,500 mg NH_4-N/l relating to methanogenic leachates.

Despite the high concentrations, dedicated leachate treatment facilities are not currently commonplace in Ireland, whereas discharge of methane-stripped leachate to Local Authority waste water treatment plants for co-treatment with municipal waste water can be considered the norm. The latter facilities are not specifically designed to treat leachate and indeed many such facilities may not include nitrogen reduction, thus the input of nitrogen-rich streams may lead to issues with nitrogen emissions at the end of the process.

Moreover, the dilution of nitrogen-rich streams such as leachates with considerably weaker municipal effluents, with subsequent nitrogen reduction efforts via conventional extended aeration does not constitute sustainable practice. The potential to use side stream technology in the pretreatment of leachate thus should be considered. Indeed Cervantes (2009) reported on various successful operations whereby the deammonification-'ANAMMOX' process was employed, using various reactor types, in treating landfill leachate.

Retrofitting side stream units at municipal waste water treatment plant sites may become a viable option when considering the potential presence of other nitrogen rich streams, which may be co-treated with imported leachate. If anaerobic digestion facilities exist at such locations, a waste heat source may also be available to improve the efficiency of the system. However, due to the high concentrations of organic matter that may be present in raw leachate, a pre-treatment stage may be necessary prior to the nitrogen reduction step, targeting the removal of carbon.

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APPENDICES

Appendix A

[extract from the *Urban Waste Water Treatment (Amendment) Regulations 2004*, S.I. No. 440.]

S.I. No. 440/2004 — Urban Waste Water Treatment (Amendment) Regulations, 2004

STATUTORY INSTRUMENTS.

S.I. No. 440 of 2004 .

URBAN WASTE WATER TREATMENT (AMENDMENT) REGULATIONS, 2004.

S.I. No. 440 of 2004 .

URBAN WASTE WATER TREATMENT (AMENDMENT) REGULATIONS, 2004.

The Minister for the Environment, Heritage and Local Government in exercise of the powers conferred on him by sections 6 and 59 of the Environmental Protection Agency Act, 1992 (No. 7 of 1992) and for the purpose of giving further effect to the Directive of the European Parliament and of the Council of 23 October 2000 (No. 2000/60/EC) [1] and to the Council Directive of 21 May 1991 (No. 91/271/EEC)[2] as amended by the Commission Directive of 27 February 1998 (No. 98/15/EC)[3] , hereby makes the following Regulations:

1. These Regulations may be cited as the Urban Waste Water Treatment (Amendment) Regulations, 2004.

2. The Urban Waste Water Treatment Regulations, 2001 (S.I. No. 254 of 2001) are hereby amended by—

(*a*) the deletion of sub-article 4(4)(*b*) thereof;

(*b*) the deletion of Part 2 of the Second Schedule thereto and the substitution therefor of the following:

"Part 2

Requirements for discharges from urban waste water treatment plants to sensitive areas. One or both parameters may be applied depending on the local situation. The values for concentration or for the percentage of reduction shall apply.

Parameters	Concentration	Minimum percentage of reduction([1])	Reference method of measurement
Total phosphorus	2 mg/l P (10,000 - 100,000 p.e.)	80	Molecular absorption spectrophotometry
	1 mg/l P (more than 100,000 p.e.)		
Total nitrogen([2])	15 mg/l N (10,000 - 100,000 p.e.)([3])	70-80	Molecular absorption spectrophotometry
	10 mg/l N (more than 100,000 p.e.) ([3])		

([1]) Reduction in relation to the load of the influent.

([2]) Total nitrogen means the sum of total Kjeldahl nitrogen (organic and ammoniacal nitrogen), nitrate — nitrogen and nitrite — nitrogen.

([3]) These values for concentration are annual means as referred to in paragraph 4 (*c*) of the Fifth Schedule. However, the requirements for nitrogen may be checked using daily averages when it is proven, in accordance with paragraph 1 of that Schedule, that the same level of protection is obtained. In this case, the daily average must not exceed 20 mg/l of total nitrogen for all the samples when the temperature of the effluent in the biological reactor is superior or equal to 12°C. The conditions concerning temperature can be replaced by a limitation on the time of operation to take account of regional climatic conditions.

and

(*c*) the insertion into Part 2 of the Third Schedule thereto under the heading "Estuaries" of the following:

"Lee Estuary/Lough Mahon — from the salmon weir (downstream of waterworks intake) to Monkstown (excluding North Channel at Great Island).

Owennacurra Estuary/North Channel — from North Channel (Great Island) upstream of Marloag Point including Owennacurra Estuary upstream to Dungourney river confluence.".

L.S.

GIVEN under the Official Seal of the Minister for the Environment, Heritage and Local Government, this 15th day of July, 2004.

MARTIN CULLEN,

Minister for the Environment, Heritage and Local Government.

EXPLANATORY NOTE.

(This note is not part of the Instrument and does not purport to be a legal interpretation.)

These Regulations amend the Urban Waste Water Treatment Regulations, 2001 by—

(*a*) designating two additional areas (in Cork Harbour) as sensitive areas, and

(*b*) making some minor technical amendments.

The Urban Waste Water Treatment Regulations, 2001 impose requirements in relation to discharges from urban waste water treatment facilities and give effect to Directive No. 91/271/EEC (the Urban Waste Water Treatment Directive) and Directive No. 2000/60/EC (the Water Framework Directive).

O. J. No. L 327/1 22.12.2000

O. J. No. L 135/40 30.05.1991

O. J. No. L 67/29 07.03.1998

Appendix B

[extract from the *European Communities Environmental Objectives (Surface Waters) Regulations 2009*, S.I. No. 272 - Schedules.]

NUTRIENT CONDITIONS

Nutrient conditions	River water body	Lake[1]	Transitional water body	Coastal water body
Total Ammonia (mg N/l)	High status ⩽0.040 (mean) or ⩽0.090 (95%ile) Good status ⩽0.065 (mean) or ⩽0.140 (95%ile)			
Dissolved Inorganic Nitrogen (mg N/l)				Good status (0 psu [2]) ⩽ 2.6 mg N/l (34.5 psu[2]) ⩽ 0.25 mg N/l High status (34.5 psu[2]) ⩽ 0.17 mg/N/l
Molybdate Reactive Phosphorus (MRP) (mg P/l)	High status ⩽0.025 (mean) or ⩽0.045 (95%ile) Good status ⩽0.035 (mean) or ⩽0.075 (95%ile)		(0-17 psu) ⩽ 0.060 (median) (35psu) ⩽ 0.040 (median)	

[1]Total phosphorus (TP) is an important measure of lake trophic status and TP measurements are included as part of the lakes monitoring programme; TP boundary conditions are yet to be established for lakes.
[2]Linear interpolation to be used to establish the limit value for water bodies between these salinity levels based on the median salinity of the water body being assessed.

Appendix C

[Schedule 1 – *Urban Waste Water Treatment (Amendment) Regulations 2010*, S.I. No. 48 (maps of all waterbodies designated *'nutrient sensitive'*)

&

Table C1 - Non-exhaustive list of sewage treatment facilities, potentially impacted by the additional designations during 2010.]

SCHEDULE 1

Sensitive Areas

Part 1

Rivers

Eastern River Basin District

River Boyne, County Meath — 6.5 km section downstream of sewage treatment works outfall at Blackcastle, Navan, County Meath. (Map1 insert A, of Part 4 to this schedule)

River Liffey — downstream of Osberstown sewage treatment works to Leixlip reservoir, County Kildare. (Map 1, insert D, of Part 4 to this schedule)

Shannon International River Basin District

River Camlin, County Longford — from sewage treatment works at Longford to entry into the River Shannon. (Map 2, insert H of Part 4 to this schedule,)

River Nenagh, County Tipperary — downstream of sewage treatment works outfall in Nenagh to entry into Lough Derg. (Map 2, insert E, of Part 4 to this schedule)

River Tullamore, County Offaly — 0.5 km section downstream of sewage treatment works outfall in Tullamore. (Map 2, insert F, of Part 4 to this schedule)

Western River Basin District

River Castlebar, County Mayo — downstream of sewage treatment works at Knockthomas to entry into Lough Cullin (Map 3, insert A, of Part 4 to this schedule)

Lakes

Shannon International River Basin District

Lough Derg and Lough Ree on the River Shannon. (Map 2, inserts E and H, of Part 4 to this schedule)

South Western River Basin District

Lough Leane, County Kerry. (Map 4, insert E, of Part 4 to this schedule)

North Western International River Basin District

Lough Oughter, County Cavan. (Map 5, insert B, of Part 4 to this schedule)

Part 2

Rivers

Shannon International River Basin District

River Brosna — downstream of Mullingar sewage outfall (opposite intersection of regional road (R400) with N52 south of Mullingar), to Lough Ennell. (Map 2, insert G, of Part 4 to this schedule)

River Hind — downstream of Roscommon Town sewage outfall, to Lough Ree. (Map 2, insert H, of Part 4 to this schedule)

Little Brosna River — downstream of Roscrea sewage outfall below its confluence with the Bunow River, to the bridge near Brosna House (Map 2, insert D, of Part 4 to this schedule)

South Western River Basin District

River Blackwater (Munster) — downstream of Mallow railway bridge, to Ballyduff Bridge (Map 4, insert A of Part 4 to this schedule,)

North Western International River Basin District

River Cavan — from the bridge at Lisdarn downstream of Cavan Town to the Annalee River confluence. (Map 5, insert C, of Part 4 to this schedule)

South Eastern River Basin District

River Barrow — downstream of Portarlington sewage outfall, to Graiguenamanagh Bridge. (Map 6, insert B, of Part 4 to this schedule)

River Triogue — downstream of Portlaoise sewage outfall, to confluence with the River Barrow. (Map 6, insert A, of Part 4 to this schedule)

River Nore — downstream of Kilkenny sewage outfall, to Inistioge Bridge. (Map 6, insert E, of Part 4 to this schedule)

River Suir — downstream of Thurles sewage outfall, to Twoford Bridge. (Map 6, insert D, of Part 4 to this schedule)

River Suir — downstream of Clonmel sewage outfall, to Coolnamuck Weir. (Map 6, insert G, of Part 4 to this schedule)

Neagh Bann International River Basin District

River Blackwater (Monaghan) — from the confluence of the River Shambles to Newmills Bridge. (Map 7, insert A, of Part 4 to this schedule)

River Proules — downstream of Carrickmacross sewage outfall, to confluence with the River Glyde. (Map 7, insert C, of Part 4 to this schedule)

Lakes

Shannon International River Basin District

Lough Ennell, County Westmeath. (Map 2, insert G, of Part 4 to this schedule)

Neagh Bann International River Basin District

Lough Muckno, County Monaghan. (Map 7, insert B, of Part 4 to this schedule)

Lough Monalty, County Monaghan. (Map 7, insert C, of Part 4 to this schedule)

Estuaries and Bays

Eastern River Basin District

Broadmeadow Estuary (Inner) — from the bridge west of Lissenhall (Broadmeadow River) to the railway viaduct. (Map 1, insert G, of Part 4 to this schedule)

Liffey Estuary — from Islandbridge weir to Poolbeg Lighthouse, including the River Tolka basin and South Bull Lagoon. (Map 1, insert F, of Part 4 to this schedule)

South Eastern River Basin District

Slaney Estuary (Upper) — from Enniscorthy railway bridge to Macmine. (Map 6, insert C, of Part 4 to this schedule)

Slaney Estuary (Lower) — from Macmine to Drinagh / Big Island (Map 6, insert C, of Part 4 to this schedule)

Barrow Estuary — from the weir at Bahana Wood to New Ross Bridge. (Map 6, insert F, of Part 4 to this schedule)

Suir Estuary (Upper) — from Coolnamuck Weir to Newtown. (Map 6, insert G, of Part 4 to this schedule)

South Western River Basin District

Bandon Estuary Upper — from Inishannon Bridge to 1 km downstream of Knockroe. (Map 4, insert C, of Part 4 to this schedule)

Bandon Estuary Lower — from 1 km downstream of Knockroe to Money Point. (SWRBD Map 4, insert C, of Part 4 to this schedule)

Blackwater Estuary Upper — from Bullsod Island (1 km downstream Lismore Bridge) to Dromana Ferry. (Map 4, insert A, of Part 4 to this schedule)

Blackwater Estuary Lower — downstream of Dromana Ferry, to near East Point, Youghal Harbour. (Map 4, insert A, of Part 4 to this schedule)

Lee Estuary / Lough Mahon — from the salmon weir (downstream of waterworks intake) to Monkstown (excluding North Channel and Great Island) (Map 4, insert B, of Part 4 to this schedule)

Owennacurra Estuary / North Channel — from North Channel (Great Island) upstream of Marloag Point including Owennacurra Estuary upstream to Dungourney river confluence. (Map 4, insert B, of Part 4 to this schedule)

Shannon International River Basin District

Lee Estuary Upper (Tralee) — from Ballymullin Bridge to 1.2 km from the seaward end of Tralee Ship Canal / Annagh Island. (Map 2, insert A, of Part 4 to this schedule)

Feale Estuary Upper — downstream of Finuge Bridge, to Poulnahaha Old Railway Bridge. (Map 2, insert B, of Part 4 to this schedule)

Cashen / Feale Estuary — downstream of Poulnahaha Old Railway Bridge, to Moneycashen. (Map 2, insert B, of Part 4 to this schedule)

North Western International River Basin District

Killybegs Harbour — Killybegs Harbour inside Kane's Rock / Carntullagh Head. (Map 5, insert A, of Part 4 to this schedule)

Neagh Bann International River Basin District

Castletown Estuary — from the weir 130 m downstream St. Johns Bridge (Castletown River) to Giles Quay / Lurgangreen. (Map 7, insert D, of Part 4 to this schedule)

Part 3

Rivers

Eastern River Basin District

River Boyne — from the point 6.5 km downstream of the sewage works outfall at Blackcastle, Navan to Marry's Weir upstream of Grove Island. (Map 1, insert B, of Part 4 to this schedule.)

River Liffey — from the Leixlip reservoir, County Kildare, to Islandbridge Weir. (Map 1, insert E, of Part 4 to this schedule.)

South Eastern River Basin District

River Barrow — from its confluence with the River Triogue to the point downstream of Portarlington sewage treatment outfall. (Map 6, insert A, of Part 4 to this schedule.)

Shannon International River Basin District

River Shannon (Upper) — from its confluence with the Camlin River to Lough Ree and from its outflow at Lough Ree to Clonmacnoise. (Map 2, insert H, of Part 4 to this schedule.)

River Fergus — from the sewage outfall at Clonroadmore, Ennis, County Clare, to the freshwater limit of the Fergus Estuary. (Map 2, insert C, of Part 4 to this schedule.)

River Brosna — from its outfall at Lough Ennell, County Westmeath, to its confluence with the River Shannon. (Map 2, insert G, of Part 4 to this schedule.)

Tullamore River — from the point 0.5 km downstream of the sewage treatment works outfall Tullamore to its confluence with the River Clodiagh (Tullamore). (Map 2, insert F, of Part 4 to this schedule.)

Estuaries and Bays

Eastern River Basin District

Boyne Estuary — from Marry's Weir upstream of Grove Island to Boyne Bar. (Map 1, insert C, of Part 4 to this schedule.)

South Western River Basin District

Clonakilty Harbour — from Clonakilty to Ring Harbour / Inchydoney Island. (Map 4, insert D, of Part 4 to this schedule.)

South Eastern River Basin District

Wexford Harbour — from Drinagh / Big Island to Rosslare Point / Raven Point. (Map 6, insert C, of Part 4 to this schedule.)

L.S.

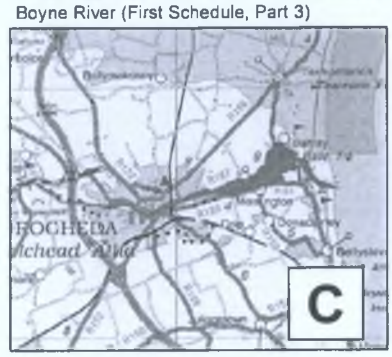
GIVEN under my Official Seal,
11 February 2010.

JOHN GORMLEY,
Minister for the Environment, Heritage and Local Government.

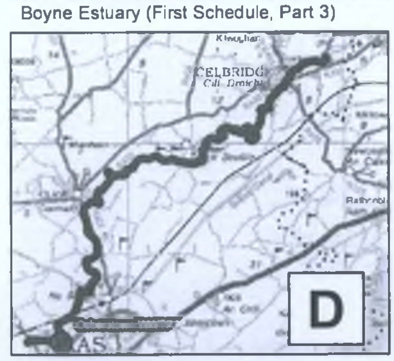
Map 1 Eastern River Basin District

Boyne River (First Schedule, Part 1)

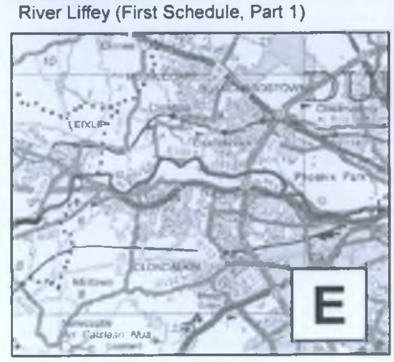
Boyne River (First Schedule, Part 3)



Boyne Estuary (First Schedule, Part 3)



River Liffey (First Schedule, Part 1)



River Liffey (First Schedule, Part 3)

Broadmeadow Estuary (First Schedule, Part 2)

Liffey Estuary (First Schedule, Part 2)

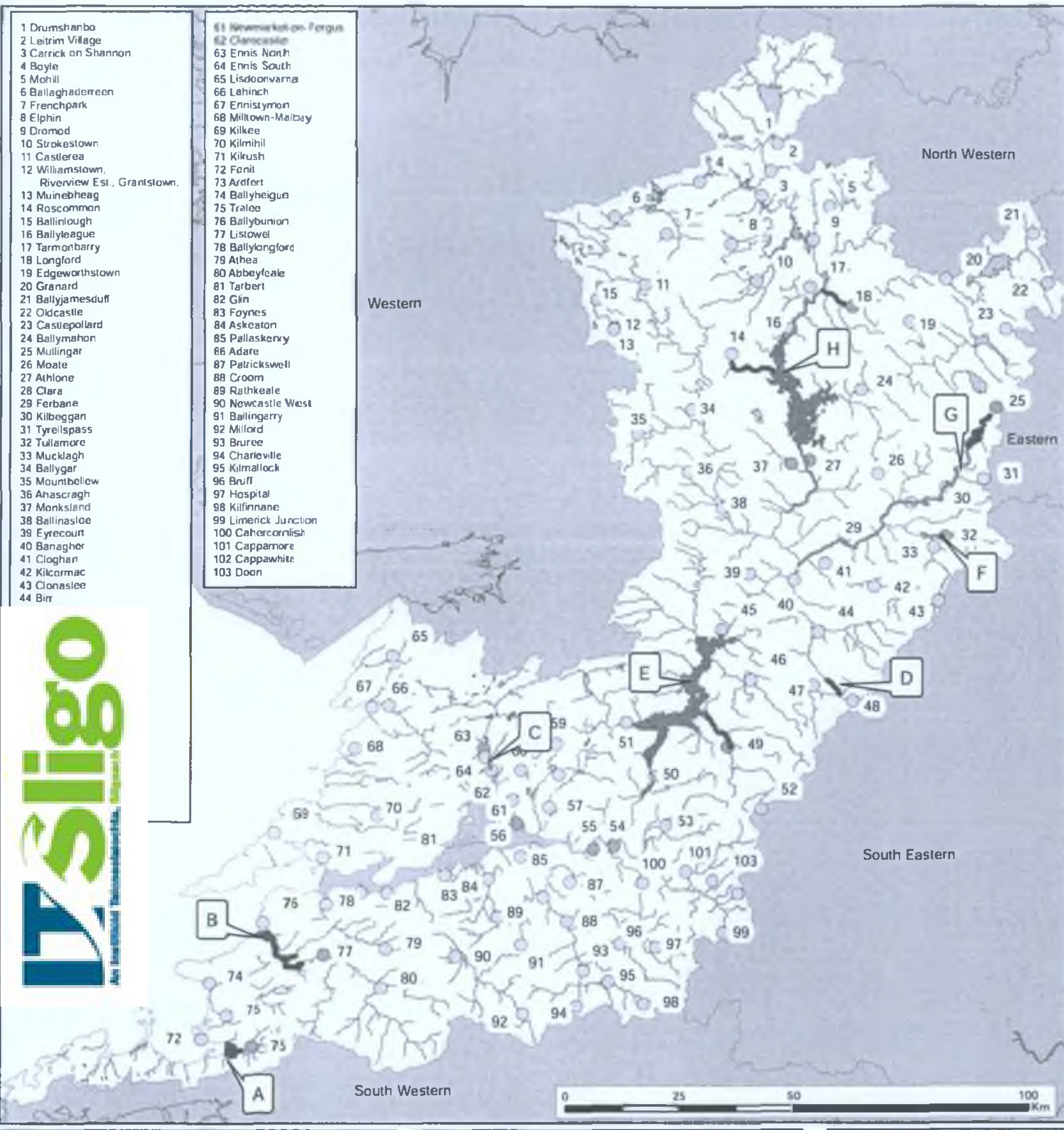
Map 2 Shannon International River Basin District

Key
River Water Bodies
Lake Water Body
Transitional Water Body
River Basin District Boundary

Agglomerations (by Population Equivalent)
> 500 < 10,000
10,000 - 100,000
> 100,000

Sensitive areas (Rivers)
First Schedule, Part 1
First Schedule, Part 2
First Schedule, Part 3

Sensitive areas (Lakes and Estuaries)
First Schedule, Part 1
First Schedule, Part 2

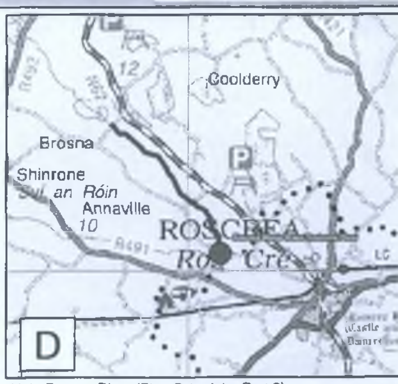


Lee Estuary Upper (First Schedule, Part 2)

Feale Estuary Upper (First Schedule, Part 2)
& Cashen-Feale Estuary (First Schedule, Part 2)

Lough Derg (First Schedule, Part 1)
& Nenagh River (First Schedule, Part 1)

River Fergus
(First Schedule, Part 3)



Little Brosna River (First Schedule, Part 2)

Tullamore River
(First Schedule, Part 1 and Part 3)

Upper Shannon River (First Schedule, Part 3), Camlin River (First Schedule, Part 1),
Hind River (First Schedule, Part 2), Lough Ree (First Schedule, Part 1),
Lough Ennell (First Schedule, Part 2),
Brosna River (First Schedule, Part 2 and Part 3)

Map 3 Western River Basin District

Key
River Water Bodies
Lake Water Body
Transitional Water Body
River Basin District Boundary
Agglomerations (by Population Equivalent)
> 500 < 10,000
10,000 - 100,000
> 100,000
Sensitive areas (Rivers)
First Schedule, Part 1

Castlebar River (First Schedule, Part 1)

Map 4 South Western River Basin District

Key

- River Water Bodies
- Lake Water Body
- Transitional Water Body
- River Basin District Boundary

Agglomerations (by Population Equivalent)

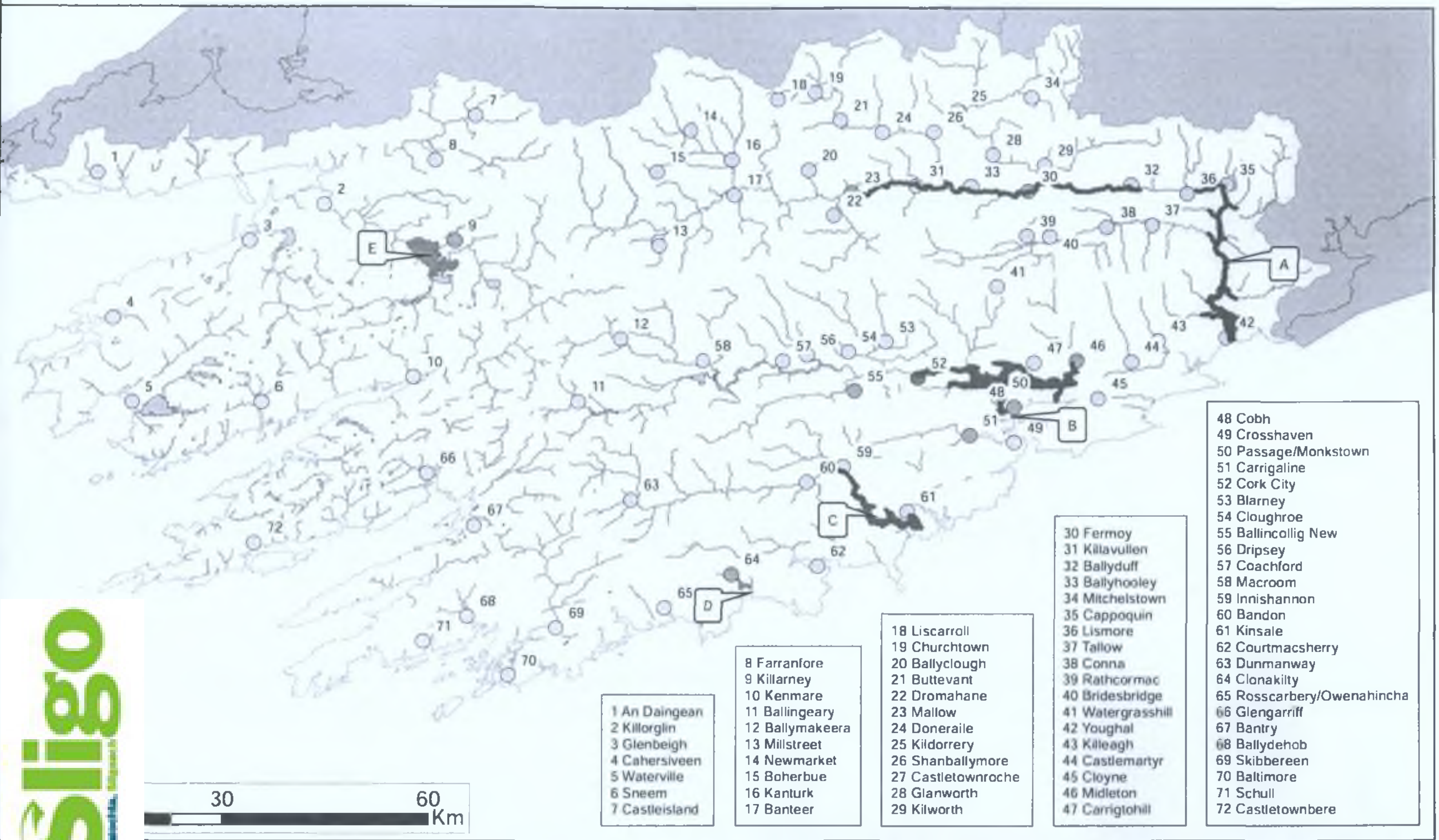
- > 500 < 10,000
- 10,000 - 100,000
- > 100,000

