The potential costs of climate change adaptation for the water industry

Final Report
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All efforts have been made to ensure that the data used, modelling methodology employed and results included in this report are reliable and complete. Results may be subject to change as new information comes to light.

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Executive Summary

The economics of climate change are presently the subject of Government review.

The purpose of the study is to identify and review existing UK and international literature to allow a possible extrapolation to give a broad magnitude for the costs of climate change adaptation for the water industry in England and Wales. Its purpose is to also identify any gaps in the work undertaken to date and to make recommendations for future analysis.

The findings from this study are intended to inform - albeit in very broad terms - the potential cost implications of different approaches for adaptation to climate change in the context of infrastructure industries like water and wastewater that provide services essential to societal welfare.

The first step in developing adaptation responses will be to determine the most appropriate approach to the management of climate change risks. This will influence how the cost burden of adapting to climate change risks is borne and by whom. In broad terms, two approaches to risk adaptation can be defined. A “precautionary” approach would seek to adapt to climate change risks through planned investment or changes in systems and / or economic behaviour. This approach underlies the analysis undertaken in this study in that we have sought to identify the potential cost of adapting water infrastructure to make it more resilient to forecast changes in climate. An alternative “market” approach could see a basket of responses and instruments based on insurance principles as a means of signalling the cost of climate change risks. Responding to climate change risks in the most efficient way will inevitably need a mix of measures that embrace both approaches. There will be trade-off between the costs of adapting and the costs of insuring against potential climate related damages.

Historical and present climatic conditions are highly connected to the design and operation of water industry infrastructure. Hence, forecasted climate change will require adaptation to minimise the impacts. This report covers three main areas issues of direct relevance to the water industry:

- Water Quality impacts;
- Stormwater management; and
- Sea-level rise.

The report, founded upon an international and UK literature review, gives examples of climate change adaptation for each of these three areas.

Future climatic scenarios developed within the UKCIP02 form the basis of impacts for each of these areas. Broadly, the future climate is expected to be characterised by drier, warmer and longer summers with more intense storm events over winter. Regional differences see larger rainfall intensity increases in the north than in the south. Sea-level rise is complicated by isostatic uplift but sea levels could rise by up to 80cm in the south east England by 2080.

Climate change impacts are inextricably linked to existing catchment processes. In that, the net or additional impacts of climate change are dependent upon the present catchment characteristics such as topography, soil type, land use, historical land use, pollution and trends that will shape the catchment in the future such as agricultural land use, urbanisation and pollution sources.

In this regard, this report has attempted to qualify the nature of external pressures that will impact upon climate change impacts. For example the impact of increased rain intensity is in part linked to urbanisation. Further urbanisation of a catchment may compound climate change stormwater impacts. Whereas, retrofitting urban areas with water tanks and increasing permeable areas (replacing concrete with gardens) may provide a buffer against increased storm intensity.

The literature suggests that climate change is expected to impact upon freshwater quality. These impacts are complex and, at this stage, highly uncertain making it difficult to estimate adaptation costs with any reasonable degree of confidence. However, the report presents as one adaptation scenario a future in which requirements on water industry effluent discharges will become more stringent in order to buffer against pressures that degrade water quality in receiving streams.

Costs of more stringency for water quality parameters are presented and discussed. There is much uncertainty surrounding not only the gap in stringency that might be expected, but also this review does suggest that meeting higher stringency may require a step change in costs. This is because retrofitting existing treatment facilities may not be feasible; instead, new more expensive technology may be required across the board.

Stormwater impacts from climate change are discussed at length. The literature provides discussion of how selected countries are planning for stormwater management given climate change. Stormwater systems have developed over a long time frame and typically have been designed to cater for an acceptable flood risk given the current and historic climate. Predictions of more frequent and intense storms suggest that extra capacity within stormwater systems will be required to maintain flood risk at acceptable levels. The cost analysis conducted assessed existing stormwater networks and looked at the cost of building additional storage for these systems. The literature review revealed that more complex but cost-effective solutions that take a broad view of what catchment features can act to buffer against excessive flows from large storm events.

It is difficult to generalise the impacts of sea-level rise on the water industry. Most notably, coastally and tidally located assets including treatment facilities and freshwater sources will be most at risk. However, the risk and the cost of either protecting, abandoning or relocating assets will be site specific and be subject to a range of factors such as asset value, proximity to sea, value of alternate assets, site specific flood defence options and costs and the nature and value of surrounding assets that may share flood defence costs.

Our broad cost assessments assume that the adaptation measures considered are undertaken now. Clearly, as is likely and sensible, if investments were to be deferred to some future time period, the scale of the present values would be lower.

Infrastructure owned and operated by the water industry is difficult to characterise in broad generic terms. Across the country, it has been designed according to site specific catchment characteristics and in the context of layers of policy objectives over varying time horizons. Characterising the costs of climate change adaptation costs across this complex heterogeneous industry especially given the heterogeneity of climate change impacts is therefore fraught with complexity.

We recommend, therefore, as a more productive avenue a focus on the development of strategies and decision making frameworks that reflect the heterogeneous nature of climate change adaptation and assist with tailor made local solutions to this far reaching phenomenon. The final section of this report includes suggestions for policy makers on how they may better target research in order to understand climate change impacts especially the interconnections with catchment processes such as urbanisation, incorporate the best available climate change research into decision-making and develop cost effective adaptation strategies.

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Tables and Figures

I. Purpose of this report

This report has been prepared by ICF International in collaboration with Risk Policy Analysts (RPA) for the Environment Agency. The report presents a review of the potential costs of climate change adaptation for the water industry in England and Wales.

Climate change science continues to erode any remaining doubt that the world's climate is changing. The evidence is becoming clearer that these changes – include warmer temperatures, more intense and variable precipitation and rising sea levels – will affect the delivery of water services. It is also becoming clearer that, regardless of how successful greenhouse gas emission reduction efforts are, the long-term momentum of the climate system is now "locked in" and *adaptation* to climate change impacts and not just *mitigation* of climate change impacts needs to now be uppermost in the minds of policymakers.

The purpose of the report is:

- To present our findings with respect to a review of potential adaptation measures and their potential costs.

  We would emphasise that the costing of climate change adaptation for any sector is fraught with difficulties. There remain many uncertainties and any costing exercise must make numerous assumptions about future policy and actions. The analysis presented in this report should, therefore, only be interpreted as an estimate broad order of magnitude for potential adaptation costs.

  Just as pressing is the need to develop decision-making frameworks that will allow adaptation strategies to be developed in ways that minimise the potential cost burdens to the water sector and the economy more generally. We, therefore, also use this report to set out some thoughts on how this might be achieved.

The rest of this report is structured as follows:

- Section II summarises the background to the project and its objectives;
- Section III presents in summary a brief overview of potential climate change impacts for water companies;
- Section IV sets out our more detailed review and analysis of potential adaptation responses and cost impacts. In line with our brief for this project, the report concentrates on adaptation responses for wastewater services;
- Section V presents our conclusions and recommendations. This includes discussion of how decision-making frameworks for water sector adaptation could be developed.

II. Background and Objectives

2.1 Background to this study

The Chancellor has appointed the Head of the Government Economic Service, Sir Nicholas Stern, to lead a comprehensive review of the economics of climate change to understand more comprehensively the nature of the economic challenges that need to be met both in the UK and globally. The review will be conducted in the context of the Government's existing energy policy commitments as set out in the Energy White Paper, and will draw on the analysis carried out for it. The Review, to be published later in 2006 will include a careful study of analytical issues which are key to policy. This study follows from the Review's focus on addressing the treatment of climate change mitigation as an international collective action problem. The findings presented in this report are intended to help inform the potential scale of adaptation requirements by the water industry in England and Wales to long-term changes in the climate.

2.2 Objectives

The purpose of this study is to identify and review existing UK and international literature to allow a possible extrapolation to give a broad magnitude for the costs of climate change adaptation by the water industry in England & Wales. The study is largely scoping in nature and part of its purpose is to make recommendations for future analysis.

The motivation for the present study follows from the Stern review's focus on addressing the treatment of climate change adaptation as an international collective action problem. The findings from this assignment will help inform the potential cost implications of different approaches for adaptation to climate change and variability in the context of infrastructure industries like water and wastewater that provide services essential to societal welfare.

2.3 Methodology

This has been a desk-based study. Our approach has been to rely on existing published evidence on climate change impacts for the water industry. We have reviewed currently available evidence for the UK, as well as relevant international evidence.

The costing analysis presented in this report, similarly, makes use of existing tools and models that were designed and developed with other objectives in mind. It has not been the purpose of this study to develop new models and tools for specifically assessing adaptation costs. This is clearly something to be addressed by future work. Where available information has permitted, we have also complemented our analysis with a number of case-studies.

III. Overview of Climate Change Issues

This section provides a brief overview of climate changes to provide the context and motivation for the current work. This overview concentrates on two specific issues:

- Climate change adaptation scenarios for the UK; and
- Potential climate impacts for water utilities.

3.1 Possible scenarios for adaptation to climate change

The UK Climate Impacts Programme (UKCIP) scenarios present four alternative scenarios of how climate change may affect the UK over the next 100 years. The scenarios are labelled:

- Low Emissions;
- Medium Low Emissions;
- Medium High Emissions; and
- High Emissions.

The scenarios relate to different projections of greenhouse gas emissions developed by the Intergovernmental Panel on Climate Change Special Report on Emissions Scenarios (SRES).

Table 1 shows the changes in global temperature and carbon dioxide concentrations for the 2080s for the four UKCIP02 scenarios. Carbon dioxide concentration in 2001 was about 370 ppm.

Table 1: UKCIP02 Climate Change Scenarios

SRES Emissions Scenario	UKCIP02 Climate Change Scenario	Increase in Global temperature (°C)	Atmospheric CO_2 Concentration (ppm)
B1	Low emissions	2	525
B2	Medium low emissions	2.3	562
A2	Medium high emissions	3.3	715
A1FI	High emissions	3.9	810

Source: Hulme et al, 2002[1]

The UKCIP02 scenarios indicate warming of between 2 and 3.9°C and reductions in annual precipitation of between 0 and 11% by the 2080s across the UK (Hulme, *et al.*, 2002). Winters across the UK could be wetter by between 5 and 30 % and summers drier with reductions in rainfall of up to 50% in the South East of England. The UKCIP02 scenarios provide baseline climate data and changes in average monthly climate for

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[1] M Hulme, GJ Jenkins, X Lu, JR Turnpenny, TD Mitchell, RG Jones, J Lowe, JM Murphy, D Hassell, P Boorman, R McDonald & S Hill: Climate change scenarios for the UK: UKCIP02 scientific report, Tyndall Centre, 112pp, 2002

each scenario and for 3 time-slices, the 2020s (2011-2030), 2050s (2031-2060) and the 2080s (2071-2100).

3.2 Socio-economic scenarios

There are many choices society can make today that will impact upon the extent and impacts of climate change. Socio-economic changes will exert significant influence on water systems and their adaptive capacity. For example, if Hurricane Andrew had hit Florida in 2002 rather than 1992, it has been estimated that the value of damages would have been double, due to increased coastal development and rising asset values[2].

In the UK, the importance of socio-economic factors has been recognised. For example, the Government sponsored programme *Foresight* Futures has developed four socio-economic scenarios to model the impact of socio-economic changes. They are:

- World Markets
- National Enterprise
- Global Sustainability
- Local Stewardship

These provide possible future socio-economic scenarios against which policy options can be compared, need for adaptation options identified – and societal requirements identified. For example World Markets and National Enterprise have lower environmental values; National Enterprise and Local Stewardship may look towards local responses. The potential implications of these socio-economic scenarios are explored further in section 4.2.10, in discussion of recent Foresight Futures work on climate change and flooding risks.[3]

The *Foresight Futures* scenarios serve to emphasise that adaptation to climate change for the water industry cannot be seen in isolation from the wider socio-economic context. For example, a World Markets perspective may elicit a quite different response to deteriorating water quality under climatic changes compared to a Global sustainability perspective. Correspondingly, the values that are embedded within institutional and decision-making frameworks will have an important bearing on the approach that is adopted for water industry adaptation to climate change.

3.3 Options for adapting to climate change risks

The views about governance and values that are reflected in the *Foresight Futures* will shape the nature and scope of adaptation responses to climate change *risks*. In many

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[2] The Association of British Insurers, June 2005. Financial Risks of Climate Change, www.abi.org.uk/climatechange

[3] Evans, E., Ashley, R., Hall, J., Penning-Rowsell, E., Saul, A., Sayers, P., Thorne, C. and Watkinson, A. Foresight. Future Flooding. Scientific Summary: Volume I, Future risks and their drivers. (2004). Office of Science and Technology, London.

respects the first step in developing adaptation responses will be to determine the most appropriate approach to the management of climate change risks.[4]

In broad terms, two approaches to risk management can be defined. The first – which can be characterised as the "precautionary" approach – would seek to adapt to climate change risks through planned investment or changes in systems and / or economic behaviour. This approach underlies the analysis undertaken in this study in that we have sought to identify the potential cost of adapting water infrastructure to make it more resilient to forecast changes in climate.

However, an alternative approach – which we would characterise as a "market" approach – could see a basket of responses and instruments based on insurance principles. There have been a number of recent developments in the insurance markets that indicates moves to understand and incorporate climate change risks into the conduct of commercial life.[5] For example, the Association of British Insurers (ABI) now hosts a dedicated climate change website and recently published a report reviewing the financial risks of climate change . Furthermore, in June 2006, Lloyds of London hosted a London conference assessing the business implications of climate change. Insurance instruments such as CAT bonds and weather derivatives could be used as instruments to divert and spread climate-related risks.[6]

These alternative approaches provide options for how the cost burden of adapting to climate change risks is managed. They will also influence who bears the financial consequences of adapting to climate change risks (e.g. public vs. private sectors; producers vs. consumers). Common to them, however, is the reality that climate change risks are likely to create significant requirements for capital, whether financed through mechanisms like water bills or through insurance premiums.

Figure 1 presents an analysis of how climate change risks could translate to the capital requirements of insurance markets. The basic principle of insurance is that the amount of risk capital required is determined by the scale of expected losses. As shown in Figure 1, the net result of climate change is predicted to be larger average annual losses and a greater frequency of large losses from extreme climatic events. Correspondingly, the capital requirement to meet those losses could increase significantly.

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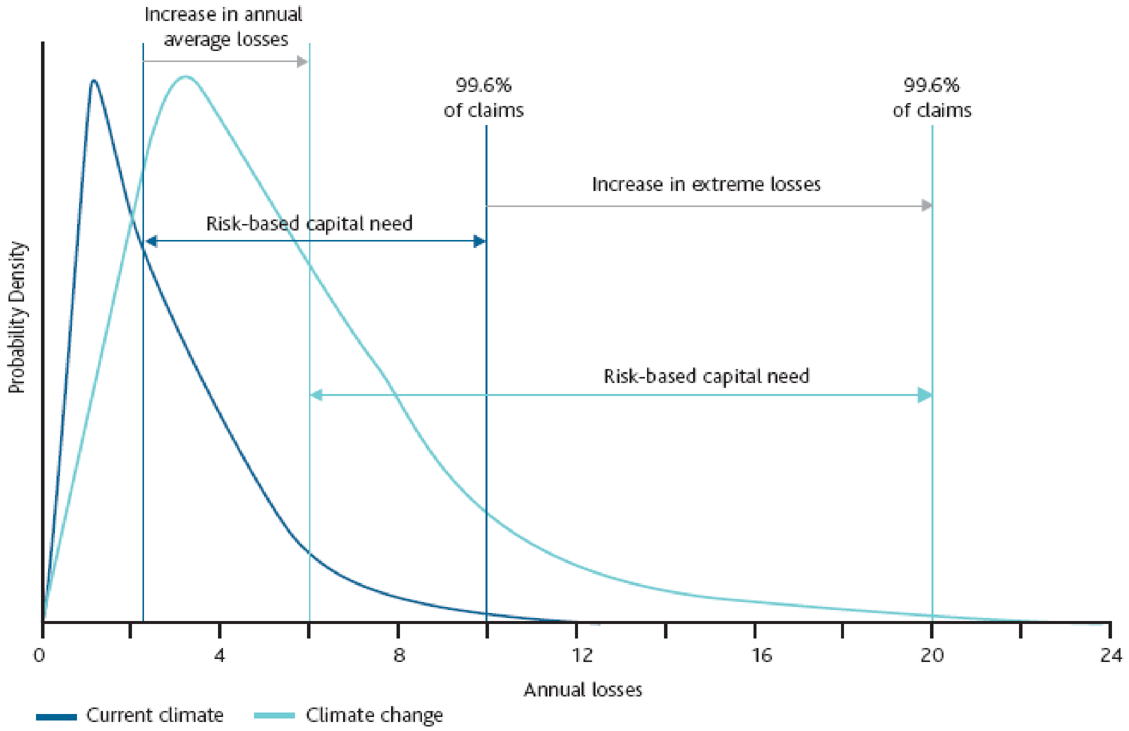
[4] Frameworks for managing climate change risks are considered, for example, in Willows, R.I. and Connell, R.K. (Eds.). (2003). Climate adaptation: Risk, uncertainty and decision-making. UKCIP Technical Report. UKCIP, Oxford.

