Inland Waterways Advisory Council

CLIMATE CHANGE MITIGATION AND ADAPTATION

IMPLICATIONS FOR INLAND WATERWAYS IN ENGLAND AND WALES

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What is the Inland Waterways Advisory Council (IWAC)?

IWAC is a statutory public body providing independent advice to the UK Government, Scottish Government, navigation authorities and other interested parties on all matters it considers appropriate and relevant to Britain's inland waterways.

IWAC was created in April 2007 by the Natural Environment and Rural Communities Act 2006. Its predecessor organisation was the Inland Waterways Amenity Advisory Council which was created in 1968. IWAC is supported by the Department for Environment, Food and Rural Affairs (Defra) and the Scottish Government.

In England and Wales, IWAC's remit covers all of the inland waterways such as:

- canals (including those managed by British Waterways, canal companies, local authorities and smaller independent bodies);
- rivers (including those which are the responsibility of the Environment Agency, British Waterways and port authorities);
- the Norfolk & Suffolk Broads; and
- the navigable drains of the Fens.

In Scotland, IWAC's remit covers inland waterways that are owned or managed by, or which receive technical advice or assistance from, British Waterways.

What is IWAC's role?

IWAC's role is to ensure that the inland waterways are developed sustainably to meet the needs of all who use and enjoy them. Once used mainly for freight transport, inland waterways now have a strong recreational and amenity use. They are an effective catalyst for the regeneration of local economies, acting as a distinctive focus to bring economic, social and environmental benefits to cities, towns and rural communities.

IWAC has published reports which include: balancing the needs of navigation and aquatic wildlife, awareness and appreciation of the canal network in Scotland, information and communication technology for the UK's inland waterways plus reducing carbon dioxide emissions by moving more freight onto inland waterways.

IWAC's work programme for 2009/10 includes:

- research into the benefits of inland waterways (in partnership with Defra);
- reports on:
  - using inland waterways to combat the effects of social exclusion;
  - implications for inland waterways with regard to climate change mitigation and adaptation;
  - revenue arrangements for a selection of overseas inland waterways;
  - funding and income arrangements for British inland waterways;
- monitoring of:
  - inland waterway use at the London Olympics site.

All IWAC reports are produced under the supervision of a Project Steering Group comprising Council members and IWAC staff. Details of the Project Steering Group for this report are given in Section 15.

More about IWAC

Please visit our website at www.iwac.org.uk for further information about IWAC and to see copies of its reports.

Contents

Summary

In 2009, IWAC received a grant from Defra to research and publish evidence of how inland waterways in England and Wales can assist in mitigating for and adapting to the effects of climate change. Current projections suggest that, by 2080, changes in climate will occur that will affect inland waterways and their management. Changes may include greater winter rainfall, drier summers, higher temperatures and more frequent extreme weather events. Secondary effects may include changes in sediment run-off, transport and accumulation and changes in flora and fauna.

This scoping report highlights the 'most likely' impacts of climate change and the potential consequences for inland waterways in England and Wales. It then identifies and assesses a range of potentially appropriate measures through which:

- changes in use of the waterways could contribute to reducing the extent of climate change (mitigation); and
- management of waterways may be modified to prepare for the anticipated effects of climate change (adaptation).

The report reaches the following conclusions.

The main mitigation opportunities are through reducing emissions of carbon dioxide by:

- increasing the amount of freight transported on the waterways instead of by road;
- reducing energy use associated with waterway infrastructure (including use of waterways as heat sources or sinks for heating or cooling adjacent buildings);
- developing renewable energy sources, such as hydropower; and
- reducing vessel emissions through improved design and improved practice by users.

Adaptation for the effects of changes in rainfall may involve:

- improved systems for collection and analysis of hydrological data to help plan for anticipated drier summers and wetter winters;
- adapting structures to accommodate greater flood flows and increased water levels;
- improved advice to users on 'Strong Stream' conditions and provision of safe havens;
- water conservation and storage to provide for navigation needs in dry summers.

Adaptation for the effects of changes in sedimentation may involve:

- limitation of sediment inputs from land by use of buffer strips and silt traps;
- encouragement of better design of boat hulls (eco-hulls) to reduce bank erosion;
- optimising dredging methods and timing to protect water quality and ecology.

Adaptation for the effects of increases in temperature may involve:

- changes in management of bankside and aquatic habitat in response to increased plant growth and a need to minimise the spread of alien species;
- steps to maintain adequate concentrations dissolved oxygen to support aquatic life;
- accommodation of increased demand for recreational use of waterways.

The boxes below provide a more detailed summary of each section of the report.

Climate change projections

Under a 'low emissions' scenario for greenhouse gases, current climate change projections suggest that by 2080, England and Wales might expect:

- an increase in precipitation, mainly in winter, of around 15%;
- a decrease in summer precipitation of up to 30%; and
- an increase of some 2^{o}-3^{o}C in average annual temperature.

These changes are likely be accompanied by an increase in water temperature and changes in sedimentation; sea levels will rise and there may be a greater frequency of extreme events.

Beyond 2080, there is the potential for more fundamental changes, notably associated with predicted sea level rise. This report does not explore climate change scenarios beyond 2080.

Understanding climate change mitigation and adaptation

There is now little doubt that climate change is happening. If the worst effects of global warming are to be avoided, it is vital for all sectors to take steps to reduce their greenhouse gas emissions. Measures which reduce a sector's contribution to the climate change problem are referred to as mitigation measures.

Whilst mitigation measures might help to lessen the scale of the problem, some impacts of global warming are now inevitable. Adaptation will therefore be essential. Adaptation measures help society prepare for and adapt to the anticipated effects of climate change by reducing vulnerability and increasing long-term resilience.

There are a number of different types of adaptation measure:

- 'no regrets' measures, which would provide benefits irrespective of the particular climate change scenario and which may also contribute to meeting other environmental objectives;
- adaptive management, which uses data and risk-based assessments to inform decisions on existing or new operations and management activities, enabling them to evolve to take account of climate change effects;
- 'win-win' opportunities, measures which meet dual objectives and may, for example, allow costs to be shared between benefiting organisations;
- longer term measures designed to provide efficient and cost-effective solutions to climate-induced problems but requiring further research or investigations before implementation; and
- 'regrets' measures, often irreversible measures which could prove counter-productive and should be avoided.

Context and methodology

In addition to the various navigation authorities in England and Wales, many other players have interests in inland waterway management and could be affected by the consequences of climate change. Of particular importance are flood defence and water resources. The EC Water Framework Directive (WFD), which introduces a new more integrated approach to water management, is also relevant because some climate change adaptation measures will also contribute towards meeting WFD objectives.

This scoping exercise collated information on a wide range of potential mitigation and adaptation measures from a variety of UK and international organisations. Whilst there are examples of actions being undertaken by British navigation authorities, some of the initiatives underway elsewhere in Europe and in North America are also of particular relevance to this report.

Reducing emissions from the inland waterways sector

Whilst the contribution of the England and Wales inland waterways sector to the overall problem of global warming is very small, urgent action is required across all sectors to mitigate the effects of climate change. The recent UK Climate Change Act requires a 26% cut in Britain's carbon dioxide emissions by 2020, and an 80% cut in all greenhouse gas emissions by 2050 (both relative to 1990 total emissions).

For the inland waterways sector, there is no panacea. Individually, many of the measures identified will make only a small difference. A combination of measures will therefore need to be implemented if the sector is to achieve a meaningful reduction in greenhouse gas emissions.

This report identifies many different measures for reducing emissions from vessels. Some, such as engine use/speed, depend for their effectiveness on the behaviour of individuals. Others would require action by Government or by navigation authorities (e.g. new standards for marine engines or the provision of electricity hook-ups using energy from a renewable source). Many measures could be promoted using incentives - for example, licence fees might be reduced for vessels meeting certain emissions or design criteria. Freight Facility Grants and Waterborne Freight Grants might similarly be made conditional on meeting emissions targets. Such potential incentives require further investigation.

Many of the measures highlighted in the mitigation section of the report rely directly or indirectly on changes in behaviour or perception. An education and awareness-raising campaign, undertaken in partnership with a range of user groups, could thus be a useful 'no regrets' measure - particularly if this exercise could also cover some of the adaptation requirements discussed in later sections. New and ongoing research and development initiatives will also be important, both to further develop alternative energy sources and to improve the efficiency of engines and vessel design.

Insofar as emissions associated with inland waterways infrastructure are concerned, many authorities have already started to move towards general 'good housekeeping' measures. However, the report has also identified a number of options whereby authorities might both contribute to a reduction in emissions and save money. In addition to generating energy locally or using energy from renewable sources, for example by developing low-head hydropower facilities or installing wind turbines on waterway land, it may be possible for some authorities to exploit opportunities for using water bodies as a source of heating or cooling. Such opportunities require investigation at a site-specific level.

Finally, moving more freight onto the principal inland freight waterways of England and Wales has the potential to result in a significant reduction of CO_2 emissions. This shift from road to water should therefore continue to be actively promoted.

Adapting to increased (seasonal) precipitation

A possible consequence for inland waterways of the projected increase in winter precipitation may be an increase in the frequency of high flow, flooding and 'Strong Stream' conditions. Reduced waterway channel freeboard and associated lack of operating headroom could similarly compromise safety of navigation. High water levels and flood flows can threaten the integrity of navigation infrastructure through seepage, overflow or erosion and the capacity of culverts, weirs and sluices might be reduced. Safety considerations are therefore likely to be a paramount consideration for inland navigation authorities.

In preparing to respond to projected increases in winter precipitation, however, it is important to be aware that it is not a case of 'one size fits all'. The particular measures required on an individual stretch of waterway will depend on site specific factors. Monitoring and effective data management will therefore be critical, if well-informed decisions are to be made on which measures are most appropriate and when they are required.

Installing or updating telemetry and SCADA (supervisory control and data acquisition) systems, generating a targeted long-term dataset and undertaking regular risk assessments are likely to be important actions for all navigation authorities. Only by collecting and managing relevant data will authorities be able to understand the actual impacts of climate change and adapt in a timely and cost-effective manner.

Depending on the particular characteristics of an inland waterway and its users, a number of adaptive management measures may then be required in response to increased seasonal precipitation. Thresholds may need to be reviewed or set to establish when Strong Stream or other warnings (e.g. lack of headroom) should be issued. The most effective means of communicating such warnings to users should be identified.

Initiatives may also be required to raise awareness amongst users about how to respond to such warnings - including the possibility of closure of the navigation. Over time, it may become apparent that further adaptive management measures are needed - for example the provision of additional temporary moorings or safe havens.

Insofar as the maintenance, modification or replacement of existing infrastructure is concerned, regular inspections will be vital to ensuring the continuing integrity (condition, capacity and resilience) of physical assets including embankments, culverts, weirs, tunnels, locks and sluices. The information thus collected will help to inform site-specific decisions on whether and when bank-raising or other strengthening or retro-fitting actions are required. Any works to replace or construct new physical assets should also be 'future-proofed' so that their design takes into account the projected effects of climate change. Working in partnership with the Environment Agency will enable the navigation authority to understand any role of navigation infrastructure in flood risk management - for example flood flow conveyance.

Finally, given the predicted reduction in summer rainfall, it may be appropriate in some inland waterway systems to explore whether increased winter precipitation can be stored so as to provide a water resource during the summer months. If such a need for additional water storage is identified, possible 'win-win' initiatives which also meet flood defence, agricultural, or nature conservation objectives should be investigated.

Adapting to reduced summer precipitation

Two key areas of concern arising from the projected reduction in summer rainfall relate to any increase in the frequency of low flow conditions particularly in natural rivers, and the possibility of water shortages affecting the supply for canals. The Environment Agency, for example, predicts that by 2050 average summer river flows in England and Wales could reduce by as much as 50 to 80 per cent.

Monitoring and data management will be essential in enabling inland navigation authorities to begin to adapt to the implications of reduced summer rainfall. Establishing the viability of navigation, ensuring effective communication of warnings and managing user expectations in the event of a navigation closure will similarly be important.

The need to secure a long-term supply of water for navigation will require affected navigation authorities both to prepare their own water resources, conservation and use strategies (i.e. understanding and setting out their requirements) and to become involved in others' strategic water planning initiatives, for example the preparation and review of river basin management plans under the Water Framework Directive.

Navigation authorities could introduce a variety of practical 'no regrets' steps to conserve water, for example undertaking maintenance so as to prevent leakage and losses, improving the management of locks, sluices and weirs to conserve water and preparing or updating Codes of Practice to help ensure user understanding.

If conditions worsen, however, more frequent use of measures such as obligatory lock-sharing or navigation restrictions or closures may be required. Other longer-term measures, potentially including incentives to encourage users to use less water-stressed parts of the network, require further investigation.

Low water levels can threaten the integrity of navigation infrastructure (for example through removal of hydraulic support from the waterside face). Asset monitoring and maintenance will thus be vital, as will future-proofing any modifications and new infrastructure.

Reduced precipitation and associated low flow conditions can have significant consequences for aquatic ecology. Whilst navigation may not be the cause of the problem in such situations, it will nonetheless be important to ensure that navigation-related activities do not exacerbate the situation. 'No regrets' measures such as awareness-raising (amongst both navigation personnel and users) should be used in the first instance but other measures may sometimes become necessary - for example releasing stored water or holding water to maintain levels, operating locks and sluices to improve aeration or placing constraints on dredging or on boating activity to avoid compounding dissolved oxygen problems.

Adapting to changes in sedimentation

Changes in the frequency and duration of severe weather events could have implications for sediment run-off, for sediment transport and for deposition or accumulation. The risk of groundings might therefore increase and there may also be a reduction in capacity (for example in storage reservoirs). Depending on their severity, such changes could have implications for the safety of navigation and for navigation authority operations such as dredging, as well as for biodiversity and the wider environment.

Where problems with sediment in run-off are identified and the inland navigation authority is the owner of the offside or riparian land, the authority may be able to create buffer strips, reed beds or similar as a 'no regrets' measure to intercept run-off and hence reduce the amount of sediment (and possibly associated pollution) entering the watercourse. In other cases, a partnership approach with relevant farmers or conservation organisations might allow a 'win-win' solution to be identified.

Another source of sediment input is the erosion of the river or canal bank at the waterline. Like buffer strips, 'green engineering' bank protection, such as willow spiling, plant rolls and coir revetments, can help to stabilise the bank and minimise erosion. Such measures can be considered 'no regrets' measures if bank protection is already required; otherwise they become an option for adaptive management. Depending on site-specific requirements, additional measures to prevent erosion due to boat wash may be needed. Vessel speed restrictions can help to limit wash, and thus erosion, and the use of vessels with eco-hulls can similarly reduce wash. Assuming voluntary measures are preferred to additional regulation, this is another area in which user education may be of value.

Where sediment has accumulated in a water body and monitoring indicates a risk to navigational safety, additional dredging might be required. As dredging can in turn have adverse environmental impacts, local factors will need to be considered to assess whether there is a viable alternative to dredging. If no such alternative exists, steps should be taken to optimise the timing and method of dredging, in order to protect water quality and ecology.

Removal of accumulated sediment from water storage reservoirs is a laborious and expensive process. Where monitoring indicates a potential problem, preventative measures such as buffer strips and silt traps should be investigated as adaptive management options. If sediment accumulates to such an extent that the capacity of the reservoir is compromised, it may be necessary to seek an alternative water resource.

Adapting to an increase in air temperature

As well as exacerbating water resource shortages, the additional evapotranspiration associated with higher air temperatures could lead to drying out and fissuring of clay embankments and other earth structures. It might also cause changes in characteristic vegetation types. Warmer summers may result in an extended growing season with consequences for vegetation management and there may be changes in land-use practices in areas adjacent to waterways.

Regular monitoring and condition assessments will be essential 'no regrets' measures, where navigation infrastructure could be affected by fissuring, settlement, erosion or undercutting. Vegetation loss or change could similarly affect structural integrity where the vegetation serves an engineering purpose, for example, if the characteristic root mat is lost, a structure potentially becomes more vulnerable. Collecting information on such potential problems will allow early consideration of adaptive management solutions.

Warmer temperatures may have other implications for vegetation management, including a requirement for more frequent cutting or clearance and the possible need for new measures to deal with alien or invasive species. Again, monitoring will be essential in informing appropriate management responses.

Warmer and drier British summers might be expected to make domestic holidays and recreation relatively more attractive - particularly when taking into account the expected increase in the frequency of intense heatwaves in the Mediterranean area. Whilst this might represent a significant opportunity for the tourism industry, it could also pose additional challenges for inland waterway managers. As discussed throughout this report, climate change is likely to result in a number of pressures on inland waterways and associated infrastructure - pressures which could be exacerbated if recreational use of both the waterway and the towpath increases. Inland navigation authorities will therefore need to be vigilant: monitoring such changes, assessing their implications and participating in relevant strategic planning and management initiatives. Local factors will determine the most appropriate management options for both water and towpath or land-based recreational activities.

Finally, in situations where increased demand means that new infrastructure or facilities are required, care must be taken to ensure that designs are both 'future-proofed', in terms of projected climate change impacts, and sustainable.

Adapting to an increase in water temperature

The raised water temperatures which it is assumed will result from increased air temperatures could create a number of (mainly indirect) problems for inland waterways.

Higher water temperatures, especially if combined with low flow conditions, can cause a reduction in dissolved oxygen, upon which much aquatic life depends. Warmer waters can also increase the growing season, providing conditions suitable for the proliferation of both water plants and algae, and there may be shifts in species' distribution, including both alien species and certain types of fish. Changes in human use of water bodies might also be anticipated, not least swimming and water contact sports - with their attendant potential health risks, particularly if rat populations also increase.

Depending on the scale of any problem and the particular local characteristics, various measures might need to be considered to enable the sector to adapt.

If monitoring identifies problems with oxygen depletion that appear to be associated with activities such as dredging or vessel movement, it may be necessary to aerate the affected water body or to constrain the activities which are causing or exacerbating the situation. Where toxic algal blooms are identified, warning notices may need to be posted or certain areas fenced off.

If aquatic weed growth forms thick mats which affect navigation use, clearance may be required. Monitoring will help to inform decisions on how and when such works should be undertaken.

Inland waterways and associated riparian zones can act as important migration corridors for wildlife. In addition to seeking 'win-win' opportunities for habitat creation, navigation authorities should ensure that maintenance works are undertaken in an environmentally responsible manner and that navigation does not exacerbate the spread of invasive or alien species. Research is required to understand better the vectors for transport of such species and guidance for users may then need to be prepared.

Insofar as human uses of navigable water bodies are concerned, local factors may mean it becomes appropriate to promote awareness-raising activities, to develop and implement a zoning policy, or to prepare an integrated management plan. In some cases, it may be necessary to resort to by-law enforcement to resolve conflicts between incompatible uses.

Conclusions

Some degree of climate change now appears inevitable, with associated increases in winter precipitation, reductions in summer rainfall, changes in sediment regimes and increased air and water temperatures. The extent and speed of such changes, and hence the magnitude of associated impacts, will depend in part on the success of mitigation measures to reduce greenhouse gas emissions. Action on mitigation is urgently needed.

Adaptation measures to increase resilience and make inland waterways better prepared to deal with the effects of climate change, will also become necessary. Whilst consideration may need to be given to modifying or replacing certain operations, assets, infrastructure etc., some such decisions will not have to be taken for several years. In the meantime, however, measures to collect, retain and manage high quality, locally relevant data, to monitor change and to improve understanding are required, in order to provide vital information to inform decision-making.

Such data will also be needed to enable navigation authorities and others to future-proof ongoing operations and new developments, so that they can withstand the projected changes in precipitation, temperature and sedimentation.

Many of the mitigation and adaptation measures described in this report could most effectively be delivered by encouraging behavioural changes. Educating users both about the implications of their actions and how modifying their behaviour can help to save both money and the planet can be an effective way of achieving shared objectives. Such awareness raising initiatives would best be undertaken through a coordinated approach involving a number of partner organisations (e.g. British Marine Federation, Royal Yachting Association, Inland Waterways Association, British Canoe Union and others).

Another important method of delivering climate change adaptation will be through strategic planning. The requirements of inland waterways under a scenario of climate change can be highlighted in or delivered through the preparation of a water strategy or via participation in a third party strategic planning exercise, for example the Environment Agency's Water Framework Directive river basin management plans. The opportunities for additional recreational use of both water areas and towpaths arising from increased air and water temperatures can similarly be included in more local integrated planning and management initiatives, prepared in partnership with stakeholders as appropriate.

The scoping report identifies a number of other potential opportunities for inland waterways to help mitigate or adapt to the effects of climate change. These include options for the generation of renewable energy, the promotion of freight movement by water and the identification of 'win-win' measures which meet not only navigation but also flood risk management, nature conservation or agricultural objectives.

The way forward

This scoping report confirms that the only realistic way for the inland waterways sector to make a meaningful contribution to reducing its greenhouse gas emissions will be through a combination of different, often local or small-scale measures. Inland navigation authorities in England and Wales, supported by the Association of Inland Navigation Authorities (AINA) where necessary, should therefore start now to:

- review the range of available mitigation measures and opportunities;
- determine which measures/opportunities are potentially most appropriate; and
- commence a programme of implementation of such measures.

Navigation authorities should consider how best to influence or assist both their users and other stakeholder organisations in taking action to reduce emissions across the wider sector. Possible priority joint initiatives in this respect might include:

- working with IWAC, UK Government and industry as appropriate to develop and promote new emissions standards and to promote freight movement by water; and
- working with AINA and a range of user and stakeholder groups to develop and promote a climate change education and awareness raising campaign to cover both mitigation and adaptation measures.

Amongst the 'no regrets' measures identified by this scoping report, arguably the most essential action for inland navigation authorities is to establish an appropriate monitoring regime. Navigation authorities in England and Wales (supported by IWAC and AINA as appropriate) should therefore begin, at a proportionate level, to:

- investigate and install or improve telemetry, SCADA or other systems for monitoring, data collection and information management;
- build capacity within their organisation to understand and be prepared to respond to the effects of climate change; and
- undertake risk-based assessments, set thresholds for action and investigate the most effective and reliable means of communicating operational changes, restrictions and warnings to users.

Navigation authorities and others intending either to modify or replace assets, or to undertake new development or restoration projects, should future-proof such initiatives to improve their resilience to the effects of projected climate change.

Where inland waterways depend for their operation on a reliable water resource, the responsible authorities should take early steps to:

- identify and implement a suite of appropriate water conservation measures; and
- where appropriate, develop a water resources, conservation and use strategy.

In all the above, synergies with the measures required under the Water Framework Directive should be explored and promoted.

Many of the ‘no regrets’ and ‘win-win’ measures identified in this report depend on (or would benefit from the involvement of) other organisations. Measures most likely to benefit from early attention include:

- working with AINA and user groups to develop and promote a climate change education and awareness raising campaign (see above);
- working with Environment Agency and others to optimise data collection and management; and
- where appropriate, preparing integrated water and/or land management plans.

Finally, there are several areas where ongoing or new research is required. The UK Government, IWAC, navigation authorities, AINA and other relevant partner organisations as appropriate should therefore support measures that seek to:

- develop alternative fuels/sources of energy, including bio-fuels, alternative energies, hybrid engines, fuel cell technology, low energy hull design;
- explore options for improving the resilience of assets and infrastructure, including use of (drought-tolerant) vegetation in engineering;
- investigate alternatives or improvements to avoid or minimise the adverse effects of dredging;
- improve innovation in water conservation;
- identify new water resources and storage opportunities;
- research and promote additional measures to reduce sediment contained in run-off from reaching water bodies;
- improve understanding of the carrying capacity of natural systems, and of water-ecology interrelationships;
- improve understanding of vectors for transfer of alien species and methods for the management or eradication of alien species; and
- explore and exploit ‘win-win’ options for habitat creation or restoration schemes.

Section 1 Introduction

In 2009, the Inland Waterways Advisory Council (IWAC) received a grant from the Department for the Environment, Food and Rural Affairs (Defra) to research and publish evidence of how inland waterways in England and Wales can assist in mitigating and adapting to the effects of climate change.

In accordance with the Terms of Reference and the proposal submitted to and accepted by IWAC in January 2009, this comprehensive scoping report firstly investigates current climate change projections.

Section 2 documents the 'most likely' impacts of climate change and goes on to provide an overview of the potential consequences, up to 2080, for inland waterways in England and Wales.

In Section 3, for clarity, the report discusses what is meant by mitigation and adaptation measures respectively.

Section 4 of the report provides a brief overview of the England and Wales inland waterways sector and highlights some of the important inter-relationships with other water management functions, particularly taking into account the objectives of the EU Water Framework Directive.

The methodology used in compiling this scoping report is then discussed, and the outcomes of an international literature search and review are summarised.

Section 5 of the scoping report discusses the need to reduce greenhouse gas emissions and provides an overview of a range of potential measures to assist the inland waterways sector in mitigating the effects of climate change.

Sections 6 to 10 then discuss respectively the practical implications of, and a range of measures to help adapt to the following anticipated effects of climate change:

- increased seasonal (winter) precipitation;
- reduced summer precipitation;
- changes in sedimentation;
- increased air temperatures; and
- increased water temperatures.

Section 11 draws conclusions in respect of the above, and Section 12 provides some suggestions as to a way forward. References and a glossary are then provided, and **Appendix 1** provides a further breakdown of current climate change projections.

