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1   11.9.   Key Uncertainties and Research Recommendations
2
3   Frequently Asked Questions
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7
8   **Executive Summary**
9
10   **The health of human populations is sensitive to shifts in weather patterns and other aspects of climate change**
11   (**_very high confidence_**). These effects occur directly, due to changing incidence in temperature and humidity
12   extremes and occurrence of floods, storms, droughts, and fires. Indirectly, health may be damaged by ecological
13   disruptions brought on by climate change (crop failures, shifting patterns of disease vectors), or social responses to
14   climate change (such as displacement of populations following prolonged drought). Variability is a risk factor in its
15   own right – it is more difficult to protect human health in a highly variable climate than one that is more stable.
16   There is emerging evidence of non-linearities in response (such as mortality due to heat waves) as climates become
17   more extreme. [11.3, 11.5]
18
19   **To date, climate change has contributed to global burden of disease (**_highly likely_**) though the global health**
20   **effects are relatively small compared with other stressors and not well quantified.** Changes in temperature,
21   rainfall and sea-level have altered distribution of some disease vectors, increased heat wave casualties, and reduced
22   food production for vulnerable populations. [11.4]
23
24   **If climate change occurs in the future as projected in scenarios (** to come **), the major effects on health will be:**
25   •   Increased risk of under-nutrition resulting from diminished food production
26   •   Greater incidence of injury and disease due to more intense heat waves, storms, floods and fires
27   •   Some reductions in cold-related injury and disease, but it is not clear how substantial these savings will be,
28   in a more variable climate, and it appears likely that positive outcomes will be exceeded by negative effects
29   of climate change
30   •   Increased pressure on disease control systems due to more favourable conditions in many parts of the world
31   for food- and water-borne diseases, and dengue and other vector-borne infections. [11.5]
32
33   **The most important effect of climate change is to multiply current risks to health.** Although new infections and
34   other conditions may emerge under climate change, the largest risks by far apply to health problems that already
35   exist. This means the most vulnerable populations to climate change impacts, world-wide, are those that currently
36   carry the heaviest burden of disease. In these settings, improvements in public health and health care are important
37   elements of adaptation for climate change. [11.6.1]
38
39   **There are opportunities to mitigate against climate change, and improve health at the same time. These co-**
40   **benefit actions include:**
41   •   Reducing local pollution and emissions of climate altering pollutants (CAPs)from energy production
42   through better combustion, energy efficiency, and shifting to renewables
43   •   Reducing rising trends of livestock production, particularly of ruminants, by shifting diets in rich countries
44   to less red meat and dairy products
45   •   Reducing CAP emissions by redesigning communities to rely on more public transport and promote
46   physical activity
47   •   Providing access to reproductive services reducing population growth over time and improving child and
48   maternal health through increased birth spacing. [11.7]
49
50
51   **11.1.   Introduction**
52
53   This chapter examines what is known about the effects of climate change on human health. We review the diseases
54   and disorders that are sensitive to climate and the factors that cause populations and individuals to be particularly

1   susceptible to ill-health due to variations in climate, and describes steps that may be taken to reduce the impacts of
2   climate change on human health. The chapter includes also a section on health "co-benefits". These arise from
3   interventions to reduce the levels of climate active pollutants that also have positive effects on human health.
4
5   In the introduction we summarise the major findings on climate change and health from the Fourth Assessment
6   Report (AR4), and indicate, in broad terms, the most important developments in the field since. We begin with an
7   outline of measures of human health, the major driving forces that act on health world-wide, recent trends in health
8   status, and projections for the remainder of this century.
9
10
11   ***11.1.1.   Background – Present State of Global Health***
12
13   *11.1.1.1.Definitions*
14
15   There are many definitions of health, but all are concerned in one way or another with the physical, social and
16   psychological well-being of individuals and groups. Health is both a condition for, and a consequence of,
17   development, and there is a similar inter-dependence between a country's social and economic progress and its
18   ability to protect its population against adverse effects of stressors such as climate change.