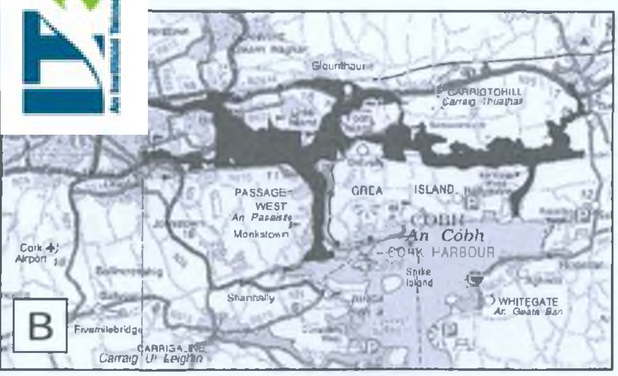
Sensitive areas (Rivers)

- First Schedule, Part 1
- First Schedule, Part 2

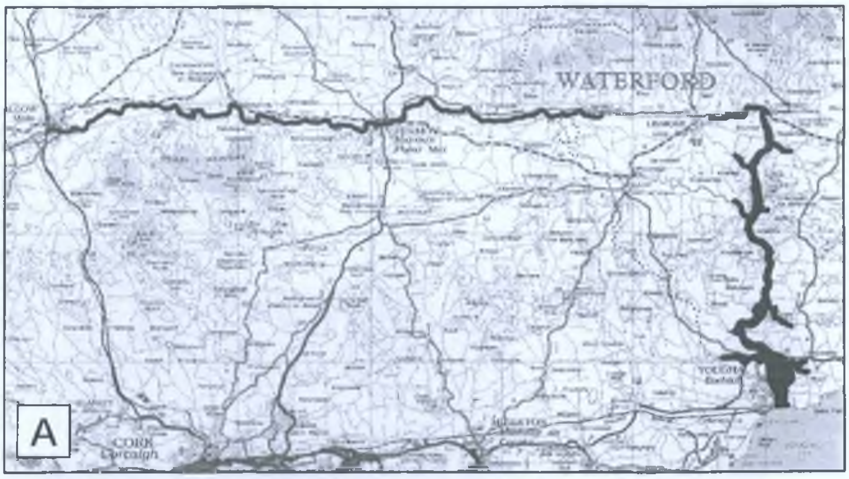
Sensitive areas (Lakes and Estuaries)

- First Schedule, Part 1
- First Schedule, Part 2
- First Schedule, Part 3





Lee Estuary/Lough Mahon (First Schedule, Part 2),
Owenacurra Estuary/ North Channel (First Schedule, Part 2)



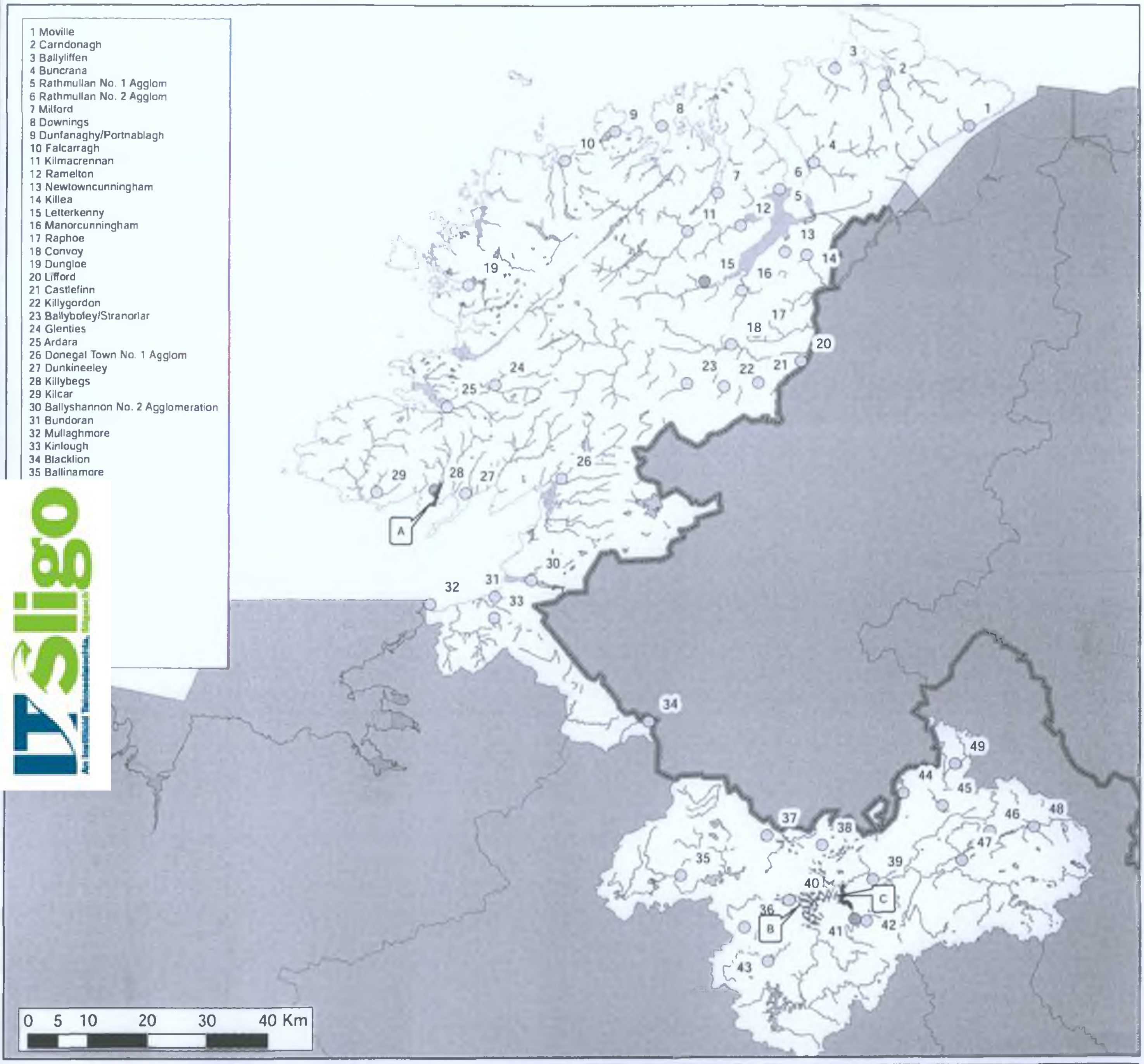
Upper Blackwater Estuary (First Schedule, Part 2), Lower Blackwater Estuary (First Schedule, Part 2),
River Blackwater (Munster) (First Schedule, Part 2)

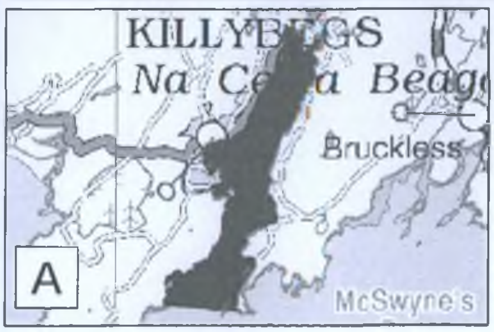
Upper Bandon Estuary (First Schedule, Part 2),
Lower Bandon Estuary (First Schedule, Part 2)

Clonakilty Harbour (First Schedule, Part 3)

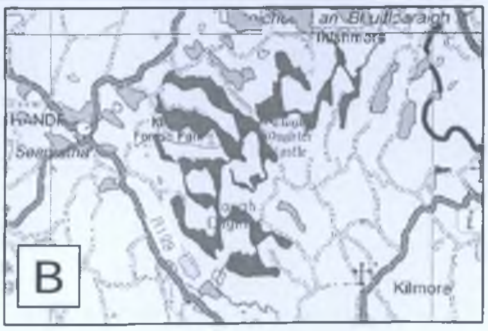
Lough Leane (First Schedule, Part 1)

Map 5 North Western International River Basin District

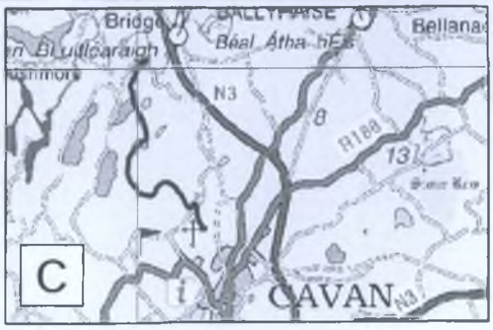




Killybegs Harbour (First Schedule, Part 2)



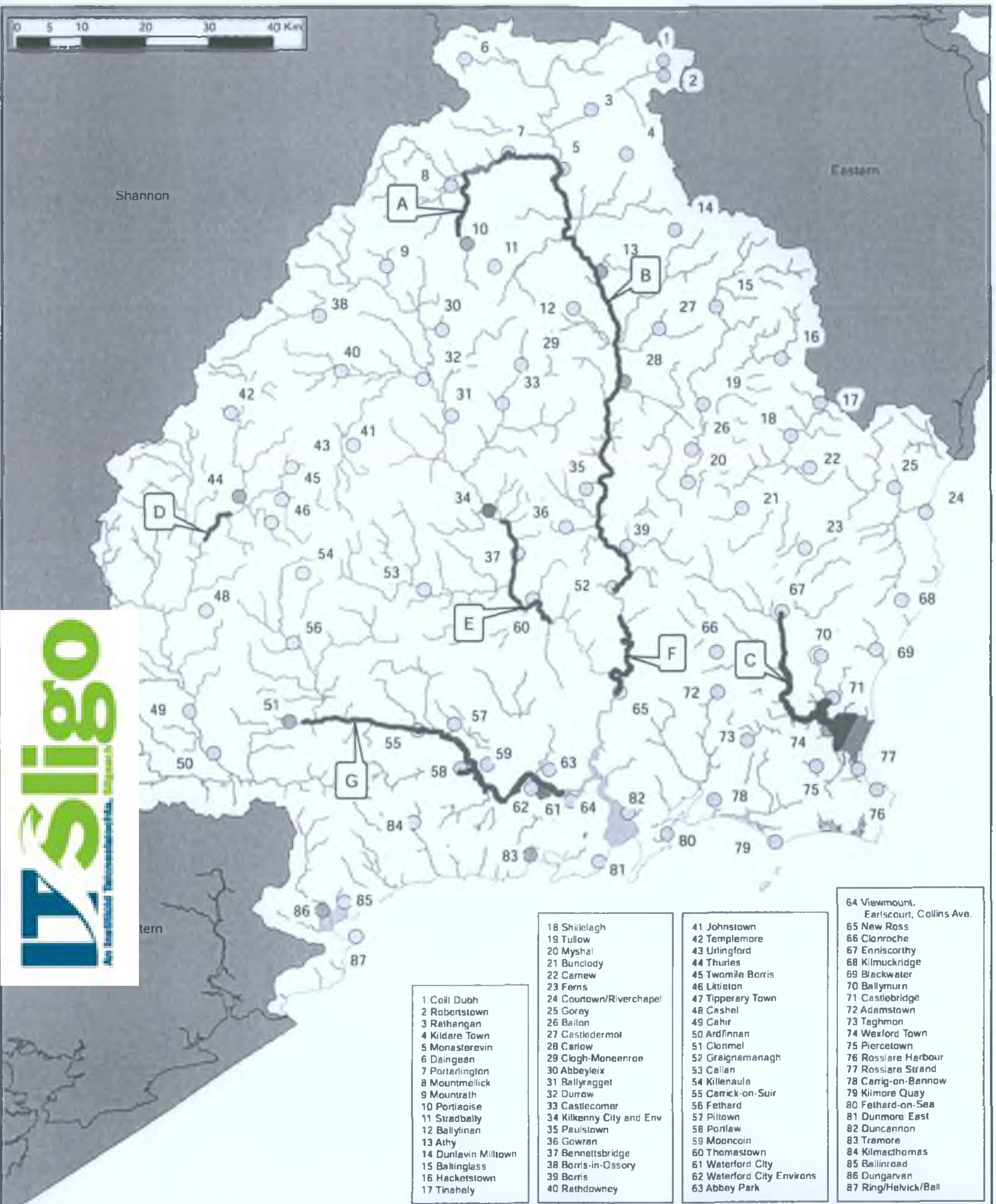
Lough Oughter (First Schedule, Part 1)



Cavan River (First Schedule, Part 2)

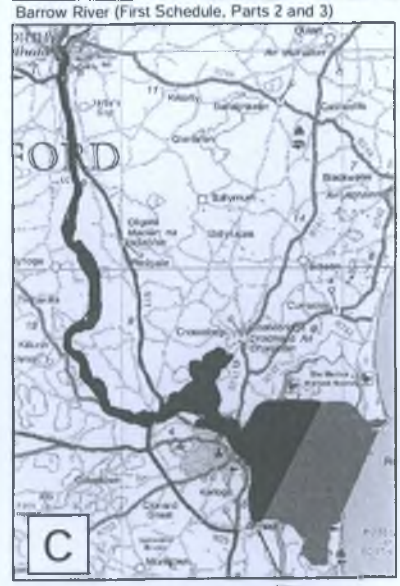
Map 6 South Eastern River Basin District

Key
River Water Bodies
Lake Water Body
Transitional Water Body
River Basin District Boundary
Agglomerations (by Population Equivalent)
> 500 < 10,000
10,000 - 100,000
> 100,000
Sensitive areas (Rivers)
First Schedule, Part 1
First Schedule, Part 2
First Schedule, Part 3
Sensitive areas (Lakes and Estuaries)
First Schedule, Part 1
First Schedule, Part 2
First Schedule, Part 3



Triogue River (First Schedule, Part 2)

Barrow River (First Schedule, Parts 2 and 3)

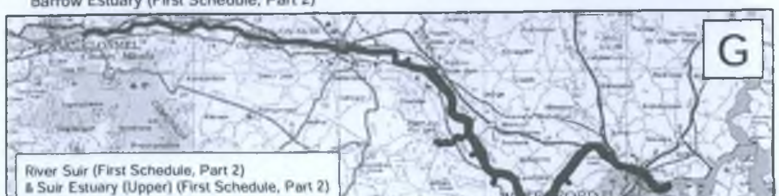


Slaney Estuary Upper, Slaney Estuary Lower (First Schedule, Part 2) and Wexford Harbour (First Schedule, Part 3)

River Suir (First Schedule, Part 2)

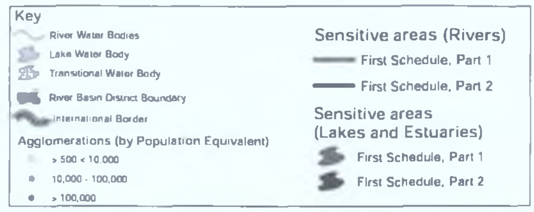
River Nore (First Schedule, Part 2)

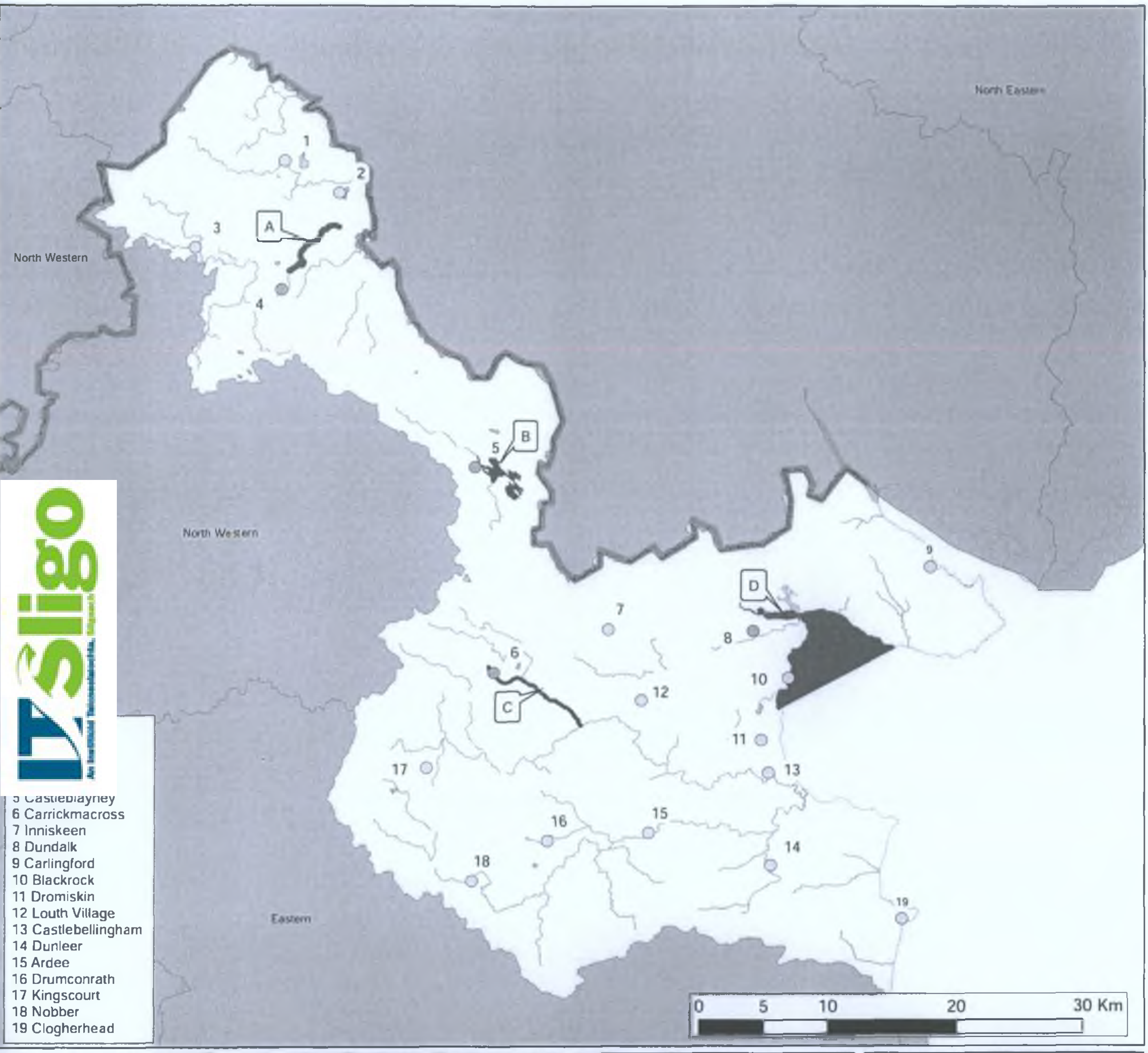
Barrow Estuary (First Schedule, Part 2)



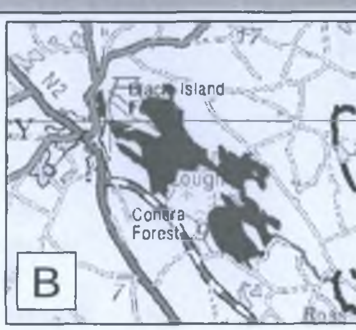
River Suir (First Schedule, Part 2)
& Suir Estuary (Upper) (First Schedule, Part 2)

Map 7 Neagh Bann International River Basin District

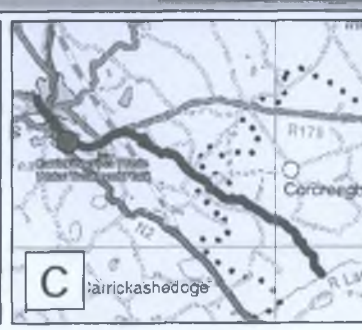




River Blackwater (First Schedule, Part 2)



Lough Muckno (First Schedule, Part 2)



Lough Monalty, Co. Monaghan
(First Schedule, Part 2),
River Proules (First Schedule, Part 2)

Castletown Estuary (First Schedule, Part 2)

Urban Waste Water Treatment (Amendment) Regulations 2010 (S.I. 48 of 2010)
Recently designated nutrient "sensitive" waterbodies

Rivers	Location Description	Agglomerations within Relevant Catchment Area
Eastern River Basin District		
Boyne	from the point 6.5km downstream of the sewage works outfall at Blackcastle, Navan to Marry's Weir upstream of Grove Island	Navan Slane Collon Tullyallen
Liffey	from the Leixlip reservoir, County Kildare, to Islandbridge Weir	Osberstown Kilmeague Ballymore Eustace Leixlip
South Eastern River Basin District		
Barrow	from its confluence with the River Triogue to the point downstream of Portarlington sewage treatment outfall	Portlaoise Mountmellick Portarlington
Shannon International River Basin District		
Shannon (Upper)	from its confluence with the Camlin River to Lough Ree and from its outflow at Lough Ree to Clonmacnoise	Longford Dromod Tarmonbarry
Fergus	from the sewage outfall at Clonroadmore, Ennis, County Clare, to the freshwater limit of the Fergus Estuary	Ennis North Ennis South Clarecastle (depending on discharge location)
Brosna	from its outfall at Lough Ennell, County Westmeath, to its confluence with the River Shannon	Mullingar Tyrellspass Kilbeggan Moate (discharges to Moate Stream to Brosna) Clara Ferbane Cloghan
Tullamore	from the point 0.5km downstream of the sewage treatment works outfall Tullamore to its confluence with the River Clodiagh (Tullamore)	Mucklagh Tullamore

uaries and Bays	Location Description	Agglomerations within Relevant Catchment Area
iver Basin District		
oyne Estuary	from Marry's Weir upstream of Grove Island to Boyne Bar	Drogheda Mornington
stern River Basin District		
nakilty Harbour	from Clonakilty to Ring Harbour/Inchydoney Island	Clonakilty
stern River Basin District		
exford Harbour	from Drinagh/Big Island to Rosslare Point/Raven Point	Enniscorthy Ballymurn Castlebridge Clonroche Ferns Wexford Town Rosslare Strand (depending on discharge location)

Appendix D

[Database of existing waste water treatment infrastructure in Ireland at January 2008 (Data sourced from Monaghan *et al.* 2009).]

List of Agglomerations without Secondary Waste Water Treatment in 2006

Ref.	Local Authority	Agglomeration	Population Equivalent (PE)	Receiving Water Type	Is Receiving Water Sensitive?	Level of Treatment		
						No Treatment	Preliminary Treatment Only	Primary Treatment Only
1	Clare	Clarecastle	2,500	Estuarine		1		
2	Clare	Corofin	500	Freshwater				1
3	Clare	Kilkee	1,330	Coastal		1		
4	Clare	Kilrush	2,600	Coastal		1		
5	Clare	Scarriff	1,300	Freshwater	Sensitive			1
6	Cork (South County)	Ballingeary	600	Freshwater				1
7	Cork (South County)	Ballymakeera	1,800	Freshwater				1
8	Cork (South County)	Carrigaline	12,000	Estuarine		1		
9	Cork (South County)	Coachford	600	Freshwater				1
10	Cork (South County)	Cobh	10,000	Coastal		1		
11	Cork (South County)	Crosshaven	2,000	Coastal			1	
12	Cork (South County)	Innishannon	833	Freshwater	Sensitive			1
13	Cork (South County)	Kinsale	5,000	Estuarine	Sensitive		1	
14	Cork (South County)	Passage/Monkstown	5,000	Estuarine		1		
15	Cork (South County)	Youghal	8,000	Estuarine		1		
16	Cork (West County)	Ballydehob	700	Estuarine				1
17	Cork (West County)	Baltimore	1,150	Coastal				1
18	Cork (West County)	Bantry	2,700	Coastal		1		
19	Cork (West County)	Castletownbere	1,100	Coastal		1		
20	Cork (West County)	Courtmacsherry	630	Estuarine		1		
21	Cork (West County)	Glengarriff	900	Coastal				1
22	Cork (West County)	Rosscarbery/Owenahincha	2,500	Coastal				1
23	Cork (West County)	Schull	1,100	Coastal				1
24	Cork (West County)	Skibbereen	3,500	Estuarine		1		
25	Donegal	Ballyshannon No. 1	500	Estuarine				1
26	Donegal	Ballyshannon No. 2	2,000	Estuarine		1		
27	Donegal	Ballyshannon No. 3	500	Estuarine				1
28	Donegal	Buncrana	5,500	Coastal				1
29	Donegal	Bundoran	9,000	Coastal			1	
30	Donegal	Carrigart	500	Estuarine				1
31	Donegal	Castlefinn	1,000	Freshwater				1
32	Donegal	Convoy	1,500	Freshwater				1

List of Agglomerations without Secondary Waste Water Treatment in 2006

Ref.	Local Authority	Agglomeration	Population Equivalent (PE)	Receiving Water Type	Is Receiving Water Sensitive?	Level of Treatment		
						No Treatment	Preliminary Treatment Only	Primary Treatment Only
33	Donegal	Donegal Town No. 1	5,400	Estuarine		1		
34	Donegal	Downings	1,000	Coastal				1
35	Donegal	Dunfanaghy/Portnablagh	2,000	Coastal				1
36	Donegal	Dungloe	2,000	Freshwater				1
37	Donegal	Dunkineeley	1,000	Coastal				1
38	Donegal	Falcarragh	2,000	Estuarine				1
39	Donegal	Glenties	1,000	Freshwater				1
40	Donegal	Kilcar	1,000	Coastal			1	
41	Donegal	Killybegs	92,000	Estuarine	Sensitive	1		
42	Donegal	Lifford	1,550	Freshwater				1
43	Donegal	Moville	2,000	Freshwater		1		
44	Donegal	Ramelton	1,000	Estuarine				1
45	Donegal	Rathmullan No. 1	800	Coastal				1
46	Donegal	Rathmullan No. 2	800	Coastal				1
47	Dun Laoghaire-Rathdown	Coliemore	1,000	Coastal		1		
48	Dun Laoghaire-Rathdown	Shanganagh	65,700	Coastal			1	
49	Fingal	Howth/Baldoyle/Portmarnock	18,000	Coastal		1		
50	Fingal	Balbriggan/Skerries	70,000	Coastal		1		
51	Fingal	Loughshinny	700	Coastal				1
52	Fingal	Lusk	3,000	Estuarine				1
53	Fingal	Rush	7,800	Coastal		1		
54	Galway County	Ahascragh	560	Freshwater			1	
55	Galway County	Clifden	4,063	Estuarine				1
56	Galway County	Clonbur	554	Freshwater			1	
57	Galway County	Dunmore	890	Freshwater				1
58	Galway County	Eyrecourt	702	Freshwater				1
59	Galway County	Glenamaddy	738	Freshwater				1
60	Kerry	Ardfert	1,500	Freshwater				1
61	Kerry	Ballyduff	800	Freshwater	Sensitive			1
62	Kerry	Ballyferriter	500	Estuarine				1
63	Kerry	Ballylongford	900	Estuarine				1
64	Kerry	Fenit	1,300	Coastal				1

List of Agglomerations without Secondary Waste Water Treatment in 2006

Ref.	Local Authority	Agglomeration	Population Equivalent (PE)	Receiving Water Type	Is Receiving Water Sensitive?	Level of Treatment		
						No Treatment	Preliminary Treatment Only	Primary Treatment Only
65	Kerry	Glenbeigh	1,900	Freshwater				1
66	Kerry	Sneem	900	Estuarine				1
67	Kerry	Tarbert	1,400	Estuarine				1
68	Kerry	Waterville	2,000	Coastal				1
69	Kildare	Ballymore Eustace	1,000	Freshwater				1
70	Kildare	Suncroft	500	Freshwater				1
71	Kilkenny	Abbey Park	924	Estuarine				1
72	Kilkenny	Bennettsbridge	640	Freshwater	Sensitive			1
73	Kilkenny	Johnstown	900	Freshwater				1
74	Kilkenny	Waterford City Environs	4,000	Estuarine	Sensitive	1		
75	Limerick County	Foynes	558	Estuarine		1		
76	Limerick County	Glin	1,386	Estuarine		1		
77	Limerick County	Pallaskenry	550	Estuarine			1	
78	Longford	Drumlish	500	Freshwater	Sensitive			1
79	Longford	Newtownforbes	500	Freshwater	Sensitive			1
80	Louth	Collon	700					1
81	Louth	Knockbridge	500					1
82	Mayo	Belmullet	2,250	Coastal		1		
83	Mayo	Killala	1,500	Coastal		1		
84	Mayo	Kiltimagh	1,000	Freshwater				1
85	Mayo	Newport	800	Estuarine				1
86	Meath	Mornington	6,000	Coastal			1	
87	Sligo	Mullaghmore	1,182	Coastal				1
88	Sligo	Rosses Point	1,409	Coastal				1
89	Sligo	Sligo	20,000	Coastal		1		
90	Tipperary South	Cappawhite	533	Freshwater	Sensitive			1
91	Waterford City	Viewmount, Earlscourt, Collins A	3,500	Estuarine		1		
92	Waterford City	Waterford City	140,000	Estuarine		1		
93	Waterford City	Williamstown, Riverview Est. Gra	3,000	Estuarine		1		
94	Waterford County	Ardmore	500	Coastal			1	
95	Waterford County	Cappoquin	950	Freshwater				1
96	Waterford County	Dunmore East	1,600	Coastal			1	

