Institution: Loughborough University		
Unit of Assessment: **C14 Geography and Environmental Studies**		
Title of case study: Adapting water and energy infrastructure to climate change		
Period when the underpinning research was undertaken: 2008-2016		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s): Robert Wilby	**Role(s) (e.g. job title):** Professor of Hydroclimatic Modelling	**Period(s) employed by submitting HEI:** Since 1 October 2008
Period when the claimed impact occurred: 2010-2020		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact (indicative maximum 100 words)

Managing risks posed by climate change is challenging because of deep uncertainty about the future plus a lack of sector-level guidance on *how* to adapt. Wilby's research into climate risk management and adaptation frameworks enabled EDF Energy and Multi-lateral Development Banks to adapt their investments in energy and water infrastructure by strengthening engineering design and technical practices. Impacts were: (1) increased safety margins for testing coastal flood defences at Sizewell C against sea level rise; (2) climate resilient upgrading and operation of hydropower infrastructure in Tajikistan; and (3) management of climate risks within infrastructure investments made by the Asian Development Bank.

2. Underpinning research (indicative maximum 500 words)

Businesses and Multi-lateral Development Banks (MDBs) are setting ambitious targets for adapting to climate change. This is because long-lived energy and water infrastructure (such as hydropower plants) must deliver intended social, economic, and environmental benefits for many decades to come, despite deep uncertainty about climate change. Meanwhile, aging assets must be refurbished to improve safety and performance under conditions that were not envisaged at the time of their design.

These are technically demanding tasks and there are limited tools or sector guidance to support practitioners – especially in low-capacity, data-sparse regions of Africa, Asia, and South America. Yet, such places are facing some of the most extreme impacts of climate change and are where most new infrastructure is yet to be built. During the period 2008-2016, Wilby addressed these knowledge gaps at Loughborough University through research into climate risk management (CRM) frameworks and development of tools for regional climate change simulation.

Conventional approaches to CRM begin with model projections of expected climate change and impacts. Thinking about how to adapt comes much later, by when decision-makers are confronted with deep uncertainty. Consequently, generic solutions – such as strengthened hazard monitoring and forecasting systems – are typically offered.

In contrast, the CRM framework devised by Wilby starts with the project goal(s) and asks, "what adaptation measures are needed to achieve these outcomes despite a wide range of plausible climate conditions?" (**R1**). A key advantage of this framework, developed with researchers at Leeds University and the UK Centre for Ecology and Hydrology, is that future climate scenarios and adaptation options are co-designed with practitioners. This leads to a deeper and shared understanding of system vulnerabilities. The CRM framework is also less resource-demanding in terms of the amount of analysis required yet provides information about adaptation and development outcomes that remains valid regardless of ongoing climate model refinement – so is effectively 'scenario-neutral' (**R2, R3**).

Wilby undertook research to test the CRM framework in practice. Early research partners were EDF Energy in the UK (**R4**) and Denver Water in Colorado (**R5**). The EDF Energy Climate Change Working Group (Chaired by Wilby) evaluated ways of adapting the new nuclear build site at Sizewell, UK to high-end sea level changes and more extreme weather. Despite deep uncertainty about credible maximum sea-level projections (and flood risk), flexibility and allowances for climate change were factored into the plan. When combined with routine monitoring, the site can now be adaptively managed into the 2200s. With Denver Water, the CRM framework was used to test the extent to which a legal instrument to reallocate water rights could offset expected drought and catchment changes over coming decades. The new drought measures were estimated to improve water supplies by 35 billion litres (enough to meet the needs of 300,000 residents of Denver).

Meanwhile, Wilby continued to enhance the functionality of his climate scenario tool – the Statistical DownScaling Model (SDSM). This was used alongside the CRM framework to simulate long daily weather series for stress-testing the performance of adaptation measures under plausible climate change conditions. Since an upgrade in 2014, SDSM has been capable of infilling missing weather information in broken meteorological records and providing extreme value statistics for rare hydro-climatic events (**R6**).

3. References to the research (indicative maximum of six references)

R1. Wilby, R.L. and Dessai, S. 2010. Robust adaptation to climate change. *Weather*, **65**, 180-185. DOI: 10.1002/wea.543.

R2. Prudhomme, C., Wilby, R.L., Crooks, S., Kay, A.L. and Reynard, N.S. 2010. Scenario-neutral approach to climate change impact studies: application to flood risk. *Journal of Hydrology*, **390**, 198-209. DOI: 10.1016/j.jhydrol.2010.06.043.