19
20   Which aspects of well-being are emphasized and valued most highly depends on social norms and values. However
21   there is less diversity in the measures of deviations from (good) health. Premature mortality is the most commonly
22   reported health statistic, generally in the form of a rate (the frequency of death in a given time period in a defined
23   age group) or average life expectancy. Commonly mortality rates are adjusted or standardized to a given age-sex
24   population structure. Life expectancy is calculated from the age-specific death rates for a population, to provide the
25   average years lived from a given age (e.g. from birth). Measures of non-fatal health outcomes include the occurrence
26   of disease and the quality of life. The former is commonly expressed as incidence i.e. new cases occurring in a given
27   population in a given time period (eg annual breast cancer incidence) or prevalence, the number of cases of a given
28   disease in a population at a specific point in time (eg proportion affected by blindness).
29
30   Quality of life survey instruments often focus on the level of functional impairment. They may also capture
31   perceptions of the extent to which a disease reduces the full quality of a healthy life. The most commonly cited of
32   these metrics is the Disability Adjusted Life Year (DALY), which combines years in full health lost due to
33   premature death and years lived with less-than-ideal health due to illness or injury (disability). DALYs are widely
34   used in estimates of population health, not only because this measure combines mortality and morbidity, but also
35   because it allows aggregation of impacts that share a common underlying cause. Hence the concept of the "burden
36   of disease" attributable to tobacco use, air pollution and other environmental exposures including climate change.
37   (World Health Organization, 2008)
38
39
40   *11.1.1.2.Trends in Health*
41
42   The Fourth Assessment Report pointed to dramatic improvement in life expectancy in most parts of the world in the
43   20th century, and this trend has continued through the first decade of the 21st century. (Christensen *et al*., 2009) It is
44   important to bear in mind that although rapid progress in a few countries (especially China) has swayed global
45   averages, most countries have experienced substantial reductions in mortality. There have been exceptions, and there
46   remain sizable and avoidable inequalities within- and between-nations according to education, income and ethnicity.
47   (Beaglehole and Bonita, 2008) In some countries, official statistics are so patchy in quality and coverage that it is
48   difficult to draw firm conclusions about health trends. (Byass, 2010) Life expectancy fell in many countries in
49   Eastern Europe in the 1980s and 1990s, and has been slow to recover. At a regional level, inequalities in mortality
50   have diminished, and convergence has been particularly marked amongst adults. (Clark, 2011) Amongst children,
51   mortality rates continue to fall, but the greatest decreases have occurred in urban areas and in wealthy parts of the
52   world. More than 20 countries, mostly in sub-Saharan Africa, showed no improvement in child mortality between
53   1990 and 2006. (United Nations, 2010) (see Box 11-1). In eastern and southern Africa, HIV/AIDS contributed to a
54   substantial rise in mortality in the 1990s with more than 20% of the adult population infected in the worst hit areas.

1   In some countries (eg Malawi, Zambia) this trend has reversed recently; elsewhere (e.g. Zimbabwe) mortality
2   remains at very high levels.(Reniers *et al.*, 2011)
3
4   _____ START BOX 11-1 HERE _____
5
6   **Box 11-1. Climate Change and the Millennium Development Goals**
7
8   The Millennium Development Goals (MDGs) were established by the world community in 2000, as a way of
9   focusing attention on some of the most pressing international development goals. Progress toward many of the
10 goals, which are to be accomplished by 2015--and any subsequent related development efforts--will be affected by
11 climate change. For example, Goal 4 states that the world community should "reduce by two thirds, between 1990
12 and 2015, the under-five mortality rate."[1] Figure 11-1 shows the current trends in reduction in child mortality
13 worldwide by cause and indicates how far they are expected to fall above the MDG reduction goal by 2015. Each
14 color represents a different child-mortality "disease wedge" with different risk factors and interventions. It also
15 indicates overall how much faster they together must decline if the MDG is even to be reached ten years late, i.e., by
16 2025.There are three ways climate change interacts with these wedges:
17   1) Two of the major causes of child mortality, diarrhoeal diseases and malaria, are directly influenced by the
18   changes in temperature and rainfall to be expected with climate change, probably making their reduction
19   more difficult as climate change proceeds.
