Institution: University of Reading

Unit of Assessment: 7 Earth Systems & Environmental Sciences

Title of case study: Assessing the effect of climate change on the flood risk to London to inform flood management strategies

1. Summary of the impact:

Protecting London from the threat of flooding is of prime importance to the nation. Work in the Unit on regional sea-level rise and on the effect of storm surges was used in the Environment Agency's Thames Estuary 2100 (TE2100) plan to assess potential change in risk. The Unit's work estimated a very unlikely maximum rise in sea level of 2.7m by 2100, considerably lower than the previous worst-case scenario of 4.2m. It confirmed that 90 centimetres was the figure that should be used for developing the plan. TE2100 concluded that a second Thames Barrier (estimated cost £10-20 billion at today's prices) would not be needed not by 2030, but may be needed by 2070. Our results have been used to define procedures for the monitoring of regional sea and Thames water levels over the next few decades, and to review decision-making procedures to ensure that the risk of flooding in London is kept within acceptable levels, while avoiding unnecessary costs

2. Underpinning research:

Climate change is expected to lead to changes in the frequency of flooding along UK coastlines, for two reasons. First, mean sea level will rise as oceans warm and glacier ice melts. Second, a change in wind and atmospheric pressure may lead to changes in the frequency of storm surges. Research at the Unit and the UK Met Office through the work of Prof. Jonathan Gregory and Dr. Jason Lowe has examined both of these components, with a particular focus on coasts around the UK. Gregory joined the Unit in 2003 and Lowe is a Met Office employee who has been on full-time secondment to the Unit (as part of the MetOffice@Reading group) since 2003. This work within the Unit was supported by funding from Defra to the Met Office under contract PECD7/12/37.

Lowe and Gregory (2005)[1] and (2006)[2] assessed potential changes in the magnitude of extreme sea levels around the UK due to climate change. They used the Met Office's HadCM3 global climate model to provide inputs to the higher resolution regional climate model HadRM3H (via an intermediate scale model), and then used the output from HadRM3H to run a storm surge model previously developed by NERC's Plymouth Oceanographic Laboratory (POL). This nested approach to providing the inputs for the storm surge model was necessary because the coarse-scale global models used to simulate the effects of future emissions of greenhouse gases do not provide fine enough details on potential changes in regional wind speeds and circulation patterns. Lowe and Gregory[1,2] estimated that, under high emissions of greenhouse gases, the height of the 50-year return period flood around the south east coast of England would increase by around 1.2m by 2100: 70cm would be due to increased storminess leading to more frequent surges, approximately 33cm would be due to the increase in sea level, and the rest would be due to the long-term sinking of south east England associated with the isostatic rebound of northern UK following the deglaciation. However, there is uncertainty in the projected change in extreme sea levels, not only because of uncertainty in the change in storminess, but also because of uncertainty in change in mean sea level at the regional scale; as oceans warm, sea level rises differently in different parts of the ocean because of differences in the density of sea water and the effect of ocean currents. Different climate models from different modelling centres make different projections of both global mean sea level change and the pattern of change across the globe (e.g., Bindoff et al., 2007[3]; Pardaens et al., 2011[4]).

As part of the underpinning research for the TE2100 plan for the Thames Estuary, in 2005 the Met Office and POL were commissioned by the Environment Agency to assess the effects of climate change on extreme sea levels in the Thames Estuary. The work was led by Lowe in the Unit with contributions from other Unit staff and Gregory in particular. The research built on Lowe and Gregory[1,2], using essentially the same methodology, but used several climate models to estimate changes in storminess around the UK and several climate models to estimate change in mean sea level around the UK in order to better characterise uncertainty. The research also contributed directly to the marine component of the UKCP09 UK climate projections[6], published in 2009 by Defra, and is described in detail in the underpinning UKCP09 science report written by Lowe[5]. Subsequently, the i-STORM group[15] was established by the Environment Agency monitor relevant developments and the Unit's research continues to input advances in the science and modelling into this process (e.g., Pardaens et al., 2011).[4]

3. References to the research:

The research at the Unit was supported by funding from DEFRA under contract PECD7/12/37, and by the Met Office (because J. Lowe is a Met Office employee on full-time secondment to the Unit and has been for all the time that this research was carried out, namely since 2003). Citations are taken from a WoS search carried out in October 2013 and 3 papers which can be used to evaluate research excellence are marked with an asterisk.

