Environment Agency

Transforming wastewater treatment to reduce carbon emissions

Report: SC070010/R2

Resource efficiency programme

Evidence Directorate

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This report is the result of research commissioned and funded by the Environment Agency.

Published by:
Environment Agency, Rio House, Waterside Drive, Aztec West, Almondsbury, Bristol, BS32 4UD
Tel: 01454 624400 Fax: 01454 624409
www.environment-agency.gov.uk

ISBN: 978-1-84911-152-2

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Dissemination Status:
Released to all regions
Publicly available

Keywords:
Wastewater treatment, Water Framework Directive, carbon critical design

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Project Number:
SC070010

Product Code:
SCHO1209BRNZ-E-P

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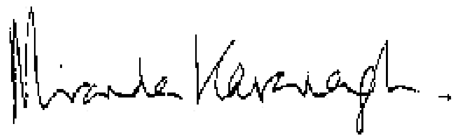

Miranda Kavanagh

Director of Evidence

Executive Summary

Without intervention, increased wastewater treatment under the Water Framework Directive (WFD) is likely to increase carbon dioxide (CO_2) emissions by over 110,000 tonnes per year from operational energy use and emissions associated with the additional processes required. This is a small increase with respect to the water industry's carbon footprint of five million tonnes (2007/2008), but the increase more than doubles the operational and capital emissions of individual works that require additional processes.

Options to offset this increase over the long–term do exist. Improved operational efficiencies, reducing the reliance on end of pipe solutions and minimising pumping and treatment of surface water runoff are part of suite of strategies which need to be considered. For example widespread use of enhanced anaerobic digestion with combined heat and power (CHP), and of energy-optimised activated sludge, could result in savings of over 102,000 tonnes of CO_2 a year, assuming 50 per cent optimisation in the industry. Using the estimate of 30 per cent of flow to a wastewater treatment works (WwTW) due to surface runoff, a further carbon saving of 110,000 tonnes of CO_2 a year could be made if WwTW do not pump storm water. There will be associated savings in treatment costs, depending on the processes used. This study has not considered the impact of future decarbonisation of UK grid energy mix on emissions.

Barriers to these potential carbon savings constitute a change or upgrade in the processes or technology currently used; proposed reductions in the Renewable Obligation Certificate value for anaerobic digestion; and the cost and disruption of diverting all runoff to surface water, which is likely to be disproportionate.

Before the carbon consequences of the WFD can be fully appreciated, and process improvements determined, there needs to be a detailed understanding of the standards that the water industry will face. This includes appreciation of how the Environment Agency translates Environmental Quality Standards (EQS) into discharge consents and links in-river chemistry to aquatic ecology, as well as application of the no-deterioration policy. Therefore, when the Environment Agency considers disproportionate cost and technical feasibility, it should also consider the mitigation steps that will be required to offset the carbon impact.

Treatment examples in this report have not been shown to match the treatment performance required to meet specific EQS. Therefore, this study only provides an indication of the potential issues and solutions.

The programmes of measures to meet WFD requirements will include management of point sources and diffuse pollution. Reducing carbon emissions while still meeting WFD obligations will require detailed understanding and optimisation of the carbon impact at the design stage. Potentially viable techniques in AMP5 are operational carbon savings; on-site power generation; supply chain management; and benchmarking.

Longer term, five key strategies that the water industry and partners could adopt to mitigate the carbon impact of the WFD are outlined here. These include **source control**, which may bring the greatest carbon savings as treatment is not required. However, the water industry has limited powers in this area. The **least-carbon end-of-pipe/process addition** strategy aims to find the least-carbon solution, acknowledging the embodied and operational carbon emissions that will be associated with additional treatment. The **increased operational efficiencies** strategy reduces demand for power through better design in the catchment, optimising the management of sewage and any combined wastewater systems to WFD criteria. **Redeveloping existing**

treatment processes focuses on switching conventional processes to lower energy alternatives. This strategy has the potential to both reduce the effluent concentration of pollutants and reduce carbon, but also presents the greatest problems. The **renewable energy generation** strategy aims to reduce operational emissions through on-site generation of energy or within the water industry asset base.

The WFD itself does not provide incentives for water companies to invest in low carbon solutions. Instead the price of energy, Climate Change Act targets for UK emission reduction, Carbon Reduction Commitment (CRC) trading scheme, and reporting requirements to include the Shadow Price of Carbon (SPC) in new scheme appraisal, may drive water companies to invest in catchment plans for carbon reduction.

The SPC now also feeds into cost-benefit analysis. However, compared to the very significant capital costs of schemes, the SPC may not offset the increased capital costs of a least-carbon solution and no case will be made for the investment. Government is currently reviewing the SPC in the context of recent UK climate change emission reduction targets.

Under the current funding regime, the savings associated with an operational efficiency can only be regarded as additional profit by the water company until the end of each periodic review (five years). After this time, the efficiency is considered base operation and the savings passed to the customer. Consequently if the industry invests in low carbon technology with income arising from efficiencies then it may only have five years to payback. However, low carbon technologies included within price limits as part of the price review cycle are valued in payback terms over their whole lives.

Recommendations

- Joint work between the water industry and Environment Agency investigating pollution source apportionment and modelling catchments to assess the associated risks should consider the carbon impacts of the proposed programmes of measures to determine the least-carbon solutions.
- Source control through product use should be considered for substances that come in contact with water**,** such as plasticisers that may drive the need for end-of-pipe treatment.
- The potential of sustainable drainage schemes to reduce emissions from water pumping and end-of-pipe treatment should be further investigated, and include local authorities, highways and other agencies that may be able to influence the management of surface water.
- The studies proposed for AMP5 to address the knowledge gap in the performance of existing technologies and end-of-pipe solutions to remove substances should include a detailed assessment of the carbon implications and of the potential impact on sludge management.
- The water industry reviews its trade effluent consenting and charging policies such that, where appropriate, trade effluent controls and charges are aligned under the 'polluter pays' principle. Some sectors may be required to make significant financial contributions, and while this may be an incentive to control emissions it may also lead to carbon-inefficient on-site treatment at the trader site. It is therefore recommended that whole carbon lifecycle risks are assessed for such changes in water industry policy.

- The Environment Agency should undertake environmental regulation in a more holistic manner, where the setting of consents is considered within a framework to ensure the potential carbon emissions of meeting EQS are understood and factored into the consenting regime.
- The Environment Agency continually reviews guidance on how WFD consenting will be regulated, so that the water industry is able to investigate potential efficiencies without the risk of failing consents. When considering disproportionate cost and technical infeasibility, the mitigation steps required to offset the carbon impact should also be considered.
- Research is needed on how major process changes will affect existing systems including whole lifecycle carbon costs, but these site investigations may be time-consuming and extensive. Methods to efficiently assess the carbon impact of redeveloping existing treatment processes should be developed.
- Further understanding is needed on how sludge make-up from new WFD-related treatment processes will affect existing sludge processes and hence CHP opportunities. The proposed AMP5 studies should consider sludge management impacts on the function of CHP.
- The combustion of biogas should be considered for regulation under Environmental Permitting Regulations and a review should be carried out to ensure that biodegradable waste can be used as digester feed.
- A study should be carried out to fully investigate opportunities for renewable energy generation across water industry functions and any blocks imposed by regulation.

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Glossary of Terms

BERR	Department of Business, Enterprise and Regulatory Reform
BLM	Biotic Ligand Models
BOD	Biochemical Oxygen Demand
BWD	Bathing Water Directive
CBA	Cost-Benefit Analysis
CCA	Climate Change Act
CCC	Committee on Climate Change
CO_2	Carbon dioxide
COD	Chemical Oxygen Demand
CRC	Carbon Reduction Commitment
CSO	Combined Sewer Overflow
DEHP	Di(2-ethylhexyl) phthalate
EDC	Endocrine-Disrupting Chemical
EQS	Environmental Quality Standards
GAC	Granular Activated Carbon
HD	Habitats Directive
M&E	Mechanical and Electrical
MBR	Membrane Biological Reactor
p.e.	Population equivalents
PLC	Programmable Logic Controller
PR	Periodic Review
PS DD	Priority Substance Daughter Directive
RAS	Return Activated Sludge
ROC	Renewables Obligation Certificate
SPC	Shadow Price of Carbon
SUDS	Sustainable Drainage Systems
TBT	Tributyltin
Tot-P	Total Phosphorus
TSS	Total Suspended Solids
UKWIR	United Kingdom Water Industry Research
UWWTD	Urban Wastewater Treatment Directive
WFD	Water Framework Directive
WIA	Water Industry Act
WwTW	Wastewater Treatment Works

1 Introduction

1.1 The water industry and the Water Framework Directive

Over 10 billion litres of sewage are produced every day in England and Wales (Ofwat, 2006). To treat this volume of sewage required approximately 2,800 GWh of energy in 2006/07, equating to 1.7 million tonnes of greenhouse gas emissions (Water UK, 2007a). Across the whole of the water industry (potable and wastewater), 515 GWh of renewable electricity was generated, and 13 per cent of the energy demand was met by renewable sources. The electricity demand required to treat sewage is expected to increase in the future as the population grows and consent standards tighten.

The Water Framework Directive (WFD) is an overarching piece of legislation which came into force in 2000 and is likely to drive investment in the water industry. It aims to achieve “good ecological status” in inland and coastal waters through River Basin Management Planning. Within the WFD are regulations relating to Annex X substances (priority and priority hazardous substances) and Annex VIII substances (including nutrients and endocrine-disrupting substances). These substances have, or will have, environmental quality standards (EQS) that will need to be complied with to meet the requirements of the WFD. Many of these substances are released to the aquatic environment from diffuse (such as agriculture and surface water runoff) and point (such as industrial inputs, wastewater treatment works (WwTW)) sources. WwTW are not a significant producer of the substances themselves, rather, the substances are present in the sewage that is accepted by WwTW. Sources to sewer include diffuse inputs from domestic and commercial properties (for example, use of cleaning chemicals, copper and lead water pipes, and laundry products) and road runoff, with point inputs from individual companies.

The tightening of discharge consents under the WFD, due to the tighter EQS, will make significant investment necessary at WwTW unless more effective source control measures, in the widest sense, can be implemented. However, lower quality objectives may set but only if it can be shown that control measures will be disproportionately costly and/or technically unfeasible.

Further investment at WwTW in techniques to treat effluent to the required level may result in more energy-intensive processes, and as a direct consequence will result in greater carbon emissions by water companies. In the recent UKWIR WW17 study led by Atkins (UKWIR, 2008a), it was estimated that if end-of-pipe treatment was required for priority substances, as listed in the daughter directive, significant increases in greenhouse gas emissions could be expected from the water industry.

Recent studies for the water industry and the Environment Agency have shown that the WwTW potentially requiring additional treatment under the WFD, at least for priority substances, are not equally spread amongst the ten combined water and sewerage companies in England and Wales (UKWIR, 2008a; Environment Agency, 2008a). Thames Water, Severn Trent Water and Anglian Water are likely to have the greatest number of WwTW requiring additional treatment, with Dwr Cymru, Northumbrian Water and South-West Water the least. The principal driver for this is the available dilution capacity of the receiving water body. In simplified terms, the Environment Agency’s consenting policy uses a combination of the EQS, the upstream concentration of the substance and the available dilution to derive a numeric consent for a treatment works.

Therefore, the size of the discharge in relation to the size of the receiving water body is important in understanding which of the WwTW would need to be upgraded.

Priority substances are not the only parameters of concern. There are also significant concerns under the WFD over phosphorous and nitrates, ammonia, endocrine-disrupting chemicals (EDCs) and other pollutants. The Habitats Directive places further requirements for the removal of nutrients. Treatment of these different parameters cannot be considered in isolation. In some cases additional treatment for one substance will lead to reductions in others; however the co-treatment of substances has not been fully investigated and multiple additional treatments may be required at some sites.

If the objectives of the WFD are to be achieved, options for lower carbon treatment techniques at end-of-pipe, and alternative catchment solutions (including source control measures) must be considered.

This report presents the results of a study on whether the WFD will inevitably increase carbon emissions from the water industry, or if alternative low-carbon treatment methods or catchment solutions could be used to reduce or offset these emissions.

2 Aims

The overall aim of this project was to gather information on energy and carbon emissions for the treatment and pumping of wastewater, to guide Environment Agency thinking on whether compliance with the WFD will inevitably increase carbon emissions from the water industry.

The key objectives of the work were to:

- Review current and emerging legislation on water quality standards.
- Identify low carbon strategies, including new technology and catchment/upstream interventions with carbon benefits.
- Assess the suitability of these techniques on carbon/energy requirements to achieve water quality standards, including effects on both the average and variance of concentrations.
- In agreement with the Environment Agency, draw up a list of wastewater treatment methods to be considered individually and in combination.
- Present scenarios developed and explain the reductions achievable by different measures.
- Provide conclusions and recommendations on the technologies and options available, along with the regulatory barriers to be addressed and issues remaining.

2.1 Approach and structure of this report

The main purpose of this report is to guide thinking on how the WFD will influence carbon emissions from wastewater treatment and what options are available to reduce or mitigate these.

First, the regulatory drivers behind investment in wastewater treatment are summarised, including the WFD and the Government's Water Strategy. Drivers for reducing carbon emissions within the water industry are also outlined.

Then, five key strategies that the water industry could adopt to minimise the carbon impact of the WFD are considered. Each of these strategies is examined and, where possible, more detail or examples are given of how they may be developed. Gaps in knowledge that may prove potential barriers to the successful adoption of the strategies are highlighted.

Options available in the short-term are discussed in more detail. The timeframe for this review is nominally set as being within AMP5. However, the report identifies and discusses barriers that will need to be overcome to permit this timeframe.

Having established the background of options available to the water industry, the report determines the current carbon baseline and assesses the carbon impact of the WFD. Three response scenarios are used to determine if the carbon impact of the WFD can be mitigated.

The report presents conclusions from the assessment and recommendations to generate a carbon mitigation response to the WFD.

3 Regulatory drivers

3.1 Current and emerging legislation

3.1.1 Water quality and quantity

The timing and requirement of different pieces of legislation will influence the investment decisions taken by the water industry. Forming a long-term plan could allow more sustainable options to be implemented via investment and policies. In addition, the Climate Change Act (2008) and related obligations should encourage water companies towards low-carbon options to meet the required effluent standards.

The water industry is governed by a number of regulations, the most important of which include:

- The Urban Wastewater Treatment Directive (UWWTD) concerning the level of treatment at a works and the removal of nutrients and basic sanitary parameters.
- The Bathing Water Directive (BWD) covering discharges to designated bathing water beaches and levels of bacteria.
- The Habitats Directive (HD) regarding the designation of protected “Natura 2000” sites. This directive covers discharges into the protected areas and reviews current and proposed discharge permissions. Levels of nutrients, toxic substances and the organic load of a discharge are regulated.
- The Water Framework Directive (WFD) providing an overarching framework for water management. The Priority Substance Daughter Directive (PS DD) states the key 33 substances and their EQS that must be achieved in water bodies. Good ecological status must also be achieved, influencing the discharge of parameters other than those covered by the PS DD. The WFD will result in the repeal by 2013 of the Groundwater Directive (80/68/EEC), the Surface Water Directive (77/795/EEC), the Freshwater Fish Directive (78/659/EEC), the Shellfish Water Directive (79/923/EEC) and the Dangerous Substances Directive (80/68/EEC). The obligations under these directives will be incorporated into the WFD.
- The Water Industry Act (WIA) dealing with the supply of water and provision of sewerage including obligations on the water companies to accept trade waste. Emission-reporting requirements under the Pollution Inventory are also issued for England under the WIA.

The requirements of these directives work together to determine the effluent quality required from a WwTW.

3.1.2 Demand management

In addition to these legal obligations, the Government’s Water Strategy (Defra, 2008a) sets out its vision for the water sector until 2030. It aims to improve efficiency, reduce demand and decrease wastage. As far as wastewater treatment is concerned, the key proposals include:

- Average consumption by 2030 anticipated to be 130 litres per person per day. The Government is confident that this will be achieved with today's technology for metering, tariffs and water efficiency. The Government, however, hopes that per capita consumption will reduce further to an average of 120 litres per person per day with improvements in technology and further innovation. The current level of usage is approximately 150 litres per person per day.
- New proposals to tackle contaminants at source (for example phosphorus in detergents).
- Promotion of sustainable drainage systems (SUDS).

In addition to the Water Strategy, Defra also issued Statutory Social and Environmental Guidance to Ofwat (Defra, 2008b). This guidance sets out how the Government expects Ofwat to contribute to key areas of social and environmental policy in the regulation of the water industry in England. The Welsh Ministers issued separate guidance for operations wholly in Wales. The key issues for England include:

- Greater emphasis on climate change mitigation and adaptation.
- New consideration for arrangements for surface water drainage.
- Water quality to remain a priority with particular focus on catchment-scale approaches and tackling diffuse pollution at source (as required under the WFD).

With regards the second point, Ofwat is expected to play a major role in encouraging more sustainable management of surface water drainage. As set out in current guidance on water charging, this should include encouraging water companies to develop area-based charges for the surface water drainage of business premises. This could be an effective way to promote SUDS and reduce storm flow discharge to WwTW.

Although managing the demand for water may, in the domestic scenario, lead to higher concentrations of household effluent, this may not significantly impact on its treatability as the difference in concentration may not be significant. However, the control of surface water drainage may significantly reduce the need for pumping and may permit treatment of relatively clean storm flow via SUDS rather than diluting the much dirtier sewage.

3.1.3 Carbon emissions and accounting

The Carbon Reduction Commitment (CRC) was announced in the Energy White Paper of 2007 (DTI, 2007), and is a mandatory UK cap-and-trade scheme, targeting carbon emissions from energy use from large non-energy intensive businesses and public sectors (defined as organisations whose mandatory half-hourly metered electricity use exceeds 6,000 MWh per year). Water companies will fall into this category of large non-energy intensive businesses. The scheme is expected to start in April 2010, with an emissions reduction target of four million tonnes (Mt) CO_2 per year by 2020. Performance in the scheme will be based on absolute carbon reductions achieved by companies. The Climate Change Act sets overall targets of at least a 26 per cent reduction in CO_2 emissions by 2020, and at least an 80 per cent reduction in GHG emissions by 2050, both against a 1990 baseline. The Committee on Climate Change has provided advice on the first three five-year carbon budgets to meet these targets (CCC, 2008). The CRC will play a major role in helping the UK to meet its emission reduction targets.

Defra's guidance to Ofwat (mentioned in Section 3.1.2) states that the Government expects companies to fully meet any obligations under the CRC. Ofwat should ensure that the industry is fully exposed to the scheme's financial incentives, and should actively support companies that want to exceed CRC targets through voluntary action.

The Government's Water Strategy strives for continued reductions in the industry's carbon footprint. This could include reducing demand; maximising efficient energy production from the industry's own processes and resources including anaerobic digestion and CHP; the capture of greenhouse gases; and through sourcing alternative renewable energy supplies.

The water industry has, through its sponsorship of UKWIR projects, developed a modelling approach to predict the carbon footprint of processes (UKWIR, 2005). In addition, the Environment Agency and water companies have developed the Pollution Inventory reporting protocol, which also provides an estimate of the greenhouse gas emissions arising from treatment processes.

Defra developed the Shadow Price of Carbon (SPC) methodology (Defra2007c), which all water companies must use in their cost-benefit analysis (CBA) to support the investment decisions made during business planning. Government continues to review the SPC in the context of new UK climate change targets.

3.1.4 Economics and incentives

The Government expects Ofwat to consider both the cost to customers, and the environmental and social benefits of company proposals that increase their uptake of renewable energy sources or reduce non-CO_2 greenhouse gas emissions. However, there is concern in the water industry that the Department of Business, Enterprise and Regulatory Reform's (BERR) changes to the Renewables Obligation Certificate (ROC) regime will stifle further investment in anaerobic digestion and energy capture.

