**Water and flood management: Costs and benefits of adaptation**

**Key Messages**

- Climate change will have a large variety of impacts on water resources by modifying global and regional hydrological cycles.
- Adaptation in water management entails a wide variety of measures, typically technical ones (e.g. dyke construction, irrigation, water reuse) but also soft measures (e.g. awareness-raising), and “green” or “ecosystem-based” approaches (e.g. artificial wetland construction, river restoration).
- Past studies have focused on supply measures although more attention is now given to demand side and behavioural measures.
- A growing number of studies better take into account issues of uncertainties and timing in the cost/benefit assessment of adaptation actions. However few suggestions are made beyond broad recommendations such as improving and expanding data and projections on climate change and carrying out studies in greater detail.
- While most studies rely on an optimization approach providing the least costly adaption options (through e.g. Cost-benefit analysis or Cost-effectiveness analysis), an increasing number of studies rely on methods that better integrate the value of flexible and robust options (e.g. through Real Options Analysis, Robust Decision Making and Iterative Risk Management/ Adaptive Management).
- Opportunity or transaction costs are increasingly considered but non-monetary metrics are not systematically considered.

**Context**

Climate change is projected to modify global and regional hydrological cycles, raising the risk of more frequent and intense floods and physical threat to infrastructure, growing water supply deficits, and changing water quality (both drinking water quality and river dilution capacity). Snow recharge and the speeding melting of glaciers may further intensify these impacts. Water being a critical natural resource for many sectors, adaptation to expected and unforeseen impacts on water resources is becoming a key priority in many countries.

Adaptation options in water management can be differentiated between technical measures (e.g. dyke construction), soft measures (e.g. awareness-raising), and “green” or “ecosystem-based” approaches (e.g. artificial wetland construction, river restoration). Supply-side options are generally more infrastructure oriented and technically intensive, focusing on increased storage capacity, improving water distribution, and developing water reuse and treatment. Demand measures aim to increase water use efficiency and reduce consumption, often through behavioral changes.

**Policy and methodological developments**

The literature on the costs and benefits of adaptation in water management is large and diverse. Here some key studies are presented for four sub-sectors: water supply, wastewater and stormwater infrastructure, river flood protection, intra-urban flooding, ecosystem-based and spatial options, low regret options and river transport.

**Studies on water supply**

At the global level, Kirschen (2007) estimate additional investment and financial flows (I&FF) for water supply at USD 9-11 billion per year in 2030. The World Bank project on “Economics of Adaptation to Climate Change” (World Bank, 2009; Ward et al., 2010) also used I&FF to estimate adaptation costs for developing countries at USD 10-11 billion per year for the period 2010-2050, based on the cost of meeting future water demand. Other aggregated estimates also exist. Hughes,
Chinowsky and Strzepek (2010) estimate adaptation costs for water supply of 1–2% of baseline costs for all OECD countries, or about USD 5.5 billion per year.

At the sub-continental level, Bosello et al. (2009) calculate the annual direct cost of adapting to a temperature increase of 2.5°C at EUR 2.655 million for Western Europe and EUR 4.263 million in Eastern Europe by 2060. In sub-Saharan Africa, Muller (2007) estimates annual costs of USD 2–5 billion to adapt and build climate-proofed urban water infrastructure. In looking at Central America, Barcena et al. (2010) estimate the cost to ensure water supply at 5–10% of 2008 GDP. Skourtos, Kontogianni and Tourkolias (2013) developed an adaptation cost database for technologies for water saving for use at the European level.

There are also a number of studies at the national level. These include studies in the Netherlands on climate proofing the water system (van Ierland, 2006; de Bruin et al., 2009) which estimated costs for retention, storage and other regional adaptation measures to total EUR 15–20 billion, and on water management in California (Tanaka et al., 2006). These studies report that adaptation costs could be high. There are also studies that use general equilibrium models to look at water adaptation costs, including Faust, Gonseth and Vielle (2012) in Switzerland, and analysis of network loss reductions by the Bank of Greece (2011) which estimated adaptation costs at EUR 68.4 million per year by 2100, which is contrasted with EUR 380 million per year in benefits through avoided damages. Metroeconomica (2006) estimate adaptation costs for anticipated water deficits in South-East England and South-East Scotland up to 2100 at GBP 6-39 million per annum, using indicative cost-curves and cost-effectiveness analysis.