List of Agglomerations without Secondary Waste Water Treatment in 2006

Ref.	Local Authority	Agglomeration	Population Equivalent (PE)	Receiving Water Type	Is Receiving Water Sensitive?	Level of Treatment		
						No Treatment	Preliminary Treatment Only	Primary Treatment Only
97	Waterford County	Kilmacthomas	600	Freshwater				1
98	Waterford County	Stradbally	500	Estuarine				1
99	Waterford County	Tallow	1,200	Freshwater				1
100	Waterford County	Tramore	12,000	Coastal		1		
101	Wexford	Bunclody	2,555	Freshwater	Sensitive			1
102	Wexford	Campile	500	Estuarine				1
103	Wexford	Duncannon	600	Coastal		1		
104	Wexford	Fethard-on-Sea	1,000	Estuarine				1
105	Wexford	Kilmore Quay	2,000	Coastal		1		
106	Wexford	New Ross	10,000	Estuarine	Sensitive	1		
107	Wexford	Rosslare Harbour	3,000	Coastal		1		
108	Wicklow	Arklow	16,997	Coastal		1		
109	Wicklow	Avoca	500	Freshwater				1
110	Wicklow	Bray	35,000	Coastal			1	
111	Wicklow	Rathdrum	1,500	Freshwater				1
112	Wicklow	Wicklow	10,000	Coastal			1	

Effluent Quality from Secondary Waste Water Treatment Plants in 2007

			Population Equivalent (PE)				
Ref.	Local Authority	Agglomeration	Agglomeration PE	Plant PE	Receiving Water Type	Sensitive?	Nutrient Removal?
1	Carlow	Borris	800	800	Freshwater	Sensitive	
2	Carlow	Hacketstown	630	630	Freshwater	Sensitive	
3	Carlow	Myshal	800	800	Freshwater		Yes
4	Carlow	Rathvilly	500	600	Freshwater	Sensitive	
5	Carlow	Ballon	1,200	1,200	Freshwater		Yes
6	Carlow	Palatine	200	1,000	Freshwater		
7	Carlow	Muinebhead	4,000	4,000	Freshwater	Sensitive	
8	Carlow	Tullow	3,900	3,900	Freshwater	Sensitive	
9	Carlow	Carlow	36,000	36,000	Freshwater	Sensitive	
10	Cavan	Ballinagh	700	600	Freshwater		Yes
11	Cavan	Ballyhaise	700	905	Freshwater		
12	Cavan	Blacklion	600	600	Freshwater		
13	Cavan	Killeshandra	600	900	Freshwater		
14	Cavan	Mullagh	950	950	Freshwater	Sensitive	Yes
15	Cavan	Ballyconnell	1,200	1,800	Freshwater		Yes
16	Cavan	Arvagh	600	1,200	Freshwater		Yes
17	Cavan	Belturbet	1,950	1,900	Freshwater		Yes
18	Cavan	Bailieborough	1,900	2,000	Freshwater	Sensitive	Yes
19	Cavan	Cootehill	1,700	3,000	Freshwater		Yes
20	Cavan	Ballyjamesduff	1,400	3,000	Freshwater	Sensitive	Yes
21	Cavan	Virginia	1,400	3,000	Freshwater	Sensitive	Yes
22	Cavan	Kingscourt	1,950	2,000	Freshwater		
23	Cavan	Cavan	13,850	21,000	Freshwater	Sensitive	Yes
24	Clare	Inagh	500	500	Freshwater		
25	Clare	Crusheen	500	500	Freshwater		
26	Clare	Kilkishen	750	750	Freshwater		
27	Clare	Kilmihil	640	640	Freshwater		

Effluent Quality from Secondary Waste Water Treatment Plants in 2007

Ref.	Local Authority	Agglomeration	Population Equivalent (PE)		Receiving Water Type	Sensitive?	Nutrient Removal?
			Agglomeration PE	Plant PE			
28	Clare	Quin	600	832	Freshwater		
29	Clare	Tulla	720	720	Freshwater		
30	Clare	Lahinch	8,400	1,500	Freshwater		
31	Clare	Lisdoonvarna	2,500	1,767	Freshwater		Yes
32	Clare	Milltown/Milbay	1,360	1,360	Freshwater		
33	Clare	Sixmilebridge	1,500	1,500	Freshwater		
34	Clare	Ennistymon	2,000	2,000	Freshwater		
35	Clare	Ennis South	4,000	4,000	Freshwater		
36	Clare	Newmarket-on-Fergus	1,940	2,774	Freshwater		
37	Clare	Shannon Town	12,500	12,500	Estuarine		
38	Clare	Ennis North	17,000	17,000	Freshwater		
39	Cork City	Cork City	323,000	413,000	Estuarine	Sensitive	
40	Cork (North) County	Ballyclough	800	800	Freshwater		
41	Cork (North) County	Ballyhooley	750	750	Freshwater	Sensitive	
42	Cork (North) County	Banteer	550	550	Freshwater		
43	Cork (North) County	Boherbue	600	600	Freshwater		
44	Cork (North) County	Bridesbridge	600	600	Freshwater	Sensitive	
45	Cork (North) County	Castletownroche	1,000	800	Freshwater		
46	Cork (North) County	Churchtown	950	700	Freshwater		
47	Cork (North) County	Conna	800	800	Freshwater	Sensitive	
48	Cork (North) County	Dromahane	850	850	Freshwater		
49	Cork (North) County	Glanworth	800	800	Freshwater		
50	Cork (North) County	Kildorrery	550	550	Freshwater		
51	Cork (North) County	Kilworth	800	800	Freshwater		
52	Cork (North) County	Liscarroll	600	600	Freshwater		
53	Cork (North) County	Rathcormac	700	600	Freshwater		

Effluent Quality from Secondary Waste Water Treatment Plants in 2007

Ref.	Local Authority	Agglomeration	Population Equivalent (PE)		Receiving Water Type	Sensitive?	Nutrient Removal?
			Agglomeration PE	Plant PE			
54	Cork (North) County	Shanballymore	600	600	Freshwater		
55	Cork (North) County	Milford	1,000	1,000	Freshwater		
56	Cork (North) County	Millstreet	1,600	1,600	Freshwater		
57	Cork (North) County	Buttevant	1,200	1,200	Freshwater		
58	Cork (North) County	Doneraile	1,100	1,100	Freshwater		
59	Cork (North) County	Kanturk	1,700	1,700	Freshwater		
60	Cork (North) County	Killavullen	1,000	1,000	Freshwater	Sensitive	
61	Cork (North) County	Newmarket	1,600	1,100	Freshwater		
62	Cork (North) County	Watergrasshill	3,000	1,500	Freshwater		Yes
63	Cork (North) County	Charleville	7,500	6,415	Freshwater		
64	Cork (North) County	Mitchelstown	6,000	6,000	Freshwater		Yes
65	Cork (North) County	Fermoy	12,960	12,960	Freshwater	Sensitive	Yes
66	Cork (North) County	Mallow	12,000	12,000	Freshwater	Sensitive	Yes
67	Cork (South) County	Cloyne	510	510	Freshwater		
68	Cork (South) County	Cloughroe	600	600	Freshwater		
69	Cork (South) County	Dripsey	600	600	Freshwater		
70	Cork (South) County	Killeagh	600	600	Freshwater		
71	Cork (South) County	Carrigtohill	4,500	4,500	Estuarine	Sensitive	
72	Cork (South) County	Bandon	6,200	8,000	Freshwater	Sensitive	
73	Cork (South) County	Blarney	8,000	8,000	Freshwater		
74	Cork (South) County	Castlemartyr	2,000	2,000	Freshwater		
75	Cork (South) County	Macroom	5,000	5,000	Freshwater		
76	Cork (South) County	Midleton	10,000	10,000	Estuarine	Sensitive	Yes
77	Cork (South) County	Ballincollig	15,000	15,000	Freshwater		
78	Cork (West) County	Drimoleague	500	500	Freshwater		
79	Cork (West) County	Dunmanway	1,500	1,500	Freshwater		

Effluent Quality from Secondary Waste Water Treatment Plants in 2007

Ref.	Local Authority	Agglomeration	Population Equivalent (PE)		Receiving Water Type	Sensitive?	Nutrient Removal?
			Agglomeration PE	Plant PE			
80	Cork (West) County	Clonakilty	15,000	15,000	Estuarine		
81	Donegal	Kilmacrennan	900	500	Freshwater		
82	Donegal	Killea	800	800	Freshwater		
83	Donegal	Killygordon	1,700	1,700	Freshwater		
84	Donegal	Ardara	2,350	2,350	Freshwater		
85	Donegal	Ballyliffen	1,000	1,000	Freshwater		
86	Donegal	Manorcunningham	1,500	1,500	Estuarine		
87	Donegal	Newtowncunningham	1,600	1,000	Freshwater		
88	Donegal	Raphoe	2,000	1,000	Freshwater		
89	Donegal	Ballybofey/Stranorlar	5,100	5,100	Freshwater		
90	Donegal	Carndonagh	5,200	5,200	Freshwater		
91	Donegal	Milford	2,000	2,000	Freshwater		
92	Donegal	Letterkenny	22,500	20,000	Estuarine		
93	Dublin	Ringsend	2,870,333	1,640,000	Estuarine	Sensitive	
94	Fingal	Toberburr	640	640	Freshwater	Sensitive	
95	Fingal	Portrane	8,000	8,000	Coastal		
96	Fingal	Malahide	13,000	21,000	Estuarine		
97	Fingal	Swords	50,000	60,000	Estuarine	Sensitive	Yes
98	Galway City	Galway City	91,600	91,600	Coastal		
99	Galway County	Moylough	328	600	Coastal		
100	Galway County	Ballygar	944	500	Freshwater		
101	Galway County	Mountbellew	1,033	700	Freshwater		
102	Galway County	Oughterard	1,731	500	Freshwater		
103	Galway County	Killimor	500	1,010	Freshwater		
104	Galway County	Gort	4,836	4,310	Freshwater		
105	Galway County	Athenry	3,639	2,500	Freshwater		

Effluent Quality from Secondary Waste Water Treatment Plants in 2007

Ref.	Local Authority	Agglomeration	Population Equivalent (PE) Agglomeration PE	Population Equivalent (PE) Plant PE	Receiving Water Type	Sensitive?	Nutrient Removal?
106	Galway County	Ballinasloe	5,667	9,000	Freshwater		Yes
107	Galway County	Headford	1,390	2,100	Freshwater		
108	Galway County	Loughrea	6,300	6,300	Freshwater		Yes
109	Galway County	Moycullen	2,500	4,000	Freshwater		
110	Galway County	Portumna	2,842	3,100	Freshwater	Sensitive	Yes
111	Galway County	Tuam	13,250	23,250	Freshwater		Yes
112	Kerry	Rathmore	500	500	Freshwater		
113	Kerry	Ballybunion	6,100	8,180	Estuarine	Sensitive	
114	Kerry	Ballyheigue	2,802	4,234	Coastal		
115	Kerry	Cahersiveen	5,063	5,000	Coastal		
116	Kerry	Castleisland	5,215	6,000	Freshwater		
117	Kerry	Dingle	8,409	8,600	Coastal		
118	Kerry	Faranfore	2,000	2,000	Freshwater		
119	Kerry	Kenmare	9,685	3,500	Estuarine		
120	Kerry	Killorglin	7,717	5,000	Freshwater		
121	Kerry	Listowel	13,653	12,500	Freshwater		
122	Kerry	Tralee	27,208	42,000	Coastal		
123	Kerry	Killarney	34,244	51,000	Freshwater	Sensitive	Yes
124	Kildare	Derrinturn	500	500	Freshwater	Sensitive	
125	Kildare	Kilmeague	700	700	Freshwater	Sensitive	
126	Kildare	Nurney	500	500	Freshwater	Sensitive	Yes
127	Kildare	Robertstown	1,000	1,000	Freshwater	Sensitive	Yes
128	Kildare	Castledermot	1,500	2,400	Freshwater	Sensitive	Yes
129	Kildare	Coill Dubh	2,000	2,000	Freshwater	Sensitive	Yes
130	Kildare	Kildare Town	5,172	7,000	Freshwater	Sensitive	Yes
131	Kildare	Monasterevin	3,967	9,000	Freshwater	Sensitive	Yes

Effluent Quality from Secondary Waste Water Treatment Plants in 2007

Ref.	Local Authority	Agglomeration	Population Equivalent (PE)		Receiving Water Type	Sensitive?	Nutrient Removal?
			Agglomeration PE	Plant PE			
132	Kildare	Rathangan	2,000	2,000	Freshwater	Sensitive	
133	Kildare	Athy	16,800	15,000	Freshwater	Sensitive	Yes
134	Kildare	Leixlip	58,204	80,000	Freshwater	Sensitive	Yes
135	Kildare	Osberstown	95,167	80,000	Freshwater	Sensitive	Yes
136	Kilkenny	Gowran	600	550	Freshwater		
137	Kilkenny	Stonyford	350	500	Freshwater		
138	Kilkenny	Urlingford	1,500	500	Freshwater	Sensitive	
139	Kilkenny	Ballyragget	1,920	1,920	Freshwater	Sensitive	
140	Kilkenny	Clogh-Moneenroe	1,740	1,740	Freshwater	Sensitive	
141	Kilkenny	Paulstown	1,000	1,000	Freshwater		
142	Kilkenny	Piltown	1,500	1,500	Estuarine		
143	Kilkenny	Callan	4,000	4,000	Freshwater	Sensitive	
144	Kilkenny	Castlecomer	2,540	2,540	Freshwater	Sensitive	
145	Kilkenny	Graignamanagh	3,000	3,000	Freshwater	Sensitive	
146	Kilkenny	Mooncoin	2,800	2,800	Estuarine	Sensitive	
147	Kilkenny	Thomastown	3,000	3,000	Freshwater	Sensitive	
148	Kilkenny	Kilkenny (Purcellsinch)	107,650	107,650	Freshwater	Sensitive	
149	Laois	Ballyroan	202	600	Freshwater		
150	Laois	Borris-in-Ossory	626	600	Freshwater		
151	Laois	Castletown	414	500	Freshwater		
152	Laois	Clonaslee	676	500	Freshwater		
153	Laois	The Swan	300	700	Freshwater		
154	Laois	Durrow	1,308	1,308	Freshwater		
155	Laois	Rathdowney	1,596	1,000	Freshwater		
156	Laois	Abbeyleix	2,209	2,300	Freshwater		
157	Laois	Ballylinan	842	2,000	Freshwater		

Effluent Quality from Secondary Waste Water Treatment Plants in 2007

Ref.	Local Authority	Agglomeration	Population Equivalent (PE)		Receiving Water Type	Sensitive?	Nutrient Removal?
			Agglomeration PE	Plant PE			
158	Laois	Mountmellick	7,500	5,000	Freshwater		
159	Laois	Mountrath	2,184	2,300	Freshwater		
160	Laois	Portarlington	7,000	8,000	Freshwater		
161	Laois	Stradbally	1,302	2,000	Freshwater		
162	Laois	Portlaoise	20,000	23,000	Freshwater	Sensitive	Yes
163	Leitrim	Carrigallen	732	501	Freshwater		
164	Leitrim	Dromahair	990	620	Freshwater		Yes
165	Leitrim	Dromod	626	518	Freshwater		
166	Leitrim	Drumshambo	1,841	960	Freshwater	Sensitive	Yes
167	Leitrim	Kinlough	1,442	700	Freshwater		Yes
168	Leitrim	Leitrim Village	1,436	501	Freshwater	Sensitive	
169	Leitrim	Ballinamore	2,514	1,380	Freshwater		Yes
170	Leitrim	Manorhamilton	2,559	1,650	Freshwater		Yes
171	Leitrim	Mohill	1,570	1,398	Freshwater		Yes
172	Leitrim	Carrick on Shannon	5,650	4,320	Freshwater	Sensitive	
173	Limerick City	Limerick City	100,000	105,000	Estuarine		
174	Limerick County	Athea	592	592	Freshwater		
175	Limerick County	Ballingarry	700	500	Freshwater		
176	Limerick County	Cahercornlish	800	800	Freshwater		
177	Limerick County	Cappamore	860	860	Freshwater		
178	Limerick County	Doon	700	700	Freshwater		
179	Limerick County	Dromcollagher	500	500	Freshwater		
180	Limerick County	Kilfinnane	900	900	Freshwater		
181	Limerick County	Murroe	500	500	Freshwater		
182	Limerick County	Oola	500	500	Freshwater		
183	Limerick County	Adare	1,600	1,600	Estuarine		

Effluent Quality from Secondary Waste Water Treatment Plants in 2007

Ref.	Local Authority	Agglomeration	Population Equivalent (PE)		Receiving Water Type	Sensitive?	Nutrient Removal?
			Agglomeration PE	Plant PE			
184	Limerick County	Askeaton	1,024	1,024	Estuarine		
185	Limerick County	Bruff	1,200	1,200	Freshwater		
186	Limerick County	Bruree	800	1,200	Freshwater		Yes
187	Limerick County	Croom	1,200	1,200	Freshwater		
188	Limerick County	Hospital	1,000	1,000	Freshwater		
189	Limerick County	Patrickswell	1,500	1,500	Freshwater		
190	Limerick County	Abbeyfeale	2,000	2,000	Freshwater		
191	Limerick County	Kilmallock	2,400	2,400	Freshwater		
192	Limerick County	Newcastle West	6,100	6,100	Freshwater		Yes
193	Limerick County	Rathkeale	2,000	2,000	Freshwater		Yes
194	Limerick County	Castletroy	13,000	13,000	Freshwater		
195	Longford	Ballymahon	2,125	2,125	Freshwater		Yes
196	Longford	Edgeworthstown	2,750	2,750	Freshwater	Sensitive	Yes
197	Longford	Granard	3,200	3,200	Freshwater	Sensitive	Yes
198	Longford	Longford	20,000	20,000	Freshwater	Sensitive	Yes
199	Louth	Louth Village	700	500	Freshwater		
200	Louth	Carlingford	1,400	1,400	Coastal		
201	Louth	Castlebellingham	1,500	1,700	Freshwater		
202	Louth	Dromiskin	1,300	1,000	Freshwater		
203	Louth	Tullyallen	1,300	1,800	Freshwater		
204	Louth	Ardee	6,000	8,266	Freshwater		
205	Louth	Blackrock	5,800	6,000	Estuarine		
206	Louth	Clogherhead	1,700	2,000	Coastal		
207	Louth	Dunleer	2,000	4,300	Freshwater		
208	Louth	Drogheda	90,000	101,000	Estuarine		
209	Louth	Dundalk	90,000	179,535	Estuarine	Sensitive	

Effluent Quality from Secondary Waste Water Treatment Plants in 2007

Ref.	Local Authority	Agglomeration	Population Equivalent (PE)		Receiving Water Type	Sensitive?	Nutrient Removal?
			Agglomeration PE	Plant PE			
210	Mayo	Ballindine	716	750	Freshwater		Yes
211	Mayo	Ballycastle	600	600	Freshwater		
212	Mayo	Belcarra	196	500	Freshwater		
213	Mayo	Shrule	399	600	Freshwater		
214	Mayo	Balla	667	1,200	Freshwater		
215	Mayo	Bangor Erris	346	1,100	Freshwater		
216	Mayo	Charlestown	1,917	1,200	Freshwater		
217	Mayo	Foxford	1,500	1,500	Freshwater		
218	Mayo	Louisburgh	1,000	1,000	Freshwater		
219	Mayo	Mallaranny	1,017	1,017	Coastal		
220	Mayo	Achill Island Central	910	4,000	Coastal		
221	Mayo	Ballinrobe	10,191	8,000	Freshwater		Yes
222	Mayo	Ballyhaunis	3,637	4,000	Freshwater		Yes
223	Mayo	Claremorris	6,753	5,333	Freshwater		Yes
224	Mayo	Cong	491	2,200	Freshwater		Yes
225	Mayo	Crossmolina	1,747	3,300	Freshwater		Yes
226	Mayo	Knock	3,401	6,200	Freshwater		Yes
227	Mayo	Swinford	1,383	6,500	Freshwater		Yes
228	Mayo	Westport	10,381	15,000	Coastal		Yes
229	Mayo	Ballina	6,538	20,000	Estuarine		
230	Mayo	Castlebar	17,828	20,000	Freshwater	Sensitive	Yes
231	Meath	Carlanstown	600	600	Freshwater		Yes
232	Meath	Drumconrath	600	600	Freshwater		
233	Meath	Kentstown	600	600	Freshwater		Yes
234	Meath	Kilmainhamwood	500	500	Freshwater		
235	Meath	Kilmessan	500	600	Freshwater	Sensitive	

Effluent Quality from Secondary Waste Water Treatment Plants in 2007

			Population Equivalent (PE)				
Ref.	Local Authority	Agglomeration	Agglomeration PE	Plant PE	Receiving Water Type	Sensitive?	Nutrient Removal?
236	Meath	Nobber	600	600	Freshwater		
237	Meath	Summerhill	700	700	Freshwater	Sensitive	
238	Meath	Kildalkey	1,500	1,500	Freshwater		
239	Meath	Longwood	700	1,500	Freshwater	Sensitive	Yes
240	Meath	Oldcastle	1,400	1,500	Freshwater		
241	Meath	Slane	1,500	1,500	Freshwater		
242	Meath	Athboy	2,500	2,500	Freshwater	Sensitive	
243	Meath	Ballivor	500	2,000	Freshwater	Sensitive	Yes
244	Meath	Duleek	2,500	2,500	Freshwater		Yes
245	Meath	Johnstown Bridge	1,800	3,500	Freshwater	Sensitive	Yes
246	Meath	Kells	5,500	8,000	Freshwater	Sensitive	
247	Meath	Stamullen	1,800	2,500	Freshwater		Yes
248	Meath	Castletown/Tara	4,000	12,000	Freshwater		Yes
249	Meath	Trim	7,500	12,000	Freshwater	Sensitive	Yes
250	Meath	Navan	25,000	40,000	Freshwater	Sensitive	Yes
251	Monaghan	Knockatallon	130	750	Freshwater		
252	Monaghan	Scotshouse	200	600	Freshwater		Yes
253	Monaghan	Smithboro	1,466	750	Freshwater		
254	Monaghan	Ballinode	341	1,000	Freshwater		
255	Monaghan	Glaslough	966	1,750	Freshwater		Yes
256	Monaghan	Inniskeen	968	1,750	Freshwater		
257	Monaghan	Newbliss	1,056	1,000	Freshwater		
258	Monaghan	Rockorry	916	1,000	Freshwater		Yes
259	Monaghan	Scotstown	528	1,000	Freshwater		
260	Monaghan	Ballybay	7,283	7,283	Freshwater		
261	Monaghan	Clones	3,893	4,500	Freshwater		

Effluent Quality from Secondary Waste Water Treatment Plants in 2007

Ref.	Local Authority	Agglomeration	Population Equivalent (PE)		Receiving Water Type	Sensitive?	Nutrient Removal?
			Agglomeration PE	Plant PE			
262	Monaghan	Emyvale	764	2,000	Freshwater		
263	Monaghan	Knockaconny	200	3,000	Freshwater	Sensitive	
264	Monaghan	Carrickmacross	12,087	12,150	Freshwater	Sensitive	Yes
265	Monaghan	Castleblayney	12,920	12,960	Freshwater	Sensitive	Yes
266	Monaghan	Monaghan	30,497	43,833	Freshwater	Sensitive	Yes
267	Offaly	Cloghan	770	800	Freshwater	Sensitive	
268	Offaly	Daingean	932	800	Freshwater		
269	Offaly	Mucklagh	750	800	Freshwater		
270	Offaly	Shinrone	800	500	Freshwater		
271	Offaly	Rhode	976	1,000	Freshwater		Yes
272	Offaly	Banagher	2,000	2,500	Freshwater	Sensitive	Yes
273	Offaly	Clara	3,500	4,500	Freshwater	Sensitive	Yes
274	Offaly	Edenderry	8,500	9,000	Freshwater	Sensitive	Yes
275	Offaly	Ferbane	1,650	3,184	Freshwater	Sensitive	Yes
276	Offaly	Kilcormac	1,480	2,000	Freshwater	Sensitive	
277	Offaly	Birr	9,680	12,000	Freshwater	Sensitive	Yes
278	Offaly	Tullamore	23,000	16,000	Freshwater	Sensitive	Yes
279	Roscommon	Ballinlough	965	800	Freshwater		Yes
280	Roscommon	Elphin	1,160	800	Freshwater		
281	Roscommon	Frenchpark	705	500	Freshwater		
282	Roscommon	Tarmonbarry	600	600	Freshwater		
283	Roscommon	Ballyleague	981	1,500	Freshwater	Sensitive	
284	Roscommon	Strokestown	1,463	1,000	Freshwater		
285	Roscommon	Ballaghaderreen	5,017	2,500	Freshwater		Yes
286	Roscommon	Boyle	3,883	6,000	Freshwater		Yes
287	Roscommon	Castlerea	2,383	3,000	Freshwater		Yes

Effluent Quality from Secondary Waste Water Treatment Plants in 2007

Ref.	Local Authority	Agglomeration	Population Equivalent (PE) Agglomeration PE	Plant PE	Receiving Water Type	Sensitive?	Nutrient Removal?
288	Roscommon	Monksland	10,733	8,139	Freshwater		Yes
289	Roscommon	Roscommon	8,967	9,550	Freshwater	Sensitive	Yes
290	Sligo	Ballisadare	1,250	575	Estuarine		
291	Sligo	Gurteen	438	600	Freshwater		
292	Sligo	Riverstown	357	600	Freshwater		
293	Sligo	Collooney	1,058	1,400	Freshwater		
294	Sligo	Enniscrone	2,447	1,400	Coastal		
295	Sligo	Strandhill	1,728	1,500	Coastal		
296	Sligo	Tubbercurry	2,154	1,400	Freshwater		
297	Sligo	Ballymote	2,390	3,000	Freshwater		
298	Tipperary North	Borrisokane	1,033	700	Freshwater	Sensitive	
299	Tipperary North	Holycross	500	500	Freshwater	Sensitive	
300	Tipperary North	Littleton	700	700	Freshwater		
301	Tipperary North	Twomile Borris	600	600	Freshwater		
302	Tipperary North	Borrisoleigh	2,077	1,000	Freshwater	Sensitive	
303	Tipperary North	Newport	983	1,720	Freshwater		
304	Tipperary North	Ballina	3,431	3,000	Freshwater	Sensitive	Yes
305	Tipperary North	Templemore	3,500	3,500	Freshwater	Sensitive	
306	Tipperary North	New Nenagh	12,782	12,000	Freshwater	Sensitive	Yes
307	Tipperary North	Thurles	22,465	12,900	Freshwater	Sensitive	
308	Tipperary North	Roscrea	9,137	26,000	Freshwater	Sensitive	Yes
309	Tipperary South	Ballyclerihan	500	500	Freshwater	Sensitive	Yes
310	Tipperary South	Killenaule	864	864	Freshwater	Sensitive	Yes
311	Tipperary South	Limerick Junction	600	500	Freshwater		
312	Tipperary South	Ardfinnan	572	1,000	Freshwater	Sensitive	Yes
313	Tipperary South	Fethard	1,920	1,920	Freshwater	Sensitive	Yes