According to Water UK (2007), the ROC regime has helped enable the water industry installed renewable energy capacity to increase from 40 MWe to 115 MWe in the current asset management planning period (2005-2010). The water industry has expressed concern at the reduction in ROC value for electricity generated from sewage gas in combined heat and power (CHP) plants from 1 ROC/MWh to 0.5 ROC/MWh, as they feel the development of CHP may no longer be economically viable, particularly for recently developed advanced digestion methods.

Water UK has estimated that advanced anaerobic digestion techniques could generate an additional 170 MWh, but suggests investment is less likely with a reduced ROC value. There is similar potential in co-digestion of municipal waste, though the water industry could only receive 0.5 ROC/MWh for this approach, while local authorities could receive 2 ROC/MWh, thus this could act as a disincentive for the optimisation of spare capacity in the water industry's digesters.

Rising energy prices and the introduction of the CRC are both encouraging reductions in energy use, and hence may help reduce carbon emissions. However, without sufficient cost savings, the capital investment in renewable energy sources may not be recouped within the five-year asset management plan/periodic review period. After this time, the efficiency (lower costs) becomes part of the base operating costs and the company is unable to recover efficiencies. The customer effectively receives the benefits of the efficiency before the capital investment is recovered. While this is of benefit to the customer, in the form of lower prices, it is a block to innovation and investment.

If the barriers to innovation and investment in low carbon technology are to be overcome, the water companies may need to include design elements that may add to the scheme out-turn costs. The SPC is clearly an important factor in the financial assessment of the scheme. If the water industry cannot demonstrate through CBA, including the SPC, that the process is cost-effective (the value of the carbon saved is higher than the additional out-turn cost) then Ofwat will not support the additional investment. The lowest carbon technology may not therefore be deemed viable under the current assessment regime. This may be the correct investment decision, using the current SPC, but it may lead to lost opportunities and future retrofitting costs.

Therefore a coordinated approach between the Government, Ofwat, Environment Agency and the water industry is required to ensure that Climate Change Act targets are met, and that incentives to investment consider the long-term planning horizon.

3.2 WFD requirements

Although the WFD requires the receiving water not to exceed EQS, the water body must also meet the appropriate ecological status. Good ecological status is defined through ecological assessments and the Environment Agency will need to consider control measures to meet the required status. There is not necessarily a direct correlation between the contribution of a specific substance and the response that the water industry discharger may need to adopt. A recent study by UKWIR on the WFD requirements for good ecological status and sustainability found that EQS were used to determine the likelihood of an intervention, while the issue of linking EQS and ecology was not addressed. Given the uncertainty that still exists in implementing the WFD, the difficulty of linking a water body's chemistry and ecology is an ongoing issue.

This report focuses on the WFD and its implications for the water industry in terms of carbon dioxide and other greenhouse gas emissions. The substances and parameters of interest in this project are principally driven by the requirements of the WFD and the legislation it replaces. However, the Environment Agency was keen to broaden the scope of this study, and so some consideration has been given to parameters outside of the requirements of the WFD.

A number of studies have been conducted for UKWIR to determine the level of risk that various WFD substances may pose to the water industry in terms of requiring additional treatment (UKWIR, 2008a; Environment Agency, 2008c). These substances include those in the Priority Substances Daughter Directive (PS DD), Annex X, and in Annex VIII, including endocrine-disrupting chemicals (EDCs, principally the steroid oestrogens) and nutrients. Table 3.1 lists the substances of interest, based on an understanding of the water industry and the studies mentioned above. The table also indicates some potential mechanisms of removal from wastewater.

Following consultation, a request was made for the inclusion within the study of *E. coli* and intestinal enterococci (faecal streptococci) along with viruses such as rotaviruses, adenoviruses and enteroviruses. Under the recently revised Bathing Water Directive (2006/7/EC) (BWD), standards have been set for *E. coli* and intestinal enterococci in coastal and inland waters. Approximately 92 per cent of bathing water sites in England are expected to meet the revised minimum long-term standards, compared to a 2007 level of 98 per cent passing the existing standards (Defra, 2007b). Investigations will need to be undertaken to determine whether any WwTW are contributing to failures before any recommendations can be made on requirements for additional treatment.

Table 3.1: Key parameters for additional treatment at WwTW.

WFD Substance	Potential mechanisms of removal				
	Biological (e.g. activated sludge, trickling filters, membrane filtration)	Adsorption (e.g. GAC, sand filters)	Chemical treatment (e.g. pH adjustment, coagulation, precipitation)	Advanced oxidation (e.g. UV, hydrogen peroxide)	Ultrafiltration (e.g. membrane filtration or reverse osmosis)
Annex X (Priority Substances)					
DEHP	•	•		•	•
Nickel		•	•		•
Lead		•	•		•
Cadmium		•	•		•
TBT	•	•		•	•
Annex VIII (Specific Pollutants)					
Steroid oestrogens	•	•		•	•
Nitrates	•		•		•
Phosphates	•		•		•
Ammonia	•				•
Copper		•	•		•
Zinc		•	•		•

Viruses

There are no standards for viruses and these are not mentioned in the Bathing Water Directive (BWD). Whilst the WFD does not revoke this directive, it does have the duty of identifying and registering protected areas, including those designated under the BWD. In the absence of any standards, or guidance on standards for these parameters, it was not possible to provide a detailed assessment for this report. However, comments have been made on the effects of the various treatment methods and catchment solutions on bacterial and viral populations.

Priority substances

As far as the priority substances are concerned, of the 6,000 WwTW in England and Wales, between approximately 2 and 10 per cent are expected to require some form of additional treatment to meet tighter consents (Environment Agency, 2008a; UKWIR, 2008a), unless upstream control measures are put in place (for example, banning the use of plasticiser DEHP). The majority of works affected are likely to be within the catchments of Severn Trent Water, Anglian Water and Thames Water, based on the dilutions available in the receiving water (Environment Agency, 2008a). Required additional removal rates are, on average, in the region of 50 to 60 per cent for both the organics and metals (UKWIR, 2008a). This is likely to present significant challenges for the water industry.

Laboratory studies have indicated that advanced techniques such as granular activated carbon (GAC) and sand filters may not be able to meet the required additional treatment and that more aggressive forms of treatment could be needed at some WwTW (UKWIR, 2008a). These figures, whilst representing best current knowledge and understanding, are based on a number of assumptions including the Environment Agency's consenting policy and upstream concentrations of the substances; until these are finalised, the number of works and additional treatment required cannot be stated with certainty.

Endocrine-disrupting chemicals

Approximately 200 WwTW are likely to require additional treatment to remove EDCs (Environment Agency, 2008c). Many of these works are different to those potentially requiring treatment for the Priority Substances. Other Annex VIII substances such as copper and zinc are likely to require treatment at the same works for the other priority substances, based on available dilutions, with additional removals in the region of 50 per cent (UKWIR, 2008a). WFD standards for phosphorus in water bodies could lead to around 30 per cent of WwTW in England and Wales requiring nutrient removal (UKWIR, 2008b). As some of these works are likely to also require treatment for priority or other Annex VIII substances, in some instances multiple treatment techniques may be required to meet tighter consent standards under the WFD.

Site investigations conducted during the Periodic Review (PR) 2009 (PR09) should allow a better view of which sewer catchments require treatment for which substances, and which treatment techniques and strategies might be most effective. Targeted planning and investment could then be undertaken in the PR14/PR19 periods. Investment in nutrient treatment has already commenced and is continuing in PR09.

3.3 Timeline

Figure 3.1 illustrates the timeline for the WFD and its PS DD and how this fits in with the periodic review cycle. Other obligations, including those under the Climate Change Act, are also shown. According to the WFD, good ecological and good chemical status (GES and GCS respectively) need to be achieved by 2015, along with priority substance EQS in water bodies. Based on the PR cycles, it is unlikely that investment in additional treatment at WwTW will begin until 2015 at the earliest, potentially compromising compliance with the WFD objectives. However, this timescale provides a good opportunity to research low-carbon treatment options rather than rushing into large-scale investment now. This would also coincide with the introduction of a key driver for the reduction in carbon emissions within the water industry: the CRC, which has the potential to further stimulate research into low-carbon options.

The UK water industry is very aware of the need to adapt to climate change. In particular UKWIR 08/CL/01/7 identifies risks, adaption strategies and critical knowledge gaps and proposes a programme that could lead to a water industry strategy focussed on sustainable adaptation.

Future-proofing any investment in treatment techniques is important. The WFD requires a review of the list of priority substances every four years as a minimum, which means that new substances could be added to the list relatively frequently. Whilst not all would be of concern to the water industry, some substances might present significant problems in their removal at a WwTW.

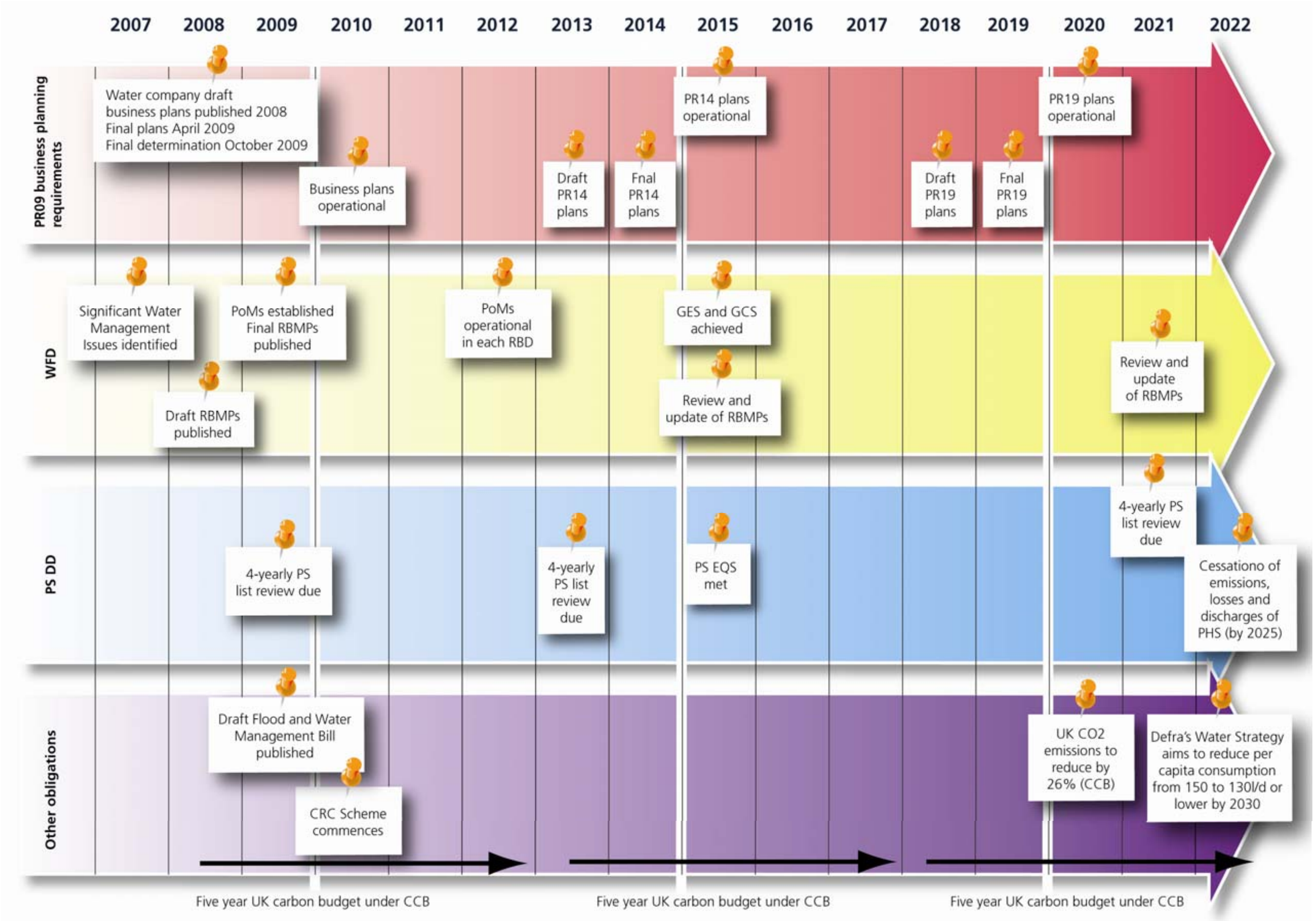

Figure 3.1: Legislative timeline for the water industry.

4 Potential responses available to the water industry

Five key strategies are outlined below which the water industry could adopt to mitigate the potential carbon impact of the WFD. Of the key strategies below, the first three are a direct response to the additional obligations under the WFD.

Key strategies:

1. **Source control:** This strategy recognises that, in some situations, the greatest carbon savings may be achieved through the control, at source, of the substance of concern, avoiding the need for treatment at the WwTW. However, the water industry, though itself a trade effluent regulator under the Water Industry Act, has limited powers to achieve this.

2. **Least-carbon end-of-pipe/process addition:** This strategy covers implementation of least-carbon treatment solutions, accepting that an increase in emissions is inevitable. End-of-pipe treatment technologies will have the effect of increasing the embodied, or structural carbon, as well as potentially increasing the operational requirements for energy. Therefore, unless there are significant changes in the conventional approach to treatment, there will almost certainly be an increase in carbon emissions as no zero-carbon treatment techniques are available.

3. **Greater operational efficiencies:** This strategy reduces demand for power through better design in the catchment, optimising the management of sewage and any combined wastewater systems Although this option may appear independent of the WFD and is part of business as usual, there are WFD implications as to what an efficient system may need to achieve and hence potentially new limits.

4. **Redeveloping existing treatment processes:** This strategy focuses on switching conventional processes to lower energy alternatives. Redeveloping processes has the potential to both reduce the effluent concentration of pollutants to meet WFD objectives, and reduce carbon. However it also presents the greatest challenges.

5. **Renewable energy generation:** This strategy considers the generation of energy through on-site generation or other generation within the water industry asset base, for example hydroelectricity. Within this study only the wastewater asset base is considered, and water supply and wind options are excluded.

Each of these strategies is considered in more detail in the following sections. Conclusions are drawn on their potential use within an overall strategy, and the gaps in knowledge that may act as barriers to their adoption are identified.

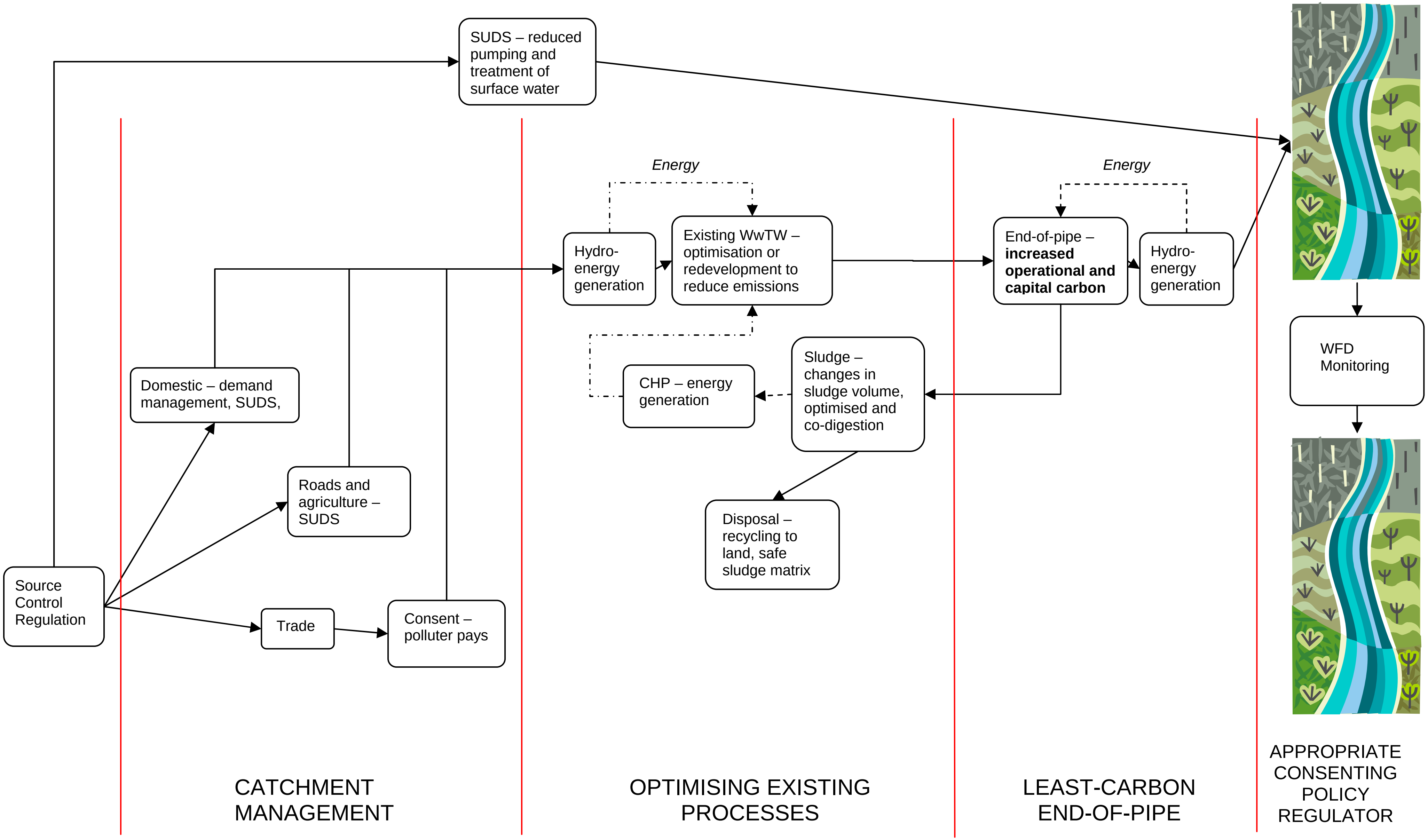

Figure 4.1: Schematic showing carbon reduction possibilities

4.1 Key Strategy: Source control

The industry has researched the sources of many of the substances of concern in order to understand the relative contributions to the sewer system. As reported in the UKWIR WW17 programme of work (UKWIR 2008 a, b, c), many of the substances may be attributed in most or in part to domestic contributions, for example copper piping in the home. As such, the opportunity for direct control at source is available primarily for trade effluent, which covers industrial discharges to sewers. In site-specific cases, and especially for chemicals used primarily in the industrial setting, controls already exist and may be reviewed if discharges result in additional treatment. The mechanism for imposing charges or controls has been established within common practice and therefore is not discussed further in this report.

Source controls of the type used in product restrictions have proved very successful in managing specific risks. There are many examples in the pesticide industry including DDT and lindane. However, such interventions lie outside the remit of the water industry and hence source control in the most part remains a tool that may only be effective if managed by the Environment Agency. Control may need to be driven at a European or world trade level as many substances are introduced within products to the UK market. Table 4.1 links the issues of source apportionment and source control. Whilst some substances are already under international control and restrictions are in place, the water industry may still find these substances in its discharges.

Table 4.1: Typical sources of substances and levels of control

WFD Substance	Sources of the substances
Annex X (Priority Substances)	
DEHP	Plasticiser, would need controls in terms of restrictions on use to stop plastics coming in contact with water.
Nickel	Ubiquitous, found in heating elements in domestic appliances.
Lead	Controlled in many applications, historic surface water contamination still found in domestic service pipes.
Cadmium	Heavily controlled in all uses (PHS).
TBT	Antifouling product for ships but may be an imported contaminant (heavily controlled).
Annex VIII (Specific Pollutants)	
Steroid oestrogens	Birth control, pregnant women, controlled chemicals and hormone replacement therapy.
Nitrates	Domestic sewage, agriculture runoff
Phosphates	Domestic sewage, agriculture runoff
Ammonia	Domestic sewage, agriculture runoff
Copper	Ubiquitous, domestic and runoff sources
Zinc	Ubiquitous, domestic and runoff sources

Trade effluent control

There are other substances for which source control is a much more difficult option due to their common occurrence in domestic, trade and diffuse discharges.