1. *J.A. Lowe, J.M Gregory (2005). The effects of climate change on storm surges around the United Kingdom, *Phil. Trans. Roy. Soc*. (London), 363, 1,313-1,328 (63 cites)
2. *J.A.Lowe, and J.M Gregory (2006) Understanding projections of sea level rise in a Hadley Centre coupled climate model, J. Geophys. Res. (Oceans), 111 (C11), C11014 (24 cites)
3. N.L Bindof et al. (incl. J. Gregory), (2007) Observations: Oceanic Climate Change and Sea Level, in: *Climate Change 2007: The Physical Science Basis*, Contribution of Working Group I to the Fourth Assessment Report of the IPCC, Cambridge University Press, Note that as a lead author, Gregory reviewed the literature but also carried out new research to compare and combine data and models. http://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch5.html
4. *A.K. Pardaens, J.M. Gregory, J.A. Lowe (2011). A model study of factors influencing projected changes in regional sea level over the twenty-first century. *Clim. Dyn.* 36(9), 2015-2033 (19 cites)
5. J.A. Lowe et al. (2009), UK Climate Projections science report: Marine and coastal projections. Met Office Hadley Centre, Exeter, UK. ISBN 978-1-906360-03-0 http://ukclimateprojections.defra.gov.uk/media.jsp?mediaid=87905&filetype=pdf

4. Details of the impact:

London and the Thames Estuary have always been subject to flood risk. There are £200 billion of capital assets in the Thames tidal floodplain, including 500,000 properties, nearly 100 tube/train stations, the City airport, 400 schools, 16 hospitals and 8 power stations, and 1.25 million people live or work below the Thames average high tide level.[16] In addition, the London economy is worth £230 billion per annum and is the centre of government as well as many other sectors. It has been estimated that the cost of a single London flooding event could be £12-16 billion,[7] with great potential for fatalities. London therefore has a high level of protection against coastal floods. Construction of the current Thames Barrier began following the enquiry into the East Coast flooding in 1953 and was completed in 1983, at a total cost of around £1.7 billion in 2012 prices. The original design of the barrier was to cope with a 1-in-1000 year event until 2030, taking into account the long-term sinking of south east England. However, the design did not take into account changes in the size of storm surges in the North Sea.

The Environment Agency (EA) launched the Thames Estuary 2100 (TE2100) project in 2002, and the final TE2100 plan was released in November 2012.[16] TE2100 was established because of a recognition that exposure to flood loss was increasing and that flood protection infrastructure – including the Thames Barrier – would need upgrading at some stage in the future. The initial planning work to identify management options used established Defra guidance on sea level rise (12 mm/year over 2055-2085, or approximately 90 cm by 2100)[8], and following the Avoiding Dangerous Climate Change conference[9] in 2005 also considered an extreme sea level rise scenario of 4.2m by 2100. Using these scenarios, a series of high level options involving different combinations of adaptation measures were developed. In 2005, TE2100 commissioned the Met Office's Hadley Centre (which resulted in Unit staff being involved), POL and (for river flood risk) NERC's Centre for Ecology and Hydrology to produce revised climate change scenarios.

The research into storm surges had two consequences. First, it used several climate models to estimate both changes in storminess and regional sea levels, demonstrating that the sea level rise assumptions made in the original plans were reasonable.[6] Second, using expert judgement and interpretation of evidence from periods of past rapid sea level rise, it produced a new estimate of a plausible (but highly unlikely) maximum sea level rise (termed the H++ scenario) of 2.7m. This was considerably lower than the extreme case previously used. The TE2100 Plan[16] recognises the importance of the Unit's findings, stating (p28):

"*These results give greater certainty that we have being planning for the right potential range of water levels this century"*

"Our previous worst-case scenario for increases in maximum water levels can be revised down."