Studies also exist on water management at the local scale. Anderson (2008) examined the economic benefits of water reuse in Sydney in the context of future water supply and demand, concluding that implementation of water saving and reuse projects could have benefits of USD 400-800 million. Mánez and Cerdà (2014) used a cost-benefit analysis to prioritise adaptation measures in Valencia and Catalonia. In Quito, Ecuador, Vergara et al. (2007) estimate the costs of investment in response to glacier melt at USD 100 million.

There are further studies in developing countries (see ECONADAPT (2015) for further information). These include studies in Central America (Bárcena, A. et al., 2010), South Africa (Callaway et al., 2006), Kenya (SEI, 2009), Ethiopia (World Bank, 2010b), Ecuador (Vergara et al., 2007), Nepal (Dhakal and Dixit, 2013), China (Kirshen et al., 2005), Costa Rica, Dominican Republic, the Gambia, Bangladesh, Honduras, and Peru (UNDP, 2011), Jordan and the Maldives (UNFCCC, 2010).

**Studies on wastewater and storm water infrastructure**

There are some estimates of the costs of adapting wastewater and storm-water infrastructure, as well as water treatment costs, under climate change. These include studies in the United Kingdom on the costs for upgrading wastewater networks due to more frequent low-flows in rivers: GBP 4-10 million (ICF International, 2007) and cost-effectiveness analysis for agriculture and sewage treatment works to comply with the EU Water Framework Directive and Habitats Directives in the context of climate change (mitigation and adaptation) at sub-catchment level (Martin-Ortega et al., 2012); in Toronto, Canada on the costs of building new treatment plants, improving the efficiency of plants or increasing retention tanks (Dore and Burton, 2001) which estimated costs as high as CAD 9.4 billion; and in Boston on the costs of extra treatment of wastewater under climate change (Kirshen et al., 2004). In Sweden, the costs of increased infrastructure were estimated for wastewater plans to address water supply contamination from climate change risks and increased separation/inactivation of micro-organisms in water treatment plants (SCCV, 2007). Sussman et al. (2014) collated national and regional estimates for adapting water infrastructure in the United States.

**Studies on river flood protection**

The World Bank's EACC study (2010) estimate the cost of river flood protection using an impact
assessments approach. For developing countries, the adaptation costs were calculated at USD 4-7 billion annually from 2010-2050. Studies which focus on a smaller scale can use more detailed hydrological models linked to probability-loss functions or depth damage functions. It is common to assess the benefits of maintaining risk protection standards in comparison with the costs of flood protection. For Europe, the economic benefits of adaptation to maintain river flood protection levels at a minimum of 1 in 100 were calculated to be EUR 8 billion per year by the 2020s and EUR 19 billion per year by the 2050s (Rojas, Feyen and Watkiss, 2013). Similar studies have been carried out at national and river-basin levels: in the Netherlands (Delta Programme, 2008; Bouwer et al., 2010) and in the United Kingdom (Evans et al., 2004; Defra, 2011). These impact assessment studies demonstrate that adaptation measures to reduce flood related damages can have high benefits, but come with substantial investment costs. This conclusion has been reinforced by investment and financial flow studies in Bangladesh (UNDP, 2011) and Nepal (IDS, 2014).

**Studies on intra-urban flooding**

Analysis of intra-urban flooding is more limited, but there are some national studies which consider the adaptation costs, such as in the United Kingdom (Evans et al., 2004) and Germany (Tröltzsch et al., 2012). At the city level, Desjarlais (2011) carried out a cost-effectiveness study of urban drainage in Montreal. In Copenhagen, a cost-benefit analysis has taken place to assess a cloudburst plan (City of Copenhagen, 2012). Gersonius et al (2013) carried out a Real Options Analysis to assess the adaptation of the urban drainage system in West Garforth, England. All of these studies have estimated high adaptation benefits but often with high investment costs as well.

