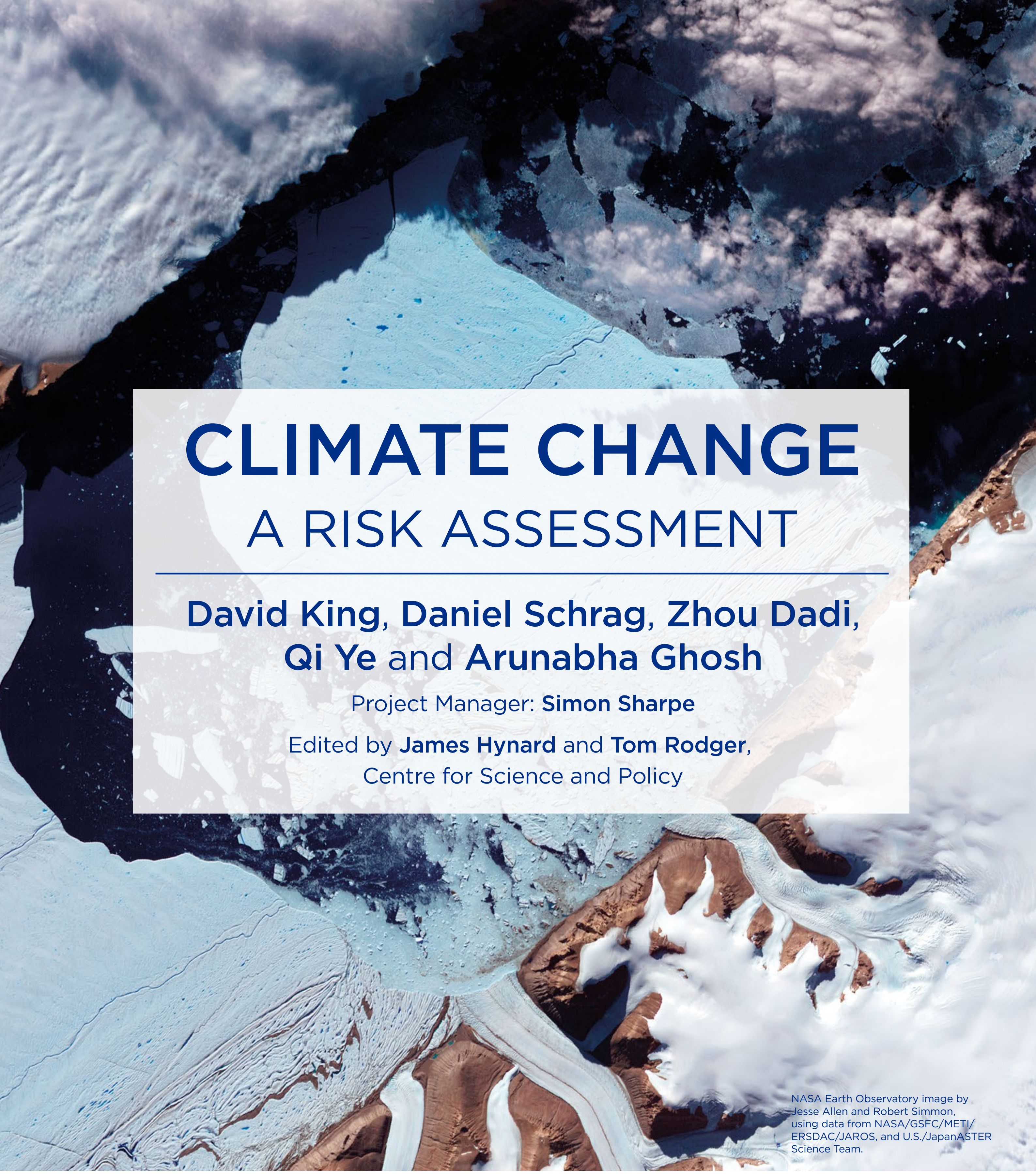
The risk of water stress



CLIMATE CHANGE

A RISK ASSESSMENT

David King, Daniel Schrag, Zhou Dadi, Qi Ye and **Arunabha Ghosh**

Project Manager: **Simon Sharpe**

Edited by **James Hynard** and **Tom Rodger**,
Centre for Science and Policy

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This report was edited and produced by the Centre for Science and Policy (CSaP) at the University of Cambridge. CSaP's mission is to promote the use of expertise and evidence in public policy by convening its unique network of academics and policy makers.

STATUS OF THIS REPORT

Sir David King led this project in his official capacity as the UK Foreign Secretary's Special Representative for Climate Change. The Foreign and Commonwealth Office commissioned this report as an independent contribution to the climate change debate. Its contents represent the views of the authors, and should not be taken to represent the views of the UK Government.

ACKNOWLEDGMENTS

The authors wish to thank all of those who contributed their time and expertise to this project, including the contributing authors to this report, and also those participants in our meetings whose names are not listed here, but whose valuable insights have contributed to our analysis.