Inland waterways in England and Wales range from larger river and tidal navigations to the narrow canals of the Midlands

Section 2 Climate change scenarios

Key findings

Under a 'low emissions' scenario, current climate change projections suggest that by 2080, England and Wales might expect:

- *an increase in precipitation, mainly in winter, of around 15%;*
- *a decrease in summer precipitation of up to 30%; and*
- *an increase of some 2°-3°C in average annual temperature,*

These changes are likely be accompanied by an increase in water temperature and changes in sedimentation; sea levels will rise and there may be a greater frequency of extreme events.

Beyond 2080, there is the potential for more fundamental changes, notably associated with predicted sea level rise. This report does not explore climate change scenarios beyond 2080.

2.1 Introduction

Since the Intergovernmental Panel on Climate Change (IPCC) was established by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) in 1988, various global, regional and local models have been set up and many detailed investigations undertaken to try to understand better and describe what is likely to happen to world climate and how different countries will be affected. Within the UK, Defra (as the original lead Government Department responsible for climate change) has produced a series of scenarios including United Kingdom Climate Impacts Programme 2002 (UKCIP02) and more recently work on the new *UK Climate Change Projections* due to be published in late spring 2009 (work until recently referred to as UKCIP08).

This scoping report does not analyse or challenge these scenarios. Rather it seeks to use the range of climate change impacts predicted for England and Wales to develop an understanding of the 'most likely' consequences for inland waterways. It then goes on to highlight the range of mitigation and adaptation measures that may need to be considered by inland navigation authorities, waterway users and other stakeholders.

2.2 Climate Change Predictions

UKCIP08 is the fifth generation of climate change models produced for the UK Government by the Met Office. These models have been progressively improved to represent the predicted changes and provide better information in terms of spatial and temporal impacts. Whilst other climate change models give differing results at a local scale, changes based upon a 5km square grid can now be made compared with the 50km square grid originally adopted.

Within the UK, the Met Office's Hadley Centre has developed modelling techniques to understand these variations and has developed projections to build a probability model of different climate outcomes.

Based on these Met Office predictions, it appears that England and Wales can expect, by 2080, an increase of some 2°-3°C in average annual temperature, an increase in winter precipitation of around 15% and a decrease in summer precipitation of up to 30%, under the 'low emissions' scenario for greenhouse gases.

Likely regional differences are illustrated on **Table 2.1** and the full range of variation (looking at estimates for 2020, 2050 and 2080 based on high and low emissions scenarios) is attached at **Appendix 1**. The high emissions scenarios indicate an additional rise of up to 3°C in average annual temperature but, in the case of precipitation, a doubling in the reduction of summer rainfall.

The potential measures described in this report therefore assume changes of the nature and magnitude indicated. In the event that the changes are larger than anticipated, the impacts may well be more severe in terms of flooding or drought, but their likely impact on the waterways will still be to increase the frequency of events such as Strong Stream, high water levels and low flow.

Finally it is worth noting that, beyond 2080, there is the potential for more fundamental changes, notably associated with predicted sea level rise (IMechE, 2009). Insofar as adaptation to climate change is concerned, it is important to be aware that this report deals only with the nature and magnitude of change predicted to occur in the next seventy years or so.

Based on these figures, and whilst there may be other local implications (for example associated with an increase in storminess or other extreme events or the predicted rise in sea level), it seems likely that the main consequences of projected climate change for inland waterways in England and Wales will be associated with some combination of the following:

- increased (mainly winter) precipitation;
- reduced summer precipitation;
- associated changes in sediment regimes;
- increased air temperature; and
- associated increased water temperature.

The practical implications of each of these changes, along with the various adaptation measures which might be required to increase the resilience of the inland waterways network are discussed in later sections of this report.

Table 2.1 Projected changes by 2080 based on low emissions scenario

Region	Annual temperature	Summer precipitation	Winter precipitation
East Midlands	+3°C	-30%	+15%
East of England	+3°C	-30%	+15%
London	+3°C	-30%	+15%
North East	+2°C	-30%	+15%
North West	+2°C	-30%	+15%
South East	+3°C	-30%	+15%
South West	+3°C	-30%	+15%
West Midlands	+3°C	-30%	+15%
Yorkshire and The Humber	+3°C	-30%	+15%
Wales	+2°C	-30%	+15%

Source: UKCIP02

Section 3 Climate change consequences and mitigation/adaptation measures

<u>Key findings</u>

There is now little doubt that climate change is happening. If the worst effects of global warming are to be avoided, it is vital for all sectors to take steps to reduce their greenhouse gas emissions. Measures which reduce a sector's contribution to the climate change problem are referred to as mitigation measures.

Whilst mitigation measures might help to lessen the scale of the problem, some impacts of global warming are now inevitable. Adaptation will therefore be essential. Adaptation measures help society prepare for and adapt to the anticipated effects of climate change by reducing vulnerability and increasing long-term resilience.

There are a number of different types of adaptation measure:

- *'no regrets' measures, which would provide benefits irrespective of the particular climate change scenario and which may also contribute to meeting other environmental objectives;*
- *adaptive management, which uses data and risk-based assessments to inform decisions on existing or new operations and management activities, enabling them to evolve to take account of climate change effects;*
- *'win-win' opportunities, measures which meet dual objectives and may, for example, allow costs to be shared between benefiting organisations;*
- *longer term measures designed to provide efficient and cost-effective solutions to climate-induced problems but requiring further research or investigations before implementation; and*
- *'regrets' measures, often irreversible measures which could prove counter-productive and should be avoided.*

3.1 Consequences of climate change

There is now general international agreement that climate change is happening albeit that likely regional variations are easier to predict in some parts of the world than others. All countries and all sectors need to act if the worst effects of global warming are to be avoided. The inland waterways sector must therefore take steps to mitigate its own contribution to global warming and a range of measures for so-doing is discussed in Section 5. However, the sector must also be realistic.

Climate change is happening; it is a fact that can no longer be ignored. Europe needs to take measures to address global warming and try to prevent possibly catastrophic changes to the climate (EC, 2008a).

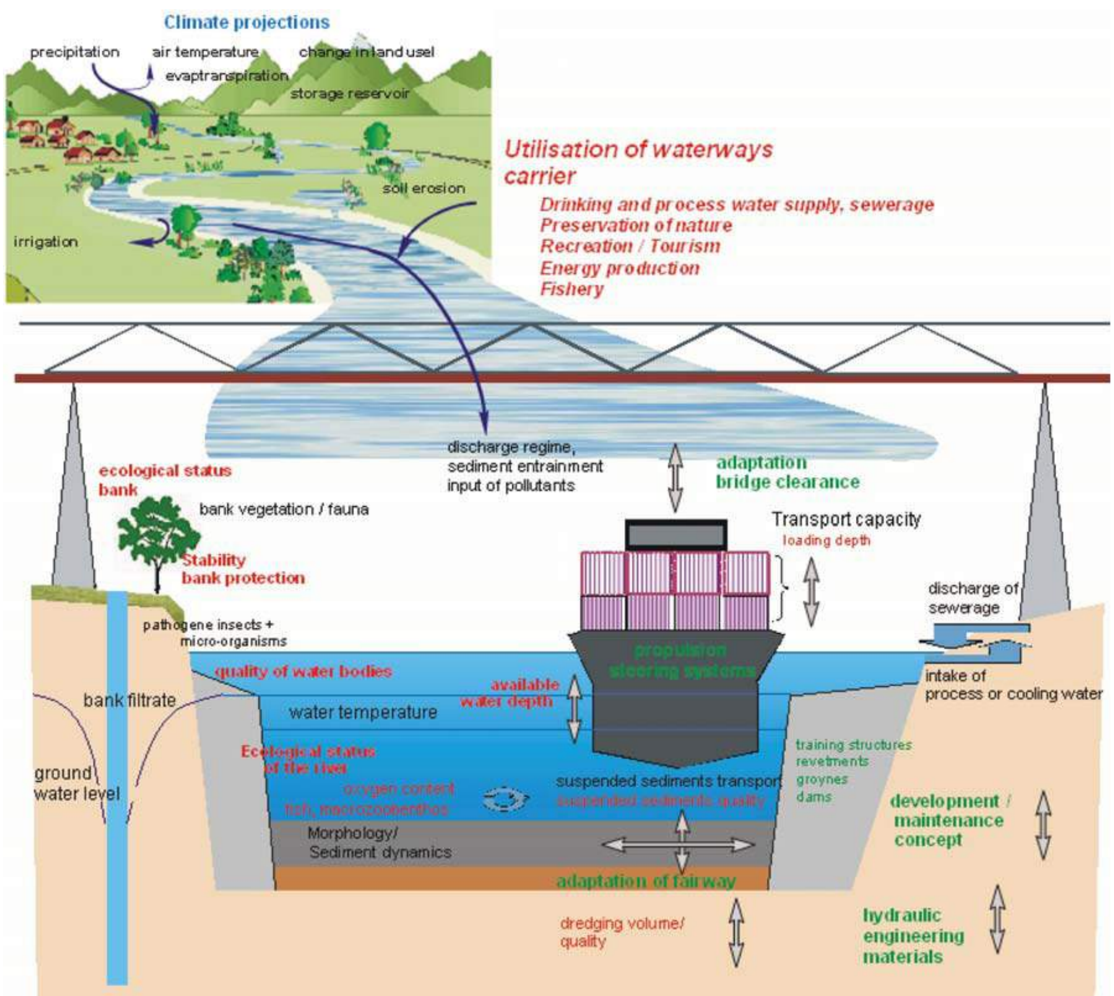
The best available scientific evidence based on observations from long term monitoring networks indicates that climate change is occurring (USGS, 2009).

In addition to the growing acceptance that climate change is happening, there is also an increasing recognition that mitigation measures will only go so far towards reducing the effects of greenhouse gas emissions. Adaptation will therefore be vital. Navigation authorities and others with responsibility for or interests in inland waterways in England and Wales therefore need to respond to a number of operational, safety and environmental challenges as well as taking a lead in encouraging behavioural change.

The Institution of Mechanical Engineers, like many other organisations, has a strong belief that we need to reduce CO_2 levels to secure long term human survival. However, we are also realistic enough to recognise that global CO_2 emissions are not reducing and our climate is changing - so unless we adapt, we are likely to face a difficult future. (IMechE, 2009)

Figure 3.1 usefully illustrates some of the many interactions between climate change and inland waterways.

Figure 3.1 Links between drivers of change and potential impacts on inland navigation



Source: PIANC (2008). Waterborne transport, ports and waterways: a review of climate change drivers, impacts, responses and mitigation (Figure courtesy of German Federal Institute of Hydrology).

3.2 Defining mitigation and adaptation

There appears to be some confusion in the climate change literature as to what is meant by mitigation. For the purpose of this report, mitigation measures and adaptation measures have been defined as follows.

Mitigation: measures to reduce the contribution of the inland navigation sector to the climate change problem.

Adaptation: measures to reduce the vulnerability of the sector and to increase the resilience of natural and human systems and infrastructure, so that inland navigation authorities are prepared for projected climate change.

Together with actions from all other sectors, mitigation measures are thus intended to prevent further rapid warming and reduce its negative impact. Such measures might involve steps to directly reduce greenhouse gas emissions or indirect measures - for example the use of alternative fuels or energy sources.

Adaptation meanwhile should help society prepare for and adapt to the foreseeable consequences of climate change without endangering the activity in question. EEA (2008) suggest that good adaptation practices should be 'appropriate, proportionate and cost effective in the long term'. Adaptation occurs mainly at sub-national and local levels but involves all levels of decision making.

Insofar as navigation interests are concerned, BMVBS (2007) suggest that an aim of adaptation should be to maintain sufficiently deep and wide channels with moderate and predictable flow velocities. Sediment balance and the state of the river bed are also important factors. PIANC (2008) also identify that two of the factors critical to safe navigation are available depth and currents/flow speed. The Environment Agency (2007) similarly focuses on Strong Stream and extreme low flow events.

However, EEA *(op cit)* note that, in practice, adaptation measures are 'rarely undertaken for the sake of climate change alone', more commonly being integrated into other cross-cutting and precautionary policy actions such as spatial planning, regional development, ecosystem or water management. This is certainly true for navigation authorities in England and Wales, most of which also have to take into account a broad range of interests including the Water Framework Directive (see Section 4.3). This scoping report therefore explores the full breadth of climate change mitigation and adaptation measures of potential relevance to inland waterway interests and activities.

3.3 Types of measure

Within the overall suite of potential adaptation measures, there are a number of ways in which individual measures might be categorised and promoted. The following terminology is therefore used in this report.

'No regrets' measures. Notwithstanding that there are still many uncertainties with regard to the implications of climate change, a number of the potential measures identified are flexible enough to provide benefits under all plausible climate change scenarios (EEA, 2008). Some measures which would help to mitigate or adapt to the effects of climate change may also be required to meet other needs, for example the objectives of the EC Water Framework Directive (WFD). Where the costs of undertaking such measures is proportionally small, where there is a high likelihood of a successful outcome (not only for climate change but also with regard to wider, e.g. environmental, objectives) and, where certainty is high (or the measure is clearly reversible), such 'no regrets' measures can often be implemented at the first opportunity.

Without suitable adaptation, any increase in frequency of high flows on river navigations may lead to more frequent closure to boats

Adaptive management. Adaptive management involves the development of existing management techniques and the development and introduction of new techniques where necessary, to enable climate change considerations to be factored into decision making procedures. By ensuring that effective use is made of existing information, by collecting additional data and by undertaking risk-based assessments, a navigation authority will be able to ensure it is well-informed and able to act when it is most cost-effective to do so. Adopting a flexible and open-minded approach to the management of waterway operations and maintenance will enable the authority both to keep abreast of change and to implement adaptation measures as and when it becomes necessary, whilst not over-committing or potentially embarking on the 'wrong' road.

'Win-win' opportunities. 'Win-win' measures are flexible, robust and adaptable measures (EEA, 2008), often characterised by the opportunity to work collaboratively with another organisation. 'Win-win' measures minimise the effects of climate change whilst also achieving other social, environmental or economic objectives usually through a single initiative. For example, creating a new water storage facility may appear to be disproportionately costly when viewed in isolation, particularly given the uncertainties still inherent in the detail of climate change predictions. However, if the Environment Agency also needs a flood storage facility and/or if a conservation organisation is interested in creating a new wetland habitat, the proposal may become both attractive and achievable.

Longer term options. Many other climate change adaptation measures may appear potentially useful but may have higher associated costs, may be less certain in their outcome, or may not (yet) be justified in climate-change and/or in economic terms. In adapting to climate change, a measured response is essential. There will almost inevitably always be some degree of uncertainty and it will therefore be necessary to balance knowledge, need and action. However, it should also be realised that additional research will rarely eliminate uncertainty completely; uncertainty should not therefore be used as an excuse for inaction if it is clear that 'no regrets' actions or 'win-win' opportunities exist.

'Regrets' measures. Whereas this report focuses on measures which appear relevant insofar as potential application to England and Wales inland navigation is concerned, 'regrets' measures should be avoided. 'Regrets' measures (a term sometimes used in WFD implementation) are typically costly, inflexible and characterised by uncertainty as to whether they will achieve their objectives, a risk that they will prove counter-productive or an element of irreversibility. 'Maladaption' in the meantime is a term sometimes used in the literature to describe measures with significant adverse and usually unintended consequences, for example measures where the associated greenhouse gas emissions offset the mitigation benefits.

Section 4 Inland waterways and climate change: context and methodology

Key findings

In addition to the various navigation authorities in England and Wales, many other players have interests in inland waterway management and could be affected by the consequences of climate change. Of particular importance are flood defence and water resources. The EC Water Framework Directive (WFD), which introduces a new more integrated approach to water management, is also relevant because some climate change adaptation measures will also contribute towards meeting WFD objectives.

This scoping exercise collated information on a wide range of potential mitigation and adaptation measures from a variety of UK and international organisations. Whilst there are examples of actions being undertaken by British navigation authorities, some of the initiatives underway elsewhere in Europe and in North America are also of particular relevance to this report.

4.1 Navigation and recreational use of the England and Wales inland waterways network

The English and Welsh inland waterways network is approximately 4500km long and lies mostly within a 'box 'the corners of which are defined by the Humber, Thames, Severn and Mersey estuaries (see **Figure 4.1**). Approximately 60% of its overall length is river based, the remainder being canals.

The waterways network is owned and managed by some twenty navigation authorities comprising a mixture of public corporations, agencies or national parks, voluntary organisations and trusts, and some are private sector companies. The scale of operation is significant - ranging from ship canals down to the narrow canal network predominately of the Midlands and the North West. Some areas are heavily used and are in fact over subscribed by boating users at peak seasons, whereas others are underutilised. Several restoration projects are currently in hand and many more are in the pipeline.

The canal network is heavily dependant on surface water run off, especially during the summer, given the highly seasonal demand that has been experienced over the last twenty years. Most older reservoirs now have a lower capacity than when originally constructed because of changes in reservoir safety requirements. The West Midland canal network is also heavily dependant upon groundwater, with supplies being distributed outwards especially to the south east.

Many of the rivers currently used for navigation have formed historic trade routes and, as a consequence, major urban developments are typically found along their length. This has three potentially important implications relevant to climate change adaptation: water is abstracted in large quantities for drinking purposes, development has created vast areas of impervious surfacing and hence contributes rapid run-off to rivers (and canals) in times of heavy rain and waterways tend to be used for the disposal of treated effluent.

Throughout the network, use of the towpaths is becoming an increasingly important facility. Opportunities to develop towpath use and to exploit the benefits or changes bought about by climate change will therefore need to be taken forward by the navigation authorities, stakeholders, partners and local communities.

Inland navigation authorities are collectively represented by the Association of Inland Navigation Authorities (AINA). AINA is currently assisting in the revision of 'Waterways for Tomorrow', which sets out the Government's policies for inland waters in England and Wales. AINA has been responsible for the publication of much industry good practice and is likely to play a leading role in developing and coordinating strategies to deal with the impacts of climate change.

Figure 4.1 Indicative[1] map showing inland waterways of England and Wales

[1] Figure is indicative and may not show all navigations, restoration schemes or proposed new waterways
Source: Inland Waterways Association

4.2 Other players in inland waterways management

The characteristics of many inland waterways in England and Wales are such that infrastructure may have a dual function or its operation may involve more than one organisation. When measures to address the potential effects of climate change and their consequences for inland waterways and inland navigation are being considered, a number of important inter-relationships therefore need to be taken into account. Some such inter-relationships are related to planning and/or policy, whilst others have more practical implications. Of particular importance in this respect are flood risk management and water resources.

The embankments of many navigable waterways are also flood defences. Locks, weirs, sluices and other structures may similarly have a flood risk management role, and the compatibility of flood risk management and navigation requirements needs to be taken into account, particularly in times of extreme events. Whereas high flows can sometimes make it difficult or indeed dangerous to operate locks, there may be a specific requirement for locks to be held open to facilitate flood conveyance downstream. Active management of weir structures may similarly be used to modulate storm pulses. According to Environment Agency (2007), channel maintenance for flood risk management purposes and/or for navigation is likely to become a key part of the response to climate change - in particular to ensure bank stability and to keep rivers open during low flow.

There is a great deal of ongoing research into flood risk management requirements under a scenario of climate change and this report does not attempt to repeat or duplicate such work. Rather, it aims to highlight the need for close cooperation between flood risk and navigation personnel, both in the operation and maintenance of existing assets and in the planning and design of future new or modified infrastructure. In particular, such activities need to take into account the sometimes differing requirements and to endeavour to identify ‘win-win’ solutions which meet the needs of both activities.

In addition to increased precipitation and flood risk management considerations, low flow and drought conditions are relevant to this report, as the operation of locks may need to be restricted in order to reduce drainage and maintain water in the network - not only to conserve ecological interests but also to help maintain the structural integrity of flood embankments, etc. The use of back-pumping to continue to allow boat passage through locks also needs to be undertaken in a way that takes account of other interests.

A number of navigations also form part of large low-level drainage systems which are managed by Internal Drainage Boards (IDB), for example the Middle Level Commissioners in the Fens. IDBs often discharge their drainage systems via pumping stations to main rivers which may be part of a navigation system - such as the River Witham in Lincolnshire. Such discharges typically increase when there is already sufficient water in the river to support navigation. However other, potential mutually beneficial water management opportunities might be explored under a scenario of climate change.

Many fenland waterways are also key ‘high level carriers’ conveying water pumped from adjacent lower-lying land

4.3 EC Water Framework Directive (WFD)

The 2000 WFD establishes a new, integrated (ecosystem-based) approach to sustainable water use and management which applies to all water bodies, including rivers, estuaries, man-made water bodies (e.g. canals, docks) and groundwater. In addition to the more familiar chemical water quality targets, it sets new ecological objectives for each water body. A key aim of the WFD is to achieve 'good ecological and chemical status' in most water bodies.

For water bodies which are designated as heavily modified (HMWB) or artificial (AWB), the respective targets will be good ecological potential and good chemical status. Good ecological potential takes into account that physical modifications are necessary to sustain specified human uses such as navigation and recreation.

Under the regulations implementing the WFD in England and Wales, a series of new, statutory river basin management plans (RBMPs) is being produced. These plans, which are being led by the Environment Agency as the WFD competent authority, will set out the programmes of measures which are required to deliver sustainable water management, prevent deterioration and ensure good status is achieved.

At European level, a project to explore the relationship between WFD management and climate change adaptation was launched in 2006 under the WFD Common Implementation Strategy (CIS). The CIS Strategic Steering Group on Climate Change and Water has thus been tasked with producing guidance on how Member States should incorporate consideration of climate change into implementation of the WFD.

To date, this activity has stressed the need for recognition of the climate change challenges in the first round of river basin plans, but has recognised that experience in designing adaptation strategies and implementing policies is still limited. Whilst ensuring the 'climate resilience' of the WFD programmes of measures will be important, concrete actions to deal with climate change issues will not be in RBMPs until the next (2015-2021) round of plans at earliest. In the meantime there is the need to build adaptive capacity.

Finally, a UK initiative related to the WFD is the Catchment Sensitive Farming programme which aims to develop measures to tackle diffuse water pollution from agriculture to meet WFD requirements. This is potentially relevant to this report in that the WFD considers sediment to be a pollutant and Catchment Sensitive Farming schemes may help to limit sediment getting into the inland waterways system.

4.4 Methodology for identification of inland waterways mitigation and adaptation measures

Given the responsibilities and inter-relationships discussed above, various methods were employed to help identify the widest possible range of potentially appropriate navigation-related climate change mitigation and adaptation measures.

In the UK, in parallel to a wide-ranging literature search and review, structured telephone interviews were carried out with most AINA members. The purpose of these surveys was to ascertain their knowledge about climate change and its predicted impacts and to establish whether any mitigation or adaptation measures are being considered or are already in place.

Amongst the authorities who are already exploring potential climate-change measures, the Environment Agency and British Waterways have undertaken/are undertaking a number of research programmes investigating issues such as low flows, water resources, Strong Streams, and geotechnical issues.

The Broads Authority, in partnership with other East Anglian organisations, is considering issues related to saline intrusion (related to sea level rise) and coastal defences, as well as the threat posed by alien species. Others, such as Cardiff Harbour Authority are taking forward initiatives to reduce their carbon footprint, whilst Bristol City Docks (in conjunction with the Environment Agency) have started to future-proof their infrastructure by anticipating the need to raise flood defences and lock gates as part of an overall flood risk management scheme.

Most of the other British navigation authorities are awaiting guidance as to what should and can be done in response to climate change predictions. Indeed, many of those contacted welcomed this IWAC report as an opportunity to give some structure to the way in which individual experiences and research programmes can be further developed and shared.

4.5 Relevant international experience

In parallel to contacting UK navigation authorities, information was also sought from a number of international organisations and individual contacts and an international literature search and review was carried out.

In many European countries and, indeed, in North America, a great deal of attention is still being paid to defining climate change scenarios and hence understanding the range of potential practical consequences for inland navigation. In this respect it should be noted that whilst there is general agreement between the various global models on climate change scenarios for the UK and elsewhere in northern Europe, there remains far more uncertainty about the likely consequences of climate change for major central European river basins such as the Rhine and the Danube and for navigable North American river systems such as the Mississippi-Missouri.

Notwithstanding this uncertainty, European navigation organisations, WFD river basin districts or countries are now beginning to consider potential mitigation and adaptation measures. Some measures are really only appropriate to the larger commercial waterway networks and to the vessels using these major rivers. Other measures, however, may be suited to (or might be adapted for) application in the mainly smaller river and canal navigations in England and Wales. Climate change measures being considered by seaports have similarly been investigated and assessed for their potential relevance to English and Welsh inland waterways.

Some of the most relevant findings from this international information collection and review exercise are summarised in **Table 4.1** below. Where potentially relevant measures are identified, these have been taken forward for more detailed assessment in Sections 5 to 10.