The water industry has control over trade effluent additions. It is likely that as consents begin to include the tighter and more numerous parameters, trade effluent will fall under greater scrutiny. As many thousands of products contain substances of concern, more detailed investigations will reveal the contributions of specific pollutants from trade effluent. However, it would be misleading to believe that, in the majority of cases, the control of trade effluent will alleviate the need for additional treatment to meet WFD requirements. UKWIR studies investigating the impact of the WFD on the water industry have all studied sewage treatment works that are predominantly domestic in nature. Therefore, it is assumed in those studies that the control of trade effluent will be of equivalent strength to the domestic sewage. In studies where specific traders have been identified as contributing to the pollutant loads, existing trade effluent control regimes have been applied.

4.1.1 Role of source control

Within the context of a low-carbon strategy, the water industry has limited control other than on trade effluent. As noted above, the sources of these substances will be outside of the water industry's control.

If the UK water industry is required to provide widespread additional treatment and faces the associated costs of meeting the WFD, under the polluter pays principle the trade effluent-charging mechanism may need to be reviewed to fully reflect the contribution of trade effluent. This is likely to impact most on substances found commonly in domestic and trade waste, as these will be where the most treatment is required. Typically, this will include metals such as copper and zinc.

Therefore, it is important to consider how planning through different agencies such as local authorities, the Highways Agency, rail transport, agriculture and the Environment Agency considers the importance of chemical use and includes control measures to reduce substances running to sewers.

If priority hazardous substances are banned at source, there will be little environmental benefit in building infrastructure to treat them. Therefore, the first knowledge gap is how source bans can be implemented. In the case of tributyltin (TBT) for example, its presence at WwTW may be derived from imported goods. The more difficult issue is how the more ubiquitous substances such as copper or phosphorous are managed. A detailed source apportionment study is needed followed by programmes of measures targeting specific pollutants. The water industry and the Environment Agency have recognised this issue and are collaborating on a UKWIR/EA project WW02 which will report source apportionment findings as well as modelling river catchments to assess the associated risks. This work will need to be completed before successful carbon-efficient source controls and targeted treatment can be identified.

4.2 Key Strategy: Least-carbon end-of-pipe/process addition

Although least-carbon end-of-pipe treatment may be considered, the available options may not be inherently low carbon. Hence, least-carbon may still pose a significant additional burden.

The barrier to this approach is that there is no detailed EU investigation on potential treatment requirements associated with the WFD. The UK leads this area and through collaborative work with the water industry and the Environment Agency, a series of investigations are planned during AMP5 to assess the performance requirements, availability and consequences of adding end-of-pipe treatment to meet WFD goals. Until these investigations are completed, the most effective treatment options may only be assumed. Therefore, in the following sections of this report, the best available information is used to understand the current carbon footprint of the water industry and what options may be considered most effective in meeting WFD requirements while presenting a least-carbon approach. The information used in this report is drawn extensively from UKWIR investigations (UKWIR 2008 a, b, c).

Table 4.2 shows greenhouse gas emissions associated with wastewater treatment options. The purpose of the table is not to provide a detailed process selection manual, rather an understanding of different options that may feed into a water company's decision-making process if additional treatment is required under the WFD.

The table presents a number of columns of data, starting with a brief description of the techniques, followed by embodied CO_2 emissions. Embodied emissions include those associated with building a new unit from scratch. Operational emissions are then presented, broken down into two categories: (1) emissions due to energy use and (2) emissions due to the biological breakdown of sewage. Other greenhouse gas emissions are summarised and only include operational emissions. Associated waste or byproducts are summarised and data on parameter removal are included in the final column to provide an indication of the impact on effluent quality.

As far as possible emission values have been expressed per million litres (Ml) of treated water. As there are economies of scale for some treatment processes (in particular for energy use), values are presented for two or three scales of works where appropriate: 2,000 p.e., 10,000 p.e. and 100,000 p.e. Assuming a daily flow of 245 litres per p.e. (UKWIR, 2008b) this gives works with daily flows of 0.45 Ml, 2.45 Ml and 24.5 Ml respectively. These values were used in the calculation of emissions per Ml of treated water.

For embodied emissions, the life span of the asset was assumed to be 20 years. In reality, mechanical and electrical (M&E) components are generally considered to have a life span of 15 years, and civil components (such as tanks and pipe work) a 50-year life span. Detailed information is required for the two components to be separated out, so for this report, the choice of a nominal 20-year life span allows the different techniques to be easily compared without requiring a detailed process analysis. The table notes where particular components are likely to need replacing more frequently.

Technique selection

Current understanding of end-of-pipe treatment options shows significant variability in the difference in embodied and operational carbon across treatment techniques. For most techniques, operational emissions are higher than embedded emissions, with the exceptions of GAC and MBRs. In the case of GACs, the filter media will require annual replacement and its embodied carbon is high. Savings could be made by exploring the possibility of using waste material as alternative media, for example coconut husks or crab shells.

Emissions from breakdown in biological processes tend to be relatively high. For advanced treatment methods whose aim is to remove parameters such as metals or recalcitrant organics rather than biological oxygen demand (BOD), the main operational emissions are from energy use.

The data presented are generic values and a number of points should be taken into consideration with its use and interpretation:

- Site-specific conditions will affect the emissions, for example through process modifications, climatic conditions, influent composition, location and size of works, civil structures already available and land availability – in some cases effluent would have to be pumped to other works to receive additional treatment due to on-site restrictions.

- The water industry is still developing its understanding of these treatment methods in terms of carbon and for process optimisation, with a number of gaps in the available data.
- With the exception of UKWIR's carbon accounting methodology (UKWIR, 2008c & 2008d), no comprehensive sets of data for end-of-pipe process energy use have been agreed across the different water companies. In general, each has its own methods, therefore, the values presented here may be different to those reported by individual water companies.
- Even within the UKWIR's methodology there are notable exceptions: for example, the carbon footprint associated with chemical dosing is not covered.

Table 4.2: Greenhouse gas emissions associated with wastewater treatment.

Technique	Description	Capital carbon dioxide emissions	Operational carbon dioxide emissions	Other greenhouse gas emissions	Associated waste or byproducts	Extent of use in water industry	Impact on effluent quality
Secondary Treatment							
Trickling filters	Biological treatment method employing biological breakdown for removal of pollutants (there is also limited adsorption onto the biomass). Wastewater is trickled over a filter bed to which the biomass is attached with the effluent leaving the bed via an underdrain before passing into a sedimentation tank.	Medium - Emissions associated with the use of concrete in the tanks and the media used. Smaller works may use steel tanks. Capital emissions vary between about 21 and 10 kg CO_2 per Ml treated (assuming a 20-year asset life) (Atkins, 2008) for a 2,000 p.e. and a 100,000 p.e. biofilter.	Low - Energy requirements of trickling filters are low and thus associated carbon emissions are not expected to be significant. Assuming that trickling filters and activated sludge have approximately the same amount of BOD removal, the following figure can be used to approximate an emission due to biological breakdown: 55 g CO_2 per p.e. per day (UKWIR, 2005). With a p.e. flow of 245 l/day, this gives an emission of 224 kg per Ml treated.	N_2O emissions are not considered to be significant due to limited denitrification in the filters. Although may be impacted by variable biofilm or temperature. Methane (CH_4) emissions due to biological breakdown are not expected to be significant as CH_4 tends not to be formed in aerobic environments. No data was found on emissions during filtration although they could be assumed to be in the same order as for activated sludge.	The biomass on the filter media eventually sloughs off and enters the sedimentation tank. This 'humus sludge' is collected and treated (for example in anaerobic digesters) before disposal or reuse.	Widespread - Trickling filters are used in about 80 per cent of works with secondary treatment (Ofwat, 2003). The works with trickling filters tend to be those less than 25,000 p.e. and particularly less than 2,000 p.e.	Greater sensitivity to seasonal fluctuations in temperature can mean that emissions from trickling filters fluctuate more than those from activated sludge plants due to potentially lower bacterial activity in the winter (and hence less biological breakdown). Treatment efficiencies for priority substances were not found to be significantly different between trickling filters and ASP in general (UKWIR, 2008a). Removal of EDCs is considered poor (in the region of 30 per cent) in conventional trickling filters (Johnson, 2006).
Activated sludge (ASP)	Biological treatment method using suspended biomass to treat the wastewater, with biological breakdown and adsorption being the main processes. The mixed liquor (biomass and wastewater mixture) is maintained in suspension by aerators. Effluent is then passed to a settlement tank.	Medium - Emissions associated with the use of concrete in the tanks. Smaller works may use steel tanks. There would be additional capital emissions associated with the aerators and accompanying civils. In the absence of any other data it could be assumed that capital CO_2 emissions would be in the region of those reported for trickling filters, as the largest part of the emissions is associated with construction of the tank itself. In reality, they would likely be higher to a certain degree.	Medium - Energy required for aeration of the plant depends on the size of the works and the composition of the sewage. Approximately 55 per cent of onsite energy use is due to the aeration of the activated sludge tanks (Soares, 2008). Any savings that can be made here could have a large impact on overall site CO_2 emissions. An average consumption value for aeration of 15 kWh per person per year has been reported (Moroney and Haeck, 2008). Using Defra's conversion factor for grid electricity, this gives a value of 88 kg CO_2 per Ml treated. If it is assumed that trickling filters and activated sludge have approximately the same amount of BOD removal then the following figure can be used to approximate an emission due to	N_2O emissions due to biological breakdown during secondary treatment were considered to be 0.004 x the N load on secondary treatment (UKWIR, 2005). Using an average influent concentration of 53 N mg/l (Metcalf and Eddy, 1991) and no removal during primary treatment, this gives an emission of 0.2 kg N_2O per Ml treated. The level of N_2O released depends on the amount of denitrification the plant achieves. CH_4 emissions due to biological breakdown are unlikely to be significant but can be calculated based on a measured emission factor of	Sludge is generated during the activated sludge process, consisting of settled solids and bacterial cells. This sludge will be treated (for example in anaerobic digesters) before disposal or reuse.	Common - Activated sludge plants (ASP) are used in about 20 per cent of works with secondary treatment (Ofwat, 2003). This number is increasing, however, as filters are replaced with ASP due to a greater demand on removal efficiency, particularly ammonia removal.	ASP can achieve greater ammonia and nutrient removal than filters. The BOD removal is also expected to be marginally higher, depending on the rate of aeration. A study found that over 70 per cent of steroid oestrogens were removed in an ASP plant (Cartmel, 2007).

Technique	Description	Capital carbon dioxide emissions	Operational carbon dioxide emissions	Other greenhouse gas emissions	Associated waste or byproducts	Extent of use in water industry	Impact on effluent quality
			biological breakdown: 55 g CO_2 per p.e. per day (UKWIR, 2005). With a p.e. flow of 245 l/day, this gives an emission of 224 kg CO_2 per Ml treated.	39 g/person/year (Czepielp *et al.,* 1993). This includes primary sedimentation emissions and so is likely to be an overestimate. Allowing 245 l/person/day, this gives an emission of 0.4 kg CH_4 per Ml treated.			
Biological Nutrient Removal (BNR)	BNRs use adsorption and biological breakdown. They have many configurations, depending on the process used and the nutrient for removal. They can use a combination of aerobic/anoxic and anaerobic zones. BNR systems designed to remove total nitrogen must have an aerobic zone for nitrification and an anoxic zone for denitrification, and BNR systems designed to remove total phosphorus must have an anaerobic zone free of dissolved oxygen and nitrate.	Medium - Emissions associated with the use of concrete in the tanks. In the absence of any other data it could be assumed that the capital CO_2 emissions would be in the region of those reported for trickling filters, as the largest part of the emissions is associated with construction of the tank itself. BNRs can be anaerobic or aerobic and each would have different capital emissions but no data was available to compare.	Medium - Energy required for aeration, sludge return and any mixing depends on the size of the works and the composition of the sewage. Power consumption is likely to be slightly higher than for a simpler activated sludge process. Assuming BNR has approximately the same amount of BOD removal as trickling filters, operational CO_2 emissions due to biological breakdown could be assumed to be the same in aerobic systems. In anaerobic systems, there would be minimal CO_2 released, with the more important GHG being methane.	The other greenhouse gas emissions depend on whether it is run as an anaerobic or aerobic system. In an aerobic system, the emissions could be assumed to be the same as for an ASP. For anaerobic systems, methane releases are likely to be higher than that estimated for ASP.	Sludge is generated during the BNR process, consisting of settled solids and bacterial cells. This sludge will be treated (for example in anaerobic digesters) before disposal or reuse.	Common - Chemical dosing (principally ferric salts) is the more common option within the water industry for nutrient removal.	BNRs are considered less reliable for nutrient removal than chemical stripping and there are concerns over its cost-effectiveness and the increased carbon emissions as it is more energy intensive (Defra, 2008c). A study found that over 60 per cent of steroid oestrogens were removed in a BNR plant (Cartmel, 2007).
Root zone treatment (reed beds)	Biological uptake and oxidation	Medium - Capital emissions vary between about 16 kg CO_2 per Ml treated (assuming a 20-year asset life) (Atkins, 2008) for a 2,000 p.e. e. reedbed.	Low - Reed beds are passive systems, although there may be some site-specific instances of pumping and as such energy use is negligible. A field and lab study in Czechoslovakia reported CO_2 emissions between 4 and 309 mg CO_2–$Cm^{-2}\,h^{-1}$ (Picek *et al.*,	A field and lab study in Czechoslovakia reported CH_4 emissions between zero and 93 mg CH_4 -$Cm^{-2}\,h^{-1}$ (Picek *et al.,* 2007). The same study reported N_2O emissions as negligible despite	Ideally the reeds should be cut down and removed after the growing season. As they may contain contaminants such as heavy metals, they	Rare - Several water companies use reed beds as a secondary or polishing step for effluent. They are well established	

Technique	Description	Capital carbon dioxide emissions	Operational carbon dioxide emissions	Other greenhouse gas emissions	Associated waste or byproducts	Extent of use in water industry	Impact on effluent quality
			2007). Emissions are likely to be greater during the growing season than winter.	denitrification occurring.	may need to be disposed of as contaminated waste. Otherwise, there is the potential for them to be used as biomass in energy generation.	for surface water drainage treatment. Reed beds can take up a lot of land space; a horizontal flow design, which is the form most commonly used in the UK water industry, requires approximately 5 m^2 per p.e. for secondary treatment and 0.5 to 1 m^2 for tertiary treatment.	
Tertiary/Advanced Treatment							
GAC (Granular Activated Carbon)	GAC is an adsorption technique. Most commonly used for drinking water treatment, it uses an organic carbon media to remove substances such as pesticides. Competition for adsorption sites can mean that removal of different substances within an effluent cannot always be easily predicted.	Capital emissions are estimated to be in the region of 4 kg CO_2 per Ml treated (assuming a 20-year asset life) (Atkins, 2008) for works between 2,000 p.e. and 100,000 p.e. This is actually an underestimate as part of this is due to the GAC media which will need to be replaced annually. If 30 Ml/d requires 720 m^3 GAC media, then 1 Ml/d cleanwater treatment requires 24 m^3 . Assuming that a 100,000 p.e. works has a daily flow of 24.5 Ml (1 p.e. = 245 l/d), the works would need 24.5 * 24 = 588 m^3 of media a year. If 950 kg CO_2/m^3 then 588 * 950 = 558,600 kg, or 558 t CO_2 are emitted due to the media alone at a 100,000	Medium - Emissions due to energy use for sand filters have been estimated between 78 kg CO_2 per Ml treated for a 2,000 p.e. works, and 66 for a 100,000 p.e. works (UKWIR, 2008a). This does not include the energy required for the regeneration of the GAC media – at present there are no facilities for the recycling of the media from wastewater plants and as such it is likely that it will have to be periodically disposed of and replaced. Although there will be some biological breakdown, the majority of the BOD will have been removed at previous stages and as such, any emissions due to biological breakdown could be considered negligible.	As for the CO_2 emissions, although there will be some biological breakdown, the majority of the BOD will have been removed at previous stages and as such any emissions due to biological breakdown could be considered negligible.	As mentioned, the GAC media will have to be periodically disposed of, most likely by landfill due to the level of contaminants, and replaced. Regeneration may be possible, but this thermal process will also be responsible for significant carbon emissions.	Rare - Commonly used in advanced water treatment works for the treatment of potable water. Not currently used for wastewater treatment, although pilot plants have been built for the Endocrine Disruptors Demonstration Programme.	The EDC demonstration programme will be trialing pilot and full scale GAC plants to determine the removal rates of EDCs. Laboratory-scale studies have indicated that GAC performs poorly for the removal of metals and DEHP; combined with sand filters the removal rates are marginally better than with sand filters alone (UKWIR, 2008a).