We wish to thank the sponsors of the project, including the UK Foreign and Commonwealth Office, the China National Expert Committee on Climate Change, the UK Government Office for Science, the Skoll Global Threats Fund, Global Challenges Foundation, the UK Institute and Faculty of Actuaries, and Willis Research Network, for their generous support. Special thanks are also due to the UK Department of Energy and Climate Change Science team, China Meteorological Administration, the CNA Corporation, and the Climate Change Science Institute at Oak Ridge National Laboratory, for their support to specific aspects of the project.

We also wish to thank all the following individuals for their practical, intellectual and moral support, which has made this project possible: James Ballantyne, Oliver Bettis, Steven Bickers, Shourjomoy Chattopadhyay, Vaibhav Chaturvedi, Partha Dasgupta, Hem Himanshu Dholakia, John Edwards, Vaibhav Gupta, Pradyot C. Haldar, Frances Hooper, Paulette Hunter Okulo, Anil Jain, Aarti Katyal, Sindhushree Khullar, Anthony W. King, Sylvia Lee, Stephan Lewandowsky, Amy Luers, Luo Yong, Lisa Matthews, Bessma Mourad, Chris Nicholson, Harriet O'Brien, Dennis Pamlin, Bob Phillipson, Benjamin L. Preston, Aditya Ramji, Sudatta Ray, Denise Sadler, Sayantan Sarkar, Mihir Shah, Surbhi Singhvi, Morgan Slebos, Wang Mengni, Nicola Willey, Ken Wright, Zhang Jiansong, Zheng Qi, Zhu Songli.

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12 THE RISK OF WATER STRESS

Professor Nigel Arnell, Director of the Walker Institute for Climate System Research.

Water resources are under stress in many regions due to increasing demands and, in places, falling quality. Climate change has the potential to change the risks of water stress.[1] The focus in this section is on strategic definitions of water stress, which are based on generalized indicators of the amount of water that is available and the demands on that resource. Operational definitions, on the other hand, are typically based on the reliability of the supply of appropriate quality water and are strongly determined by local conditions.

What do we want to avoid?

The most widely used sets of indicators of high-level water resources stress are based on the ratio of total resources to population ('resources per capita') and the proportion of resources that are withdrawn for human use.[2] The first is simpler but does not reflect stresses introduced by high per-capita water use, for example where there is significant irrigation for agriculture; on the other hand, data on current and future water withdrawals can be highly uncertain.

There are three widely used thresholds for defining levels of water stress on the basis of per capita availability. Basins or countries with average annual resources between 1000 and 1700 m^3 per capita per year are typically classed as having 'moderate water shortage', and if resources are below 1000 m^3 per capita per year then the region is classed as having 'chronic water shortage'. If resources are below 500 m^3 per capita per year then the shortage is 'extreme'.[3] The thresholds are essentially arbitrary, although derive ultimately from an assessment of exposure to water resources stress in Africa.[4]

In 2010, almost 3.6 billion people, out of a global population of around 6.9 billion, were living in watersheds with less than 1700 m^3 per capita per year (Table W1), and almost 2.4 billion were living in watersheds with less than 1000 m^3 per capita per year (chronic water shortage).[i] Approximately 800 million people were living in watersheds with less than 500 m^3 per capita per year (extreme water shortage).

i. The methods used here to estimate future risks to water resources are summarised in the Annex.

Table W1: **Numbers of people (millions) living in water-stressed watersheds.** The figures for 2050 are based on a medium population growth assumption, and the ranges represent the effects of low and high growth assumptions.

	2010				2050			
	<1700m3/capita/year	<1000m3/capita/year	<500m3/capita/year	Population	<1700m3/capita/year	<1000m3/capita/year	<500m3/capita/year	Population
N. Africa	162	150	94	209	254 (226-326)	244 (213-282)	216 (153-248)	329 (292-383)
W. Africa	54	17	4	309	484 (373-610)	367 (185-489)	37 (20-117)	756 (616-926)
C. Africa	3	0	0	110	11 (10-14)	8 (6-9)	6 (0-8)	239 (202-277)
E. Africa	94	10	2	193	326 (272-441)	299 (159-381)	103 (13-221)	418 (349-496)
Sn Africa	47	20	0	210	186 (133-282)	101 (45-177)	24 (4-35)	488 (396-609)
S. Asia	1,394	1,172	199	1,706	2121 (1,906-2,526)	1,802 (1,512-2,183)	746 (628-1,003)	2,390 (2,151-2,722)
SE Asia	7	0	0	605	27 (25-31)	0 (0-0)	0 (0-0)	791 (728-889)
E Asia	1,202	691	386	1,546	1084 (1,035-1,184)	643 (613-660)	359 (340-388)	1,434 (1,375-1,510)
Central Asia	1	0	0	46	65 (57-80)	2 (1-2)	0 (0-0)	70 (62-84)
Middle East	166	93	71	214	356 (295-397)	310 (222-344)	190 (164-209)	379 (339-420)
Australasia	0	0	0	35	0 (0-0)	0 (0-0)	0 (0-0)	50 (50-45)
W. Europe	220	123	20	411	220 (239-165)	138 (166-55)	23 (24-15)	425 (441-344)
C. Europe	51	8	0	118	23 (24-20)	1 (8-1)	0 (0-0)	102 (103-96)
E. Europe	20	4	3	221	9 (8-18)	4 (3-4)	4 (3-4)	186 (178-196)
Canada	6	6	0	35	7 (8-5)	7 (8-5)	7 (8-0)	44 (45-31)
US	78	54	27	312	99 (102-75)	74 (76-56)	38 (39-26)	390 (402-303)
Meso-America	58	26	0	197	124 (112-154)	61 (53-101)	31 (28-37)	279 (250-346)
Brasil	0	0	0	195	0 (0-0)	0 (0-0)	0 (0-0)	237 (218-269)
South America	15	4	4	198	46 (29-56)	19 (17-25)	6 (5-7)	278 (251-329)
Global	3,576	2,376	809	6,868	5449 (4,853-6,382)	4,079 (3,286-4,774)	1,789 (1,430-2,317)	9,283 (8,444-10,273)