[5] This comes on the back of a number of recent weather-related events that have been associated with significant economic losses, both in the UK and globally.

[6] CAT is shorthand for "Catastrophic"

Figure 1: Theoretical impact of climate change on probability loss distribution and implications for risk capital requirements.



Source: The Association of British Insurers, June 2005. Financial Risks of Climate Change

Responding to climate change risks in the most efficient way will inevitably need a mix of measures that embrace both the “precautionary” planning approach and the “market” insurance approach. Clearly, where the costs adaptation are low but the benefits of lower expected losses are greatest then investing in adaptation will be most economic. Where adaptation costs are significant, the economic solution may be to make greater use of insurance based instruments to pool the costs of the risks. Determining the best mix of approaches should be the subject of further investigation.

3.4 Impacts of climate change for water utilities

We now present below a framework for the assessment of the impacts of climate and socio-economic change on water utilities in England & Wales.

Over longer strategic planning horizons (30-50 years), the existing research literature suggests that changes in temperature and rainfall will:

- have a major impact on river flows with large decreases in average summer flows and small increases in average winter flows throughout the UK;
- increase winter flood risk from fluvial, coastal, and sewerage systems;
- increase the demand for water, by a small percentage for domestic demands and significantly for some industries and irrigated agriculture; and

- impact on the water environment with potential positive and negative impacts on water quality, physical habitat, and aquatic ecology.

Table 2 provides a summary of the potential range of impacts and the related adaptation measures that can be anticipated.

Table 2: Potential Effects of Climate Change on Water Utilities

Climate Change Physical Effect	Effect on Water Utilities	Adaptation Measure(s)
Drinking Water		
Higher temperatures	Poorer influent quality/ increased concentration of microbes, other temp-dependent pollutants	Increased treatment costs to maintain same quality
Sea level rise	Salt water intrusion (primarily ground water systems)	Hydrologic barriers, desalinization, alternative sources
Higher proportion of precipitation in more intense events ("lumpier" hydrology)	High flows: more runoff creates higher concentrations of non-point source pollutants Low flows: More frequent droughts, so if system does not have ample supply, could exacerbate problems	Generally higher treatment costs during high-flow periods; Potential need for alternate supplies during droughts
Wastewater		
Higher temperatures	If effluent limits are based on ambient water quality, dissolved oxygen standard will be slightly harder to meet	Discharge less BOD, increase treatment costs
Higher proportion of precipitation in more intense events ("lumpier" hydrology)	If effluent limits are based on ambient water quality under specific low-flow conditions, receiving stream will have lower flows for a given recurrence interval	Tighter effluent limits on all pollutants will require higher treatment costs
Stormwater		
Higher proportion of precipitation in more intense events ("lumpier" hydrology)	For combined sewer systems, if standards are expressed in terms of hydrologic design conditions (e.g., no more than 4 overflows per year), it will be harder to meet the standard Design flows will be exceeded more frequently	Increase margin of safety in design specifications (implies higher hydraulic capacity, higher costs)

Source: ICF International

3.5 Key questions for investigation

We now define they key questions for investigation in this study. Following discussions at the project inception meeting, it was decided to focus the study on climate change impacts for wastewater services. This reflected the view that water resource questions have to date received most attention, whereas comparatively less has been paid to wastewater services and the implications of climate change for sewerage infrastructure.

The areas that will be examined in this study are the following:

- What are the incremental costs of treatment for sewerage works, given that the design flow conditions for receiving streams may be lower?
- What are the incremental costs of controlling combined sewer overflows, given the potential increases in the intensity and variability of precipitation events?
- How vulnerable might water services (including sewerage) infrastructure be to flooding risks associated with sea-level rise?

3.6 Tasks and approach

To address these questions, we have:

- Undertaken a review of available literature to
    - Qualitatively identify the types of incremental costs that the water industry may incur to adapt to climate change (see Table 1 for a summary of relevant adaptation measures)
    - Collect information on existing quantitative studies of costs, to the water industry, of adapting to climate change, both in the UK and internationally.
- Developed, where feasible, an estimate of order-of-magnitude costs.
- Identify the key requirements needed to support a more complete and accurate estimate of costs.

IV. Review and Analysis

This section presents our review and analysis of the three key areas identified for this study. That is:

- Possible incremental costs of sewage treatment associated with adapting to flow and temperature impacts from climate change;
- The incremental costs of adapting sewerage networks (specifically combined sewer overflows), given the potential increases in the intensity and variability of precipitation events; and
- The vulnerability of network infrastructure to flooding risks associated with sea-level rise.

Our review highlights that is it easier to be reasonably precise about the nature of these potential impacts and risks. It is much more difficult to be as precise about the likely costs of adaptation, principally because climate change will not be the only factor that drives decision-making about water industry investment. It is also clear that a rigorous process of option appraisal would in reality be required to judge cost-effective adaptation measures for the water industry. It is not within the scope of the present work to undertake this type of option appraisal. Rather, we apply some reasoned sets of assumptions to identify the potential order of magnitude for adaptation costs. This should act as a prompt for further and more detailed investigations.

4.1 Water Quality

This section reviews potential impacts upon water body water quality from climate change. It then assesses how these potential water quality outcomes may impact upon the water industry and provides preliminary cost estimates for selected parameters.

Climate change is largely expected to exacerbate anthropogenic impacts on water quality. These impacts have been described qualitatively in the literature, but quantification of impacts is highly uncertain (Australian Greenhouse Office, 2003; U.S. Global Change Research Program, 2000; New Zealand Ministry for the Environment, 2004). Notably, the UKCIP02 Scientific Report and the 2003 report *CCDeW: Climate Change and Demand for Water* make no reference to potential climate change impacts on water quality and the subsequent implications upon demand. The site specific nature of water quality issues is an important consideration for guiding the prudent response of UK policy makers.

Low summer flow events are expected to become more extreme. Lower flows combined with higher temperatures and concentrated nutrient loads may decrease dissolved oxygen levels and increase eutrophication.

Increased intensity of storm events is expected to scour more river banks (dry catchment soils will be more susceptible to erosion exacerbating this issue), collect more urban and agricultural pollution and hence contribute more sediment and pollution to water bodies. These effects are dependent entirely on catchment characteristics, and in particular land use, hence the net impact of increased storm flow may increase or decrease pollution concentrations.

Water biota, particularly mircofauna and flora, is expected to change in response to altered chemical concentrations (increased carbon dioxide and nutrients), warmer temperatures and periodic drying of waterbodies.

Examples:

Lagarosiphon major Curly Waterweed is known to displace native species and other weeds (eg *Elodea nuttallii*: Nuttall's Pondweed) as conditions become more eutrophic.

The growth rate and biomass of *Myriophyllum aquaticum* (Parrot's Feather) typically increases with increased eutrophication. Parrot's Feather favours still or slow flowing, shallow water bodies, can tolerate months of drought and can survive winter frosts buried in mud.

Eichhornia crassipes (Water Hyacinth), a major weed in places such as India, Australia and the US, is common in the UK but due to its inability to survive frosts has not become naturalised. A warmer less frosty climate that enables it to naturalise presents a significant threat of invasion.

Nutrient effects on water quality may be buffered as plant growth accelerates in response to warmer temperatures. Heightened plant growth may have its own consequences especially for invasive weedy species.

Climatic changes that create conditions favourable for invasive species may increase the impacts on more than just the indigenous species they displace. Aquatic weeds such as *Eichhornia crassipes* (Water Hyacinth), *Crassula helmsii* (Australian Swamp Stonecrop), *Azolla filiculoides* (Water Fern) and *Lagarosiphon major* (Curly Waterweed) form dense mats or stands that may block water industry infrastructure and irrigation, navigation and river channels.

A study by Freeman[7] et al (1993) simulated the reduction in wetland water table height that could be anticipated from climate change models within a laboratory using cores of peat-soil from a riparian wetland. The manipulation increased the rate of release of many solutes including nitrate, sulphate, dissolved organic carbon, sodium, chloride, iron and magnesium. The study suggests that in the future, climatic change impacts could reverse wetlands beneficial effects.

These water quality impacts of climate change are highly dependent upon changes to other catchment processes. Increased status quo urbanisation and deforestation will further increase flood intensity and pollution loads whereas sustainable urban development, forestry (which may be encouraged for carbon sequestration) and catchment sensitive farming practices could also increase the resilience of water bodies to buffer against climate change impacts.

4.1.1 Cost analysis

The interdependency of catchment water quality drivers and climate change impacts means that a costing exercise is not straightforward. Policy makers have a range of

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[7] Freeman, C., Lock, M.A. and Reynolds, B. 1993 Climate-Change and the release of immobilized nutrients from Welsh Riparian Wetland Soils. Ecological Engineering, 2(4), pp 367-373

response options available to maintain water quality objectives. Accurate costing of impacts would look at the costs of climate change relative to other catchment processes such as urbanisation, other investment drivers such as the Water Framework Directive, agricultural practices, land use, historical conditions etc.

Our task was to look at potential costs of the water industry only. These costs, in reality, would be highly dependent on the actions of other sectors. For the purposes of this exercise we have modelled a scenario where declining water quality has resulted in regulators enforcing greater stringency on consents for discharges to watercourses. This regulatory pressure must be viewed in the context of existing drivers, notably the Water Framework Directive (WFD) which may require investment in technology to reduce pollution loads from water-water treatment facilities.

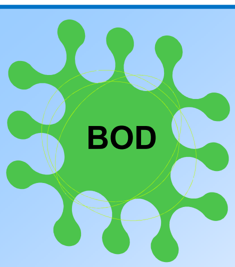
We stress that an appropriate response to climate change may or may not involve direct investment in further waste water treatment. This is especially relevant in the context of significant recent and future planned investment by the water industry, and the magnitude of the costs we forecast.

We have used separate modelling tools to identify the cost impacts. Specifically we consider BOD and Ammonia parameters and then nutrient pollution sources (nitrogen and phosphates.

This approach reflects the current water industry costing tools that are available to the project team. We are not aware of any costing tool that has been developed yet to specifically identify the incremental costs sewage treatment costs for England and Wales associated with climate change adaptation. In practice, the complexity of climate change impacts on water quality and the interdependence of available technology options would mean that it is unlikely to be the case that the underlying pollution reduction options are separable (in the way that is assumed here). Hence, ideally any costing methodology should recognise that adaptation measures in practice will be integrated across water quality parameters and that an integrated approach is likely to be more cost-effective.

4.1.2 BOD and Ammonia parameters

This section presents details of an initial costing analysis of waste water impacts arising from temperature changes and changes to flows in receiving waters. All other things given, higher temperatures and lower flows would mean that to achieve a given level of ambient water quality the loads of biological oxygen demand (BOD) and ammonia in the effluents discharged by sewerage companies would need to be further reduced. This means that more stringent discharge consent requirements could be required at wastewater treatment works to enable water quality to be maintained.



BOD – biological (biochemical) oxygen demand is a test used to measure the concentration of biodegradable organic matter present in a sample of water.

The standard wet chemistry analysis for the level of organic matter in wastewater is the 5-day biochemical oxygen demand test (BOD_5).

BOD_5 measures the rate of uptake of oxygen by micro-organisms in the sample of water at a fixed temperature over 5 days.

The cost approach applies an estimated cost function derived from a previous industry study undertaken to estimate the costs of achieving good ecological status (under Water Framework drivers). The model used a simple dilution method to determine potential changes in consents precipitated by a reduction in base flows. Based on previous ICF work in the United States (see Annex 2) our modelled costs are based on a range of 20% to 50% for the reduction in base flows.

Estimates of cost based on these assumptions are likely to be high. Simple dilution produces tighter standards than the models for England and Wales used to calculate permit conditions. Furthermore, the effect on base flows is reduced because river flows are supported by the flows from upstream discharges.

Assumed Consent Standards

The cost function predicts treatments costs (capital and operating) associated with different consent of meeting tighter consents on BOD and Ammonia at inland and estuarine sewage treatment works in England & Wales.

The previous study estimated the cost of meeting possible WFD objectives expressed in terms of BOD and Ammonia concentrations in effluent discharged from sewage works. These objectives and the means for delivering them remain unknown. However, these future requirements should in effect provide the baseline from which the additional costs of climate change adaptation can be identified. These additional costs are clearly dependent on the choice of WFD baseline. To identify the fullest possible range for the additional costs, we have adopted upper and lower bounds for our baseline:

- The upper or tight baseline is represented by the consent requirements of 5mg/l BOD, 1mg/l Ammonia. This is significantly tighter than current standards and is likely to ensure that all discharges are of good (i.e. RE2) quality.
- The lower or slacker baseline is represented by 25 mg/l BOD, 5mg/l Ammonia levels. This is intended to broadly reflect the current position, before any WFD related investment.[8] For example, requirements under the UWWTD to install secondary treatment would in most cases be met by a 25 mg/l BOD consent as this would typically equate to a BOD removal rate of 95%.[9]

The cost estimates are the additional costs associated with a tightening of consent requirements over an above these WFD targets due to the reduction in river flow.

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[8] This approach undoubtedly over-simplifies the current consent setting process, but our purpose is not accuracy at works level per se but to provide a broad characterisation of consent requirements.

[9] June Return data for 2004-05 suggests an average BOD loading per litre of wastewater discharged to sewerage systems in England and Wales of about 380 mg/l. This implies a removal efficiency of 93% is achieved by a 25 mg/l standard. Secondary treatment as required by the UWWTD typically removes about 95% of BOD loadings.

Table 3 sets out our assumptions for the consent baseline and the required standards under different climate change scenarios

Table 3: Consent Standards, baseline and incremental requirements due to climate change

Contaminant		Upper bound standard	Lower bound standard
WFD Baseline	BOD	**5 mg/l,**	**25 mg/l,**
	Ammonia	**1 mg/l**	**5 mg/l**
Climate change adaptation scenario (20% reduction of baseline)	BOD	**4**	**20**
	Ammonia	**0.8**	**4**
Climate change adaptation scenario (50% reduction of baseline)	BOD	**2.5**	**12.5**
	Ammonia	**0.5**	**2.5**

Source: Based on *UKWIR, 2002*

Estimates of the cost of upgrading all inland / estuarine sewage treatment works (WwTWs) to the tighter consents on BOD and Ammonia will be carried out using regression analysis, incorporating the unit cost of improvements at WwTWs in the period 2000-05. The results are based on actual industry costs and a database of the discharge consents for all non-coastal WwTWs with numeric consents in England and Wales.