Effluent Quality from Secondary Waste Water Treatment Plants in 2007

Ref.	Local Authority	Agglomeration	Population Equivalent (PE)		Receiving Water Type	Sensitive?	Nutrient Removal?
			Agglomeration PE	Plant PE			
314	Tipperary South	Cahir	3,000	3,000	Freshwater	Sensitive	
315	Tipperary South	Carrick-on-suir	6,000	6,000	Freshwater	Sensitive	Yes
316	Tipperary South	Cashel	2,280	2,280	Freshwater	Sensitive	
317	Tipperary South	Tipperary Town	4,750	4,750	Freshwater	Sensitive	Yes
318	Tipperary South	Clonmel	40,000	40,000	Freshwater	Sensitive	Yes
319	Waterford County	Ballinroad	700	750	Estuarine		
320	Waterford County	Lismore	1,600	1,500	Freshwater	Sensitive	
321	Waterford County	Portlaw	1,500	1,250	Freshwater	Sensitive	
322	Waterford County	Ring/Helvick/Ball	600	1,000	Coastal		
323	Waterford County	Dungarvan	13,000	20,000	Coastal		
324	Westmeath	Ballynacarrigy	400	600	Freshwater		Yes
325	Westmeath	Clonmellon	500	500	Freshwater		
326	Westmeath	Multyfarnham	300	700	Freshwater		
327	Westmeath	Delvin	900	1,250	Freshwater		
328	Westmeath	Rochfortbridge	1,700	1,500	Freshwater		
329	Westmeath	Castlepollard	2,000	6,500	Freshwater		Yes
330	Westmeath	Kilbeggan	2,000	2,460	Freshwater		
331	Westmeath	Killucan	850	2,500	Freshwater		Yes
332	Westmeath	Kinnegad	2,800	4,800	Freshwater		Yes
333	Westmeath	Moate	3,000	5,000	Freshwater		Yes
334	Westmeath	Tyrellspass	800	2,000	Freshwater	Sensitive	Yes
335	Westmeath	Athlone	22,200	30,000	Freshwater	Sensitive	Yes
336	Westmeath	Mullingar	23,000	25,000	Freshwater	Sensitive	Yes
337	Wexford	Adamstown	535	900	Freshwater		
338	Wexford	Ballymurn	600	600	Freshwater	Sensitive	Yes
339	Wexford	Bridgetown	500	500	Freshwater	Sensitive	

Effluent Quality from Secondary Waste Water Treatment Plants in 2007

Ref.	Local Authority	Agglomeration	Population Equivalent (PE) Agglomeration PE	Plant PE	Receiving Water Type	Sensitive?	Nutrient Removal?
340	Wexford	Carrig-on-Bannow	600	600	Estuarine		Yes
341	Wexford	Clonroche	1,000	650	Freshwater		
342	Wexford	Piersetown	600	800	Freshwater		Yes
343	Wexford	Taghmon	1,000	650	Freshwater		
344	Wexford	Castlebridge	1,000	1,750	Estuarine	Sensitive	
345	Wexford	Ferns	1,200	1,200	Freshwater	Sensitive	
346	Wexford	Blackwater	1,200	2,000	Freshwater		
347	Wexford	Gorey	6,500	6,500	Freshwater		
348	Wexford	Kilmuckridge	1,000	2,000	Freshwater		
349	Wexford	Rosslare Strand	4,000	7,000	Coastal		
350	Wexford	Courtown/Riverchapel	10,000	12,000	Coastal		
351	Wexford	Enniscorthy	8,500	16,500	Estuarine	Sensitive	
352	Wexford	Wexford Town	17,000	45,000	Estuarine	Sensitive	Yes
353	Wicklow	Ballinaclash	300	900	Freshwater		Yes
354	Wicklow	Dunlavin Milltown	700	600	Freshwater		
355	Wicklow	Kilpedder	600	600	Freshwater		
356	Wicklow	Rathnew	1,530	600	Freshwater		
357	Wicklow	Redcross	1,040	800	Freshwater		
358	Wicklow	Shillelagh	550	800	Freshwater		
359	Wicklow	Ashford	1,090	1,090	Freshwater		
360	Wicklow	Aughrim	1,112	1,200	Freshwater		
361	Wicklow	Laragh	500	1,000	Freshwater		
362	Wicklow	Newcastle	1,000	1,000	Freshwater		
363	Wicklow	Tinahely	1,000	1,200	Freshwater		
364	Wicklow	Roundwood	1,322	1,600	Freshwater		
365	Wicklow	Baltinglass	3,391	3,000	Freshwater		

Effluent Quality from Secondary Waste Water Treatment Plants in 2007

Ref.	Local Authority	Agglomeration	Population Equivalent (PE) Agglomeration PE	Plant PE	Receiving Water Type	Sensitive?	Nutrient Removal?
366	Wicklow	Blessington	4,500	6,000	Freshwater		Yes
367	Wicklow	Carnew	1,800	2,400	Freshwater		
368	Wicklow	Enniskerry	3,000	6,000	Freshwater		Yes
369	Wicklow	Kilcoole	1,529	2,400	Freshwater		
370	Wicklow	Greystones	28,000	30,000	Coastal		
		Total	5,201,712	4,409,553			112

Appendix E

[Questionnaire 1 - Research queries formulated during the case study and interview stage of the study.]

<u>**Questionnaire No. 1**</u>

1. Does an existing nitrogen emission limit apply to the plant?
2. Does the treatment process include dedicated nitrogen removal?
3. What Mixed Liquor Suspended Solids (MLSS) is maintained in the aeration basins?
4. Are nitrogen concentrations monitored in the influent, and if so, is nitrogen measured in the form of TKN, organic nitrogen or ammonia?
5. Are there records of Total Nitrogen or ammonium concentrations in the final effluent?
6. Does continuous flow recording occur on the inlet and outlet from the plant? If so, are the records digitally available?
7. Are there records available for organic loadings to the plant for a period of, say, the previous 12 months?
8. What recycle streams are you aware of within the treatment/sludge handling process?
9. Are there flow records pertaining to recycle streams?
10. Has there ever been laboratory analysis undertaken on recycle streams to determine the constituents and strength of same?
11. Is there any spare or unused tankage on site that might potentially be re-used as a side stream reactor?
12. Is there any particular industry feeding into Dundalk, which may be having an adverse affect on the treatment process?
13. Is landfill leachate imported to Dundalk?
14. Does any form of chemical dosing of sewage occur within the treatment process or on the drainage network?
15. At what exact location in the treatment process is the recycle streams returned to the main stream?

16. What is the exact location in the treatment process where influent samples are abstracted, i.e. before or after the recycle stream return?

17. What is the fate of surface water falling on hard stand areas?

Sludge Handling:

18. Are there records of sludge imports, e.g. tonnages or volumes?

19. How is the imported sludge analysed – what parameters are measured?

20. Are there any chemical or other additives to the sludge process that may affect a side stream treatment process, or that may affect the pH of the recycle streams?

21. What percentage dry solids does the centrifuge process typically achieve?

22. What is the typical apportionment of dewatered sludge quantities being fed forward for lime dosing and for thermal drying?

23. What temperature are the digesters maintained at?

24. Explain the method of heat production for the digesters.

25. If there is too much heat produced in the digesters, how is this controlled?

26. Does sludge wasting practices differ much throughout the seasons?

27. Is biogas used to power the Combined Heat and Power Plant?

Appendix F

[Questionnaire 2 – Queries for Validation of the Nitrogen Mass Balance.]

Questionnaire No. 2

1. The "Digestion Pump Rate" figures in the 1st table of the attached spreadsheet - is this the pumping rate on a rising main between the PFTs and the Digestors (or between the Digestors and Sludge Holding Tanks)?

2. Is there overlap from when the WAS pumps stop and the Digestor feed pump starts (in other words are the PFTs being drawn down at the same time as being filled)?

3. Is all thickened sludge from PFTs sent on to digestors, or do the PFTs discharge elsewhere (with the exception of course of supernatant over v-notch) ?

Would the PFTs tend to spill during the day (after WAS pumps stop) when the digestors are being fed? (say, as a result of sludge acceptance from other plants - I am trying to work out if daytime spills will need to be added to daily volume supernatant from PFTs).

Would both PFTs ever be filled simultaneously at night by WAS pumps? Your data seems to suggest that either PFT1 or PFT2 is chosen for filling on any particular night.

6. Do you have any data on water usage for: screen backwashing system (if this contributes to supernatant sump), launder unit to screening compaction, grit removal water feed and sludge drier feed)?

7. Is sludge acceptance (imports) data available relating to the days flow/levels are measured?

8. Does all the thickened sludge from the digestors go on for dewatering or is some exported in liquid form? If so, does this practice vary during the year?

9. Is all dewatered cake sent to drier? If not, what is the normal practice for this?

10. What type of preliminary screen is in use at Dundalk (Beltafine?)- does it need a filter unit for feeding final effluent as backwash water to prevent nozzle clogging?

11. I need to get a representative idea of % Dry Solids feeding into Centrifuge units and % out as cake, to work out representative volumes of centrate.

12. Is there representative data available regarding feed rates to centrifuges?

13. Is there any data on the water feed rate to the scrubber in drier building? If not, is there a model type?

14. To work out domestic foul rate, could you please confirm the number of staff on site?

Appendix G

[Cost Estimates and Assumptions.]

Assumptions: Conventional Upgrade - General

1 Contract will bid at beginning of 2011 (Year 1)

2 Construction Phase will last for 5 months (including commissioning), commencing in May 2011 (Year 1) and completion at end September 2011

3 First year of Operation will be 2011 (Year 1)

4 Professional Fees will arise and will be spread evenly over 5-month period

5 All of the cash flows associated with the project are stated in 2011 prices or brought to 2011 prices by use of assumed inflation values shown

6 Discount Rate used is 5% throughout

7 All items of capital and operating expenditure are derived from estimates and are stated net of tax

8 The plant to be constructed will cater for the Phase 1 Design Capacity of 179,535 p.e., but modified for nitrogen reduction provisions

9 Professional costs are based on scale of fees on capital cost estimate (as a substitute for lump sum estimate)

10 Plant replacement costs and schedule are estimated by referring to projects of similar nature

11 Other professional costs and employer overheads are estimated as a percentage of capital costs

umptions: Conventional Upgrade - Necessary Upgrading Works

12 As the design hydraulic capacity of the plant will not change, checks on the Preliminary Treatment Units and Stormwater Holding Facilities will not require upsizing

13 Removal efficiencies in First Stage Units have been estimated at values shown in the design spreadsheets

14 Design Checks on peripheral channels on both First and Second Stage Clarifiers will not require modification

15 For improved nitrogen removal efficiencies in the main treatment process, the total volume in the aeration tanks will need to increase to approx. 14,000m3. This volume would include for both nitrification and denitrification zones

16 It is seen as prudent to include moveable baffles between VD and VN for future expansion

17 All existing tankage and equipment will be utilised.

18 Additional air blowers, sludge mixers, pumping equipment, etc. will be a necessity for the upgrade

19 Assume 2 nr. duty and 2 nr. standby blowers existing, each with motor size of 180kW. Noise control will be in the form of integrated acoustic hood on each proposed unit - also located in enclosed building

20 Existing sludge Handling equipment will be adequate to deal with upgraded works

21 The Final Clarifiers will be capable of handling the expected upgraded duty if the SVI has a value near 100 ml/g. In practice the SVI may be significantly higher at Dundalk. Retrofitting of lamellae plates would not be possible due the rotating bridge scrapers. For environmental reasons, dosing with chemical coagulants would not be favoured.

Option A – Cost Estimate
[Conventional Upgrade]

UPGRADE OF DUNDALK WWTP - CAPITAL WORKS
Cost Estimate (April 2010)

Description	Estimated Cost	Sub-total
Preliminaries		
General Items / Preliminaries (@20%)	€236,802.61	
		€236,802.61
Modification and/or Demolition of Existing Plant and Structures		
Flow Mixing Chamber modifications	€15,175.00	
Flow Splitting Chamber No.2 modifications	€12,000.00	
Pipelines and Underground Services	€23,050.00	
Modification (Demolition) of Existing Hardstands and Lighting	€3,500.00	
Upgrade of SCADA System	€25,000.00	
Upgrade to Electricity Supply (if necessary)	€12,000.00	
		€90,725.00
Protection and Diversion of Existing Services	€10,000.00	
		€10,000.00
Provision and Installation of Structures, Plant and Materials		
Additional Aeration/Anoxic Lanes - Civil Structures	€850,888.07	
Pipelines and Interconnecting Pipework	€40,000.00	
Diffused Aeration System	€22,000.00	
Additional Air Blower Units (2Nr. 180kW units reqd.)	€34,000.00	
Additional Sludge Mixers	€10,000.00	
…onal Sludge Handling Pumps	€22,700.00	
… Control	included	
		€979,588.07
…istration, Workshop and Ancillary Buildings		
…sion to Air Blower Building	not required	
…sion to Store	not required	
		€0.00
…frastructure		
…	€36,500.00	
…ge	€6,000.00	
…ains (extension of)	€5,000.00	
…g	€12,500.00	
Ducting	€10,000.00	
Landscaping	€10,000.00	
Miscellaneous Additional Items	€10,000.00	
		€90,000.00
Requirements of Employer's Representative		
Test in manufacturers works	€5,000.00	
Telephone/Fax Charges	€1,500.00	
Light and Heat Charges	€2,500.00	
Furniture, Equipment and Instrumentation	€1,200.00	
Progress Photographs	€1,000.00	
Computer System	€2,500.00	
		€13,700.00
Provisional Sums		
Archaeological Monitoring	not required	
		€0.00

Summary of Capital Works

General Items / Preliminaries (@20%)	€236,802.61
Modification and/or Demolition of Existing Plant and Structures	€90,725.00
Protection and Diversion of Existing Services	€10,000.00
Provision and Installation of Structures, Plant and Materials	€979,588.07
Administration, Workshop and Ancillary Buildings	€0.00
Site Infrastructure	€90,000.00
Requirements of Employer's Representative	€13,700.00
Provisional Sums	€0.00
Total Estimated Cost of Capital Works	**€1,420,815.68**

Tests on Completion

SCADA System	€2,500.00	
Aeration System	€4,200.00	
Biological Treatment Process (process commissioning)	€10,000.00	
Preparation of presentation of test data	€1,000.00	
Training of Plant Operatives	€5,000.00	
Total Estimated Cost of Tests on Completion		**€22,700.00**

SUMMARY

Capital Works	€1,420,815.68
Tests on Completion	€22,700.00
TOTAL ESTIMATED COST OF CONSTRUCTION (Excluding VAT)	**€1,443,515.68**

UPGRADE OF DUNDALK WWTP - PLANNING & SUPERVISION COSTS
Cost Estimate (April 2010)

Description	Estimated Cost	Sub-total
Planning Expenditure		
Detailed Design	€20,794.39	
Addendum to Contract Documents	€44,209.71	
Site Investigations (on aeration basin footprint)	€10,000.00	
Resident Staff on Site Investigations	€2,500.00	
Advertising/Publicity	€3,000.00	
Legal Expenses	€3,500.00	
Other	€4,000.00	
Total for Planning Expenditure (Exclusive of VAT)		€88,004.10
Construction Supervision Expenditure		
Resident Engineering Staff	€25,000.00	
Project Supervision	€65,004.09	
Legal Expenses	€2,000.00	
Total for Construction Expenditure (Exclusive of VAT)		€92,004.09
Total Cost of Planning and Supervision Costs (Exclusive of VAT)		**€180,008.19**
Employer Overheads		
...ntage of Capital Costs (Treatment Works Construction Costs) ...ed to represent employer		2.00%
... for Employers Overheads (Exclusive of VAT)		**€28,870.31**

UPGRADE OF DUNDALK WWTP - ESTIMATED OPERATIONAL COSTS (APPORTIONMENT TO UPGRADE ONLY)
Cost Estimate (April 2010)

Description	Fixed Costs	Variable Costs	Total Costs
Labour (Incl. PRSI, Overtime & Allowances)	€20,000.00		€20,000.00
DBO Contractor Overheads	€12,000.00		€12,000.00
PMS (Procedure Monthly Status Reporting)	€8,000.00		€8,000.00
Materials (Additional Bulkfloc to aeration, etc.)		€15,000.00	€15,000.00
Electricity Supply		€166,243.40	€166,243.40
Miscellaneous		€7,500.00	€7,500.00
Total Operational Costs (Excl. VAT)	**€40,000.00**	**€188,743.40**	**€228,743.40**

UPGRADE OF DUNDALK WWTP - ESTIMATED PLANT REPLACEMENT COSTS (APPORTIONMENT TO UPGRADE ONLY)

Cost Estimate (April 2010)

SCHEDULE OF CAPITAL REPLACEMENT

Description	Estimated Cost	Year 1	2	3	4	5	6	7	8	9	10
Actuated Valves	€2,800.00									€2,800.00	
Air Blower No. 1	€17,000.00										
Air Blower No. 2	€17,000.00									€17,000.00	
Air Compressor	€5,100.00										
Internal MLSS Recirculation Pump No. 1	€3,000.00						€3,000.00				
Internal MLSS Recirculation Pump No.2	€3,000.00										
Aeration Basin Scour Pump No. 1	€1,900.00										€1,900.00
Aeration Basin Scour Pump No. 2	€1,900.00										
Aeration Basin Scour Pump No. 3	€1,900.00										
rn Activated Sludge Pump No. 1	€4,500.00										
rn Activated Sludge Pump No. 2	€4,500.00										
lus Activated Sludge Pump No. 1	€1,000.00										€1,000.00
lus Activated Sludge Pump No. 2	€1,000.00										
ic Tank Sludge Mixer No. 1	€3,000.00							€3,000.00			
ic Tank Sludge Mixer No. 2	€3,000.00										
ic Tank Sludge Mixer No. 3	€3,000.00										
trical Panel Components	€1,000.00					€1,000.00					
umentation Replacement	€3,000.00					€3,000.00					
l		**€0.00**	**€0.00**	**€0.00**	**€0.00**	**€4,000.00**	**€3,000.00**	**€3,000.00**	**€0.00**	**€19,800.00**	**€2,900.00**

Discount Rate 5.00%

	Year 0 2010	Year 1 2011	Year 2 2012	Year 3 2013	Year 4 2014	Year 5 2015	Year 6 2016	Year 7 2017	Year 8 2018	Year 9 2019	Year 10 2020
Inflation Rate	1.00%	1.00%	1.00%	1.00%	1.50%	2.00%	2.00%	2.00%	2.50%	2.50%	3.00%
Cumulative Inflation Rate	100.00%	101.00%	102.01%	103.03%	104.06%	105.62%	107.73%	109.89%	112.09%	114.89%	117.76%

Costs - Nominal

			Year 0 2010	Year 1 2011	Year 2 2012	Year 3 2013	Year 4 2014	Year 5 2015	Year 6 2016	Year 7 2017	Year 8 2018	Year 9 2019	Year 10 2020
Capital Costs	Total NPV	Total Cost											
Construction Works	€1,388,524.61	€1,457,950.84		€1,457,950.84									
Planning & Supervision	€168,098.35	€180,928.23	€88,004.10	€92,924.13									
Employer Overheads	€27,770.49	€29,159.02		€29,159.02									
Plant Replacement Costs	€31,193.50	€36,916.46						€4,224.85	€3,232.01	€3,296.65		€22,747.89	€3,415.06
Total (a)	**€1,615,586.95**	**€1,704,954.55**	**€88,004.10**	**€1,580,033.99**	**€0.00**	**€0.00**	**€0.00**	**€4,224.85**	**€3,232.01**	**€3,296.65**	**€0.00**	**€22,747.89**	**€3,415.06**
ating Costs	Total NPV	Total Cost											
ır	€166,819.40	€217,569.96		€20,200.00	€20,606.02	€20,812.08	€21,020.20	€21,335.50	€21,762.21	€22,197.46	€22,641.41	€23,207.44	€23,787.63
Contractor Overheads	€100,091.64	€130,541.97		€12,120.00	€12,363.61	€12,487.25	€12,612.12	€12,801.30	€13,057.33	€13,318.48	€13,584.84	€13,924.47	€14,272.58
	€66,727.76	€87,027.98		€8,080.00	€8,242.41	€8,324.83	€8,408.08	€8,534.20	€8,704.89	€8,878.98	€9,056.56	€9,282.98	€9,515.05
ials	€125,114.55	€163,177.47		€15,150.00	€15,454.52	€15,609.06	€15,765.15	€16,001.63	€16,321.66	€16,648.09	€16,981.06	€17,405.58	€17,840.72
icity Supply	€1,386,631.18	€1,808,478.47		€167,905.83	€171,280.74	€172,993.55	€174,723.48	€177,344.34	€180,891.22	€184,509.05	€188,199.23	€192,904.21	€197,726.81
llaneous	€62,557.27	€81,588.73		€7,575.00	€7,727.26	€7,804.53	€7,882.58	€8,000.81	€8,160.83	€8,324.05	€8,490.53	€8,702.79	€8,920.36
(b)	**€1,907,941.80**	**€2,488,384.58**		**€231,030.83**	**€235,674.55**	**€238,031.30**	**€240,411.61**	**€244,017.79**	**€248,898.14**	**€253,876.11**	**€258,953.63**	**€265,427.47**	**€272,063.15**
Cost of Project (a + b)	€3,523,528.75	€4,193,339.13											
NPV of the Project	**€3,523,528.75**												

Option B – Cost Estimate
['SHARON' System]

UPGRADE OF DUNDALK WWTP - CAPITAL WORKS - SHARON SYSTEM
Cost Estimate (April 2010)

Description	Estimated Cost	Sub-total
Preliminaries		
General Items / Preliminaries (@20%)	€80,234.95	
		€80,234.95
Modification and/or Demolition of Existing Plant and Structures		
Modifications at pipework. Divert to SHARON System	€12,000.00	
Pipelines and Underground Services	€7,000.00	
Modification (Demolition) of Existing Hardstands and Lighting	€3,500.00	
Upgrade of SCADA System	€35,000.00	
Upgrade to Electricity Supply (if necessary)	€12,000.00	
		€69,500.00
Protection and Diversion of Existing Services	€10,000.00	
		€10,000.00
Provision and Installation of Structures, Plant and Materials		
Additional Aeration/Anoxic Lanes - Civil Structures	€148,974.73	
Pipelines and Interconnecting Pipework	€25,000.00	
Diffused Aeration System	€7,500.00	
Additional Air Blower Units (2Nr. 50kW units reqd.)	€16,500.00	
Additional Sludge Mixers	€8,000.00	
In-line Centrate Pump (Duty/Standby)	€8,000.00	
Upgrade to Condensate Pumps (Duty/Standby)	€10,000.00	
...ol Storage Unit and Dosing System (provisional)	€8,000.00	
...xchanger - Cooling System (provisional	€15,000.00	
... Inlet Screen	€2,000.00	
...ontrol	included	
		€248,974.73
...stration, Workshop and Ancillary Buildings		
...on to Air Blower Building	not required	
...on to Store	not required	
		€0.00
...rastructure		
	€20,000.00	
...ge	€6,000.00	
Fire Mains (extension of)	€5,000.00	
Lighting	€6,000.00	
Ducting	€5,000.00	
Landscaping	€5,000.00	
Miscellaneous Additional Items	€10,000.00	
		€57,000.00
Requirements of Employer's Representative		
Test in manufacturers works	€7,000.00	
Telephone/Fax Charges	€1,500.00	
Light and Heat Charges	€2,500.00	
Furniture, Equipment and Instrumentation	€1,200.00	
Progress Photographs	€1,000.00	
Computer System.	€2,500.00	
		€15,700.00
Provisional Sums		
Archaeological Monitoring	not required	
		€0.00

Summary of Capital Works		
General Items / Preliminaries (@20%)		€80,234.95
Modification and/or Demolition of Existing Plant and Structures		€69,500.00
Protection and Diversion of Existing Services		€10,000.00
Provision and Installation of Structures, Plant and Materials		€248,974.73
Administration, Workshop and Ancillary Buildings		€0.00
Site Infrastructure		€57,000.00
Requirements of Employer's Representative		€15,700.00
Provisional Sums		€0.00
Total Estimated Cost of Capital Works		**€481,409.67**

Tests on Completion		
SCADA System	€2,500.00	
Aeration System	€3,000.00	
Biological Treatment Process (process commissioning)	€20,000.00	
Preparation of presentation of test data	€1,000.00	
Training of Plant Operatives	€5,000.00	
Total Estimated Cost of Tests on Completion		**€31,500.00**

SUMMARY	
Capital Works	€481,409.67
Tests on Completion	€31,500.00
ESTIMATED COST OF CONSTRUCTION (Excluding VAT)	**€512,909.67**

UPGRADE OF DUNDALK WWTP - PLANNING & SUPERVISION COSTS - SHARON SYSTEM
Cost Estimate (April 2010)

Description	Estimated Cost	Sub-total
Planning Expenditure		
Detailed Design (Patent Holders - Fee)	€30,000.00	
Design Fee Civil Elements	€9,139.59	
Addendum to Contract Documents	€16,107.88	
Site Investigations (on tank footprint)	€8,000.00	
Resident Staff on Site Investigations	€2,500.00	
Advertising/Publicity	€3,000.00	
Legal Expenses	€3,500.00	
Other	€4,000.00	
Total for Planning Expenditure (Exclusive of VAT)		€76,247.48
Construction Supervision Expenditure		
Resident Engineering Staff	€25,000.00	
Project Supervision	€25,247.48	
Legal Expenses	€2,000.00	
Total for Construction Expenditure (Exclusive of VAT)		€52,247.48
Total Cost of Planning and Supervision Costs (Exclusive of VAT)		**€128,494.95**
Employer Overheads		
...age of Capital Costs (Treatment Works Construction Costs) assumed to ...nt employer		2.00%
...r Employers Overheads (Exclusive of VAT)		**€10,258.19**

UPGRADE OF DUNDALK WWTP - ESTIMATED OPERATIONAL COSTS (APPORTIONMENT TO UPGRADE ONLY)
Cost Estimate (April 2010)

Description	Fixed Costs	Variable Costs	Total Costs
Labour (Incl. PRSI, Overtime & Allowances)	€25,000.00		€25,000.00
DBO Contractor Overheads	€12,000.00		€12,000.00
PMS (Procedure Monthly Status Reporting)	€8,000.00		€8,000.00
Materials (methanol - provisional.)		€15,000.00	€15,000.00
Electricity Supply		€17,470.24	€17,470.24
Miscellaneous		€7,500.00	€7,500.00
Total Operational Costs (Excl. VAT)	**€45,000.00**	**€39,970.24**	**€84,970.24**

UPGRADE OF DUNDALK WWTP - ESTIMATED PLANT REPLACEMENT COSTS (APPORTIONMENT TO UPGRADE ONLY)

Cost Estimate (April 2010)