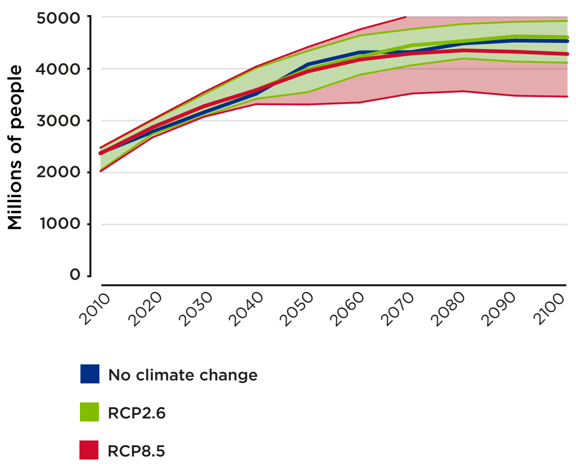
How will exposure to water stress change in the future?

Through the 21^{st} century, changes in total population will result in changes in exposure to water resources stress. By 2050, under a medium population growth assumption,[5] the number of people living in watersheds with less than 1000 m^3 per capita per year will increase to around four billion – a bigger proportion of the global population than in 2010. The effects of population growth on the number of people living in watersheds with less than 500 m^3 per capita per year are even more pronounced: it will double by 2050 to around 1.8 billion people. The magnitudes of the changes are influenced to a certain extent by the assumed changes in population (as shown in Table W1[6]), but even under low-growth assumptions there are significant increases in exposure to water scarcity at global and regional scales.

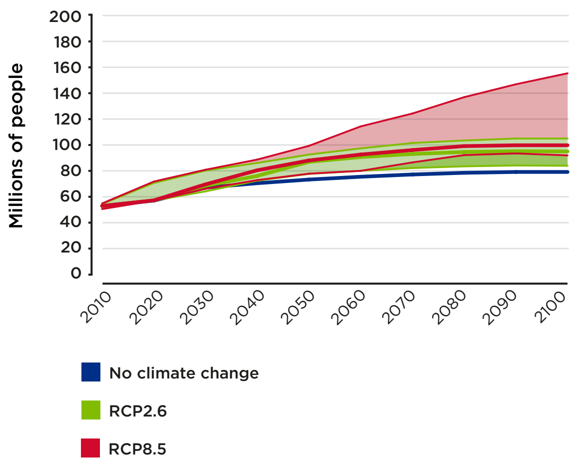
Climate change will also affect the number of people living in water-stressed conditions. Figure W1 shows the change in numbers of people living in watersheds with chronic water shortage (less than 1000 m^3 per capita per year) through the 21^{st} century, for the globe as a whole and for five regions, under no climate change and under two different climate change pathways (RCP2.6 and RCP8.5, low and high greenhouse gas emission scenarios respectively). The shaded areas show the range of potential numbers due to uncertainty in the pattern of resource change due to climate change. The plots all assume the medium population growth projection.

Figure W1: **The number of people living in water-stressed watersheds (<1000m^3/ capita/year), with and without climate change.** The plots show two climate pathways (RCP2.6 and RCP8.5). The solid line represents the median estimate of impact for each pathway, and the shaded areas show the 10% to 90% range. A medium growth population projection is assumed.