R3. Poff, N.L., Brown, C.M., Grantham, T.E., Matthews, J.H., Palmer, M.A., Spence, C.M., Wilby, R.L., Haasnoot, M., Mendoza, G.F., Dominique, K.C. and Baeza, A. 2016. Sustainable water management under future uncertainty with eco-engineering decision scaling. *Nature Climate Change*, **6**, 25-34. DOI: 10.1038/nclimate2765.

R4. Wilby, R.L., Nicholls, R.J, Warren, R., Wheater, H.S., Clarke, D., and Dawson, R.J. 2011. Keeping nuclear and other coastal sites safe from climate change. *Proceedings of the Institution of Civil Engineers: Civil Engineering*, **164**, 129-136. DOI: 10.1680/cien.2011.164.3.129.

R5. Yates, D., Miller, K.A., Wilby, R.L. and Kaatz, L. 2015. Decision-centric adaptation appraisal for water management across Colorado's Continental Divide. *Climate Risk Management*, **10**, 35-50. DOI: 10.1016/j.crm.2015.06.001.

R6. Wilby, R.L., Dawson, C.W., Murphy, C., O'Connor, P. and Hawkins, E. 2014. The Statistical DownScaling Model – Decision Centric (SDSM-DC): Conceptual basis and applications. *Climate Research*, **61**, 251-268. DOI: 10.3354/cr01254.

The above research was enabled by competitive funding from EPSRC and NERC, as well as from EDF Energy. The research outputs were published in peer-reviewed journals with global reach and/or visibility to target professionals. Outputs **R1**, **R2** and **R4** were cited in three reports of the Intergovernmental Panel on Climate Change. These were the Special Report on Extremes in 2012; Climate Change 2014: Impacts, Adaptation and Vulnerability; and the Special Report on Climate Change and Land in 2019. Output **R4** was also referred to by a UK Government Foresight on the Future of the Sea. SDSM (**R6**) has been applied in more than 500 research studies, covering at least 50 countries.

4. Details of the impact (indicative maximum 750 words)

Pathways to the impacts

Wilby's Climate Risk Management (CRM) framework and climate scenario tool (SDSM) equipped businesses and MDBs with improved procedures and technical standards for strengthening the climate resilience of their long-lived infrastructure investments. This was achieved through pathways of technical assistance and secondments, *in situ* training programmes, and co-development of practical guidance with project teams.

Successful adaptation to future climate threats is more likely to arise when risks and options are factored into infrastructure designs and operating rules. According to the founder of the Alliance for Global Water Adaptation (AGWA), Wilby's CRM "*helped to transform the way that partner organizations manage water basins in light of climate change scenarios … This thinking was subsequently enshrined within the 2015 World Bank 'Decision Tree Framework', which makes explicit reference to the work of Wilby as foundational to the framework. At least 25 billion US dollars are invested annually in water infrastructure by the World Bank following the Decision Tree Framework…*" (**S1**).

Thanks to the high visibility of his work with the World Bank, Wilby was invited to give technical advice on climate risk and vulnerability assessment to other non-academic organizations. Examples include: shaping the methodologies applied by the second UK Climate Change Risk Assessment under the auspices of the Committee on Climate Change; advising the World Bank and International Fund for Agricultural Development on climate adaptation in Yemen; evaluating strategic research opportunities and proposals for the Department for International Development ClimDev-Africa, CIASA and WISER programmes; and developing guidance on the evaluation of physical climate hazards for the United Nations Environment Programme Finance Initiative (UNEP-FI) working group (**S2**).

The tool and scenarios produced by SDSM, were cited in National Communications submitted by Non-Annex I parties, such as Niger (2016), Iran (2018), and Yemen (2018) to the United Nations Framework Convention on Climate Change; a key graphic from output R1 appears in the National Communication of Bangladesh (2018).

Evidence is given below of specific impacts on climate adaptation design standards, technical capacities, and procedures adopted by three organizations: (1) EDF Energy at Sizewell; (2) the European Bank for Reconstruction and Development (EBRD) in Tajikistan; and (3) the Asian Development Bank (ADB) for investments across Asia.