SCHEDULE OF CAPITAL REPLACEMENT

Description	Estimated Cost	Year 1	2	3	4	5	6	7	8	9	10
Actuated Valves	€2,800.00									€2,800.00	
Air Blower No. 1	€8,250.00										
Air Blower No. 2	€8,250.00									€8,250.00	
Air Compressor	€4,000.00										
Centrate Pump No. 1	€4,000.00						€4,000.00				
Centrate Pump No.2	€4,000.00										
Condensate Pump No. 1	€5,000.00										€5,000.00
Condensate Pump No. 2	€5,000.00										
Anoxic Tank Sludge Mixer No. 1	€2,650.00							€2,650.00			
...ic Tank Sludge Mixer No. 2	€2,650.00										
...ion Tank Sludge Mixer No. 1	€2,650.00										
...ical Panel Components	€1,000.00					€1,000.00					
...mentation Replacement	€3,000.00					€3,000.00					
... Exchanger Parts	€5,000.00								€5,000.00		
...se Screen	€2,000.00										
...anol Dosing Pump	€1,800.00										
		€0.00	**€0.00**	**€0.00**	**€0.00**	**€4,000.00**	**€4,000.00**	**€2,650.00**	**€5,000.00**	**€11,050.00**	**€5,000.00**

			Year 0 2010	Year 1 2011	Year 2 2012	Year 3 2013	Year 4 2014	Year 5 2015	Year 6 2016	Year 7 2017	Year 8 2018	Year 9 2019	Year 10 2020
Discount Rate 5.00%													
Inflation Rate			1.00%	1.00%	1.00%	1.00%	1.50%	2.00%	2.00%	2.00%	2.50%	2.50%	3.00%
Cumulative Inflation Rate			100.00%	101.00%	102.01%	103.03%	104.06%	105.62%	107.73%	109.89%	112.09%	114.89%	117.76%
Costs - Nominal													
Capital Costs	Total NPV	Total Cost											
Construction Works	€493,370.26	€518,038.77		€518,038.77									
Planning & Supervision	€120,480.55	€129,017.43	€76,247.48	€52,769.95									
Employer Overheads	€9,867.41	€10,360.78		€10,360.78									
Plant Replacement Costs	€29,399.31	€35,633.74						€4,224.85	€4,309.35	€2,912.04	€5,604.31	€12,695.16	€5,888.03
Total (a)	**€653,117.53**	**€693,050.72**	**€76,247.48**	**€581,169.50**	**€0.00**	**€0.00**	**€0.00**	**€4,224.85**	**€4,309.35**	**€2,912.04**	**€5,604.31**	**€12,695.16**	**€5,888.03**
...ting Costs	Total NPV	Total Cost											
...r	€208,524.25	€271,962.45		€25,250.00	€25,757.53	€26,015.10	€26,275.25	€26,669.38	€27,202.77	€27,746.82	€28,301.76	€29,009.30	€29,734.54
Contractor Overheads	€100,091.64	€130,541.97		€12,120.00	€12,363.61	€12,487.25	€12,612.12	€12,801.30	€13,057.33	€13,318.48	€13,584.84	€13,924.47	€14,272.58
	€66,727.76	€87,027.98		€8,080.00	€8,242.41	€8,324.83	€8,408.08	€8,534.20	€8,704.89	€8,878.98	€9,056.56	€9,282.98	€9,515.05
...ials	€125,114.55	€163,177.47		€15,150.00	€15,454.52	€15,609.06	€15,765.15	€16,001.63	€16,321.66	€16,648.09	€16,981.06	€17,405.58	€17,840.72
...icity Supply	€145,718.73	€190,049.94		€17,644.94	€17,999.60	€18,179.60	€18,361.40	€18,636.82	€19,009.55	€19,389.74	€19,777.54	€20,271.98	€20,778.78
...llaneous	€62,557.27	€81,588.73		€7,575.00	€7,727.26	€7,804.53	€7,882.58	€8,000.81	€8,160.83	€8,324.05	€8,490.53	€8,702.79	€8,920.36
(b)	**€708,734.20**	**€924,348.55**		**€85,819.94**	**€87,544.92**	**€88,420.37**	**€89,304.57**	**€90,644.14**	**€92,457.03**	**€94,306.17**	**€96,192.29**	**€98,597.10**	**€101,062.02**
Cost of Project (a + b)	€1,361,851.73	€1,617,399.27											
NPV of the Project	$\boxed{€1,361,851.73}$												

Option C – Cost Estimate
[Combined 'SHARON'/'ANAMMOX' System]

UPGRADE OF DUNDALK WWTP - CAPITAL WORKS - COMBINED SHARON/ANAMMOX SYSTEM
Cost Estimate (April 2010)

Description	Estimated Cost	Sub-total
Preliminaries		
General Items / Preliminaries (@20%)	€88,794.19	
		€88,794.19
Modification and/or Demolition of Existing Plant and Structures		
Modifications at pipework. Divert to SHARON/ANAMMOX System	€12,000.00	
Pipelines and Underground Services	€7,000.00	
Modification (Demolition) of Existing Hardstands and Lighting	€3,500.00	
Upgrade of SCADA System	€35,000.00	
Upgrade to Electricity Supply (if necessary)	€12,000.00	
		€69,500.00
Protection and Diversion of Existing Services	€10,000.00	
		€10,000.00
Provision and Installation of Structures, Plant and Materials		
Additional Aeration/Anoxic Lanes - Civil Structures	€124,770.93	
Granular sludge media	€10,000.00	
Pipelines and Interconnecting Pipework	€25,000.00	
Aeration System	€7,500.00	
Additional Air Blower Units (2Nr. 50kW units reqd.)	€16,500.00	
Additional Sludge Mixers	€8,000.00	
In-line Centrate Pump (Duty/Standby)	€8,000.00	
le to Condensate Pumps (Duty/Standby)	€10,000.00	
trol - dosing system (provisional)	€12,000.00	
xchanger - Cooling System (provisional)	€15,000.00	
Inlet Screen	€2,000.00	
nium-Nitrite Monitoring System x 2	€50,000.00	
Control	included	
		€288,770.93
stration, Workshop and Ancillary Buildings		
ion to Air Blower Building	not required	
ion to Store	not required	
		€0.00
rastructure		
Roads	€20,000.00	
Drainage	€6,000.00	
Fire Mains (extension of)	€5,000.00	
Lighting	€6,000.00	
Ducting	€5,000.00	
Landscaping	€5,000.00	
Miscellaneous Additional Items	€10,000.00	
		€57,000.00
Requirements of Employer's Representative		
Test in manufacturers works	€10,000.00	
Telephone/Fax Charges	€1,500.00	
Light and Heat Charges	€2,500.00	
Furniture, Equipment and Instrumentation	€1,200.00	
Progress Photographs	€1,000.00	
Computer System.	€2,500.00	
		€18,700.00
Provisional Sums		
Archaeological Monitoring	not required	
		€0.00

Summary of Capital Works		
General Items / Preliminaries (@20%)		€88,794.19
Modification and/or Demolition of Existing Plant and Structures		€69,500.00
Protection and Diversion of Existing Services		€10,000.00
Provision and Installation of Structures, Plant and Materials		€288,770.93
Administration, Workshop and Ancillary Buildings		€0.00
Site Infrastructure		€57,000.00
Requirements of Employer's Representative		€18,700.00
Provisional Sums		€0.00
Total Estimated Cost of Capital Works		**€532,765.11**
Tests on Completion		
SCADA System	€2,500.00	
Aeration System	€3,000.00	
Biological Treatment Process (process commissioning)	€25,000.00	
Preparation of presentation of test data	€1,000.00	
Training of Plant Operatives	€5,000.00	
Total Estimated Cost of Tests on Completion		**€36,500.00**

SUMMARY

Capital Works	€532,765.11
Tests on Completion	€36,500.00
ESTIMATED COST OF CONSTRUCTION (Excluding VAT)	**€569,265.11**

UPGRADE OF DUNDALK WWTP - PLANNING & SUPERVISION COSTS - SHARON/ANAMMOX SYSTEM
Cost Estimate (April 2010)

Description	Estimated Cost	Sub-total
Planning Expenditure		
Detailed Design (Patent Holders - Fee)	€50,000.00	
Design Fee Civil Elements	€10,031.37	
Addendum to Contract Documents	€16,733.85	
Site Investigations (on tank footprint)	€8,000.00	
Resident Staff on Site Investigations	€2,500.00	
Advertising/Publicity	€3,000.00	
Legal Expenses	€3,500.00	
Other	€4,000.00	
Total for Planning Expenditure (Exclusive of VAT)		€97,765.22
Construction Supervision Expenditure		
Resident Engineering Staff	€25,000.00	
Project Supervision	€26,765.22	
Legal Expenses	€2,000.00	
Total for Construction Expenditure (Exclusive of VAT)		€53,765.22
Total Cost of Planning and Supervision Costs (Exclusive of VAT)		**€151,530.44**
Employer Overheads		
age of Capital Costs (Treatment Works Construction Costs) assumed to nt employer		2.00%
r Employers Overheads (Exclusive of VAT)		**€11,385.30**

UPGRADE OF DUNDALK WWTP - ESTIMATED OPERATIONAL COSTS FOR 2011 (APPORTIONMENT TO UPGRADE ONLY)
Cost Estimate (April 2010)

Description	Fixed Costs	Variable Costs	Total Costs
Labour (Incl. PRSI, Overtime & Allowances)	€25,000.00		€25,000.00
DBO Contractor Overheads	€12,000.00		€12,000.00
PMS	€8,000.00		€8,000.00
Materials (acid, base addition, etc.)		€16,700.00	€16,700.00
Electricity Supply		€11,646.83	€11,646.83
Miscellaneous		€7,500.00	€7,500.00
Total Operational Costs (Excl. VAT)	**€45,000.00**	**€35,846.83**	**€80,846.83**

UPGRADE OF DUNDALK WWTP - ESTIMATED PLANT REPLACEMENT COSTS (APPORTIONMENT TO UPGRADE ONLY)

Cost Estimate (April 2010)

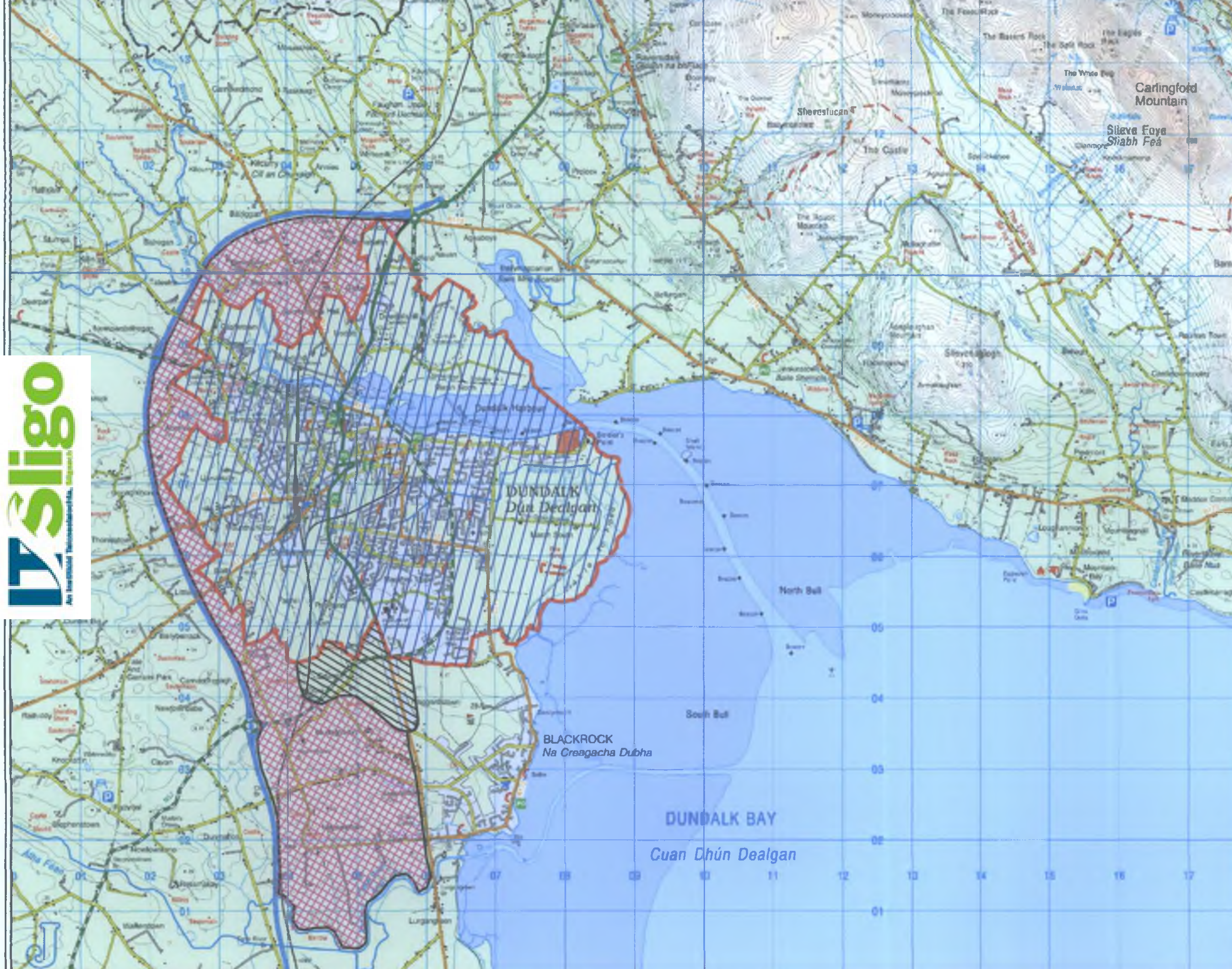
SCHEDULE OF CAPITAL REPLACEMENT

Description	Estimated Cost	Year 1	2	3	4	5	6	7	8	9	10
Actuated Valves	€2,800.00									€2,800.00	
Air Blower No. 1	€8,250.00										
Air Blower No. 2	€8,250.00									€8,250.00	
Air Compressor	€4,000.00										
Centrate Pump No. 1	€4,000.00						€4,000.00				
Centrate Pump No.2	€4,000.00										
Condensate Pump No. 1	€5,000.00										€5,000.00
Condensate Pump No. 2	€5,000.00										
Anoxic Tank Sludge Mixer No. 1	€2,650.00							€2,650.00			
A...ic Tank Sludge Mixer No. 2	€2,650.00										
...on Tank Sludge Mixer No. 1	€2,650.00										
...ical Panel Components	€1,000.00					€1,000.00					
...mentation Replacement	€6,000.00					€6,000.00					
...Exchanger Parts	€5,000.00								€5,000.00		
...e Screen	€2,000.00										
...osing Pump	€1,000.00										
		€0.00	**€0.00**	**€0.00**	**€0.00**	**€7,000.00**	**€4,000.00**	**€2,650.00**	**€5,000.00**	**€11,050.00**	**€5,000.00**

	Total NPV	Total Cost	Year 0 2010	Year 1 2011	Year 2 2012	Year 3 2013	Year 4 2014	Year 5 2015	Year 6 2016	Year 7 2017	Year 8 2018	Year 9 2019	Year 10 2020
Discount Rate 5.00%													
Inflation Rate			1.00%	1.00%	1.00%	1.00%	1.50%	2.00%	2.00%	2.00%	2.50%	2.50%	3.00%
Cumulative Inflation Rate			100.00%	101.00%	102.01%	103.03%	104.06%	105.62%	107.73%	109.89%	112.09%	114.89%	117.76%
Costs - Nominal													
Capital Costs	Total NPV	Total Cost											
Construction Works	€547,578.82	€574,957.76		€574,957.76									
Planning & Supervision	€142,364.04	€152,068.09	€97,765.22	€54,302.87									
Employer Overheads	€10,951.58	€11,499.16		€11,499.16									
Plant Replacement Costs	€32,417.06	€38,802.38						€7,393.49	€4,309.35	€2,912.04	€5,604.31	€12,695.16	€5,888.03
Total (a)	**€733,311.50**	**€777,327.39**	**€97,765.22**	**€640,759.79**	**€0.00**	**€0.00**	**€0.00**	**€7,393.49**	**€4,309.35**	**€2,912.04**	**€5,604.31**	**€12,695.16**	**€5,888.03**
ating Costs	Total NPV	Total Cost											
r	€208,524.25	€271,962.45		€25,250.00	€25,757.53	€26,015.10	€26,275.25	€26,669.38	€27,202.77	€27,746.82	€28,301.76	€29,009.30	€29,734.54
Contractor Overheads	€100,091.64	€130,541.97		€12,120.00	€12,363.61	€12,487.25	€12,612.12	€12,801.30	€13,057.33	€13,318.48	€13,584.84	€13,924.47	€14,272.58
	€66,727.76	€87,027.98		€8,080.00	€8,242.41	€8,324.83	€8,408.08	€8,534.20	€8,704.89	€8,878.98	€9,056.56	€9,282.98	€9,515.05
ials	€139,294.20	€181,670.91		€16,867.00	€17,206.03	€17,378.09	€17,551.87	€17,815.15	€18,171.45	€18,534.88	€18,905.58	€19,378.21	€19,862.67
icity Supply	€97,145.82	€126,699.96		€11,763.29	€11,999.74	€12,119.73	€12,240.93	€12,424.54	€12,673.04	€12,926.50	€13,185.03	€13,514.65	€13,852.52
llaneous	€62,557.27	€81,588.73		€7,575.00	€7,727.26	€7,804.53	€7,882.58	€8,000.81	€8,160.83	€8,324.05	€8,490.53	€8,702.79	€8,920.36
(b)	**€674,340.94**	**€879,492.01**		**€81,655.29**	**€83,296.56**	**€84,129.53**	**€84,970.83**	**€86,245.39**	**€87,970.30**	**€89,729.70**	**€91,524.30**	**€93,812.40**	**€96,157.71**
Cost of Project (a + b)	€1,407,652.44	€1,656,819.40											
NPV of the Project	**€1,407,652.44**												

Appendix H

[Map of Dundalk Agglomeration and waste water treatment plant location
Layout plan of Dundalk WWTP.]



TREATMENT WORKS

DUNDALK TOWN BOUNDARY

EXISTING AGGLOMERATIONS

(DUNDALK TOWN) LOUTH CO. CO. WATER SERVICES AUTHORITY

LOUTH CO. CO. WATER SERVICES AUTHORITY

PROPOSED AGGLOMERATIONS

LOUTH CO. CO. WATER SERVICES AUTHORITY

NOTES

1. FIGURED DIMENSIONS ONLY TO BE TAKEN FROM THIS DRAWING
2. ALL DRAWINGS TO BE CHECKED BY THE CONTRACTOR ON SITE
3. ENGINEER TO BE INFORMED BY THE CONTRACTOR OF ANY DISCREPANCIES BEFORE ANY WORK COMMENCES
4. ALL LEVELS SHOWN RELATE TO ORDNANCE SURVEY DATUM AT MALIN HEAD

Rev	Date	Description	By	Chkd

Client: LOUTH COUNTY COUNCIL

Project: DUNDALK WASTE WATER DISCHARGE LICENCE APPLICATION

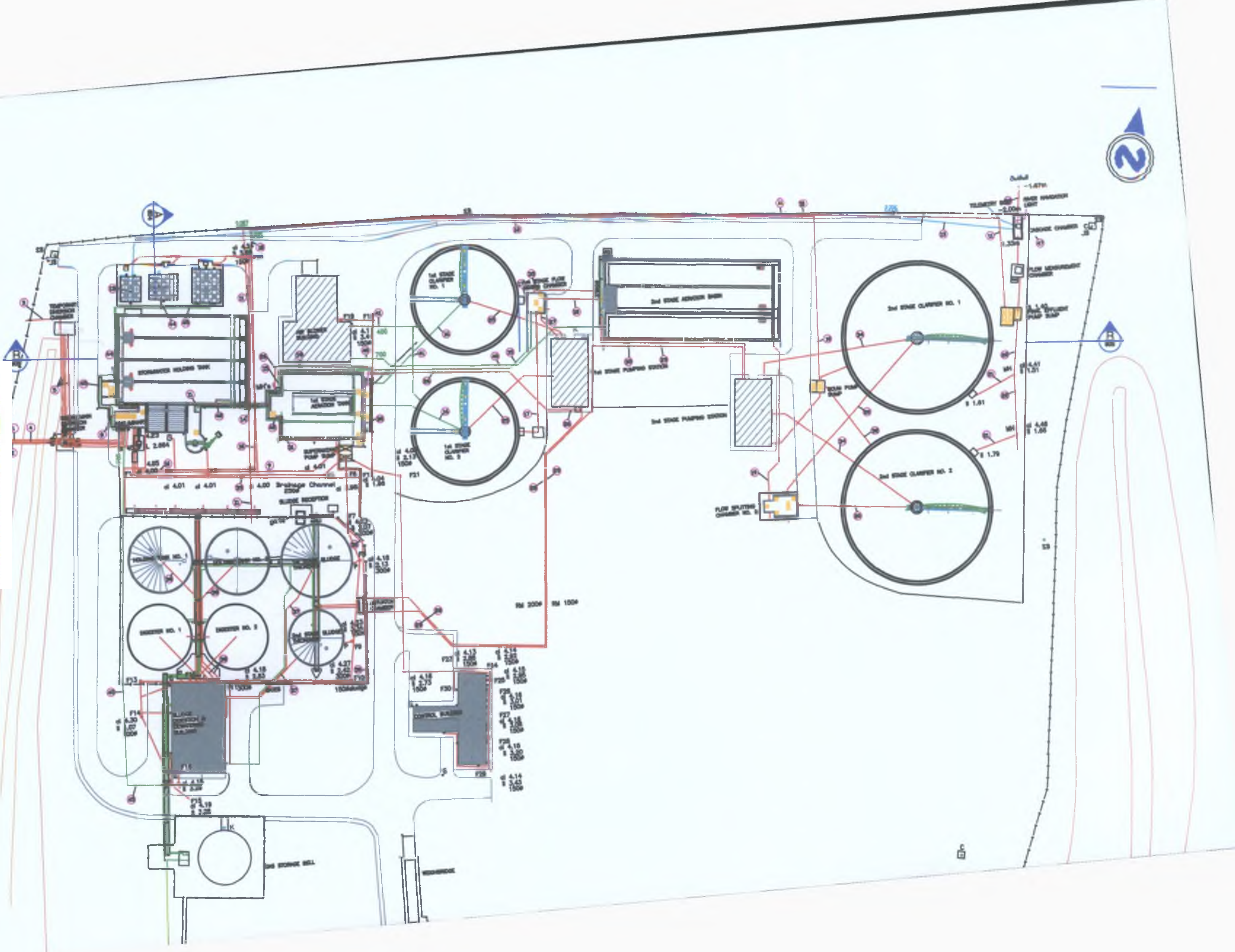
Title: AGGLOMERATE EXTENT & BOUNDARY SHOWING LOCAL AUTHORITY AREAS & WWTP LOCATION (NON-TECHNICAL SUMMARY)

Scale @ A3:	1 : 50,000	
Prepared by: R.K.	Checked: E.S.	Date: DEC '07
Project Director:	MICHAEL F. GARRICK	

TOBIN

TOBIN Consulting Engineers, Market Square, Castlebar, Co. Mayo, Ireland.

Drawing No.: FIGURE 1 | Revision: A



2nd STAGE CLARIFIER NO. 1
2nd STAGE CLARIFIER NO. 2
2nd STAGE AERATION BASIN
STORMWATER HOLDING TANK
Drainage Channel
CONTROL BUILDING
DIGESTER NO. 1
GAS STORAGE BELL
WEIGHBRIDGE

Appendix I

[2009 Monitoring Data for Influent and Effluent at Dundalk Waste Water Treatment Plant.]