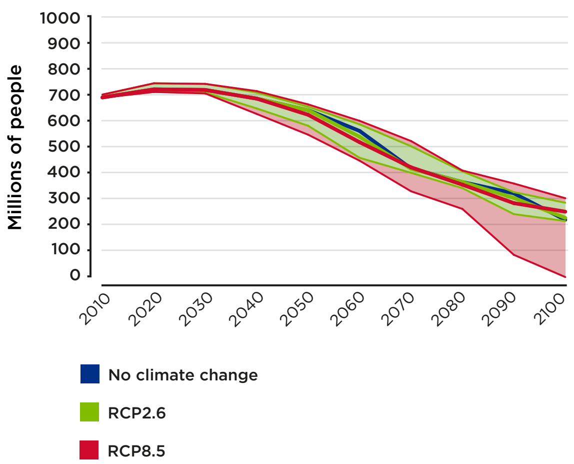
Global: water stressed population



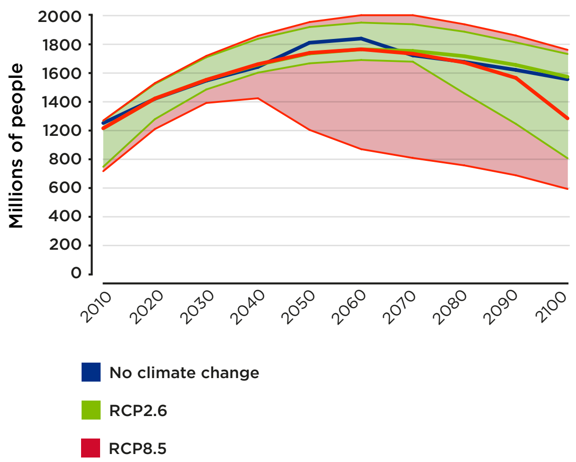
US: water stressed population



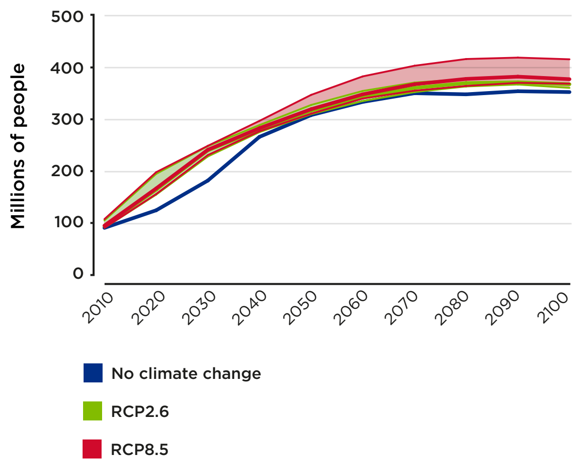
East Asia: water stressed population



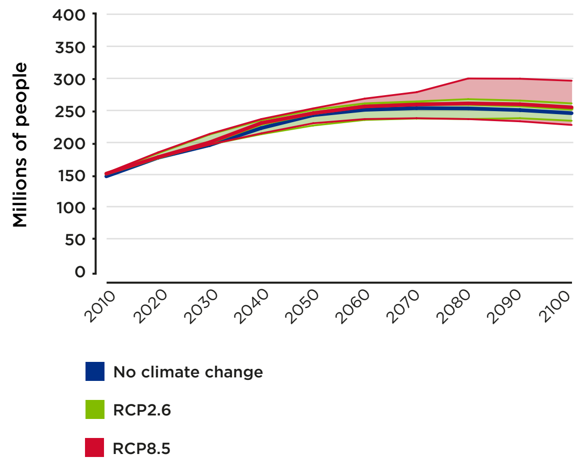
South Asia: water stressed population



Middle East: water stressed population



North Africa: water stressed population



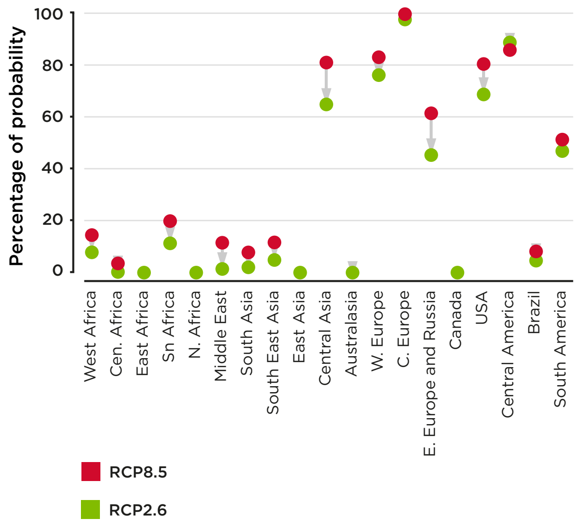
In the absence of future climate change, the numbers of people living in watersheds with chronic water shortage decreases in East Asia from 2030, and in South Asia from 2060. If climate change is included, it results in more rainfall and river runoff in East Asia. This combines with the reduction in population to reduce apparent water shortage – but there is a chance (shown by the shaded area) that climate change would slow the reduction in exposure to water shortage. Similarly, Figure W1 shows that climate change could substantially increase the number of people living in watersheds with chronic water shortage in south Asia – or reduce them. In the US and the Middle East climate change is very likely to increase exposure throughout the century, and in North Africa is more likely than not to produce an increase in exposure.