Maintenance of coastal defences and effects of saline intrusion are critical issues for protection of the waterways of The Broads. Management decisions will need to take into account sea-level rise and anticipated increased storminess

Table 4.1 International climate change initiatives relevant to inland navigation

Source	Relevant initiatives
Inland Navigation Europe	Inland Navigation Europe (a membership organisation working to promote freight traffic on the inland waterway network) highlight on their website some of the key climate change issues and challenges facing inland shipping in mainland Europe (http://www.inlandnavigation.org/en/factsandfigures/environmental_issues/climate_change.html). Amongst other things, the site: • notes the relatively low contribution to greenhouse gas emissions of inland shipping when compared to rail and road transport; • highlights the range of alternative energy sources being considered, including biofuels and fuel cell technology (the latter being apparently the most promising); • acknowledges the effects of more frequent peak floods in winter and longer low water levels due to drier summers (the latter considered to be the most significant climate change impact); • describes the development of lightweight vessels which can navigate effectively in low water levels and also use less fuel; and • promotes other opportunities for eco-innovation including advising tempomaat (ATM) and river information systems for advanced voyage planning. INE acknowledge that climate change is already having an effect on inland waterways but stress that more research is required before key strategic decisions on investment for adaptation can be made. To this end, they point to a major research project involving a comprehensive investigation into the effects of climate change on European inland waterway networks. This work, which is being led by the Belgian company TML will include research into spatial and infrastructure planning as well as new technological and operational concepts (new vessels, new propulsion systems, new materials). Further information on this relatively new project should become available at http://www.tmleuven.be/home.htm)
World Ports Climate Initiative	Several organisations (International Association of Ports and Harbours (IAPH), American Association of Port Authorities (AAPA); European Sea Ports Organisation (ESPO)) as well as individual port authorities have now signed up to the World Ports Climate Initiative (WPCI). This initiative will focus on creating awareness about the measures ports can take to fight global warming. It also includes specific projects dealing with: • carbon footprint calculation; • on-shore power supply; • environmental ship-indexing (emissions-based); • clean terminal equipment; • energy efficiency; • modal shift in hinterland transport; • low carbon fuels/fuel-based approaches; and • alternative power (solar, wind, hydro). However, the WPCI notes that cost-benefit analysis will play an important role in determining the viability of such measures. More information about the WPCI can be found at http://www.iaphworldports.org/wpci_2008/index.html

Source	Relevant initiatives
PIANC	PIANC, a global organisation providing guidance for sustainable waterborne transport infrastructure for ports and waterways, has an ongoing climate change work theme comprising a number of initiatives: • a recently completed report prepared by a Task Group of international experts entitled 'Waterborne transport, ports and waterways: a review of climate change drivers, impacts, responses and mitigation'. This report, which reviews climate change impacts on maritime and inland navigation, also highlights potential adaptation and mitigation responses, and identifies reductions in speed as 'probably the single most efficient measure in reducing fuel consumption and hence greenhouse gas emissions'. The report is freely available at http://www.pianc.org/downloads/envicom/envicom-free-tg3.pdf; • a proposal for a standing Climate Change Task Group to monitor global developments in climate change science and responses, and to identify and implement follow up actions. This may include a dedicated inland navigation climate change discussion forum; and • a proposal for a web-based climate change information platform.
European Commission	There are various ongoing European initiatives, both research projects and practical applications aimed at supporting EC legislation. Of particular relevance to inland waterways is an activity on Climate Change and Water set up in 2007 under the Common Implementation Strategy for the Water Framework Directive. This ongoing activity has been tasked with producing guidance on how Member States should incorporate consideration of climate variability and change into WFD implementation. In addition to highlighting the importance of policy integration, the work will explore both the need to build adaptive capacity and the delivery of adaptation actions and measures. Outputs to date highlight that 'successful adaptation to climate change will depend on the extent to which the issue is integrated into the implementation of water regulation and other sectoral policies' and note that improving water efficiency is 'key for adaptation'. Further information on this CIS activity can be found at: http://circa.europa.eu/Public/irc/env/wfd/library?l=/framework_directive/climate_adaptation&vm=detailed&sb=Title There is also an initiative dealing with biodiversity and climate change at: http://circa.europa.eu/Public/irc/env/biodiversity_climate/library
USA	The report Climate Impacts on Inland Waterways (US Dept. of Transportation, 2005) concludes that climate change is likely to affect the inland navigation on the Mississippi River in two ways: i) changing river flows including an increased frequency of floods and low flow events, and ii) changing the amount of commodity traffic, its origins and its destinations. The report also documents a number of potential adaptations to such climate change and variability: • reviewing water-use master plans to balance multiple uses of water, including navigation; • ensuring habitat protection and enhancement; • increasing dredging; and • climate change feasibility studies to future-proof navigation projects. They conclude, however, that with the current state of knowledge, it does not now make sense to build expensive infrastructure *in anticipation* of potential climate change. Rather, water resources and transportation managers should continue to monitor climate conditions and their effects on hydrology and adapt policies and operating procedures if significant changes are detected. Plans should then be evaluated based on their resiliency, robustness and reliability under a range of uncertain scenarios.

Source	Relevant initiatives
Danube River Basin	Climate change is an issue of basin-wide significance on the Danube, not least following recent instances of navigation being suspended due to high water, low water or ice formation. Climate change in the region is being addressed in part through the implementation of the WFD. In particular it is proposed that a detailed adaptation strategy will be included in the second cycle WFD river basin management plan. In the meantime, efforts are focusing on research and awareness-raising and the following are amongst the various initiatives being explored on the Danube: • environmentally-friendly vessel design to carry high cargo loads at less draught whilst also retaining maximum manoeuvrability and high propulsion efficiency in shallow water sections; and • the further development of river information systems (telematics systems and information services) to increase safety and efficiency of inland waterway transport. A number of research projects are also cited as being relevant to climate change, extreme weather events and inland navigation in the region: Glowa Danube, Glowa Elbe, KLIWAS (see below), CLAVIER, CECILIA, PREVIEW
Germany	Much of the work to date in Germany has focused on climate projections and the potential consequences for navigation and waterways (e.g. flood flows, low flows, biodiversity implications, etc.). However, whilst recognising that more work is needed to reduce knowledge gaps and uncertainties, a major five-year research project (KLIWAS) has also been launched which will, amongst other things, include an analysis and evaluation of local and regional adaptation options. More information can be found at http://www.bafg.de/nn_265022/M2/DE/05__KLIWAS/kliwas__en.html
Netherlands (Rotterdam)	In the Netherlands there is a programme to subsidise commercial shippers to install cleaner engines. Incentives may also be provided to encourage the early introduction of the EU regulation on cleaner fuels, and there are initiatives to improve the energy-efficiency of ships. There is also an adaptation programme involving the Port of Rotterdam which focuses on: • monitoring of water levels and forward planning to cope with low flow events; • making 'room for the river' to accommodate flood flows, whilst also recognising the need to maintain sufficient water depth for safe navigation; and • investigations into possible future ship designs which use lighter materials and draw less water.

Section 5 Measures to reduce greenhouse gas emissions

Key findings

Whilst the contribution of the England and Wales inland waterways sector to the overall problem of global warming is very small, urgent action is required across all sectors to mitigate the effects of climate change. The recent UK Climate Change Act requires a 26% cut in Britain's carbon dioxide emissions by 2020, and an 80% cut in all greenhouse gas emissions by 2050 (both relative to 1990 total emissions).

For the inland waterways sector, there is no panacea. Individually, many of the measures identified will make only a small difference. A combination of measures will therefore need to be implemented if the sector is to achieve a meaningful reduction in greenhouse gas emissions.

This report identifies many different measures for reducing emissions from vessels. Some, such as engine use/speed, depend for their effectiveness on the behaviour of individuals. Others would require action by Government or by navigation authorities (e.g. new standards for marine engines or the provision of electricity hook-ups using energy from a renewable source). Many measures could be promoted using incentives - for example, licence fees might be reduced for vessels meeting certain emissions or design criteria. Freight Facility Grants and Waterborne Freight Grants might similarly be made conditional on meeting emissions targets. Such potential incentives require further investigation.

Many of the measures highlighted in this section of the report rely directly or indirectly on changes in behaviour or perception. An education and awareness-raising campaign, undertaken in partnership with a range of user groups, could thus be a useful 'no regrets' measure - particularly if this exercise could also cover some of the adaptation requirements discussed in later sections. New and ongoing research and development initiatives will also be important, both to further develop alternative energy sources and to improve the efficiency of engines and vessel design.

Insofar as emissions associated with inland waterways infrastructure are concerned, many authorities have already started to move towards general 'good housekeeping' measures. However, the report has also identified a number of options whereby authorities might both contribute to a reduction in emissions and save money. In addition to generating energy locally, or using energy from renewable sources, for example by developing low-head hydropower facilities or installing wind turbines on waterway land, it may be possible for some authorities to exploit opportunities for using water bodies as a source of heating or cooling. Such opportunities require investigation at a site-specific level.

Finally, moving more freight onto the principal inland freight waterways of England and Wales, has the potential to result in a significant reduction of CO_2 emissions. This shift from road to water should therefore continue to be actively promoted.

5.1 Climate change context

One of the principal causes of climate change is the emission of carbon dioxide (CO_2) as exhaust gases from hydrocarbon-fuelled energy production. Such emissions contribute most of the 'carbon footprint' of the activity in question, although other gases emitted, such as nitrous oxide, also contribute to the greenhouse effect.

In 2007, the UK's total greenhouse gas emissions amounted to well in excess of 630 million tonnes of carbon dioxide equivalent (ENDS, February 2009). This represented a slight (1.7%) fall on the 2006 total. However, over the same period, emissions from the wider transport sector rose by 9.5% (1.3 million tonnes equivalent).

In November 2008 Royal Assent was granted for an Act on climate change that sets the world's first legally binding targets for reducing greenhouse gas emissions. A 26% cut in Britain's carbon dioxide emissions is required by 2020, and an 80% cut in all greenhouse gas emissions will be needed by 2050 (both relative to 1990 total emissions). The latter is in line with a subsequent non-legislative resolution adopted by the European Parliament in February 2009 and illustrates very well the magnitude of change needed to make a real difference.

A target of this size can only be met if all sectors take action to reduce their carbon dioxide emissions, irrespective of the proportion of their initial contribution.

The amount of CO_2 emitted by the inland waterways of England and Wales has not previously been quantified but there are two key sources:

- emissions associated with the generation of energy to operate the network, including lighting, back-pumping, lock and bridge operation, service/maintenance vehicles, etc - there is no information on the total 'carbon footprint' of such inland navigation authority operations; and
- carbon dioxide emitted by vessels using the waterways themselves.

A recent AINA study estimated that there are approximately 83,000 craft on the inland waterways in England and Wales, of which some 16,000 are un-powered. There are also some 1,000 workboats. It can therefore be estimated (very crudely) that the associated annual production of CO_2 is just over 82,000 tonnes (see **Table 5.1**). This is obviously a very small percentage of the UK total. However, whilst it is important on the one hand to be clear that this is a relatively small contribution to the overall problem, the inland navigation sector should not use this as an excuse for non-action.

Table 5.1 Climate change impacts affecting England and Wales inland waterways

Type of craft	Numbers	Weekly usage (weeks/annum)	Daily usage (days/week)	Litres/day	Litres/annum
Powered	62393	5	7	8	17470040
Trip or restaurant	1765	42	6	12	5337360
Hire boat	2030	25	6	12	3654000
Powered day boat	889	21	7	8	1045464
Work boats	1000	50	5	15	3750000
				Total (litres)	**31256864**
				****Equivalent carbon dioxide (tonnes)**	**82206**

**Diesel produces 2.63kg of CO_2 per litre of fuel consumed

Over 15000 registered boats are based on the Thames, including over 9000 craft with internal combustion engines

Whilst no specific target has been provided to the inland navigation sector by the UK Government, it is assumed that the national reduction target of 26% by 2020 and 80% by 2050 should be applied if possible. Steps must therefore be taken *inter alia* by navigation authorities, to reduce the land based carbon footprint of inland waterways as well as that of vessels.

For vessels, there are four possible ways to contribute to achieving this target:

- behavioural measures to reduce the use of engines;
- greater efficiency and cleanliness of engines;
- greater efficiency in hull design; and
- use of alternative fuels or engine systems.

Insofar as navigation infrastructure is concerned, a variety of measures can be taken to reduce emissions or alternative energy sources can be explored. There are also a number of opportunities for navigation authorities to contribute indirectly to a reduction in emissions through the generation of renewable energy or by promoting the shift of freight from road to water transport. Potential measures are therefore discussed in the following sub-sections.

5.2 Reducing emissions from vessels: use of engines

The use of the engine is an individual decision and is a matter that may be driven by personal views on climate change, by behaviour influenced by peer group pressure, by financial stimuli such as the level of tax levied on fuel or the level of perceived operating and ownership costs, and may be affected by the physical characteristics of the vessel itself.

The way in which a vessel is handled on an inland waterway can significantly alter its fuel consumption. The hydro-dynamic interaction of the vessel when it moves through a confined channel limits the speed of the vessel to the extent that even if more power is applied, little increase in speed will be noticed (or only at the expense of very excessive power and thus fuel consumption). At the same time significant wash will be created - to the detriment of other craft and especially damaging to the banks of the waterway. Thus self-imposed speed restrictions could save fuel (and money) and hence reduce emissions.

In addition to emissions associated with vessel speed, it is usual practice for craft to keep their engines running when in locks *inter alia* to hold their position. This is especially the case with narrow locks. In cases where locking activities take some time to complete, a further reduction in emissions might be achieved if engines were to be turned off and vessels were to be moored and managed manually, as is the practice in Thames locks.

To achieve the potential benefits associated with reduced engine use, a significant change in user behaviour would be required. This would probably best be achieved via a major education and information campaign. Given the range of users who would need to be targeted, such an initiative would most effectively be developed in conjunction with key partner organisations such as the British Marine Federation, Royal Yachting Association and Inland Waterways

Association. It may also need to be backed up with greater monitoring of behaviour and, if necessary, enforcement measures with suitable penalties.

5.3 Reducing emissions from vessels: efficiency and cleanliness of engines

The design and maintenance of engines plays a vital role in reducing greenhouse gas emissions, not only in terms of CO_2 but also nitrous oxide (N_2O). However, a number of steps can be taken to improve the efficiency and cleanliness of engines and hence reduce emissions of such greenhouse gases, as well as other polluting gases.

All new marine engines now installed in leisure craft are subject to the requirements of the 1994 EC Recreational Craft Directive (as amended). This specifies the level of exhaust emission gases and is aligned to the conventions used for cars and commercial vehicles. However, the longevity of a typical vessel means that engines are not often replaced and, as a consequence, the average performance specification of engines will decline relative to improvements created by built in obsolescence within the automotive industry. Thus the change created by technological advancement over time will not necessarily follow. There are also large numbers of old engines with low efficiencies and no emission control system built into them. As these are incapable of being upgraded, they thereby create a fleet that will continue to produce a higher level of exhaust emissions compared to a fleet of vehicles that is regularly maintained, then scrapped and replaced.

One option to reduce emissions could be to require an exhaust emission test to be applied to all craft as part of the four yearly BSS examination (i.e. similar to that applied as part of an MOT test for vehicles). However this would need to be thought through very carefully and fully consulted upon because of the wider implications for all inland waterway vessels, especially older and historic vessels.

With regard to commercial craft, many of those currently operating on inland waterways have engine sizes below the thresholds set by the EC and the UK Maritime and Coastguard Agency (MCA) and, as a result, no requirements are set for exhaust emissions controls. As a consequence, there are no real drivers to reduce emissions from inland commercial craft through engine design and maintenance, particularly taking into account the cost of doing so, and the marginal financial basis of the industry.

Marine diesel engines often have a long life and many are maintained in use in vessels for their historic value

In the Netherlands, SenterNovem, an agency of the Dutch of Ministry of Economic Affairs, has introduced a subsidy of up to 40% to vessel operators to fit engine management systems to reduce the emissions from diesel engines to help upgrade and modernise their inland commercial fleet. (http://www.senternovem.nl/sn/index.asp)

A similar process could be encouraged in the UK for commercial vessels but previous attempts to promote such a policy within UK Government have not been successful. One solution could be to make all Freight Facility Grants or Waterborne Freight Grants for vessels conditional on the vessels to be used meeting current emission standards (and ensuring that the grant could include for the necessary upgrades).

Finally, standards should be adopted to cover all marine engines used in commercially operated craft on the inland network - including trip, restaurant and freight boats with engines below the current regulated sizes.

This could be achieved either by means of licensing conditions by the inland navigation authorities or by the introduction of specific regulations by the MCA

5.4 Reducing emissions from vessels: eco hulls

One of the greatest potential areas of improved efficiency in fuel consumption is via the development of hull design. An efficient hull design can result in less underwater 'drag' and wash creation, thereby reducing fuel consumption.

Considerable work on hull design has already been undertaken in the glass fibre sector, where the development of moulds and repetitive castings has led to some improvement. However, with traditional steel narrow boats, the ability to weld flat pieces of steel together at low cost has resulted in little being done to improve hull efficiency - with more interest being shown in looking at styling above the water line.

Where research has been undertaken in the past, the findings have not been introduced into the vessel manufacturing sector - primarily because the additional cost has not been attractive to purchasers. Further, as the case study below illustrates, where hull improvements have been made, the typical consequence has been that the vessels get 'driven' faster. Thus no resultant reduction in fuel consumption is achieved. However if behavioural change can be promoted such that speeds are maintained at a lower level, it is estimated that energy consumption could be reduced by 15%.

Alvechurch Boat Centre Eco-Hulls Case Study

Around ten years ago, the Alvechurch Boat Centre, one of the leading English Hire Boat operators, undertook some research in conjunction with British Waterways and the University of Glasgow to investigate the development of an eco-hull design for the replacement of their hire boat fleet.

Following this research, some 14 craft were constructed and entered into service. The costs in fabricating the hulls, which included the provision of a bulbous underwater bow and changes to the stern to allow the propeller to get a more efficient " grip" of the water, resulted in an additional average cost of £1,000 per boat.

Research carried out on these craft demonstrated that the eco-hull design resulted in a 15 -30% reduction in bow wave, a 5-10% reduction in the stern wave and up to 40% less pressure disturbance on the canal bed - thereby also diminishing the environmental impacts on plant, fish and animal life within the canal waters.

Given the above results, it was anticipated that there would be an annual saving in fuel costs which would, in turn, justify the extra investment over the operating life of the hull. However, the craft were in fact driven faster - so the breaking wash was the same as before, and fuel consumption increased accordingly.

As a consequence when the craft were due to be replaced again, tradition hulls were fabricated. Eco hulls are still available and are constructed by the Alvechurch Boat Builders but only as one-off orders.

Source: Alvechurch Boat Company (personal communication, 2009)

The increase in fuel costs due to the removal of the derogation on red diesel may provide an opportunity for the industry to persuade boaters to invest in eco-hulls or to slow down. This is potentially a situation in which everybody wins: boaters would save money, greenhouse gas emissions would be reduced and lower levels of bank damage and sediment resuspension would both help reduce the navigation authorities' maintenance costs and minimise environmental damage.

It might be possible to provide an incentive to encourage boaters to upgrade or to invest in more sustainable vessels by introducing a discounted licence fee as for electric boats (see below). A reduced fee could be payable for craft that pass an emissions test as part of the four yearly Boat Safety Scheme (BSS) examination and/or for those with a hull which is certified as being 'eco-friendly'. Whilst the latter would need to be part of a very long term process because of the longevity of existing boat hulls, it may nonetheless serve to encourage eco-hulls in new builds.

5.5 Alternative fuels and engine systems

A number of possible alternative sources of fuel exist including the use of **bio-fuels** like bio-diesel and bio-ethanol as a plant based replacement or additive for petrol and diesel. Various options exist - both as to the sources of these fuels and to the proportions that can be added to mineral oil based fuels (or replace them in their entirety). The reuse of cooking oils as a replacement for diesel is also now being actively promoted.

Bio-fuels mean that less CO_2 is emitted, and the overall plant/fuel life cycle of bio-fuels is argued to be carbon neutral http://www.thegreencarwebsite.co.uk/biofuels.asp. However, there are now an increasing number of arguments against the increasing use of bio-fuels due to the wider social and environmental implications of the switch from growing crops to growing 'fuel' plants, particularly given the continuing significant increase in the world population.

Another 'alternative fuel' option for craft is the development of **electric boats**. For a number of years the Environment Agency and British Waterways have been encouraging the use of electric boats by offering a 20% or 25% reduction in licence fees for electric craft and through investment in hook-up pillars to provide charging points. The provision of hook-up pillars in itself has further lowered the overall level of emissions by reducing the need for boat engines/ generators to be run to recharge batteries and to provide domestic electrical supplies on board moored craft. However, attempts should be made to ensure that the electricity supply to such hook-ups is sourced from a 'green' supplier wherever practicable.

Notwithstanding both the generally reduced operating costs and the various environmental benefits, there has been reluctance on the part of users to invest in electric boats due to their higher capital cost and the need for regular replacement of traction batteries. There has thus been a limited take up, with only 1600 licensed craft currently being used on the UK network (Electric Boat Association, 2007). Some vessels have been specially set up so as to monitor power consumption, efficiency etc., but no significant results have yet been published.

Finally it should be pointed out that whilst electric boats may offer what appears to be a 'carbon free' form of boating, the greenhouse gas emissions associated with the electricity used to recharge the craft have to be considered. In some cases, the production of such electricity may have used methods with conversion efficiencies poorer than for a small marine diesel engine.

Related to the development of electric boats, and partly as a result of the interest in hybrid cars, some work has been carried out recently to develop hybrid vessels for use on inland waters. A **hybrid system** allows the engine to be operated in its optimum mode, charging a battery pack that is in turn used to power the vessel. In a situation such as a Strong Stream, however, the main engine can be put into direct drive thus increasing the power performance of the craft.

The use of this technology should be further explored and if suitable, promoted. By way of an incentive, navigation authorities could offer a discount on licences for craft fitted with a hybrid engine, in much the same way as for electric boats.

Whilst the option of wind-assisted vessels might also be explored further, other sources of energy being actively considered at the present time include Liquefied Petroleum Gas (LPG) which is now becoming more familiar in use in cars) and hydrogen fuel cells. Further information on alternative fuels and engine systems can be found in a publication resulting from a major research project undertaken by the British Marine Federation and the Royal Yachting Association as part of their joint Green Blue initiative. Their report, prepared by May and Anderton (2007) and entitled 'Research into Alternative Fuels and Engine Systems in Recreational Vessels' is available from http://www.thegreenblue.org.uk/research/documents/TheGreenBlueAltFuelsreport-FinalamendedJuly2007.pdf

5.6 Reducing emissions from navigation-related infrastructure

No estimate has yet been produced of the collective carbon footprint derived from the operation and maintenance of navigation infrastructure. Some navigation authorities are collecting and monitoring data to determine their own footprint and thus set targets to reduce it. Whilst efforts could (and arguably should) be made in the future to determine this overall footprint (e.g. to show that inland navigation as an industry is acting responsibly), the purpose of this report is to highlight the range of measures available to contribute to such reductions.

It is apparent from the structured telephone interviews (see Section 4.4) that inland navigation authorities are already taking a number of steps to reduce energy demand. British Waterways currently monitors its electricity consumption both to reduce its footprint and, via an energy broker, to procure 'green electricity' at lower tariffs. A similar process is adopted by the Environment Agency and it is recommended that all navigation authorities look at their sites where significant energy is consumed.

Insofar as navigation infrastructure operations are concerned, the use of advanced technology to control pumping equipment should already be fully exploited either through the use of SCADA (*Supervisory Control And Data Acquisition*: typically a computer system monitoring and controlling a process) or telemetry to optimise energy consumption or via the installation of new, more efficient pump motors. Significant savings can be made when compared to older equipment that may well have been in place for ten or twenty years or even longer. The analogy to the improvements in domestic heating boilers over the recent years is relevant here.

SCADA systems in use on the Manchester Ship Canal

The application of the Building Research Establishment Environmental Assessment Method (BREEAM) standards for buildings (http://www.breeam.org/) will help to reduce energy consumption and therefore cost - as well as making the buildings more comfortable to work in. Other good housekeeping measures such as switching off lights and computers, etc., using low energy bulbs, reducing boiler temperatures, cycling, using public transport or car-sharing, and many other ideas are both well-documented and promoted by organisations such as The Carbon Trust http://www.carbontrust.co.uk/default.ct.

As from December 2012, the UK Government will require companies using more than approximately £0.5M of energy per annum to report on their emissions to comply with the 2008 Climate Change Act. Steps will therefore need to be taken by some navigation authorities to identify and quantify their sources of emissions, and undertake regular monitoring (HMSO, 2008, *Briefing note to the Climate Change Act 2008*. See http://www.opsi.gov.uk/acts/acts2008/en/ukpgaen_20080027_en_1).

Broads Authority Dragonfly House Case Study

In 2008, the Broads Authority moved into the 'greenest' office in Norwich which it shares with its key environmental partners, the Environment Agency and Natural England. 'Dragonfly House' is rated as 'excellent' on the Building Research Establishment's BREEAM scale. BREEAM measures the environmental performance of buildings by awarding credits for achieving a range of environmental standards and levels of performance. Each credit is weighted according to its importance and the resulting points are added up to give a total BREEAM score and rating.

Dragonfly House

Photovoltaic panels

Some of the key features of the new building that give it an excellent rating are:

- environmentally friendly building materials: the office is clad in sustainably sourced timber, with brise soleil sunshades to reduce the solar gain;
- air drawn through an earth duct (a large pipe buried 3m underground) will help to warm the building in winter and cool it in summer. Propane powered chillers will be used to cool the temperature in the computer room. Propane has virtually no global warming impact and, due to the clever design of the building, the cooling requirement is much smaller than for a conventional office building;
- rooftop solar panels are expected to heat 35% of the water used in the building;
- rainwater which falls on the building roof will be collected, filtered and stored in an underground tank for use in flushing toilets. The storage tank can hold 30,000 litres of water; and
- a sustainable urban drainage system will reduce the risk of flooding and protect water quality.