Dundalk WWTW 2009

					Influent analysis results						Final Effluent analysis results					
Date	Inlet Flow (m^3)	Influent BOD load	Supernatent Flow (m^3)	Outlet Flow (m^3)	BOD mg/l O_2	COD mg/l O_2	pH	SS mg/l	TN mg/l N	TP mg/l P	BOD (mg/l O_2)	COD (mg/l O_2)	pH	SS (mg/l)	TN (mg/l N)	TP (mg/l P)
1-Jan-2009	19406		947	15383		446						22				
2-Jan-2009	20222		1434	15879		333						21				
3-Jan-2009	19413	3649.644	809	15372	188	532		242			1.7	18		1		
4-Jan-2009	19932		1018	15681		342						13				
5-Jan-2009	20946		1050	16122		392	7.51					21	7.44			
6-Jan-2009	20210		1292	16112		543	7.29					19	7.49			
7-Jan-2009	19881	5089.536	729	16090	256	556	6.54	514			3.1	21	7.48	2	27.1	5.2
8-Jan-2009	19904		750	16131		524	7.19					21	7.5			
9-Jan-2009	20493		723	16275		486	7.11					22	7.36			
10-Jan-2009	18847		1315	11500		660						20				
11-Jan-2009	26148	7504.476	739	11033	287	676					3	21		9		
12-Jan-2009	29504		715	11976		519						35				
13-Jan-2009	21732		1190	9535		377						27				
14-Jan-2009	32104		2065	12094		358	7.12					26	7.35			
15-Jan-2009	30469	10786.026	621	12682	354	808	7.05	489			21.15	65	6.97	46.5	15	3.57
16-Jan-2009	25270		784	12243		374	6.81					27	7.01			
17-Jan-2009	30727	6176.127	1136	18423	201	461		173			3.6	20		5		
18-Jan-2009	26471		821	21748		235						22				
19-Jan-2009	27883		852	22347		230	7.41					17	7.48			
20-Jan-2009	27222		898	22419		295	7.01					17	7.14			
21-Jan-2009	27869		750	23236		315	7.37					21	7.45			
22-Jan-2009	36010		1234	33267		315	6.84					95	6.99			
23-Jan-2009	25770	3865.5	546	22687	150	275	7.33	59			6.1	21	7.34	4	9.9	2.08
24-Jan-2009	24660		639	20632		286						35				
25-Jan-2009	26139	4391.352	623	15611	168	515		128			18.3	53		19.5		
26-Jan-2009	23813	3548.137	521	16555	149	361		103			10	41		6		
27-Jan-2009	30207		1178	25701		395						72				
28-Jan-2009	26044		1471	21191		384						62				
29-Jan-2009	26511		1392	20069		379	7.08					49	7.32			
30-Jan-2009	30870		1160	22153								136				
31-Jan-2009	47645		1513	43546		466						496				

Dundalk WWTW 2009

Date	Inlet Flow (m^3)	Influent BOD load	Supernatent Flow (m^3)	Outlet Flow (m^3)
1-Feb-2009	40510	2916.72	644	37239
2-Feb-2009	31082		274	28558
3-Feb-2009	42045	5213.58	1223	36734
4-Feb-2009	35386		1121	32713
5-Feb-2009	34615		1228	31713
6-Feb-2009	31375		1009	28978
7-Feb-2009	27357	2544.201	1304	25512
8-Feb-2009	29202		831	24142
9-Feb-2009	28512		960	19017
10-Feb-2009	27433		1488	17498
11-Feb-2009	26301	4142.4075	1252	16704
12-Feb-2009	26867		1441	16876
13-Feb-2009	25177		1179	14577
14-Feb-2009	23813		1355	17197
15-Feb-2009	22860	6858	1086	19247
16-Feb-2009	22827		931	20190
17-Feb-2009	22747		1380	20810
18-Feb-2009	23202	10371.294	1361	21131
19-Feb-2009	23662	9015.222	1874	21930
20-Feb-2009	21926		1663	20234
21-Feb-2009	20661	4338.81	1348	19249
22-Feb-2009	20141		1490	18507
23-Feb-2009	21371		1325	19649
24-Feb-2009	20627		1633	18515
25-Feb-2009	20667		811	18486
26-Feb-2009	20787		1550	17602
27-Feb-2009	21255	5738.85	1236	16433
28-Feb-2009	20351		1480	15315

Influent analysis results

Date	BOD mg/l O_2	COD mg/l O_2	pH	SS mg/l	TN mg/l N	TP mg/l P
1-Feb-2009	72	134		68		
2-Feb-2009		145	7.61			
3-Feb-2009	124	260	8.17	151		
4-Feb-2009		218	7.06			
5-Feb-2009		209	7.51			
6-Feb-2009		243	7.17			
7-Feb-2009	93	222		78		
8-Feb-2009		337				
9-Feb-2009		258	7.11			
10-Feb-2009		389	6.95			
11-Feb-2009	157.5	302	6.98	116		
12-Feb-2009		418	7.22			
13-Feb-2009		396	7.22			
14-Feb-2009		617				
15-Feb-2009	300	831		442		
16-Feb-2009		492	7.75			
17-Feb-2009		676	7.11			
18-Feb-2009	447	949	7.14	476		
19-Feb-2009	381	821	7.25	536		
20-Feb-2009		512	7.23			
21-Feb-2009	210	601		278		
22-Feb-2009		552				
23-Feb-2009		553	8.01			
24-Feb-2009		951	7.31			
25-Feb-2009		694	7.22			
26-Feb-2009		561	7.33			
27-Feb-2009	270	627	7.06	290		
28-Feb-2009		615				

Final Effluent analysis results

Date	BOD (mg/l O_2)	COD (mg/l O_2)	pH	SS (mg/l)	TN (mg/l N)	TP (mg/l P)
1-Feb-2009	20.25	61		41		
2-Feb-2009		32	7.72			
3-Feb-2009	12.3	38	7.37	21.5	14.5	1.36
4-Feb-2009		95	7.17			
5-Feb-2009		18	7.57			
6-Feb-2009		20	7.22			
7-Feb-2009	6.3	23		7.5		
8-Feb-2009		23				
9-Feb-2009		23	7.29			
10-Feb-2009		20	7.06			
11-Feb-2009	4.6	19	7.08	6	11.2	1.1
12-Feb-2009		34	7.45			
13-Feb-2009		37	7.17			
14-Feb-2009		39				
15-Feb-2009	5.4	36		5.5		
16-Feb-2009		35	7.76			
17-Feb-2009		31	7.35			
18-Feb-2009	6.7	28	7.22	7.5		
19-Feb-2009	6.9	37	7.38	6	14.5	4
20-Feb-2009		46	7.42			
21-Feb-2009	5.2	40		4		
22-Feb-2009		33				
23-Feb-2009		35	8.25			
24-Feb-2009		29	7.71			
25-Feb-2009		33	7.38			
26-Feb-2009		25	7.48			
27-Feb-2009	5.6	38	7.24	4	17.1	3.16
28-Feb-2009		39				

Dundalk WWTW 2009

Date	Inlet Flow (m^3)	Influent BOD load	Supernatent Flow (m^3)	Outlet Flow (m^3)	Influent analysis results						Final Effluent analysis results					
					BOD mg/l O_2	COD mg/l O_2	pH	SS mg/l	TN mg/l N	TP mg/l P	BOD (mg/l O_2)	COD (mg/l O_2)	pH	SS (mg/l)	TN (mg/l N)	TP (mg/l P)
1-Mar-2009	20101	5909.694	770	15271	294	899		460			5.7	41		13		
2-Mar-2009	19983	10011.483	488	15811	501	870	7.96	562			9.2	37	7.93	5.5	15.1	3.84
3-Mar-2009	23552		1255	19758		575	7.56					51	7.7			
4-Mar-2009	20491		1189	18830		858	7.82					67	7.78			
5-Mar-2009	20690		1330	19752		757	7.84					72	7.81			
6-Mar-2009	20037		1182	19434		738	7.79					54	7.83			
7-Mar-2009	23892	8362.2	1329	22724	350	1068		479			8.7	56		12.5		
8-Mar-2009	26480		1085	24774		845						72				
9-Mar-2009	25986		1066	24019		615	8.03					282	8.02			
10-Mar-2009	26516	8034.348	1333	24487	303	743	7.97	485			14.25	51	8.03	15	12.5	2.43
11-Mar-2009	23216	5014.656	972	21266	216	486	8.02	244			13.5	50	8.03	14.5		
12-Mar-2009	22937		1098	20348		658	7.81					50	8.05			
13-Mar-2009	22654		1726	20005		494	7.38					50	7.48			
14-Mar-2009	20979		1444	18674		759						47				
15-Mar-2009	19515	7220.55	1357	18624	370	1187		790			15.6	65		12.5		
16-Mar-2009	19558		1261	19101		629	7.71					88	7.72			
17-Mar-2009	18233		1354	18230		532						586				
18-Mar-2009	18871	1566.293	1250	18549	83	241	8.03	178			44.4	124	7.9	75	21.8	4.29
19-Mar-2009	19095		1309	18602		128	8.2					255	8.06			
20-Mar-2009	19294	3087.04	1280	18727	160	512	7.51	382			66	248	7.96	153.5		
21-Mar-2009	18507	4330.638	1410	17748	234	887		510			15.9	106		64.5		
22-Mar-2009	17910		1618	16296		700						52				
23-Mar-2009	19136		1294	17026		683	7.88					51	7.88			
24-Mar-2009	19067		1792	17194		878	7.42					88	7.52			
25-Mar-2009	18728	4888.008	1474	16503	261	673	7.51	345			21.4	89	7.61	46		
26-Mar-2009	20303	5116.356	1335	16572	252	777	7.13	266			5.2	34	7.41	9.5	24.7	2.19
27-Mar-2009	21586		1539	14314		881	7.41					35	7.62			
28-Mar-2009	18110		1632	12034		698						39				
29-Mar-2009	18216	3570.336	909	13358	196	759		382			4.1	34		1.5		
30-Mar-2009	18860		1229	10675		376	7.95					32	7.9			
31-Mar-2009	17983		1423	9950		348	7.85					31				

Dundalk WWTW 2009

Date	Inlet Flow (m^3)	Influent BOD load	Supernatent Flow (m^3)	Outlet Flow (m^3)	Influent analysis results						Final Effluent analysis results					
					BOD mg/l O_2	COD mg/l O_2	pH	SS mg/l	TN mg/l N	TP mg/l P	BOD (mg/l O_2)	COD (mg/l O_2)	pH	SS (mg/l)	TN (mg/l N)	TP (mg/l P)
1-Apr-2009	16624		998	9767		523	7.68					34	7.69			
2-Apr-2009	22004		1433	13765		684	7.37					35	7.2			
3-Apr-2009	22004	4884.888	1311	13764	222	609	7.71	275			2.9	26	7.71	6	24.5	0.87
4-Apr-2009	22768	3529.04	1070	19096	155	1282		838			7.2	45		9.5		
5-Apr-2009	16615		1501	13438		784						38				
6-Apr-2009	25322	1671.252	1179	20517	66	416	7.99	164			5.6	38	8.05	6.5	15.1	1.47
7-Apr-2009	24229		1369	14072		530	7.62					38	7.7			
8-Apr-2009	24930	7553.79	1362	12808	303	765	7.82	392			10.2	47	8.03	7.5		
9-Apr-2009	27556		895	13034		501	7.72					51	7.88			
10-Apr-2009	25146		1538	12101		485	7.9					43	7.86			
11-Apr-2009	21705		1654	11223		547						43				
12-Apr-2009	18662	4814.796	1152	10465	258	642		188			3.8	36		3.5		
13-Apr-2009	24382		1527	12783		514						37				
14-Apr-2009	28456	4837.52	1167	23226	170	514	7.81	212			4.65	38	7.64	9.5	13	0.87
15-Apr-2009	29117		1224	25021		416	8.8					30	8.7			
16-Apr-2009	22993		1203	20413		404	7.85					23	7.84			
17-Apr-2009	20890		1233	17232		483	7.8					28	8.03			
18-Apr-2009	19796	2494.296	1134	15980	126	317		123			4.5	32		0		
19-Apr-2009	18660		1535	14497		271						26				
20-Apr-2009	19194		1278	14848		812	7.26					31	7.63			
21-Apr-2009	21035		746	15580		719						36				
22-Apr-2009	20346	5493.42	1471	15196	270	973	7.42	534			3.8	40	7.49	0	26.5	3.7
23-Apr-2009	20722		1213	15416		1000	6.89					31	7.2			
24-Apr-2009	20901		1454	13792		561	7.15					35	7.35			
25-Apr-2009	27457		1675	14781		1039						42				
26-Apr-2009	28177	6142.586	1343	14244	218	599		211			9.8	55		33		
27-Apr-2009	33467		2934	15156		421	7.53					35	7.84			
28-Apr-2009	23124		5842	12254		460	7.05					26	7.12			
29-Apr-2009	21610		1133	11959		462	6.81					29	6.85			
30-Apr-2009	37715	7354.425	1549	18528	195	457	7.27	236			<6	28	7.32	10	n/a	2.22

Dundalk WWTW 2009

Date	Inlet Flow (m^3)	Influent BOD load	Supernatent Flow (m^3)	Outlet Flow (m^3)	Influent analysis results: BOD mg/l O_2	COD mg/l O_2	pH	SS mg/l	TN mg/l N	TP mg/l P	Final Effluent analysis results: BOD (mg/l O_2)	COD (mg/l O_2)	pH	SS (mg/l)	TN (mg/l N)	TP (mg/l P)
1-May-2009	28174	1521.396	1651	16646	54	341		140			1.4	27	7.98	5	21.7	4.53
2-May-2009	22596	2101.428	1635	14203	93	372		299			3.1	33		0		
3-May-2009	20457		728	13117		704						30				
4-May-2009	21501		1243	13553		557						32				
5-May-2009	24395		1406	14555		400						28	8.22			
6-May-2009	24319		1255	13262		483						26	7.89			
7-May-2009	24468		1584	12571		327						32	7.87			
8-May-2009	26918	5383.6	1436	11985	200	548		331			2.5	29	8.02	1	24.2	2
9-May-2009	22702		1560	11525		1129						33				
10-May-2009	20570	2931.225	1121	10815	142.5	423		223			2.8	27		3		
11-May-2009	21233	3503.445	1258	11537	165	418		150			2.8	28	7.4	4	20.4	0.96
12-May-2009	20436		1459	11239		575						28	7.31			
13-May-2009	20264	4093.328	1166	11575	202	505		192			3.9	27	7.37	5		
14-May-2009	21702		1361	12276		402						18	7.34			
15-May-2009	38385		1636	19873		947						31	7.44			
16-May-2009	32666	4213.914	1386	19158	129	276		200			6.4	28		5		
17-May-2009	25786		1149	16015		354						29				
18-May-2009	25009		893	15699		281						29	7.72			
19-May-2009	35797	6443.46	1427	19162	180	505		184			3.8	27	7.45	1.5	18.4	1.74
20-May-2009	42762		1242	31600		471						28	7.17			
21-May-2009	42011		1535	28137		227						36	7.23			
22-May-2009	34454		1535	21681		335						30	7.17			
23-May-2009	27611		1452	17163		466						22				
24-May-2009	25288	3148.356	1106	13390	124.5	307		130			2.7	24		7		
25-May-2009	25726		938	12570		301						26	7.02			
26-May-2009	25476		1262	11807		526						42	7.12			
27-May-2009	25158	3698.226	1240	11105	147	366		149			10.4	52	6.94	7	11.9	1.89
28-May-2009	23395		1484	11140		401						32	6.98			
29-May-2009	22369		1394	15447		512						35	6.98			
30-May-2009	21339	4417.173	1264	11399	207	806		138			3.6	23		20		
31-May-2009	20022		1338	11342		1311						24				

Dundalk WWTW 2009

Date	Inlet Flow (m^3)	Influent BOD load	Supernatent Flow (m^3)	Outlet Flow (m^3)	Influent analysis results						Final Effluent analysis results					
					BOD mg/l O_2	COD mg/l O_2	pH	SS mg/l	TN mg/l N	TP mg/l P	BOD (mg/l O_2)	COD (mg/l O_2)	pH	SS (mg/l)	TN (mg/l N)	TP (mg/l P)
1-Jun-2009	19344		886	11602		535						23				
2-Jun-2009	20423		932	13525		408	6.84					30	7.01			
3-Jun-2009	20378		1277	15794		1116	7.11					30	7.38			
4-Jun-2009	21077	3920.322	1115	15840	186	466	7.09	125			4.4	26	7.16	5.5	24.4	1.34
5-Jun-2009	20360		1480	14766		490	7.12					36	7.37			
6-Jun-2009	24947		1284	15880		1652						39				
7-Jun-2009	19698	2895.606	1018	13861	147	788		84			4.2	23		6.5		
8-Jun-2009	20161		938	12819		384	7.14					28	7.03			
9-Jun-2009	21358		1317	12530		499	6.71					27	6.84			
10-Jun-2009	20302	4831.876	1931	12251	238	530	6.8	230			5.7	36	6.9	7.5		
11-Jun-2009	20147		1667	12469		434	6.78					30	7.08			
12-Jun-2009	19732	4360.772	1591	12889	221	465	6.85	170			5.8	33	7	7.5	25.2	2.88
13-Jun-2009	19915	4480.875	2194	12969	225	721		451			4.6	38		6.5		
14-Jun-2009	23433		1191	15167		580						45				
15-Jun-2009	21536	5168.64	1783	16580	240	690	7.52	333			7.9	42	7.76	11.5	19.8	<3
16-Jun-2009	19770		1538	15696		405	6.81					39	7.28			
17-Jun-2009	40272		1267	37920		617	6.89					28	6.96			
18-Jun-2009	29848		926	24761		156	7.43					20	7.41			
19-Jun-2009	20533		793	16171		315	7.02					29	7.16			
20-Jun-2009	24672		1079	18711		467						22				
21-Jun-2009	21094	3628.168	1417	15360	172	509		209			3.7	22		5		
22-Jun-2009	21611		1448	14328		382	6.08					27	6.34			
23-Jun-2009	21573	4109.6565	2116	12933	190.5	355	6.72	124			4.1	28	6.93	5.5	11.9	1.26
24-Jun-2009	21484	3705.99	1218	12071	172.5	460	6.87	156			4	23	7.07	7.07		
25-Jun-2009	21047		1534	10803		493	6.75					26	6.98			
26-Jun-2009	20030		891	10085		421	6.68					28	6.9			
27-Jun-2009	18131	5874.444	772	9898	324	790		464			3.2	28		10		
28-Jun-2009	18001		712	10075		473						30				
29-Jun-2009	19397		520	10840		439	7.54					25	7.28			
30-Jun-2009	19996		425	11465		484	7.08					18	7.26			

Dundalk WWTW 2009

Date	Inlet Flow (m^3)	Influent BOD load	Supernatent Flow (m^3)	Outlet Flow (m^3)	Influent analysis results						Final Effluent analysis results					
					BOD mg/l O_2	COD mg/l O_2	pH	SS mg/l	TN mg/l N	TP mg/l P	BOD (mg/l O_2)	COD (mg/l O_2)	pH	SS (mg/l)	TN (mg/l N)	TP (mg/l P)
1-Jul-2009	28115	4048.56	683	16097	144	352	7.06	185			5.3	32	7.04	17.5	16.3	1.89
2-Jul-2009	38295		1286	22318		500	7.44					21	7.46			
3-Jul-2009	31795		870	21022		220						26				
4-Jul-2009	30924		592	19439		297						21				
5-Jul-2009	24536	4085.244	592	16314	166.5	432		178			3.4	22		4		
6-Jul-2009	26920		1184	15582		261	7.06					27	7.29			
7-Jul-2009	25293		614	16092		462	6.68					26	6.95			
8-Jul-2009	22202	9458.052	1154	14403	426	848	6.8	226			16.2	50	7.07	16		
9-Jul-2009	21893	2649.053	1061	13483	121	406	6.79	91			8	23	7.27	5		
10-Jul-2009	21382		1387	13110		3650	6.72					44	6.84			
11-Jul-2009	25985	1663.04	1789	13885	64	303		163			3.4	38		2.5		
12-Jul-2009	31936		1106	17834		118						37				
13-Jul-2009	32720		1244	18025		929	7.24					29	7.21			
14-Jul-2009	34279		1015	21286		296	6.6					10	6.69			
15-Jul-2009	29072		1479	18839		381	6.73					20	6.72			
16-Jul-2009	25625		1412	17457		92	6.56					28	6.78			
17-Jul-2009	22824	3834.432	1211	16019	168	467	6.74	208			4	23	6.78	8	24.3	4.6
18-Jul-2009	22064		1527	15598		947						25				
19-Jul-2009	21194		1003	14532		405						35				
20-Jul-2009	22282	3743.376	1287	13481	168	536	7.1	285			3.6	26	7.18	5	19.8	1.47
21-Jul-2009	29802		1370	14160		565	6.63					27	6.9			
22-Jul-2009	31901	6364.2495	930	14711	199.5	473	6.77	265			7.5	32	6.88	10.5		
23-Jul-2009	40731		998	18118		674	6.62					46	6.66			
24-Jul-2009	41066		1486	18233		643	6.65					37	6.62			
25-Jul-2009	37245	8380.125	1388	17255	225	652		433			6.2	30		11		
26-Jul-2009	44759		829	20252		657						25				
27-Jul-2009	37159		1242	18954		199	6.77					50	6.97			
28-Jul-2009	36156	2784.012	1309	20053	77	200	6.91	100			3	26	6.91	4.5	13.6	1.38
29-Jul-2009	31668		1036	20442		371	6.6					30	6.84			
30-Jul-2009	29642		1047	20488		400	6.78					32	6.91			
31-Jul-2009	28729		1672	18383		488	6.85					41	7.19			

Dundalk WWTW 2009

					Influent analysis results						Final Effluent analysis results					
Date	Inlet Flow (m^3)	Influent BOD load	Supernatent Flow (m^3)	Outlet Flow (m^3)	BOD mg/l O_2	COD mg/l O_2	pH	SS mg/l	TN mg/l N	TP mg/l P	BOD (mg/l O_2)	COD (mg/l O_2)	pH	SS (mg/l)	TN (mg/l N)	TP (mg/l P)
1-Aug-2009	25377		2565	18833		695						30				
2-Aug-2009	21479	3898.4385	1171	16464	181.5	455		225			3.9	24		1		
3-Aug-2009	26338		1185	17771		533						29				
4-Aug-2009	24792		1277	16540		1800	6.66					27	6.85			
5-Aug-2009	23022	3637.476	1485	14455	158	429	6.74	191			3.1	21	6.99	1.5	18.5	1.05
6-Aug-2009	22513		839	13601		493	6.58					28	6.93			
7-Aug-2009	22280		1473	12979		526	6.65					30	6.83			
8-Aug-2009	23237	18357.23	1490	13323	790	4320		2202			3.4	56		0.1		
9-Aug-2009	21101		1215	12801		866						49				
10-Aug-2009	22125		1076	12633		285	7.13					44	7.19			
11-Aug-2009	21344		1614	12740		738	6.87					38	7.37			
12-Aug-2009	20871	5050.782	1805	13313	242	581	6.65	219			3.2	27	7.03	6		
13-Aug-2009	20012	7264.356	1589	12869	363	991		861			4.5	30		9	22	2.9
14-Aug-2009	20466		1588	14028		1565	6.75					23	6.84			
15-Aug-2009	23845		1692	16313		558						27				
16-Aug-2009	19427	1981.554	1114	15031	102	308		130			3.2	22		2		
17-Aug-2009	20083		1670	14745		708	6.84					26	7.1			
18-Aug-2009	25885		1488	15148		498	7.2					28	7.44			
19-Aug-2009	27050		1570	13916		545	6.9					29	7.2			
20-Aug-2009	43961		1496	20086		462	6.87					26	7.18			
21-Aug-2009	35113	5214.2805	1515	17658	148.5	302	6.91	231	21.9	4.86	5.2	17	7.22	3	9.8	0.99
22-Aug-2009	29950	2605.65	1041	14993	87	207		139			3.4	21		1.5		
23-Aug-2009	34790		907	17220		215						24				
24-Aug-2009	34151	1659.7386	816	16140	48.6	114	7.03	64	20.7	2.52	1.8	14	7.04	1	11.7	1.59
25-Aug-2009	25603		1072	13828		336	6.77					16	7.03			
26-Aug-2009	37542		1071	19236		309	6.68					29	6.68			
27-Aug-2009	32581		890	21341		160	7.15					15	7.21			
28-Aug-2009	31541		1325	20976		303	6.58					17	6.76			
29-Aug-2009	26905		915	19459		416						19				
30-Aug-2009	28116	5482.62	562	19639	195	608		349			2.6	11		1		
31-Aug-2009	35939		783	22560		341	6.97					19	7.05			

Dundalk WWTW 2009

					Influent analysis results						Final Effluent analysis results					
Date	Inlet Flow (m^3)	Influent BOD load	Supernatant Flow (m^3)	Outlet Flow (m^3)	BOD mg/l O_2	COD mg/l O_2	pH	SS mg/l	TN mg/l N	TP mg/l P	BOD (mg/l O_2)	COD (mg/l O_2)	pH	SS (mg/l)	TN (mg/l N)	TP (mg/l P)
1-Sep-2009	42686	3969.798	683	26627	93	264	7.02	179	20	3.72	3.4	24	7.03	3	10.1	1.41
2-Sep-2009	41728		792	26155		287	6.85					17	7.09			
3-Sep-2009	42672		769	26082		208	7.12					123	7.26			
4-Sep-2009	36136		927	21755		263	6.94					26	7.08			
5-Sep-2009	34246	3852.675	1168	20167	112.5	335		230			2	13		6		
6-Sep-2009	34900		869	18701		331						15				
7-Sep-2009	31511		717	16606		240	6.96					10	7.24			
8-Sep-2009	21259		1183	16006		292	6.92					11	7.09			
9-Sep-2009	29878	4526.517	1097	17154	151.5	391	6.82	158	17.2	4.75	2.6	24	7.06	1.5	5.7	1.54
10-Sep-2009	27337		1151	18268		588	6.71					23	7.04			
11-Sep-2009	25763		1129	18428		779	6.8					28	7.21			
12-Sep-2009	23841		938	17412		493						35				
13-Sep-2009	22380	4968.36	1319	16668	222	635		400			3.2	22		2.5		
14-Sep-2009	23294		1236	17356		584	7.62					18	7.94			
15-Sep-2009	23308		1266	17193		474	7.13					25	7.34			
16-Sep-2009	23099		1181	16606		547	6.81					28	7.56			
17-Sep-2009	22676	4217.736	1381	14334	186	667	7.21	384	29.5	9.44	2.8	25	7.39	3	6.5	0.93
18-Sep-2009	23805		1334	12553		466	7.12					20	7.5			
19-Sep-2009	23069	5190.525	1282	11276	225	719		413			3.1	30		4		
20-Sep-2009	21645		1141	10872		461						41				
21-Sep-2009	23681		1118	11413		389	6.64					24	6.84			
22-Sep-2009	22677		1512	11128		419	6.59					30	6.67			
23-Sep-2009	21594		843	12201		380	6.51					30	6.69			
24-Sep-2009	21299		841	13427		567	6.59					170	6.76			
25-Sep-2009	20533	3819.138	868	14116	186	475	6.63	211	45.6	8.2	8.4	32	7.16	11.5	19.6	3
26-Sep-2009	20279		764	14846		901						29				
27-Sep-2009	18836	2910.162	522	14529	154.5	345		185			7.5	39		10.5		
28-Sep-2009	20070	3251.34	492	15381	162	190	7.11	344	32.46	5.99	6	52	7.12	11	12.54	3.25
29-Sep-2009	19696		448	15766		568						43				
30-Sep-2009	20322		1291	15779		676	6.63					29	6.89			

Dundalk WWTW 2009

Date	Inlet Flow (m^3)	Influent BOD load	Supernatent Flow (m^3)	Outlet Flow (m^3)	Influent analysis results: BOD mg/l O_2	COD mg/l O_2	pH	SS mg/l	TN mg/l N	TP mg/l P	Final Effluent analysis results: BOD (mg/l O_2)	COD (mg/l O_2)	pH	SS (mg/l)	TN (mg/l N)	TP (mg/l P)
1-Oct-2009	20243		687	15005		838	6.65					23	6.94			
2-Oct-2009	20901		1545	14242		518	6.7					20	7.09			
3-Oct-2009	20521	4863.477	1434	12209	237	659		353			2.9	25		5.5		
4-Oct-2009	19174		1257	11159		443						25				
5-Oct-2009	20306		1118	10857		395	6.97					33	7.15			
6-Oct-2009	24316	5641.312	879	11800	232	498	6.79	288	43.5	8.2	4.2	27	7.07	11	18.3	1.98
7-Oct-2009	21021		1285	10541		782	6.63					42	7.07			
8-Oct-2009	20495		1196	10471		612	6.71					14	6.97			
9-Oct-2009	24342		1382	11952		547	6.83					22	7.14			
10-Oct-2009	23309		1256	13255		518						26				
11-Oct-2009	18921	2894.913	1106	12187	153	427		195			2.8	21		6		
12-Oct-2009	19083		1036	12840		490	7.17					20	7.36			
13-Oct-2009	19936		1193	13581		372	7.18					25	7.42			
14-Oct-2009	19657	4186.941	1290	12741	213	468	6.98	198	35.7	8.35	5.3	33	7.12	11.5	14	4.35
15-Oct-2009	19257		1275	12198		602	6.72					30	7.22			
16-Oct-2009	19819		1115	11829		602	6.67					34	6.95			
17-Oct-2009	18902	7541.898	1261	11015	399	810		321			2.25	24		5		
18-Oct-2009	22275		1048	10947		504						25				
19-Oct-2009	25985		956	12536		609	6.85					96	7.2			
20-Oct-2009	34104		1242	13588		430	6.85					45	7.05			
21-Oct-2009	31085		1238	14061		256	6.72					26	6.94			
22-Oct-2009	31864	4237.912	1375	14822	133	299	6.67	131	21.9	5.05	3.7	21	6.9	4.5	11.8	0.75
23-Oct-2009	24807		1209	15053		254	6.98					22	7.18			
24-Oct-2009	30855		1295	18898		391						20				
25-Oct-2009	27200	2937.6	1015	19567	108	393		213			2.5	28		2.5		
26-Oct-2009	15562		907	17369		491						22				
27-Oct-2009	26779		1016	18952		363	6.9					21	7.25			
28-Oct-2009	23736		749	17823		368	6.91					21	6.99			
29-Oct-2009	24993		1583	18304		482	6.78					28	7.16			
30-Oct-2009	28800	11865.6	1341	18354	412	412	7.09	230	11.9	2.4	14	14	7.24	2	32.4	6.85
31-Oct-2009	28956		1327	18049		294						13				