Impact 1: Increased safety margins for testing coastal flood defences at Sizewell C against sea level rise

Credible maximum sea level rise scenarios for the UK east coast developed by Wilby were cited in the planning application submitted by EDF Energy to the Planning Inspectorate in May 2020 under the Planning Act 2008 (**S3**). Extreme sea level scenarios are required to test the design of the main Sizewell C sea defences as part of the Main Development Site Flood Risk Assessment. The planning application (section 5.3.2) states that

> "*It is proposed to use the UKCP18 RCP8.5 at 95%ile* [Met Office 2018 UK Climate Projections UKCP18] *allowances for the normal breach and coastal inundation scenarios for all considered epochs. For the scenario with breach of main Sizewell C sea defences, that are designed for 1 in 10,000-year event, it is proposed to use more conservative allowances derived from previous studies, namely the BECC* [Wilby] *Upper allowance.*"

As a result, more stringent climate change allowances for sea level rise are embedded in the planning application (Table 5.3) for key points in time of the Sizewell C development. By year 2140 (the phase by which the interim spent fuel store is decommissioned), simulations of main sea defences must withstand more conservative upper-bound sea level change scenario of 3.920 metres (Wilby) compared with 1.815 metres (UKCP18). By year 2190 (the theoretical maximum site lifetime), the sea level rise scenarios are 4.820 metres (Wilby) compared with 2.645 metres (UKCP18).

Impact 2: Climate resilient upgrading and operation of hydropower infrastructure in Tajikistan

Hydropower provides 98% of the electricity supply in Tajikistan but the sector is highly vulnerable to climate change because of potential reductions in snow and ice stores, plus changing risks to infrastructure from avalanches, floods and mudslides. Wilby increased the adaptive capacity of the hydropower sector by providing technical assistance to EBRD through Phase 1 of the Pilot Programme for Climate Resilience (PPCR) in Tajikistan (**S4**). His technical evaluation of reservoir inflow scenarios for the rehabilitation of the Qairokkum hydropower plant underpinned three adaptation strategies (**S4**). These were replacement of old turbines with more efficient equipment, replacement and installation of additional generating capacity, or partial replacement with phased retirement of turbines. Subsequently, EBRD and PPCR exercised the third option and invested $75 million, with wider provisions for national capacity building in climate monitoring, climate risk assessment, and seasonal forecasting (see Phase 2 below). Wilby also delivered seven training modules for hydropower engineers and planners in Tajikistan during the period 2016-2020.

Practical insights gained from the Qairokkum rehabilitation project (above) were later incorporated within the International Hydropower Association (IHA) *Hydropower Sector Climate Resilience Guide* (**S5**). Wilby presented key recommendations on ways of applying the guidance in data sparse/low capacity regions during an international hydropower workshop held at the EBRD headquarters in London, January 2019. The IHA guide provides a point of reference on climate resilience for hydropower engineers in over 100 member organizations across more than 80 countries.

Phase 2 of the programme included activities for strengthening technical capacities in climate resilience amongst professionals within the hydropower sector of Tajikistan and beyond. Wilby co-designed and delivered a new professional development programme on climate risk management techniques with counterparts in the energy sector of Tajikistan. Participants came from Tajik Hydromet (state agency), Barqui Tokik (the national electricity supplier), and the Tajik Technical University. His “recipe” for long-range forecasting of river flows was followed by Tajik Hydromet in winters 2019 and 2020 to anticipate inflows to the largest hydropower plant in Tajikistan (**S6**). Wilby’s technique enabled reservoir managers to predict whether there would be more, less, or average inflow for energy production three months before the standard forecast issued at the start of the spring snowmelt season.

Impact 3: Management of climate risks within infrastructure investments of the Asian Development Bank

From 2017, Wilby assisted ADB’s Sustainable Development and Climate Change Department to reform processes and practices for managing climate risks to their adaptation investments. By then, his CRM framework was already visible within operational advice such as the ADB *Guidelines for Climate Proofing Investment in the Water Sector* (**S7**). However, his 2017 review of ADB procedures laid out a programme of work for rationalizing practices and building capacity/guidance in climate risk management. This materialized in a new set of operating principles for climate-proofing infrastructure projects, co-developed with other ADB consultants (**S7**). The new processes were subsequently rolled-out via training workshops delivered by Wilby at ADB headquarters in Manila, Philippines in 2018 and 2019.