Establishing the actual costs of meeting WFD requirements will require river basin plans for each catchment, implying that the tightening of discharge consents will vary with local conditions, rather than being the same across the country. Hence, it is important too recognise that for present purposes it is assumed that all works in England and Wales are required to meet the same, tighter consents. The modelling does reflect, however, the actual starting point at works level and hence costs will reflect the gap between current actual consents and the assumed tighter consent.

The cost function

The cost function used in this analysis is based on actual schemes for four water and sewerage companies Ofwat assumed in the PR99 determinations for AMP3 quality improvements. The data includes the original consent levels, the new consent levels for that period, the population equivalent (PE) served by the works and the capital and operating expenditure for each improvement. The cost of upgrading WwTWs will depend on both the magnitude of improvement required and the size of the works.

However changes in consent levels subsequent to PR99 may mean that the original technology, and operational costs, is no longer applicable as there have been

Annex 2 describes ICF research in the USA into climate change adaptation costs for water treatment facilities in the Great Lakes Region (GLR). Under climate change, flow within receiving waters collecting water treatment facility effluent is expected to decline. The study assesses the costs of reducing the total maximum daily limits for BOD_5 in water treatment facility effluent to maintain receiving water quality. The standard wet chemistry analysis for the level of organic matter in wastewater is the 5-day biochemical oxygen demand test (BOD_5).

There is currently very little information on BOD5 TMDLs for wastewater treatment facilities in the United States. Even though there has been significant progress in listing impaired reaches, most jurisdictions have yet to implement mitigation measures, especially those that result in more stringent standards for point sources.

The study found that costs were highly sensitive to increases in stringency. They reflect the fact that treatment improvements have a higher unit cost at the high end of the range than the low end.

The changes in design flow add significantly to the costs of TMDL implementation. At the low end, a 20% reduction in flow (and commensurate 20% improvement in treatment efficiency) would translate to annual incremental treatment costs of $7 million to $18 million. At the high end (57% flow reduction), annual costs increase by $49 million to $86 million.

improvements to meet these increasing standards. The information on technology, and operating costs, would ideally be updated to reflect current technology approaches.

Details of the data and subsequent results from the original study can be found in Annex 1.

Predicted incremental costs

Estimates of the incremental costs of the improvements in compliance are presented below.

Table 4: Results of incremental cost analysis for BOD / Ammonia

Scenario	20% reduction in flows	50% reduction in flows
Pre- WFD Baseline		
Incremental Present Value Costs (£m)	**120**	**370**
Present value cost per unit of BOD Reduction (£/kg/annum)	**11.22**	**11.40**
Incremental Equivalent Annual Costs (£m)	**8**	**25**
Post- WFD Baseline		
Incremental Present Value Costs £m	**60**	**150**
Present value cost per unit of BOD Reduction (£/kg/annum)	**15.38**	**15.84**
Incremental Equivalent Annual Costs (£m)	**4**	**10**

Source: ICF Calculations- note that a 50% reduction in flows represents an extreme scenario

The cost estimates in the table above highlight the importance of the baseline that is assumed for climate change adaptation.

If the starting point is broadly current water quality status, then the assumed flow reductions due to climate change would generate an incremental cost in present value terms of between £120m to £370m.

If the starting point, by contrast, is based on a tighter WFD standard for consents, then the present value cost estimate is somewhat lower – in the range £60m to £150m. This simply reflects that with WFD investment allowed for in the baseline the level of BOD and ammonia removal efficiency will already be even higher. In the case of the pre-WFD baseline scenario, the modelled change equates to moving from about 95% removal of BOD in wastewater to 97.5% removal. For the post-WFD scenario the change in treatment efficiency equates to moving from 99% to 99.5% removal of BOD.

Table 4 also highlights an important difference between the scenarios in terms of the unit cost of removal. The more stringent the starting point, then the higher will be the unit cost of further pollution removal associated with climate change adaptation. The unit costs of BOD removal (£ per kg per year) are about 40% higher under the post-WFD scenario compared to the pre-WFD scenario. With existing technology this simply reflects the fact that ever more stringent abatement requirements will become more expensive in unit cost terms. One reason for this would be increasing the energy requirements of meeting more stringent conditions with current technology.

This rising unit cost of removal would have important ramifications for choosing the most cost-effective set of options for adapting to the water quality impacts of climate change. Our modelling would suggest that technical solutions at treatment works will become less cost-effective as standards become more stringent due to other influences such as the WFD.

Limitations and caveats

It is important to note that the costs derived above were based on the following assumptions:

- A linear relationship between flow reductions and consent requirements that is uniform across England and Wales;
- The calculation is based on a simple dilution model. In many places river flows are supported by upstream discharges.
- It is assumed that the technological options (essentially secondary treatment processes) that underlie the cost function will be capable of delivering the more stringent standards assumed in the modelling. If alternative technical options are required (perhaps tertiary treatment or secondary treatment augmented by increased chemical dosing), then these are more likely to imply a step increase in the underlying cost function

4.1.3 Phosphate Loads

Investment in phosphate load reduction from sewage effluent discharges has been a priority of current and previous policy. Significant investment, in the order of a billion pounds, by the water industry in AMP2, 3 and 4 has contributed to significant reductions in phosphate loadings in effluent discharges.

To meet WFD requirements for effluent phosphate loads, OFWAT (2005) suggested that current treatment technologies may not be sufficient to meet more stringent standards.[10] Furthermore, companies expect supply restrictions on phosphate removing chemicals such as ferric. In this climate, new processes and technologies are seen as essential. OFWAT also expect to see an increase the quantity and type of sludge produced, which is likely to require additional investment in sludge treatment and disposal technologies, possibly including additional incinerators.

Figure 2 shows the OFWAT (2005) estimates for increased unit cost of three standards for effluent P concentration consents at different sized works. The unit costs of more stringency are significantly higher for all size works.

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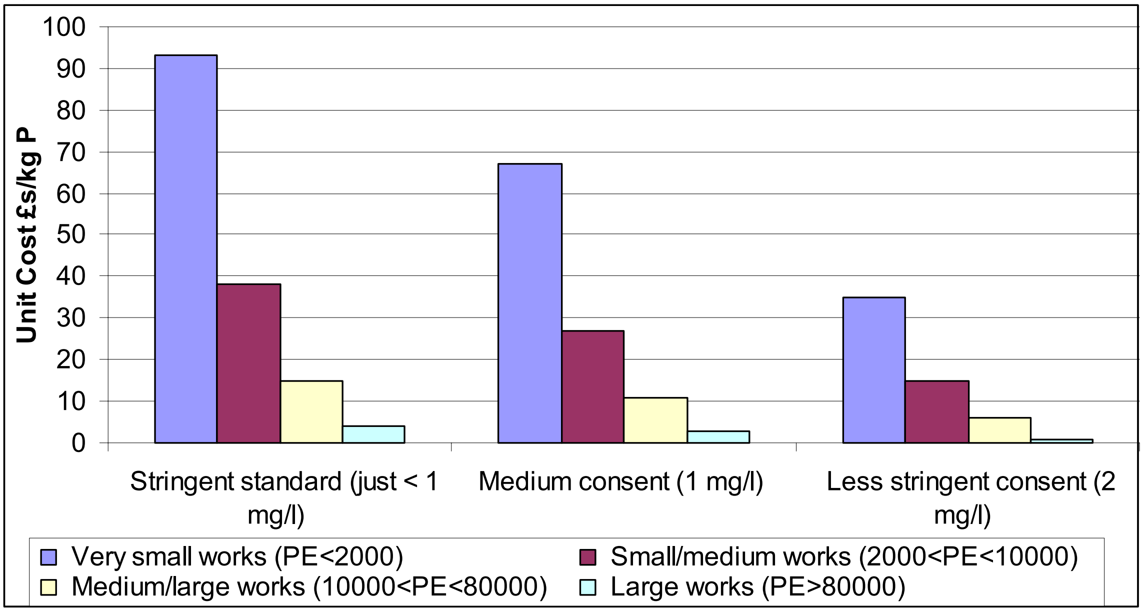
[10] Ofwat (2005) Water Framework Directive. Economic Analysis of Water Industry Costs, Final Report prepared by Arup and Oxera,

Figure 2: Unit cost £s per kg of P removal.



Source: Ofwat (2005)

These OFWAT costs were the cost of installing new treatment works at sites without existing phosphate treatment. The cost of improving stringency at existing sites will be very different.

The conclusion of the OFWAT analysis was that despite the possibility that biological treatment processes may become more efficient with temperature rises, to improve water quality standards further just to meet WFD requirements may require a step change in costs.

On the assumption that climate change could require – as for BOD and ammonia parameters – more stringent P standards, the OFWAT analysis suggests that achieving further load reductions in the future will come at a high unit cost.

Any cost estimate of what may be required to maintain P concentrations under climatic changes would be, at this stage, extremely uncertain. As discussed, climate change is one among many drivers of catchment water quality. Given OFWAT's non-linear costs of treatment, water industry costs should not be viewed in isolation from the costs of addressing other phosphate drivers.

A rigorous estimate for costs must predict climate change impacts but also assess processes such as urbanisation and trends in rural land use which will ultimately drive how much phosphate the water industry can safely discharge to watercourses. For example, widespread changes in agricultural practice that saw widespread adoption of catchment sensitive farming practices might completely buffer against the impacts of climate change. Moreover, at some point on the cost function, it will also become more cost beneficial (for the water industry) to target phosphate reduction from agricultural sources than from water industry.

4.1.4 Nitrogen Loads

Water industry investment has also begun to target reductions in nitrogen loads from wastewater treatment works.
Given the significant environmental issues that might be associated with nitrogen loadings, it would seem reasonable to anticipate that any changes to flows in rivers under climate change could require even tighter consent requirements to reduce N pollution loads discharged to water courses.

As with P, deriving cost estimates for N is at this stage extremely uncertain. Potential future investment for N to meet a range of policy drivers could be in the order of £billions. It remains difficult to assess how much of the potential additional cost would be solely attributable to climate change drivers or instead can be anticipated as a result of other drivers such as the WFD. Whatever, the ultimate driver the key point would be that action to reduce N (and P) loadings from water company discharges are likely to result in significant costs (and also be energy intensive given the available technological options). For example, each £100m of additional annual cost for the sewerage industry equates to about a 2.5% increase in average sewerage bills or about £3-4.

Given the scale of potential future costs of investment to reduce nitrogen loads, a prudent approach would be to take advantage of the relatively long planning horizons for adapting to climate changes and the already certain expenditure drivers and to adopt strategies that ensure economy-wide least cost solutions. We discuss a possible framework further in section V.

4.1.5 Water quality summary

As mentioned above, climate change may exacerbate existing anthropocentric pressures on water quality. It is reasonable to anticipate that the extra pressures that climate change may place on water bodies could increase treatment costs for the industry but the magnitude of these costs is highly dependent upon the response elsewhere in the catchment. The above analysis gives *only a broad indication of the potential scale* of wastewater treatment costs as summarised below.

Table 5: Present value costs (£billions) of maintaining water quality standards under climate change induced flow reduction scenarios

Parameter	20% reduction		50% reduction	
	Low	High	Low	High
Ammonia and BOD	0.06	0.12	0.15	0.37

Source: ICF calculations- These numbers are designed to indicate the broad magnitude of the costs and are not useful for indicating likely costs.

Much uncertainty surrounds future stringency requirements especially in the context of seasonal trends in ambient receiving water quality. Despite this uncertainty, given the long life (up to 50 years) of some water quality treatment facilities, it may be sensible to consider climate change information for long-lived water quality investment planning.

This effort, however, needs to be balanced against the resource costs of such investigations. In the short to medium term, it may well be more prudent to invest resources in further investigation about the impacts of climate change on water quality.

Furthermore, it is expected that vastly improved cost information about the costs of different options to meet water quality objectives will become available from work required to meet the objectives of the water framework directive.

Such work streams will equip policy makers with the information and policy tools required to cost-effectively adapt to climate change impacts on water quality.

4.2 Stormwater management

A number of countries have researched strategies to adapt to the risks climate change poses for sewerage infrastructure and its ability to cope with more varied and intense precipitation events. This section provides a review of international case-studies to identify recent thinking on climate change adaptation for sewer systems, a brief discussion about modelling sewer networks within catchments and finally sets out an approach for estimating the potential costs of adapting sewer systems within England and Wales to climate change risks.

4.2.1 Impacts of Climate Change on Sewer networks: Melbourne Case Study

The Melbourne study (Howe, 2005) assessed implications of IPPC predicted outcomes from climate change.

Higher winter peak flows are forecast and whilst in general system capacity is expected to be adequate, site specific problems are expected. Furthermore, higher system flows will place more stress on the network and this in combination with lower highly concentrated and more corrosive summer flows will add to maintenance costs and a decrease in asset lives.

Other issues cited include: increased pipe failure from dry soil collapse, odour problems from lower summer flows, longer system travel times and higher temperatures and increased corrosion from salt water intrusion from higher sea levels.

Despite the potential for significant costs, the Melbourne study concluded that uncertainty and large spatial variation for both climate change impacts and appropriate mitigation strategies do not justify broad wide sweeping initiatives. Instead, the study recommended

- On-going monitoring including periodic review of climate change scenarios, population projections, network characteristics and the implications for natural and water resource systems;
- Continual review of best practices adopted throughout the world for management for climate change and variability;
- Incorporation of climate change implications and assessment to the extent possible in the design, planning and operation of major network systems. In effect a “no-regrets” policy and the use of contingency plans for climate change. A “no regrets” policy is one that would generate net benefits whether or not there is climate change);
- Development of a strategy for climate change that looks at adaptation and prioritisation of planned activities to maximise resilience against climate change; and
- Focus on high risk areas.

The risk of increased flooding of combined sewer overflows (CSOs) is cited as being extremely uncertain. The risk will be dependent upon other factors other than climate change including development patterns, sewer system repairs and renewal rates.

4.2.2 Impacts of Climate Change on Sewer networks: Canada Case Study

As with Melbourne, Canada faces legacy infrastructure issues with dealing with the predicted implications of climate change (Watt, 2003).

Sewer planning and policy in Canada is slow, hence the existing process of addressing current quality and quantity problems caused by past policies and urban expansion is slow.

A key strength of the Canadian review is its assessment of future planning options in the context of the layers of historical policies that influence best management practice today.

- 1880-1970 - Initial planning policy aimed to decrease localised flooding events
- 1970s - Policy aimed to minimise both local and downstream flooding impacts
- 1990's - Flood management policy now seeks to meet broader range of social, economic and environmental management goals. Externalities such as insurance, legal and environmental pollution are all considered through the planning process.

Stormwater management strategy has focused on delaying the passage of water through the catchment via many small to medium scale management options with the intention of reducing peak flow loads. Instead of directing storm water to existing or new traditional sewer infrastructure, a flexible and open minded approach sees water from roof tops diverted onto gardens or into water tanks, slow flow street drainage partially and temporarily floods streets and water is directed onto public and school green spaces to soak into the ground.

Options that increase capacity of existing storages (be they lakes, dams, gardens, roads, rooftops etc) are also encouraged. The open minded approach to finding least cost solutions is cautioned with respect to the need to educate the public about strategies such as flooding school grounds and partial street flooding.

4.2.3 Impacts of Climate Change on Sewer networks: New Zealand Case Study

Since March 2004, New Zealand legislation has required councils to take climate change effects into account in their decision-making. Extensive guidance covering sea level rise, flood risk, drought, farmer perspective, and stormwater management is available online at: http://www.climatechange.govt.nz/resources/local-govt/guidance.html

Predictions for impacts of climate change in New Zealand echo those of other regions: a high degree of uncertainty coupled with spatially variable results. One notable difference relates to New Zealand's topography and the importance of orographic precipitation (rainfall that occurs as air masses rise due to mountain ranges).