20   2) Malnutrition/under-nutrition, which is likely to be exacerbated as climate change progresses, is a major
21   contributor to all the child-mortality wedges represented here, hampering their reduction as climate change
22   proceeds
23   3) On a more positive note, improving combustion of solid-fuel in poor households will both help reduce one
24   of the major wedges, ALRI, and mitigate climate change through reduction in CAPs, a co-benefit.
25
26 [FOOTNOTE 1: http://www.un.org/millenniumgoals/childhealth.shtml]
27
28 [INSERT FIGURE 11-1 HERE
29 Figure 11-1: Projected Child Mortality, 2008-2030, Including Climate-Sensitive Causes. Sources: Mortality
30 projections by cause from WHO. Population projections from UN DESA. Child mortality rates from IGME.
31 (Interagency Group for Child Mortality Estimation, 2011; United Nations, Department of Economic and Social
32 Affairs, Population Division., 2011; World Health Organization, 2008).]
33
34 _____ END BOX 11-1 HERE _____
35
36 Aside from mortality, less is known about trends in other aspects of health. In high-income countries, there are signs
37 that the reduction in mortality has been accompanied by decline in disability and improvement in physical function.
38 (Manton, 2008)There are improvements evident also in some of the biggest causes of ill-health in low-income
39 countries. The incidence of tuberculosis world-wide appears to be falling, albeit unevenly. It is difficult to interpret
40 malaria statistics – reported declines in total number of cases world-wide must be treated with caution, and progress
41 appears to be most erratic in countries with highest incidence, but the fall in deaths from malaria is encouraging.
42 (World Health Organization, 2009b; World Health Organization, 2011b) WHO estimates that the number of new
43 cases of infection with HIV fell by about 16% between 2000 and 2008. (World Health Organization, 2011b)
44 However, not all indicators are positive. For instance, child under-nutrition, implicated in about a third of all deaths
45 under 5 years, has become more common in a number of countries since 2005, and about 180 million children
46 world-wide are stunted (short for their age) as a consequence. (World Health Organization, 2011b)
47
48 For specific causes of death, the patterns differ widely by region. The dramatic decline in cardiovascular disease in
49 high-income countries is not seen in parts of the world that are developing rapidly, such as India and China. In those
50 countries, the numbers of deaths from heart disease and stroke are increasing for two reasons; ageing populations
51 and prevalent risk factors such as high blood pressure and cigarette smoking. (Samb *et al.*, 2010) Cancer and mental
52 disorders such as depression are also reported more commonly than previously in low and middle income countries,
53 and infectious diseases remain the cause of a substantial amount of early death and morbidity. Maternal mortality
54 (deaths in pregnancy and childbirth) shows the greatest variation between wealthy and disadvantaged regions

1   globally, no region is tracking sufficiently strongly to reach the Millennium Development Goal for this indicator,
2   and progress appears to have stalled altogether in some countries. (Hogan *et al*., 2010; World Health Organization,
3   2011b).