Calculating risk

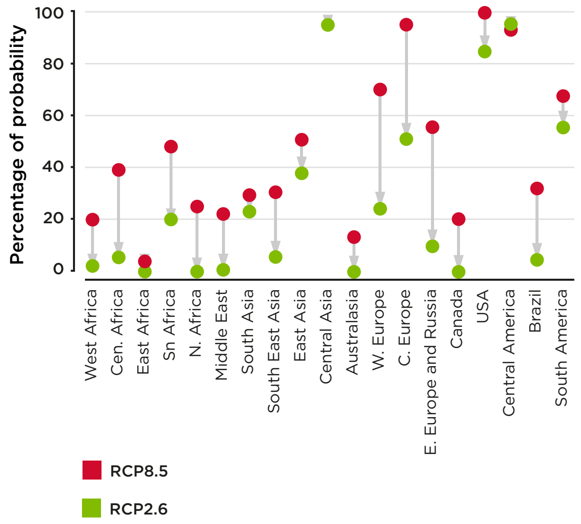
Figure W2 shows the risk by region that climate change increases by more than 10% the numbers of people living in watersheds with chronic water shortage under the two climate pathways. By 2050, the largest of these probabilities are in central Asia, Europe, the USA, Central America and southern America. By 2100, the probabilities that exposure to shortage will increase are considerably greater in most regions than in 2050. Under the low emissions climate pathway the probabilities are smaller in most regions than under the high emissions pathway, particularly by 2100.

Figure W2: **The risk that climate change increases by more than 10% the numbers of people living in water-stressed watersheds, relative to the situation with no climate change, under the two climate pathways**. A medium growth population projection is assumed.

2050: Probability number of people with chronic water shortage increasing by more than 10%



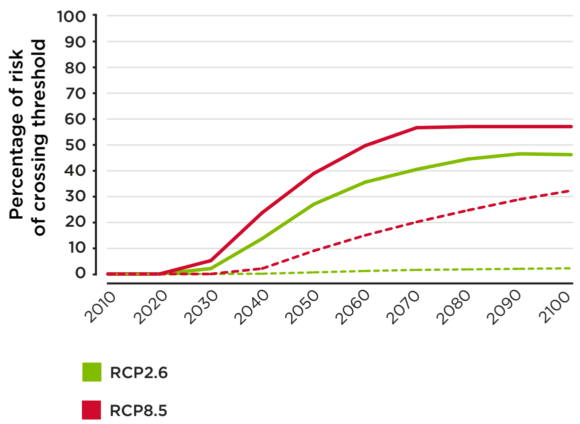
2100: Probability number of people with chronic water shortage increasing by more than 10%



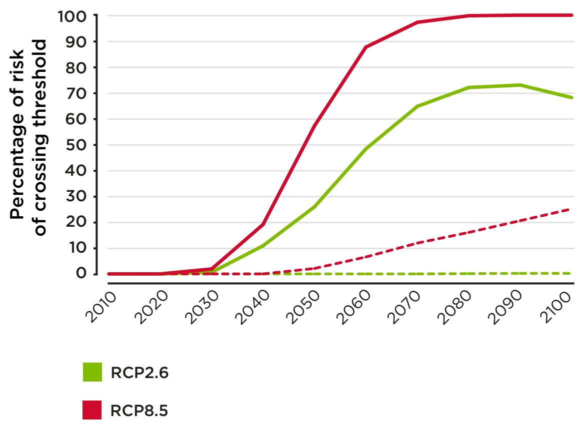
The risks posed by climate change to water scarcity can also be assessed at the basin scale. Figure W3 shows the probability that resources per capita falls below defined thresholds in nine major basins that are, or likely will be, exposed to water resources stresses (note that the thresholds vary between basins). The dotted lines show probability of falling below the thresholds under the two climate pathways assuming population remains at 2010 levels, and the solid lines show probability under the medium growth population projection. The difference between the solid and dotted lines represents the effect of population change on probability (and of course this difference varies with population projection).

Figure W3: **Risk of resources per capita falling below specified thresholds for nine illustrative watersheds under two climate pathways (note that the thresholds vary between watersheds).** The dotted line shows risk with current (2010) population, and the solid line shows risk under the medium population growth projection

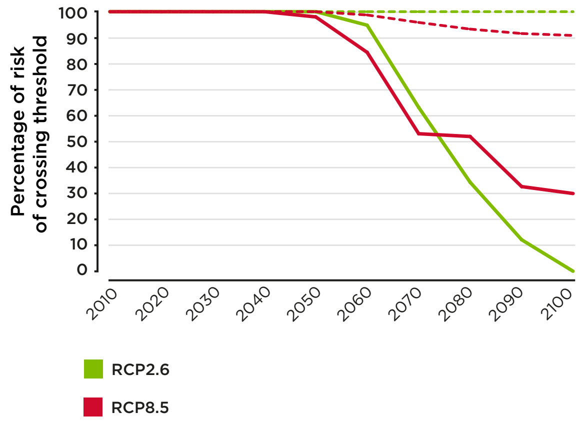
Sacramento: risk of falling below 1700m³/capita/year



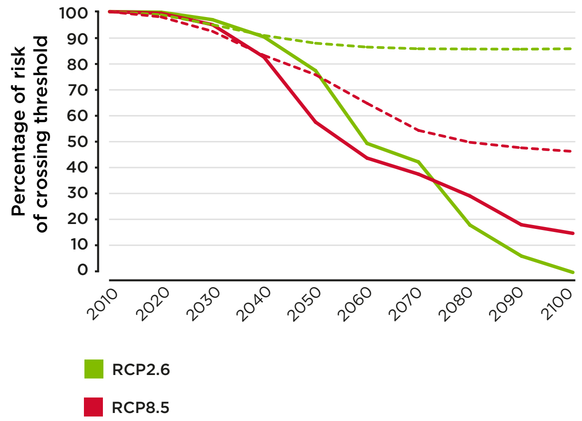
Rio Grande: risk of falling below 1000m³/capita/year