"Such a reduction in worst-case scenario for this century means that a tide-excluding barrage will

not be necessary to manage flood risk this century and can be dropped from our final options"

The cost of this second barrage has been estimated to be approximately £10 billion (in 2012 prices)[16], and would need to be accommodated in the Government's financial planning. As noted by Reeder and Ranger (2012)[18] of the proposed developments: "*These types of investments tend to be difficult or costly to reverse (i.e. they have high 'sunk costs'), are high-stakes and their design is dependent on what assumptions are made today about the climate over its lifetime (e.g. the appropriate height of a sea wall will depend on assumptions about sea level rise over the next few decades). This means that if forecasts are incorrect today, the project can become maladapted to climate, exposing society to greater risks, wasted investments or unnecessary retrofit costs*." They also note the success of the TE2100 in handling this problem: "*The TE2100 project demonstrates that robust adaptation planning is possible even where dealing with long-lived decisions with high sunk-costs and deep uncertainty over future climate risks*." The TE2100 plan also defines the monitoring, reviewing and the decision-making procedures that will be needed to keep the risk to London, including the storm surge risk from the east and the fluvial risk to the west, within acceptable levels.[10]

The associated monitoring costs are also calculated. Part of this continued evaluation is undertaken through the i-STORM international network of moveable storm barriers, which includes representation from the UK (the Thames Barrier), the Netherlands, Russia and Italy[15]. The aim of i-STORM is to share experience and methods; Lowe sits on the science panel for the network, bringing his experience of climate change to i-STORM. The experience of TE2100 has being used to inform similar projects elsewhere in the world.[18,19]

Because of its importance to such a large population the TE2100 plan has received considerable media attention[11-14] and has great economic implications. A quantification of economic importance of the recommendations was commissioned by NERC from the DTZ/UGL consultancy and traces the impact of storm surge modelling work at POL.[20] Because that modelling was deployed via Lowe and Gregory (2005)[1] and Lowe et al. (2009)[5] into TE2100, the findings are relevant here. The NERC-DTZ report summarises the financial impacts to be: safeguarding the London Economy – £94 million per flood day; safeguarding property in the Thames Estuary area – £2 billion per annum; giving confidence to future London investment – £2.1 billion per annum; value of human lives in the Thames floodplain – £31.25 billion per annum.

The research used to construct the scenarios for extreme water levels for TE2100 also contributed directly to the UKCP09 climate projections.[6] The UKCP09 climate projections were published by Defra in 2009, and provide climate information designed to help those needing to plan how they will adapt to a changing climate. UKCP09 was developed by incorporating the needs of users of climate projections, and also by making use of advances in climate science since the previous set of UK scenarios was published in 2002. In particular, the UKCP09 projections take a probabilistic approach, and construct probability distributions for changes in relevant climate, marine and coastal variables. The Marine and Coastal Projections Report[5] presents scenarios for changes in mean sea level and storm surge around the UK (along with wave heights and ocean temperatures), and was led by the Unit's Dr Lowe. These scenarios show ranges in change in mean sea level and storm surge, based on the use of multiple climate models. Chapter 7[17] of the UKCP09 report gives a case study of the use by TE2100 of the sea-level rise and storm surge projections (given in Chapters 2–4 of the report) and demonstrated how the UKCP09 results could be used in practice. The UKCP09 sea level and storm surge scenarios have since 2010 been incorporated as Supplementary Guidance[21] into the Environment Agency's revised Flood and Coastal Erosion Risk Management Appraisal Guidance (FCERM-AG)[22]. This guidance is used in all coastal flood management projects in England, and has been applied in all appraisals started since August 2011. The UK's Climate Change Risk Assessment[23], published in 2012, used the UKCP09 sea level rise scenarios to estimate future exposure to coastal flooding.

The Thames Region Climate Change Programme Manager of the Environment Agency notes that[24] "*The TE2100 project was the first major infrastructure planning project to put adapting to the impacts of climate change at its centre……Jason [Lowe]'s research commissioned by the TE2100 project formed the majority of the input to the UKCP09 marine projections and has proved very valuable not only to the TE2100 plan but also to the wider UK in understanding the scale of challenge to adapt to rising sea levels and changing weather patterns*."