Technique	Description	Capital carbon dioxide emissions	Operational carbon dioxide emissions	Other greenhouse gas emissions	Associated waste or byproducts	Extent of use in water industry	Impact on effluent quality
		p.e. works. Per Ml treated, this equates to 558,600 / (24.5 * 365) = 62 kg CO_2 per Ml treated. (Atkins, 2008).					
Sand filters	Sand filters are a filtration technique, used in drinking water treatment and as a final polishing step for some effluents.	Medium - No data was available on the CO_2 emissions associated with sand filters, but they could be assumed to be in the region of those estimated for GAC plants.	Medium - Emissions due to energy use for sand filters have been estimated between 88 kg CO_2 per Ml treated for a 2,000 p.e. works, 102 kg for a 10,000 p.e. works and 89 for a 100,000 p.e. works (UKWIR, 2008a). Although there will be some biological breakdown, the majority of the BOD will have been removed at previous stages and as such any emissions due to biological breakdown could be considered to be negligible. However, if this step is preceded with an advanced oxidation technique such as ozone or UV, biological breakdown will occur.	As for the CO_2 emissions, although there will be some biological breakdown, the majority of the BOD will have been removed at previous stages and as such any emissions due to biological breakdown could be considered to be negligible.	Sand filters will need to be backwashed periodically with the wash water and sludge requiring treatment and disposal.	Common – Frequently used in potable water treatment. Also used as a polishing step at some wastewater treatment works.	Laboratory studies have shown that sand filters generally offer less than 25 per cent removal for metals and variable removals for DEHP (UKWIR, 2008a). Higher removal rates were seen with spiked effluent samples. Sand filters were also included in the EDC demonstration programme although no results are publicly available as yet to determine its efficiency.
Membrane Biological Reactor (MBR)	MBRs are an advanced type of ASP, using filtration and biological breakdown to remove substances.	Capital emissions are likely to be relatively high given the requirements for pumps, tanks and the membranes themselves. The membranes have been reported as being made of chlorinated polyethylene (Ryan, 2007), or polyvinyl difluoride (Malekar, 2007)	A study of an MBR plant in Wessex Water reported average energy consumption of 1.98 kWh/m^3 from the most energy intensive parts (aeration and pumping) (Ryan, 2007). This sits within the range reported for submerged membrane systems of 0.8 to 4 kWh/m^3 (Englehardt, 2003, in Ryan, 2007). Using Defra's conversion factor for grid electricity, this equates to between 420 and 2,000 kg CO_2 per Ml treated. No data could be found on CO_2 emissions due to biological breakdown in MBRs, but given that the BOD removal is greater in such systems compared to ASP or TF, it could be assumed that the associated emissions would also be greater.	In the absence of any data, it could be assumed that N_2O and CH_4 emissions would not be significant as the system remains aerobic. This means that CH_4 should not form in significant amounts, and that denitrification is unlikely to occur so limited amounts of N_2O should form.	Sludge is scoured from the surface of the membranes to prevent clogging. This sludge must then be treated before disposal.	Rare - MBRs are increasing in use across the water industry, although they are still relatively rare.	MBRs were included in the EDC demonstration programme although no results are publicly available as yet to determine its efficiency. It is expected that they will be efficient at removing all the substances of interest, with the exception of the most soluble metals (such as nickel).
Reverse Osmosis (RO)	Reverse osmosis uses hyper-filtration to remove pollutants.	Capital emissions are estimated to be up to 31 kg CO_2 per Ml treated for a 2,000 p.e. works (assuming a 20-year asset life). There is a significant reduction with	There are few examples where RO has been used for wastewater, but a plant in Singapore reportedly uses between 0.7 to 0.9 kWh/m^3 of domestic wastewater treated (with a capacity of 10,000 m^3/d production, roughly equivalent to a		The highly concentrated waste stream may require specialised sludge treatment.	Rare - Only recently starting to be considered as part of effluent reuse schemes.	No data was found on the removal efficiencies of RO regarding the parameters of interest. However, given that it is hyperfiltration, it is expected that the majority will be

Technique	Description	Capital carbon dioxide emissions	Operational carbon dioxide emissions	Other greenhouse gas emissions	Associated waste or byproducts	Extent of use in water industry	Impact on effluent quality
		increase size with emissions of 2 kg CO_2 per Ml treated for a 100,000 p.e. works (assuming a 20-year asset life) (Atkins, 2008) . RO requires very high quality effluent to avoid membrane fouling and would require tertiary treatment, including ultra-filtration beforehand.	50,000 p.e. works) (Singapore Water, 2002). Using Defra's conversion factor for grid electricity, this gives a value of between 370 and 470 kg CO_2 per Ml treated. Although there may be some biological breakdown, the majority of the BOD will have been removed at previous stages and as such any emissions due to biological breakdown could be considered negligible. There will also be emissions associated with the periodic (5 to 10 year) replacement of the membranes and the frequent use of hypochlorite or similar for cleaning.				removed to a sufficient level.
Chemical dosing	Chemical dosing is commonly used to remove nutrients by precipitation and filtration	Medium - Capital emissions vary between about 27 and 0.5 kg CO_2 per Ml treated (Atkins, 2008) (assuming a 20-year asset life) for a 2,000 p.e. and a 100,000 p.e. These emissions arise predominantly from the construction of chemical storage tanks and dosing pumps.	Low - Energy use will come from the pumping requirements for the dosing. As any resulting biological breakdown is likely to be negligible, any CO_2 emissions should be negligible as well.	Biological breakdown is likely to be negligible and thus emissions of N_2O or CH_4 should not be significant.	As the technique involves encouraging precipitation, a higher amount of sludge might be expected to be produced.	Widespread - Chemical dosing is perhaps one of the most common methods for nutrient removal in the water industry.	Ferric dosing for phosphorus removal has been shown in a laboratory-scale study to remove copper, mercury, lead and DEHP by over 50 per cent; metals such as zinc, nickel and cadmium were not effectively removed (UKWIR, 2008a). Therefore, there may be some co-benefit of ferric dosing on other parameters of interest.
Advanced oxidation systems	There are a number of possible methods of oxidation, for example UV, hydrogen peroxide and ozone.		Operational emissions depend upon the size of the plant and the composition of the sewage (for example, this will affect the strength and duration of UV treatment required). Emissions due to energy use for UV have been estimated between 112 kg CO_2 per Ml treated for a 2,000 p.e. works and 78 kg for a 100,000 p.e. works (UKWIR, 2008a). CO_2 is a breakdown product of oxidation and it is estimated that for every Ml of secondary effluent treated, 12 kg CO_2 will be emitted (See Appendix 1 for details).	The main byproducts of oxidation should be CO_2 and H_2O. No N_2O or CH_4 should be produced.	None	Rare - Oxidation techniques are well used on the potable water side to disinfect the water and to remove pesticides. These techniques are also used at works discharging to designated bathing water areas.	Oxidation of more recalcitrant organics is unlikely to be complete. Instead, larger molecules may have been broken down into smaller ones which then biodegrade in further treatment steps (e.g. sand filters or some form of biological removal). A trial in Germany found that ozone treatment at 5 mg O_3/l significantly reduced the oestrogenicity of effluent; levels of ozone up to 12 mg O_3/l also broke down many pharmaceuticals and made them more amenable to

Technique	Description	Capital carbon dioxide emissions	Operational carbon dioxide emissions	Other greenhouse gas emissions	Associated waste or byproducts	Extent of use in water industry	Impact on effluent quality
							biological treatment (Ried, 2006). Bacteria and viruses should also be removed with oxidation techniques.
Sludge Treatment							
Anaerobic digestion (with/ without CHP)	In anaerobic digestion organic matter is broken down by bacteria in the absence of oxygen. The materials ferment in a closed vessel and produce a biogas which is a mixture of about 60 per cent methane and 40 per cent carbon dioxide, with other trace gases, such as hydrogen sulphide.	Medium - Capital emissions will be associated with the tanks, heaters and pumps.	Low - Most of the energy use for anaerobic digestion is in the heating of the sludge. Most systems use the gas produced to heat the sludge rather than drawing off the grid. Emissions depend upon the level of treatment that the sludge receives before hand and type of AD employed (thermo or mesophilic). Biogas contains CO_2, in smaller relative quantities than CH_4. The combustion of the digester gas, for example through flaring, will also result in the formation of CO_2. These emissions have been estimated as 25.4 kg CO_2 per tonne of sludge (raw dry solids) processed without CHP (UKWIR, 2005). With CHP, emissions are estimated to be 0.549 kg CO_2 per kg of sludge processed (UKWIR, 2005).	As the sludge breaks down anaerobically, CH_4 is produced. If the gas is captured for use in CHP, emissions should be minimal, with perhaps five per cent escaping. Without CHP, an emission of 18 kg CH_4 per tonne of sludge (raw dry solids) treated (UKWIR, 2008c)	Biogas is produced as a byproduct of anaerobic digestion and can be used as a renewable energy source, both for heat and power, and as a transport fuel. The digestate (treated liquid) from anaerobic digestion contains useful nutrients and can be used as a fertiliser and soil conditioner.	Widespread	

Diminishing returns of substance removal and carbon implications

Given the lower EQS that needs to be achieved, smaller concentrations of substances need to be removed. It is widely established that as effluent treatment targets are lowered, some physical and metabolic processes become more resource-intensive. For example, in adsorption processes there will be competition with active sites from other substances. In biological processes there may be the need to develop different communities of treatment organisms in separate process stages, or provide longer contact time and hence larger processes.

Even with enhanced biodegradation in earlier stages of treatment, some recalcitrant organics and metals do not behave in a predictable way (such as DEHP) and have to be removed with more aggressive methods. In general, the lower the level of substance in the wastewater to be treated, the higher the carbon emissions. In addition, these advanced techniques tend to produce a sludge that is relatively high in the parameters of interest, making its treatment and reuse or disposal difficult.

Previous research has shown that lower EQS generate greater CO_2 emissions from increased operational energy use (UKWIR, 2008a). Figure 4.1 shows the increase in carbon emissions for nickel if the proposed EQS was to change from the current value of 20 µg/l to the previously proposed value of 1.7µg/l. The graph can also be used to show how carbon emissions increase with ever decreasing amounts of substance to be removed, due to the diminishing returns of substance removal.

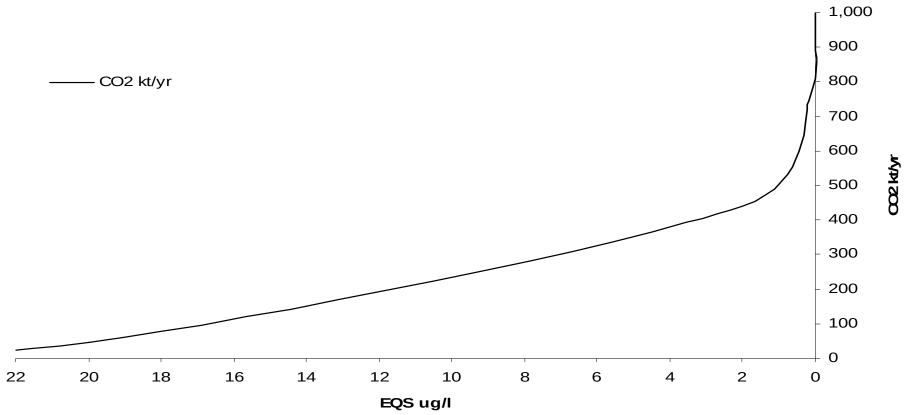

Figure 4.2 Estimated CO_2 emissions from energy use of sand filters introduced for the treatment of nickel.

(after UKWIR, 2008a)

Sidestream and process addition

Sidestream processes are part of biological phosphorus removal techniques that have the advantage of reducing or eliminating conventional chemical treatments. In the side stream process, the aerobic sludge (high in phosphorous) is settled out and put through an anaerobic phase where the phosphorous is released back into the water. The sludge is settled again and the solids recycled to the aerobic phase to bind more phosphorous. The result of the sidestream process is that more phosphate is stripped out and released in a smaller volume of water.

For example, waste activated sludge is commonly blended with primary sludge prior to sludge digestion: this means anaerobic digestion inevitably operates under sub-optimal conditions as waste sludge from aerobic processes degrade under anaerobiosis. The introduction of pre-treatment strategies such as ultrasound does have an impact but whether there is an overall carbon saving is questionable. The benefits that might be achieved by considering the flowsheet more holistically need to be considered, for example by treating parts of flows, blending different streams for treatment, and/or recycling components. However, the impacts of such operational interventions are very much site-specific and the performance, with respect to the conventional operation of the plant and its ability to meet WFD requirements, would need to be determined.

The addition of sidestream processes may also be considered under least-carbon options; these may form part of a treatment process and help remove substances from return lines.

4.2.1 Key Strategy: Role of least carbon end-of-pipe/process addition

Process selection will inevitably play an important role in reducing the overall emission impact of the WFD. Where additional end-of-pipe solutions are required to meet tighter standards, there will be greater embodied and operational carbon emissions. The opportunities to reduce emissions may exist in the use of sidestream processes, which could enhance an aspect of the process and hence bring benefits such as enhanced biogas generation. However, if sidestream processes have the ability to enhance the treatment process, and save energy, they would be considered on a site-by-site basis and as such independently of the WFD requirements.   For this strategy to be appropriate, the performance of the processes needs to be proven.

Given that tighter discharge consents will push up demand on infrastructure and energy requirements, it is important to ensure that consents are appropriate, as a precautionary stance to protect the receiving water may have a significant impact on carbon emissions.

The most significant gap in our understanding is the performance of existing technologies to remove many of the substances of concern, as is the ability of end-of-pipe solutions. Therefore any study that highlights potential industry responses is assuming that lab-based studies can foretell the implementation of end-of-pipe solutions. This is a major assumption that ignores potential influencing factors in a catchment rather than a laboratory setting.

4.3 Key Strategy: Greater operational efficiencies

Planning and design

There is an opportunity to reduce carbon emissions within the planning process for new wastewater treatment. Plans that optimise pumping and the management of surface water, and deploy efficient aeration systems will all help reduce carbon emissions.

Planning for future process extensions at a treatment works or adding headroom within designs may also generate a long-term least-carbon solution. Such design options may incur additional design and build costs at the time of construction. Hence the design horizon is a critical issue for carbon optimization.

Strategic least-cost long-term wastewater investment planning is a concept that was recently explored in a project for UKWIR (UKWIR, 2007). The study aimed to fit into an integrated investment planning process by highlighting the need to coordinate investment through different drivers, seeking to identify whole catchment solutions and looking at the potential effects of other initiatives on the supply-demand balance. It highlighted the need to identify all feasible options and to obtain whole-life-cost estimates, including operating and capital costs and environmental/social costs and benefits, to derive least-cost solutions.

The project comprised a series of steps to enable the water company to identify options and then chose the “least cost whole life solution to providing the wastewater service”. A similar principle could be applied to carbon emissions, although it is possible that a least-carbon cost option would not be the same as a least-financial cost option.

Designs entailing headroom and additional process flexibility to address future tighter discharge standards will require decisions that cannot easily be demonstrated in a cost-benefit analysis study, for it is the potential risk of meeting future tighter standards rather than the actual benefit of meeting specified standards that need to be considered. The whole-life carbon footprint, balancing embodied and operational carbon will be required to identify the optimal solution.

Operations

The water industry has been seeking operational savings independently of the WFD and these approaches to saving have, more recently, been targeting carbon reductions. The main goal has been cost savings; however, most interventions should also reduce carbon emissions. Table 4.3 highlights potential savings, indicating their impact, and notes the potential barriers to implementation. The table in Appendix 2 provides a more detailed assessment of interventions across the collection, treatment and sludge management functions.

Some techniques may also be part of the design process; for example, the use of transport and road logistics methods would help determine optimum site locations of treatment centres. This could also help to identify where treatment centres should be placed to be close to the source of sludge, in order to minimise tanker movements.

As carbon management becomes established within business processes, it is likely that companies will develop supply chain management with a view to identifying and enhancing efficiencies through the supply chain.

Compared to other process industries, the level of process monitoring is poor in municipal wastewater treatment; better process monitoring would help identify quick wins because ‘if you cannot measure it, you cannot manage it’. Hence, process monitoring will help provide the information necessary to reduce the carbon footprint of processes through subsequent optimisation of their operation. In addition to the cost of the instrumentation itself, implementation of such a policy would also require considerable training of process staff or outsourcing.

Overall efficiency savings and a lower carbon footprint are goals linked to the WFD in terms of the additional risk that tighter standards place on the business. The issue facing the water industry is to better understand the impact of an optimisation on its compliance risk. The table in Appendix 2 makes this link; however, a more detailed view of the risks associated with operating under the WFD is considered below.

Table 4.3: Operational interventions and potential barriers to uptake.

Technique	Potential saving and description	Barriers to uptake
Reducing aeration in AS	Good - 50 per cent saving by the upgrade to micro bubble diffuser, additional savings by reducing aeration when ammonia levels low in winter.	Few – replace aerators at end of design life; immediate control of levels possible.
Power voltage regulation	Good - 10 per cent saving has been used on many sites.	Few- site specific.
Reducing pumping costs	Good - 30 and 50 per cent on currently inefficient sites possible; reduced flows also lowers pump costs.	Significant - Fewer inefficient sites remain.
Process optimisation	Medium to good - Improved aeration, moving to percentile consenting policy, agreeing with traders to discharge at night,	Few - Lack of monitoring.
Anaerobic treatment	Good - ~24 per cent - 44 per cent emission reduction compared to an aerobic system. Capture of the gas for energy generation would lower overall emissions.	Significant - Not suitable storm water or other potential 'shock loads'. Potentially cost-effective option for new works.
Pyrolysis or gasification	No data - Pyrolysis and gasification both turn wastes into energy-rich fuels.	
Incineration with energy recovery	Good - Disposal of sewage via incineration with energy recovery. Crossness WwTW produced 20 GWh.	Significant - Sites must comply with IPC regulations. Local objections may exist.
Enhanced anaerobic digestion	Good - Induction of cell lysis in the sludge before anaerobic digestion could increase the biogas production by 30 per cent.	Medium - The change from 1 to 0.5 ROC/kWh could make investment in enhanced techniques less viable economically.
Vermistablisation	Medium - The use of worms is a low energy system suitable for smaller works, negating the need for sludge transport to centralised facilities.	Limited - Only suitable for small works as loading rates are between 1.5 and 2 kg DS/m^2/week.
Optimisation of sludge transport	Medium - Optimisation of the transport of sludge between WwTW and treatment centres.	Limited - The markets for the reuse or disposal of the sludge will determine the strategies.
Agricultural land	Medium - Recycling to land is seen as the Best Environmental Practicable Option in most cases.	Medium - Must follow the Safe Sludge Matrix. Pressure from supermarkets and the public may decrease future use.
Use in biomass crops	Limited - Sludge is used to amend the soil for biomass crops.	Significant - Must follow the Safe Sludge Matrix. Application may increase the runoff of phosphorus.
Hydropower	Limited - The conveyance of sewage to and from the WwTW presents a potential source of energy.	Medium - The sewer catchment needs to be large to provide economic pay back.
Fuel cells – wastewater	Limited - Microbial fuel cells with domestic sewage as their feedstock.	Research required. .
Fuel cells – sludge	Limited - Fuel cells utilising methane from sludge	Significant - The current high cost of fuel cells is likely to be prohibitive in England and Wales.
SUDS	Medium - Mimic as closely as possible natural drainage; this could represent a saving of 15,000 tonnes CO_2 a year.	Few - There is an automatic right to connect which could act as a potential barrier to the use of SUDS.
Separation of sewers	Limited - Construction of new surface water sewers.	Significant - The financial cost of this work is likely to be prohibitive.
Demand management	Limited - Reducing the current demand could see benefits in pumping and treatment costs.	Significant - The increase in the population will increase total demand.
Removal of P	Good - Phosphorus in laundry and dishwashing detergents contribute to 25 per cent of the total load to a WwTW.	Medium - Problems replacing phosphates in dishwashing detergents.
Banning of DEHP	Good - DEHP is one of the key priority substances likely to lead to widescale upgrading of WwTW in England and Wales.	Significant - The banning of the use of a substance can only be done at EU level.
Other		
Seasonal treatment	Medium - E.g. Stop ultraviolet disinfection treatment outside of the bathing season.	Medium - Decisions by Defra will steer any future proposals for such a measure.
Consent setting policy	Good - WwTW effluents are on average at least one fifth of the consent in order to minimise the number of breaches.	Medium - The Environment Agency is currently investigating the possibility of revised consents.

Operating under new consent conditions

Work for United Utilities has also shown that the influent statistical distributions for sanitary parameters, including BOD and suspended solids, mean that a WwTW can aim to treat to half the consent value to ensure that the effluent quality will meet the consent 95 per cent of the time. For metals, it is likely that the works would have to work to a fifth or a tenth of the consent value to ensure it is met 95 per cent of the time, due to the variance in influent concentrations and in the process efficiency. It is not known what this value might be for the organic compounds of interest, as there is currently insufficient data to determine the variance in influent concentrations and process efficiency.

Treating to a level below the consent poses two issues within the context of this study. First, it will mean that a greater number of WwTW will need additional treatment than estimated in previous research (UKWIR, 2008a and Environment Agency, 2008a), with an associated increase in carbon emissions. Secondly, it could mean that nanograms or even picograms of substances will need to be removed from the effluent, which could be difficult, as smaller amounts of substance are harder to remove.

If a consent is based on a percentile compliance, allowing a number of exceedences per year before the consent is deemed to have been breached, water companies should perhaps run the processes closer to the consent rather than achieve 100 per cent compliance at the higher associated carbon cost. However, until the efficiency and variation in advanced treatment processes are known, the level of removal to which the works needs to aim as an average operational target will be unknown. It may be many years until the performance data is available to manage the plant with such confidence.

When the carbon impacts of meeting EQS has been reviewed at a European level, the proposed EQS value has been revised. In the case of nickel, initial papers by the European community proposed an EQS of 1.3 ug/l, which was subsequently changed to 1.7 ug/l (CIS, 2005). The potential carbon impact of meeting this EQS was discussed by Defra in its Daughter Directive Impact Assessment Report (Defra, 2007e) and it is understood that the issue was raised to the EU. The final WFD (24/12/2008) contains an EQS of 20 ug/l for nickel (EU 2008); there has been no official explanation of the move from 1.7 ug/l to 20 ug/l. The outcomes of this change in EQS for nickel are an investment saving and reduction in potential carbon emissions. This indicates that precautionary standard setting can produce substantial carbon impacts. In such situations, the Environment Agency aims to take a pragmatic view.