Wilby’s contribution to the training included worked examples of the CRM for ADB specialists, sector teams and departments across Asia and the Pacific region. This was supported by a raft of other resources to embed allowances for climate change in project designs (**S8**). His “go to” compendium of climate information sources helps ADB Project Preparatory Technical Assistance teams to source essential data for climate risk assessments. His 2020 Knowledge Product, and 2020 *Manual on Climate Change Adjustments* (**S8**) show engineers how to incorporate allowances for climate change in detailed designs of roads, culverts, and coastal infrastructure.

During 2019-2020, Wilby also provided technical reviews of 28 *Climate Risk Country Profiles* on behalf of ADB and the World Bank (**S9**). Each profile synthesizes information about climate change, disaster risk reduction, and adaptation actions and policies at the country level. ADB and the World Bank state that these profiles

> “*are designed as a quick reference source for development practitioners to better integrate climate resilience in development planning and policy making …to facilitate upstream country diagnostics, policy dialogue, and strategic planning by providing comprehensive overviews of trends and projected changes in key climate parameters,*

sector-specific implications, relevant policies and programs, adaptation priorities and opportunities for further actions" (**S9**).

According to a former ADB Senior Climate Change Adaptation Specialist, Wilby "*has been making substantial contributions to improving ADB's operational procedures and practice for managing climate risks to investment projects*" (**S10**). The legacy of his research has been upgrades to substantial infrastructure investments as well as to operating procedures for energy and water systems so that intended development outcomes are delivered despite climate change.

5. Sources to corroborate the impact (indicative maximum of 10 references)

S1. Testimonial from the founder of the Alliance for Global Water Adaptation (AGWA) about Wilby's influence on the development of the World Bank's Decision Tree Framework. This testimonial refers to: World Bank, 2015. *Confronting Climate Uncertainty in Water Resources Planning and Project Design: The Decision Tree Framework*. International Bank for Reconstruction and Development, Washington DC.

S2. This report lays out state-of-the-art tools and data for assessment of physical climate-related risks and opportunities by international banks. UNEP Finance Initiative, 2020. *Charting a New Climate*. Chapter 6. Physical Risk Correlation Analysis of FI Portfolios. United Nations Environment Programme, pp66-85.

S3. EDF Energy, 2020. *The Sizewell C Project. Section 5.2 Main Development Site Flood Risk Assessment*. Appendices 1-7 Part 14 of 14. See Sections 2.3.1, 2.3.3, 2.3.5, 2.3.6, Table 2.2, Section 5.3.2, Table 5.2, Section 5.4.10, Tables 5.3 and 5.4, and Reference #8, which refer to the BECC (2014) scenarios authored by Wilby.

S4. Evidence of Wilby's contribution to Phase 1 of the Pilot Programme for Climate Resilience (PPCR) in Tajikistan: ADB, 2014. *Building the Analytical Base: A Summary of Results from Phase 1 of the Pilot Program for Climate Resilience in Tajikistan*. Asian Development Bank, Manila, Philippines.EBRD, 2016. *Qairokkum hydropower: Planning ahead for a changing climate*. Sustainable Energy Initiative, European Bank for Reconstruction and Development, London.

S5. International Hydropower Association, 2019. *Hydropower Sector Climate Resilience Guide*. London, United Kingdom.

S6. Seasonal outlooks produced by Tajik Hydromet for inflows to Nurek reservoir in 2019 and 2020 (in Russian). These follow the step-by-step methodology developed by Wilby.

S7. Evidence of embedding of CRM frameworks within ADB procedures is given by: ADB, 2016. *Guidelines for Climate Proofing Investment in the Water Sector*. Asian Development Bank, Manila, Philippines; ADB, 2020. *Principles for Climate Risk Management Approach for Climate Proofing Projects*. Working Paper No. 69. Asian Development Bank, Manila, Philippines.

S8. Evidence of resources co-developed with ADB for practitioners is given by: ADB, 2018. *Information Sources to Support ADB Climate Risk Assessment and Management*. Asian Development Bank, Manilla, Philippines; ADB, 2020. *Climate Change Adjustments for Project Design in Viet Nam*. Knowledge Product IM200148-2. Asian Development Bank, Manilla, Philippines; ADB, 2020. *Manual on Climate Change Adjustments for Detailed Engineering Design of Roads Using Examples from Viet Nam*. Asian Development Bank, Manilla, Philippines.

S9. Evidence of resources co-developed with ADB/ World Bank Group for policymakers and development planners is given by the Climate Risk Country Profiles for Afghanistan, Maldives, Sri Lanka, and Vietnam.

S10. Testimonial from a Senior Climate Change Adaptation Specialist at ADB.