4
5
6   *11.1.1.3. Projections for Global Health in the 21ˢᵗ Century*
7
8   Most commentators anticipate mortality rates will continue to fall world-wide, and WHO estimates the total burden
9   of disease (measured in DALYs per capita) will be cut by as much as 30% in 2030, compared with 2004. (WHO,
10 2008; World Health Organization, 2008)These projections assume that economic and social development continue
11 without interruption, particularly among poor populations, and as already noted, the global figures are driven by
12 trends in a few large countries (China and India in particular). Less optimistic development scenarios would undo
13 some of the improvements that have occurred, and might lead to a resurgence in HIV/AIDS, a slow down in
14 improvements in child health indicators, and acceleration in the number of deaths caused by tobacco and road traffic
15 crashes. (Mathers and Loncar, 2006) In any event, the underlying causes of poor health are expected to change
16 substantially, with much greater prominence of chronic diseases and injury, largely due to changes in population
17 structure. On its "baseline development" scenario, WHO projects the top three causes of burden of disease in 2030,
18 world-wide, to be depression, ischemic heart disease and road traffic accidents. (World Health Organization, 2008)
19
20
21 **11.1.2.   Major Findings of AR4**
22
23 AR4 concluded that climate change is already adding to the global burden of disease and premature deaths [add in
24 chapter and section]. Examples cited included impacts on nutrition, changes in disease-carrying vectors, new
25 patterns of allergic conditions resulting from changed climate and a increase in deaths caused by heat waves.
26 Looking ahead, the AR4 listed threats to health that may be aggravated by climate change, ranging from
27 malnutrition to ground-level atmospheric pollution, altered patterns of mosquito-borne diseases, and casualties due
28 to storms, floods and other extreme climate events. AR4 anticipated some potential positive effects on health (such
29 as reduced deaths and injuries caused by extreme cold) but concluded that these would be outweighed by the
30 negative consequences of climate change. Disease and injury due to climate change would not, according to AR4, be
31 evenly spread, but would be concentrated in groups such as the urban poor, coastal communities, the elderly and
32 children, and subsistence farmers.
33
34 The published burden of disease assessment reviewed in AR4 found that nearly 90% of the burden of disease due to
35 the climate change that had occurred at the start of this century was estimated to fall on young children in
36 developing countries, mainly because of their vulnerability to malaria, malnutrition, and diarrheal diseases.
37 (McMichael, 2004) This underlines the point that climate change does not create new diseases or other health risks,
38 but exacerbates existing ones, particularly in populations already highly vulnerable.
39
40 Although poverty is a pervasive cause of vulnerability to climate change, AR4 concluded that economic
41 development alone would be insufficient to ameliorate the risk. The manner of development, the social distribution
42 of the fruits of economic growth, and investments in critical institutions and services such as education and health
43 care would be important as well as focused efforts in particular regions, for example where sea-level rise will affect
44 populations.
45
46
47 **11.1.3.   Developments since AR4**
48
49 The numbers of papers and reports on climate change and health have grown considerably since the publication of
50 the AR4. In April 2012, there were approximately 13,500 publications on climate change listed in PubMed, the US
51 National Library of Medicine database. Almost two thirds of these were published after 2006. In addition, there are
52 many reviews, reports and international assessments that do not appear in listings such as PubMed but include
53 important information nevertheless. For instance, the World Development Report 2010 (The World Bank, 2010), the
54 Climate Vulnerability 2010 report (DARA, 2010), and the 2011 UN Habitat report on cities and climate change

1   (United Nations Human Settlements Programme, 2011). However, many of these publications were reviews and
2   commentaries, and the number of quantitative studies linking climate change and health is much smaller. One
3   review of the scientific literature from 2008 to 2011 identified 40 studies, most focused on high-income countries.
4   (Hosking and Campbell-Lendrum, 2012)
5
6   In the last 5 years many countries have carried out national assessments of impacts, vulnerability and adaptations to
7   climate change. In addition to National Adaptation Programs of Action that countries must prepare as one of their
8   obligations under the UN Framework Convention on Climate Change, international bodies such as the World Health
9   Organization and the UN Development Program have promoted adaptation planning with a particular emphasis on
10 health.