Dundalk WWTW 2009

					Influent analysis results						Final Effluent analysis results					
Date	Inlet Flow (m^3)	Influent BOD load	Supernatent Flow (m^3)	Outlet Flow (m^3)	BOD mg/l O_2	COD mg/l O_2	pH	SS mg/l	TN mg/l N	TP mg/l P	BOD (mg/l O_2)	COD (mg/l O_2)	pH	SS (mg/l)	TN (mg/l N)	TP (mg/l P)
1-Nov-2009	41380	7448.4	1384	29028	180	577		303			3	8		3.5		
2-Nov-2009	40612	1388.9304	1059	24873	34.2	100	6.92	37	19.5	1.64	3.2	10	7.2	<5	5.5	0.86
3-Nov-2009	39767		1134	20635		100	6.97					16	7.13			
4-Nov-2009	37271		647	18213		145	6.87					29	6.97			
5-Nov-2009	37078		910	20191		116	7.03					22	7.5			
6-Nov-2009	37261		809	20086		324	6.95					25	7.1			
7-Nov-2009	34958	6292.44	711	19339	180	521		335			2.9	23		3		
8-Nov-2009	31819		667	21094		154						19				
9-Nov-2009	32844		724	22317		184	7.16					23	7.32			
10-Nov-2009	36753	4483.866	1241	25322	122	297	6.95	168	22.8	4.75	5.3	27	7.16	9	9.5	1.02
11-Nov-2009	35052		1168	25578		245	7					34	7.21			
12-Nov-2009	42940		1261	37746		265	7.04					92	7.44			
13-Nov-2009	39378		1176	30167		142	6.83					13	7.05			
14-Nov-2009	39657		1009	20497		233						17				
15-Nov-2009	37810	4367.055	981	19908	115.5	336		199			3.5	16		0.5		
16-Nov-2009	44346		876	25863		186	6.98					18	7.1			
17-Nov-2009	41283		994	22654		284	6.86					17	7			
18-Nov-2009	45596	3693.276	964	36473	81	224		109	18.9	3.15	3.9	25		5	7.6	2.22
19-Nov-2009	45608		1061	36373		117	6.94					16	6.99			
20-Nov-2009	45564		1027	41124		94	6.72					15	6.95			
21-Nov-2009	45502	1719.9756	736	39136	37.8	106		31			2.2	22		<5		
22-Nov-2009	45230		614	35814		73						19				
23-Nov-2009	45236		631	49314		147	6.98					20	7.16			
24-Nov-2009	45211		740	51956		176	7.03					21	7.15			
25-Nov-2009	44838		433	48762		196	6.89					17	6.95			
26-Nov-2009	42236	5448.444	689	39965	129	273	6.61	85	16.8	3.9	3.8	25	6.99	<5	3.8	0.57
27-Nov-2009	39377		545	41743		210	6.54					67	6.85			
28-Nov-2009	33498		544	29454		252						20				
29-Nov-2009	32234	4641.696	458	24896	144	458		202			5.7	30		6		
30-Nov-2009	31102		420	26335		303	6.93					24	7.2			

Dundalk WWTW 2009

Date	Inlet Flow (m^3)	Influent BOD load	Supernatent Flow (m^3)	Outlet Flow (m^3)	Influent analysis results: BOD mg/l O_2	COD mg/l O_2	pH	SS mg/l	TN mg/l N	TP mg/l P	Final Effluent analysis results: BOD (mg/l O_2)	COD (mg/l O_2)	pH	SS (mg/l)	TN (mg/l N)	TP (mg/l P)
1-Dec-2009	35002		911	23058		289	6.63					28	6.97			
2-Dec-2009	31988		1034	16775		147	6.34					88	6.6			
3-Dec-2009	31207		1065	17076		351	6.77					26	6.96			
4-Dec-2009	32864	7558.72	1184	17631	230	578	6.71	241	24.4	6	4	25	6.98	19	6.5	1.12
5-Dec-2009	43316	2826.369	1162	25649	65.25	203		184			34.8	153		83.5		
6-Dec-2009	38519		998	19087		100						58				
7-Dec-2009	36621	3076.164	696	18389	84	124	7.04	37	13.6	1.92	7.3	27	7.14	12	6.7	0.72
8-Dec-2009	35597		1196	22042		155	6.86					20	7.01			
9-Dec-2009	33262		1033	23848		158	6.76					24	6.92			
10-Dec-2009	28692		929	23111		159	6.82					23	6.96			
11-Dec-2009	28150		1127	23198		227	6.54					16	6.84			
12-Dec-2009	26358		908	21564		228						22				
13-Dec-2009	25119	3064.518	761	21372	122	245		109			2.7	22		5		
14-Dec-2009	25508		883	22185		186						22				
15-Dec-2009	24928	3066.144	825	21157	123	294	7.05	51	17	3.72	2.7	26	7.22	5	7.8	0.84
16-Dec-2009	25032	3078.936	1118	21656	123	274	6.76	71			2.4	28	7	5		
17-Dec-2009	24665		1359	20537		294	6.61					27	6.84			
18-Dec-2009	24761		1060	20373		442	6.71					16	6.91			
19-Dec-2009	23951	5891.946	1245	20294	246	780		265			2.4	24		5		
20-Dec-2009	22853		893	19319		455						21				
21-Dec-2009	23398		1024	19502		474	6.77					25	6.96			
22-Dec-2009	23709		1323	16440		488	6.6					21	6.83			
23-Dec-2009	23303	6944.294	1343	18240	298	606	6.84	240	33.2	7.7	3	30	7.01	2.5	9.4	0.62
24-Dec-2009	20808		1493	16651		569	6.58					24	6.77			
25-Dec-2009	20561		514	17893		309						27				
26-Dec-2009	21092		1249	17776		207						21				
27-Dec-2009	21106	3070.923	1243	17858	145.5	371		256			2.4	24		5		
28-Dec-2009	21207		1276	18829		504						25				
29-Dec-2009	25011		1293	18431		439	6.91					17	7.15			
30-Dec-2009	32387	6930.818	1208	23223	214	490	6.54	175	34.2	7.45	3.2	23	6.81	4.5	11.4	2.54
31-Dec-2009	30707		1161	26653		210	6.63					28	6.62			

Appendix J

[Dundalk WWTP – Reject Streams Analytical Results & Estimated Nitrogen Mass Balance Calculations.]

DUNDALK WWTP - SUPERNATANT ANALYSIS - FEB 2010

Recycle Stream Source	Parameter									
	Temp °C	pH	SS mg/l	COD mg/l	Ammonia mg/l NH_4 -N	Total N mg N/l	Total P mg P/l	BOD mg/l	Nitrate mg N/l	Nitrite mg N/l
Centrate										
17/02/2010	21.0	7.59	160.0	361.0	1,152.0	1,093.1	101.9	48.0	< 0.27	< 0.008
18/02/2010	19.0	7.82	165.0	384.0	1,116.0	1,097.2	129.4	40.0	1.31	< 0.008
22/02/2010	20.0	7.98	123.0	337.0	1,221.0	1,073.1	107.3	33.0	< 0.27	< 0.008
23/02/2010	21.0	7.96	122.0	405.0	1,047.0	1,093.1	107.1	50.0	< 0.27	< 0.008
24/02/2010	20.6	7.72	126.0	436.0	1,140.0	996.4	98.2	10.0	< 0.27	< 0.008
Average	**20.3**	**7.81**	**139.2**	**384.6**	**1,135.2**	**1,070.6**	**108.8**	**36.2**	**0.48**	**< 0.008**
Sludge Thickeners Supernatant										
17/02/2010	10.0	7.58	5,676.0	7,510.0	34.0	444.1	92.4	550.0	< 0.27	0.159
18/02/2010	10.0	6.34	5,392.0	7,260.0	28.2	437.4	69.5	550.0	0.95	< 0.008
22/02/2010	9.7	6.55	6,036.0	8,580.0	18.4	453.0	153.9	1,500.0	< 0.27	0.011
23/02/2010	9.2	7.79	48.0	531.0	45.6	61.0	19.3	550.0	< 0.27	< 0.008
24/02/2010	8.9	6.95	22.0	209.0	31.2	43.7	11.3	185.0	< 0.27	< 0.008
ge	**9.6**	**7.04**	**3,434.8**	**4,818.0**	**31.5**	**287.8**	**69.3**	**667.0**	**0.41**	**0.039**
e Drier Condensate										
18/02/2010	32.0	6.75	3,460.0	3,430.0	117.5	237.4	54.8	260.0	< 0.27	< 0.008
22/02/2010	32.1	7.74	5,928.0	5,120.0	116.5	304.6	169.9	600.0	< 0.27	< 0.008
ge	**32.1**	**7.25**	**4,694.0**	**4,275.0**	**117.0**	**271.0**	**112.4**	**430.0**	**< 0.27**	**< 0.008**
ninary Treatment Units Wash Water										
17/02/2010	9.6	8.03	296.0	447.0	18.8	37.0	4.1	25.0	< 0.27	0.076
23/02/2010	8.0	6.87	254.0	889.0	25.9	29.1	4.8	240.0	< 0.27	< 0.008
24/02/2010	8.5	6.95	125.0	164.0	12.2	18.5	3.6	25.0	1.06	0.072
ge	**8.7**	**7.28**	**225.0**	**500.0**	**19.0**	**28.2**	**4.2**	**96.7**	**0.53**	**0.052**
ter Return Effluent										
18/02/2010	10.0	6.51	4.5	31.0	19.2	28.2	0.7	< 2.0	4.4	0.816
22/02/2010	10.0	7.56	5.0	46.0	19.5	28.0	2.1	12.0	3.95	3.896
Average	**10.0**	**7.04**	**4.8**	**38.5**	**19.4**	**28.1**	**1.4**	**7.0**	**4.18**	**2.356**
Control Building Foul										
23/02/2010	7.0	7.15	24.0	86.0	25.0	27.0	4.0	14.0	1.97	0.041
Average	**7.0**	**7.15**	**24.0**	**86.0**	**25.0**	**27.0**	**4.0**	**14.0**	**1.97**	**0.041**

NITROGEN MASS BALANCE

	Ammonia as NH_4-N	Nitrate as N	Nitrite as N	Total Nitrogen as N	Flow (Q in m^3/d)	Avg. N-Load (kg/d)*	% of Influent N Load
Main Process Flows:							
Influent					26,478 m3/d	735.3 kg/d	100.00%
Effluent					18,120 m3/d	205.0 kg/d	27.88%
Recycle Streams:							
Sludge Thickening & Dewatering Processes					Estimated Q		
Picket Fence Thickeners (Primary & Waste Activated Sludge)	31.5 mg/l	0.41 mg/l	0.039 mg/l	287.8 mg/l	550.0 m3/d	158.3 kg/d	21.53%
PFT 17/02/2010	34.0 mg/l	< 0.27 mg/l	0.159 mg/l	444.1 mg/l			
18/02/2010	28.2 mg/l	0.95 mg/l	< 0.008 mg/l	437.4 mg/l			
22/02/2010	18.4 mg/l	< 0.27 mg/l	0.011 mg/l	453.0 mg/l			
23/02/2010	45.6 mg/l	< 0.27 mg/l	< 0.008 mg/l	61.0 mg/l			
24/02/2010	31.2 mg/l	< 0.27 mg/l	< 0.008 mg/l	43.7 mg/l			
trifuge Reject Waters	1135.2 mg/l	0.48 mg/l	< 0.008 mg/l	1070.6 mg/l	94.8 m3/d	101.5 kg/d	13.81%
Centrate 17/02/2010	1152.0 mg/l	< 0.27 mg/l	< 0.008 mg/l	1093.1 mg/l			
18/02/2010	1116.0 mg/l	1.31 mg/l	< 0.008 mg/l	1097.2 mg/l			
22/02/2010	1221.0 mg/l	< 0.27 mg/l	< 0.008 mg/l	1073.1 mg/l			
23/02/2010	1047.0 mg/l	< 0.27 mg/l	< 0.008 mg/l	1093.1 mg/l			
24/02/2010	1140.0 mg/l	< 0.27 mg/l	< 0.008 mg/l	996.4 mg/l			
dge Drying & Associated Air Handling							
Scrubber Wash Water	117.0 mg/l	< 0.27 mg/l	< 0.008 mg/l	271.0 mg/l	275.1 m3/d	74.6 kg/d	10.14%
AS 18/02/2010	117.5 mg/l	< 0.27 mg/l	< 0.008 mg/l	237.4 mg/l			
22/02/2010	116.5 mg/l	< 0.27 mg/l	< 0.008 mg/l	304.6 mg/l			
ilter Return Water	19.4 mg/l	4.18 mg/l	2.356 mg/l	28.1 mg/l	17.3 m3/d	0.5 kg/d	0.07%
BFR 18/02/2010	19.2 mg/l	4.40 mg/l	0.816 mg/l	28.2 mg/l			
22/02/2010	19.5 mg/l	3.95 mg/l	3.896 mg/l	28.0 mg/l			
Preliminary Treatment & Washdown Areas	19.0 mg/l	0.53 mg/l	0.052 mg/l	28.2 mg/l	37.0 m3/d	1.0 kg/d	0.14%
17/02/2010	18.8 mg/l	< 0.27 mg/l	0.076 mg/l	37.0 mg/l			
23/02/2010	25.9 mg/l	< 0.27 mg/l	< 0.008 mg/l	29.1 mg/l			
24/02/2010	12.2 mg/l	1.06 mg/l	0.072 mg/l	18.5 mg/l			
Domestic Foul Line from Admin Building	25.0 mg/l	1.97 mg/l	0.041 mg/l	27.0 mg/l	0.5 m3/d	0.013 kg/d	0.002%
23/02/2010	25.0 mg/l	1.97 mg/l	0.041 mg/l	27.0 mg/l			
				Reject Streams - Total	**974.7 m3/d**	**335.9 kg/d**	**45.7%**
				Remainder in Dewatered Sludge		194.4 kg/d	26.44%
						Balance	100.00%

* Based on monitoring from August 2009 to December 2009

Appendix K

[Conventional Design for Upgrade of Main Treatment Process at Dundalk WWTP – Design Spreadsheets.]

DUNDALK WASTE WATER TREATMENT PLANT
PROCESS MODELLING OF PRIMARY SETTLEMENT TANKS

THE PRIMARY SETTLEMENT TANK DESIGN USED IN THIS SPREADSHEET IS BASED ON THE MANUALS OF BRITISH PRACTICE IN WATER POLLUTION CONTROL - UNIT PROCESSES - PRIMARY SEDIMENTATION.

1	**REVIEW FLOWS**	**Phase 1A**
	DRY WEATHER FLOW	18,088.00 m^3 / day
	3 x DRY WEATHER FLOW	48,837.60 m^3 / day
	MAXIMUM FLOW	**565.3 l/sec**
2	**SELECT NUMBER OF TANKS REQUIRED**	
	NUMBER OF TANKS AVAILABLE	**2 No.**
3	**SELECT HYDRAULIC RETENTION TIME @MAXIMUM FLOW**	1.67 hours
	GIVING A DESIGN VOLUME OF	**3392.08m^3**
	VOLUME PER TANK =	**1696.04m^3**
4	**SELECT UPWARD FLOW RATE @ MAXIMUM FLOWRATE**	1.44m^3 /m^2 / hour
	TOTAL SURFACE AREA REQD v PROVIDED	1413.72 m^2
	CHECK UPWARD FLOWRATE AT D.W.F.	0.53m^3 /m^2 / hour
	NUMBER OF TANKS PROVIDED	2 No.
	SURFACE AREA PER TANK	706.86 m^2
	TANK DIAMETER	30.00 m
	NEAREST WHOLE NUMBER DIAMETER	**30.00 m**
	TANK CIRCUMFERENCE	94.2 m
	MAXIMUM OVERFLOW RATE	259.09m^3 /m / day
	OVERFLOW RATE AT DWF	95.96m^3 /m / day
5	**CALCULATE TANK VOLUMES AND DIMENSIONS**	
	VOLUME OF SLUDGE CONE	
	ASSUME DEPTH OF SLUDGE CONE	2.00 m
	ASSUME TOP DIAMETER OF SLUDGE CONE	3.20 m
	ASSUME BOTTOM DIAMETER OF SLUDGE CONE	1.86 m
	THEN TOTAL VOLUME OF SLUDGE CONE	**10.31m^3**
	VOLUME OF MAIN HOPPER	
	ASSUME DEPTH OF MAIN HOPPER	2.23 m
	ASSUME TOP DIAMETER OF MAIN HOPPER	30.00 m
	ASSUME BOTTOM DIAMETER OF MAIN HOPPER	3.20 m
	THEN TOTAL VOLUME OF MAIN HOPPER	**587.98m^3**
	FLOOR SLOPE OF MAIN HOPPER	**9.46 degrees**
	VOLUME OF REMAINING SECTION	**1097.75m^3**
	=> A SIDE WALL DEPTH OF	**1.553 m**
	DESIGN OF SUPERNATENT CHANNEL	
	SELECT SUPERNATENT CHANNEL WIDTH	0.60 m
	INTERNAL DIAMETER OF TANK	30.0 m
	THICKNESS OF WALLS (2 x 0.3)	0.6 m
	RADIUS AT CENTRE LINE OF CHANNEL	30.6 m
	LENGTH OF CHANNEL @ C.L (= CIRCUMFERENCE @ C.L. RADIUS)	96.1 m
	LENGTH OF HALF CHANNEL	48.1 m
	ALLOW A FALL OF 100mm => SLOPE OF 1 in	
	ALLOW A FALL OF 125mm => SLOPE OF 1 in	
	ALLOW A FALL OF 150mm => SLOPE OF 1 in	
	ALLOW A FALL OF 200mm => SLOPE OF 1 in	
	ALLOW A FALL OF 250mm => SLOPE OF 1 in	

	SELECT VELOCITY IN SUPERNATENT CHANNEL	1.085 m / s
	Q = AV	
	Qmax / day =	48,837.60 m^3 / day
	Q max Per Tank / day =	24,418.80 m^3 / day
	Q max /sec	0.1413m^3 / sec
	=> Area Required	0.1302 m^2
	AssumeChannel Width = W =	0.60 m
	Then channel depth =	0.217 m
	m= hydraulic mean depth =area of cross section of flow / wetted perimeter	
	=A / w.p	0.125918762
	where w.p . = W+2D	
	Chezy Coefficient C = 1/n . m^(1/6)	
	n = 0.015 for ordinary concrete	0.0150
	=>C=	47.20
	NOW:- Q = AC $\sqrt{mi}$	
	=> (Q / AC $)^2$ = mi =	0.0005288
		0.004200
	=> i =	0.004158
	Slope of channel required **= 1 in**	**241**
	CHECK CHANNEL SLOPE REQUIRED AT Q min	
	SELECT VELOCITY IN SUPERNATENT CHANNEL	0.8 m / s
	Qmin / day =	18,088.00m^3 / day
	Q min Per Tank / day =	9,044.00m^3 / day
	Q max /sec	0.0523m^3 / sec
	=> Area Required	0.0654 m^2
	Assume Channel Width = W =	0.60 m
	Then channel depth =	0.109 m
	m= hydraulic mean depth =area of cross section of flow / wetted perimeter	
	=A / w.p	0.0800
	where w.p . = W+2D	
	Chezy Coefficient C = 1/n . m^(1/6)	
	n = 0.015 for ordinary concrete	0.0150
	=>C=	43.76
	NOW:- Q = AC /m i	
	=> (Q / AC $)^2$ = mi =	0.000334492
		0.004183708
	=> i =	0.004158
	Slope of channel required **= 1 in**	**241**
6	***SUMMARY OF PRIMARY SETTLING TANK DIMENSIONS***	
	NUMBER OF TANKS REQUIRED	**2 No.**
	INTERNAL DIAMETER	**30.00 m**
	SIDE WALL DEPTH	**1.6 m**
	SUPERNATENT CHANNEL WIDTH	0.60 m
	DEPTH OF MAIN HOPPER	2.23 m
	TOP DIAMETER OF MAIN HOPPER	30.00 m
	BOTTOM DIAMETER OF MAIN HOPPER	3.20 m
	FLOOR SLOPE OF MAIN HOPPER	**9.46 degrees**
	DEPTH OF SLUDGE CONE	2.00 m
	TOP DIAMETER OF SLUDGE CONE	3.20 m
	BOTTOM DIAMETER OF SLUDGE CONE	1.86 m

	DUNDALK WWTP	
	DESIGN OF AERATION BASINS	
		Phase 1A
	DESIGN INPUT DATA	
	POPULATION EQUIVALENT STAGE ONE	
	POPULATION EQUIVALENT STAGE TWO	179535 P.E.
	DRY WEATHER FLOW STAGE ONE	
	DRY WEATHER FLOW STAGE TWO	18,088.00m³ / day
	MAXIMUM MULTIPLES OF DWF FOR FULL TREATMENT	2.7
	OPERATING TEMPERATURE	10.00 °C
	RAW SEWAGE SPECIFICATION	
	RAW SEWAGE B.O.D. CONCENTRATION:-	595.54 mg / l
	ASSUMED RAW SEWAGE SUSPENDED SOLIDS CONCENTRATION:-	392.30 mg / l
	ASSUMED RAW SEWAGE PHOSPHOROUS CONCENTRATION:-	12.00 mg / l
	ASSUMED RAW SEWAGE NITROGEN CONCENTRATION:-	
	Organic Nitrogen Concentration	19.00 mg / l
	Ammoniacal Nitrogen Concentration	25.00 mg / l
	Total Kjeldahl Nitrogen Concentration	44.00 mg / l
	FINAL EFFLUENT SPECIFICATION	
	FINAL EFFLUENT B.O.D. :-	25.00 mg / l
	FINAL EFFLUENT SUSPENDED SOLIDS:-	35.00 mg / l
	FINAL EFFLUENT PHOSPHOROUS:-	N / A
	FINAL EFFLUENT NITROGEN AS SET OUT ON P. 4 - 16 OF THE E.I.S. :-	10.00 mg / l
	SLUDGE RETURN FLOWRATE	1 DWF
	ESTABLISH FLOWS TO AERATION BASINS	Phase 1A Conditions
	Each aeration stream will be designed for a P.E of 5000 persons i.e. four tanks to be provided at stage one ,with the remaining two tanks to be provided at stage two.	
	thus :-	
	PHASE TWO DRY WEATHER FLOW TO AERATION BASINS	18,088m³ / day
	3 TIMES D.W.F.	48,838m³ / day
	SLUDGE RETURN @ 1 D.W.F.	18,088m³ / day
	TOTAL FLOW	**66,926m³ / day**
	MAXIMUM FLOW TO EACH BASIN =	**16,731m³ / day**
2	**STATEMENT OF ORGANIC LOADING**	
	ORGANIC LOADING IN RAW SEWAGE	
	REF.C ARTICLE 2 SUB PARAGRAPH 6 DEFINES B.O.D.	60 g BOD/hd/d
	LOAD AS 60g B.O.D ./PER CAPITA PER DAY	
	AT A FLOW OF 250 l / h / d THIS EQUATES TO	240.00 mg / l
	IN THE CASE OF DUNDALK HOWEVER	
	POPULATION EQUIVALENT PHASE TWO	179,535.00 P.E.
	DRY WEATHER FLOW STAGE TWO	18,088.00m³ / day
	ESTIMATED TOTAL DAILY BOD LOAD TO PRIMARY SETTLEMENT STAGE =	10,772.10 kg/ day
	THEREFORE ORGANIC LOADING OF RAW SEWAGE IS ESTIMATED AS : -	**596 mg / l**
	ESTIMATED TOTAL DAILY SUSPENDED SOLIDS LOAD TO PRIMARY SETTLEMENT STAGE =	7,096.00 kg/ day
	THEREFORE SUSPENDED SOLIDS LOADING OF RAW SEWAGE IS ESTIMATED AS : -	**392 mg / l**
	REMOVAL EFFICIENCY OF B.O.D. IN THE PRIMARY SETTLEMENT TANKS	30.00%
	ONGOING B.O.D. LOAD	**417 mg / l**

	TOTAL DAILY BOD LOAD TO AERATION STAGE =	
	POPULATION EQUIVALENT x BOD / CAP / DAY / ***1000***	7540.47kg B.O.D./day
	REMOVAL EFFICIENCY OF SUSPENDED SOLIDS. IN THE PRIMARY SETTLEMENT TANKS	60%
	ONGOING SUSPENDED SOLIDS. LOAD	**157 mg / l**
	TOTAL DAILY SUSPENDED SOLIDS LOAD TO AERATION STAGE =	**2838.40kg SS./day**
3	**SELECT PROCESS TYPE**	
	EXTENDED AERATION	
	Because of the long sludge age associated with the extended aeration process nitrification will occur. As a consequence it will also be necessary to de- nitrify.Accordingly the process is defined as :-	
	EXTENDED AERATION WITH NITRIFICATION / DENITRIFICATION	
	(SERIES PRE- DENITRIFICATION)	
	REFER TO PAGE 23 ATV 131 TO WORK OUT REQUIRED DENITRIFICATION CAPACITY	
	ASSUMED RAW SEWAGE NITROGEN CONCENTRATION:-	
	Total Kjeldahl Nitrogen Concentration	44 mg / l
	Required Nitrogen Level in Final Effluent	10 mg / l
	Required Nitrogen removal	34 mg / l
	Influent B.O.D. concentration at aeration stage	**417 mg / l**
	Biological Uptake of N in surplus sludge	0.05 kg/kg BOD
	N Concentration removal with surplus sludge	20.84 mg / l
	remaining N to be removed in Nitrification/denitrification process	23.16 mg / l
	Final Effluent N Standard	10.00 mg / l
	required Nitrogen removal	13.16 mg / l
	kg nitrogen per kg B.O.D.	**0.03**
	FROM TABLE 4 SELECT REQUIRED VALUE OF Vd / Vat TO ACHIEVE THE DESIRED RESULT	
	From calculations above , the ratio of kg nitrogen per kg B.O.D. =	0.03
	From table 4 the corresponding value of Vd / Vat (using upstream series Denitrification)	0.2
	SELECT SLUDGE AGE t_{ds} (SRT) FROM TABLE 2	
	REFER TO TABLE No.2 OF ATV STANDARD A131 (P.17)	
	With Nitrification and Denitrification (at 10 deg c)	
	V d / V at = 0.3	SRT = 10 DAYS (MINIMUM)
	V d / V at = 0.4	
	Looking at a lower operating temperature of say 8 **deg c** and using the formulae set out on page 62 of ATV 131 the following value for sludge age can be derived	
	$t_{ds\,(nitrification)} = 2.3 \times 2.13 \times 1.103^{(15-T)}$	8.00 days
	t_{ds} *(nitrif / denitrif) =tds(nitrification) / (1 - V d / V at)*	10.00 days
	SELECT tds > MINIMUM AT 10 DEGREES CENTIGRADE)	***10.00 days***

5	<u>**SELECT MLSS CONCENTRATION (D $_{SAT}$)**</u>	
	From Table 3 Page 19 ATV 131, For an Activated Sludge	
	System with primary sedimentation and also with nitrification /	
	denitrification MLSS (D $_{SAT}$) is normally taken as:	**2.5 - 3.5 kg / m³**
	SELECT MLSS (D $_{SAT}$)	***3.50 kg/m³***
6	<u>**CALCULATE SPECIFIC SURPLUS SLUDGE PRODUCTION**</u>	
	PRODUCTION OF SOLIDS =	
	SS_B x BOD LOAD AERATION TANK.	
	Where:-	
	$SS_B = SS_{BOD5} + SS_P$	
	SS_{BOD5} = Specified Solids Production (kg solids /kg BOD applied)	
	SS_P = Specified Chemical Sludge Production (kg solids /kg BOD applied)	
	due to chemical Phosphorous Removal. =	
	<u>***6.8P (influent) in kg / kg BOD5***</u>	
	BOD (influent)	
	Note: - In the case of the Dundalk Plant it is not proposed to remove	
	phosphates and therefore the "SSP" component is not applicable	
	Load to Activated Sludge plant	
	Flow	18088.00m³ / day
	BOD Concentration after Primary Settlement stage	417 mg / l
	BOD Load	7540.47kg B.O.D./day