The guidance is comprehensive in its discussion of impacts and methods to incorporate predictions into decision-making processes. The guidance also recommends modelling methods, provides extensive literature references and advises on the availability and access to key information sources such as water quality databases to facilitate climate change adaptation.

4.2.4 Impacts of Climate Change on Sewer networks: USA case study

ICF International has supported the development of “Smart Growth” planning guidance by the USEPA. Smart Growth brings together best management practices to design and retrofit urban communities to make best use of available resources- particularly water and energy. Smart Growth strategies operate at the interface between urban development, urban economic activities and the environment. It has been developed from an in depth understanding of the drivers behind this interface including;

- catchment hydrology
- pollutant sources
- economic and social activities linked to hydrology and pollution
- urban environmental qualities

Smart Growth strategies take a similar line to the open minded Canadian approach of disaggregating the stormwater network. However, Smart Growth is focused on revealing and quantifying cost-benefit ratios of strategies to deliver optimal outcomes.

The Smart Growth Network, a coalition of more than 30 environmental, real estate, historic preservation, development, academic, and governmental organisations, has developed a set of principles reflecting the experiences of successful communities around the US (see Table 6).

Table 6: Smart Growth Principles

1 Create a range of housing opportunities and choices.
2 Create walkable neighborhoods.
3 Encourage community and stakeholder collaboration.
4 Foster distinctive, attractive places with a strong sense of place.
5 Make development decisions predictable, fair, and cost effective.
6 Mix land use.
7 Preserve open space, farmland, natural beauty, and critical environmental areas.
8 Provide a variety of transportation choices of smart growth.
9 Strengthen and direct development toward existing communities.
10 Take advantage of compact building design.

Accounting for the existing baseline catchment conditions is crucial to a Smart Growth strategy and hence Smart Growth principles are designed to be adaptable to local resource availability and distribution, stakeholder requirements and local policies. Smart Growth gives guidance on the benefits of upgrading existing infrastructure, infill developing strategies, regional planning and redevelopment.

Smart Growth has been developed to be closely aligned with existing regulations, policies, public perceptions and catchment targets for example limits on pollution loads. Smart Growth identifies, with sound evidence, the outcomes (both positive and negative) of its planning policies such that they can be easily explained and presented to stakeholders. Smart Growth involves and is flexible to stakeholder considerations hence much of Smart Growth harmonises well with existing planning but this is entirely dependent on specific local and regional factors. In cases where Smart Growth has identified weaknesses in existing policies, suggested improvements are backed up by sound evidence.

Overcoming political, institutional and public perception barriers can be challenging. Smart Growth sets out a framework for providing information clearly which includes examples of where the technique has been adopted, or is in the development stage, suggests measurable goals, recommends professional advisors, outlines useful "points to consider" in adopting the technique and it describes, and if available, quantifies the benefits. Costs and savings estimates are also discussed.

For example, some policies prevent infill development in order to maintain storm mitigating permeable land. However, grassy lawns may act like impervious surfaces and infill development compared to building on greenfield sites, especially when water tanks are attached, is likely to reduce overall catchment imperviousness. Furthermore, infill development will gain the efficiency advantages of compact urban design.

Compact urban design is promoted strongly by Smart Growth. Studies have shown that verses diffuse urban communities, compact design

- reduces commuting distances and saves people time,
- reduces road pollutants
- requires less infrastructure hence less maintenance costs and specifically for water less leakage
- decrease water consumption (less losses and fewer gardens)
- encourages sustainable transport (public transport, walking and bike riding)
- has less impervious surfaces hence run off is minimised

The end result of compact urban design is that people save money, time and have a reduced impact on the environment.

Urban forestry is promoted for its role in abatement of urban heat island effects, carbon absorption, shade provision and aesthetics. In addition, Garland City, Texas estimated that its urban tree canopy's rain harvesting reduced its storm water storage requirements by 513 MLs (for the average maximum two-year 24-hour storm event). The city estimated that it saves $2.8 million annually, calculating the cost of construction funding over the 30-year life of a facility.

A key lesson for climate change planning from the Smart Growth approach is from its integrated catchment focus.

4.2.5 Impacts of Climate Change on Sewer networks: South East England, UK Case Study

The work of the South-East Regional Assembly on climate change is a good example of integrating planning policy with climate change forecasts. It applies its own form of Smart Growth principles to the traditional twin-track approach of improving supply and minimising demand.

One of its goals is to provide sufficient supply but not over supply such that they avoid paying the environmental, social and economic costs of resources that are not needed.

A key message from the report was to:

> "Identifying appropriate adaptation responses will require careful assessment of the risks facing a given area from climate change, and the specific circumstances of individual development sites."

Strategic planning to minimise the future risk of flooding should:

- Adopt a risk-based approach to development in, or affecting, flood risk areas
- Identify areas of flood risk and designate flood washlands / storage areas.
- Identify key pressures on sewerage systems,

4.2.6 Summary of case studies

The UK is not alone in facing significant investment to adapt to the impacts of climate change. Climate change is just one among many changes to catchments that are likely to impact upon CSOs and neither one should be considered in isolation. In effect, the additional impacts of climate change will be dependent upon trends in urbanisation, smart growth adoption, agricultural practices, costs of sewer network upgrades, ambient resilience of receiving water bodies to CSO overflows and more.

All of the case-studies recognise the heterogeneity across space and time in potential problems and hence the need for tailored site specific diverse approaches.

A critical issue, particularly for the UK, but one not widely discussed, is bringing catchment stormwater infrastructure under the one guiding policy umbrella. Water companies have to manage their CSOs in the light of changes to the catchment hydrology from climate change, urban development and local catchment storm management. However, they have little control over the planning process that will influence catchment hydrology. Furthermore, policy planners, developers and catchment citizens are not directly responsible for the impacts they have on CSOs.

Unravelling the policy framework for implementing best management storm water management is a significant challenge or enabling least cost strategies to climate change adaptation.

4.2.7 Catchment and Sewer network modelling

Modelling the impact of increased precipitation on sewerage network within catchments is a complex and difficult process. The New Zealand report: *Incorporating climate change into stormwater design - Why and how*? provides an excellent description of this process.[11]

Variables that can influence a catchment's response include:

- *Permeability of the surfaces* – Though the relationship can be complex as areas that are permeable can act like concrete given sufficient rainfall intensity, local topography and previous saturation;
- Soil type and pre-storm soil conditions (saturation, dryness);

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[11] Available at: http://www.climatechange.govt.nz/resources/local-govt/stormwater-design-mar05/index.html

- Topography- steep catchments typically result in higher peaking but shorter floods;
- Geology; groundwater recharge, soil type and local sediment characteristics;
- Past flood history: in a flood sequence, the first flood may move slowly as it works to flatten vegetation, fill up lagoons, carry lots of sediment and overcome any river dams. A second flood will as a result move much quicker;
- Rainfall - intensity and duration;
- Water management and storage options- how much head room is left in catchment storage capacity.

Variables that impact the response of the sewer network include:

- The degree of connectivity between the catchment's hydrological system and the sewerage system;
- System hydraulics and capacity (channel capacity and storage capacity);
- Current and future predicted loads relative to capacity; and
- Location of CSOs within the network and catchment

Surface runoff is generated in 3 ways.

- Rate of rainfall exceeds the infiltration capacity of the surface substrate
- Rainfall falls on soil that is already saturated
- Water that has infiltrated upstream may flow laterally and exfiltrate elsewhere

The variables discussed above all impact in part on the shape of the flood hydrograph and the ultimate size of the flood peak.

It is the flood hydrograph and in particular the size of the peak flow that drive storm water sewer design. By looking at past flood peaks over time, hydrologists determine the sewer capacity required to keep CSO spill events within acceptable limits.

4.2.8 Stormwater climate change forecasts for England & Wales

Climate change models forecast that future winter rainfall events will be larger and more intense thus higher peaking flood events are predicted. England's stormwater infrastructure development has been influenced by layers of policy over the last century. The increased likelihood of higher peaking floods can be expected to increase the likelihood of CSOs spill events.

Recent UKWIR[12] research reviews the possible impact of climate change on sewerage system performance, and implications for future design to maintain current levels of service. The modelling applied IPCC emissions scenario based on the medium-high scenarios. This predicted many areas in the UK would experience 20 – 40 per cent greater rainfall depths, with the Midlands and East Wales are not expected to experience any increase, though other parts of the UK could experience up to 60 per cent or more.

The assessment of the effect of climate change on inflows to waste water treatment works was based on five sewer network models from across the UK covering a range of different catchment characteristics, including topography, urbanisation and size. Rainfall inputs, both for flooding and intermittent discharge analysis, were derived for present and projected 2080 climate conditions for each of four rainfall gauges.

The primary implication of the study was that the potential changes to sewerage system performance to adapt to the future climate are likely to be large if they are addressed only by modifying the network infrastructure. Some of the study's relevant findings were:

- CSO spill volumes are expected to increase by up to 180% across the UK in summer and winter, with much smaller increases experienced in spill frequency.
- The frequency of spills for the whole year is much greater with the number of additional spills in the South being from 3 to 7 per year, but as much as an additional 12 times in the North. The implications are that to maintain spill frequencies to present day performance (of 10 spills per year) would require storage volumes to increase by around 10 m3/ha in the drier areas and between 25 to 70 m3 /ha in the wetter areas. During the summer the frequency of spills nearly doubles in the North (from 3 to 6) but showed little change in the South.
- A reduction in summer flows is likely to reduce the amount of water available for the dilution of any polluting CSO discharges. Winter flows are likely to increase significantly in the north of the UK and to a lesser extent in the South by the 2080s.
- The impact of climate change on WWTW inflows are likely to be small and will have minimal effect on biological processes. The water quality analysis undertaken indicates minimal impact on receiving waters in the south with increasing impacts in the north of the UK. However the predicted reduction in river base flows will have a significantly greater detrimental impact on river quality than the change in sewerage system performance. Water quality has a minimal impact on receiving waters in the South (assuming no change in river base flow) with the likelihood of impact increasing in the North.
- Storage solutions to meet coastal CSO impact standards were also shown to need to increase significantly for the 2080 to meet compliance; a 6 fold increase needed to meet the 10 spill per annum standard for shellfish waters was necessary and a 7 fold increase needed to meet 3 spills per bathing season standard.
- A comparison of additional storage required to meet salmonid water quality standards was carried out, for 2080, 2080 with a 20% reduction in river flow due to

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[12] Climate Change and the Hydraulic Design of Sewerage Systems: Summary Report (03/CL/10/0); Climate Change and the Hydraulic Design of Sewerage Systems Volume IIIA – Change in the Performance of Sewerage Networks (03/CL/10/6), UKWIR.

climate change. In the North, an increase in storage of around 61% was needed to meet salmonid water quality standards in 2080, while a further increase of around 110% was needed for 2080 with a 20% reduction in river flow. In the south, around 40% storage capacity was needed, though with a 20% reduction in water flow on 2080, an increase of around 20% would be needed. The effect of reduced river base flow of 20% leads to an additional 60% volume requirement for both areas. This is consistent across all regions based on small water courses, with expectation that the impact for large water courses may be larger.

- For many areas in UK, climate change may result in an 40% increase in rainfall depths in excess of the current values with a subsequent doubling of flood frequency and volume. Following an increase in rainfall will result in storage volumes to prevent internal property flooding needing to increase by more than two fold.

The UKWIR study also highlighted the significant areas of uncertainty in the estimation and modelling. Uncertainty in predicting future rainfall patterns suggests that approaches to sewer design should move towards a risk based approach rather than meeting design standards.

Individual catchment characteristics have an important bearing on the results, and aggregating these affects to produce results at the national level may reduce the applicability of the resulting estimates. Following from this, the impacts of changes in river flows on sewer network (as opposed to treatment) assets have not been estimated as part of the study as they are dependent on site specific characteristics.

4.2.9 Estimate for Adaptation Costs for England and Wales

The headline conclusion from the UKWIR study is the potential need for significantly increased storage in sewer systems to allow the change in stormwater flows to be managed. This is the subject to the caveat that the solutions for storm storage may be at their limit in terms of accommodating some of the forecast impacts. However, to provide some indication of the potential scale of required storage solutions in expenditure terms we set out some cost estimates below.

Our estimates of increased storage capacity requirements are derived from the five catchment /sewer network models presented in the UKWIR (2003) study. The 5 models were meant to be representative catchments covering

- 1 flat rural coastal site;
- 1 flat rural inland site;
- 1 flat suburban inland site;
- 1 moderately steep suburban coastal site; and
- 1 steep inland urban area.

The UKWIR models covered only 0.016% of the total UK land area and hence should be considered as only highly stylised representations of actual catchments. The sites were ambitiously designed to be characteristic. Indeed, the steep urban site could be seen as a worst-case scenario representation of urban sites.

Ten year rainfall data from 4 gauges distributed north to south (London, Birmingham, Manchester and Fife) in the UK formed the baseline. This was compared to estimated precipitation from UKCIP 2002 climate change predictions.

The level of variation between sites and across scenarios within the UKWIR work highlights a significant weakness of a broad brush approach and emphasises that further more detailed catchment-based modelling is essential for improving cost estimates.

Further system storage capacity may be desired anyway for adaptation to climate change forecasts of longer drier summers

In some cases extra storage will serve duel benefits of capturing excess winter storm flows for use within the catchment over the summer period. However, a trade-off between managing storages for reserves and as buffers for storms needs to be recognised.

As with the impacts, the options available to accommodate the impacts of increased flood volume will vary according to local catchment and system characteristics.

2001 ODPM data provided breakdowns of land-use across England for each local authority[13]. This data was used to estimate what area of the UK could be described as rural, urban and suburban. The UKWIR estimates of extra volume predicted within urban, suburban and rural catchments were then used to derive possible total storage requirements.

An upper bound Ofwat storage cost estimate of £650K per 3000 m^3 of storage at a CSO site was applied to the data giving a unit storage cost of £217 per m^3.

Ofwat's 2003-04 June Returns data provided the sewer network catchment area.

Cost Methodology

To estimate total costs the general formula we apply is:

$$\text{Extra Storage Cost (£)} = \text{Hectares}_{ijk} \times \text{Extra Vol}\left(\text{m}^3\right)\text{per Hectare}_{\text{ijk}} \times \text{Storage Cost (£)}_{\text{ijk}}$$

Where i = coastal and inland
j = urban, rural or suburban
k= north, middle and south

Total hectares were estimated using OFWAT June Return data. Only areas served by CSOs were included. The June Return reporting requirements indicate that some unquantified level of error is applicable to these estimates.

Coastal and inland land area distinctions were approximated for each water company area of operation.

Urban, rural and suburban land area classification was approximated from the 2001 ODPM Generalised Land Use Database Statistics for England. Urban areas were those deemed to have a ratio of more than 30% between built up land (buildings, roads and paths) to permeable (green space). Rural areas had a built up land ratio of less than 5%. Suburban was anything between 5-30%. This classification is based on ICF judgements and sensitivity analysis is recommended.[14]

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[13] http://www.odpm.gov.uk/pub/477/DetailedmapshowingEnglishLocalAuthoritesPDF138mb_id1139477.pdf

[14] We undertook some limited sensitivity analysis as outlined below.

The ODPM data is stratified into 357 local authorities. Whilst local authority divisions do not equate water company divisions, in the absence of more suitable data, it was seen as a good proxy for urban, suburban, rural divisions within water company areas.

The estimation of extra storage volume required per hectare across coastal and inland sites was derived from UKWIR data. One rural coastal site and one suburban coastal site were modelled by UKWIR. The suburban coastal data was used to approximate the urban coastal site.

Urban, rural and suburban classification for the estimation of extra storage volume required per hectare was derived from UKWIR data. Three inland sites were modelled by UKWIR: one each for urban, suburban and rural.