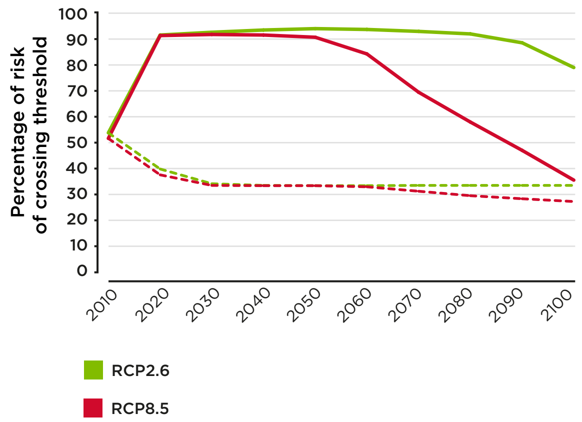
Yangtse: risk of falling below 1700m³/capita/year



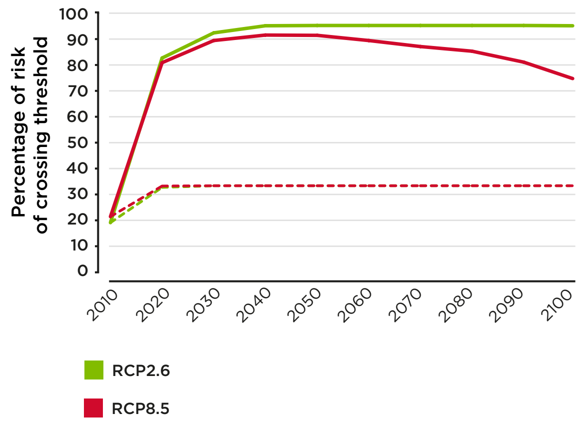
Huang He: risk of falling below 500m³/capita/year



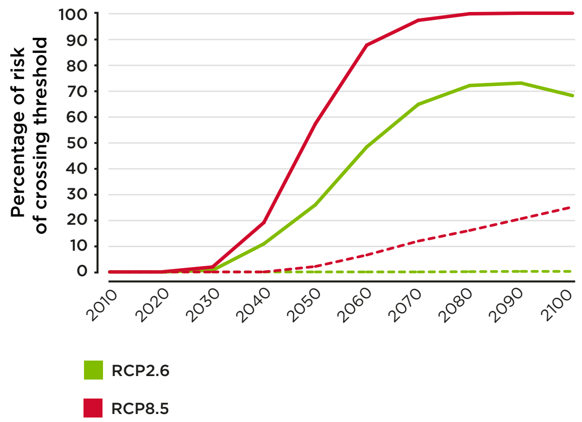
Ganges: risk of falling below 1700m³/capita/year



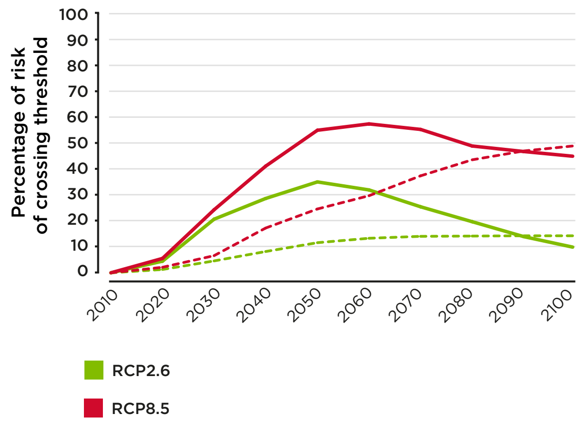
Indus: risk of falling below 500m³/capita/year



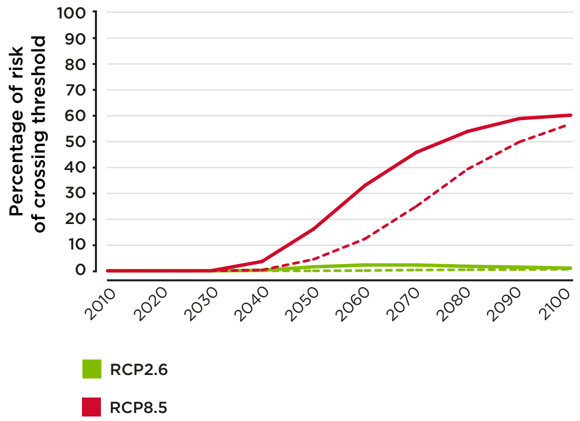
Tigris-Euphrates: risk of falling below 500m³/capita/year