4.3.1 Role of greater operational efficiencies

As an adaptive response to the WFD and developing low-carbon options, the optimisation of current processes and planning to ensure flexibility in future upgrades are important. However, these aspects of business management are driven primarily by carbon and cost control rather than a direct strategy to reduce WFD impacts on the process. If the WFD did not exist, these business activities might still occur.

Reducing flows to a works could make one of the biggest carbon savings. However, the capital expenditure required to divert flows away from sewage treatment works in the UK, in any appreciable quantities, would be large. The whole life carbon cost would need to be considered to ensure that the embodied carbon was balanced with the operational carbon saving. Hence, this is a critical aspect of planning.

As with source control, partners and agencies should be involved in planning infrastructure development, and issues such as separate drainage should be considered within the catchment. This aspect of optimisation is not independent of the WFD and is critical to reduce the overall impact of WFD carbon emissions.

The level of operational risk should be fully understood and it is possible that, until the water industry is able to operate according to WFD requirements, treatment processes cannot be fully optimised.

The water industry and Environment Agency needs to develop a joint understanding of the challenges in order to deliver low-carbon holistic solutions. Gaps in our understanding that will need to be addressed include detailed understanding of how WFD consenting will be regulated, so that the water industry is able to investigate potential efficiencies without the risk of failing consents. There is also the need for long-term planning and partner involvement.

4.4 Key Strategy: Redeveloping existing treatment processes

Least-carbon wastewater treatment may not be the least capital cost solution and includes a number of barriers to implementation, such as understanding the management, servicing and long-term ownership of a very diverse asset base.

Motivations to create a low carbon asset base include the need to improve energy efficiency and thereby reduce costs, reduction in carbon emissions from a corporate social responsibility perspective, and to contribute to the UK's overall mitigation targets. Within the context of the WFD, the switch from conventional processes to lower energy alternatives may also entail demonstrating that novel technologies will meet water quality performance objectives.

Although there may appear to be many barriers to implementation, and hence the temptation to disregard this option, the WFD brings the need for new technologies for end-of-pipe treatment options and the barriers noted above are also true for these novel processes. The WFD will require the assessment of novel technologies, and therefore the revision of existing treatment processes may not be more difficult than adding end-of-pipe treatments.

Options are presented in detail in Appendix 2, and include an assessment of the viability of the approach. Four examples are outlined below for discussion:

- **Powdered activated carbon addition to the ASP:** This process has been used in industrial wastewater treatment and has a low carbon footprint in that it requires no additional contact tanks. However, the powdered activated carbon is lost in the process and the sludge generated needs incinerating. In some cases, this may be a lower carbon option but may be site-specific.
- **Controlled pollutant inflows to WwTW, storage of diluted flows in the sewer network and/or on-site storm/balancing tank to return flow for treatment in dry weather flow conditions (e.g. mininimum oxygen requirements):** Systems are limited by storage capacity and combined sewer overflow (CSO) load discharges control. This could potentially improve the treatment for all consented pollutants: BOD/COD, TSS, Ammonia, Tot-N, Tot-P, and boost removal of priority substances, both biodegradable and non-biodegradable.
- **Chemical dose control on pumps (variable speed dosing pumps): influent total-phosphorus (Tot-P) sensors linked to ferric dosing**

Programmable Logic Controller (PLC) for flexible dosing regimes: A typical control strategy for chemical dosage aims for a low Tot-P level at the outlet of the WwTW. This may be achieved by an online estimate of the phosphorus loading and an online phosphorus measurement at all system stages, with the ability to adjust chemicals dose within minutes.

- **Conversion to anaerobic treatment:** Cranfield University recently presented a flow sheet for a partial anaerobic system for wastewater treatment (Soares, 2008). It reported that such a system could reduce overall CO_2 emissions by 24 per cent and the energy demand by 44 per cent compared to a conventional aerobic system with anaerobic digestion of sludge. Methane emissions would, of course, be higher from an anaerobic system, but CO_2 and N_2O could be expected to be lower, depending on the exact conditions of the plant. Capture of the gas for energy generation would mean that the overall emissions could be lower than for aerobic treatment. However, the ability for such a system to meet WFD consents is unknown, and the capital cost of conversion is also unknown.

4.4.1 Role of redeveloping existing technologies

Each of these examples shows that while options exist and benefits may be derived in terms of reduced carbon emissions, the water industry will need to consider interaction with the existing infrastructure, assess the whole life carbon cost of the benefit, assess the additional operating risks and understand how the option may fit within the existing consenting regime. These issues are more profound than in the case of adding an additional end-of-pipe solution.

The gaps in our understanding that act as general barriers to implementation are the uncertainties in the WFD requirements, but also the tools to assess the long-term carbon benefits, which are now becoming available. Research is needed to understand how a significant process change will affect existing systems. Furthermore, for such engineering to be cost-effective, the applicability across many works needs to be considered.

4.5 Key Strategy: Energy generation

Despite many opportunities for the water industry to generate additional energy through wind or hydroelectric means, these options are not specifically linked to the wastewater function investigated in this study. Furthermore, they are not directly linked to WFD obligations and, depending upon the infrastructure or commercial circumstances of the company, may not represent the same opportunity to all.

Within this study, only renewable generation from the wastewater asset base is considered, such as additional use of combined heat and power, and the use of hydraulic energy generation within the wastewater network and discharge points.

Although these options have been identified, they are strictly not affected by the WFD. Companies have already investigated and used such energy generation methods to optimise energy use and make cost savings. As such, these options are included in this report to indicate what technologies are currently available to address future wastewater treatment requirements, and indicate their likely carbon footprint.

In addition to recovering energy via anaerobic digestion, direct recovery of energy from waste through incineration may be considered. This technique is included in this report even though fits more into the category of process optimisation rather than energy generation within wastewater, as discussed above.

Examples are presented in Appendix 2 and an assessment of their potential application within AMP5 is provided in Table 5.1. The options include:

Micro-hydro generation: Turbines are installed to generate electricity on outfall pipes, or the pressure usually released from a pressure release valve is used to turn a turbine. Turbines have also been used at the reception works and sewer outfalls.

These opportunities are independent of the WFD and it is unlikely that the WFD driver will have any impact on the water industry decision to adopt them. Implementation can bring operational cost savings and potentially reduce carbon emissions.

Combined heat and power from sludge digestion: The option includes optimisation of operations to increase sludge production and hence increase biogas production. There are additional sludge treatment steps, for example the disruption of cells to enhance the availability of the organics and improve digester efficiency.

The co-digestion of organic waste improves digester efficiency by up to 80 per cent (normally 45 per cent sludge is destroyed) and will significantly increase biogas production. The acceptance of food waste from trade discharges delivered into the digester by tanker has been practiced, especially for off-specification dairy products.

Like micro-hydro generation, the CHP option may appear to be independent of the WFD. However, this is not the case. If the water industry adopts new end-of-pipe treatments, such as additional filters, more sludge will be generated, although this sludge is likely to be of lower quality as a feed. Tertiary sludge will then make up a greater proportion of the digester feed and reduce the performance of the CHP system.

4.5.1 Role of increased energy generation

Micro-generation is a relatively new approach in sewage treatment; it has proven successful but is site-specific and the experience of running and maintaining the infrastructure needs to be factored into the overall carbon balance. The industry has applied CHP to the sludge digestion process for many years and many forms of enhanced treatment have been developed.

It is reasonable to assume that these technologies will help mitigate the water industry's carbon footprint and the main goal will be generating electricity; these aspects are independent of the WFD.

The energy produced will be used on-site as there are significant costs in connecting to the national grid. In most cases the location of the energy generated will be at the WwTw, therefore the company can use the energy on-site or in-house.

Another consideration is the mechanism for applying and claiming ROCs. The industry cannot claim the carbon reduction for installations for which the ROCs have been sold, and currently renewable energy production is typically only cost-effective by selling the ROCs. This may mean that the carbon savings are not seen as having been made, as the industry will not report them as part of a reduced carbon footprint.

To help this strategy, the gaps in our understanding need to be overcome by carrying out work to support the technical assessment of micro-generation across the industry. We also need to investigate the impact of end-of-pipe treatments on the sludge stream during the proposed AMP5 investigations. Further assessment of the role of ROCs and carbon trading as a stimuli for adoption should be considered.

5 Developing options in AMP5

Having developed an understanding of generic strategies that the water industry could adopt to reduce carbon emissions while also meeting WFD obligations, this section of the report identifies techniques to consider or develop in AMP5. It also identifies the benefits that options may bring and highlights barriers to adapting such techniques.

5.1 Potential techniques and their adaptability

It is not possible in this study to determine the number of sites where such techniques may be applied in England and Wales. Therefore, where possible, the techniques are considered in terms of their adaptability. An assessment or weighting has been developed as outlined below:

- If the technique could be applied in potentially hundreds or thousands of locations, it is considered highly adaptable. It is, however, likely that such a technique has already been adopted by the water industry, and therefore the potential carbon reductions cannot be applied across the whole industry.
- If the technique is considered applicable at fewer locations (hundreds), it is considered adaptable.
- If the technique is location or process-specific and may relate to locations in the order of tens to a hundred, it is considered of limited application.

These techniques may generate carbon savings in the ranges indicated (Table 5.1), and on a per-site basis, the savings may at first appear modest. However, if routinely considered at the design stage, and applied at all appropriate sites, the cumulative cross-industry saving could be substantial.

Table 5.1 Potential techniques and their adaptability.
Location or process specific but many locations (hundreds possibly thousands): **Highly adaptable**
Location or process specific fewer locations (hundreds): **Adaptable**
Location or process specific few locations (tens to hundred): **Limited application**

Activity	Reduction	Barriers
Operational carbon savings		
Better management of recycle flows – biological treatment (1)	Many internal recycles of effluent within a works are poorly managed and excessive. Efficient control of Return Activated Sludge (RAS), backwash, wetting rates etc could generate a 50 per cent reduction in the energy used in the actual treatment process and a five to 10 per cent reduction in overall site power use. **Highly adaptable**.	May need telemetry or data gathering on site. Site-specific. investigation required to identify optimum sites (benchmarking).
Process monitoring (1)	Implementation of detailed process monitoring to understand cost and performance of all processes of a works resulting in a 10 to 20 per cent reduction in power used on site. Also opportunities to bring savings on chemical dosing (hence carbon of transport), up to 20 per cent in some cases. **Highly adaptable**	May need telemetry or data gathering on site. Again, site-specific and requires benchmarking/site investigations.
Sludge transport optimisation (2)	Companies transport sludge from sewage treatment works to sludge treatment centres by road. Savings in transport frequency and volumes can be made by improving thickness of sludge, and matching production to treatment centre (quality and quantity). Savings: five per cent in transport miles. **Highly adaptable**	Will need model of sludge management processes and distances between works and sludge treatment centres.
Pumping station operation (3)	Pro-active management of pumping station levels to vary levels depending on time of day and rain events. Could save up to five per cent of site power use. **Adaptable**	This may be both within the sewerage system and at head works. Requires switching equipment and software required to monitor and operate. Higher operational costs.
Control mechanism for wash water, inlet macerators and sludge stirrers (4)	Frequently such plants are operational 24 hours a day, every day, even when they are not required. These drives are circa 7 kW, so whilst savings are not large per site they can be replicated across many sites, up to two per cent site power. **Adaptable**	Site benchmarking and site survey required to demonstrate savings.
UV treatment (5)	As a process the relationship between inputs (power and effluent flow/quality) and output is poorly understood leading to considerable overtreatment. Treatment may only be required during bathing water season - as performed by NWL. **Limited application**	Design reviews: 1) Redundancy in banks of lights for fail. 2) Move to technologies that may improve switching on and off and make the system more responsive to dose needs.

Activity	Reduction	Barriers
Pump scheduling & water supply optimisation [3]	Load shifting to cheaper energy tariff. Taking full advantage of available storage in the network to fill tanks using lowest cost electricity: • Peak charge avoidance – Triad and peak capacity charges • Operating pumps closer to best efficiency point • Maximising production from lowest cost treatment plant/sources • Supplying water via shortest, hydraulically most efficient route through network hence reducing carbon emissions. Claims made by software supplier: five to 10 per cent carbon reduction **Adaptable**	Supervisory Control And Data Acquisition (SCADA) requirements and specialist software.
Energy balancing: do not accept over voltage and hence reduce equipment risk and power use [6]	Average optimisation level of from five to 10 per cent • Reduce kWh consumption by 10 to 20 per cent • Reduce electricity costs by 10 to 20 per cent • Reduce maintenance costs • Protect electrical equipment from transients • Improve power quality and power factor • Suppress harmful harmonics **Adaptable**	Will need equipment on site and site survey to determine most effective savings.
On-site generation		
Micro-hydro generation [7]	Turbines to generate electricity on an outfall pipe or the pressure usually released from a pressure release valve is used to turn the turbine. Saving on carbon is very site specific. US examples given. Turbines at reception works or final effluent: An example being 15 kW 2.6 m head Design, installation and commissioning of a 15 kW crossflow turbine installed in the final discharge pit at a sewage works, offsetting on-site consumption. **Limited application**	Sewerage catchment survey to ascertain carbon payback. Note: Need to use electricity where generated as connection to the grid is expensive. Examples based on electricity generation and cost saving: Need to perform carbon balance over lifetime of unit.
Digestion [8]	Better management of digestion with reference to benchmarking of gas yield. Specific focus on solid loading rates and feed dry solids. Best practice feed dry solids of 6-7 per cent but normal practice may be 2-3 per cent. Consequently wasting large amount of energy heating water unnecessarily – also leads to hydraulic retention issues. Improved performance – up to 25 per cent - of digesters leading to increase in biogas. **Adaptable**	Will generate more renewable power – if CHP is installed.

Activity	Reduction	Barriers
Receiving other waste	The co-digestion of organic waste: improves digester efficiency up to 80 per cent (normally 45 per cent sludge destruction). **Adaptable**	As above but also may then become an issue for biosolids to agriculture depending on the type and classification of the imported organic waste. Digesters and CHP needed. Sources of waste and screening if likely to contain plastics etc.
Supply chain management		
Low carbon production and operation of units Equipment: Encouraging manufacturers to make equipment in the UK.	Procurement generally motivated by cost not carbon. Need to consider how to manage carbon accounting and carbon credits through the supply chain. The suppliers that claim carbon benefits will need to be audited and determine how carbon savings are reported to avoid benefits being claimed by the suppliers as well as the water industry. **Highly adaptable**	
Performance management		
Benchmarking	Inter-company benchmarking of key processes – e.g. activated sludge plant energy use. Helps to quickly identify poorly performing sites enabling much more effective use of scarce process experts. **Adaptable**	There may be inter and intra company benchmarking opportunities. Benchmarking is a means to an end and is an operational cost.

References / Reference technology providers:
1) Case study written by Meniscus on Wessex Water. Published In Water & Waste Treatment July 2002 http://www.environmental-expert.com/contact_us.asp
2) Atkins model development: Commercially in confidence used by 2 UK water companies
3) Aquadapt: http://www.ua.es/es/internacional/internacionalizacion/aquadapt/: Sponsors include Yorkshire Water.
4) Atkins: Process team experience at number UK water companies
5) UV: DTI project developing UV QuayTechnology: Atkins report
6) An example provider: Powerperfector: powerPerfector House 1-10 Praed Mews, London W2 1QY
7) Presentation of US technology: Rentricity Inc. P.O. Box 1021, Planetarium Station, New York, New York 10024
8) Meniscus inter-company benchmarking study of non-nitrifying and nitrifying activated sludge plant performance for UK Water Energy Managers Forum – UKWEMF

5.1.1 Assessment of the wider implications of integrated catchment management

The magnitude of increase in carbon emissions due to the WFD depends on the sewer catchment solutions implemented by water companies. The effluent from some WwTW may require additional treatment for just one parameter to meet a tighter discharge consent, and others may require treatment for several parameters. Land availability on-site and the current set up of the works may mean that it is more economical, and possibly better in terms of carbon emissions, to pump the effluent to another works for treatment. In other cases, it might be more efficient to close down a works and divert the flow to a works discharging to coastal waters (to take advantage of greater dilution capacity of the receiving water and, theoretically, a less stringent discharge consent).

Works with a daily flow of less than 250 m^3 tend not to have numeric consents; 250 m^3/day roughly equates to a p.e. of 1,000. If this situation continues under the WFD, there would be no requirement for such works to be upgraded, as tighter EQS would not change their consent conditions. Therefore, widespread use of small works and community-scale treatment (for example package plants) would be less costly in carbon terms than any strategy of merging works and creating mega treatment centres.

However, community-scale treatment may not be a popular option in some areas. Section 101a of the Water industry Act 1991 gives individuals and groups of householders the right to apply to be connected to the public sewer where there is an environmental or amenity problem with the current drainage system and connection is more efficient than upgrading the system. While this right is not in question, the balance between system upgrades and connections is often debated between the Environment Agency and water companies. Defra is in the process of revising the guidelines to make them clearer, and it would be interesting to see whether these can stimulate community solutions rather than connections to the public sewer.

Pumping, at approximately 100 kg CO_2 per Ml per km, is a major cost. Avoiding or minimising pumping would be one strategy for a water company to minimise carbon emissions. Integrated sewer catchment management, optimising the treatment at WwTW and related pumping requirements could be one way of achieving lower carbon emissions. Catchment and water company investigations would need to be performed to find the optimal solution.

5.2 Barriers to implementation

The barriers to implementation identified in Table 5.1 are technique-specific; however there are more general barriers to adapting new techniques.

The techniques identified as potentially viable in AMP5 are operational carbon savings; on-site generation; supply chain management; and benchmarking.

These techniques, while associated with the wastewater function,and important for carbon management, do not include source control or the least-carbon-end-of pipe process. The reasons for this are:

- In the case of source control; the water industry does not have the necessary statutory powers to control the use of products, and can only control trade effluent.
- In the case of end-of-pipe treatment; the performance data and extent of WFD issues are unknown and subject to investigation in AMP5.

As a consequence, opportunities to mitigate WFD carbon emissions will only develop during AMP5.

5.2.1 Financial performance

The current method of accounting for efficiencies gives a water company only five years before the gained efficiency is then considered part of base operation; the company cannot then derive further profit from the investment, even though the benefits could still be received into the future.

The balance between lower-cost-high-carbon emissions versus higher-cost-lower-carbon emissions is going to be a difficult issue to manage. It may be possible to make operational carbon savings but these are offset by the initial high capex cost and the need to maintain equipment that is more complex, but brings such savings.

Carbon is not just about power use: carbon savings can potentially be made throughout the industry through better design and operation of the whole water and wastewater infrastructure; investigating opportunities and demonstrating the benefits may become difficult without carbon modelling. The industry is developing its own approach through UKWIR, however clarity is needed on the boundaries and approaches to carbon planning that would be acceptable within the regulatory framework.

5.2.2 Clarity in carbon trading and carbon value

The water industry is a major purchasing power in the UK. In regions it may be the largest employer and may buy equipment, IT, chemicals, transport services and many servicing and technical support services. There is significant scope to encourage carbon-smart operations; however, the industry does not have a carbon-based purchasing strategy. Trading of carbon credits through the supply chain and recognition of good carbon practice needs to be introduced at the regulator level, so that the industry directly benefits from the positive influence that it may bring. Trading and credits may be important tools to influence change. This would also help the industry to determine the boundaries of carbon accounting, for example, inclusion of chemical source, production or processing, transport to site.