Storage costs would vary according to many factors but since we do not have sufficient data we have used a simple benchmark Ofwat estimate of £650K per 3000m^3 to approximate the cost across all areas.

Sewerage companies were finally allocated to North, Middle and South regions to map them to the UKWIR predictions for storage flows.

Cost Estimates

This modelling approach suggests that the costs of increasing storage capacity to maintain current CSO standards would be of the order of £10s of billions. **The data and calculation reported below suggest an overall present value cost estimate of some £15 billion**. Close to £9 billion of that estimate is accounted for by the three sewerage undertakers in the North (United Utilities, Yorkshire and Northumbrian). The “Middle” undertakers account for about £1 billion, with the remainder of £5 billion spread across the sewerage companies in the “South”.

In terms of annual cost impacts, the figure of £15 billion would translate to an **annual cost requirement of between £0.9 billion to £1.1 billion** assuming discount rates in the 5-6% range and typical industry asset lives in the 30 to 40 year range. This represents approximately ¼ of current annual costs for sewerage undertakers in England & Wales.

Key assumptions that impact upon the estimates include:

- The difference between suburban and urban is much less important than the ratio of impervious land to permeable used to classify land as rural. Costs rise exponentially as more land is classed as not rural (either suburban or urban), i.e. as the ratio impervious: permeable is decreased. [15]
- The amount of a catchment area classed as being part of a coastal catchment is very significant. Decreasing the inland area increases costs linearly.
- Decreasing the amount of catchment area decreases costs linearly.

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[15] For example, a rural ratio of 10% (as opposed to 5%) decreases the total cost estimate to £10 billion. By contrast a rural ratio of 2.5% (as opposed to 5%) increases the total cost estimate to £30 billion. Whereas for urban ratios in the range 25% to 50%, at a constant rural ratio of 5%, total costs are in the much narrower range of £15.2 to £15.5 billion.

- The relationship between cost of storage and total costs is linear
- Altering the location is less relevant.

The cost estimate is clearly broad-brush, but it implies very significant levels of expenditure and is consistent with related work described in section 4.2.10 below. This related work also provides more of a comparison between storage and alternative adaptation responses (including sewer upsizing and sustainable drainage systems). We emphasise that orders of magnitude of this kind should encourage both more detailed focused work on catchment / sewer network modelling and a rigorous assessment of the costs of alternate storage options.

Table 7: Cost estimate for stormwater adaptation in England and Wales

Sewerage Company	Location	CSOs	pop 000s	Area of sewerage district	Drained area km2	Coast line kms	DA/CA	% Inland	% Urban	% Suburban	% Rural	Drained Area has	Inland vol per ha	Coast vol per ha	Inland Volume	Coastal Volume	Estimated Present value Cost (£m)
Yorkshire	North	1784	4609	13652	2685	152	17.66	80%	0%	26%	73%	268500	1.30	214.50	278228	11518634	£2,556
Wessex	South	970	2475	10144	2146	425	5.05	20%	1%	7%	91%	214600	0.59	26.80	25131	4601299	£1,002
Thames	South	442	12635	13331	3074	126	24.45	90%	73%	27%	0%	307385	7.41	199.37	2048711	6128244	£1,772
Southern	South	236	4062	10550	1491	558	2.67	5%	2%	22%	76%	149077	0.84	55.43	6264	7849596	£1,702
South West	South	1045	1404	10764	815	416	1.96	10%	1%	7%	91%	81500	0.59	26.80	4772	1965898	£427
Severn Trent	Middle	2176	8190	23081	5272	0		100%	6%	13%	81%	527200	0.55	56.21	288649	0	£63
Northumbrian	North	308	740	9295	1287	264	4.88	70%	1%	23%	76%	128700	1.24	197.53	111559	7626711	£1,677
United Utilities	North	1877	6581	15378	2068	236	8.76	50%	2%	28%	71%	206800	1.38	235.68	143024	24369559	£5,311
Dwr Cymru	Middle	1707	2990	21874	1299	697	1.86	40%	1%	7%	91%	129900	0.48	29.29	24688	2282745	£500
Anglian	Middle	1088	5414	27057	1566	973	1.61	70%	2%	11%	87%	156600	0.51	40.09	56416	1883293	£420
		10545	43684	155126								2170262					**£15,430**

4.2.10 Foresight Flood and Coastal Defence

Related cost evidence is provided by work undertaken as part of the Foresight Future work on flood defence under climate change scenarios. [16]

The Foresight Flood and Coastal Defence project set out to produce a long-term vision for the future of flood and coastal defence in the UK. Here we present a summary of the main findings of their study, focusing on urban drainage, and sewer flooding risk.

The study analyses the performance of the existing main-sewer catchments in terms of flooding within the urban area, with a number of proposed solutions. In each case, the outline dimensions for the response were determined for the specified return period of storm input, using the normal design standards currently adopted by sewerage undertakers. These were then related by unit costs to direct capital costs. The estimates of the numbers of properties originally flooded and subsequently protected for the whole of each catchment were then combined with flooding frequency to estimate the costs for response implementation and residual expected annual damage (EAD). Additional costs for the local drainage and the flooding internal to properties were also included. Table 8 summarises the catchment characteristics. The EAD and cost curves are assumed to be applicable across the UK population of 59 million (2001 census).

Table 8: Modelled catchments in the Foresight Flooding Study

Nature of catchment and locality	Area (ha)	Impervious area (%)	Population	Population density (Person/ha)	Number of properties	Property density (prop/ha)
1 Market town (northern England)	1384	29	85500	62	38636	28
2 Inland city with major watercourses (Scotland)	3934	34	263026	67	77413	20
3 Coastal City (Wales)	2027	21	212241	60	31099	15
4 Inland town (northern England)	727	15	15700	22	7212	10

Source: Evans et al (2004)

The costs presented in the Foresight study are also dependent on the service standards for flood risk protection that are adopted and these will vary across the socio-economic scenarios.

However, these costs are also dependent on the socio-economic scenario adopted. Table 9 below summarises the Foresight assumptions. These highlight a higher level of

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[16] Evans, E., Ashley, R., Hall, J., Penning-Rowsell, E., Saul, A., Sayers, P., Thorne, C. and Watkinson, A. *Foresight. Future Flooding. Scientific Summary: Volume I,* Future risks and their drivers. (2004). Office of Science and Technology, London.

protection under the World Markets and National Enterprise, implying a greater weight on the avoidance of material damage and a greater acceptance of flood risks under local stewardship and global sustainability.

Table 9: Urban Flooding Protection levels in the 2080s from the Foresight Flooding Study

	Level of protection (return period in years)		
Scenario	**Flooding of property**	**Flooding external to property**	**Flooding of highways**
World markets	100	30	10
National enterprise	100	30	10
Local stewardship	30	5	2
Global sustainability	50	10	5

Source: Evans et al (2004)

Table 10 illustrates the cost of below-ground storage and conveyance options per property at risk of flooding for each rainfall scenario against the varying catchments types that were modelled.

Table 10: Option unit cost of response per property at risk of internal flooding- main drainage only in the Foresight Flooding Study

Catchment	Unit cost (£ 000's) per at risk property for return period in years	Present day			2080s		
		10	30	100	10	30	100
1	Storage	146	194	209	68	98	77
	Conveyance	79	76	57	28	27	17
2	Storage	75	112	137	114	141	174
	Conveyance	258	238	222	191	145	149
3	Storage	896	789	696	771	702	660
	Conveyance	1678	829	435	930	514	238

Source: Evans et al (2004)

Again, the above data indicate the importance of site-specific characteristics. In catchment 1, the proximity of watercourses that could accept discharges from the urban area makes the conveyance option more cost-effective. However, the interaction between the urban catchment and local watercourses in catchment 2 and the tidal interactions in catchment 3 has a profound effect on costs in these areas. The study indicates a 50 to 100% increase in relative costs for responses in the catchments with these interactions. The results also indicate that the catchment-wide storage solutions both for the inland and coastal catchments (2 and 3 above, respectively) will require large storage volumes to resolve all predicted flooding.

While the relative costs of storage requirements and rainfall is significantly higher than for solutions that involve increasing pipe sizes, the overall cost is significantly less. The costs of 'upsizing' are much higher where there are interactions with watercourses or tide levels. The alternative responses, retrofitting source controls or managing flood pathways, were also costed. However, source control depends heavily on the availability and cost of land for surface storage. While such solutions could be more cost-effective in terms of capital expenditure the high costs of introducing these types of system into existing urban areas may mean they will only be effective in new developments.

The comparisons of solutions are presented in Table 11 for the four solutions considered in this analysis:

- disconnected drainage ('discon');
- upsizing of the drainage system ('upsize');
- the introduction of sustainable urban drainage ('SUDS'); and
- below-ground storage ('below').

It was also expected that conventional engineering solutions would be favoured under the World Markets and National Enterprise scenarios, whereas softer engineering solutions such as SUDS would be more widely adopted under the local stewardship and global sustainability scenarios.

Table 11: Relative unit costs for options considered in the Foresight Flooding Study

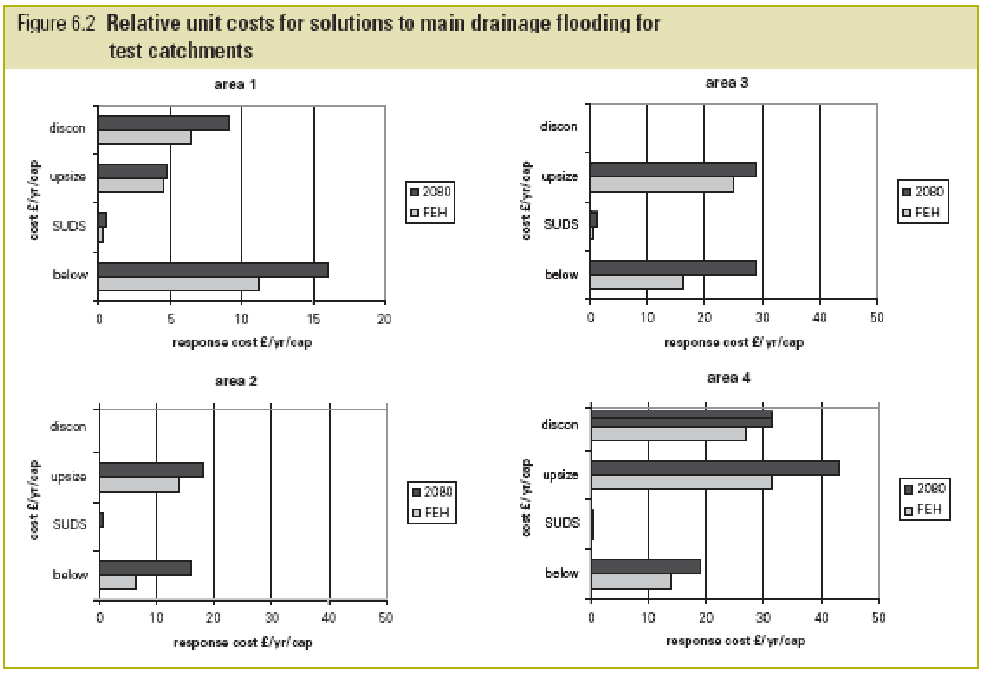


Figure 6.2 Relative unit costs for solutions to main drainage flooding for test catchments

Source: Evans et al (2004)

The costs are significantly determined by circumstances that are catchment-specific and thereby national averages are not considered meaningful. The analysis is based on figures for England and Wales and uncertainty in the data is suggested as plus or minus a factor of three or more.

A focus of the Foresight study was to estimate the incremental cost of protecting against flood risks under conditions of climate change. Table 12 provides estimates of the costs of responding to current flood risks for the three categories: internal property flooding; flooding external to properties; and highway flooding. Table 13 estimates the costs to achieve the same standard of protection under climatic conditions forecast for the 2080s under the National Enterprise scenario. The National Enterprise scenario can be interpreted as placing a relatively high weight on insuring against flood damage to material property, as well as tending to reflect the adoption of conventional engineering solutions such as upsizing and storage.

Table 12: Cost of responding to intra-urban flooding under current climatic conditions (£ millions)

Flood type	Public sewers	Private sewers	Overland flow	total
Flooding of property- 100 year protection	1475	1125	1475	4075
Flooding adjacent to property- 30 year protection	294	224	294	813
Flooding of highways- 10 year protection	92	70	92	256
Total cost	1862	1420	1862	**5145**

Source: Evans et al (2004)

Table 13: Cost of responding to intra-urban flooding under projected (2080s) climatic conditions (£ millions)

Flood type	Public sewers	Private sewers	Overland flow	total
Flooding of property- 100 year protection	6613	5045	6613	18273
Flooding adjacent to property- 30 year protection	1143	872	1143	3158
Flooding of highways- 10 year protection	367	280	367	1016
Total cost	8125	6198	8125	**22449**

Source: Evans et al (2004)

Under current climate conditions, the (present value) costs of responding to intra-urban flood events are estimated to be:

- Internal property flooding - £4billion
- External property flooding - £0.8 billion
- Highway flooding - £0.3 billion
- Total - £5.1 billion

Under future climate conditions forecast for 2080, the forecast costs increase to:

- Internal property flooding - £18billion
- External property flooding - £3 billion
- Highway flooding - £1 billion
- Total - £22 billion

In other words, adaptation to climate change could increase costs of responding to intra-urban flooding events by some £17 billion.

The Foresight study also provides some information on the relative costs of alternative storm-water adaptation options for achieving the protection standards noted above. However, these costs are also dependent on the socio-economic scenario adopted. Table 14 reports these relative costs.

Table 14: Relative annual costs of intra-urban flood protection as specified for each scenario (£ millions)

Flood type	World markets	National enterprise	Local stewardship	Global sustainability
Below ground storage	2617	2387	664	1044
SUDS (above ground storage)	90	82	23	36
Upsizing of main sewers	2230	2034	566	890
Disconnections	1173	1070	298	468

Source: Evans et al (2004)

The Foresight report is careful to avoid any implication that these cost comparisons allow the conclusion that options like SUDS are clearly the most preferable option. As it points out no feasibility of this option was explored, the cost assumptions are based on simple multiplier for land acquisition and widespread adoption is not likely to be practical. Of more note perhaps is the implication that traditional engineering solutions would require very significant levels of expenditure in the billions.

In practice the Foresight work considers that a mix of options would be required and this mix would vary across the socio-economic scenarios. Allowance for the feasibility of implementation and the likely mix under each scenario produces the cost estimates shown in Table 15. These range from about £500m per annum under World Markets to just over £100m per annum under Global Sustainability.

Table 15: Annual Costs of intra-urban flood protection by socio-economic scenario

	World markets	National enterprise	Local stewardship	Global sustainability
Cost of response likely to be used under this scenario (£million per year)	540	260	400	110
Residual flood risk multiplier	0.6	0.5	0.7	0.4
Residual EAD (£ million per year)	4200	2400	490	720
Uncertainty in EAD	2000-8000	1000-5000	200-1500	300-2000

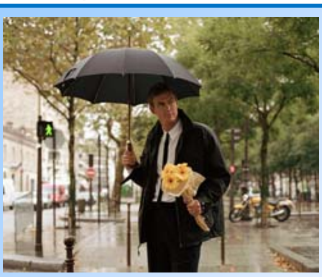
Source: Evans et al (2004)

Table 15 also shows how the scenarios compare in terms of residual flood risk and an estimate of the damages associated with that residual flood risk. The risk multipliers show measure on a scale of 0 to 1, the effectiveness of the responses under each scenario is reducing future flood risks. The scale of the estimated damages also reflects the assessment of the absolute risk multipliers and these are significantly higher under World Markets and National Enterprise (with higher return standards required) compared to the other scenarios.