Source: Broads Authority Press Release 8th December 2008

5.7 Alternative fuel sources for navigation-related infrastructure

There are a number of opportunities to use alternative fuel sources to reduce emissions, albeit that many are small scale and applicable only in certain situations.

Electricity supplies can be purchased as green energy and the Environment Agency and British Waterways are already doing this.

The use of solar panels and ground or water source heat pumps are beginning to be exploited. Some of the grant regimes now available can make such proposals financially and environmentally sustainable in providing heating and hot water for buildings.

Remote power needs for control equipment or lighting can be met using solar panels and small wind turbines which charge up battery packs. Lighting, SCADA and telemetry equipment, for example, can be installed at significant savings as no mains-connected electricity supply is then required. A good example here is the use of such micro-generators for the monitoring and control of remote reservoirs or feeders.

Other more innovative local initiatives may also be worth exploring. For example, the Cardiff Harbour Authority collects all waterborne timber brought into its impounded area by the Rivers Taff and Ely, chips the material and uses it as a fuel source for some of its buildings. Not only are energy costs saved but the disposal cost of the material (which otherwise would go to landfill) is much reduced.

5.8 Opportunities for renewable energy generation

In addition to meeting expectations to optimise their own activities, some navigation authorities may in fact be able to benefit from climate change because of the requirement upon others to mitigate and/or reduce their carbon footprint.

Several examples already exist and there may be a significant number of other situations in which developments in technology can be exploited - not only reducing the impact upon the atmosphere, but potentially also producing a financial benefit for inland navigation authorities. In this regard it is worth noting that the 2008 Climate Change Act introduces feed-in tariffs to boost small scale renewable energy production of less than 50kW. This may offer a potentially useful opportunity for navigation authorities and others to exploit.

Auchinstarry Marina Geothermal Heat Pump

Auchinstarry Marina is located on the Forth and Clyde Canal near Kilsyth. It has moorings for 64 boats and hard standing for a further 40-50. It has a facility block containing showers, toilets, a laundry and an office. British Waterways, in deciding as part of its policy to reduce its energy consumption by 5% per annum for five years, decided to use a heat pump drawing heat from the marina basin to heat the marina facilities.

The original design was based on the building being serviced by a number of electrical convector heaters with a total load of 6.12kW and five 10.5kW instantaneous electric showers. All of this plus hot water for the laundry has been replaced with the heat pump. A 50% grant was received from the Scottish Community and Householder Renewable Initiative towards the total cost of some £8,000. It is anticipated that the project will be paid back over 5 or 6 years and that some 4.7 tonnes of CO_2 per annum will not be emitted to the atmosphere.

Source: British Waterways Case Study Capital Projects (personal communication, 2009)

Cooling and heating of buildings: there has been considerable interest in the use and development of ground source heat pumps for some time. However, the exploitation of water bodies to provide a source of heat has only recently started to be explored. The same ground source heat pump technology can be used, but with the heat collecting coil being immersed in a river, canal, marina or other water basin, to allow the heat to be gathered and extracted. This can provide a simpler and cheaper installation solution than trenching in ground adjacent to the building being heated. The heat thus extracted can be used to heat navigation authority buildings, facility blocks etc.

The right to install the pipe work can also be 'sold' to adjacent businesses; making the technology available to buildings in city centres could therefore produce an income for navigation authorities.

In addition to using canals and rivers as a heat source, it is possible to use them in the summer time as a heat 'sink' for the cooling of buildings. A similar process to that used for a heat pump is employed whereby a coil of pipe can be immersed in the water and used to cool air-conditioning units as an alternative to blowing air through them.

London's waterways provide opportunities for green energy solutions though heat exchange technology

Cooling is achieved more efficiently, with less local heating of the atmosphere taking place and reduced noise pollution. The system could also be used to 'dump' surplus heat from heating systems during the winter - whether for offices or even for district heating schemes. However, in all cases it will be essential to ensure that the ambient temperature of the canal or river water is not increased by more than 3^{o}C because of the ecological changes that may result.

British Waterways Heat Exchange Technology Case Study

British Waterways provides a green energy solution for waterside businesses: canal water cools office building.

By using British Waterways' canal water, pharmaceutical giant GlaxoSmithKline (GSK) will be lowering energy bills and reducing CO_2 emissions at its waterside headquarters in West London.

This green initiative recycles water from the Grand Union Canal and uses heat exchange technology to cool the GSK building in Brentford, providing a sustainable alternative to traditional air conditioning systems.

In addition to GSK, other institutions that use canal water to heat and cool waterside buildings include a university, a shopping centre and a hotel. It has been estimated that a further 1,000 businesses could take this opportunity to lower their energy bills and reduce their impact on the environment. This would be the equivalent of removing 400,000 family cars from the roads and provide total annual energy savings of £100m.

Source: British Waterways Monthly, January 2009

Low head hydropower: the ability to extract power from rivers has been one of the key drivers for economic and social development over the millennia. With the advent of steam technology and the more recent developments in the generation of electricity, the use of river generated power had diminished, if not been eliminated, with the exception of certain heritage locations.

With the demand for green energy increasing and other developments in civil and electrical engineering, low head hydropower is again considered to be a potentially viable means of generating power. However the economics of the construction of 'run of the river' plants are extremely marginal (a minimum flow of 15 cumecs and an available head of 2.5m seem to be the key prerequisites).

Only one such facility is currently in operation on the UK's navigations but a number of proposals are in hand at other locations and, with the benefit of financial support under the UK Government's former Non Fossil Fuel Obligation or the Climate Change Act 2008, a number of other sites will be developed.

The use of the rivers gives a steady and generally predictable energy output although generated output will diminish during flood flows and may have to be curtailed during low flows. In the latter respect, the associated opportunity to consider the installation of movable weirs (e.g. using flexible weir crests) could also assist in water retention for other purposes. The need to install modern fish passes as a consent requirement of any such development will similarly assist in maintaining the natural regime of the river.

Wind turbines: as an alternative to, or to complement, low head hydropower installations, a number of locations owned by the inland navigation authorities are potentially suitable for the installation of wind turbines. Indeed, organisations like Partnerships for Renewables (a Carbon Trust Enterprise) are working with public sector bodies such as Environmental Agency and British Waterways to develop some such sites. In promoting the use of such technology, the navigation authorities can reduce their own carbon footprint by generating their own electricity and thus offsetting the energy consumption of pumping stations and other installations. Wind turbines may also provide a funding opportunity for waterways.

5.9 Freight by water

Considerable research into increasing the volume of freight carried on inland waterways in England and Wales has already been undertaken by IWAC (2008a) in its report *Deceasing our Carbon Footprint: moving more freight onto the inland waterways of England and Wales* and by Sea and Water (now Freight by Water) (2008). Following research by the Tyndall Centre for Climate Change Research, Freight by Water showed that moving freight by road produced 0.08 tonnes of carbon for every thousand freight tonne-kilometres. By comparison, the equivalent figure for waterborne freight is 0.02 tonnes per thousand tonne kilometres, a 75% reduction in CO_2 emissions.

Oil tanker barge on the Humber, bound for inland waterways in industrial Yorkshire

However, a number of barriers to a shift to freight by water were also identified and these will need to be removed if the full potential of the larger inland waterways to contribute to a reduction in CO_2 emissions is to be realised. Recommendations included:

- better promotion of waterborne freight by the water freight industry and navigation authorities, with Freight by Water playing a major role;
- the UK and Welsh Assembly Governments undertaking a comprehensive study of the opportunities for, and the barriers to, increasing freight transport by water, aiming to produce recommendations that can be adopted as a useful contribution towards reducing the UK's carbon footprint;
- greater adherence by planning authorities to existing planning policy guidance and statements which promote the use of waterways for freight transport, particularly Planning Policy Guidance 13 on transport (PPG13), coupled with stronger support for waterborne freight in future policy statements;
- greater consideration of waterborne freight transport in regional plans (e.g. regional spatial strategies and regional transport strategies), particularly around London;
- greater consideration of waterborne freight transport in decisions on planning permission, for example using Section 106 agreements;
- continuing modernisation of the waterway freight carrying industry; and
- removing bottlenecks on key waterways – for example, increasing headroom on the Aire and Calder Navigation.

IWAC (2008a) also highlighted two additional measures which it believes the UK and Welsh Assembly Governments should take:

- increasing availability of, and publicity for, grant-aid schemes for infrastructure and craft (because there is no other mechanism at present to pay for the environmental benefits of waterways transport); and
- improving co-operation between all relevant departments to ensure that both UK and Welsh Governments' policies relevant to inland waterways are implemented in a coordinated way.

The IWAC report (2008a) categorised inland waterways into four groups:

1. principal inland freight waterways
2. main British Waterways (BW) freight waterways
3. intermediate and 'other freight potential' waterways; and
4. smaller waterways.

The greatest opportunities for transfer of freight to water are on inland waterways accessible to river-sea ships, as here at Goole

This report identified that the use of the first two categories of waterways has the potential to result in a significant reduction of CO_2 emissions by moving freight from road to water. The use of the English narrow and broad canal and river networks, however, whilst possibly suitable for very local or niche markets, will not make a meaningful contribution to an overall reduction in emissions.

Container barge and tug at Irlam on the Manchester Ship Canal

In order to realise the significant opportunity provided by the first two categories, the recommendations made by IWAC and listed above would need to be carried out.

Another useful measure would be for grant funding requirements to be modified to require all freight operations in receipt of these grants to use vessels that are fully compliant with current exhaust emissions legislation with funding potentially available to help achieve this.

River Lee 2012 Olympics Case Study

With the 2012 Olympics being designated as the 'Green Olympics', delivery of construction materials to site is being undertaken by developing the rail and waterway network alongside and into the Olympic site. Waterborne freight will ensure that sufficient quantities of material arrive directly on site and in good time. The construction phase, which began in summer 2008, will generate large volumes of construction materials. The Olympic Delivery Authority and the CLM Consortium are committed to moving at least 50% of the construction materials by rail and water.

Prescott Lock model

Freight carried by water in this way should remove around 170,000 lorry journeys from London's congested road network during the development phase and over 17,500 lorry journeys each year thereafter. This equates to reductions in CO_2 emissions of some 16,000 tonnes during the development phase and by 440 tonnes a year thereafter. Water used as a mode of transport will thus reduce the environmental impact of freight transport on roads and contribute towards delivering a 'green' Games.

The investment made in the Olympic site will create a waterway capable of being used for both freight and leisure purposes not only during construction but also during the 'legacy' phase (i.e. up to 2020). Indeed, the waterways could be used indefinitely for the transport of recyclables away from new communities established during the legacy period. Overall, the use of water-freight in such a high profile project should assist with the furtherance of the coastal and inland-shipping industry throughout the UK.

Source: Sea and Water's brief on the use of water to build the Olympics. April 2007

5.10 Summary of measures

Table 5.2 summarises the various measures which could contribute to reducing the wider inland waterways sector's contribution to global warming. For each measure, reference is made to its likely applicability (to vessel or waterway type etc.), possible barriers to implementation are highlighted and the organisations likely to be involved in its delivery are identified. In each case, an attempt is also made to classify the measure, including whether it might be suitable for implementation in the short- or long-term.

Table 5.2 Summary of climate change mitigation measures

Objective	Relevant to	Measure	Potential barriers to implementation	Delivery - co-deliverers	Short-medium term measures	Potential longer term measures
Reduce emissions from vessels	Recreational craft, commercial vessels	Education: encourage reduced speed, switch off engine in larger locks, etc.	Behaviour	Navigation authority, RYA, BMF, IWA, vessel operators	No regrets	Enforce (with penalties if voluntary approach fails)
	Commercial vessels	Make freight grants conditional on meeting emissions targets	Political will, Government support	Government, industry		Investment in infrastructure
	Commercial vessels	New standards for marine engines	Regulatory provision	Government, MCA, navigation authority, industry		EU legislation
	Recreational craft, commercial vessels	Discount licence fee for meeting emissions standards, eco-hulls and electric boats	Cost	Navigation authority, vessel owners, industry	Win-win	
	Recreational craft, commercial vessels	Research alternative energy sources	Technical, economic viability	Industry		Research
	Recreational craft, commercial vessels	Provide bank-side electricity hook-ups	Cost, availability of renewable electricity	Navigation authority, vessel operators	No regrets	
Reduce infrastructure -related emissions	Wider sector	Reduce carbon footprint (energy demand)	Willingness to adapt	Navigation authority, vessel operators, industry	No regrets	
	Wider sector	'Good housekeeping' measures	Willingness to adapt	Navigation authority, vessel operators, industry	No regrets	
	Assets, infrastructure	Green energy, micro-renewables	Availability, site suitability, cost, Government support	Navigation authority, industry	No regrets	
Seek opportunities to help reduce other sectors' emissions	Wider sector	Exploit heat pumps, wind turbines, low-head hydropower turbines	Site suitability, return on investment	Navigation authority, industry	Win-win	
	Wider sector	Freight by water	Planning issues, promotion	Government, industry, navigation authority	No regrets	Fiscal controls (e.g. carbon tax on road transport)

Section 6 Adaptation measures: increased (seasonal) precipitation

Key findings

A possible consequence for inland waterways of the projected increase in winter precipitation may be an increase in the frequency of high flow, flooding and Strong Stream conditions. Reduced channel freeboard and hence a lack of operating headroom could similarly compromise safety of navigation. High water levels and flood flows can threaten the integrity of navigation infrastructure through seepage or erosion, and the capacity of culverts, weirs and sluices might be reduced. Safety considerations are therefore likely to be a paramount consideration for inland navigation authorities.

In preparing to respond to projected increases in winter precipitation, however, it is important to be aware that it is not a case of 'one size fits all'. The particular measures required on an individual stretch of waterway will depend on site specific factors. Monitoring and effective data management will therefore be critical if well-informed decisions are to be made on which measures are most appropriate and when they are required.

Installing or updating telemetry and SCADA (supervisory control and data acquisition) systems, generating a targeted long-term dataset, and undertaking regular risk assessments are likely to be important actions for all navigation authorities. Only by collecting and managing relevant data will authorities be able to understand the actual impacts of climate change and adapt in a timely and cost-effective manner.

Depending on the particular characteristics of an inland waterway and its users, a number of adaptive management measures may then be required in response to increased seasonal precipitation. Thresholds may need to be reviewed or set to establish when Strong Stream or other warnings (e.g. lack of headroom) should be issued. The most effective means of communicating such warnings to users should be identified. Initiatives may also be required to raise awareness amongst users about how to respond to such warnings - including the possibility of closure of the navigation. Over time, it may become apparent that further adaptive management measures are needed - for example the provision of additional temporary moorings or safe havens.

Insofar as the maintenance, modification or replacement of existing infrastructure is concerned, regular inspections will be vital to ensuring the continuing integrity (condition, capacity and resilience) of physical assets including embankments, culverts, weirs, tunnels, locks and sluices. The information thus collected will help to inform site-specific decisions on whether and when bank-raising or other strengthening or retro-fitting actions are required. Any works to replace or construct new physical assets must also be 'future-proofed' so that their design takes into account the projected effects of climate change. Working in partnership with the Environment Agency will enable the navigation authority to understand any role of navigation infrastructure in flood risk management - for example flood flow conveyance.

Finally, given the predicted reduction in summer rainfall, it may be appropriate in some inland waterway systems to explore whether increased winter precipitation can be stored so as to provide a water resource during the summer months. If such a need for additional water storage is identified, possible 'win-win' initiatives which also meet flood defence, agricultural, or nature conservation objectives should be investigated.

6.1 Climate change context

The predicted increase in winter precipitation discussed in Section 2, combined with any increase in extreme weather events (including summer storms), will have a number of implications not only for flooding but also for navigation.

During flood conditions (i.e. when a river is out of bank), navigation may have to be restricted or suspended in the interests of safety because of increased flow velocities or currents or because the line of the channel is not visible. The same impacts on navigation may occur even if there is no flooding as such (i.e. if the river remains within its banks): closures or restrictions may become necessary because even relatively moderate increases in flow rates (e.g. as little as 1m/s on some waterways) can result in 'Strong Stream' conditions.

There has historically been little attempt on most rivers to collate and correlate data on navigation restrictions with information on occurrence of high water levels or Strong Stream events. Further, whilst the various climate models appear to agree on the likelihood of increased winter precipitation in England and Wales, recent work by the Environment Agency suggests that the relationship between increased precipitation and Strong Stream events is not necessarily straightforward.

The results of the Environment Agency's 2007 modelling of flow rates for the Thames, Nene and Great Ouse were surprising in that they appear to suggest that the frequency of Strong Stream events will decrease under the UKCIP02 medium-low and medium-high scenarios for a time horizon up to 2080. One theory put forward for this conclusion is that greater evaporation will have a smoothing effect on soil moisture deficits. However it is also important to be aware that the research did not assess the full range of climate model and emission scenarios, nor did it take into account changes in seasonality or storminess.

More research is probably therefore needed before definitive conclusions can be drawn. In the meantime, however, this scoping report explores the range of options which might need to be considered in the event that increased winter precipitation does cause problems for the inland navigation sector.

In addition to possible changes in the frequency of Strong Stream events, reduced channel freeboard and hence operating clearance (i.e. headroom) under bridges, in tunnels, etc. is another important consideration for the safety of navigation.

High water levels and flood flows can also affect the effectiveness of navigational infrastructure. A lack of freeboard combined with potential for increased bank erosion, scour, seepage or overtopping can threaten the stability or integrity of embankments, supports and other structures, potentially increasing the risk of failure. The capacity of culverts, weirs and sluices might similarly be compromised by high flow levels. Flood waters typically carry more debris which then requires clearance from screens, behind structures, and there will be extra wear and tear on locks and sluices as a result of the need to use such structures to facilitate flood conveyance. Indeed, the use of navigation infrastructure to assist in flood risk management raises issues of its own.

Embankment failures on canals present risks to life and property and repairs are often costly, as seen on the Monmouthshire and Brecon Canal in 2008

Finally, it is worth noting that increased winter rainfall may also offer opportunities to the navigable inland waterways if it is somehow possible to divert and store the excess water to help alleviate predicted low flow situations during the summer months.

6.2 Responding to Strong Stream conditions

Whereas many might anticipate a higher frequency of Strong Stream events to result from the predicted increase in winter rainfall, the outcomes of the Environment Agency project provide a useful illustration of the uncertainties which remain inherent in dealing with climate change predictions. Good local data will therefore be vital to decision making at a site-specific level. If inland navigation authorities are to be well-equipped to respond to the possible implications of climate change, an essential first step for many will be to improve or install monitoring and recording systems. Telemetry or SCADA therefore have a potentially important role to play in enabling navigation authorities to prepare to deal with the consequences of any significant changes in precipitation affecting inland waterways in England and Wales.

Generating a targeted, long-term dataset, combined with an effective working knowledge of the waterway system and associated infrastructure, will also enable navigation authorities to set thresholds for action - for example on Strong Stream flows.

In the case of expected Strong Stream events, warnings will need to be provided to waterway users. The Environment Agency's recently improved system provides a model which is working well. IWAC's report entitled *Information and Communication Technology for the UK's Inland Waterways* (2008c) includes some proposals on the provision to users of reliable information as to the condition of their rivers (e.g. using variable message boards, text or web-based warnings, etc. over and above the traditional methods of local on-site signage). In future, navigation authorities will also need to take into account the possibility that another consequence of climate change - increased air temperature - could lead to an increase in recreational use of water bodies and, potentially, a greater proportion of inexperienced boaters.

If, over a period of time, monitoring data confirm that the frequency of Strong Stream conditions is indeed increasing on a particular waterway, a number of other measures may be required.

Sufficient safe havens and/or additional strategically placed moorings will need to be provided to ensure that all craft can safely ride out Strong Streams or flood events. These facilities will need to have safe access to shore and facilities for crews.

During regular winter floods in York, boats normally moored on this reach (King's Staith) are moved to safer locations

Information will need to be provided to users on how to respond to Strong Stream advice warnings. Similarly, if (temporary) closure of the navigation is likely, it is important that users understand what is happening and what is required of them, and are properly prepared to respond in a safe and responsible manner.

If there are still outstanding concerns about safety on a particular waterway (e.g. because Strong-Stream-related incidents are becoming commonplace) and depending on local circumstances, it may become necessary for example to specify minimum equipment requirements for vessels and/or to work with navigation associations and training providers to ensure the competence of crew (e.g. by training courses, workshops, on-line training exercises or leaflets). Effective and visible enforcement may also need to be considered.

6.3 Channel freeboard and clearance

Even if flow velocities are not significantly increased, high water levels alone can have significant implications for navigational safety. Depending on the particular characteristics of the river or canal system, raised water levels can create problems where there are bridges or other structures such as tunnels with limited headroom or where there is limited channel freeboard on an embankment.

Almost complete loss of headroom at historic bridges during floods, as seen here on the Warwickshire Avon at Tewkesbury, inevitably causes closure to navigation

As with Strong Stream events, navigation authorities will need to identify all such potential problem locations on their network, set thresholds for action and ensure that their monitoring regime is sufficient for them to be able timely and effective warnings. Again, SCADA or telemetry has a potentially important role.

Many of the practical measures that navigation authorities will need to consider, in the event of high water levels causing problems with clearance or headroom, are the same as those discussed above for Strong Stream events (e.g. ensuring effective communication with users including responding appropriately to warnings, provision of safe havens/moorings).

However, in the case of continuing high water levels, another option where a particular structure is causing a significant long-term problem may be to investigate the technical and economic viability of raising the embankment and/or structure in question (e.g. through consideration of the original licensing/consenting conditions or the activation of a 'lift and shift' clause if available in the Land Drainage Consent).

6.4 Maintenance, modification, or replacement of infrastructure

Regular asset inspection and condition assessments, which in turn help to set priorities for maintenance, should already be a key navigation authority activity. If the frequency of high flow conditions increases as a result of climate change, it follows that measures to ensure the integrity (condition, capacity and resilience) of navigation infrastructure become even more important if overtopping and/or failure are to be prevented. Carrying out assessments to determine the resilience of embankments, culverts, weirs, tunnels, locks, sluices, etc. to increased flood flows, rise in water levels, diminution of channel freeboard, damage by debris, increased temperatures, etc. will enable navigation authorities to identify potentially vulnerable locations.

A risk based approach, informed amongst other things by telemetry or SCADA systems, can then be used to identify any need to increase maintenance activity or undertake modifications to future-proof structures as required. For example, embankments may need to be strengthened and side weirs may need to be extended, etc. With significant work likely to be undertaken in the next few years to overcome arrears of maintenance or to meet WFD requirements, a positive approach can be undertaken.

Retrofitting of existing structures may similarly be an option - for example flood and lock gates can have increased operating levels retrospectively applied, as has recently taken place at Bristol City Docks (personal communication, 2009).

Generic or site-specific research may also be necessary, for example to improve understanding of the potential geotechnical implications of high flows for canals carried on embankments, or to assess new opportunities for flood storage (see below).

Finally, it may be the case that increased levels of winter precipitation, combined with higher water levels, could make certain maintenance activities more difficult or time consuming, because of the possibility of increased flooding of cofferdams or lock closures. If this is the case, maintenance programmes will need to be adjusted accordingly.

New outer gates fitted at Bow Locks were designed to protect the Lee Navigation and surrounding land from predicted higher tidal surge levels in the future

6.5 Operation of navigation infrastructure to convey flood flows

There are many, complex inter-relationships between navigation infrastructure and flood risk management. Working with the Environment Agency and other responsible organisations, navigation authorities will need to consider extending the role of navigable waterways in flood attenuation or conveyance (i.e. greater use of locks, sluices, pumps, etc. to help attenuate flood flows/improve flood conveyance, use of canals to absorb flood waters). Such dialogue might identify the need to prepare joint initiatives or management plans along with guidance for the operators of navigation infrastructure.

Insofar as the specific role of the navigation network in conveying floodwaters is concerned, steps may also need to be taken to install warning systems to allow for better management of flood flows, the provision of better discharge arrangements and investment in flood/stop-gates to minimise the impact of any flood or failure upon a canal system and its neighbours. Such activities will need to be associated with developments in the telemetry/SCADA systems to provide remote reporting and operation of discharge structures.

In all of the above, care should be taken to identify and reconcile any potential conflicts between safety of navigation and flood conveyance requirements.

6.6 Culvert capacity

A further area of potential concern under a scenario of climate change relates to the capacity of culverts under canals which, due to increased upstream precipitation, may not be of adequate capacity to transmit the flow resulting in local flooding. Some problems of this nature have been experienced over the last two decades associated with the impacts of development and the significant increase in run off rates from associated impervious surfaces. It appears that following the Bybrook Barn Case against Kent County Council, the full liability for flooding and the upgrading of culverts lies with the culvert owner (RPC, 2007). The clearance of associated trash screens in high flow conditions will also be important if the full capacity of the culvert is to be ensured.

Canal overflow weirs may require increased capacity

6.7 Climate-proofing future developments

As navigation infrastructure is replaced or as new development projects are commissioned, all such works should be 'future-proofed' against predicted rises in water levels and to cope with other aspects of climate change. Defra currently requires all flood defence work to be 'future-proofed' and the same principal should be applied to inland navigation infrastructure. In addition to ensuring that new embankments, lock gates, sluices, etc. are designed to take account of predicted increases in precipitation, temperature, water levels, etc., navigation-related buildings and other facilities can also be 'future-proofed'. For example, new facilities and offices can be constructed on ground above predicted flood levels or with the ground level used for parking or storage. Electrical systems and equipment can be installed above predicted flood levels to prevent damage when inundated, provision can be made for egress from building during times of flooding and facility blocks and waterside staff accommodation can be improved with the use of impervious materials, thereby speeding up re-occupation after a flood.