A similar issue is the valuation of ROCs and the SPC. These factors directly impact on the water industry investment strategy.

5.2.3 Exporting power

Electricity cannot easily be supplied into the grid as the cost of connection is high and the supply contracts are difficult to manage. In many instances the water company will produce to meet its own needs, and there is no incentive to develop surplus power generation or generate power at low energy sites.

5.2.4 Uncertainty in WFD implementation

In the future there will be monitoring points to assess compliance with the WFD, in addition to existing monitoring at or downstream of discharges. The future consenting approach will need to consider the results from WFD monitoring sites and reflect on other monitoring data. We also need to understand: (1) the dynamics between ecology and chemistry at monitoring sites; (2) how consents should be used to achieve good ecological status; and (3) how the no-deterioration policy will be implemented.

There is also uncertainty over diffuse pollutants such as phosphorous. The water industry may represent a significant proportion of the discharged pollutant load, however current investigations (UKWIR WW02) are underway by the water industry and Environment Agency to determine the sources of diffuse pollution. Until the study has reported, it will not be possible to know the level of treatment required from the water industry.

The uncertainty surrounding the consenting policy needs to be addressed before there can be any serious planning to meet WFD-based consents.

5.2.5 Uncertainty in the performance of technologies

As noted above the performance requirements, as defined by the Environment Agency's consenting policy, are the basis by which the water industry will select the best treatment processes. However, work needs to be done to establish the effectiveness of additional end-of-pipe or sidestream processes in reducing the pollutants of concern and if adopting such techniques will incur additional compliance or process issues.

This lack of information has been recognised by both the Environment Agency and the water industry and is subject to a planned series of investigations in AMP5. The optimised response by the water industry cannot be determined until these studies have reported their findings in 2012.

Notwithstanding these issues, the following section of the report provides an assessment of the potential impact of the WFD on carbon emissions and the approaches that may be taken by the water industry to reduce these impacts.

6 An assessment of carbon emissions under the WFD

This report developed scenarios to explore various strategies for the water industry to conform to the WFD, including their ability to reduce carbon emissions. Previous sections have identified overall strategies, of which some are already being implemented by the water industry for reasons other than the WFD.

The scenarios are also considered against the background of year-on-year increases in GHG emissions. Water UK's State of the Water Sector report (Water UK, 2008a) concludes that '*despite improved efficiency in abstracting, treating and supplying water, population demographics and consumption growth, along with more stringent treatment standards, are driving energy use up'*. The lack of historical data, and changes in reporting and measurement, do not allow a precise estimate of the rate of increase over the last 20 years. However, based on currently available data, and advice from the project steering group, this report assumed an annual one per cent increase since 1990. The resulting 20 per cent increase between 1990 and 2010 was applied to wastewater treatment emissions and was assumed to be a result of the Urban Waste Water Treatment Directive.

Our approach assessed the impact on the 10 per cent of works over 2,000 p.e. which may require upgrading (UKWIR, 2008a), by:

- identifying current wastewater treatment processes;
- assessing the associated energy and carbon emissions to provide a baseline;
- developing scenarios with which to consider the impact of low carbon options on WwTW emissions and on water quality.

6.1 Current wastewater treatment processes

The water industry uses a number of treatment processes with many variations and significant site-specific issues. As it was not be possible to assess them all, a range of treatment processes was selected, based on the list of substances and parameters provided in Section 3.2.

This range aimed to cover conventional treatments as well as others that are less-well used, but which may be required under the WFD. The list of wastewater treatment processes was agreed with the Environment Agency.

As far as possible, carbon emissions were expressed as CO_2 or CO_{2eq} per mega litre (Ml) of wastewater treated. In addition to carbon emissions and energy use, data were gathered on emissions of other greenhouse gases, waste and byproduct generated. The extent of use within the water industry was provided.

The emissions from different treatment processes depend upon the size of the works; there are economies of scale in many cases and so the per Ml emissions may be lower for larger works than smaller ones. In order to provide a basis for comparing the different processes, as well as the low carbon options developed above, three different sizes of works were assessed where appropriate: a small works (2,000 p.e.), a medium works (10,000 p.e.) and a large works (100,000 p.e.).

The key data sources used were:

- UKWIR, 2008a. *Dangerous Substances and Priority Hazardous Substances/Priority Substances under the Water Framework Directive*, WW17204 (in press).
- UKWIR, 2005. *Workbook for quantifying greenhouse gas emissions*, 05/CL/01/3.
- Peer-reviewed papers published in journals.

The key assumptions made during the assessment were:

- Only secondary and tertiary treatment methods were considered, as it was assumed that all works had preliminary and primary treatment as a minimum and that the WFD would require the more advanced methods.
- The guidelines to Defra's GHG conversion factors for company reporting (Defra 2007c) were used to convert energy use into CO_2 emissions. Unless otherwise specified, it was assumed that grid electricity was used to power treatment at WwTW and the rolling average conversion factor of 0.523 kgCO_2/kWh was used for consistency (although for longer term investments the value of 0.43 kg/kWh is also valid in some of the scenarios).
- CO_2 equivalents were calculated based on global warming potentials published by Defra (2007c).

Two idealised works were used to illustrate the potential increase in carbon emissions with WFD requirements and to provide a baseline. The majority of 2,000 p.e. works in England and Wales have primary treatment followed by biological filters only, and the majority of 100,000 p.e. works have primary treatment followed by activated sludge only (UKWIR, 2008a). It was assumed that pumping emissions would be the same in current and future scenarios and so these were not included in the calculations. These two examples were used to illustrate carbon emissions in Section 6.2.

6.2 Baseline carbon assessment

The approximate emissions for a 2,000 p.e. works are:

	Capital emissions (Kg/Ml treated)	Operational emissions - biological (Kg/Ml treated)	Operational emissions – power (Kg/Ml treated)
Biological filters	22	224	0
Total = 246 Kg/Ml treated			

The approximate emissions for a 100,000 p.e. works are:

	Capital emissions (Kg/Ml treated)	Operational emissions - biological (Kg/Ml treated)	Operational emissions – power (Kg/Ml treated)
Activated sludge	10	224	88
Total = 322 Kg/Ml treated			

None of these values take into account pumping emissions. Additional emissions will depend on the sludge management and disposal options but these will not influence the achievement of WFD water quality standards (although the chosen treatment could influence the resulting sludge treatment).

6.3 Development of carbon assessment scenarios

A number of scenarios were developed to assess whether the WFD will inevitably lead to higher carbon emissions from the water industry. It was assumed that all required measures would be put used to achieve the required water quality standards in each case. The scenarios chosen are shown in Table 6.1.

Table 6.1 Scenarios developed for analysis of carbon emissions.

Scenario		***Reasoning***
1	"Not carbon critical" – No restriction on emissions	This scenario provides an indication of the magnitude of increase in emissions as a result of the WFD if no accompanying offsetting or reduction measures are taken.
2	"Stabilisation" – No increase in carbon emissions based on 2006 levels	2007/08 emissions from the whole of the water industry was five million tonnes CO_{2eq} (Water UK, 2008b). This scenario represents perhaps the minimum regarding carbon emission mitigation from the wastewater sector of the Industry.
3	"Carbon critical" – Optimised aeration, enhanced CHP and surface water reduction	This scenario selects three mitigation techniques from Table 4.2 that offer significant potential operational saving while having limited barriers to their uptake.

The following sections present the carbon and water quality implications of treatment options to meet the WFD, and the implications of any measures to reduce flow or offset carbon emissions by methods such as renewable energy generation. It is assumed that the works will require upgrading to meet tighter consents for the substances identified in Table 3.1. The associated carbon emissions have been calculated from Table 4.2. Gaps in knowledge are highlighted.

6.3.1 Scenario 1

"Not carbon critical" – no restriction on emissions

Scenario 1 covers the situation where treatment to meet the WFD requirements is implemented at any cost. Two examples are provided below.

<u>2,000 p.e. works</u>

This involves an upgrade to activated sludge with denitrification for ammonia removal, chemical dosing for phosphorus removal, and GAC to remove specific pollutants and priority substances.

The additional emissions for a 2,000 p.e. works are as follows:

	Capital emissions (Kg/Ml treated)	Additional operational emissions - biological(Kg/Ml treated)	Operational emissions – power(Kg/Ml treated)
Activated sludge with denitrification	22	0 *	88
Chemical dosing	27	0	0
GAC	4	0	78
Sum totals	**53**	**0**	**166**
Total additional emissions = 219 Kg/Ml treated			

Note: *Biological emissions are considered to be the same as biological filters due to similar BOD removal rates.

Upgrade of the 2,000 p.e. works could increase CO_{2eq} emissions by over 219 kg per Ml treated, taking the total to over 465 kg CO_{2eq} per Ml treated (which does not include the carbon costs of regenerating or replacing the GAC media). This represents an increase in emissions of 90 per cent. In energy emission terms only, the increase would be from zero to 166 kg CO_2 per Ml treated.

<u>1000,000 p.e. works</u>

This involves chemical dosing for phosphorus removal and GAC for removing specific pollutant and priority substances

The additional emissions for a 100,000 p.e. works are as follows:

	Capital emissions(Kg/Ml treated)	Additional operational emissions - biological(Kg/Ml treated)	Operational emissions – power(Kg/Ml treated)
Chemical dosing	0.5	0	0
GAC	4	0	78
Sum totals	**4.5**	**0**	**78**
Total additional emissions = 82.5 Kg/Ml treated			

Upgrade of the 100,000 p.e. works will increase CO_{2eq} emissions by over 83 kg per Ml treated, taking the total to over 405 kg CO_{2eq} per Ml treated (which does not include the carbon costs of regenerating or replacing the GAC media itself). This represents an increase in emissions of 25 per cent. In energy emission terms only, the increase would be from 88 to 166 kg CO_2 per Ml treated (a 90 per cent increase).

Other treatment options include advanced oxidation followed by sand filtration, MBRs and reverse osmosis. Given the financial costs of these options, it is unlikely that they would ever be considered for a works of 2,000 p.e. Instead, if the effluent from the smaller works neede further treatment, it might have to be pumped to a larger works. If the 100,000 p.e. works was to have advanced oxidation and sand filtration instead of GAC, total emissions would increase by over 30 per cent, and energy-related emissions by almost 300 per cent. With an MBR, this increase would be in the region of 400 per cent (energy emissions by 1,200 per cent), and reverse osmosis over 130 per cent (energy emissions by 550 per cent).

None of the tertiary techniques have been proven to remove priority substances or specific pollutants and therefore it can only be assumed that these techniques will be effective. With low EQS and resulting discharge consents, energy-intensive treatments such as advanced oxidation are likely to be required at some works. It is not possible to estimate the implications for the variation in effluent concentrations.

Additional data is required to determine the effectiveness of each treatment option in removing the parameters of interest.

Scenario 1 emission implications

Upgrading a 'typical' 2,000 p.e. works to meet the demands of the WFD could increase total on-site emissions by 90 per cent compared to the current situation, including capital and operation related emissions.

For a 100,000 p.e. works, emissions could increase by over 25 per cent. If more advanced techniques are required, emissions could increase by over 130 per cent.

In terms of what this might mean for England and Wales, if 10 per cent of works over 2,000 p.e. require upgrading (UKWIR, 2008a) this approximates to 900,000 Ml per year undergoing additional treatment. If average total emissions increase by 150 kg CO_2 per Ml treated at these works, taking an average of the two size examples, this could see carbon emissions increase by over 135,000 tonnes a year, including capital and operation-related emissions.

In terms of energy-related emissions only, carbon emissions could increase by over 110,000 tonnes a year.

If works smaller than 2,000 p.e. were upgraded, emissions would increase further, as the majority of WwTW (about 75 per cent of the total number, but two per cent of the flow) are less than 2,000 p.e.

Therefore the water industry would need to adopt strategies to reduce the impact of the WFD for the wastewater function of its operations by at least the 110,000 tonnes CO_2 per year.

6.3.2 Scenario 2

No increase in carbon emissions

Scenario 2 considers adopting some of the easier-to-achieve efficiencies in order to investigate if a target of zero carbon increase is feasible.

As discussed previously there are numerous ways in which overall emissions could be reduced. The industry would need to mitigate the projected increase in energy-related emissions of 110,000 tonnes CO_2 a year estimated under Scenario 1.

The two most effective approaches would be optimisation of activated sludge and the wider use of CHP. As discussed, these two approaches are widely established already and hence only a percentage of the existing treatment capability could be upgraded.

Optimised aeration of activated sludge could save 44 kg CO_2 per Ml treated, which would go some way to mitigating increases from additional treatment at WwTW. Around 23 per cent of WwTW in England and Wales have ASP (UKWIR, 2004) although based on the spread of the size of works this is assumed to equate to 75 per cent of the total flow. It is also assumed only half of all ASPs currently have optimised aeration. Historically, the only instruments used to optimise aeration were oxygen sensors for aeration control or probes for recording outflow turbidity as a measure of plant efficiency. In this sense all plants are optimised and companies have invested to improve the approach. However, more advanced techniques are now available, such as systems that regulate oxygen input on the basis of ammoniacal nitrogen levels (NH4-N), and the assumption that these are deployed at half of all works is a conservative one, based on discussions with a number of UK water companies. A number of enhancements in diffuser design and aeration technologies are also being marketed, although there was insufficient time to assess the whole market for such technologies.

Therefore increasing efficiency at 50 per cent of ASPs could save 60,000 tonnes CO_2 per year.

Widespread enhanced CHP could also be used to offset emissions. For every kg of sludge, 0.3 m^3 of biogas is produced (UKWIR, 2005). For every 1 m^3 of biogas, 2 kWh of useable electricity is produced in CHP, with the remainder used for heating or escaping (Electrigaz, 2006). If an assumed 80 per cent of the total renewable energy generation in the water industry is due to CHP, currently an estimated 212 million m^3 of biogas is produced every year by anaerobic digestion for use in CHP.

If enhanced anaerobic digestion is undertaken, biogas production is predicted to increase by up to 30 per cent. Assuming this could be applied to 50 per cent of existing CHP sites, this would mean that renewable energy generation from CHP could increase from 530 GWh to 610 GWh a year. This increase represents about one per cent of the total 2006/07 energy demand of 8,290 GWh (Water UK, 2008a). It also reduces the volume of sludge, and so carbon savings can be made from reduced transportation and reuse or disposal requirements.

Emissions savings from an annual 80 GWh reduction are 42,000 tonnes CO_2 per year.

However, the reduction in the ROC value for anaerobic digestion from one to 0.5 ROC/kWh may prove to be a barrier.

Scenario 2 emission implications

The underlying assumption in this estimate is that the approaches considered are not currently used at 50 per cent of the sites and the energy saving would be 102,000 tonnes CO_2 per year.

Therefore to achieve the stabilisation of emissions at 2006 levels, the industry would need to adopt other options considered more difficult to achieve.

There are significant uncertainties in this modelling; the wastewater function of the water industry is likely to require not only significant investment to meet the initial requirements of the WFD but also potentially significant investment to offset the carbon impacts of the WFD.

Therefore, when the Environment Agency considers disproportionate cost and technical infeasibility, it should consider also the mitigation steps and associated costs required to offset the carbon impact.

6.3.3 Scenario 3

"Carbon critical" - Optimised aeration, enhanced CHP and surface water reduction

Scenario 3 considers the need to meet Climate Change Act goals and seeks a 26 per cent reduction in carbon emissions by 2020 from 1990 levels. This target is for UK emissions as a whole, not water industry specific, but it is a useful benchmark to consider.

Implementing enhanced anaerobic digestion and increasing the energy efficiency of aeration at activated sludge plants will mitigate the impacts of enhanced treatment as a result of the WFD, but it will not be enough to achieve the significant reductions required as part of the CCA.

This scenario considers further possible gains by including surface water reduction as another potential operational saving, which has limited barriers to uptake. Reducing the flow to a works could be one of the most useful ways of making emissions savings.

An estimated 30 per cent of the flow to a works is due to surface runoff (Environment Agency, 2008b). With 3,650,000 Ml sewage flowing to WwTW a year (Ofwat, 2006), 1,095,000 Ml are surface runoff. If for every Ml of sewage pumped 100 kg CO_2 is emitted (Table 4.2), this means that the pumping of storm water alone is responsible for 110,000 tonnes CO_2 a year. There will be associated savings in the treatment costs, depending on the processes used. Thus, any flow reduction that can be achieved will help reduce emissions through energy use.

However, diverting all runoff to surface water would likely be a costly exercise of many billions of pounds across England and Wales, and would be a highly disruptive activity in towns and cities as roads are dug up to access the pipes.

There is also the question of how the water industry carbon footprint is calculated. If the footprint includes emissions due to biological treatment, that is biodegradation in treatment and biological respiration, water companies would need to seek massive reductions to offset the biological emissions: for biological filters, 90 per cent of emissions would be biologically derived, and 60 per cent for ASP.

Scenario 3 emission implications

Greater use of enhanced anaerobic digestion and increased energy efficiency of aeration at activated sludge plants, plus reducing the surface water flows to WwTW, could help reduce emissions relative to that required by the CCA. A saving of 110,000 tonnes CO_2 a year could be made if WwTW did not pump storm water; however, the cost of changing this practice would be disproportionate and highly disruptive.

Carbon accounting is a relatively new process, but the water industry is well placed in this area through the use of a consistent accounting method (UKWIR, 2008c & 2008d) for annual reporting to Ofwat and Defra, and for business plan purposes. When considering or reviewing accounting boundaries, the water industry, Ofwat and the Environment Agency should consider the potentially large contribution from bio treatment processes. Carbon dioxide arising from biotreatment processes are currently defined as short-cycle emissions however, and therefore excluded from company's carbon footprint calculations.

6.4 Overview of the predicted WFD implications

Scenario 1 shows that the water industry could see a significant rise in the embodied and operational carbon emissions from wastewater treatment from roll-out of the WFD. Scenarios 2 and 3 could, with major investment, mitigate the predicted impact. Figure 6.1 shows that it will be difficult to meet Climate Change Act targets; it includes annual capital and operating emissions from the 10 per cent of works likely to require additional processes:

- **Baseline –** 2010 emissions assuming activated sludge at all WFD-affected works.
- **Assumed 1990 emissions –** back-calculated from 2010 based on an annual one per cent increase.
- **Scenario 1 –** increased emissions following the addition of denitrification, chemical dosing and GAC to the 10 per cent of works affected by the WFD.
- **Scenario 2 –** post-WFD mitigation by water industry-wide optimised aeration and enhanced CHP.
- **Scenario 3 –** post-WFD mitigation by water industry-wide optimised aeration, enhanced CHP and complete surface water reduction.

This study has indicated the maximum potential carbon reduction acheivable; however, this would be difficult to achieve via wastewater treatment in isolation. The consideration of catchment management and diverting surface runoff in Scenario 3 provides a theoretical option, however the magnitude of this option cannot be overstated. A much broader study is necessary to assess all of the renewable energy options available to the industry to make up this shortfall.