**Studies on ecosystem-based and spatial options**

In OECD countries, there is a move towards options beyond engineered control, such as: watershed management including enhanced conservation and restoration, natural flood plain management and natural protection structures as an alternative to concrete structures. The costs and benefits of these types of options have been reviewed in studies on ecological variants on flood defences in the Netherlands (De Bel, Schomaker and van Herpen, 2011), wetland restoration in Stockholm (Kettunen, 2011), flood storage in the United Kingdom (EA, 2009c) and in Germany (Teichmann and Berghöfer, 2010; TEEB DB, 2014). It is important to note that the benefits of such options are often delivered in the future because of the time required for full ecosystem establishment (Naumann et al., 2011).

**Studies on low regret options**

As with studies on coastal zone adaptation, recent studies on river and pluvial water flooding has moved towards assessing low-regret options and increased consideration of uncertainty. A number of such options have been studied which present high benefit-to-cost ratios: improved meteorological information and early warning systems (EASPE, 2002; Desbarte, 2012; World Bank, 2012); disaster risk management as well as emergency response plans (Hawley et al., 2012); creating an enabling environment for adaptation (Wilby and Keenan, 2012); enhanced maintenance of drainage and sewage systems (ECA, 2009; Ranger et al., 2011); risk transfer including insurance, reserve funds and risk pools (Jongman et al., 2014); household level adaptation responses (ASC, 2011; World Bank, 2011; Poussin et al. 2015); and integrated water resource management (Mechler, 2005).

Many promising options are considered “behavioural” options, relating to education, preparedness, emergency responses and forecasts and warning systems. These are low-regret options, but they are not cost free (Wilby and Keenan, 2012), and it is thought that as climate change increases the benefits they provide will also increase (ECA, 2009). Furthermore, these sorts of options present particularly high benefit-to-cost ratios in developing countries (Moench et al., 2009).

**Studies on river transport**

Adaptation costs for river transport, which is important on the major river systems of Europe, has
been considered in some studies, such as the analysis of Jonkeren (2009) along the Rhine.

Main implications and recommendations

The objectives of the different studies of course vary widely based on scale, scope, and methods. Many studies focus on providing the least costly adaption options to reach climate targets (Skourtos et al., 2013; Metroeconomica, 2006; Darch et al. 2011). Others aim to present a set of strategies which perform well across multiple tested scenarios, in other words strategies which can be considered robust (Lempert and Groves, 2010; Groves et al., 2013).

Few studies to date have considered opportunity and transaction costs. This is often due to the complexity of including such factors, or in the case of Muller (2007) because they are considered too “site-specific” to be applied to broader assessments.

A growing number of studies better take into account issues of uncertainties and timing in the cost/benefit assessment of adaptation actions. However few suggestions are made beyond broad recommendations such as improving and expanding data and projections on climate change and carrying out studies in greater detail (Bank of Greece, 2011).

Often, studies examine the effects of various discount rates on benefit-to-cost ratios of adaptation options. The discount rate of 4% is often chosen as a benchmark, as it falls close to the middle of many ranges considered (van Ierland, 2006; de Bruin et al., 2009).

The consideration of distributional and equity effects, has been noticeably lacking for the most part. Some studies do acknowledge that lower-income populations will be most affected by climate change, but such factors are usually seen as being outside the scope of the study (Bank of Greece, 2011; Dhakal and Dixit, 2013; Jeuland and Whittington, 2013). Dhakal and Dixit (2013) suggest incorporating local stakeholders into future studies to develop mechanisms to take these factors into account.

The concept of autonomous adaptation is mostly lacking from economic studies of climate adaption in the water sector, with a few notable exceptions (e.g. Koopman et al. 2015).

Bibliography


ASC (Adaptation Sub Committee) (2011), Research to identify potential low-regrets adaptation options to climate change in the residential buildings sector, a report prepared by Davis Langdon for the Adaptation Sub Committee.

Bank of Greece (2011), The environmental, economic, and social impacts of climate change in Greece, Climate Change Impacts Study Committee, Athens.