Incorporating such measures into new development will help to minimise the costs of repair or replacement in the event of inundation, return the system to normal operations very quickly and thus help to inspire confidence in users. Subject to the appropriate economic tests, such innovative approaches can also demonstrate value for money in that simple increases in capacity are being built into the network at low cost.

Bristol City Docks Future-Proofing Case Study

As part of the refurbishment of Bristol City Docks a replacement gate strategy has been drawn up by the City Council to assess the replacement and future-proofing of all navigational gates used in the operation and protection of the City's Floating Harbour.

At the western end of the Harbour, where it meets the tidal River Avon, one set of steel mitre gates acts as a link in the main flood defence for Bristol. Responsibility for the replacement of these gates lies with the Environment Agency and consultants Halcrow have been appointed by the City Council to draw up the business justification for the proposed replacement.

The gates are currently 10.65m wide and 10.33m high. The replacement gates will be designed to initially cope with existing tidal surges but will be capable of being raised in height by a further 0.9m on an incremental basis to cope with future as yet undetermined rises in sea level without the need for any additional civil engineering works being undertaken. The projected cost of the works is in excess of £1M.

The design performance of the gates will thus be sufficient to reassure the Agency that the gates are 'future-proofed' and can thus be included in its short to medium term funding strategies sourced from either Defra funding or the local land drainage levy.

Source: Halcrow Group Ltd. (personal communication, 2009)

6.8 Opportunities for the creation of new water storage facilities

Finally, an important opportunity for navigation might exist if higher winter rainfall can be used to help offset lower summer precipitation. In particular, navigation authorities may be able to work with other organisations (Environment Agency for flood defence, conservation bodies, farmers/land owners and even water companies) to explore and exploit opportunities to store water locally for use during the drier summer months. This could have the dual advantage of reducing Strong Stream events and/or flood risk, whilst providing water to support navigation operations, maintain existing water-dependent habitats, or for use in irrigation.

There is a wide range of possible options for water storage and management. These range from the development of new off-line marinas or balancing pond reservoirs designed specifically with navigation needs in mind, to washlands for flood storage or wetlands to provide new wildlife habitat (for example for overwintering birds). Given the increased rates of evaporation and transpiration which might be expected under a scenario of climate change, however, underground as well as surface water storage options might be considered.

Any significant proposed new water storage facility would need to meet a variety of planning and environmental criteria (see for example, the discussion in Section 9.6, including reference to the PIANC Working with Nature position paper). However, such water management facilities could often be designed to be multi-purpose - thus providing the type of 'win-win' initiative encouraged *inter alia* under the Water Framework Directive.

Particularly in areas where navigation operations are already heavily dependent on locally stored water or in areas where low flow events and/or water shortages might be anticipated in future, navigation authorities might therefore usefully enter into discussions with flood defence, conservation or agricultural organisations to begin to explore the likely need for, and technical/economic viability of, a more diverse portfolio of water storage opportunities. Whilst many such opportunities will often be relatively small-scale, with effort and innovation it may be possible to identify an option or options which can make a meaningful contribution.

Pumped discharges from local drainage systems may be able to play a part locally in the development of additional water supplies for low lying canals and rivers such as in the Fens. These drainage systems could potentially form a low level reservoir with the ability to hold water and pumping into main rivers and canals could be controlled to top up navigation levels when required. However, this must not be done in a way that is detrimental to the local land drainage and irrigation function and there is a potential conflict of interest, in that extra water to support navigation is likely to be needed in summer when water is normally retained in the low-level system to support irrigation abstractions.

6.9 Summary of measures

Table 6.1 summarises a variety of potential measures which might be used to help adapt to the consequences of increased precipitation. For each measure, reference is made to its likely applicability (to vessel or waterway type, etc.). Possible barriers to implementation are highlighted and the organisations likely to be involved in its delivery are identified. In each case, an attempt is also made to classify the measure, including whether it might be suitable for implementation in the short- or long-term.

Table 6.1 Summary of adaptation measures for increased winter precipitation

Objective	Relevant to	Measure	Potential barriers to implementation	Delivery - co-deliverers	Short-medium term measures	Potential longer term measures
Respond to increased frequency of Strong Stream conditions	Rivers/canals, recreational craft, commercial vessels, infrastructure	Install or improve monitoring /recording systems, telemetry, SCADA	Cost	Navigation authority	No regrets	
	Recreational and commercial vessels	Identify risks and communicate warnings effectively	No significant barriers	Navigation authority	No regrets	
	Rivers and canals, all vessels	Provide extra moorings/ safe havens	Cost	Navigation authority	Adaptive management	
	Rivers and canals, recreational and commercial vessel operators	Education: aim to modify behaviour regarding safety preparedness	Willingness to adapt	Navigation authority, BMF, RYA, IWA, training providers	No regrets	Regulate/ enforce if necessary
Respond to increased frequency of reduced headroom	Rivers and canals, recreational craft, commercial vessels, infrastructure	Install or improve monitoring and recording systems, telemetry, SCADA	Cost	Navigation authority	No regrets	
	Recreational and commercial vessels	Identify risks, effective warnings	No significant barriers	Navigation authority	No regrets	
	Rivers and canals, recreational and commercial vessel operators	Education to modify user behaviour regarding safety preparedness	Willingness to adapt	Navigation authority, BMF, RYA, IWA, users, training providers	No regrets	Regulate/ enforce if necessary
	Rivers and canals, all vessels	Provide extra moorings/ safe havens	Cost	Navigation authority	Adaptive management	

Table 6.1 Summary of adaptation measures for increased winter precipitation (continued)

Objective or issue	Relevant to	Measure	Potential barriers to implementation	Delivery; co-deliverers	Short-medium term measures	Potential longer term measures
Respond to wider implications of increased rainfall	Rivers and canals, infrastructure and assets	Future-proof maintenance programmes, modify navigation assets and infrastructure	Cost, need to protect heritage	Navigation authority, Environment Agency for flood risk and flood conveyance	Capacity building, adaptive management	Research, funding
	Rivers and canals, infrastructure and assets	Raise overhead structures (bridges, etc)	Ownership of structure and land, technical and economic viability, consents	Navigation authority, owner of structure, regulator	Adaptive management	Research, funding
	Rivers and canals, infrastructure and assets	Future-proof new development	Cost	Navigation authority, developer, regulator	Adaptive management	Research, funding
	Storage reservoirs, canals and rivers	Investigate/plan new water storage facilities	Land ownership, consents	Navigation authority, Environment Agency, farmers, conservation bodies	Adaptive management	Research
	Storage reservoirs, canals and rivers	Develop new water storage facilities, apply PIANC 'Working with Nature' concept	Technical and economic viability	Navigation authority, Environment Agency, farmers, conservation bodies	Win-win	Research, funding

Section 7 Adaptation measures: reduced (seasonal) precipitation

Key findings

Two key areas of concern arising from the projected reduction in summer rainfall relate to any increase in the frequency of low flow conditions particularly in natural rivers, and the possibility of water shortages affecting the supply for canals.

Monitoring and data management will be essential in enabling inland navigation authorities to begin to adapt to the implications of reduced summer rainfall. Establishing the viability of navigation, ensuring effective communication of warnings and managing user expectations in the event of a navigation closure will similarly be important.

The need to secure a long-term supply of water for navigation will require affected navigation authorities both to prepare their own water resource, conservation and use strategies (i.e. understanding and setting out their requirements) and to become involved in others' strategic water planning initiatives, for example the preparation and review of river basin management plans under the Water Framework Directive.

Navigation authorities could introduce a variety of practical 'no regrets' steps to conserve water, for example undertaking maintenance so as to prevent leakage and losses, improving the management of locks, sluices and weirs to conserve water and preparing a Code of Practice to help ensure user understanding.

If conditions worsen, however, more frequent use of measures such as enforced lock-sharing, or navigation restrictions or closures, may be required. Other longer-term measures, potentially including incentives to encourage users to use less water-stressed parts of the network, require further investigation.

Low water levels can threaten the integrity of navigation infrastructure (for example through removal of hydraulic support from the waterside face). Asset monitoring and maintenance will thus be vital, as will future-proofing any modifications and new infrastructure.

Reduced precipitation and associated low flow conditions can have significant consequences for aquatic ecology. Whilst navigation may not be the cause of the problem in such situations, it will nonetheless be important to ensure that navigation-related activities do not exacerbate the situation. 'No regrets' measures such as awareness-raising (amongst both navigation personnel and users) should be used in the first instance but other measures may sometimes become necessary - for example releasing stored water or holding water to maintain levels, operating locks and sluices to improve aeration or placing constraints on dredging or on boating activity to avoid compounding dissolved oxygen problems.

7.1 Climate change context

Changes in precipitation, notably the projected reduction in summer precipitation of up to 30% by 2080, will potentially have some significant implications for inland waterways in England and Wales, limiting navigation as a result of insufficient depth and/or restrictions on lock operation. Canals could be particularly severely affected but, as illustrated by the low flow problems experienced on the Thames in 1976 (*Environment Agency Science Report SC030303*, 2007), many rivers will also be susceptible to the consequences of reduced precipitation.

Whereas it is expected that there will be a wide range of potential issues and challenges for inland waterways as a result of reduced summer precipitation, two key concerns are associated with:

- reduced flow levels in navigable rivers; and
- water resource shortages affecting water supply for canals.

The water resources supplying the canal network and individual lengths of canal are currently managed on an annual basis, on the presumption (and hope) that both reservoirs and spring or river feeders will be naturally replenished. There is no ability to carry over stocks of water on a strategic longer-term basis.

It is considered that, with the predicted reduction in summer precipitation, summer flows into reservoirs and feeders could diminish by up to 15% by 2020. Reductions in rainfall are likely to be compounded by greater evaporation and transpiration associated with higher ambient air temperatures, higher soil moisture deficits in surrounding land and possible increases in leakage due to minor cracking of embankments.

An increased frequency of low flow conditions on navigable rivers should also be anticipated. For example, work carried out by the Environment Agency (2007, *op cit*) into the possible impacts of climate change on inland navigations indicates that the baseline drought condition experienced in 1976 on the Thames could happen twice as often by 2040 and by 2020 some type of restriction on navigation will be twice as likely to occur in any one year as at the present time. Whilst the analysis also reveals a large degree of uncertainty about these projections, especially further into the future, it nonetheless appears likely that some measures will be required to manage a number of navigation risks associated with such conditions (not least the increased risk of grounding) and to help avoid conditions which could potentially lead to the need to temporarily close affected stretches of the waterway to navigation. This conclusion is confirmed by more recent work from the Environment Agency: a press release in March 2009 indicates that, by 2050 average summer river flows in England and Wales could reduce by as much as 50 to 80 per cent (Environment Agency, 2009).

Whilst certain waterway systems may need to secure a supplementary water supply, it is clear that more effective management of existing water resources will become vital in all cases. Such efficiencies might be achieved, *inter alia* by reducing losses out of the network (e.g. via managing back-pumping) and through better husbandry of existing resources (e.g. using SCADA or telemetry technology).

Some waterways are sources of water for public supply, such as the Chelmer and Blackwater Navigation, where the water company supports infrastructure maintenance

Another consequence of lower summer rainfall could be an increase in demand for recreational use of inland navigations - in turn potentially exacerbating many of the problems described above. Navigation authorities will need to understand these demands to be able to justify investment in infrastructure and equipment to reduce losses and manage existing and future water supplies.

In order to address the various consequences for inland waterways of reduced summer precipitation, a hierarchy of measures is required. In the first instance, measures should be explored which aim to reduce the likelihood of low flow conditions affecting navigation and navigation-related activities and infrastructure. Other measures will then be needed to ensure that the implications for navigation of such events are minimised, and finally strategies will be required to manage such events when they arise.

Finally, it is worth noting that measures to respond to climate change will need to be implemented taking into account recent changes in the statutory and regulatory framework including, amongst other things, with the implementation of the EU Water Framework Directive and the new licensing regime for water abstraction. .

7.2 Responding to low flow conditions

As with high flow events, monitoring, data collection and information management will be equally important in enabling navigation authorities to understand and respond appropriately to low flow conditions. Thus the measures discussed in Section 6.2 apply equally here. Installing or improving telemetry or SCADA systems, maintaining a long-term data base, using this information to set risk-based thresholds, and ensuring effective communication of warnings to users will also be important 'no regrets' measures in responding to the issues raised by reduced summer precipitation.

7.3 Strategic planning and management measures

In order to manage limited water resources effectively so as to reduce the likelihood of a low flow event occurring, a number of strategic planning and management initiatives will be required. These will necessarily involve both navigation authorities and a range of partner and stakeholder organisations.

Navigation authorities will need to make more use of the opportunities provided to enshrine relevant inland navigation's water requirements in strategic initiatives being prepared at national level (for example, through Defra's Future Water initiative, see http://www.defra.gov.uk/Environment/water/strategy/) and regionally, in relevant regional spatial strategies and local plans, water industry plans, etc.

Another potentially useful and certainly timely initiative, however, is the preparation of river basin management plans (RBMPs). Under the Water Framework Directive, these statutory plans are being prepared (2009) with the objective of delivering good (ecological and chemical) status via sustainable water management by 2015 (see Section 4.3). Climate change is becoming an increasingly important component of these river basin plans and it is anticipated that the second round plans (due in 2015) will include specific climate change mitigation and adaptation measures.

Given that other sectors are already making their needs and expectations clear, inland navigation authorities urgently need to engage fully in the preparation and review of these plans. Such engagement will enable the sector to raise awareness of the issues it faces, and to ensure that its requirements are acknowledged and adequately accommodated.

Given the current climate change projections, it is conceivable that there will be considerable competition for water in future - for domestic, industrial and agricultural use, to ensure the dilution of sewage and to support environmental interests, as well as for navigation. In certain areas, careful planning to balance these multiple uses will become essential. There will therefore be considerable pressure on navigations authorities to ensure that their interests are considered as far as practicable and to manage their users' expectations against a statutory framework which will influence the allocation of scarce water resources.

To this end, and in order to ensure that their participation in the above strategic level planning initiatives is well-informed, it will be essential that all navigation authorities develop a water strategy. Such strategies, which will need to be founded on a proper assessment of the current and future situation, will enable navigation authorities to highlight any deficits and, where appropriate, to take action to protect their existing abstraction rights and to balance their possible future demand against the requirements of other abstractors. It is suggested that such work is undertaken so as to attain a 1in 20 year standard against closure in the event of shortages.

If the water strategy preparation exercise highlights that additional water resources are indeed likely to be required, the navigation authority will need to consider a variety of options. Necessary water management actions may include:

- increased use of local feeders, either gravity or pumped feeds;
- development of new, or increased yields from existing boreholes;
- local back-pumping at flights or individual locks;
- increased or new reservoir capacity; and
- network management strategies to control use of resources remotely.

Some canal reservoirs, such as this one at Daventry, are already insufficient to meet water needs in dry summers and supply is supplemented by back-pumping at locks

7.4 Operational water supply and water conservation measures

As a matter of good practice in the light of current climate change projections, all navigation authorities should be prepared to take practical steps to conserve water. Some such measures will be 'no regrets' measures which will deliver benefits irrespective of the prevailing conditions. Other measures might only be applicable or justifiable in situations where low flow conditions are imminent or already present.

Good practice with regard to the operation of navigation infrastructure might include:

- maintaining the system so as to eliminate leakages and limit losses as far as practicable;
- careful management of infrastructure such as locks, sluices and weirs (e.g. investment in back-pumping, using renewable energy wherever possible to reduce greenhouse gas emissions); and
- a network management strategy to control use.

A voluntary Code of Practice might also be drawn up to educate users about water conservation measures. Any such documentation should also help users to understand why, in extreme conditions, it may be necessary to close a particular stretch of waterway.

Based on experience with historic extreme low flow or drought conditions, other measures which might be introduced progressively in anticipation or as conditions worsen include:

- enforced lock sharing;
- overnight closures;
- introduction of a curfew for cruising;
- ensuring that canal pounds are not excessively 'robbed' of water to service downstream lengths; in some cases this may require the locking or physical removal of operating gear

such as spindles and paddle rods to prevent unauthorised use;

- retaining water within the system using sluices, weirs or temporary structures to raise weirs;
- restoration of side ponds at locks (plus provision of clear instructions) to help conserve water supplies; and
- closing canals until resources are replenished and adequate to support use.

Restoration and use of historic side ponds at locks could save water. This principle is also used in 'economiser' locks on major modern waterways in continental Europe.

Longer term options might include incentives (e.g. reduced licence fees or moorings charges) to encourage users to move to a less 'stressed' part of the network, providing this can be achieved without other unacceptable impacts, for example on ecology.

Where a drought order has been issued or where drought conditions are prevailing, the Environment Agency may set a minimum water level which is to be maintained to protect the infrastructure and the ecological value of the waterway (the Minimum Flow). In such cases, it will become critical for the navigation authority to manage its operations in a way which maximises the availability of navigation for the longest possible period - for example using the water conservation measures outlined above. However, in this situation it is entirely feasible that, as in past droughts, closures will have to be imposed from time to time and users' expectations will therefore have to be managed accordingly.

7.5 Infrastructure vulnerability

Navigation authorities will need to ensure that their routine asset monitoring and maintenance activities identify any structures which could potentially be vulnerable if low flow/drought conditions reduce or remove hydraulic support from the waterside face. Structures which could be vulnerable in the event of rapid drawdown should similarly be identified and monitored. In both cases, if significant risks are identified the structures will need to be strengthened or modified accordingly (or rapid drawdown avoided where possible).

Lower water levels may occasionally result in damage to lock cills (e.g. if deeper drafted craft impact upon them). Steps should therefore be taken to ensure that a minimum under-keel clearance is maintained. Alternatively it may be necessary to close the navigation until water levels recover sufficiently to remove the risk. Lock and bridge approaches may similarly become more vulnerable to damage as craft attempt to sail in shallower conditions. However, long term dredging should be used to address this issue as good practice would require such approaches to be cleared.

Finally, as discussed in Section 6.7, whenever significant modifications or made to existing infrastructure, or when new assets are being planned, care should be taken to future-proof such activities. This will help to ensure that such infrastructure will be able to withstand the projected future effects of climate change over its design life.

7.6 Ecological effects

Reduced precipitation and associated low flow conditions have the potential to affect aquatic habitats detrimentally, including marginal areas and adjacent wetlands. If water levels drop, water-dependent species of flora and fauna are vulnerable and their survival may be compromised. Depending on the duration of the event, certain plant species may die-back or be lost and associated insects, fish and birds might be threatened as a result - through losing a source of food, through exposure to predators or due to an interruption in up- and down-stream connectivity.

In addition to marginal or bankside habitats, nearby wetland areas may depend on navigable rivers and canals for their water supply, whether directly through side channels, via infrastructure such as sluices or, occasionally, through seepage. As a result of the historic loss of wetland habitats over many years (due to land drainage, infilling for development, etc.), many remaining wetland areas are protected under international, national or local initiatives.

Depending on the nature of the protection, either the conservation agencies or the Environment Agency (e.g. through the designation of water protection zones, see Section 7.7) could require measures to be taken - which could, in turn, have implications for navigation. In some situations, maintaining water levels to support wildlife will also be beneficial for navigation.

Similarly, where water loss is a result of drying out, fissuring or malfunction of navigation infrastructure such as sluices or locks, it will be in the navigation authority's interest to remedy the problem. In other cases, however, making water available to protect wildlife interests might further reduce the amount available for lock and sluice operations, etc. There is thus the potential for conflict, and careful management will be needed to ensure that a balance is achieved between the requirements of navigation and those of nature.

As it seems likely that low flow conditions will occur much more frequently due to climate change (see Section 7.1), navigation authorities would benefit from an improved understanding of site-specific ecology-water interdependencies. Such an understanding would enable them to anticipate any problems, to explore potential 'win-win' opportunities to store excess winter rainfall (e.g. as discussed in Section 6.8) and to develop a contingency plan including measures such as releasing fresh water from storage where available or using lock, sluice and weir operation to aerate the water.

Lock gate replacement at Braunston – prevention of leakage at locks will become increasingly important

Finally, in extreme low flow conditions, as water resources diminish during the summer season it will become increasingly important to retain sufficient water within the river reach or canal pound to protect the ecology. As a consequence, there may be situations in which the use of locks has to be temporarily suspended.

7.7 Pollution

As indicated above, the reduced capacity for flushing or dilution during periods of low flow could lead to additional water quality problems associated with inputs from sewage treatment works, run-off from agricultural land, discharges, etc. As a consequence, problems with oxygen depletion, algae or weed growth and/or increased concentrations of contaminants in sediments (which can act as a 'sink' for pollutants) might be anticipated (for example, see BMVBS, 2007).

Whilst such issues may arise largely irrespective of navigation use of the waterway, care will be required to ensure that the environmental problems are not exacerbated by either vessel movement or navigation related activities such as dredging. To this end, navigation authorities will need to remain appraised of the outcomes of (routine) monitoring undertaken by the Environment Agency and others. Indeed, in certain situations, it may be prudent for navigation authorities to carry out their own monitoring of relevant parameters (e.g. water level, turbidity, dissolved oxygen, certain chemical parameters) in order to inform decision-making on operations and activities (e.g. dredging, sluice or lock operation) which could affect water status.

Depending on the nature, severity, spatial extent and longevity of the problem, measures might be required to minimise sediment resuspension or reduce the duration of oxygen deficits, for example via:

- artificial aeration of the water;
- spatial, temporal or methodological constraints on dredging;
- additional (temporary) speed restrictions in areas of low under-keel clearance; and/or
- making water available from storage, by managing weir overflow, etc.

It will also be important to ensure that discharges from vessels (particularly of black water) do not exacerbate the problem: this could be a particular issue insofar as houseboats are concerned.

In most cases, the preferred way of ensuring that navigation does not exacerbate the identified problem would be through an education campaign aimed at modifying the behaviour of users or navigation authorities as appropriate.

In this respect, there may be lessons to be learned from the 'Green Blue' initiative which is aimed mainly at marine recreational users. The Green Blue uses a combination of posters, leaflets and brochures, stickers, and other communication tools including the Internet to ensure that both boat clubs and vessel owners are aware of, and have the opportunity to contribute to addressing, a number of navigation-related environmental issues (see http://www.thegreenblue.org.uk/about/index.asp).

A similar example from the Boat Safety Scheme involved the issue of 'good practice' briefing packs and leaflets to the hire boat industry and to individual boaters warning about the dangers of carbon monoxide.

In the event of a prolonged and serious water quality problem, it is possible that regulatory measures may be required, either by the navigation authority or by third parties. For example under the Water Framework Directive it is intended to extend the Environment Agency's powers to identify 'water protection zones', areas within which any activity affecting ecological or chemical water status could be (temporarily or permanently) constrained or prevented. Further information about the proposed new WPZ powers can be found at http://www.defra.gov.uk/corporate/consult/water-protection-zones/. Similarly, if protected species or habitats are adversely affected, the conservation agencies might require certain measures to be implemented or activities constrained.

7.8 Summary of measures

Table 7.1 summarises a variety of potential measures which might be used to help adapt to the consequences of reduced summer precipitation. For each measure, reference is made to its likely applicability (to vessel or waterway type, etc.), possible barriers to implementation are highlighted, and the organisations likely to be involved in its delivery are identified. In each case, an attempt is also made to classify the measure, including whether it might be suitable for implementation in the short- or long-term.

Table 7.1 Summary of adaptation measures for reduced summer precipitation

Objective or issue	Relevant to	Measure	Potential barriers to implementation	Delivery: co-deliverers	Short-medium term measures	Potential longer term measures
Respond to increased frequency of low flow conditions	Rivers and canals, recreational and commercial vessels, infrastructure	Install/improve monitoring systems, telemetry, SCADA	Cost	Navigation authority	No regrets	
	Recreational and commercial vessels	Identify risks, communicate warnings effectively	No significant barriers	Navigation authority	No regrets	
Consider navigation water demand in strategic planning	Infrastructure, assets, storage reservoirs	Water resources strategic planning (e.g. WFD)	Lack of data in some cases	Navigation authority, Environment Agency, local authorities, water industry	Adaptive management	Research
	Above plus canals and rivers	Develop water strategy	Lack of data in some cases	Navigation authority	Adaptive management	Research
Ensure operational water supply	Storage reservoirs, canals and rivers	Adopt water conservation/ management measures	Lack of knowledge	Navigation authority	Capacity building, no regrets	Research
	Recreational and commercial vessels	Education regarding measures for water conservation	Willingness to adapt	Navigation authority, BMF, RYA, IWA, users	No regrets	
	Rivers and canals, recreational craft	Incentives, e.g. to use 'less stressed' water bodies	Willingness to adapt	Navigation authority, users	No regrets	Research
	Rivers/canals, recreational craft	Regulate user numbers to ensure water conservation	Willingness to adapt	Government, Navigation authority		Regulation if voluntary approach is ineffective
Reduce infrastructure vulnerability	Rivers and canals, storage reservoirs, infrastructure	Improve resilience via maintenance, modifications	Cost	Navigation authority	No regrets	

Table 7.1 Summary of adaptation measures for reduced summer precipitation (continued)

Objective or issue	Relevant to	Measure	Potential barriers to implementation	Delivery: co-deliverers	Short-medium term measures	Potential longer term measures
Protect vulnerable ecology	Rivers and canals, storage reservoirs, feeders	Improve understanding of ecology	Lack of data in some cases	Navigation authority, BMF, RYA, IWA, users	Capacity building, no regrets	Research
	Rivers and canals, storage reservoirs, feeders	Avoid impacts, contingency planning	Data availability	Navigation authority, conservation agencies	Adaptive management	Research
	Rivers and canals, storage reservoirs, feeders	Release water for wildlife	Availability, implications for navigation	Navigation authority, Environment Agency, water companies	Adaptive management	Research
Prevent pollution	Rivers and canals, storage reservoirs, feeders	Targeted water quality monitoring	Cost	Navigation authority, Environment Agency, conservation agencies	Adaptive management	Research
	Rivers and canals, storage reservoirs, feeders	Constrain activities to avoid pollution	Behaviour	Navigation authority, BMF, RYA, IWA, users	Adaptive management	Research
	Rivers and canals, storage reservoirs, feeders	Education regarding pollution prevention	Willingness to adapt	Navigation authority, BMF, RYA, IWA, users	No regrets	

Section 8 Adaptation measures: changes in sedimentation

Key findings

Changes in the frequency and duration of severe weather events could have implications for sediment run-off, for sediment transport, and for deposition or accumulation. The risk of groundings might therefore increase and there may also be a reduction in capacity (for example in storage reservoirs). Depending on their severity, such changes could have implications for navigational safety and for navigation authority operations such as dredging, as well as for biodiversity and the wider environment.