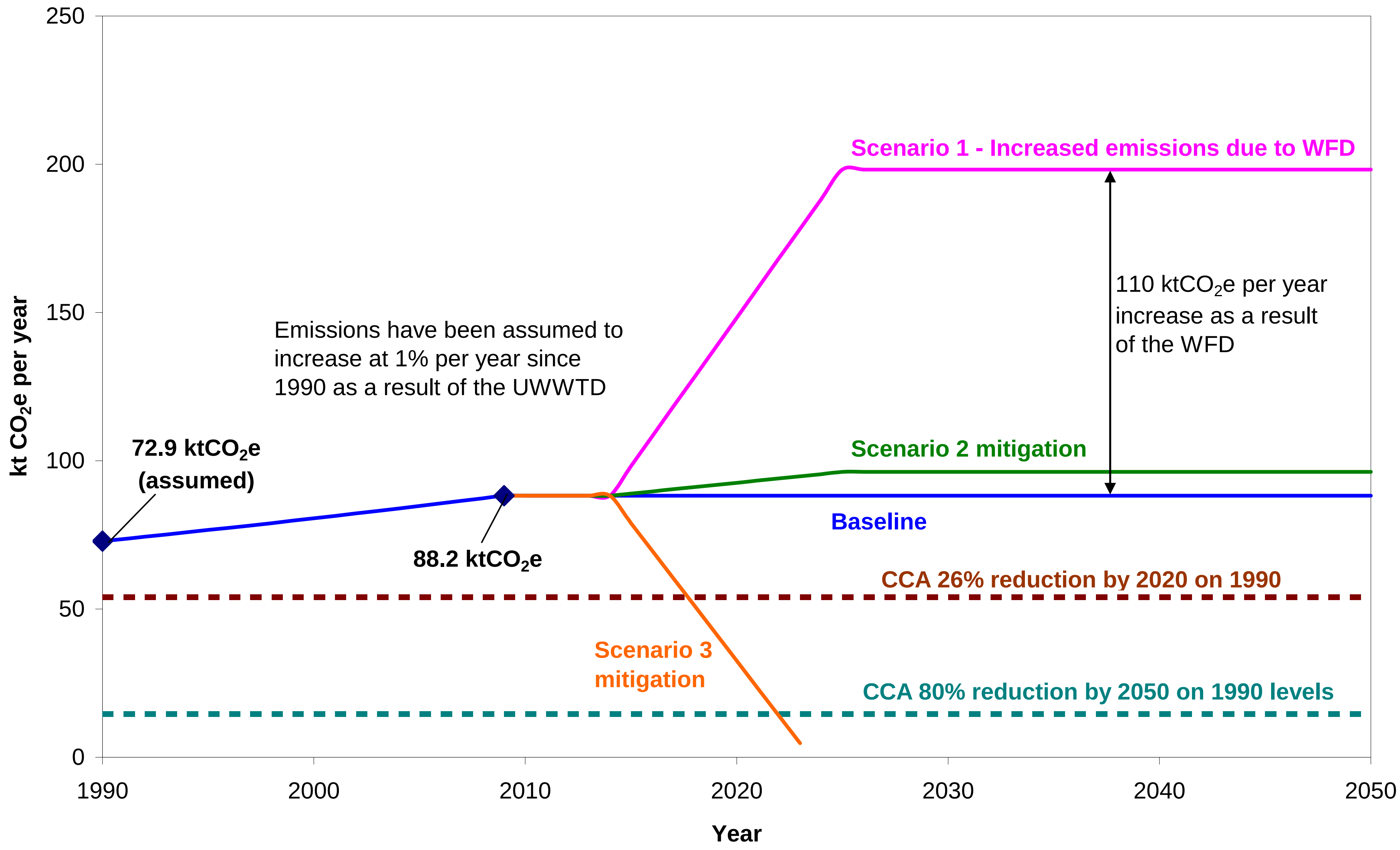

Figure 6.1: Capital and operational emissions from works liable to require improvements as a result of the WFD.

6.5 Timing and phasing

This study has identified knowledge gaps and uncertainties in potential technical solutions and what may be implemented to meet the WFD requirements. It is highly likely that the water industry will not be in a position to offer detailed responses to the WFD within AMP5 due to the need to complete the proposed investigations.

For the water industry to be able to respond in AMP6, the Environment Agency will need to ensure that it defines an acceptable programme of measures in 2012, so that the business planning, associated cost-benefit and cost-effectiveness analyses can be performed.

If end-of-pipe processes are to be used, it is necessary to establish the effectiveness of different processes before optimisation can be achieved. The Environment Agency is also likely to require, through environmental monitoring, evidence of whether standards have been met and the aims of the WFD achieved.

Investment in AMP5 will predominantly focus on investigations, with process optimisation taking place as part of the business-as-usual case for the water industry. This will be followed by potentially significant investment towards the middle and end of AMP6, followed by monitoring and optimisation within AMP7.

7 Conclusions

7.1 WFD requirements

Before the carbon consequences of the WFD can be fully appreciated, and process improvements determined, a detailed understanding is needed of the standards required of the water industry. It will be especially important to determine how the Environment Agency translates EQS into discharge consents and links chemistry to ecology, as this will greatly influence the level of additional treatment (and hence carbon emissions) required at WwTW. These issues also apply to the no-deterioration policy.

7.2 Carbon impact of the WFD

Increased treatment under the WFD has been estimated by this study to increase carbon emissions by over 110,000 tonnes a year due to operational energy use associated with the wastewater treatment processes. This may be considered a small increase with respect to the water industry's carbon footprint, but is significant with respect to the wastewater function studied.

Widespread use of enhanced anaerobic digestion with CHP, and of energy optimised activated sludge, could see savings of over 102,000 tonnes CO_2 a year assuming 50 per cent optimisation in the industry.

There are significant uncertainties associated with this modelling. The wastewater function of the water industry is likely to require not only major investment to meet the initial requirements of the WFD, but also significant investment to offset the carbon impacts of the WFD. Therefore, when the Environment Agency considers disproportionate cost and technical infeasibility, it should also consider the mitigation steps required to offset the carbon impact.

Although this study has indicated potential carbon reductions through improved catchment management and diverting surface runoff, the magnitude of this option cannot be overstated. A much broader study is required to assess all of the renewable energy options available to the industry to make up this shortfall. This study has not considered the impact of future decarbonisation of UK electricity mix on industry emissions. For example, the Committee on Climate Change project a 45 per cent fall in grid average emission factor by 2020.

7.3 Role of new technology

A detailed understanding is needed of the effectiveness of potential techniques to treat the substances of concern. The treatment examples in this report have not been shown to have the treatment performance required to meet the EQS. Therefore, this study may only be considered as indicating the potential issues.

7.4 Planning and process design

Given that programmes of measures to meet WFD requirements will include management of point sources and diffuse pollution, it will be critical for partners to work together to understand the relative impacts of pollutants on receiving water ecology.

While the water industry has achieved efficiencies, driven by the increasing cost and instability in the supply of power, these are considered insufficient to offset the impact of WFD. The regulatory environment does not currently offer the incentives needed to drive carbon reductions, as the industry is targeted on financial and quality measures that have yet to effectively include carbon.

Delivery of the ‘big wins’ that will be needed to reduce carbon emissions while still meeting WFD obligations will require the incorporation of a detailed understanding and optimisation of the carbon impact at the design stage.

7.5 Investment strategies

The WFD itself does not provide incentives for water companies to invest in low carbon solutions. Instead the price of energy, financial and reputation impacts associated with the Carbon Reduction Commitment (CRC), and reporting requirements to include the SPC in new scheme appraisal, may drive water companies to research and invest in sewer catchment plans for carbon reduction. The UK’s long-term strategy for adoption of renewable energy generation and subsequent decarbonisation of energy supply is likely to push the cost of energy higher, driving further efficiencies.

The SPC feeds into scheme cost-benefit analysis; however, compared to the capital costs that schemes may present, the SPC may not offset the costs and no case will be made for the investment, although Government are currently reviewing the SPC in the context of recent climate change emission reduction targets.

Under the current funding regime, the savings associated with an operational efficiency can only be regarded as additional profit by the water company until the end of that periodic review (five years). After this time, the efficiency is considered base operation and the savings passed to the customer. Consequently if the industry invests in low carbon technology with income arising from efficiencies then it may only have five years to payback. However, low carbon technologies included within price limits as part of the price review cycle are valued in payback terms over their whole lives. This issue is of concern across all innovation, but especially where the payback hinges on the relatively low SPC cost. The incentive to invest is only favoured for schemes that will significantly reduce chemical or energy costs, with carbon savings having less weight in investment decisions.

It is anticipated that significant investments will be made within the middle to late AMP6 period, tailoring off in AMP7, and which will comprise predominantly environmental monitoring and optimisation.

8 Recommendations

The recommendations below offer strategies that may be adopted by the water industry. They are not, however, actions specific to the water industry and, where appropriate, partners and other organisations are identified.

Source control

In some situations the most significant carbon savings may be achieved through the control, at source, of the substance of concern, as this avoids the need for treatment at the WwTW.

A detailed source apportionment study is needed followed by programmes of measures targeting specific pollutants. The water industry and the Environment Agency have recognised this issue and are collaborating on a UKWIR/EA project WW02 which will report source apportionment findings as well as modelling river catchments to assess the associated risks. This project should consider the carbon impacts of the proposed programmes of measures.

Following on from the above study, programmes of measures in the ongoing WFD cycles should communicate project results to partners in order to establish least-carbon solutions. However, the relatively low SPC may mean that the least-carbon solutions are not the least-cost solutions.

Source control through product use should be considered for substances that come in contact with water, for example plasticisers that may drive the need for end-of-pipe treatment. However, these issues may be trans-boundary and outside of the water industry's control.

Least carbon end-of-pipe/process addition

The biggest knowledge gap which underlies the response of the water industry is the ability of existing technologies to remove many of the substances of concern, which is unknown, as is the ability of end-of-pipe solutions to remove the substances. Therefore any assessment of the water industry's options is flawed without reducing this knowledge gap.

Studies are proposed in AMP5 to address this knowledge gap and these studies should include a detailed assessment of the carbon implications of end-of-pipe treatment, and of the potential impact on sludge management.

If the water industry is required to adopt end-of-pipe solutions, the cost of wastewater services to the public could rise significantly. In such an event, it is recommended that the water industry reviews its trade effluent consenting and charging policies such that, where appropriate, trade effluent controls and charges are aligned under the polluter pays principle. However, specific trader sectors may be required to make financial contributions, and while this may be an incentive to control emissions it may also lead to carbon-inefficient on-site treatment at the trader site. Hence it is also recommended that whole carbon lifecycle risks are assessed for such changes in water industry policy.

These studies should also include Annex VIII substances and EDCs so as to avoid the need for further work in later cycles of the WFD.

Greater operational efficiencies

Optimisation of the design of the wastewater treatment is being considered by the industry, and there is recognition of the long-term least-cost approach. This includes an element of least-carbon long-term planning, however to be effective there needs to be integrated management by the Environment Agency, local authorities and water industry. It is also critical that the financial modelling and business development practices promoted by Ofwat recognise the value of such an integrated approach. A general recommendation is made for all parties to recognise the holistic nature of potential low-carbon operations. There may therefore be a requirement for Defra to develop the cross-organisational guidance.

The Environment Agency should undertake environmental regulation in a more holistic manner, so that the setting of consents is considered within a framework which ensures the potential carbon emissions of meeting EQS are understood and factored into the consenting regime.

Ofwat should consider the innovation cycle and the five-year conversion from efficiency savings to baseline operational. The industry is having to be more innovative and needs sustainable investment planning with technology payback periods.

With regard to planning, drivers at present to reduce carbon emissions relate to energy use, the inclusion of the SPC in scheme assessment, and from 2010, the introduction of the CRC. To target other emissions, for example arising from biological breakdown, policy measures should be put in place, with the support of the Government and Ofwat, to facilitate reporting and accounting of these emissions.

The Environment Agency should provide more guidance on how WFD consenting will be regulated so that the water industry can explore potential efficiencies without the risk of failing consents. It may be necessary to develop a few test cases or catchments and provide “draft” approaches, so that all parties can assess impacts in more detail, which may in turn lead to refinements of the guidance. This should include no-deterioration policy assessments as well as the link between chemical and biological WFD requirements.

Redeveloping existing treatment processes

Research is needed on how major process changes will impact existing systems including whole lifecycle carbon costs. This type of site investigation may be time-consuming and extensive. Methods to assess the carbon impact of redeveloping existing treatment processes should be developed.

Energy generation

Energy generation is currently being investigated and directed by other initiatives. To assess the possible impacts on/for energy generation under the WFD, further understanding is needed on how sludge make-up from new treatment processes will affect existing sludge processes and hence CHP opportunities. The proposed studies under AMP5 should consider sludge management impacts on the function of CHP.

Biogas does appear to satisfy European guidance criteria for by-product status. It is recommended that the combustion of biogas be considered for regulation under Environmental Permitting Regulations. A review is needed to ensure that biodegradable waste can be used as digester feed.

A much wider study is required to fully investigate the opportunities for renewable energy generation across water industry functions. Such studies should ideally include local authorities, highways and other partners who may be able to influence the management of surface water.

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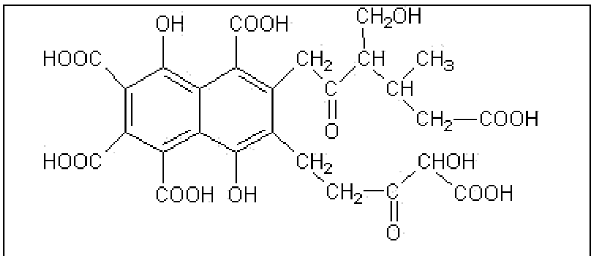
Appendix 1 – Estimation of CO_2 release from ozonation

The following section presents the calculations to estimate CO_2 released due to the ozonation of secondary effluent.

The dissolved organic carbon (DOC) concentration in secondary effluent has been reported in the region of 20 mg/l (UKWIR, 2004). A reasonable assumption would be that all of the DOC was fulvic acid. Thirty-one per cent of DOC has been calculated to be removed during ozonation (Wataru-Nishijima *et al.,* 2003), based on an experiment using secondary effluent from a WwTW and an ozone dose of 5.2 mg O_3/l. The following presents the calculations used to estimate the amount of CO_2 released during ozonation.



Model structure of fulvic acid by Buffle

$C_{27}H_{26}O_{18}$ = 638 g
$C_{27}H_{26}O_{18}$ + $16.3O_3$ = $27CO_2$ + $13H_2O$
1 mol Fulvic = 27 mol CO_2
if all DOC = Fulvic = 20 mg/l
1 mol = 638 g: equals 1 mmol = 638 mg/l: equals 1 μmol = 638 μg/l
20 mg/l Fulvic/DOC = 31.3 μmol
creates 27 times CO_2 = 846 μmol CO_2 if all destroyed.
But only 31 per cent destruction so: 262 μmol CO_2 produced
CO_2 = 44 g/mol
262 μmol = 11.5 mg CO_2 produced from 31 per cent of 20 mg/l DOC = 6.2 mg/l DOC treated

= 11.5/6.2 = 1.9 kg CO_2 for every kg DOC

For every litre treated, 11.5 mg of CO_2 is produced reacting with 6.2 mg DOC
Therefore 1 Ml = 11.5 kg CO_2

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Appendix 2 - Developing carbon optimised strategies in the wastewater industry

Technique	Description and potential saving	Barriers to uptake	Impact on effluent quality
Energy optimised conventional treatment			
Reducing aeration costs in activated sludge	Conventional aeration systems can be split into two types, broadly speaking: surface aerators and diffusers. The former tend to have oxygen transfer capabilities of between 1 and 2 kg O_2 per kWh. Coarse bubble diffuser capabilities tend to be in the region of 1 kg O_2 per kWh and micro bubble diffusers 2 kg O_2 per kWh (Kadar and Siboni, 1998). The upgrade of a coarse diffuser to a micro bubble diffuser could result in significant energy, and hence carbon, savings. Novel, low energy systems could also be used to aerate the activated sludge plants. Data suggests that up to 50 per cent of the energy use of traditional activated sludge aerators could be saved by using co-current downflow contactors instead of conventional systems (NIG, 2005). Based on the data in Table 4.2, this could represent an operational saving of 44 kg CO_2 per Ml treated. Severn Trent Water investigated how modifying the aeration levels according to ammonia levels would influence energy consumption. The idea was to prevent excess air being used when ammonia levels were low. The results showed average energy savings of 20 per cent in summer and 10 per cent in winter. Controls have already been installed at 10 sites, with plans for further installations at large works (Severn Trent Water, 2008a).	A cost benefit analysis of replacing working kit (the aerators) would need to be undertaken to ensure that long-term carbon savings were realised once capital and operational were taken into account. Generally speaking, M&E kit such as the aerators would be replaced every 10 to 20 years. Times when they were going to be replaced would present an ideal opportunity to use more efficient techniques. Controlling aeration levels due to the ammonia load may provide a more short-term cost-effective method for reducing energy demand with current aeration equipment.	Increasing the efficiency of aeration systems should not result in any detrimental effects on the effluent quality. Equipment to modify the aeration levels according to ammonia levels would need either a backup or frequent monitoring to ensure that it was in full working order and that treatment wasn't compromised.
Reducing pumping costs	A number of measures that could be taken here, and research suggests that improvements in operation and performance could give energy savings of between 30 and 50 per cent (Yates and Weybourne, 2001). Energy audits of the systems used to maximise their current efficiency could highlight areas for improvement. Reducing pumping costs goes hand in hand with reducing the flow to WwTW. Lower flows mean that the wet wells before the pump take longer to fill and hence the pumps do not go off so often.	There may be a lack of capital expenditure and/or incentives to replace less efficient pumps with more modern varieties. As with all the options, the potential for energy savings is highly site-specific. Many water companies have implemented a number of energy efficiency measures under PR04 and there may be increasingly limited opportunities for further savings.	The optimisation of pump efficiency should not impact on effluent quality.
Process optimisation	WwTW are by nature dynamic systems, both because of the predominantly biological treatment systems, but more so because of the fluctuations in the composition and strength of the received sewage. Although the hydraulics of the process will to some extent even out the sewage influent variation, there is still the likelihood that the works will outperform its consent to ensure that the consent is actually met. This is especially true where Maximum Allowable Concentrations rather than consenting based on per centile is applied. Examples of process optimisation may include: instrumentation on aeration to improve control as noted above, agreeing with traders to discharge at night	The dynamic nature of the sewage quality means that the operator can only make changes based on monitoring information, of which there are limited on-line systems and the rate of effective change may be limited by the biological system response. However, moving form a MAC to percentile consenting policy allows companies to operate closer to the ideal and match average performance to consenting requirements.	Optimising the process to avoid over treating could potentially increase the risk of breaching a discharge consent.

Technique	Description and potential saving	Barriers to uptake	Impact on effluent quality
	(lower background due to the domestic diurnal flow).		
Treatment techniques - wastewater			
Anaerobic treatment	Cranfield University recently presented a flow sheet for a partial anaerobic system for wastewater treatment (Soares, 2008). They reported that such a system could reduce overall CO_2 emissions by 24 per cent and the energy demand by 44 per cent compared to a conventional aerobic system with anaerobic digestion of sludge. Methane emissions would of course be higher from an anaerobic system than an aerobic one, but CO_2 and N_2O could be expected to be lower, depending on the exact conditions of the plant. Capture of the gas for energy generation would mean that the overall emissions could be lower than for aerobic treatment. There are several different techniques within the scope of anaerobic treatment and each may represent different carbon savings and costs.	The traditional view of anaerobic treatment is that it is only suitable for high strength (eg industrial) effluents and/or within sub-tropical or tropical climates due to the requirements of the microbial communities within the treatment. Recent research has shown that anaerobic systems may actually be feasible in temperate climes Not suitable for works receiving storm water or other potential 'shock loads'. This could limit its applicability across England and Wales as it is estimated that 30 per cent of the flow to a WwTW is storm flow (Environment Agency, 2008b). Trials would need to be conducted to ensure its effectiveness. Requires post-treatment to ensure effluent is of sufficient standard (as is likely the case with other secondary treatment processes so may not be a significant barrier to uptake). Cost effectiveness of replacing existing aerobic works with anaerobic systems would need to be assessed. Potentially cost effective option for new works but carbon and cost savings are unlikely to be sufficient to warrant the replacement of existing working treatment. Not commonly used within the water industry in the UK	No evidence was found on the efficiency of anaerobic treatment in the removal of the parameters of interest, although it has been reported that it is capable of over 80 per cent COD removal (Soares, 2008). This compares favourably to average BOD removals in biological filters and ASP of between 60 and 95 per cent (Lester and Birkett, 1999).Thus it could be expected that anaerobic treatment would be as effective as aerobic secondary treatment for some of the removal of the parameters of interest.
Treatment of sludge			
Pyrolysis or gasification	Pyrolysis and gasification both turn wastes into energy-rich fuels by heating the waste under controlled conditions. Whereas incineration fully converts the input waste into energy and ash, these processes deliberately limit the conversion so that combustion does not take place directly. Instead, they convert the waste into valuable intermediates that can be further processed for materials recycling or energy recovery. Pyrolysis is undertaken in the absence of oxygen and produces char, syngas (similar to natural gas) and a bio-oil (similar to diesel oil). Gasification has a limited about of oxygen and produces syngas. Both are energy-intensive processes and no data could be found on relative energy costs or GHG emissions.		The treatment of sludge should not impact on the effluent quality.
Incineration with energy recovery	A number of water companies dispose of their sewage via incineration with energy recovery. One such facility at Crossness WwTW in London produced 20.1 GWh of energy in 2005 from the sludge generated by the treatment of sewage from over two million people in London. This energy meets over three	Sites must comply with IPC regulations. Local objections may exist but the successful construction and operation of such sites across England and Wales shows that they are not always insurmountable.	The treatment of sludge should not impact on the effluent quality.