4.2.11 Alternative Strategies and Costs

A very real uncertainty is whether the increase in rainfall predicted under climate change scenarios can be accommodated with the continued use of conventional solutions such as provision of storage is unlikely to be sustained in the future. As the Foresight study has shown more likely – and indeed more flexible – will be adaptation strategies that incorporate a range of approaches and options.

Above ground conveyance and near surface closed conduit conveyance of surface waters may provide a better alternative to the construction of more conventional drainage or large storage tanks. Infiltration and retention / detention systems like SUDS were considered likely to be more sustainable as they tackle the problems of increased surface run off at source. SUDS can also be designed to control pollutants in surface run off. However as SUDS systems generally require more land-take so they may be more difficult to retrofit in dense urban areas.



American Forests (1999) performed a case study on the Baltimore-Washington area using Landsat images collected from 1973 – 1997 and found that the tree cover declined from 51% to 37%. During this time there was a 19% increase in storm water runoff. The cost for managing this additional runoff comes to $1.08 billion in the development of expanding the gray infrastructure for storm water retention.

Remedial measures may also be required simply in order to achieve substantial reductions in storm water inputs to maintain current levels of performance. These could take the form of targeted household subsidies, similar to those that have been used in the water and energy efficiency area – see case study overleaf.

Strategies to mitigate the impacts of higher peaking floods are diverse and generally require a catchment based approach. In general, the intention of such strategies will be to either increase the capacity of the network to absorb the extra flow, reduce the extra flow total volume through local storage or to delay the movement of flood water through the catchment to decrease the peak flow height.

Strategies may include:

- Reducing impervious services within the catchment via narrowing roads, replacing concrete with gardens and creating rooftop gardens;
- Urban forestry canopies that catch water – see example across;
- Diverting hard surface runoff (roof-tops, car parks etc) to rainwater harvesting tanks or lakes;
- Diverting storm water to permeable surfaces such as gardens or playing fields
- Slow flow drains that cause temporary localised flooding
- Encouraging Smart Growth development
- Expanding or building new catchment storages
- Increasing the capacity of sewer systems

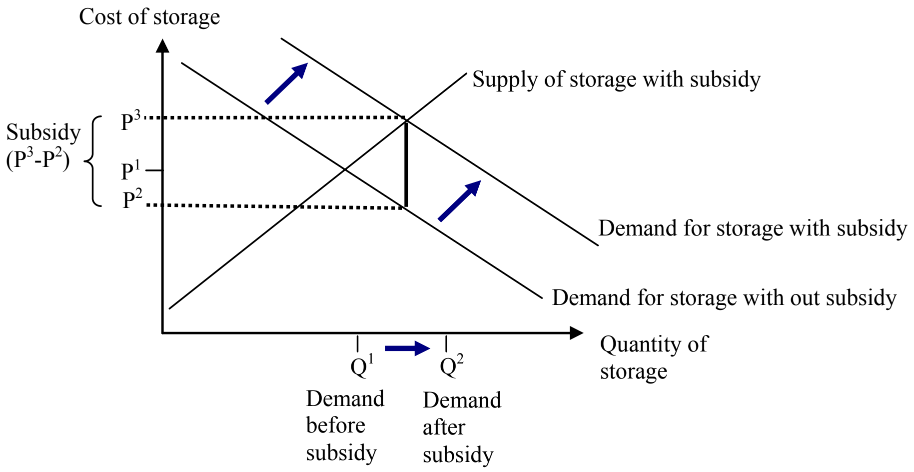
Catchment based storm water storage options are likely to be diverse and the most effective solutions will be tailored to existing catchment-specific infrastructure and conditions.

This serves to emphasise the likely limitation of our costing exercise in section 4.2.9 that has applied uniform assumptions across England & Wales. In practice, well designed adaptation strategies will take account of local conditions in ways that have not been possible in this study. This requires clear frameworks for developing adaptation strategies and we conclude this report with some thoughts on this area.

Case study: Encouraging Decentralised Rainwater Storage

One possible strategic storage option that exists may be to tap into the existing demand for household rooftop rainwater water storage tanks and offer a subsidy to encourage the market to expand. Currently, many householders have installed rainwater tanks for a variety of reasons including security of supply, alternative supply option to water gardens especially in case drought orders are enforced and some people install tanks for altruistic reasons. This market for is stylised in the figure below.

Figure: Supply and demand for household storage facilities.



In figure 3 a subsidy or rebate equalling P3-P2 is offered to water tank purchasers, shifting the quantity demanded from Q1 to Q2. The dynamics of the subsidy have been simplified but basically the subsidy which is shared by the suppliers of tanks (including plumbers who install the tanks) and the purchasers of tanks lowers the price customer's pay and increases demand for water tanks.

The uptake of water tanks may also be influenced by more than just a subsidy. The duel benefit of water tanks for providing water for gardens and storm storage mean that a lack of summer rainfall will encourage water tank installations. Hence we might expect demand to increase as climate change impacts take effect. A combination approach of subsidy with promotion may increase awareness of tank installation benefits and further increase demand. Assessing the shape and slope of the demand curve enables one to estimate the effect of a given subsidy on increasing catchment storage. Given, the long-term planning horizon for climate change, clever approaches to applying the subsidy might be feasible. The subsidy rate could be staged such that initially a promotional campaign shifts demand up. After say 5 years, a low subsidy rate is introduced to further increase demand. Gradually increasing this subsidy over 30 years will allow planners to develop and accurate estimate of the shape of the demand curve and target the optimal level of catchment storage. Naturally, the marginal cost of the subsidy per m3 storage created should not rise above that of other catchment storage options.

So long as administration costs are not prohibitive, optimising this strategy may involve stratifying the market and offering higher subsidies in catchments where the cost of alternate storage options is greatest and or the benefits of storage are greatest. Other factors influencing this market include the price of substitutes such as concrete (instead of gardens) and household water from water service providers. Policies to restrict these, such as hosepipe bans, should increase demand for water tanks.

4.3 Sea Level Rise

UKCIP 02 predictions show variable rates of sea-level rise across the UK largely due to local isostatic uplift and subsidence. Relative to the 1961-1990 average level, sea level rise in South West England could be as high as 19cm by 2020, 44cm by 2050 and 80cm by 2080.

This is in contrast to North West England where maximum predictions for sea level rise are 11cm by 2020, 30cm by 2050 and 63cm by 2080.

Isostatic uplift is the rise of land masses that were depressed by the huge weight of ice sheets during the last ice age. Northern UK has a glacial history whilst the south does not. As the north rises, the south is subsiding. This subsidence compounds the south's vulnerability to sea-level rises.

Expected impacts include salt-water intrusions in fresh surface and ground water sources, flooding of low lying tidal/ coastal assets and corrosion of infrastructure from salt water intrusion.

Sea level rise impacts are expected to be compounded by the associated increases in storm surge and high energy wave activity. However, these are difficult to predict and likely to be influenced by site specific characteristics.

The net effects of sea-level changes for the water industry will depend on many factors such as the cost of flood defence, availability of alternate resources or supply options, frequency and intensity of impacts and the size of the resource affected.

4.3.1 Assessing vulnerability to Sea Level Rise

The basic characteristics for developing a costing scenario for vulnerable water company supply resources could be as follows:

Surface water supply

- Intake point is below the fall line
- Intake point is in a fresh but tidal reach.
- There are no downstream dams.
- Wetlands with brackish water plants are close to the intake point (the closer, the more vulnerable).

Ground water supply

- Potentiometric surface (in an unconfined aquifer, water table elevation) is close to sea level (the closer, the more vulnerable)
- Proximity to the coast (the closer, the more vulnerable)
- High pumping rates (more likely to result in large "drawdown cones")
- Evidence of salt water intrusion in similar hydrogeologic settings

In addition, it is advisable to screen both surface water and ground water supplies for "value". In recent work for USEPA, ICF applied this screen to the GW-based supplies, and developed a score based on (1) population served by the water supply and (2) availability of alternative water supplies.

Investigating the impacts upon infrastructure would require a similar screening process however; it would be complicated by allowances for existing asset life spans, existing and options for cost effective flood defence, costs and options for relocating assets and the value of the assets.

For example, two significant sewerage assets on the Thames are located below the existing flood defence barrier – see Table 16

Table 16: Population served by potentially vulnerable sewerage infrastructure on the Thames

	Population Equivalent (PE) served		Trade Effluent load	
	PE (millions)	% of Thames total	kg/ day	% of Thames total
Beckton WwTW	2.7	20%	28516	19%
Crossness WwTW	1.88	14%	13443	9%
Total Thames	13.47		150129	

Source: http://www.ofwat.gov.uk/aptrix/ofwat/publish.nsf/Content/navigation-jr-sewage-explanatory-factors-tables

Becton and Crossness have flood defence designed to offer acceptable protection against the flood risk expected up until 2030[17]. Given, the importance of these sites and practical improbability of finding cost-effective alternatives it is likely that existing flood defence will need be replaced or bolstered to offer protection against future climatic conditions. However, considering the location of other non-water related assets to these sites, it is likely that the additional flood defence costs will be shared amongst many benefactors.

4.3.2 Case Study: The New Zealand Experience

Recent climate change guidance from New Zealand has highlighted that:[18]

- Climate change will affect not just sea-level rise, but most physical drivers that shape coastal margins and ecosystems, such as winds, waves, storms, sediment supply and sea temperature.
- Predicting shoreline response as a result of climate change is complex, and simpler conceptual models based solely on sea-level rise are of limited use. Beach response will also depend on factors such as sediment supply, wave climate, storm frequency and alongshore changes in sediment movement.
- Diversity of coastal types requires local or regional investigations and solutions.
- Topography and cadastral databases for coastal margins need to be upgraded before the scale of the sea-level rise impacts and feasible response options can be assessed on local, regional, and national scales.

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[17] http://www.environment-agency.gov.uk/regions/thames/323150/335688/341764/341787/344610/?version=1&lang=_e

[18] http://www.climatechange.govt.nz/resources/local-govt/guidance.html

4.3.3 Case Study: US Experience

One US study conducted by the USEPA (2005) developed and applied a multi-stage screening process and vulnerability assessment to a sample of about 500 systems. Whilst no cost estimates were provided the results suggest that several million people are served by coastal surface water systems that are unprotected (by a dam or other structure) from sea-level rise.[19]

4.3.4 Summary for Sea-Level Rise

Further site specific information is required to estimate total costs of sea-level rise for water industry assets. The spatial heterogeneity of sea-level rise risks makes a case for site specific climate change risk assessments for individual assets.

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[19] US EPA 2005, The Vulnerability Of Public Water Systems To Sea Level Rise

V. Conclusions and Recommendations

Whilst the cost assessments presented in this report are subject to many caveats and very significant uncertainties, our analysis nevertheless suggests that adapting to climate change impacts for water quality and storm-water management could potentially result in significant costs for the water industry. In terms of order of magnitudes for the potential costs the impacts could reasonably run into billions of pounds. Table 17 summarises our estimates, expressed in terms of the potential scale for the present value of costs. These assessments assume that the adaptation measures considered are undertaken now (we are **not** recommending that this be so). Clearly, if investments were to be deferred to some future time period, the scale of the present values would be lower.

Table 17: Summary table of potential scale for adaptation costs

Category	Estimated Scale of Costs (Present values)
Water Quality	Millions- Billions
Stormwater Management	Billions – 10 to 20
Sea-level rise	n/a

Source: ICF calculations. These assessments are best estimates given significant uncertainty

This assumes most critically that traditional engineering solutions adopted in the water industry to date would emerge as the preferred adaptation options. We would caution against any immediate assumption that such solutions should indeed define the adaptation response to these potential impacts. It is clear that much better evidence on the potential impacts at the catchment level are needed, more analysis of the technically feasible options is required and more thorough economic appraisal of the available options is essential.

It is not yet clear, however, how the ever growing body of scientific and technical knowledge on climate change impacts is best applied within existing decision-making frameworks. The constraints of short time horizons and competing pressures on resources (both in the government and corporate sectors) will always be present and the actions needed to adapt to climate change will need to be determined in this context.

We believe there are four key elements to converting knowledge about climate change impacts into strategies and actions for climate change adaptation:

- **Recognise that climate change is not yet a "driver" of decisions.** Many other water management problems are more immediate, better characterised, addressed by clear statutory and regulatory bodies, and targeted by resources and institutions aimed at solving them. In contrast, the impacts of climate change are (mostly) far into the future and some aspects are hard to predict. The implication is that it is unlikely to be productive to regard climate change as the primary issue driving decisions (as presumed in several methodologies for adaptation decision-making). Instead decision-making should focus on situations where climate change adaptation can be addressed as a component of a broader, multi-faceted water management issue.

- **Recognise that few adaptation questions in water management have to (or can) be answered now**. To get a handle on where and how adaptation should be considered, it is useful to identify three categories: (1) decisions that address issues unlikely to be affected by climate change, (2) those that address issues that probably will be affected, and which could benefit from decision support in the short term, and (3) those issues that will probably be affected but where adaptive actions can (and often should) be postponed and addressed later.
- Develop tools to help classify water management decisions, and provide appropriate decision support systems to promote outcomes that increase resilience. This probably needs to include:
  - *Summary and accessible information on climate impacts and how those impacts affect the resources and systems that are being managed*. This would include an understanding of the magnitude of climate change risk relative to other stressors on water systems and the magnitude of climate change uncertainty relative to uncertainty in other decision factors that drive water sector decision-making.
  - *A systematic approach to identify decisions that would benefit in the near term from consideration of opportunities for climate change adaptation*. US EPA's Global Change Research Program (GCRP) has been developing such an approach, with support from ICF. The approach revolves around two key criteria, each of which has several subfactors:
    - Timing and Time Horizon: Whether Climate is Likely to Change during the Time Period Governed by the Decision
      - How often the decision is made
      - Planning horizon, implementation period, appropriate discount rates and project lifetime
    - How High are the Stakes? The Potential Benefits and Costs of Accounting for Climate Change
      - Reversibility of the decision
      - Magnitude of likely climate change impacts, specifically on the resource of concern
      - The potential for adaptive responses to mitigate any negative impacts of climate change.
      - Current trends in decisions are maladaptive.
      - Priority attached to natural and human resources that are threatened.
      - The magnitude of investment costs.
  - *Decision support tools for water management decisions in Category 2*. For decisions that would benefit by addressing adaptation opportunities in the short term, there is an immediate application for decision support tools. For example, engineering design objectives for combined sewer overflow controls are often expressed in terms of the "rational method," which is keyed to hydrologic statistics on precipitation intensity, duration, and frequency (IDF). Decision support could be provided in the form of rules-of-thumb on how to adjust IDF to anticipate climate change, or recommendations for an additional margin of

safety; such tools would provide a straightforward, clear way to incorporate climate change within the existing framework. Equally, decision-support may take the form of structured decision-making tasks (as illustrated in Annex 4).

  - *For actions in Category 3, best practices for evaluation and feedback to detect impacts of climate change and decide how to adapt.*

- **Develop responses that reduce risk from climate change and other stressors.** In some cases, the symptoms of climate change are similar to the symptoms from other stressors. One of the principal effects of climate change is a "flashier" hydrologic cycle, where a higher proportion of annual precipitation falls in intense events, and with more pronounced dry periods. This, too, accentuates high and low stream flows. Whether the hydrologic changes are driven by long-term changes in land use or in climate change, the adaptive measures are the same – riparian zone buffers, "soft" approaches to increasing infiltration (rain barrels, green roofs, infiltration trenches) and the like. Moreover, in a policy environment where it is much harder to motivate action to address climate change than most other stressors, if the cures are the same, there is no need to differentiate how much of the symptom is due to climate change versus land use change.

  More work is needed to identify such opportunities for "no-regrets" policies where a co-benefit could be a reduction in climate change-related risks while addressing more immediate and more certain problems. This "co-benefits" approach has been a keystone in the arena of greenhouse gas mitigation, and it could be applied more widely in adaptation.