Where problems with sediment in run-off are identified and the inland navigation authority is the owner of the offside or riparian land, the authority may be able to create buffer strips, reed beds or similar as a 'no regrets' measure to intercept run-off and hence reduce the amount of sediment (and possibly associated pollution) entering the watercourse. In other cases, a partnership approach with relevant farmers or conservation organisations might allow a 'win-win' solution to be identified.

Another source of sediment input is the erosion of the river bank at the waterline. Like buffer strips, 'green engineering' bank protection such as willow spiling, plant rolls and coir revetments can help to stabilise the bank and minimise erosion. Such measures can be considered 'no regrets' measures if bank protection is already required; otherwise they become an option for adaptive management. Depending on site-specific requirements, additional measures to prevent erosion due to boat wash may be needed. Vessel speed restrictions can help to limit wash and thus erosion and the use of vessels with eco-hulls can similarly reduce wash. Assuming voluntary measures are preferred to additional regulation, this is another area in which user education may be of value.

Where sediment has accumulated in a water body and monitoring indicates a risk to navigational safety, additional dredging might be required. As dredging can in turn have adverse environmental impacts, local factors will need to be considered to assess whether there is a viable alternative to dredging. If no such alternative exists, steps should be taken to optimise timing and method of dredging, in order to protect water quality and ecology.

Removal of accumulated sediment from water storage reservoirs is a laborious and expensive process. Where monitoring indicates a potential problem, preventative measures such as buffer strips and silt traps should be investigated as adaptive management options. If sediment accumulates to such an extent that the capacity of the reservoir is compromised, it may be necessary to seek an alternative water resource.

8.1 Climate change context

Changes in the frequency and duration of severe weather events will in turn have implications for sediment accumulation and transport. More winter precipitation, for example, may mean an increase in the amount of sediment reaching water bodies through run-off or erosion of river banks due to changes in flow regimes. Increases in sedimentation may be compounded by lower summer flow rates reducing the potential for the natural downstream transport of accumulated sediment. In other cases, increased winter flows may improve sediment removal from the navigation.

Where sediment accumulates, navigable water depths may reduce and the risk of groundings may increase. There may also be a reduction in capacity (for example in storage reservoirs). Further, if this increase in sedimentation leads to an increased requirement for dredging (i.e. in addition to current requirements), there may be additional problems associated with the resuspension of sediment or smothering resulting from the deposition of this re-suspended sediment. Issues associated with the potential build up of contaminants in sediment and oxygen depletion are dealt with in Sections 7.7 and 10.2.

Depending on their severity, changes in sedimentation could have significant implications for inland navigational safety and hence for navigation authorities' operational activities, as well as for biodiversity and the environment. A range of adaptive management measures will therefore need to be considered.

8.2 Measures to reduce sediment entering water bodies from agricultural run-off

Much of the sediment entering navigable waterways is derived from agricultural land (Environment Agency, undated, Broads Authority, 2007). Without preventative or mitigating measures, it is likely that increased winter rainfall and any increase in the frequency of (summer) storm events will result in further increases in run-off and hence sedimentation.

Where an inland navigation authority is also the owner of offside or riparian land, it may be possible for the authority to create buffer strips, reed beds or similar in areas adjacent to the river or canal to intercept run-off and hence reduce the amount of sediment (and possibly associated pollution) entering the watercourse. Buffer strips work by reducing the velocity of run-off and relying on the 'roughness' of vegetation to trap the sediment. Buffer strips should generally be 1-5m wide, dry, free-draining, aerobic and planted with appropriate species (e.g. grasses) to provide effective sediment management (Environment Agency, undated).

In addition to acting as a sediment sink, buffer strips can be used to assimilate and transform nutrients and to break down pesticides. However, they are only effective in this role of removing soluble pollutants in land which is not under-drained.

Buffer strips can also play a role on urban canals

Buffer strips can make a significant contribution to habitat and wildlife diversity as they support both fauna and flora. Appropriately planted and maintained, they can also benefit the farmer, for example by providing a habitat for beetles and other predators of crop pests and by preventing the migration of harmful weeds. Buffer strips can therefore often be promoted as a 'win-win' measure.

Other opportunities to prevent the deposition of sediment prior to the water entering the canal or river (e.g. via sump pounds from intensively-used shallow and hence turbid canals) should also be actively considered. The creation and continuing maintenance of silt traps across the inflows to canals or reservoirs can provide one such option with potentially significant long term economic and operational benefits in that permanent adjacent disposal procedures can be established. The creation of reed beds can also allow fine particulate sediment to be removed. Silt traps may also be appropriate on the outflows from sump pounds of busy shallow (and thus highly turbid) canals onto rivers. It is essential, however, that all types of existing or newly created silt traps are regularly maintained.

Agricultural run-off is a matter of concern under the Water Framework Directive, not only from the point of view of preventing sedimentation *per se*, but also in stopping nutrients and pesticides entering the water body. In this respect, it is not only the creation of buffer strips but also the adoption of other forms of agricultural good practice (e.g. cultivation methods) which are relevant. This in turn links in to Defra's Catchment Sensitive Farming (CSF) programme which aims to develop measures to tackle diffuse water pollution from agriculture *inter alia* to meet Water Framework Directive (WFD) requirements. It is also worth noting that an ongoing (March 2009) Defra consultation (http://www.defra.gov.uk/corporate/consult/gaec/consultation.pdf) is considering a possible requirement for the creation of 6m buffer strips adjacent to all vulnerable water-bodies.

Thus where the navigation authority is not also the riparian land owner, it will be important for it to work with the Environment Agency, the farming community and others to raise awareness of areas of common concern. More specifically, in areas where agricultural run off is a problem not only under the WFD but also for navigation, measures to address this problem could be included in the relevant River Basin Management Plan.

Case Study: Buffer Strip Creation at the Grand Western Canal Country Park

The desirability of creating offside buffer strips to reduce silt and nutrient inputs and to improve wildlife habitats in the Grand Western Canal Country Park and Local Nature Reserve (a 17km rural stretch of isolated waterway in Devon) was first identified in the 1990s. However, significant work to bring this about only commenced in 2003.

A Countryside Stewardship Scheme agreement with Defra offered the opportunity to claim capital payments for some 4km of offside banks to be fenced to create wildlife strips. The other main elements of the agreement were hedge restoration, coppicing bankside trees, disabled access improvements, and annual revenue payments for the on-going management of the wildlife strips.

Prior to 2003, most of the offside ownership was not fenced and was routinely grazed by adjacent landowner's stock, leading to short cropped vegetation and problems of erosion (poaching) caused by cattle feeding on the bankside and drinking from the canal. Where the adjacent land was used for arable farming, a portion of the canal holding was often ploughed and cropped.

All adjacent offside landowners have a right for their livestock to drink from the canal, enshrined when the canal was built. To enable stock to drink whilst fencing off the majority of the bank, surfaced drinking points were therefore constructed. Approximately half the cost of the work was covered by Countryside Stewardship capital funding and over the ten years of the agreement, £13k will have been received in revenue payments for managing the strips (mowing and raking where necessary to prevent scrubby growth).

Source: http://www.devon.gov.uk/gwcbufferstripcasestudy.pdf

8.3 Prevention of bank erosion

Bank erosion resulting in the release of sediment into the waterway, can be largely prevented through the use of steel sheet piling. However, piling is both very expensive and environmentally undesirable as it results in the loss of habitat, interrupts connectivity, etc. By helping to stabilise the river bank, buffer strips can also help to reduce sediment input, however, there are many other 'green engineering solutions' to help reduce river bank erosion, for example using willow spiling, plant roll, willow mattress or hurdle or coir matting revetments, log toes, etc. (see, for example, AINA, 2008, Broads Authority, 2004; BAW, 2006). Geotextiles may also be used to promote or support a more environmentally-friendly, naturally vegetated riverbank.

Geotextile bank protection limits erosion by boat wash, while reed planting behind can create a buffer for land run-off

In addition to (soft)-engineering solutions, vessel speed and hull design can both be relevant considerations in reducing river bank erosion. The benefits of limiting speed (whether through behavioural change or regulation and enforcement) to prevent breaking wash, and the potential longer-term opportunities associated with the development of eco-hulls are discussed in Sections 5.2 and 5.4 respectively.

8.4 Removal of accumulated sediments in rivers and canals

Once sediment has accumulated in the system to the extent that it impacts upon safe navigation, it must generally either be moved or removed. This is most often achieved by dredging: thus a consequence of climate change may be a requirement for more dredging. However, dredging itself can cause a variety of environmental impacts, several of which could be exacerbated by climate change-induced low flow and/or increased water temperatures. There are also wider implications associated with increased dredging - in terms not only of increased costs but also the additional greenhouse gas emissions from dredging plant. Thus alternatives to simply increasing dredging frequency and/or amounts may need to be considered.

Where new or increased dredging is necessary, efforts should be made to confine activity to the centre of the channel and mooring areas, so as not to disturb marginal vegetation. Options for the beneficial use of the sediment arising should be investigated (e.g. for habitat creation in low-lying areas where flood risk management strategies aim to restore natural flood plains but where the land has settled/been drained and where sediment could thus be accommodated). There may also be beneficial agricultural uses for the material. In these cases, partnership working with the Environment Agency and/or with the local agricultural community will be vital.

On some rivers, it may be possible to anticipate and limit sediment accumulation through flow manipulation (e.g. the construction of training walls or groynes). Elsewhere, sluice or lock operations are used to assist in shifting accumulated sediment (i.e. by increasing flow rates). However, changes in existing procedures may be a high risk strategy without a thorough prior assessment. Hydrodynamic or agitation dredging techniques (such as water injection dredging or ploughing) similarly rely on re-suspending the accumulated sediment such that it is entrained and carried downstream by the natural currents.

Some infrastructure serves both navigation and water management functions, as here at Denver Sluice, where management of flows is crucial to limitation of sedimentation in the tidal Great Ouse navigation downstream, as well as for flood management and maintenance of public water supplies

Where sediment is trapped behind an obsolete structure, the removal of the structure might be investigated to restore natural sediment transport pathways. Sediment by-passing (i.e. physically removing the sediment and replacing it back into the system downstream of the retaining structure) may also provide an alternative but locally viable solution.

In all the above situations, local conditions will dictate the most appropriate action. It is therefore essential that the navigation authority actively monitors areas where sediment is accumulating (see for example Section 7.2 which discusses monitoring requirements to deal with extreme flow conditions).

In parallel to, or informed by, the collection of relevant data, the navigation authority should establish which measures are likely to be both technically viable (given the prevailing natural/physical characteristics) and cost-effective in the event that sediment movement or removal proves necessary. In due course, any such works will also have to be undertaken with in the overall framework of a licensed disposal programme and the associated environmental impact assessment.

Finally, if increased sedimentation cannot be prevented, or if it is not sustainable to continue to move or remove accumulated sediment (e.g. for technical or cost reasons), it may be necessary to explore the use of shallower draft vessels on the affected waterway system(s).

8.5 Prevention and removal of accumulated sediments in storage reservoirs

Where water is stored above ground in reservoirs as an essential part of waterway management (to provide for periods of lower rainfall or peaks in usage) run -off from agricultural land may result in increased sedimentation. Whilst buffer strips (Section 8.2) or silt traps could be used to reduce the amount of sediment reaching such storage reservoirs, not all the options for moving or removing sediment discussed in Section 8.4 for rivers and canals will be appropriate. The creation of silt traps across inflows to reservoirs (also canals) should also be considered. The long term economic and operational benefits of silt traps with adjacent disposal opportunities can be significant. The creation of reed beds as part of the initiative will further allow nutrient-rich fine particulate sediment to be managed. All silt traps, however, require regular maintenance to ensure their continuing effectiveness.

Once deposited, the clearance of silt from large surface reservoirs is an expensive and laborious process. It can be undertaken using long reach excavators, with spoil being removed to adjacent fields, but a more favoured approach is for a floating mini cutter suction dredger to be used to pump the material to lagoons for drying and then spreading on adjacent ground. However, due to the upland location of some reservoirs, this is not always practicable. All silt removal options tend to be expensive and, subject to its availability, it may be prudent to explore an alternative source of water.

If it is necessary to seek a new or alternative water resource, the issues associated with the commissioning of new water supplies are discussed in Section 7. However, if water scarcity precludes the development of new water resources, research into improvements in the design and clearance of silt traps may be justified.

8.6 Environmental implications of increased sedimentation and sediment management

If it is not possible to adopt measures which move additional sediment through the waterway system at 'natural' suspended sediment concentrations, the moving or removal of the additional accumulated sediment could cause environmental deterioration. Particularly in a situation where water temperature has increased as a result of climate change or where low flow conditions predominate, it may be necessary to impose constraints on dredging, sediment disposal or other actions to move sediment.

In many cases, seasonal constraints might be anticipated in order to avoid exacerbating problems associated with low levels of dissolved oxygen (e.g. avoiding dredging during the summer months). However, such constraints would also need to take issues of navigational safety in the interim period (e.g. if dredging of scours in rivers formed by winter floods is delayed until after the summer, the busiest season).

Small scale dredger on the Chesterfield Canal

If temporary closure of the navigation is to be avoided, it may be necessary to explore and employ dredging methods specifically designed to minimise the resuspension of sediments (e.g. certain types of enclosed bucket or clamshell dredger). Whilst such methods may prove technically viable in many cases, they will often have significantly higher associated costs.

Another important consideration, if run-off, dredging or flow manipulation will lead to increased suspended sediment concentrations, will be the destination of the re-suspended sediment. In particular, it will be important to avoid the smothering of protected and/or particularly vulnerable habitats. Developing a good understanding of local physical processes, possibly including modelling to determine the eventual fate of the suspended sediments, will therefore be central to the environmental investigations required prior to undertaking any works (see also Section 9.6 where the need to future-proof new developments is discussed). Such investigations will, in turn, depend on the availability of adequate data, which again emphasises the importance of early identification and monitoring of potentially susceptible areas.

8.7 Summary of measures

Table 8.1 summarises a variety of potential measures for adapting to anticipated changes in sedimentation. For each measure, reference is made to its likely applicability (to vessel or waterway type, etc.), possible barriers to implementation are highlighted and the organisations likely to be involved in its delivery are identified. In each case, an attempt is also made to classify the measure, including whether it might be suitable for implementation in the short- or long-term.

Table 8.1 Summary of adaptation measures for changes in sedimentation

Objective or issue	Relevant to	Measure	Potential barriers to implementation	Delivery; co-deliverers	Short-medium term measures	Potential longer term measures
Reduce sediment run-off into water body	Rivers, canals, storage reservoirs, feeders	Buffer strips, reed beds, silt traps	Land ownership	Navigation authority (if riparian land owner), with Environment Agency, farming community, volunteers	Adaptive management, win-win	
Prevent bank erosion	Rivers, canals	Soft engineering bank protection	Land ownership	Navigation authority	No regrets, adaptive management	
	Rivers, canals	Introduce/enforce speed limits, educate users	Willingness to adapt	Navigation authority; BMF, RYA; IWA; users	No regrets; adaptive management	Severity of problem, behavioural approach success
	Rivers, canals, all vessel types	Vessel (hull) design to minimise wash	Cost, lack of knowledge, behaviour	Inland navigation industry; BMF		Research, economic viability
Remove accumulated sediment	Rivers, canals	Increase dredging	Cost, greenhouse gas emissions, environmental impacts	Navigation authority	Adaptive management	
	Rivers, canals	Constraints on dredging timing and/or method	Environmental impacts	Navigation authority Licensing body	Adaptive management	
	Rivers, canals	Beneficial use of dredged sediment	Environmental impacts, permitting regime	Environment Agency, agricultural community	Win-win	Research
	Rivers, canals	Flow manipulation structures/methods	Uncertainty, environmental impacts	Navigation authority, Environment Agency		Research
	Rivers, canals	Remove obsolete structures, sediment by-passing	Cost	Navigation authority, owner of structure		Severity of problem, economic viability
Remove accumulated sediment	Rivers, canals	Vessel design (shallow draft)	Cost	Navigation authority, inland navigation industry, BMF		Severity of problem, economic viability
	Storage reservoirs	Silt trap clearance, design	Cost, disposal site availability	Reservoir owner, navigation authority	Adaptive management	Economic viability, research, licensing of disposal

Section 9 Adaptation measures: increase in air temperature

Key findings

As well as exacerbating water resource shortages, the additional evapotranspiration associated with higher air temperatures could lead to drying out and fissuring of clay embankments and other earth structures. It might also cause changes in characteristic vegetation types. Warmer summers may result in an extended growing season with consequences for vegetation management and there may be changes in land-use practices in areas adjacent to waterways.

Regular monitoring and condition assessments will be essential 'no regrets' measures where navigation infrastructure could be affected by fissuring, settlement, erosion or undercutting. Vegetation loss or change could similarly affect structural integrity where the vegetation serves an engineering purpose: for example, if the characteristic root mat is lost, a structure potentially becomes more vulnerable. Collecting information on such potential problems will allow early consideration of adaptive management solutions.

Warmer temperatures may have other implications for vegetation management including a requirement for more frequent cutting or clearance and the possible need for new measures to deal with alien or invasive species. Again, monitoring will be essential in informing appropriate management responses.

Warmer and drier British summers might be expected to make domestic holidays and recreation relatively more attractive - particularly when taking into account the expected increase in the frequency of intense heatwaves in the Mediterranean area. Whilst this might represent a significant opportunity for the tourism industry, it could also pose additional challenges for inland waterway managers. As discussed throughout this report, climate change is likely to result in a number of pressures on inland waterways and associated infrastructure - pressures which could be exacerbated if recreational use of both the waterway and the towpath increases. Inland navigation authorities will therefore need to be vigilant: monitoring such changes, assessing their implications and participating in relevant strategic planning and management initiatives. Local factors will determine the most appropriate management options for both water and land-based (e.g. towpath) recreational activities.

Finally, in situations where increased demand means that new infrastructure or facilities are required, care must be taken to ensure that designs are both 'future-proofed', in terms of projected climate change impacts, and sustainable.

9.1 Climate change context

Predicted increases in air temperature will have a variety of direct and indirect implications for inland waterways.

In addition to exacerbating water resource shortages and low flow conditions as discussed in Section 7.1, increased evaporation and transpiration can also affect structural integrity. There may be direct effects associated with the drying out and weakening or fissuring of clay embankments and other earth structures. There may also be indirect effects resulting from climate-induced changes in characteristic (e.g. river bank) vegetation, or if a warmer climate leads to any extension in the range of burrowing animals - either indigenous or introduced species. Any of these factors could cause weaknesses and increase the risk of failure.

Depending on the nature and magnitude of changes in precipitation, warmer summers may also extend the growing season - with potential implications for vegetation management. Insofar as terrestrial ecosystems are concerned (see Section 10 for impacts on aquatic ecosystems), this might result in an increased requirement for cutting or weed management on embankments, towpaths, etc. However, where vegetation plays an engineering role (for example, where a dense root-mat contributes to bank stability), it may be necessary to facilitate a transition to suitable alternative species in order to help maintain structural integrity.

Any changes in the growing season could also affect land-use practices in areas adjacent to waterways, in turn potentially changing (exacerbating) impacts on run-off and sedimentation (see Section 8).

Warmer and drier UK summers, when combined with the expected increase in extreme summer heatwaves further south in Europe and anticipated increases in transport costs, are likely to make UK-based holidays more attractive. There is similarly likely to be a generally greater demand for recreational resources close to where people live. Such factors could lead to an increase in both land- and water-based recreational use of English and Welsh inland waterways, providing opportunities for the sector but also introducing additional risks (*inter alia* associated with numbers or relative experience of waterway users, congestion, etc.) and pressures (both on existing infrastructure and for new development). Proactive planning and management, undertaken in consultation with stakeholders and partner organisations, will therefore be required if benefits are to be realised whilst avoiding adverse effects.

9.2 Water resource issues

Insofar as increased evaporation and transpiration would exacerbate water resource shortages, potential adaptation measures have already been discussed in Section 7.

9.3 Structural implications of increased evapotranspiration

Regular monitoring, inspection and condition assessments will be essential where there is the potential for the structural integrity of navigation assets to be affected by fissuring, settlement, erosion or undercutting. Clay soils, which are frequently used in the construction of embankments and reservoirs, are particularly susceptible to changes in moisture content. Drying out and subsequent re-wetting can lead not only to settlement and an associated loss of freeboard but also to an overall reduction in strength and ultimately failure.

Indirect effects on soils due to vegetation loss or change, or the activities of burrowing fauna, can also cause weaknesses and increase the risk of failure. For example, river bank stability might be affected, particularly at times of high flow, if more competitive annual plants take over from endemic plants with multi-annual growth and hence dense root mats which bind the soil together (BMVBS, 2007). The increased risk of climate-induced stress in trees can also cause problems if trees on river banks, canal embankments or reservoir headbanks topple, in turn causing the partial or full collapse of the earth structure. In the event that burrowing is identified as threatening the integrity of a structure, advice on possible responses may need to be sought from Natural England or Countryside Council for Wales.

The impact of climate change and the role of vegetation in bank stability is currently the subject of two Engineering and Physical Sciences Research Council projects:

- climate impact forecasting for slopes (CLIFFS), a network infrastructure forum including large infrastructure owners such as Network Rail and British Waterways (see http://cliffs.lboro.ac.uk/); and

- biological and engineering impacts of climate change on slopes (BIONICS), an associated project which has included the construction of a heavily instrumented, full size clay embankment to enable the simulation of future environmental and vegetation changes (see http://www.ncl.ac.uk/bionics/).

The potential increased risk of failure under a scenario of climate change reinforces the need for frequent and effective monitoring and inspection of all retaining structures. The outcomes of this monitoring will be required to inform decisions on maintenance activity and to identify where modification (e.g. strengthening) or replacement of an asset is required to maintain stability. In some cases, it may be necessary to identify measures to limit the impact of any failure - for example, developing a contingency plan to dewater or draw down impounding structures. Monitoring needs are discussed further in Section 7.2.

The drought conditions that will be experienced more often during the summer may well also cause shrinkage of clay soils, notably in the South of England. Due to the age of many of the navigation structures and the design parameters at the time of construction (i.e. shallow footings of 600mm or less and little tensile strength) clay shrinkage may cause damage. Regular asset inspection and good vegetation management should therefore be employed to reduce the risk of failure. Additional strengthening or underpinning of susceptible structure will have to be considered on a case by case basis and built into future funding and maintenance programmes as required.

9.4 Vegetation management

Monitoring, undertaken by either the navigation authority or third parties, will facilitate the detection of any potentially significant change in characteristic vegetation types (i.e. as a result of the predicted northward movement of temperature- or moisture-sensitive species; see, for example, BBC (2006)) including the spread of invasive, non-indigenous or alien species.

Additional resources may be required for tree management to keep navigation channels clear in the future

Monitoring outcomes, including the monitoring being undertaken by the Environment Agency under the WFD and by conservation agencies with regard to protected sites, will help inform decisions on revised vegetation management measures, for example:

- identifying whether any loss or change in vegetation type is occurring which may threaten the integrity of the structure through loss of root mat, fissuring, erosion, etc. This will in turn enable a decision to be taken on whether and how to introduce different (e.g. drought tolerant) vegetation species with suitable engineering properties or whether an alternative form of bank protection is required (see Section 8.3);
- highlighting any requirement to increase the frequency of cutting or vegetation clearance – for example where towpath or bankside vegetation growth is affecting access, where there is excessive encroachment of river bank vegetation into navigation channels or where overhanging branches causing a hazard to navigation;

- undertaking environmentally friendly maintenance (e.g. working only from one side of the water course and leaving the other side undisturbed);
- identifying the introduction/spread of, and implement measures to manage or eradicate, invasive or alien species such as Japanese knotweed or giant hogweed. This is particularly important in protected sites or where protected species are present; and
- determining whether the (additional) application of biocides is required (assuming this is environmentally acceptable).