Bárcena, A. et al. (2010), The Economics of Climate Change in Central America, ECLAC Subregional Headquarters in Mexico, Mexico City and Centreal American Integration System (SICA), El Salvador.

Bosello, F., C. Carraro and E. De Cian (2009), An Analysis of Adaptation as a Response to Climate Change, Working Paper, No. 26, Department of Economics Ca’ Fosari University of Venice.


City of Copenhagen (2012), Københavns Kommunes Skybrudsplan 2012, City of Copenhagen, Copenhagen.


Desbartes, J. (2012), Adaptation Cost Assessment of Early Warning Systems and Implementing Measures, Report as part of the EC Project Methodologies for climate proofing investments and measures under cohesion and regional policy and the common agricultural policy, IEEP.


EA (2009), Using science to create a better place: Ecosystem services case studies, Environment Agency, Bristol.


ECA (2009), Shaping climate-resilient development: A framework for decision-making, a report of the Economics of Climate Adaptation working group, Economics of Climate Adaptation.


Hawley, K., M. Moench and L. Sabbag (2012), Understanding the economics of flood risk reduction: A preliminary analysis, Institute for Social and Environmental Transition-International; Boulder CO.


Jonkeren, O. (2009), Adaption to climate change in inland waterway transport, Vrije Universiteit.


Máñez, M. and A. Cerdà (2014), Prioritisation Method for Adaptation Measures to Climate Change in the Water Sector, CSC Report 18, Climate Service Center, Germany.


Metroeconomica (2006), Climate Change Impacts and Adaptation: Quantify the Cost of Impacts and Adaptation, Report to Defra, London.

Moench, M. et al. (2009), Rethinking the costs and benefits of disaster risk reduction under changing climate conditions, in Moench, M. et al. (eds.), Catalyzing Climate and Disaster Resilience, ISET-Nepal, Kathmandu.


SEI (Stockholm Environment Institute) (2009), The Economics of Climate Change in East Africa: Downing, T. et al. Report for DFID and DANIDA.


measures in Germany]. Climate Change, No. 10/2012, UBA, Dessau,

UNDP (2011), Assessment of Investment and Financial Flows to Address Climate Change (Capacity
development for policy makers to address climate change). Country summaries.

UNFCCC (2010), Synthesis report on the National Economic, Environment and Development Study
(NEEDS) for Climate Change Project, FCCC/SBI/2010/INF.7, United Nations Framework
Convention on Climate Change, Bonn.

van Ierland, E.C. et al. (2006), A qualitative assessment of climate change adaptation options and
some estimates of adaptation costs. Routeplanner subprojects 3, 4 and 5, Wageningen UR.

Vergara, W. et al. (2007), Economic impacts of rapid glacier retreat in the Andes, EOS Transactions

Ward, P.J. et al. (2010), Partial costs of global climate change adaptation for the supply of raw
industrial and municipal water: A methodology and application, Environmental Research Letters,

Wilby, R.L and R. Keenan (2012), Adapting to flood risk under climate change, Progress in Physical

World Bank (2009), Evaluating Adaptation via Economic Analysis, Guidance Note 7, Annex 12,
World Bank.

World Bank (2010), The Costs to Developing Countries of Adapting to Climate Change: New
Methods and Estimates. The Global Report of the Economics of Adaptation to Climate Change
Study Consultation Draft.

World Bank (2010b), Ethiopia – Economics of adaptation to climate change, World Bank,
Washington, DC.

World Bank (2011), Natural Hazards, UnNatural Disasters: The Economics of Effective Prevention,
World Bank, Washington, DC. World Bank (2010), Economics of Adaptation to Climate Change –
Ecosystem Services, Discussion Paper, No. 7, World Bank, Washington, DC.

World Bank (2012), A Cost Effective Solution to Reduce Disaster Losses in Developing Countries:
Hydro-Meteorological Services, Early Warning, and Evacuation, World Bank, Policy Research

Further Information
Overview of costs and benefits of adaptation at the national and regional scale
Using cost and benefits to assess adaptation options [pdf]
Contact
Josselin Rouillard
Partner
Ecologic Institute
Paul Watkiss Associates