We conclude the report with five specific recommendations for future work on climate change adaptation strategies for the water sector.

Recommendation 1: Understand catchment connectivity

Adaptation costs for the water industry need to be viewed in the context of other drivers within river catchments/basins that will potentially amplify or mitigate against climate change impacts on the UK water industry.

The development of Smart Growth planning principles in the US (section 4.5.4) is built upon establishing the connections between urban development and cost effective water management. Following this example, research that establishes strong evidence based links between urban and rural land use and impacts upon the water industry and water resource management in general is required.

Given the potential costs of climate change, there is a strong argument for increased investment in catchment based hydrological models that incorporate smart growth type ideas.

Recommendation 2: Unravel the policy framework

Following on from a greater understanding of the connections between land use and water management outcomes, it is essential that the policy drivers impacting upon the catchment processes are clearly identified.

The New Zealand example where local councils are required to incorporate climate change predictions into decision making processes has set an excellent precedent.

Whilst the UK is yet to take such steps, there are opportunities with the strong link between the work that is going on to implement the Water Framework Directive and adapting to climate change.

Choosing the right scale at which to direct policy is an important issue. The disjunction between governing boundaries such as council districts and catchment boundaries will require cooperation and coordination of strategies where relevant.

Equally, the private ownership of water industry in England and Wales creates a unique set of challenges. Currently, privatised water companies are responsible for many of the outcomes of land use changes and council planning that impact upon water quality, stormwater surges and wastewater loads. Yet water companies have little control over land use and council planning processes. Conversely, those responsible for catchment drivers are largely not proportionately responsible for their impacts.

Recommendation 3: Connect climate change research with decision makers

It is crucial that the most up to date scientific research feeds into important policy decision-making processes and also that research is focussed on the needs of decision makers.

The facilitation of stronger connections between decision makers and researchers and streamlining of information will help to ensure that climate change research is relevant and utilised.

Priority areas for streamlining information to decision makers are those for long lasting decisions that are made today that will be impacted upon by future climate change conditions. This is particularly important for decisions that are costly or impossible to reverse.

Recommendation 4: Involve all decision-makers

Whilst end of pipe water industry solutions may be required in some cases, it is evident from international experience, such as Smart Growth, that the community can play a significant supporting role for mitigating and adapting to climate change impacts. Encouraging community support may see more rainwater tanks installed, roof-top gardens, concrete replaced with gardens and greater support for government and industry programs to mitigate impacts. Climate change adaptation should therefore be viewed as integral to policies such as market transformation programmes (MTP) that are seeking to influence behavioural changes through the dynamic of the marketplace.[20]

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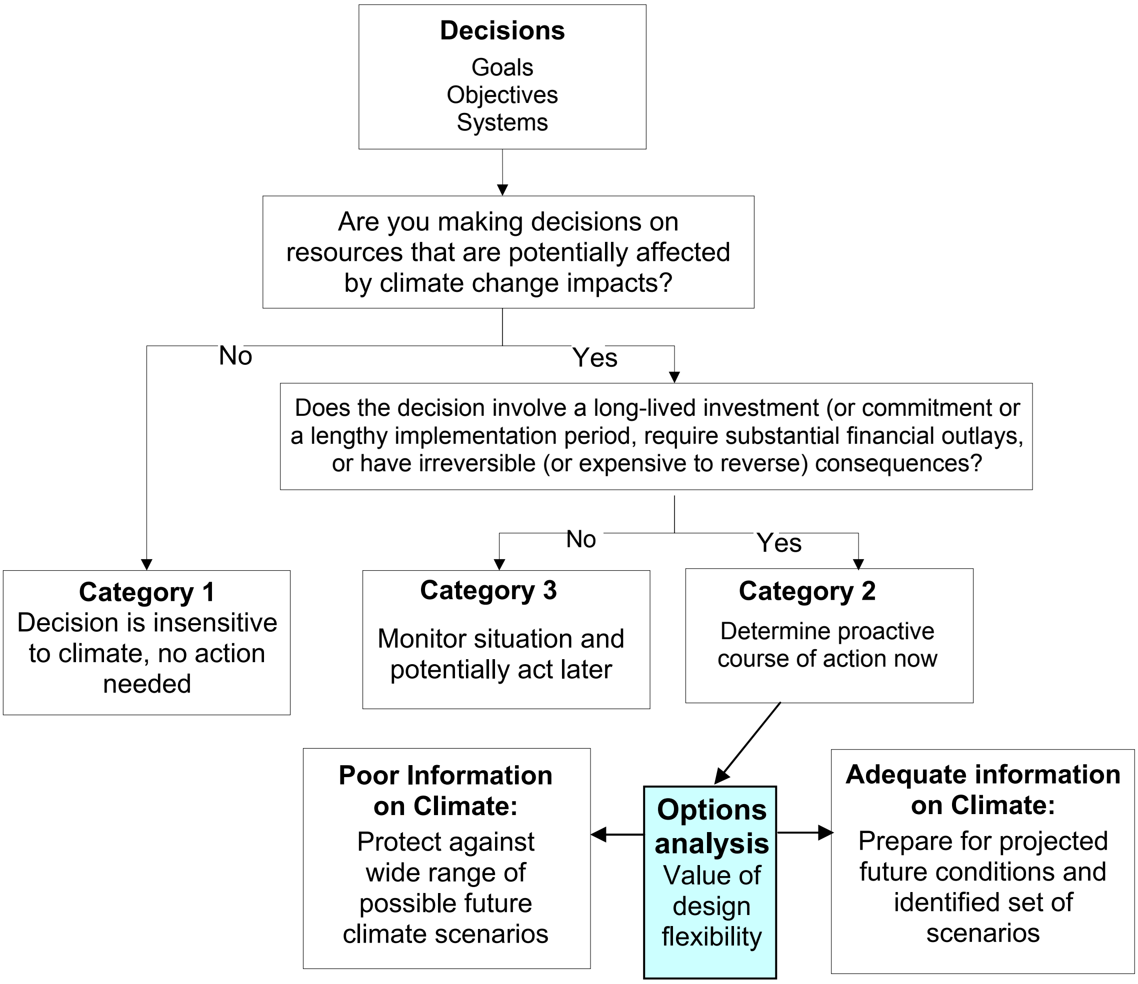
[20] The Defra sponsored UK Market Transformation Programme attempts to understand and influence the drivers for changes in product markets that impact on environmental objectives. For example, energy efficiency or more recently water efficiency.

Recommendation 5: Incorporate decision making frameworks

The above considerations point to the need for a systematic and structured approach to climate change adaptation decision making. We outline below a potential decision-making framework that incorporates many of the requirements already noted above.

Figure 3: Climate change decision making framework



Within category 2 actions, for example, it is important to appreciate the role of lead-times in mitigating the risk posed by irreversible decisions. There are not many investments that are truly irreversible within immediate timescales. For example, a decision to spend £500million on a new reservoir to maintain supply security in the face of climate change, typically may require 20 years before it is commissioned. So decision-makers have time to obtain better information on actual need and re-appraise the initial decision. Moreover, in the meantime smaller scale options that are less costly and are reversible (e.g. demand management) can be employed allow us larger scale investment to be deferred or avoided.

Option value analysis provides a methodology for understanding and quantifying the benefits of flexibility in developing adaptation strategies. It essentially determines if there is positive economic value to building in flexibility to the investment decision For example, option value analysis helps assess if, in the presence of uncertainty about the need, the flexibility offered by low cost (but less certain outcome) options are preferable to the high cost of an additional engineering margin that is irreversible. The evolving role of insurance markets highlighted in section 3.3 will no doubt be integrated with the enhancement of flexible and cost effective financial option based instruments.

Water management routinely involves complex, highly uncertain systems, and climate change will make many of these systems even more complex and uncertain. It is clear that the past is not a reliable guide to the future. To adapt successfully, there will be a need to plan for climate change in current investment decisions. But in most situations, the greater need will be to design long-term strategies to refine our understanding of the effects of climate change, evaluate the types of responses that are necessary as the nature and magnitude of climate-related impacts become clearer, and revise planning and implementation processes to incorporate climate change among the key stressors on water systems.

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Annex 2 Cost Function and Data for BOD & Ammonia Parameters

Cost Function

Given that compliance with many of the tightened consents could be achieved through either capital intensive investment or operational activity, the cost function models net present value per pe of capex and opex (discounted over 30 years at 5% per year) as the dependent variable. This dependent variable was expressed in natural logarithms.

The underlying model was hypothesised to take the form:

$$\ln \ \text{unit cost}_\text{i} =$$

$$f\begin{pmatrix}\text{Current BOD}_\text{i}, \text{Change in BOD}_\text{i}, \text{Current Ammonia}_\text{i}, \\ \text{Change in Ammonia}_\text{i}, \ln \text{PE served}_\text{i}, \\ \text{Dummy variables for works size and if current consent tight}\end{pmatrix} + \varepsilon_i$$

The possibility of the underlying cost relationships being non-linear was allowed for through the inclusion of quadratic terms and interactions between explanatory variables.

The a priori expectations were that:

- Unit costs would be declining in pe served (indicating economies of scale)
- Unit costs would be positively related to the BOD and Ammonia parameters and squared terms would indicate whether those relationships were constant or non-linear (indicating diminishing or increasing returns).

The ordinary least squares (OLS) method was used to estimate the model.

Once an estimated regression was obtained that explained unit costs, this was applied to data on the existing consents at inland / estuarine WwTWs for the ten water and sewerage companies in England and Wales. In order to obtain the *Change in BOD* and *Change in Ammonia* variables a level for the tighter consent was hypothesised and the difference between the current consent and the new consent standard was found. The hypothesised consent was critical to the exercise as it represents the consent that might be required. The predicted unit costs are then used to estimate aggregate costs for England & Wales using:

$$\sum_i \exp\left(\ln \mathit{predicted\ unit} \cos t_i\right) \cdot \text{pe served}_\text{i}$$

The data for all but one company represents the discharge consent position at the beginning of the AMP 3 programme. This means that allowed AMP3 expenditures, (net of the expenditure for the one company) are subtracted from the estimated costs. Expenditure relating to nutrient removal or UV dis-infection was not included, to ensure costs only costs on physico-chemical determinands are included. Moreover, an “inland / estuarine” share for UWWTD[21] upgrade costs

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[21] UWWTD: Urban Waste Water Treatment Directive

in AMP3 was based on an estimated share of total pe served by inland and estuarine WwTWs (88%).

Cost database

The cost database was developed for four water and sewerage companies. This reflected companies to which the project team had the most detailed access. Table 18 summarises the descriptive statistics for the explanatory variables of interest.

Table 18: Descriptive statistics for explanatory factors

Statistics	PE	Current BOD (mg/l)	Current Ammonia (mg/l)	Change in BOD (mg/l)	Change in ammonia (mg/l)
Mean	**13977**	**52**	**30**	**29**	**16**
Sd	**43865**	**51**	**17**	**47**	**16**
Max	**540516**	**360**	**95**	**320**	**90**
Min	**20**	**10**	**0**	**0**	**0**

Where summer and winter consents were applicable, only summer consents were recorded.

Discharge consent database

Information on current consents was obtained from sewerage companies. Receiving waters were classed as inland / river, groundwater, estuarine or coastal. For nine of the ten companies a complete list of numeric consents and associated pe was provided. For one company only a summary of the consents associated with different types and locations of works was available.

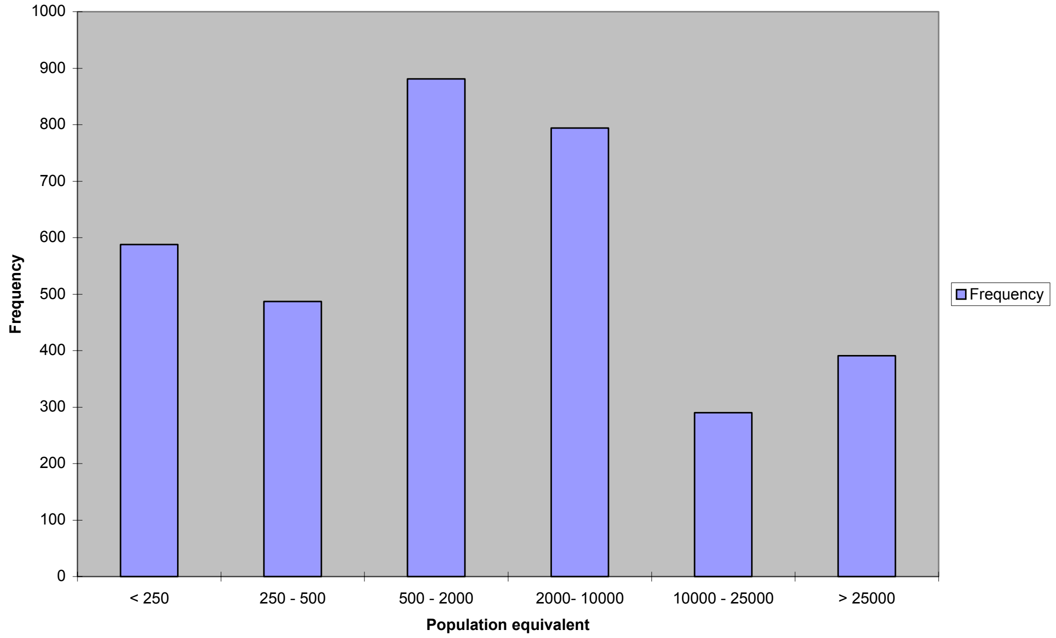
In order to apply the regression results to these data sets various adjustments to the data were undertaken:

- Any WwTW which had descriptive consents or for which there was no population equivalent data was removed.
- For any WwTW with an ammonia consent but no numeric BOD consent, a BOD discharge equal to the average for the data set was assumed.
- For any WwTW with a BOD consent but no numeric Ammonia consent, an Ammonia discharge of 30mg/l was assumed based on expert opinion.

In total 3,701 WwTWs were included, covering a total pe in excess of 60m. From the Ofwat June Return Database the total pe discharged to WwTW in England and Wales in 2001 was 62.7m, indicating good coverage by the data set.

Figure 4 shows the size distribution of WwTWs based on the bands reported in Table 17 of the annual June Returns to Ofwat.

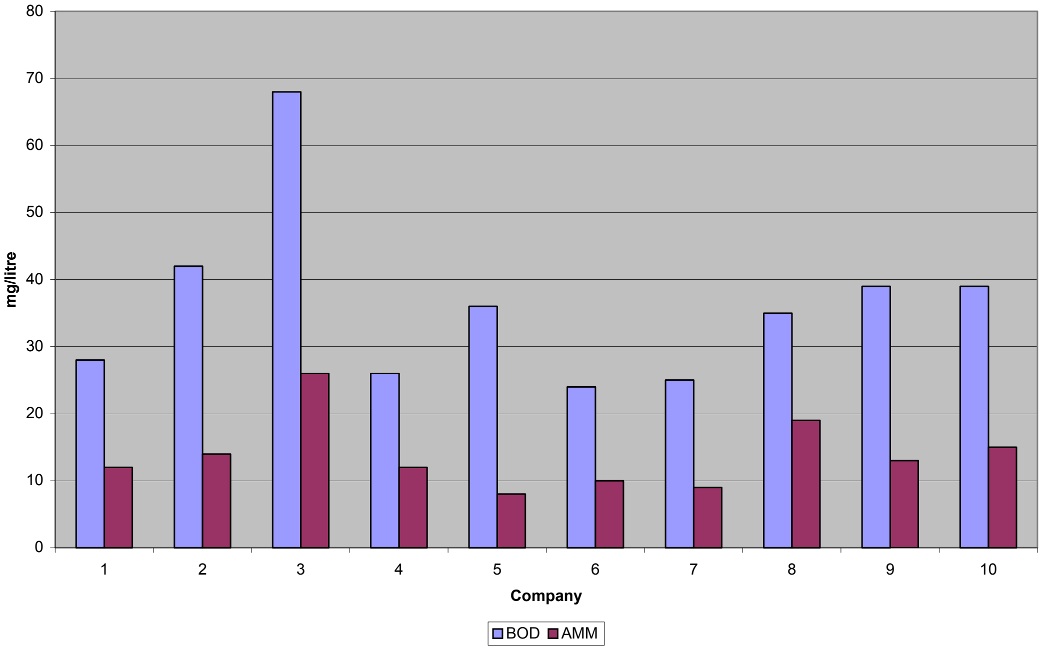
Figure 4: WwTW size distribution in consent database



For inland and estuarine works total pe served was 56.1 million by 3,383 works.