9.5 Increased recreational demand: pressure on existing infrastructure

Warmer summers are likely to provide a significant opportunity for UK-based tourism, including recreational water use of inland waterways and adjacent land-based resources. However, careful forward planning will be required to ensure that associated pressures are managed such that the sustainability of the activity is not compromised and the potential benefits can be realised. In particular, Sections 6 and 7 above highlight some of the potential risks associated with both increased flow rates and, particularly, with more frequent and prolonged low flow conditions and water resource shortages predicted to result from climate change.

National and regional strategic planning and management initiatives (and, if appropriate, related strategic environmental assessments) will have an important role to play in sustainably accommodating any significant increase in demand for use of existing infrastructure and other supporting facilities. However, whereas such an approach may help to alleviate pressures in certain areas and identify opportunities in others, strategic planning alone will not be able to resolve all the issues.

Some combination of the following measures is therefore may also be required:

- research and investigations (e.g. to improve understanding of the carrying capacity of both natural and human systems under a range of climate-change scenarios);
- education and awareness raising aimed at minimising problems/ensuring sustainability through voluntary and behavioural responses (e.g. conserve water, minimise erosion, prevent resuspension);
- incentives: carrot-and-stick measures (e.g. climate-aware marketing combined with a pricing structure to encourage greater use of the shoulder seasons, charging increased licence fees for high use areas of the network to encourage craft to use under-utilised areas or shortening closure periods during the winter to extend the availability of the network);
- voluntary or regulatory constraints on certain activities and operations *inter alia* to conserve water (e.g. locking practices, including back-pumping, developing moorings away from areas of high use to low use areas of the network); and
- regulation and enforcement to deal with unlawful use such as swimming or inappropriate use of water craft.

Warmer weather for longer periods will also lead to increased use of towpaths and river banks *inter alia* by walkers and cyclists. There will be associated opportunities to work in close liaison with partner organisations, the local community and other stakeholders to develop and exploit the potential benefits of using towpaths in particular as access to local facilities including schools.

As part of such initiatives, consideration should be given to improvements (e.g. in surfacing) to all weather use, to reduce maintenance and to allow for multiple uses, all assuming adequate management regimes are in place.

A further practical aspect of any significant increase in air temperature relates to ensuring the operational viability of operating equipment. All mechanical and electrical equipment must therefore be designed to operate at higher temperatures, additional cooling or larger cables may be required and potential problems resulting from heat-expansion will need to be anticipated and resolved (e.g. with swing bridge operation).

Swing bridges may experience increased expansion

9.6 Increased recreational demand: new development

If demand for inland navigation infrastructure and facilities outstrips supply and new development is proposed, reference will need to be made to relevant strategic plans as these will provide the context within which site specific new development might take place.

New infrastructure such as storage reservoirs, new marinas and water-side developments and other significant projects (e.g. canal restoration initiatives) will typically already have to go through a site-specific environmental impact assessment (EIA) process in order to identify and avoid, mitigate or compensate for any potentially significant environmental impacts. Such projects will also be subject to Article 4(7) of the Water Framework Directive if the proposals could adversely affect the ecological or chemical status of the water body. Article 4(7) of this Directive sets out the conditions under which new modifications which adversely affect water status can be allowed.

As part of the process of setting the objectives for a new project, care should be taken to understand the natural environment – including projected climate change scenarios – and to work with other interested parties to identify 'win-win' opportunities. PIANC's recent position paper *Working with Nature* (PIANC, 2008) encourages project proponents to work with natural processes to deliver environmental protection, restoration or enhancement outcomes alongside their project objectives and suggests that this can be achieved by:

- focusing on achieving the project objectives in an ecosystem context rather than on assessing the consequences of a predefined project design; and
- focusing on identifying 'win-win' solutions rather than simply minimising ecological harm.

Further advice on working with nature conservation interests is given in IWAC (2008b).

In order to make new infrastructure, marinas, etc. resilient in the light of anticipated further changes in climate, it will be necessary to ensure that proposals are 'climate proof'. Thus, insofar as current knowledge and understanding allows, their design should incorporate the measures necessary to prevent their objectives or effectiveness being compromised should there be further changes in precipitation, sedimentation or temperature.

New marinas may be required to cope with greater demand

Whereas there are knowledge gaps in this respect and some technical solutions still have to be developed, many potential solutions are available including the various 'no regrets' and 'win-win' measures highlighted in this report.

Regulatory requirements are already in place to help ensure that new development is sustainable. Whilst climate-proofing is also likely to be included within this regulatory framework in due course, voluntary measures to achieve this should be taken in the meantime - not least to ensure the resilience and therefore longevity of the proposed development. Adopting PIANC's Working with Nature approach to project development should help to ensure that proposed developments are both climate proof and sustainable.

9.7 Summary of measures

Table 9.1 summarises the variety of potential measures for adapting to the changes associated with the projected increase in air temperature. For each measure, reference is made to its likely applicability (to vessel or waterway type, etc.), possible barriers to implementation are highlighted and the organisations likely to be involved in its delivery are identified. In each case, an attempt is also made to classify the measure, including whether it might be suitable for implementation in the short- or long-term.

Table 9.1 Summary of adaptation measures for increased air temperature

Objective or issue	Relevant to	Measure	Potential barriers to implementation	Delivery; co-deliverers	Short-medium term measures	Potential longer term measures
Prevent structural deterioration and failure related to drying out	Rivers, canals, storage reservoirs, other navigation infrastructure	Monitoring, research maintenance, modification or replacement of structures	Cost Heritage issues	Navigation authority Environment Agency[1] Conservation agencies[2]	Adaptive management	
Modify vegetation management procedures to match growing season	Rivers, canals	Use vegetation species with suitable engineering properties	Uncertainty	Navigation authority Environment Agency[1]		Research
	Rivers, canals	Investigate alternative forms of bank protection	Cost	Navigation authority, Environment Agency[1]		Severity of problem
	Rivers, canals, storage reservoirs, towpaths	Increase frequency of cutting or weed clearance	Cost	Navigation authority, landowner, Environment Agency[1], conservation agencies[2], volunteers	Adaptive management	Increased use of water, towpaths, etc.
	Rivers, canals, storage reservoirs, towpaths	Eradicate/manage invasive or alien species	Technical viability Cost	Navigation authority landowners, Environment Agency conservation agencies[2], volunteers	Adaptive management	Research, severity of problem
	Rivers, canals, storage reservoirs, towpaths	(Additional) application of biocides	Environmental impacts	Navigation authority, landowner, Environment Agency	Adaptive management	Severity of problem

Table 9.1 Summary of adaptation measures for increased air temperature (continued)

Objective or issue	Relevant to	Measure	Potential barriers to implementation	Delivery: co-deliverers	Short-medium term measures	Potential longer term measures
Sustainably manage increased use of existing facilities	Rivers, canals, towpaths, other navigation infrastructure	Prepare strategic planning and management initiatives to help deliver integrated, sustainable use	Cost	Navigation authority, local authority, national/regional Government, Environment Agency, stakeholders	Adaptive management	Investment in supporting facilities: access, toilets, car parks
	Rivers, canals, towpaths, other navigation infrastructure	Research on the carrying capacity of natural and human systems	Funding	Navigation authority, conservation agencies, academia		Research
	Rivers, canals, towpaths, other navigation infrastructure	Education and awareness raising, changes in behaviour	Willingness to adapt	Navigation authority, waterway users	No regrets	
	Rivers, canals, towpaths, other navigation infrastructure	Incentives, pricing structures, fiscal measures	Administration, regulatory basis, ownership	Navigation authority Asset owners or managers		Severity of problem, economic viability
	Rivers, canals, other navigation infrastructure	Voluntary or regulatory constraints on operations	Willingness to adapt	Navigation authority	Adaptive management	
	Rivers, canals	Enforcement	Need for new legislation or byelaws	Navigation authority		Behaviour, severity of problem
Ensure sustainable, climate-proof new development	Rivers, canals, other navigation infrastructure	Climate proof new developments, apply PIANC 'Working with Nature' concept	Knowledge gaps, funding	Navigation authority Local authority Developer Stakeholders	Adaptive management	Research, regulation

[1] if also a flood defence [2] if protected sites or species affected

Section 10 Adaptation measures: increase in water temperature

Key findings

The raised water temperatures which it is assumed will result from increased air temperatures could create a number of (mainly indirect) problems for inland waterways.

Higher water temperatures, especially if combined with low flow conditions, can cause a reduction in dissolved oxygen, upon which much aquatic life depends. Warmer waters can also increase the growing season, providing conditions suitable for the proliferation of both water plants and algae and there may be shifts in species' distribution, including both alien species and certain types of fish. Changes in human use of water bodies might also be anticipated, not least swimming and water contact sports - with their attendant potential health risks particularly if rat populations also increase.

Depending on the scale of any problem and the particular local characteristics, various measures might need to be considered to enable the sector to adapt.

If monitoring identifies problems with oxygen depletion that appear to be associated with activities such as dredging or vessel movement, it may be necessary to aerate the affected water body or temporarily to constrain the activities which are causing or exacerbating the situation. Where toxic algal blooms are identified, warning notices may need to be posted or certain areas fenced off.

If aquatic weed growth forms thick mats which affect safety of navigation, clearance may be required. Monitoring will help to inform decisions on how and when such works should be undertaken.

Inland waterways and associated riparian zones can act as important migration corridors for wildlife. In addition to seeking 'win-win' opportunities for habitat creation, navigation authorities should ensure that maintenance works are undertaken in an environmentally responsible manner and that navigation does not exacerbate the spread of invasive or alien species. Research is required to better understand the vectors for transport of such species and guidance for users may then need to be prepared.

Insofar as human uses of navigable water bodies are concerned, local factors may mean it becomes appropriate to promote awareness-raising activities, to develop and implement a zoning policy, or to prepare an integrated management plan. In some cases, it may be necessary to resort to by-law enforcement to resolve conflicts between incompatible uses.

10.1 Climate change context

Predicted increases in air temperature will be accompanied by increases in water temperature, which could, in turn, create a number of (mainly indirect) problems for navigation authorities.

Higher summer water temperatures (particularly when combined with low flow conditions) will lead to a reduction in the amount of dissolved oxygen upon which many aquatic organisms depend. Even small reductions in dissolved oxygen can have significant implications for aquatic ecosystems. Depleted levels of dissolved oxygen could lead to constraints being placed upon on a number of navigation-related activities which might otherwise exacerbate the situation.

Warmer waters also have the potential to increase the growing season and particularly to provide conditions suitable for the proliferation of both algae and water plants (e.g. floating pennywort). Eutrophic conditions are also likely to be encountered more frequently resulting in more extensive algal blooms.

As with increased air temperatures, increased water temperatures could also promote a climate-induced (typically northwards) shift in the distribution of certain species or the loss of other species which are unable to adapt to the warmer and/or drier conditions (UNEP *et al*, 2006; EEA, 2008). In addition to the potential implications for protected sites and species, alien species such as Chinese mitten crabs, floating pennywort, and zebra mussels could create problems especially for navigation authorities unaccustomed to dealing with them (see, for example, www.waterscape.com, 2009).

Finally, warmer waters could also make English and Welsh inland waterways more attractive for both swimming and water contact sports. This raises both potential health risks and safety management issues. For example, an existing problem that may be exacerbated under a scenario of climate change (not least if warming led to an increase in rat populations) is the risk of users being infected with Leptospirosis (Weil's Disease) (Levett, 2001). Safety management issues may also arise if swimmers and boaters are both using the same body of water.

Finally, changes in ambient water temperature may alter the size and type of fish stocks. This could, in turn, re-establish angling as a major new user of certain canals and rivers, resulting in anglers also competing for recreational water space. In order to manage the full range of recreational activities to ensure that they are both sustainable and safe, management initiatives, such as zoning, may need to be implemented where this is practicable.

10.2 Oxygen deficits

Any increase in the frequency of low dissolved oxygen conditions could have a number of implications for navigation.

Sluice, weir and lock operations may need to be modified in an attempt to stimulate flow, cause aeration and hence increase the amount of oxygen in the water. However, this could detrimentally affect navigation, particularly if reduced precipitation rates already mean that operational water supplies (upstream or in storage) are depleted. Depending on the nature and cause of the problem (i.e. what is being affected and whether or not navigation activities are implicated), consideration may need to be given to measures involving injecting air or oxygen directly into the water. Whilst an example of this process is provided by the use of the 'Thames Bubbler' operated by Thames Water Utilities (http://www.shipphotos.co.uk/pages/thamesbubbler.htm), shore-based facilities including compressors, pumps, bubblers or air/oxygen lances are more typically appropriate for use in tackling local problems in inland waterways.

Permanently installed aeration facilities can be used to maintain adequate levels of dissolved oxygen and prevent formation of near-bed layers of saline water with depleted oxygen, as seen here at the Tawe Barrage in Swansea

If significant problems with oxygen depletion are experienced, activities which lead to the re-suspension of sediment may need to be constrained temporarily to avoid exacerbating the situation. This may be necessary because the disturbance of organic-rich sediment can create an additional demand for oxygen, further depleting the available supply, and hence potentially causing problems for aquatic fauna including fish. The Environment Agency has a duty to maintain and protect freshwater fisheries including salmon and sea trout. As water temperatures rise, the number of days when warmer water could deter the upstream passage of salmon for example will increase.

Case Study: Oxygenation at Salford Quays

Water quality in the once heavily polluted Salford Quays is now so dramatically improved that its biodiversity is booming and it has some of the fastest growing fish in the country. For the last three years liquid oxygen has been pumped into a 2km stretch of the former docks area at Salford Quays at the rate of 15 tonnes a day as part of a multi-million pound programme to bring the waters back to life. The project is the first of its kind in the world and remains unique. It is part of a massive programme of action across England's Northwest to improve water quality levels, which has also seen salmon returning to the river Mersey and led the Commonwealth Games to stage the triathlon in the waters of the Quays.

The oxygenation process and the research are the work of aquatic specialists APEM, working in partnership with the Mersey Basin Campaign, United Utilities, the Environment Agency and the Manchester Ship Canal Company. The project has been funded largely by £3.5 million from United Utilities, along with a £500,000 Millennium grant through English Partnerships.

Source: North West Regional Development Agency website. June 2005. http://www.nwda.co.uk/pdf/Natures_Edge.pdf

Potential measures to help ensure that inland navigation does not exacerbate the climate-induced problem - for example seasonal constraints on dredging or temporary speed limits - are discussed in Section 7.7. Additional dredging to ensure adequate under keel clearance might also be considered.

10.3 Aquatic plant management

Warmer water temperatures could lead to the proliferation of both algal blooms and various types of water plant. As a consequence, measures may need to be taken either for reasons of animal and human health, safety (e.g. to prevent fouling of propellers) or visual amenity.

Eutrophication (or nutrient enrichment) can lead to the formation of algal blooms. At low flows and warm temperatures, planktonic algae can grow more. While algal photosynthesis contributes oxygen to the water during the daytime, algal respiration uses up oxygen and produces CO_2 at night. The depletion of dissolved oxygen concentrations at night by algal blooms can have adverse effects on fish. These effects are exacerbated by the wide daily variations in pH caused by changes in CO_2 concentrations (pH is a measure of how acid or alkaline the water is). Dissolved oxygen concentrations in rivers can also be reduced as the blooms break down. Certain algae release toxins, which may affect aquatic wildlife, in particular Cyanobacteria (blue-green algae), which thrive on the weather extremes that are likely to accompany climate change (Energy Saving Trust, 2008).

Algal blooms may affect navigation authorities insofar as users of adjacent areas are concerned (especially by livestock and dogs) and warning signs may be required on towpaths or affected areas may need to be fenced off. There may also be visual amenity issues. Treatment, for example using carbon or ozone-based products, is possible but expensive so would be considered only if essential.

Algal growth caused by nutrient rich agricultural run-off, as here at Bottom Lock on Kyme Eau, will be increased by rises in water temperature, causing additional hindrance to navigation and adverse effects on aquatic ecology

Weed growth involving filamentous algae and higher plants, however, can have more direct implications for navigation. Species such as the non-native floating pennywort root into the shallow margins of water bodies and form thick mats of floating vegetation which, *inter alia* make it difficult for vessels to pass through. Work to clear this species on the River Soar was undertaken in 2008 by British Waterways, the Environment Agency and others (see below). On the Chelmer and Blackwater Navigation, regular hand clearance by volunteers has been successful in keeping clear a waterway that was at one time virtually un-navigable because of growth of this weed.

Whilst associated greenhouse gas emissions need to be considered, mechanical cutting and the removal of weed from the waterway (in order to avoid water quality deterioration) is generally the most effective method of clearance. Aquatic herbicides can cause other types of environmental damage and can cause problems for public water supplies. Their use requires permission from the Environment Agency.

The control of waterway weeds has been undertaken in the past using grass carp but this is largely ineffective in managing canal channels and carp can stir up sediment. Further, with the higher expected ambient temperature of water under a scenario of climate change, grass carp may be able to breed in the UK, leading to them becoming a permanent alien nuisance species (see below).

The most effective combination of measures to clear floating vegetation will typically be a site-specific decision and can be expensive. Where the climate-induced spread of either native or non-native invasive plant species might compromise navigational safety, regular monitoring will be required to inform a decision on the optimum (i.e. most cost-effective) method and frequency of clearance works.

Alien aquatic species (floating pennywort) growth almost blocking a navigable waterway in the Bow Back Rivers

Clearing of Floating Pennywort on the River Soar and Grand Union Canal: Case Study

Since 2007, a £100K initiative was run by British Waterways, the Environment Agency, Leicester City Council and local volunteer groups, has involved the clearance of over 6,000 tonnes of floating pennywort from the River Soar and Grand Union Canal.

Monthly monitoring and an extensive aerial survey conducted in October 2008 have shown that the combined efforts of the three agencies have resulted in a significant reduction in the number and spread of the plant on the River Soar, compared with the same survey carried out in 2007.

Floating pennywort is an invasive plant, introduced to Britain's waterways during the 1980s. Since it was first sighted in the region five years ago, its rapid growth of up to 20cm per day meant it quickly spread downstream. The plant roots into shallow margins of water bodies, forming thick mats of floating vegetation that create numerous ecological and operational problems. Pennywort starves the waterway of oxygen, which has an adverse effect on other aquatic life. It also poses a threat to other wildlife sites along the river corridor, increases flood risk by restricting drainage of the watercourse and causes navigation problems for boaters who are unable to pass through thick masses of plant life. The most effective method of eliminating the weed is by physically removing every fragment of the plant, and controlling re-growth using an approved herbicide.

Source: http://www.waterscape.com/features-and-articles/news/2373/river-soar-pennywort-clearance-proves-successful. February 2009

10.4 Species distribution

Whilst navigation may not be directly responsible for any change of species distribution, measures might be required to ensure that inland navigation neither exacerbates the climate-induced loss of protected species/habitats nor contributes to the spread of alien species.

Insofar as helping to protect vulnerable species and habitats is concerned, maintenance or clearance works should be undertaken in an environmentally friendly manner wherever practicable – for example by working only from one side of the water course and leaving the other side undisturbed. Avoiding development which detrimentally affects protected sites or species is also important.

Similarly it should be recognised that inland waterways and associated riparian zones can act as vital corridors for biodiversity migration, providing opportunities for indigenous species associated with the waterways and nearby verges, hedgerows and woodlands, to move – enabling them to remain in favourable environments as the climate changes. New habitats to facilitate this process or to support threatened species can also be created. In this regard, there may be opportunities for navigation authorities to work in partnership with other (agricultural and wildlife) organisations to promote the creation of buffer strips, wetland areas, off-line basins or ponds, and other habitats (e.g. for vulnerable species).

Measures to address the problems caused by aquatic alien species will be promoted under the Water Framework Directive. These measures are likely to focus on preventing the spread of species into new areas as well as managing existing problems. As such, measures might include the development and implementation of management plans for invasive non-native species, sharing and developing best practice for species control and the provision of advice on identification and eradication to land managers.

Measures might also be needed to help ensure that inland navigation does not exacerbate the climate-induced spread of non-indigenous (i.e. alien) species. This is particularly important when it is considered that certain types of aquatic plant can spread if just a small fragment is transported to another water body.

Boats can be a vector for alien species, such as zebra mussels seen here on a narrow boat hull, although there are also many other potential vectors (e.g. fishing gear)

Insofar as navigation authorities are concerned, therefore, two measures will be particularly important:

- research and monitoring to help understand possible vectors for the spread of non-indigenous species, notably the potential role of vessels or navigation infrastructure operation and maintenance; and
- awareness-raising measures amongst both navigation authority personnel and users, for example to help prevent inter-basin transfer of species (e.g. weed) on recreational vessels.

10.5 Human use of navigable water bodies

As far as water-temperature induced changes in the human use of water bodies are concerned, research and monitoring will be required better to understand the nature and scale of any problems. Because of the possible risks to users, it would be better for the navigation authority to be pro-active in monitoring changes in patterns of use to enable the identification of potential problems and the development of an appropriate response. In this respect, the following actions might be amongst those considered in partnership with the relevant stakeholder groups:

- development of multi-use management plans for waterways, towpaths and other inland waterway infrastructure/facilities;
- education and awareness raising, not only for navigation but for all users;
- zoning of waterways to facilitate multi-use, manage user conflicts and prevent environmental damage; and
- bye-law enforcement.

Specifically with regard to swimming in navigable waters, whilst it is possible in some cases to provide permitted swimming areas on navigable waterways, such as the designated bathing waters on Windermere, recurring problems of unauthorised swimming, especially during school holidays, need to be monitored and managed. An on-going programme of education (about both health and safety risks) and enforcement may also be required.

10.6 Summary of measures

Table 10.1 summarises the variety of potential measures for adapting to the changes associated with the anticipated increase in water temperatures. For each measure, reference is made to its likely applicability (to vessel or waterway type, etc.), possible barriers to implementation are highlighted and the organisations likely to be involved in its delivery are identified. In each case, an attempt is also made to classify the measure, including whether it might be suitable for implementation in the short- or long-term.

Table 10.1 Summary of adaptation measures for increased water temperature

Objective or issue	Relevant to	Measure	Potential barriers to implementation	Delivery: co-deliverers	Short-medium term measures	Potential longer term measures
Manage oxygen deficit	Rivers, canals	Modify sluice, weir and lock operation to aerate water bodies	Navigational viability, safety	Navigation authority, Environment Agency	Adaptive management	Research into effectiveness, alternatives
Appropriate aquatic plant management	Rivers, canals, water storage reservoirs	Warning signs re algal blooms, fence-off affected area	No significant barriers	Navigation authority, landowner	Adaptive management	
	Rivers, canals	(Increased) physical vegetation clearance	Cost	Navigation authority, volunteers	Adaptive management	
	Rivers, canals, water storage reservoirs	Clear vegetation using biocides	Environmental impacts	Navigation authority, Environment Agency		Depends on severity of problem
React to changes in species distribution	Rivers, canals	Good practice maintenance (e.g. work from one bank)	Willingness to adapt	Navigation authority	Adaptive management	
	Rivers, canals	Habitat connectivity and creation (buffer strips, wetland areas, off-line basins or ponds)	Lack of knowledge	Navigation authority, conservation agencies, farming community, volunteers	Win-win	Research and monitoring
	Rivers, canals	Understand vectors for spread of alien species	Lack of knowledge	Navigation authority, Environment Agency		Research and monitoring
	Rivers, canals	Awareness raising activities to prevent inter-basin transfer	Willingness to adapt	Navigation authority, waterway users, RYA, IWA, BMF, BCU	No regrets	
Manage potential user conflicts	Rivers, canals, towpaths, other facilities	Awareness raising, education, good practice re multiple uses	Behaviour	Navigation authority, waterway users, RYA, IWA, BMF, BCU, local community	No regrets	
	Rivers, canals, towpaths	Management plan development, zoning different uses	Willingness to adapt	Navigation authority, waterway users, relevant stakeholders	Adaptive management	Education, information
Ensure user health and safety	Rivers, canals, other water bodies	Education, awareness raising regarding health and safety risks	Willingness to adapt	Navigation authority, RYA, IWA, BMF, BCU, local groups	Adaptive management	
	Rivers, canals	New/existing bye-law enforcement for inappropriate uses	Resources, appropriate penalties	Navigation authority	Adaptive management	

Section 11 Conclusions

11.1 Overview

Some degree of climate change now appears inevitable, with associated increases in winter precipitation, reductions in summer rainfall, changes in sediment regimes and increased air and water temperatures. The extent and speed of such changes, and hence the magnitude of associated impacts, will depend in part on the success of mitigation measures to reduce greenhouse gas emissions. Action on mitigation is urgently needed. Notwithstanding the proportionately small contribution of inland waterways activities to the overall problem of global warming, every sector needs to implement measures to reduce greenhouse gas emissions if the Government's targets of a 26% reduction in emissions by 2020 and an 80% cut by 2080 are to be realised.

This scoping report identifies a number of measures both for climate change mitigation and for adaptation to its consequences. Mitigation actions need to be implemented as a matter of urgency and as such should be a priority for the sector.

Consideration may need to be given to modifying or replacing certain operations, assets and infrastructure, in order to increase their resilience and make inland waterways better prepared to deal with the effects of climate change. Whilst decisions on many such potentially appropriate adaptation measures may not have to be taken for several years, measures to collect data, monitor change and improve understanding are important. These will need to be put in place in the short term in order to provide vital information to inform future decision-making.

The summary tables in Sections 5 to 10 demonstrate that several other 'no regrets' measures have been identified (i.e. relatively low cost measures which would be expected to have a benefit irrespective of the specific climate change scenario), along with a number of options for introducing flexible, adaptive management procedures. Adaptive management approaches, informed by risk-based assessments, will become increasingly important in enabling the inland waterways sector to begin the process of adapting to climate change (dealing with challenges and exploiting opportunities), whilst not over-committing or potentially embarking on the 'wrong' road.