Karun: risk of falling below 1000m³/capita/year



Moulouya: risk of falling below 500m3/ capita/year

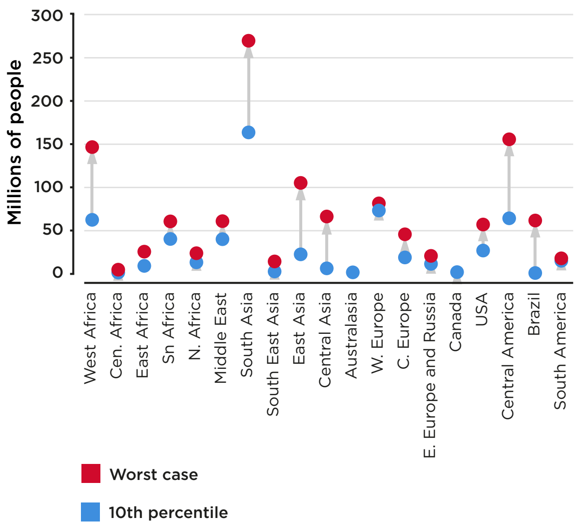


What is a plausible worst case for water stress due to climate change?

There are considerable uncertainties in the projected impacts of climate change on water stress, even assuming a single projection for changes in population. The chance of impacts exceeding some defined threshold – as shown in the previous section – represents one aspect of this uncertainty, but another assessment of risk can be based on a plausible 'worst case'.

By 2050, up to 620 million people may be added to the 4 billion people (Table W1) living in watersheds with chronic water shortage, under high emissions and the most extreme climate scenario. Figure W4 shows the 'worst case' by region in 2050, along with the 10th percentile from the distribution of impacts (the upper part of the shaded region in Figure W1). In some regions the worst case is little different to the 10th percentile, but in others is considerably larger reflecting greater uncertainty in projected impacts. However, the worst cases shown in Figure W4 do not occur simultaneously: the global 'worst case' is not equal to the sum of the regional worst cases. Under no one plausible pattern of climate change does every water-stressed region see the maximum reduction in runoff.

Figure W4: **Plausible 'worst case' impacts of climate change in 2050 on water stress.** The graph shows the increase in numbers of people living under chronic water shortage under the RCP8.5 climate pathway and the medium growth population projection. There is a 10% probability that the impact is greater than that shown by the blue dots, and the red dots show the maximum calculated impact



The assessment in Figure W4 is based on the assumption that all the climate models used to estimate impacts are equally plausible, and that they span the range of potential regional climate change impacts. This, of course, is not necessarily the case. The global-scale impacts are largely dominated by impacts in south and, to a lesser extent, east Asia, and are therefore very sensitive to projections of how the south Asian monsoon may change (see box on Variation in the Indian monsoon).

Variation in the Indian monsoon

Professor Brian Hoskins, FRS

In impact studies, it is assumed that the set of available projections of future climate from the state-of-the-art climate models spans the space of possible climates. In particular, in determining the risk posed by increasing greenhouse gases it is assumed that the worst case scenarios in any region are included amongst the model projections. However, climate models developed and tested in the context of the climate of the 20th century have known deficiencies, some of which are common to most models. Some of these deficiencies are likely to influence the simulation of future extreme climate changes. Further, it is not clear that the climate models are able to simulate any major climate change due to the crossing of a threshold in the climate system that could occur. This could, for example, be of the nature of the onset of significant greenhouse gas emissions from melting permafrost, the destabilization of the West Antarctic Ice Sheet or a drastic reduction in the overturning circulation in the Atlantic Ocean. Palaeo-climate runs with the models show that they are unable to simulate just how different the monsoon systems of the world have been in the past. For example the Sahara was green with vegetation some seven thousand years ago. However, climate models do not produce this big change in rainfall. One recent study concluded, *"State-of-the-art climate models are largely untested against actual occurrences of abrupt change. It is a huge leap of faith to assume that simulations of the coming century with these models will provide reliable warning of sudden, catastrophic events."*[7]

The amazing thing about the Indian summer monsoon is the large effect of a small variation from one year to year: 10% more rainfall and there are floods, 10% less and there are huge problems for farmers. In any year monsoon active and break periods occur. Breaks that last more than a couple of weeks also cause major agricultural problems. Climate models are in general projecting a slight strengthening of monsoon rainfall, but it should be recognized that the changes in particular monsoons, such as that in India, could be much more significant than this suggests. Given the large perturbation of the climate system due to greenhouse gas emissions, we should be prepared that the future Indian Monsoon could have average rainfall outside the current normal range, and the variability between one year and another and in the active-break cycle could be very different.

What do we know, what do we not know, and what do we think?

Our estimates of future risks are based on (i) projections of regional future climate change, (ii) projections of hydrological consequences of climate change and (iii) projections of future population and exposure to water resources stress. What happens in practice also depends on future adaptation.

Projections of regional future change depend partly on the assumed rate of growth in emissions and partly on the projected patterns of changes in regional and seasonal climate – particularly precipitation. Whilst the broad patterns of precipitation changes are reasonably consistent between models, the details and the precise magnitudes of change differ. The quantitative estimates of impacts on water stress therefore vary, and these tend to be larger than the apparent differences in precipitation change between climate models. This is because exposure to water shortage is concentrated in particular regions of the globe, and it is at the local to regional scale that the differences between climate models are greatest.