There is considerable national variation in current consent levels. Figure 5 below shows the average BOD and Ammonia consents for each company.

Figure 5: Average current BOD and Ammonia consents by company



It should be noted that the average figures mask an important determinant of consents at the present time, which is whether a works discharges to a river, an estuary or the coast. River consents tend to be tighter than the others' therefore companies with a preponderance of WwTWs on rivers will have higher average consents. However, even without this distinction there is variation across the country in consents. Ideally separate analyses should be carried out for coastal, estuarine and river WwTWs.

Estimated Regression

Specification testing established the preferred model to be highly non-linear, involving quadratic terms and interactions between explanatory variables. Since the objective was to maximise the predictive power of the estimated model, this outcome was preferred to more intuitive models. Figure 6 summarises the preferred model.

Figure 6: Regression model specification

Ln WLC_pe_(£K_per_pe) = b0 + b1*Current_BOD*lnpe*Dummy_<10,000_PE + b2*Dummy_for_current_tight_consents +
b3*Change_in_BOD*Change_in_BOD*lnpe +
b4*Current_Ammonia*Dummy_<10,000_PE*Dummy_for_current_tight_consents + b5*Current_Ammonia +
b6*Current_Ammonia*Dummy_<10,000_PE + b7*Change_in_ammonia*lnpe*Dummy_(10K_to_25K_PE) +
b8*Change_in_ammonia*lnpe*Dummy_for_current_tight_consents

Table 19 presents the estimated regression used to predict costs.

Table 19: Estimated cost regression model

Coefficient	Estimate	Standard Error	T- statistic	P-value
b0	-0.876	0.227	-3.861	0.000133
b1	-0.00835	0.00108	-7.730	1.045e-13
b2	-3.602	0.350	-10.31	4.856e-22
b3	2.416e-05	5.808e-06	4.160	3.969e-05
b4	0.09486	0.01652	5.742	1.966e-08
b5	-0.04977	0.01143	-4.354	1.733e-05
b6	0.03701	0.00949	3.900	0.000114
b7	0.02307	0.00666	3.466	0.000591
b8	-0.02909	0.00772	-3.766	0.000193
R^2	0.525	**F statistic**	50.67	
R^2 adjusted	0.514	**P-value**	<0.0001	

Notes: The dummy variable for existing tight consents was defined as = 1 where current BOD = 20, current ammonia = 20; = 0 otherwise.

Annex 3: Climate Change and Wastewater Treatment Costs in the Great Lakes Region of the United States

The United States Environmental Protection Agency's (EPA) Office of Research and Development has for many years been supporting research on the affects of climate change on water resource management. A study conducted in 2003 examined possible cost impacts of climate change on Total Maximum Daily Load (TMDL) implementation, focusing on Publicly Owned Treatment Works (POTWs) discharging to impaired streams or rivers in the Great Lakes Region (GLR) of the United States. A bounding analysis framework was created that allows the evaluation of various combinations of scenarios for (1) additional treatment associated with TMDL implementation and (2) the effect of climate change on low flows, and how these combinations affect the cost of municipal wastewater treatment at POTWs. This Annex provides a brief overview of this study.

BACKGROUND

A TMDL is the maximum amount of a given pollutant that a waterbody can receive and still meet the water quality standard (WQS) for its designated use. The TMDL is the sum of loadings from point sources, such as POTWs and industrial facilities, and nonpoint sources, such as urban and agricultural runoff, and natural sources. One of the key factors driving a TMDL determination for a stream or river is the amount of water available to assimilate the pollutant load. EPA's guidance for the TMDL program recommends use of the 7Q10, or 7-day, 10-year recurrence interval low flow for a given reach. This flow value is used because it allows for consistency in water quality standards, and it represents a situation where a stream or river is vulnerable to pollution impacts.

The standard wet chemistry analysis for the level of organic matter in wastewater is the 5-day biochemical oxygen demand test (BOD_5). In reaches impaired for low dissolved oxygen (DO), TMDLs are typically specified in terms of BOD_5 loadings. Although in some cases excessive nitrogen or phosphorous loadings may be the driving factor behind DO impairment, this study focuses only on BOD_5.

EFFECT OF TMDLs ON POTWs – "Step 1"

The objective of this study was to estimate the treatment costs, attributable to climate change, of complying with the TMDL program. The scope was limited to a set of POTWs in impaired reaches in the Great Lakes Region of the United States. As the TMDL program is only in its initial stages of implementation, two steps had to be characterized in incremental treatment. Step 1 is the incremental treatment beyond currently required levels (i.e., Best Practicable Technology) associated with implementation of the TMDL program. Step 2 is the incremental treatment, due to climate change, required to meet more stringent TMDLs that account for anticipated reductions in receiving stream flow.

There is currently very little information on BOD_5 TMDLs for POTWs in the United States. Even though there has been significant progress in listing impaired reaches, most jurisdictions have yet to implement mitigation measures, especially those that result in more stringent standards for point sources. Given the diversity of flow, loading, and water quality situations where BOD_5

TMDLs will need to be established, and the variety of wasteload allocation approaches that can be used by individual jurisdictions, it is difficult to determine what effect TMDLs will have on the treatment efficiency of a typical POTW. However, there are some reports on existing TMDLs that provide insight as to the eventual impacts of TMDL implementation on POTWs. None of these accounts for the potential effect of climate change.

A final report entitled *Total Maximum Daily Loads for the Middle Cuyahoga River,* published by the Ohio Environmental Protection Agency in March of 2000, examines TMDLs for several pollutants related to DO and the subsequent effluent changes for POTWs in the middle Cuyahoga River.[22]. This report not only provides an example for high and low bounds, it also demonstrates the importance of stream flow on TMDLs. An EPA report[23] describes the TMDL process for the Christina River Basin. The report details two TMDL allocation scenarios –“level 1” and “level 2” – involving 5 POTWs discharging to reaches within this basin.

Even though information on the effects of the TMDL program on POTW treatment efficiency is quite limited, it is clear that there will be a wide range in terms of incremental efficiency. A bounding analysis approach was used to bracket the likely costs. For the “step 1” load reduction a low end value 12% (the average for POTWs in the Christina Basin for the less stringent scenario in that study) and a high end value of 50% (the reduction required of all POTWs in the Middle Cuyahoga Basin for the more stringent scenario) were chosen.

EFFECT OF CLIMATE CHANGE ON TMDLs – “Step 2”

Within the bounding analysis framework used in this study, Step 1 is the incremental treatment beyond currently required levels associated with implementation of the TMDL program. Step 2 is the incremental treatment, due to climate change, required to meet more stringent TMDLs that account for anticipated reductions in receiving stream flow.

The effect of climate change on streamflows in the GLR is highly uncertain. An EPA website reports that states the GLR may experience an average increase in annual precipitation of 11% (for Minnesota) to 25% (for Illinois) over the next 100 years.[24] Flow is a function of precipitation intensity and frequency, evapotranspiration and infiltration rates, and natural and anthropogenic hydrologic characteristics.

Given the complexity of the interactions, it is not surprising that there are few estimates of the effects of climate change on flows during low-flow conditions. In the bounding analysis framework to estimate the likely range of cost impacts, a low end estimate and a high end estimate of the effect of climate change on 7Q10 were developed. A general characterization of impacts of climate change in the GLR estimated that annual freshwater flows into the Great

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[22] $CBOD_5$ is *carbonaceous* biochemical oxygen demand, as distinct from total biochemical oxygen demand (BOD), which includes both carbonaceous and nitrogenous oxygen demand. BOD and CBOD are the same if there is no degradable nitrogen in the sample analyzed.

[23] US EPA. 2002. *Executive Summary: Total Maximum Daily Loads of Nutrients and Dissolved Oxygen Under Low Flow Conditions in the Christina River Basin, Pennsylvania, Delaware and Maryland*. pp. ix-x.

[24] This number is an average of values for seasonal changes in precipitation for states in the GLR reported by the US EPA on the Global Warming: State Impacts website. http://yosemite.epa.gov/OAR/globalwarming.nsf/content/ImpactsStateImpacts.html

Lakes from streams and rivers could decrease by 20%.[25] This was chosen to represent the low end estimate in the screening analysis.

The most relevant information found was a study by Eheart et al.[26] that specifically investigated climate change impacts on 7Q10 flows. The basin studied in this paper is the Sangamon River upstream of Monticello, Illinois. The results of the study show clearly that climate change is likely to have a significant effect on low-flow conditions, at least for the scenarios studied. When demand for irrigation water is taken into account, the reductions in flow are even more pronounced. Eheart et al. report a 57% reduction for a doubling of the standard deviation of precipitation, which was chosen as the high end value for the bounding analysis.

The bounding analysis assumes that there is a direct linear relationship between streamflow and the BOD_5 TMDL so that a 20% reduction in 7Q10 flow will require a 20% reduction in loading to maintain the same level of water quality. It was also assumed that the reduction in basin-wide TMDL translates directly into a proportional reduction in BOD_5 effluent concentration from POTWs.

RESULTS

The review of TMDL implementation (Step 1) and effects of climate change on streamflow (Step 2) resulted in selection of a low end and high end value for each step. Step 1 provides different scenarios for the reference case where TMDLs are fully implemented; Step 2 shows the effect of climate change. Four scenarios were evaluated, representing the combinations of the four Step1/Step 2 values, as shown in Exhibit 1.

Exhibit 1. Bounding Analysis Values.

Step	Low End	High End
Step 1. TMDL Load Reduction (% with respect to pre-TMDL case)	12%	50%
Step 2. Design Flow Reduction (% with respect to current 7Q10)	20%	57%

To characterize POTW treatment costs under each of the four scenarios, a cost model based on POTW BOD_5 treatment cost data published by the National Research Council (NRC) in 1993 was used, and a series of POTW cost equations published by Syed Qasim in 1996. The cost curves are derived from annual capital cost and operating and maintenance (O+M) cost data published by the NRC for a 20 MGD plant for a range of BOD_5 removal efficiencies. A set of cost equations presented by Qasim were used to scale these curves to reflect different POTW sizes. The cost model simulates annual costs along a continuous range of treatment efficiencies between 85% and 98%, and between a range of POTW design flows from 0.1 to 10 MGD.

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[25] U.S. EPA. *Global Warming - Impacts: Great Lakes.* http://yosemite.epa.gov/OAR/globalwarming.nsf/content/ImpactsWaterResourcesGreatLakes.html

[26] Eheart, et al. 1999. *The Effects of Climate Change and Irrigation on Criterion Low Streamflows Used for Determining Total Maximum Daily Loads*. Journal of American Water Resources Association. 35(6): pp. 1365-1372

To apply the cost curves the current national average level of BOD_5 removal efficiency – 85% – is the pre-TMDL baseline was assumed.[27] The next step was to calculate the reference case (i.e., with TMDL) removal efficiency. The cost model estimates the cost for each POTW, based on removal efficiency and flow, and sums across all POTWs for each scenario. Exhibits 2 and 3 show the results for the region. The cost results are reported with respect to the pre-TMDL baseline, as well as incremental to the TMDL reference case. In the pre-TMDL baseline, annual POTW treatment costs are about $305 million. With TMDLs, costs are predicted to increase by $13 million to $52 million per year (for the low end and high end, respectively).

Exhibit 2. Annual Cost Estimates for Low End TMDL (Step 1), with Low End and High End Design Flow Reductions (Step 2)

	Percent Change in Load (Ref case is wrt BPT; flow cases are wrt ref case)	Percent Removal Efficiency	Annual Cost ($million)	Incremental Annual Cost wrt BPT ($ million)	Percent Cost Increase wrt BPT	Incremental Annual Cost wrt TMDL reference case ($ million)	Percent Cost Increase wrt TMDL reference case
Pre TMDL case: BAT	0%	85.0%	$305	NA	NA	NA	NA
Reference Case: with TMDL Load Reduction (low end)	12%	86.8%	$318	$13	4%	NA	NA
Design Flow Low End: with TMDL Load Reduction	20%	89.4%	$337	$32	10%	$19	6%
Design Flow High End: with TMDL Load Reduction	57%	94.3%	$367	$61	20%	$49	15%

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[27] U.S. EPA. 1998. *Progress in Water Quality*. Office of Water. pg 3. http://www.epa.gov/owm/wquality/index.htm

Exhibit 3. Annual Cost Estimates for High End TMDL (Step 1), with Low End and High End Design Flow Reductions (Step 2)

	Percent Change in Load (Ref case is wrt BPT; flow cases are wrt ref case)	Percent Removal Efficiency	Annual Cost ($ million)	Incremental Annual Cost wrt BPT ($ million)	Percent Cost Increase wrt BPT	Incremental Annual Cost wrt TMDL reference case ($ million)	Percent Cost Increase wrt TMDL reference case
Pre TMDL case: BAT	0.0%	85.0%	$305	NA	NA	NA	NA
Reference Case: with TMDL Load Reduction (high end)	50.0%	92.5%	$358	$52	17%	NA	NA
Design Flow Low End: with TMDL Load Reduction	20.0%	94.0%	$365	$60	20%	$7	2%
Design Flow High End: with TMDL Load Reduction	57.0%	96.8%	$444	$138	45%	$86	24%

The changes in design flow add significantly to the costs of TMDL implementation. At the low end, a 20% reduction in 7Q10 (and commensurate 20% improvement in treatment efficiency) would translate to annual incremental treatment costs of $7 million to $18 million. At the high end (57% reduction in 7Q10), annual costs increase by $49 million to $86 million. The cost results are driven primarily by the increment in treatment efficiency that is required in each scenario. They also reflect the fact that treatment improvements have a higher unit cost at the high end of the range than the low end.

The incremental costs associated with changes in design flow appear significant both in absolute terms (millions of dollars) and relative terms (percentage of pre-TMDL costs). In the scenarios shown here, the TMDL program would increase POTW costs by about 4 to 17 % over current levels. Incremental costs to keep pace with reduced flows add another 2 to 24%.

Annex 4: Example of Decision Support Framework for CSO Spills

Task

CSO spill event frequency to meet standards

---Baseline---

Do catchment CSOs meet current standards?
- Spill Frequency
- Water Quality

What are the main drivers of CSO spill events? How are they changing spill likelihood?
- Urban hydrology
- Climate
- Connectivity of sewer to catchment
What monitoring occurs and are there key information gaps?

What is asset renewal plan for current CSO infrastructure?

What is asset renewal plan for connected catchment stormwater infrastructure?

--Planning---

How might future standards change?
- WFD
- Climate change

Given trends and forecasts, will existing stormwater infrastructure and CSOs meet future standards? If not, when might they fail?

What are the options for mitigating impacts and costs?

What demand will infrastructure need to account for over its life span? When will it need to meet what capacity?

What works will need to be done anyway to meet non climate change impacts, when, and what extra will need to be done to mitigate against climate change impacts? Does long life infrastructure need to account for climate change now or is it feasible to allow options for retrofitting capacity in the design?

--Strategy Questions---

Which entities have influence, responsibility and accountability for catchment objectives?

For key infrastructure, how is trend and climate change information currently feeding into decision making processes?

When will decisions to change CSOs have to be made?

What monitoring is required to detect change and measure project success?