Technique	Description and potential saving	Barriers to uptake	Impact on effluent quality
	quarters of the site's energy demand (Thames Water, 2008). Ash is produced as a byproduct (about 7,500 tonnes in 2005 at Crossness). In the case of Crossness, a proportion of this ash is used to make bricks and aggregates. Another example is at Yorkshire Water's Knostrop WwTW which treats sewage from the Leeds conurbation, with an equivalent population of 940,000. The incinerator itself burns 3.3 tds/h of sludge cake (Hand-Smith, 1999). The cake is discharged into a 15 tonne bed of sand fluidised by hot air, which evaporates the remaining water and incinerates the sludge to an inert ash at a temperature in excess of 850^{o}C. Heat is recovered from the hot flue gases to preheat the combustion air and to generate steam, which is used to pre-dry the feed sludge in order to avoid supplementary fuel use, and to reheat the flue gases to prevent a visible plume. The project cost £32 million in 1998. Severn Trent Water, Thames Water, Yorkshire Water and Southern Water all have incineration with energy recovery plants. In most cases these have been in operation for over 10 years.		
Enhanced anaerobic digestion	Induction of cell lysis in the sludge before anaerobic digestion could increase the biogas production by 30 per cent (Sonico, 2005; Eco-Solids International, 2008). Acid phase digestion could also increase biogas production by a similar degree (Severn Trent Water, 2008b)	The water industry suggest the change to the ROC value for anaerobic digestion in the water industry from 1 to 0.5 ROC/kWh could make investment in enhanced techniques economically unviable.	The treatment of sludge should not impact on the effluent quality.
Vermistablisation	The use of worms (the tiger worm, *Eisenia foetida* is the most commonly used one in the UK) have been trialled for the treatment of sludge. It is a low energy system suitable for smaller works, negating the need for sludge transport to centralised facilities. Energy may be required in the winter to keep the tanks at a minimum temperature of 12^{o}C; for an insulated 500 p.e. units this equates to roughly 10,000 kWh (£600/yr, 2006 prices) or 10.5 kg CO_2 per p.e. (Cooper-Smith, 2006). The system is suitable for both primary and secondary sludges. Trials have been conducted in several UK water companies including Scottish Water, Yorkshire Water and United Utilities. The results have demonstrated their suitability for small works and the resulting compost (called vermicast) had a high nutrient value, making it a promising soil amendment product (Atkins, 2002)	Only suitable for small works as loading rates are between 1.5 and 2 kg DS/m^2/week (Cooper-Smith, 2006), so above about 500 p.e. the land requirements may be limiting. Has been reported that anaerobically digested sludge is toxic to the tiger worm (Hartenstein and Mitchell, 1978). However, as such treatment is only likely at small works, it is unlikely that this would ever be an issue.	The treatment of sludge should not impact on the effluent quality.
Optimisation of sludge transportation	Models have been developed to optimise the transport of sludge between WwTW and treatment centres. Use of these models and studies to determine the most sustainable or carbon-efficient methods of sludge management within or between water companies could result in significant carbon savings. For example, sludge treatment centres at individual works may be more efficient in some cases than transporting the sludge to centralised facilities.	The methods and markets for the reuse or disposal of the sludge will ultimately determine the strategies used by water companies	The treatment of sludge should not impact on the effluent quality.

Technique	Description and potential saving	Barriers to uptake	Impact on effluent quality
Reuse/disposal of sludge			
Agricultural land	Approximately 62 per cent of the one million tonnes (dry solids) of sludge arising in the UK a year is recycled to agricultural land (Water UK, 2006). Recycling to land is seen as the Best Environmental Practicable Option in most cases. Emissions of GHG could be expected in the form of CO_2 and N_2O. Methane emissions are not expected as the soil should not be anaerobic. A Defra study reported that measured emissions of N_2O from soil amended with organic manures such as digested sewage sludge and inorganic fertilisers were not significantly different and in the region of 0.35 to one per cent of applied N (Defra, 2002).	Recycling on agricultural land is a traditional use of sewage sludge (also called in this instance 'biosolids'). The use of sludge in this route must follow the Safe Sludge Matrix. Pressure from supermarkets and the public means that this route of recycling may decrease in the future, despite its benefits.	The disposal of sludge should not impact on the effluent quality.
Use in biomass crops	The idea of using sludge to amend the soil for biomass crops (namely miscanthus and short rotation coppiced willow) is not new. Collaborative research trials are being conducted to look at the possibility of growing biomass crops using partially treated wastewater (Water Renew, 2007). No data on production rates per application of sludge or wastewater were available to assess its effectiveness in offsetting carbon emissions compared to its use on agricultural land. In Northern Ireland, approximately 3,000 tonnes DS sludge is applied as fertiliser to willow plantations (POST, 2007), indicating that it is a potential route for reuse.	Disposal of sludge must follow the Safe Sludge Matrix, but the standards are no more onerous than for other non-food crops. Research for Defra has shown that the application of sewage sludge may increase the runoff of phosphorus due to the low nutrients needs of energy crops. The report states that they therefore may not be a suitable outlet for the regular disposal of sludge (Defra, 2007a). Potential routes for disposal will be limited to whether or not plantations exist locally. If land is available, on-site growing and burning of the energy crops could provide an energy source for use at the WwTW.	
Renewable energy generation			
Hydropower	The conveyance of sewage to and from the WwTW presents a potential source of energy. In Australia, Sydney Water has commissioned a hydroelectric generator to capture energy from wastewater flowing down a drop shaft into the deep ocean outfall at its North head WwTW. It is also installing mini-turbine engines along some of its high flow pipes to allow hydroelectric generation (Sydney Water, 2007).	Yorkshire Water has used hydropower at the intake of a WwTW. However, the sewer catchment needs to be large to provide economic pay back for the units.	The generation of renewable energy should not impact upon effluent quality.
Fuel cells – wastewater	Numerous research projects are currently being undertaken into the feasibility of microbial fuel cells with domestic sewage as their feedstock. Penn State University in the USA is one institution researching their use for the generation of electricity (rather than traditional hydrogen) from sewage. One article suggested that a fuel cell running off the sewage within a 100,000 p.e. works could generate 51 kW (New Scientist, 2004) which seems very low and it is assumed that the units are incorrect. Another article reports that a mere 10-50 milliwatts of energy per m^2 of electrode have been produced in lab-scale trials at Penn State University (PSL, 2004), which again does not seem too promising. They did, however, report an 80 per cent reduction in BOD which	Much research needs to be done on fuel cells and wastewater before it could be considered a serious option. At the moment, its power-generating capacity limits its potential within the water industry.	The generation of renewable energy should not impact upon effluent quality.

Technique	Description and potential saving	Barriers to uptake	Impact on effluent quality
	demonstrates at least its effectiveness in sewage treatment.		
Fuel cells – sludge	Fuel cells using methane from sludge treatment are more established than from wastewater as mentioned above. A molten carbonates fuel cell (MCFC) demonstration plant in 700,000 p.e. Renton WwTW, Washington State, USA produced 1 MW with the gas from a mesophilic anaerobic digester (Bush, 2006). The trial itself cost $23 million, with an estimated installation cost of between $5 and $8 million per MW, working out at $0.045 to 0.065 per kWh (US EPA, 2006). The fuel cell plant is expected to have a design life of 30 years, although the fuel cell stacks themselves may need replacing up to every five years (KC, 2005). Other full scale-trials and installations of MCFC are being done in Germany where it is reported that with the Government's National Innovation Programme and recent legislation on renewable energy, fuel cells should become cost-effective option in the near future (Gutemann, 2007). Another trial is currently being conducted in Spain, with EC LIFE funding. It involves the design and demonstration of four CHP Plants using two 5 kW Solid Oxide Fuel Cells (SOFC) working with landfill gas and biogas from anaerobic digestion (BIOSOFC, 2007). The aim is to look at the energy, environmental and economic costs of using a CHP system based on SOFC fed with biogas from anaerobic digesters treating waste from landfill and slaughter houses. The results, due in late 2008/09, could be informative on the feasibility of using fuel cells in the water industry.	The current high cost of fuel cells is likely to be prohibitive in England and Wales. However, their cost is likely to come down as more industries and companies use them. The cells are still at the research stage, although far more advanced that ones using wastewater, and thus they are likely to be a long-term option rather than something that could be installed in the next couple of PR cycles.	The generation of renewable energy should not impact upon effluent quality.
Reducing the flow to WwTW			
SUDS	Sustainable drainage systems aim to mimic as closely as possible the natural drainage from a site and to treat the runoff to prevent pollution. A number of techniques are used, depending on the situation. The SUDS Manual published by CIRIA in 2007 provides detail on each of the techniques and the suitable conditions. The application of SUDS in circumstances where surface water would otherwise be discharged to a combined sewer will results in reductions in electricity used in pumping the combined wastewater as the volume and rate of wastewater would be reduced. There would also be a reduction in the pollutant load on the works as the 'first flush' of roads, car parks and gully pots would be removed. No data could be found on the capital GHG emissions of implementing SUDS. Operational emissions are expected to be low, although there may be some biological breakdown in storage ponds. The magnitude of any potential energy savings is difficult to quantify as it is so site-specific – the length of pipe work and the number of pumping stations for	Currently there is an automatic right to connect surface water drains or sewers to the public sewerage system (Section 106 of the water industry Act 1991) which could act as a potential barrier to the use of SUDS. This is under review by the Government. The Government envisages that piped drainage will continue to have a role but a greater range of drainage approaches should be considered when surface water drainage systems are designed and constructed in the future. The management responsibility for the SUDS can be contentious.	The use of SUDS could prevent the 'first flush' of pollutants reaching a WwTW. Reduction of flow could also help prevent the scouring of sewage pipes due to high velocity flows during storms (where deposited sediment etc is removed from the pipes). Again, this would reduce the pollutant load to the works. Reduction in storm flows could mean that concentrations of substances from predominantly domestic sources (eg EDCs, DEHP,

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	example. However, some general assumptions can be made to give an idea of the potential magnitude of any savings. It has been calculated that in the region of 1,500,000 Ml of runoff from urban areas flows to WwTW every year in England and Wales (Environment Agency, 2008b). This value is based on the estimate that 49 per cent of the flow to WwTW comes from combined systems (UKWIR, 2008a) and that 30 per cent of the total flow to WwTW is from runoff (Environment Agency, 2008b). Estimating energy requirements and hence carbon emissions per Ml treated is difficult. However, as an example, it has been calculated by Atkins that 20 Ml/d raised 50 m vertically over a distance of 1,000 m in a 500 mm pipe with 72 per cent pump efficiency would require 0.1987 kWh/m^3. Using Defra's conversion factor of 0.523 kg CO_2/kWh for grid electricity, it can be estimated that for every Ml pumped, 100 kg CO_2 is emitted. If just one per cent of the total runoff to sewer could be diverted to surface waters, this could represent a saving of 15,000 tonnes CO_2 per year.		copper and phosphorus) remain more constant in the influent as they are not diluted as often. Furthermore, CSOs should not go off as often. Surface water runoff can be quite polluted and so by preventing its treatment at WwTW, there is the possibility of local failures of EQS in receiving waters for substances such as lead which are found in runoff.
Physical separation of sewers	The same benefits as SUDS could also be achieved through the separation of a combined sewerage system into separate foul and surface water sewers. This would typically require the construction of a new surface water sewer and reconnection of individual sewer connections to the new sewer. Dwr Cymru are currently undertaking a programme of sewer separation. These benefits could only be achieved where it was possible to discharge to a nearby watercourse without additional pumping. The carbon emission saving in reduced pumping and treatment would be offset by the construction of the addition sewer and the possibly significant disruption during construction.	The level of disruption would be significant. Many, if not most, of the cities in England and Wales are on combined systems and hundreds of km of sewers would need to be accessed. The financial cost of this work is also likely to be prohibitive; Yorkshire Water calculated that it would cost in the region of £6 billion to separate out all their sewers (Ofwat, 2007).	Separating the sewers would have the same benefits on effluent quality and impacts on water quality as SUDS.
Demand management	Despite the Government's aim to reduce water demand from 150 l/p/d to 120 l/p/d by 2030, population increase is expected to increase the required capacity at WwTW in England and Wales to above that currently provided (even with reductions in domestic water demand). Reducing the current demand could see benefits in pumping and treatment costs.	Although more water-efficient products are coming onto the market, the predicted increase in the population will mean that there will be an increase in total water demand (and hence the total amount released to sewer).	Due to the increase in population, the impact on effluent quality may be neutral in the long term.
Source control			
Removal of phosphates from laundry and dishwashing detergents	Phosphorus in laundry and dishwashing detergents contribute to 25 per cent of the total load to a WwTW (Defra, 2008c). The majority of the load to a works comes from urine and faeces (64 per cent).	The Government is working to phase out the use of phosphates in domestic laundry detergents (Defra, 2008a). Replacing phosphates in dishwashing detergents may be harder as the industry state that the alternatives that exist are mildly abrasive and can dull glassware overtime, which the public are unlikely to find acceptable.	The removal of phosphorus from detergents will lead to a decrease in influent and hence effluent concentrations. However, given the significance of other inputs, many works are still likely to require additional treatment to meet tighter consents.

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Banning of DEHP	DEHP is one of the key priority substances likely to lead to widescale upgrading of WwTW in England and Wales. It is used as a plasticiser in pipes including those commonly found within domestic properties. Due to its widespread use, only a ban on its use in plastics that come in contact with water could reduce future levels in sewage. If DEHP were banned, the approximate number of WwTW requiring additional treatment for priority substances would fall from 10 per cent to 5 per cent of works (based on available dilutions, that 10 per cent of the EQS is used as a downstream target in consent setting and that priority hazardous substances are controlled at source) (UKWIR, 2008a). If a technology such as sand filters was used, emission of 200,000 tonnes CO_2 per year might be avoided, or annual GHG emissions from the water industry due to additional treatment required for priority substances might be expected to increase by 11 per cent as opposed to 16 per cent due to operational energy use alone (calculated from UKWIR, 2008a).	Banning of the use of a substance can only be done at EU level. For the EC to be convinced of the need for a ban, detailed information is needed on the costs and benefits. The water industry has supplied its own studies on the presence, removal and costs of DEHP but further studies would be required before the EC would consider a ban. The replacement of existing pipe work may also need to be considered, although it has been estimated to have a present value cost (PVC) in the region of £4.5 billion in houses less than five years old (where leaching rates have been found to be highest), compared to a PVC of £7 billion for end-of-pipe treatment (UKWIR 2006 and UKWIR 2008a). There are also social implications of replacing pipe work in domestic dwellings that might make it impossible to undertake.	Average concentrations of DEHP in influent have been reported as 5 µg/l (UKWIR, 2004). The majority of this is believed to arise from domestic properties. Any ban on its use (with or without pipe replacement) would result in a decrease in this concentration.
Other			
Seasonal treatment	As an example, the Bathing Water Directive (BWD) aims to protect designated bathing water sites from faecal pollution during the bathing season (May to September). A common method of meeting the standards set under the Directive is UV treatment at WwTW. This is an energy-intensive method and the consents are set such that WwTW have to operate this treatment all year round, despite the Directive only requiring it during the summer. In 2006 Northumbrian Water applied to the Environment Agency to stop UV treatment at six of its WwTW outside of the bathing season. They claimed that it could save in the region of 2,000 tonnes CO_2 per year (Hewinson, 2006). Similarly, with nutrient removal there could be an argument for only treating sewage during the summer months when the risks posed by excessive nutrients are greatest. However, the WFD standards for phosphorus, for example, are year round standards, unlike those under the Bathing Water Directive and thus agreement may be needed at the European level.	Seasonal treatment is a controversial option. Northumbrian Water's proposal was met with widespread criticism from environmental groups, despite its potential carbon saving.	The seasonal use of UV would result in poorer receiving water quality out of season, but this would be mitigated to some degree by lower replication rates of bacteria and viruses in the lower temperatures. The BWD would still be complied with.
Consent setting policy	Historically the Environment Agency's RQP model (a combined distribution Monte Carlo model) has been used calculate consents by taking flows from the WwTW and upstream receiving water and combining them in order to calculate an effluent concentration to meet a downstream target concentration (generally ranging from 110 per cent of upstream concentrations to upstream concentration + 10 per cent of EQS). The issue with this approach is that the value estimated using the model to meet the downstream target 95 per cent of the time is then translated into an absolute value for the consent applied to the WwTW final effluent. This process has the effect of requiring WwTW effluents	The Environment Agency is currently investigating the possibility of using the BLMs for copper and zinc. The nickel BLM is yet to be tested properly but it is expected that the results will be as promising as the copper and zinc ones.	Modernised consenting policies may impact on effluent quality in as much as the consent standards may be more proportionate to the environmental harm the effluent poses. Therefore, the resulting water quality should not be any worse than before.

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	to on average be at least one fifth of the consent to minimise the number of breaches. With an absolute value set for a consent, 100 per cent compliance cannot be statistically guaranteed. This methodology is over precautionary for most substances and drives unnecessary investment in tertiary technology, which still may not be able to ensure compliance in cases where consents are particularly stringent. The Environment Agency has proposed amending the consent requirements to something more in line with that used for sanitary determinands such as BOD, suspended solids and ammonia; namely setting a 95 percentile consent, with an upper tier limit to protect for short-term discharges of twice the 99.5 per centile. A change to this type of compliance assessment methodology, bearing in mind it has yet to be agreed, could have a significant impact on the target effluent quality (and hence required investment) at WwTW. Another important aspect of the consenting regime is that for dangerous substances these consents are set for the total concentration of the metal. However, most EQS within the receiving water are based on dissolved concentrations for metals, which assumes that after discharge any particulate metal is released into the dissolved phase and becomes bioavailable. This is a precautionary approach as it assumes that all of the metal is released into the dissolved phases and that all of that metal is bioavailable. In reality for most metals this is not the case, as they adsorb strongly to particulate material (e.g. lead, chromium and mercury) or complex with ligands present in the receiving water to significantly reduce bioavailability (e.g. copper, zinc and to a degree, nickel). Recent research conducted by Atkins for the Environment Agency has demonstrated the feasibility of using the Biotic Ligand Models (BLMs) to estimate the bioavailability for certain metals (copper and zinc). The use of such models could provide a more accurate representation of risk to the aquatic environment of a metal and as such are likely to reduce the number of WwTW requiring additional treatment to meet tighter standards.		

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