As climate models improve their representation of atmospheric dynamics and the distribution of precipitation then the precise quantitative estimates of impacts on water stress will change, but for years to come differences between models will remain and there will therefore be a distribution of potential climate change impacts for any one place.

The impacts of climate change on water shortage are assessed by using a hydrological model to translate climatic changes to changes in runoff. As with climate models, different hydrological models can give different responses to the same input data. Comparisons of the effects of hydrological model uncertainty are still in their infancy,[8] but early indications are that adding impact model uncertainty adds to the range of potential impacts. Moreover, it is likely that hydrological models have similar biases (they all tend to overestimate river flows in dry regions, for example) and none yet explicitly incorporate the effects of changes in glacier volumes which may affect future resources in some regions.

Projections of future population are also uncertain (as shown in Table W1), because they are based on different assumptions about changes in fertility rates, mortality rates and migration. It is not possible to assign likelihoods to different population projections, so it is necessary to estimate risks separately under different plausible population narratives and projections.

Finally, the actual effects of climate change on 'real' water shortages will depend on the management infrastructure and institutions which are put in place to cope with water shortage. There is already a very considerable difference between developed and developing countries. Some management interventions will offset the effects of climate change, but others may not. The effects of future adaptation on the 'real' consequences of future water shortages will therefore depend on (i) the extent to which adaptation takes place (limited by a number of factors including finance and institutional capacity, alongside potential physical constraints such as the availability of feasible locations for storage reservoirs) and (ii) how effective the adaptation measures are in practice.

Lessons from risk assessment

The key conclusions from this section are therefore:

- Climate change alters substantially the future risk of exposure to water shortages, but the effects are strongly exaggerated or reduced by changes in population. Put the other way, the pressures on water resources posed by increasing populations are substantially altered – exaggerated or reduced – by climate change.
- Climate change reduces the probability of exposure to water shortages in some regions – particularly in parts of east and south Asia - but this may be associated with substantial changes in flood risk (see chapter 14).
- The risks posed by climate change are typically less under low emissions than high emissions, but the difference varies from place to place depending on how close watersheds in a region are to the water shortage threshold. In some cases, risks are less under high emissions than low emissions, because larger increases in runoff are enough to push watersheds out of the water shortage category.

Production of this chapter was supported by the AVOID 2 programme (DECC) under contract reference 1104872.

Endnotes

1. Jimenez-Cisneros, B.E., Oki, T., Arnell, N.W., Benito, G., Cogley, J.G., Doll, P., Jiang, T. & Mwakalila, S.S. (2014) 'Freshwater resources. In Field', C.B., Barros, V. et al. (eds) Climate Change 2014: Impacts, Adaptation and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press: Cambridge. 229-269.
2. Falkenmark, M., Berntell, A., Jagerskog, A., Lundqvist, J., Matz, M. & Tropp, H. (2007) On the verge of a new water scarcity: a call for good governance and human ingenuity. SIWI Policy Brief. Stockholm International Water Institute. Rijsberman, F. (2006) Water scarcity: fact or fiction? Agricultural Water Management 80 (1-3) 5-22.
3. Falkenmark, M., Berntell, A., Jagerskog, A., Lundqvist, J., Matz, M. & Tropp, H. (2007) On the verge of a new water scarcity: a call for good governance and human ingenuity. SIWI Policy Brief. Stockholm International Water Institute. Kummu, M., Ward, P.J., de Moel, H & Varis, O. (2010) Is physical water scarcity a new phenomenon? Global assessment of water shortage over the last two millennia. Environ. Res. Lett. 5 (July-September 2010) 034006 doi:10.1088/1748-9326/5/3/034006
4. Falkenmark, M. (1989) 'The massive water scarcity now threatening Africa: why isn't it being addressed?' Ambio 18 (2) 112-118
5. Shared Socio-economic Pathway (SSP) 2. https://secure.iiasa.ac.at/web-apps/ene/SspDb/. This is similar to the UN 2012 medium population projections.
6. SSP1 and SSP3 are used to represent the extremes: these are very similar to the UN 2012 low and high population projections.
7. Valdes, P. (2011). 'Built for stability'. Nature Geoscience 4, 414-416. doi:10.1038/ngeo1200
8. Schewe, J., Heinke, J., Gerten, D., Haddeland, I., Arnell, N.W., Clark, D.B., Dankers, R., Eisner, S., Fekete, B., Colon-Gonzalez, F.J., Gosling, S.N., Kim, H., Liu, X., Masaki, Y., Portmann, F.T., Satoh, Y., Stacke, T., Tang, Q., Wada, Y., Wisser, D., Albrecht, T., Frieler, K., Piontek, F., Warszawski, L. & Kabat, P. (2014) Multi-model assessment of water scarcity under climate change. Proceedings of the National Academy of Sciences 111, 3245-3250 doi.10.1073/pnas.1222460110