Background information

6. UK Climate Projections, UKCP09, Defra, http://ukclimateprojections.defra.gov.uk/
7. London Assembly, Environment Committee, London under threat? Flooding risk in the Thames Gateway (2005) http://legacy.london.gov.uk/assembly/reports/environment/flood_thamesg.pdf
8. Defra Flood and Coastal Defence Project Appraisal Guidance. FCDPAG3 Economic Appraisal Supplementary Note - Climate Change Impacts October 2006. http://bit.ly/HwIgrn
9. H. Schellnhuber et al. (2006) (eds) *Avoiding Dangerous Climate Change* (Cambridge University Press) http://bit.ly/1aPDEHi
10. Sarah Lavery (TE2100 Project Manager), Environment Agency, Thames Estuary 2100- http://www.gre.ac.uk/__data/assets/pdf_file/0004/473782/Sarah-Lavery_TE2100-pdf.pdf
11. Ministers plan new Thames barrier as flood risk rises, Independent, 27 August 2007 http://ind.pn/1dZGpbY
12. Thames Barrier to hold until 2070, BBC News, 31 March 2009 http://news.bbc.co.uk/1/hi/england/london/7973623.stm
13. New Thames Barrier delayed for 40 years, London Evening Standard, 31 March 2009 http://www.standard.co.uk/news/new-thames-barrier-delayed-for-40-years-6932789.html
14. No need to replace Thames Barrier says former manager, New Civil Engineer, 21 Feb 2013 http://bit.ly/1iB78JJ
15. i-STORM: International network for storm surge barriers https://www.i-storm.org/

5. Sources to corroborate the impact

16. The Environment Agency, The TE2100 Plan: http://bit.ly/17y2wVu
17. UK Climate projections, Part 7, Thames Estuary 2100 case study. http://ukclimateprojections.defra.gov.uk/media.jsp?mediaid=87898&filetype=pdf
    We include this reference here to make clear the importance of the Unit's research to both UKCP09 and TE2100. This is part 7 of Lowe et al. (2009)[5] that the Unit (via the Met Office) was commissioned to write by Defra, that has been released on the Defra Website as part of UKCP09.[6] This is also the technical report supporting TE2100.[15] Lowe & Gregory (2005)[1] is one of just two references listed in section 7.8 (References), showing the work's central importance to both UKCP09 and TE2100.
18. T. Reeder and N. Ranger (2012) How do you adapt in an uncertain world? Lessons from the Thames Estuary 2100 project, World Resources Report, Washington DC. http://bit.ly/1h6SZsa
19. R.J. Nicholls et al. (2011) Constructing Sea-Level Scenarios for Impact and Adaptation Assessment of Coastal Areas: A Guidance Document, TGICA Task Group, IPCC http://www.ipcc-data.org/docs/Sea_Level_Scenario_Guidance_Oct2011.pdf
20. Storm Surge Prediction and its Impact on the UK Economy, DTZ/NERC report http://www.nerc.ac.uk/business/casestudies/documents/storm-surge-report.pdf
21. Adapting to Climate Change: Advice for Flood and Coastal Erosion Risk Management. Environment Agency (2010) http://bit.ly/1f920ws (The Unit's input is via the use of UKCP09 predictions which were based on the work of Lowe and Gregory[1])
22. Flood and Coastal Erosion Risk Management Guidance. http://www.environment-agency.gov.uk/research/planning/116705.aspx (For England the guidance recommends use of the UKCP09 predictions which were based on the work of Lowe and Gregory[3])
23. Policy paper: UK Climate Change Risk Assessment: Government Report (25 January 2012) https://www.gov.uk/government/publications/uk-climate-change-risk-assessment-government-report. Details are provided in the Technical Report on the Floods and Coastal Erosion Sector.
24. Testimonial letter from Regional Climate Change Programme Manager, Thames Region, Environment Agency (available upon request)