	Suspended Solids Concentration after Primary Settlement stage (D_{SO})	2838.40kg SS /day
	Assumed Inlet Nitrogen(Ammonia)	44.00 mg / l
	Asumed inlet Phosphorous	12.00 mg / l
	Nitrogen / BOD ratio	**0.11**
	D_{SO} / BOD ratio	**0.38**
	Sludge Age (SRT)	**10.00 days**
	From Table 8 - P29 -of ATV131	
	By Interpolation of values in the table SS_{BOD5} =	***0.65kg / kg B.O.D.***
	From Above Formula , SSp =	
	$\dfrac{6.8P\ (\text{influent})\ \text{in kg / kg BOD5}}{BOD\ (\text{influent})}$	
	SSp=6.8 x 12/240	Not applicable
	$SS_B = SS_{BOD5} + SS_P$	**0.65kg / kg B.O.D.**
	PRODUCTION OF SOLIDS = SS_B x BOD LOAD AERATION TANK.	**4901.31kg/day**
7	**CALCULATE B_{DS} (= SLUDGE LOADING or F / M RATIO)**	
	$B_{DS} = 1 / (SS_B \times t_{DS})$	**0.15kg/kg/day**
	From Design Assumptions Above For Extended Aeration Activated Sludge Systems is normally taken as:	***<0.15***
	F / M IS WITHIN THIS RANGE	
	CALCULATE B_V (BOD5 VOLUMETRIC LOADING)	
	$BV = DS_{AT} / (SS_B \times t_{DS})$	0.54 kg BOD5 / m³ . d
	CALCULATE THE TOTAL VOLUME OF THE AERATION TANKS	
	$V_{AT} = Bd_{BOD5} / (B_{DS} \times DS_{AT}) =$	14,003.73m³
	$V_{AT} = Bd_{BOD5} / B_V =$	14,003.73m³
	Actual Volume provided	**14,100.00m³**
	RETENTION TIME @ DWF	**18.58 hours**
	RETENTION TIME @ 3 X DWF	**6.88 hours**
	A nominal retention period of at least 5h at D.W.F is required in conventional activated sludge systems to produce a final effluent to 20 / 30 standard	
10	**CALCULATE AERATION BASIN VOLUME**	
	V_{AT} = Total Volume of aeration tanks (Anoxic + Aerobic)	14,003.73m³
	Value of Vd / Vat (using upstream series Denitrification)	**0.2**
	V d = Volume of aeration tank (Denitrification Zone)	2,800.75m³
	V_N = Volume of aeration tank (Nitrification Zone)	11,202.98m³
	NUMBER OF BASINS	6 No.
	VOLUME PER BASIN V_{AT}	2,333.96m³

11	**SELECT AEROBIC BASIN CHARACTERISTICS**	
	BASIN VOLUME (AEROBIC) FROM STEP 10 ABOVE	11202.98m³
	NUMBER OF BASINS	6 No.
	LIQUID VOLUME PER BASIN	1867.16m³
	SELECT LIQUID DEPTH @ 5m FOR DIFFUSED AERATION	**5.00 m**
	SELECT TANK LANE WIDTH @	**7.18 m**
	REQD TANK LANE LENGTH	***52.01***
	FREEBOARD	**1.90 m**
	TOTAL TANK DEPTH	**6.90 m**
12	**SELECT ANOXIC BASIN CHARACTERISTICS**	
	BASIN VOLUME (ANOXIC) FROM STEP 10 ABOVE	2800.75m³
	NUMBER OF BASINS	6 No.
	LIQUID VOLUME PER BASIN	466.79m³
	SELECT LIQUID DEPTH @ 5m FOR DIFFUSED AERATION	**5.00 m**
	SELECT TANK LANE WIDTH @	**7.18 m**
	REQD TANK LANE LENGTH	***13.00 m***
	FREEBOARD	**1.90 m**
	TOTAL TANK DEPTH	**6.90 m**
	FINAL TANK DIMENSIONS	
	LANE WIDTH	**7.18 m**
	LIQUID DEPTH	**5.00 m**
	FREEBOARD	**1.90 m**
	TOTAL TANK DEPTH	**6.90 m**
	LANE LENGTH AEROBIC	**52.01 m**
	LANE LENGTH ANOXIC	**13.00 m**
	TOTAL LENGTH	**65.01 m**
	SAY	**65.0 m**
	Actual As- Built at Phase 2	
	MLSS RETURN RATE FOR DENITRIFICATION	
	ASSUMED RAW SEWAGE NITROGEN CONCENTRATION:-	
	Assumed Organic Nitrogen Concentration	19.00 mg / l
	Assumed Ammoniacal Nitrogen Concentration	25.00 mg / l
	Total Kjeldahl Nitrogen Concentration	**44 mg / l**
	N removal with surplus sludge	**20.8 mg / l**
	FINAL EFFLUENT NITROGEN :-	10 mg / l
	Nitrogen to be removed	13 mg / l
	BOD loading	417 mg / l
	Nitrogen to BOD ratio	0.03

V d / V at	0.2
%age removal reqd	29.90%
With reference to table No. 5 - P24 - ATV 131	
Minimum necessary return feed ratio @ 33% removal of nitrogen	0.5
Minimum necessary return feed ratio @ 50% removal of nitrogen	1
Required recirculation rate at calculated percentage removal value	**0.50**
It should be noted that this return feed ratio is the total of	
the Internal return circuit (Qri) and the external circuit (Qrs)	
as illustrated in the diagram on P.22 of Atv 131)	
Now from our design of the final settlement tanks we have determined that	
the ratio of return sludge to Incoming Flow, RV =	
DESIGN NOTE	
THE AERATION BASINS HAVE BEEN CONSTRUCTED SO THAT THE BAFFLE	
WALL THAT SEPARATES THE DENITRIFICATION ZONE FROM THE	
NITRIFICATION ZONE IS MOVEABLE AND CAN BE POSITIONED TO	
CORRESPOND WITH EITHER Vd / Vat = 0.4 OR Vd / Vat = 0.2	
THIS WILL ALLOW THE BASIN TO OPERATE INITIALLY ON A PARTIAL	
DENITRTIFICATION BASIS(FOR OPERATIONAL REASONS) ,AND TO INCREASE	
THE DENITRIFICATION PORTION OF THE BASIN IF IT IS THUS DICTATED BY	
LEGISLATION IN THE FUTURE.	
(SEE COMMENTS ON PAGE 23 OF ATV131)	
DETERMINE SLUDGE FLOW RATE WITH SELECTED VALUE OF SRT	
SLUDGE AGE OR SLUDGE RESIDENCE TIME (SRT) =	
Mass of sludge solids undergoing aeration	
(Mass of sludge solids wasted + Mass of solids lost in effluent) per day	
SRT = SLUDGE AGE (t_{DS}) = Vat x DS_{AT} / [(Qss.DS_{SS}) + (Qe.DSe)]	
where :-	
Vat = Volume in the aeration basin (m³)	14,003.73m³
DS_{AT} = MLSS concentration in aeration basin (mg / l)	**3,500.00 mg / l**
Qss = Sludge wastage rate (m³ / day)	?
DS_{SS} = MLSS concentration in the waste sludge stream (mg / l) *	**7,500.00 mg / l**
Qe = Q - Qss =Effluent discharge rate (m³ / day)	?
DSe = the Suspended Solids Concentration (mg / l) inthe effluent	**35.00 mg / l**
t_{DS} = Sludge Age in days	10.00 days
* *Note:- Settlement tank sludge will be @ 0.75% solids i.e MLSS of waste*	
sludge will be 7,500 mg / l.	
Q = D.W.F	18,088.00m³ / day
Qe = Q -Q ss	
THEREFORE, SUBSTITUTING Qe WITH Q - Qss	
SRT = SLUDGE AGE (t_{DS}) = Vat x DS_{AT} / [(Qss.DS_{SS}) + (Q.DSe - Qss.DSe)]	
HENCE	
Qss ={ (Vat x DS_{AT}/ t_{DS}) - (Q.DSe) } / (DS_{SS} - DSe) =	***571.76m³ / day***
WHICH EXPRESSED AS A PERCENTAGE OF DRY WEATHER FLOW =	***3.16%***

13	**CHECK ORGANIC LOADING**	
	organic loading = Q x BOD / Vat x 1000	
	where	
	BOD=60g BOD per capita @ 250l / h / d =(60/250) x 1000	416.88 mg / l
	V at = total liquid capacity of the aeration tank in m^3	14003.73m^3
	Q= rate of flow of influent wastewater to the tank in m^3 / day	18088.00m^3 / day
	Organic Loading =	**0.54 kg BOD / m^3 / day**
	For Extended Aeration Activated Sludge Systems is normally taken as:	
	Organic Loading is therefore in the correct range.	
14	**SELECT METHOD OF AERATION**	
	Fine Bubble Diffused Aeration is selected for the following reasons	
a	Lower running costs	
b	Lower Maintenance costs (Less Cleaning of walls,Main Motive units can be serviced outside of tanks etc.)	
c	Safer from a health point of view.(no Aerosols)	
	CALCULATE QUANTITY OF OXYGEN REQUIRED TO BE TRANSFERRED TO MIXED LIQUOR. FOR CARBONACEOUS AND NITROGENOUS OXIDATION	
	OL = $\frac{Co}{Co-Cx}$ (OVc . fc + OVn . fn) in kg O2/kg BOD 5	
	where	
	OVc= Specific Carbonaceous Oxygen Uptake Rate.	
	OVn = Nitrogenous oxygen uptake rate	
	= (4.6 NO3-Ne + 1.7 NO3-Nd)/BOD5 infl.) in kg O2/kg BOD	
	fc = Peak Factor Allowed for hourly variations	
	fn = Peak Factor Allowed for hourly variations in Nitrogenous Oxygen Demand	
	Co = O2 saturation Dependant on t ° c	
	Cx = Required O2 concentration in the aerobic part of the plant	
	NO3-Ne = Final Effluent Nitrogen Concentration	
	NO3-Nd = Denitrified Nitrogen Concentration	
	Raw Sewage B.O.D. Concentration:-	416.88 mg / l
	Operating Temperature =	10.00 °C
	REFER TO ATV 131 STANDARD TABLE 9. P.31	
	Select OVc from table of SRT vs Temperature (By interpolation)	***1.04***
	REFER TO ATV 131 STANDARD TABLE 10. P.31	
	Select fc =	***1.20***
	Select fn =	***1.80***
	Nitrogen Concentration in Raw Sewage	44.00 mg / l
	NO3-Ne = Final Effluent Nitrogen Concentration	10.00 mg / l
	NO3-Nd = Denitrified Nitrogen Concentration	**13.16 mg / l**
	REFER TO TABLE 5.1 OF REF B (N.F. GRAY.)	REF.B TABLE 5.2
	Select Co from Table of Temperature vs DO	**11.30 mg / l**
	Select Cx	**2.00 mg / l**

	OVn =	**0.16kg O2 / kg B.O.D.**
	Then OC Load =	**1.88kg O2 / kg B.O.D.**
	POPULATION EQUIVALENT x BOD / CAP / DAY / ***1000***	**7540.47kg B.O.D./day**
	Total O2 required to Mixed Liquor =	**14138.82kg/day**
	CALCULATE O2 REQUIRED AT STANDARD CONDITIONS	
	OC reqd at standard conditions = $\frac{OC}{\alpha.\beta}$	
	SELECT VALUE OF ALPHA	**0.72**
	SELECT VALUE OF BETA	0.9
	OC reqd at standard conditions =	***21819.17kg/day***
14	**CALCULATE POWER REQUIREMENTS**	
	PREDICTED EFFICIENCY OF AERATION SYSTEMS	
	Fine Bubble Diffused Aeration to Mixed Liquor	1.00 kgO2/kwH
	Fine Bubble Diffused to Aeration at Standard Conditions	1.25 kgO2/kwH
	kw Required for Fine Bubble Diffused Aeration to Mixed Liquor	14138.82 kgO2/kwH
	kw Required for Fine Bubble Diffused Aeration at Standard Conditions	17455.34 kgO2/kwH
	Quantity of Air Blowers	6 Nr.
	Duty Air Blowers	4 Nr.
	Standby Air Blowers	2 Nr.
	AIR BLOWER REQUIREMENTS	
	Absorbed Power per Unit per Hour for Aeration	147.28 kw
	Motor Efficiency	90%
	Overload Factor	1.1
	Required Power	163.64 kw
	Shaft Power Required	180.01 kw
	Yearly Operating Cost at €0.1147/kwh	€313,275.39
	Yearly Operating Cost relating to Upgrade Portion only	€166,243.40
	Shaft Power Required	**180 kW**
	Nearest Motor Size	**180 kW**
	DIFFUSERS	
	Total Air Flow	16805.17 m3/hr
	Air Flow Per Blower	4201.29 m3/hr
	Air Flow per Tank	2800.86 m3/hr
	Air Flow per Diffuser	3.00 m3/hr
	No. of diffusers required per tank	934
	Area of each diffuser	.025 m2
	Total Area of Diffusers	23.34 m2

Area of Aerobic Basin	373.43 m2
Diffuser Density with Vd/Vat = 0.3	6.25 %
CRITICAL MINIMUM AIR FLOW RATE FOR MIXING (AEROBIC ZONE)	
Area of Aerobic Basin	373.43 m2
Critical Minimum Air Flow Rate for Mixing (Aerobic Zone)	1.50 m/hr
Minimum Air Flow	560.15 m3/hr
ANOXIC ZONE MIXING REQUIREMENTS	
Anoxic Zone Liquid Volume	466.79 m3
Minimum Mixing Requirement @ 10w/m3 of liquid volume	4.67 kW
Mixer Absorbed Power	4.7 kW
Motor Efficiency	80.00%
Overload Factor	1.1
Shaft Power Required	6.42 kW
Nearest Motor Size	8 kW
HEADER PIPEWORK	
Total air flow rate in header pipe	16805.17 m3/hr
	4.67 m3/s
This equates to a Compressed Air Flow Rate of	2.82 m3/s
Recommended Velocity	6.00 m3/s
Cross Sectional Area of Branch Pipe	0.47 sq m
Diameter of Branch Piepes	0.77 m
say	**0.80 m**
Anoxic Zone Mixing Requirements	
Anoxic Zone Liquid Volume	466.79m³
Minimum Mixing Requirement@ 10w / m³ of liquid volume	4.67 kW
Mixer Absorbed Power	4.67 kW
Motor Efficiency	**90%**
Overload Factor	**1.1**
Shaft Power Required	**5.71 kW**
Nearest Motor Size	**6.00 kW**
DESIGN OUTPUTS	
QUANTITY OF AERATION BASINS REQUIRED	6 No.
MAXIMUM FLOW TO EACH BASIN	16731.40m³ / day
TOTAL DAILY BOD LOAD	7540.47kg B.O.D./day
SELECTED SLUDGE RESIDENCE TIME	10.00 days
SELECTED MLSS CONCENTRATION	3.50 g / l
BIOLOGICAL SLUDGE PRODUCED	0.65kg / kg B.O.D.
CHEMICAL SLUDGE PRODUCED	Not Applicable
TOTAL SURPLUS SLUDGE SOLIDS PRODUCED	4901.31kg/day
F / M RATIO	0.15kg/kg/day
HYDRAULIC RETENTION TIME @ D.W.F.	18.58 hours
AERATION (AEROBIC) LIQUID VOLUME REQUIRED	11,202.98m³
HYDRAULIC RETENTION @ MAXIMUM FLOW	6.88 hours
SLUDGE FLOW RATE	571.76m³ / day
SLUDGE FLOW EXPRESSED AS A PERCENTAGE OF DWF	3.16%
ADDITIONAL ANOXIC ZONE LIQUID VOLUME	2,800.75m³
TOTAL VOLUME ANOXIC AND AEROBIC	14,003.73m³
ORGANIC LOADING	0.54 kg BOD / m³ / day
AERATION SECTION OF BASIN CHARACTERISTICS	

	NUMBER OF BASINS	6 No.
	LIQUID VOLUME PER BASIN	1867.16m³
	SELECT LIQUID DEPTH @ 5m FOR DIFFUSED AERATION	5.00 m
	SELECT TANK WIDTH @	7.18 m
	REQD TANK LENGTH	52.01
	FREEBOARD	1.90 m
	TOTAL TANK DEPTH	6.90 m
	ANOXIC SECTION OF BASIN CHARACTERISTICS	
	BASIN VOLUME (ANOXIC) FROM STEP 12 ABOVE	2,800.75m³
	NUMBER OF BASINS	6 No.
	LIQUID VOLUME PER BASIN	466.79 m3
	SELECT LIQUID DEPTH @ 5m FOR DIFFUSED AERATION	5.00 m
	SELECT TANK WIDTH @	6.00 m
	REQD TANK LENGTH	15.560 m
	FREEBOARD	1.90 m
	TOTAL TANK DEPTH	6.90 m
	FINAL TANK DIMENSIONS	
	WIDTH	7.18 m
	LIQUID DEPTH	5.00 m
	FREEBOARD	1.90 m
	TOTAL TANK DEPTH	6.90 m
	LENGTH AEROBIC	52.01 m
	LENGTH ANOXIC	15.560 m
	TOTAL LENGTH	67.57 m
	SAY	67.6 m
	TOTAL O2 REQUIRED TO MIXED LIQUOR	14138.82kg/day
	ALPHA FACTOR	0.72
	BETA FACTOR	0.90
	TOTAL O2 REQUIRED AT STANDARD CONDITIONS	21819.17kg/day
	QUANTITY OF AIR BLOWERS	6 No.
	AIR BLOWER MOTOR SIZE	180.00 kW
	ANOXIC ZONE MIXER SIZE	8.00 kW
	qa' (Air Flow Rate)	16805.17 m3/hr
	Air Flow per Blower	4201.29 m3/hr
	Air Flow per diffuser	3.00 m3/hr
	Number of Diffusers per tank	934 Nr.
	Area of each Diffuser	.025 m2
	Total Area of Diffusers	23.34 m2
	Area of Aerobic Basin	373.43 m2
	Diffuser Density	6.25 %

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DESIGN OF FINAL SETTLEMENT TANKS

	ATV STANDARD A 131 - P. 33	**Phase 1A Upgrade**
	SLUDGE VOLUME INDEX SVI	$\leq$ 180 ml / g
	COMPARATIVE SLUDGE VOLUMES CSV	$\leq$ 600 ml / l
	RETURN SLUDGE FLOW Q_{RS}	$\leq$ 1.5 Q_T
1	**SLUDGE VOLUME FLOW RATE qSV**	
	ATV STANDARD A 131 - P. 36 para 4	
	$q_{sv} \leq$ 500 l / (m².h) for DS_e < 20 mg / l	500.00 l / (m².h)
2	**SURFACE FLOW RATE q_A**	
	ATV STANDARD A 131 - P. 35 para 4.2.2	
	qA = qsv / CSV = qsv / DS_{AT} *SVI	
3	**SLUDGE VOLUME INDEX SVI**	
	SVI is selected from the table on p.36 based on values of B_{DS} used in the aeration basin design	
	B_{DS} =	0.15kg/kg/day
	From Table on p.36 (or FM Ratio from previous calcs)	
	SVI (Wastewater with high organic commercial parts) =	99.50 ml / g
4	**DRY SOLIDS CONTENTS IN AERATION TANKS D_{SAT}**	
	based on values used in design of the aeration basins, DS_{AT} =	3.50 kg/m3
	SURFACE FLOW RATE q_A	
	qA = qsv / CSV = qsv / DS_{AT} *SVI =	**1.44 m³ /m² / hour**
5	**RECIRCULATION RATIO RV**	
	DRY SOLIDS CONTENT OF THE RETURN SLUDGE DS_{RS}	
	* Note:- Settlement tank sludge will be @ 0.5% solids i.e MLSS of waste sludge DS_{RS} will be 5,000 mg / l.	8.00 kg/m³
	From Fig .1 p. 38 ATV 131	
	RV =	**0.9**
6	**DRY SOLIDS CONTENT ON THE SECONDARY SEDIMENTATION TANK FLOOR DSTF**	
	ATV STANDARD A 131 - P. 40	
	for blade scrapers DS_{RS} is approximately equal to 0.7*DS_{TF}	
	DS_{TF} =	**11.43 kg/m³**
7	**NECESSARY THICKENING TIME t_t in h FOR DS_{TF}**	
	From Fig .2 p. 40 ATV 131 t_t = (DS_{TF}*SVI/1000) ^3	1.47 hours
8	**SETTLEMENT TANK DIMENSIONING TO ATV 131 STANDARD.**	
	Height of Clear Water Zone.	
	h_1 = Fixed value in m	
	Height of Separation Zone.	
	h_2 ={ 0.5.qA (1 + RV) } / {1 - CSV / 1000 }	
	Calculate a a value for CSV	
	qA = qsv / CSV => CSV = q_{SV} / qA	
	h_2 =	
	Height of Storage Zone.	
	h_3 ={ 0.45.qSV (1 + RV) } / 500	

	Height of Thickening and Removal Zone.	
	h4 = { qSV (1 + RV) t_t } / C	
	Select a value for **C** (Concentration value depending on the sludge thickening time), from table on p.44 of ATV 131.	
	h4 =	
	NECESSARY SECONDARY SEDIMENTATION TANK DEPTH	
	h tot	
	h tot selected.	
9	**REVIEW FLOWS**	
	DRY WEATHER FLOW	*18,088.00 m³ / day*
	3 x DRY WEATHER FLOW	48,837.60 m³ / day
	MAXIMUM FLOW	**48,837.60 m³ / day**
10	**SELECT NUMBER OF TANKS REQUIRED**	
	NUMBER OF TANKS REQUIRED	**2 No.**
11	**SURFACE FLOW RATE q_A =**	1.44m³ /m² / hour
	THEREFORE TOTAL SURFACE AREA REQUIRED	2932.00 m²
	CHECK UPWARD FLOWRATE AT D.W.F.	0.26m³ /m² / hour
	NUMBER OF TANKS REQUIRED	2 No.
	SURFACE AREA PER TANK A_{ST}	1466.00 m²
	TANK DIAMETER	43.20 m
	NEAREST WHOLE NUMBER DIAMETER	**43.20 m**
	TANK CIRCUMFERENCE	135.7 m
	MAXIMUM OVERFLOW RATE	179.92m³ /m / day
	OVERFLOW RATE AT DWF	66.64m³ /m / day
	VOLUME OF SLUDGE CONE	
	ASSUME DEPTH OF SLUDGE CONE	2.16 m
	ASSUME TOP DIAMETER OF SLUDGE CONE	3.20 m
	ASSUME BOTTOM DIAMETER OF SLUDGE CONE	2.68 m
	THEN TOTAL VOLUME OF SLUDGE CONE	**14.68m³**
	VOLUME OF MAIN HOPPER	
	ASSUME DEPTH OF MAIN HOPPER	2.63 m
	ASSUME TOP DIAMETER OF MAIN HOPPER	43.20 m
	ASSUME BOTTOM DIAMETER OF MAIN HOPPER	3.20 m
	THEN TOTAL VOLUME OF MAIN HOPPER	**1388.78m³**
	FLOOR SLOPE OF MAIN HOPPER	**7.50 degrees**
	VOLUME OF REMAINING SECTION	**2,199.00m³**
	TOTAL VOLUME OF ONE SETTLEMENT TANK	**3,602.46 m³**
	TOTAL VOLUME OF ALL FINAL SETTLING TANKS	**7,204.92m³**
12	***CHECK HYDRAULIC RETENTION TIME @MAXIMUM FLOW***	***3.54 hours***
13	***CHECK HYDRAULIC RETENTION TIME @MINIMUM FLOW***	***9.56 hours***
14	**DESIGN OF SUPERNATENT CHANNEL**	
	SELECT SUPERNATENT CHANNEL WIDTH	0.60 m
	INTERNAL DIAMETER OF TANK	43.2 m
	THICKNESS OF WALLS (2 x 0.3)	0.60 m
	RADIUS AT CENTRE LINE OF CHANNEL	43.8 m
	LENGTH OF CHANNEL @ C.L.(= CIRCUMFERENCE @ C.L. RADIUS)	
	LENGTH OF HALF CHANNEL	
	ALLOW A FALL OF 100mm => SLOPE OF 1 in	
	ALLOW A FALL OF 125mm => SLOPE OF 1 in	
	ALLOW A FALL OF 150mm => SLOPE OF 1 in	
	ALLOW A FALL OF 200mm => SLOPE OF 1 in	
	ALLOW A FALL OF 250mm => SLOPE OF 1 in	

SELECT VELOCITY IN SUPERNATENT CHANNEL	1.1 m / s
Q = AV	
Qmax / day =	48,838m^3/day
Q max Per Tank / day =	24,419m^3/day
Q max /sec	0.1413m^3 / sec
=> Area Required	0.13 m2
AssumeChannel Width = W =	0.60 m
Then channel **depth** =	0.218 m
m= hydraulic mean depth =area of cross section of flow / wetted perimeter	
=A / w.p	0.126254826
where w.p . = W+2D	
Chezy Coefficient C = 1/n . m^(1/6)	
n = 0.015 for ordinary concrete	0.0150
=>C=	47.22
NOW:- Q = AC $\sqrt{mi}$	
=> $(Q / AC)^2$ = mi =	0.000523495
=> i =	0.004146333
Slope of channel required = 1 in	**241**

Appendix L

[Design Information on Full-scale 'SHARON' systems located throughout the Netherlands (sourced from Mulder *et al.* 2006).]

SHARON Plant	Commissioned	Main Plant Capacity (P.E.)	Main Plant Treatment Type	Max. Loading (kg N/d)	Design Loading (kg N/d)	% N load as compared with main plant	Inlet Concentration (mg NH4-N/l)	Design Flow (m^3/d)	Max. Flow (m^3/d)	Application	Reactor Configuration	ART (Days)
Utrecht	1997	400,000	2 Stage AS	900	420	15	500 - 700	840	1500	centrate	2 tanks	3 to 6
Rotterdam-Dokhaven	1999	470,000	2 Stage AS	830	540		1,000 - 1500	760	1200	centrate	single	1.3 to 1.8
Zwolle	2003	200,000		410	420	15-20	400 - 600	600	720	centrate	2 tanks	1.3 to 1.8
Beverwijk	2003	326,000		1,200	900	30	700 - 900	900	1200	centrate/drying	2 tanks	1.3 to 1.8
The Hague-Houtrust	2005	930,000		1,300			900 - 1200			centrate	single	1.5 to 1.8
Groningen-Garmerwolde	2005	300,000		2,400		34	700 - 800			centrate/drying	2 tanks	1.4 to 1.5

Mulder et al. 2006
...s with sludge drying, the condensate can have temperatures of up to 70deg C, thus a cooling system is necessary
...ons with relatively low wastewater temperatures (below 25deg C) and low inlet concentrations (below 700mg NH_4-N/l) may need additional heating
...onal heating may be sourced through on site biogas

...ON Plant	Anoxic Retention Time in Days (USEPA)	Volume (m^3)	Combined Reactor Volume (m^3)	Ammonia Removal %	TN Removal %	pH	pH Control	Oxygen (mg/l)	Influent Temperature Range	Heating/ Cooling Equip. Installed	Comments
...ht	1.25	3,000/1500	4500	90 - 95			methanol		20 to 30	Heat Exchanger	Heat Exchanger decommissioned. Not required.
...dam-Dokhaven	0.5 - 1.4	1800	1800	85 - 98	>95%	6.8-7.2	methanol	1.0 - 1.5		Heat Exchanger	
...e		900/450	1350	85 - 95							
...wijk		1500/750	2250	94	88%						
...ague-Houtrust		2000	2000	85 - 98	>95%		no caustic reqd.			No	
Groningen-Garmerwolde		4900/2450	7350	> 95	>95%						