Most of the other measures highlighted by this project are either 'win-win' measures (where a project could deliver a range of different benefits) or longer term measures which will require further research and development or may only be justified under certain scenarios. Measures which would be inappropriate in the UK inland waterways context or which appeared to carry a significant risk of 'maladaptation' (inflexible or potentially counter-productive measures) were not included in this report.

Different measures will have different delivery mechanisms. Many measures might fall to the inland navigation authorities to implement. Some will require action by users and, in other cases, a range of partner organisations might be involved in delivery. The measures can also be grouped according to a range of generic themes. Sections 11.2 to 11.10 discuss the range of mitigation and adaptation measures according to the following:

- mitigating inland waterways' contribution to global warming;
- monitoring;
- training and capacity building;
- adaptive management;
- future-proofing;

- communication and awareness raising initiatives;
- strategic planning and management;
- exploiting opportunities; and
- research.

11.2 Mitigating inland waterways' contribution to global warming

This report identifies a number of ways in which the inland waterways sector can contribute, directly or indirectly, to a reduction in greenhouse gas emissions. Amongst these, measures might be driven by:

- Government and industry (e.g. potential emissions standards for marine engines, placing of emissions conditions on Freight Facility and Waterborne Freight Grants, incentives to promote freight by water);
- navigation authorities (e.g. discounted licence fee for eco-hulls, electric boats or boats meeting defined emissions standards, provision of electric hook-ups, development of alternative energy sources/micro-renewable energy schemes); and
- wider inland waterways sector (e.g. calculation and reduction of carbon footprint, implementation of 'good housekeeping' measures).

In addition, the role of education and awareness-raising to promote changes in user behaviour in relation to reducing greenhouse gas emissions is discussed in Section 11.7, wider opportunities to help other sectors reduce their carbon emissions are identified in Section 11.9 and outstanding research requirements are highlighted in Section 11.10.

11.3 Monitoring

Monitoring is clearly identified as a key 'no regrets' climate change adaptation measure. High quality, locally relevant data will be vital whatever the eventual extent (scenario) of climate change. The collation, review and management of such data will be of fundamental importance in understanding and responding to the effects of climate change in a well-informed, appropriate and timely manner. Without these data, those responsible for decision making will be unable to decide what measures are needed and when.

An essential first step for many authorities will therefore be to improve or install monitoring and recording systems. Simple telemetry or SCADA have a potentially important role to play in enabling navigation authorities to prepare to deal with the consequences of any significant changes in precipitation and temperature affecting inland waterways in England and Wales via the collection of data including:

- flow rates, Strong Stream conditions; and
- water levels, low flow, channel freeboard, headroom.

Such systems may also help in optimising energy use insofar as certain infrastructure or assets are concerned and, once initial surveys/condition assessments have taken place to identify potentially vulnerable locations, in informing the issuing of warnings.

Site-specific data may also be needed on certain water quality parameters (e.g. dissolved oxygen, turbidity) if Environment Agency data collected as a requirement of the WFD prove inadequate to support decision making on navigation related activities.

Not all data need to be collected by the navigation authority itself. Rather the onus will be on the authority to establish which other organisations are collecting potentially relevant data, to secure access to such data (possibly on a *quid pro quo* basis) and to collect the data needed to fill important gaps (i.e. the data needed to inform the authority's decision making on issues such as safety and structural integrity). Related to this, given that climate change will happen over a period of decades, it will become increasingly important to ensure that very long term records are maintained, that the storage system is long term and that record keeping and storage is not arbitrarily abandoned (UNESCO, 2009).

11.4 Training and capacity building

Whilst it will be vital to collect and collate data to enable the assessment of the various physical and environmental consequences of climate change, navigation authorities will need to develop the capacity to handle and respond to such information. In particular, key personnel are likely to require a certain amount of training if data use is to be optimised via adaptive management processes.

Capacity building or training may required to enable various key staff to develop expertise in some or all of the following areas:

- data handling and management;
- carbon footprint calculations, reducing energy consumption, alternative energy sources;
- ecological vulnerability;
- water conservation measures; and
- future-proofing modifications or new developments.

Training or capacity building within certain user groups may also prove to be of value if experience demonstrates that users are not able to respond appropriately or if vessels are not properly equipped to deal with the anticipated consequences of climate change (e.g. response to Strong Stream, low flow, clearance or closure warnings). Any such requirements would need to be taken forward with the organisations representing the user groups concerned. Volunteer organisations may be able to contribute directly to implementation of some measures.

11.5 Adaptive management

Climate change is a long term problem. Data will need to be collected, retained and analysed over a period of decades. A comprehensive, long-term data set will enable trained individuals within navigation authorities to understand the nature, rate and local implications of climate change, and to make decisions accordingly. Properly managed, such datasets will give navigation authorities time - not only to plan when and how to adapt and the extent of adaptation needed but also to secure the necessary funds.

Two key elements of adaptive management are therefore flexibility and preparedness. Being prepared should enable navigation authorities to remain 'in control' and to identify optimum solutions. Flexibility in management helps to ensure that solutions can be modified as conditions change. If adaptive management concepts are not adopted, a potential consequence is that climate change will result in sub-optimum or unnecessarily expensive solutions.

Effective monitoring and data management should enable navigation authorities to deal with risks proactively, not least by being able to set thresholds for actions and issue warnings as required on a wide range of issues, including:

- Strong Stream advice;
- water level (headroom or clearance, low flow conditions);
- risk of flooding;
- closure of navigation;
- algal blooms (risk to dogs, livestock); and
- swimming and other water contact sports (health risks).

The following list summarises other key areas of navigation authorities' maintenance and management responsibility which may require some level of adaptation depending on the magnitude and local consequences of climate change. In a number of cases adaptation will need to involve one or more partner organisations (or co-deliverers):

- improving resilience/ensuring structural integrity of navigation assets and infrastructure to cope with high flow, low flows, desiccation and so on;
- provision of new facilities (e.g. moorings or safe havens for use in time of Strong Stream, reduced clearance or low flow);
- future-proofing maintenance activities by incorporating modifications to works programmes or fixed assets necessary to accommodate or improve resilience to climate-change (see also Section 11.6 below);
- assessing and implementing operational changes to conserve water (control of leakage and losses, lock operations);
- vegetation management (cutting frequency or method, for terrestrial and aquatic species, management of invasive or alien species, use of biocides);
- ensuring inclusion of navigation water-needs in relevant strategic plans (see Section 11.8 below) and, where appropriate, seeking ('win-win') opportunities to develop new water storage facilities or to reduce sediment run-off into water bodies;
- encouraging behaviour change amongst users (see Section 11.7 below) supported by regulatory provisions if necessary (e.g. speed limits);
- investigating incentives or pricing mechanisms to contribute towards solutions to climate change-induced problems (e.g. promotion of eco-hulls, incentives for climate-friendly vessels, regulation of user numbers in 'water-stressed' systems and providing incentives for use of 'less stressed' waters);
- improving understanding of water-ecology inter-relationships and promoting any changes needed to ensure that navigation-related activities do not exacerbate climate change-induced environmental problems (e.g. oxygen deficits, spread of alien species);
- actions to contribute to or meet third party needs (e.g. stimulate flow for aeration, convey flood flows); and
- introducing constraints on potentially damaging activities and encouraging preparation of contingency plans where appropriate (e.g. release of water to support wildlife).

11.6 Future-proofing

Under a scenario of climate change, both existing activities or operations and new development proposals will need to be 'future-proofed' to ensure their ability to withstand projected changes in precipitation, temperature and sediment regimes. Navigation authorities and other responsible bodies may therefore need to investigate and where appropriate (i.e. subject to technical, economic, environmental and regulatory viability) implement future-proofing initiatives in respect of some or all of the following:

- raise overhead structures, bridges, etc. where these significantly and frequently compromise clearance;
- raise embankments to reduce flood risk and/or increase channel freeboard;
- extend side weirs, retrofit gates and so on to accommodate changes in water level and flow;
- replace ineffective bank protection with environmentally friendly climate-proofed solutions, introduce drought resistant vegetation with suitable engineering properties;
- review dredging activities with respect to timing, methods, etc. if required to protect water status, also flow manipulation and clearance of silt traps;
- remove obsolete structures if causing problems (e.g. trapping sediment); and
- promote eco-hulls to reduce emissions, bank erosion, sediment disturbance.

Insofar as potential new developments are concerned, PIANC's 'Working with Nature' position paper promotes a flexible approach which enables climate change considerations to be taken into account early in the project development process.

11.7 Communication and awareness raising

Many of the measures described in this report could be delivered most effectively by encouraging behavioural changes. Educating users both about the implications of their actions and how, by modifying their behaviour, they can save both money and the planet, can be an effective way of achieving shared objectives. The alternative, for example of increased charges or increased regulation and enforcement, can be a useful reminder of why a voluntary approach provides the optimum way forward.

Educating and raising awareness of climate change issues will necessarily require a coordinated approach involving a number of partner organisations (e.g. British Marine Federation, Royal Yachting Association, Inland Waterways Association, British Canoe Union) and the use of a variety of media (posters, leaflets, stickers, press and newsletter articles, internet, press releases, radio and television interviews and so on). The preferred means of communicating a particular message will depend, amongst other things, on whether the behaviour change in question needs to be made nationally or locally. Furthermore, in addition to targeting adult users, experience suggests that involving children - whether through their boating clubs or directly though schools - can be a very effective way of getting the message across.

Insofar as the topics to be covered by such an education campaign are concerned, key areas are likely to be:

- reducing emissions: cost savings associated with responsible engine use (slowing down, switching off engine in locks, using electric hook-ups, etc.), opportunities provided by alternative fuel technologies, by eco-hulls, calculating carbon footprint;
- incentives: such as reduced licence fees for vessels meeting certain environmental criteria;
- safety issues: understanding and responding to warnings such as Strong Streams, headroom (including location and use of safe havens), low flow, vessel safety (crew competence, equipment), algal blooms (risk to dogs, livestock), swimming (health risks);
- water conservation: locking practices, choice of boating destination, recycling/general water use on board;
- water quality: grey and black water disposal, implications of breaking wash or re-suspending sediments; and
- sustainable use: of waterways and of towpath, understanding climate-change induced pressures on natural environment, role of management plans and zoning, prevention of spread of alien species.

This type of communication and awareness-raising action represents a 'no regrets' measure in climate change terms as the work involved can be relatively low cost and is likely to result in benefits irrespective of the details of the climate change scenario.

11.8 Strategic planning and management

Some of the adaptive management activities mentioned in Section 11.5 could potentially involve - or indeed might depend upon the actions of - other organisations. In some of these cases, a new strategic or management plan might be prepared; in others, the inclusion of an appropriate measure(s) in a strategic plan such as the Water Framework Directive River Basin Management Plans (RBMP) might offer an important delivery route. Elsewhere, a site or project-specific approach might be necessary.

If existing and/or future water availability is of concern in a particular inland waterway system or to a particular authority, consideration should be given to preparing a navigation water strategy. Such a document, which would be informed *inter alia* by the authority's monitoring programme as well as discussions with third parties (for example, Environment Agency or water companies), should attempt to quantify the authority's water resource requirements, identify confirmed and potential sources of water, assess and propose appropriate water conservation measures and highlight any anticipated deficit.

A navigation authority may similarly need to work with others to prepare a management plan if the temperature increases associated with climate change lead to a significant increase in user numbers and/or the diversity of activities undertaken. In such cases, it will be important to work with the local community, representatives of user groups and other relevant organisations such as the Environment Agency or nature conservation bodies, to develop and implement an integrated (site) management plan, potentially including for the zoning of conflicting uses.

Insofar as the Water Framework Directive is concerned, both joint sustainable water management initiatives, and navigation-specific measures which somehow depend on the actions of others should be highlighted in the relevant RBMP. Subject to further investigation or analysis, potential adaptation measures which might be included (most probably in the second round of plans due to be published in 2015) are:

- water conservation or management measures which help to improve the status of water bodies (e.g. through eradication or management of alien species, removal of obsolete structures, development of 'win-win' measures, see below); and
- measures to avoid deterioration in water status (e.g. operation of infrastructure to stimulate flow/aeration, provision for release of water to support ecology, other contingency plans).

Finally, any proposed new physical modifications or other new developments that could affect water status at water body level – for example securing new water resources or developing new water storage facilities - will also need to be highlighted in the RBMP.

11.9 Exploiting opportunities

This report identifies a number of potential opportunities for inland waterways both in helping to mitigate, and in adapting to, the effects of climate change.

With regard to opportunities to reduce the emission of greenhouse gases, navigation authorities may be able to identify and exploit opportunities for the generation of renewable energy, notably with regard to:

- heat pumps for cooling and heating buildings;
- low head hydropower; and
- wind turbines.

Such options may become particularly attractive given the provisions in the 2008 Climate Act which encourage small scale energy production.

Another high profile opportunity on appropriate inland waterways might be realised if incentives can be provided to encourage the carriage of freight by water.

In terms of climate change adaptation measures, this report highlights a number of opportunities, notably potential 'win-win' measures which could allow a number of different interests to realise their objectives. The main opportunities identified in this respect comprise:

- buffer strips or reed beds which not only reduce the run-off of sediments into water bodies but create valuable marginal habitat and can provide agricultural benefits;
- new water storage facilities which could also provide flood defence and/or nature conservation (i.e. wetland) benefits;
- environmentally friendly bank protection which can both reduce erosion and provide marginal habitat; and
- beneficial use of dredged materials for habitat creation or agricultural use.

11.10 Research

Finally, it is clear that there remain many uncertainties with regard to the implications of climate change, and the viability of potential mitigation or adaptation responses. Whilst uncertainty should not be used as an excuse for inaction, there are clearly many areas where research might generate new solutions or improve confidence in others. Further developments in relevant technologies to mitigate the effects of change are also urgently needed.

Insofar as the inland waterways sector is concerned, in addition to research aimed at improving understanding of the likely consequences of climate change, some of the main areas requiring research and development as highlighted by this scoping report are:

- bio-fuels, alternative energies, hybrid engines, fuel cell technology;
- options for improving the resilience of assets and infrastructure including use of (drought-tolerant) vegetation in engineering;
- innovation in water conservation and water resources/storage opportunities;
- additional measures to reduce sediment in run-off reaching water bodies;
- better establishing the carrying capacity of natural systems and water-ecology inter-relationships;
- habitat creation schemes comprising 'win-win' opportunities; and
- vectors for transfer of alien species, methods for management or eradication of alien species.

Section 12 Way Forward

12.1 Taking forward the findings of this scoping study

This scoping report identifies a number of areas in which navigation authorities and others involved in the operation, management and use of inland waterways in England and Wales can take action to mitigate or adapt to the consequences of climate change. Some measures are for the longer-term and some will be very site-specific. However, several measures would benefit from early attention: these measures are discussed further below.

12.2 Climate change mitigation: actions for navigation authorities

Measures to mitigate climate change impacts are urgently required across all sectors. The findings of this report suggest that the only realistic way for the inland waterways sector to make a meaningful contribution to reducing its greenhouse gas emissions will be through a combination of different, often local or small-scale, measures. Inland navigation authorities in England and Wales, supported by AINA where necessary, should therefore take immediate action to:

- review the range of mitigation measures and opportunities highlighted in this scoping report;
- determine which measures and opportunities are potentially most appropriate to the nature and scale of their own operation (practical, cost-effective, etc.); and
- commence a programme of implementation of those measures and opportunities.

12.3 Climate change mitigation: joint initiatives

Navigation authorities should consider how best to influence, and where appropriate to assist, their users and other stakeholder organisations in taking action to reduce emissions across the wider inland navigation sector. Possible priority joint initiatives in this respect might include:

- working with IWAC, UK Government and industry as appropriate to develop and promote new emissions standards, to explore the possibility of introducing incentives such as discounted licence fees or conditional grants, to promote freight movement by water; and
- working with AINA and a range of user and stakeholder groups to develop and promote a climate change education and awareness raising campaign: such a campaign should cover both mitigation and adaptation measures.

12.4 Climate change adaptation: actions for navigation authorities

This report identifies a wide range of potential measures which could help the inland waterways sector adapt to the consequences of climate change.

Actions described as ‘no regrets’ measures should provide benefits irrespective of how climate change affects inland waterways. They may, for example, lead to cost savings, or they may help to meet other environmental or water management objectives (e.g. under the Water Framework Directive).

Amongst these ‘no regrets’ measures, arguably the most essential action for inland navigation authorities is to establish an appropriate monitoring regime.

Without relevant, long-term data, navigation authorities will be unable to understand exactly how climate change is affecting the areas for which they are responsible, and it will therefore be difficult for them to make informed decisions about how to respond. As many climate change effects could have some potentially important safety implications, navigation authorities in England and Wales, supported by IWAC and AINA as appropriate, should begin to take action at a proportionate level to:

- investigate and install or improve telemetry, SCADA or other systems for monitoring, data collection and information management;
- build capacity within their organisation to understand and be prepared to respond to the effects of climate change; and
- undertake risk-based assessments, set thresholds for action and investigate the most effective and reliable means of communicating operational changes, restrictions and warnings to users.

Another potentially important 'no regrets' measure of immediate relevance to navigation authorities is future-proofing. Navigation authorities and others intending either to modify or replace existing assets and infrastructure or to undertake new development or restoration projects should future-proof such initiatives to improve their resilience to the effects of projected climate change.

A number of other 'no regrets' measures will be particularly relevant to inland waterways which depend for their operation on a reliable water resource. Authorities responsible for such waterways should take early steps to:

- identify and implement a suite of appropriate water conservation measures; and
- where appropriate, develop a water resources, conservation and use strategy.

Many of the other measures highlighted in Sections 6 to 10 of this report are described as 'adaptive management' measures. Relatively few of these measures will be universally useful. Rather, their implementation would be informed by an evaluation of monitoring data and risk-based assessments demonstrating their site-specific suitability.

In all the above cases, not least to avoid duplication and to save money, synergies with the measures required under the Water Framework Directive should be explored and promoted.

12.5 Climate change adaptation: joint initiatives

Many of the 'no regrets' and 'win-win' measures identified in this report depend on (or would benefit from the involvement of) other organisations. Whereas many such measures are site-specific and would likely be identified through monitoring as possible future adaptive management initiatives (e.g. the development of new water storage facilities, the creation of buffer strips, beneficial use of dredged material), others may be of more immediate relevance.

'No regrets' adaptation measures which would most likely benefit from early attention include:

- working with AINA and user groups to develop and promote a climate change education and awareness raising campaign (see above);
- working with Environment Agency and others to ensure that data collection and management are optimised so as to promote sharing and avoid duplication of effort; and
- where appropriate, preparing integrated water and/or land management plans including measures for zoning, contingency planning and biodiversity protection as necessary.

12.6 Climate change mitigation and adaptation: research and development

Finally, as indicated in Section 11.10, this scoping report has highlighted a number of areas where ongoing or new research is required to enable the inland waterways sector to further reduce its contribution to global warming, and to improve its ability to adapt to the consequences of climate change. The UK Government, IWAC, navigation authorities, AINA and other relevant partner organisations as appropriate should therefore support measures that seek to:

- develop alternative fuels/sources of energy, including bio-fuels, alternative energies, hybrid engines, fuel cell technology, also hull design;
- explore options for improving the resilience of assets and infrastructure including use of (drought-tolerant) vegetation in engineering;
- investigate alternatives or improvements to avoid or minimise the adverse effects of dredging;
- improve innovation in water conservation;
- identify new water resources and storage opportunities;
- research and promote additional measures to reduce sediment in run-off reaching water bodies;
- improve understanding of the carrying capacity of natural systems, and of water-ecology interrelationships;
- improve understanding of vectors for transfer of alien species and methods for the management or eradication of alien species; and
- explore and exploit 'win-win' options for habitat creation or restoration schemes.

Section 13 Glossary and Abbreviations

AAPA	American Association of Port Authorities
AINA	Association of Inland Navigation Authorities
AWB	Artificial Water Body
BCU	British Canoe Union
BMF	British Marine Federation
BMVBS	German Federal Ministry of Transport, Building and Urban Affairs
BREEAM	Building Research Establishment Environmental Assessment Method
BSS	Boat Safety Scheme
CIS	Common Implementation Strategy of the water Framework Directive
Cofferdam	usually a temporary construction of steel or timber to keep water out of locks or other navigational structures or river beds to permit maintenance or construction
CO_2	Carbon Dioxide
Cumecs	Cubic metres of water per second, a measure of (river) flow rate
Defra	Department for Environment, Food and Rural Affairs
EEA	European Environment Agency
EC	European Commission
ESPO	European Sea Ports Organisation
EU	European Union
Eutrophication	an increase in chemical nutrients in an ecosystem that leads to undesirable changes associated with macrophyte, algal or cyanobacterial growth (such as diminished oxygen levels) which interfere with legitimate uses of the water body.
Evapotranspiration	a term describing the transport of water into the atmosphere from soil (soil evaporation), from water surfaces and from vegetation transpiration
Freeboard	of a channel - height from normal water level to lowest part of adjacent canal or river bank
Geotechnics	application of scientific methods and engineering principles to soil, rock and the ground
Geotextile	man-made fabric used to reinforce soil or river/canal banks, or used as a filter membrane in earthworks
HMWB	Heavily Modified Water Body
IAPH	International Association of Ports and Harbours
IDB	Internal Drainage Board
IMechE	Institution of Mechanical Engineers
INE	Inland Navigation Europe
IPCC	Intergovernmental Panel on Climate Change
IWA	Inland Waterways Association
Low head hydro	the generation of hydro-electricity from river weirs using a small differential head
MCA	Maritime and Coastguard Agency
NOx	a generic term for mono-nitrogen oxides (NO and NO_2) produced during combustion
Overtopping	when water levels rise, and the increase exceeds freeboard, water will flow over adjacent banks causing flooding and possible failure of embankments or structures
PIANC	global organisation providing guidance for sustainable waterborne transport infrastructure for ports and waterways
RBMP	River Basin Management Plan
RYA	Royal Yachting Association
Saline intrusion	the influx of sea water into an area that is not normally exposed to high salinity levels, potentially altering aquatic habitats or groundwater quality

SCADA	Supervisory Control And Data Acquisition: remote monitoring or operating equipment linked by radio or telephone to a control room
Shoulder season	either the late spring or early autumn period each side of the main summer holiday season
Strong Stream	denotes a high river flow condition that may be dangerous for navigation but is not a flood
UKCIP	United Kingdom Climate Impacts Programme
UNEP	United Nations Environment Programme
USGS	United States Geological Survey
WFD	Water Framework Directive
WMO	World Meteorological Organisation
WPCI	World Ports Climate Change Initiative

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The report provides advice on climate change issues in relation to navigable inland waterways in England and Wales and illustrative examples of measures for mitigating and adapting to the effects of climate change. It also identifies areas where further research is recommended.

However, the success of specific approaches will vary according to the characteristics and use of the waterway concerned and IWAC urges readers to refer to more detailed information referenced in the report and to local circumstances before committing to any particular course of action. Neither IWAC nor its advisers can be held responsible for any planning or operational decisions made in relation to this study's findings.

Steering Group

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Appendix 1 - Variations in UK Climate Change Predictions

Appendix Table 1 Variations in UK Climate Change Predictions for 2020, 2050 and 2080 for Low and High Emissions Scenarios

		Low Emissions			High Emissions		
Region	Decade	Annual daily temperature +C	Summer precipitation +%	Winter precipitation +%	Annual daily temperature +C	Summer precipitation +%	Winter precipitation +%
East Midlands	2020	1	-15	15	1	-15	15
	2050	2	-30	15	3	-30	15
	2080	3	-30	15	5-6	-60	30
East of England	2020	1	-15	15	1-2	-15	15
	2050	2	-30	15	3	-30	15
	2080	3	-30	15	5	-60	30
London	2020	1	-15	15	2	-15	15
	2050	2	-30	15	3	-30	15
	2080	3	-30	15	4	-60	30
North East	2020	1	-15	15	1	-15	15
	2050	2	-15/30	15	2	-30	15
	2080	2	-30	15	3	-45	30
North West	2020	1	-15	15	1	-15	15
	2050	2	-30	15	3	-30	15
	2080	2	-30	15	4	-45	30
South East	2020	1	-15	15	2	-15	15
	2050	2	-30	15	3	-30	15
	2080	3	-30	15	5	-45	30
South West	2020	1	-15	15	1	-15	15
	2050	2	-30	15	2	-30	15
	2080	3	-30	15	3/4	-60	30
West Midlands	2020	1	-15	15	1	-15	15
	2050	2	-30	15	3	-30	15
	2080	3	-30	15	4/5	-60	30

Region	Decade	Low Emissions			High Emissions		
		Annual daily temperature +C	Summer precipitation +%	Winter precipitation +%	Annual daily temperature +C	Summer precipitation +%	Winter precipitation +%
Yorkshire & The Humber	2020	1	-15	15	1	-15	15
	2050	2	-30	15	3	-30	15
	2080	3	-30	15	4	- 45/60	30
Wales	2020	1	-15	15	1	-15	15
	2050	2	-30	15	3	-30	15
	2080	2	-30	15	4	- 60	30
Scotland	2020	1	-15	15	1	-15	15
	2050	2	-15	15	2	-30	15
	2080	2	-30	15	4	-30	30

Source: UKCIP 2009 Climate Change Programme