11
12 Since the AR4, there have been developments in the methods applied to investigate climate change and health. They
13 include more sophisticated modeling of possible future impacts (for example, work linking climate change, food
14 security, and health outcomes) (Nelson *et al.*, 2010) and improved measures of personal exposures to heat (Maloney
15 and Forbes, 2011). Other developments include coupling of high-quality, longitudinal mortality data sets with down-
16 scaled meteorological data, in low-income settings (for instance, through the INDEPTH Network) (see Box 11-2).
17
18 _____ START BOX 11-2 HERE _____
19
20 **Box 11-2. Climate Change and Mortality – a Long-Term Observational Study in African and Asian**
21 **Populations**
22
23 Given the dearth of scientific evidence of the relationship between weather/climate and health in low- and middle-
24 income countries, we report on a collaborative study from sub-Saharan Africa and Asia. The INDEPTH Network
25 currently has 43 members in 20 countries in Africa, Asia and Oceania. Using standardized health and demographic
26 surveillance systems members have collected information on births, migration and deaths by cause over an average
27 of 20 years (www.indepth-network.org). Currently, there are about 3.4 million people under surveillance.
28
29 To study long-term relationships between weather and health, the authors collected information on all deaths
30 occurring in 11 INDEPTH populations between 1.1.2000 and 31.12.2009 contributing about 10 million person-years
31 of observation over 10 years. Time dependent methods were used for relating remodeled meteorological data, such
32 as temperature and rainfall of the day the death occurred of death and several time intervals (from 1 day to 1 month)
33 before. Analyses related rainfall and high temperature events to mortality, with varying time lags. Studies are being
34 conducted on both monthly and daily numbers of deaths. Age stratified analysis has shown seasonality in the
35 number of deaths is different in different age groups. Sex stratified analysis revealed potential differences in
36 susceptibility to weather related factors according to gender. In the elderly population deaths related to dust storms
37 and heat have been more pronounced compared with other ages. For example, in Nounain Burkina Faso, the relative
38 risk of dying for the elderly above 60 years is associated with the temperature on the day preceding the death, as
39 shown in Figure 11-2, and the effect of daily rainfall on subsequent death from diarrheal diseases in Bangladesh is
40 shown in Figure 11-3.
41
42 [INSERT FIGURE 11-2 HERE
43 Figure 11-2: Relationship between the risk of dying and temperature on the preceding day. Y-axis: log(RR), XS-
44 axis: Temp in °C, lagged by one day.]
45
46 [INSERT FIGURE 11-3 HERE
47 Figure 11-3: The effect of daily rainfall on daily mortality in diarrheal diseases in AMK HDSS, Bangladesh]
48
49 By further extending the time frame of observation and applying appropriate modeling techniques, it may be
50 possible to detect impacts of climate change, as well as the effects over a shorter time frame of varying weather
51 conditions. (Source: *Global Health Action*, Special Volume, forthcoming).
52
53 _____ END BOX 11-2 HERE _____
54

1   New and emerging topics – It is difficult to identify work that is absolutely novel, but there are a number of areas
2   that have grown considerably in the last 5 years. Studies of the ways in which responses to climate change may
3   affect health, so-called "co-benefits", have multiplied. (Haines and McMichael A., Smith K., Roberts I., Woodcock
4   J., Markandya A., Armstrong B., Campbell-Lendrum D., Dangour A., Davies M., Bruce N., Tonne C., Barrett
5   M.,Wilkinson P., 2009) Another important, emerging topic is effects of greenhouse emissions other than those
6   resulting from warming. A prime example is ocean acidification (Doney *et al.*, 2008)– the effects on calcifying
7   marine species is well documented and the risks for coral reefs are now more closely defined than they were at the
8   time of the AR4, but the implications for human health specifically have not been explored. There have also been
9   new publications on the interactions among climate, socioeconomic conditions and health, for example related to
10 occupational conditions (Kjellstrom *et al.*, 2009b) and malaria (e.g. (Béguin *et al.*, 2011; Gething *et al.*, 2010)) In
11 general, there is more work underway on the interactions between climate and socioeconomic and other health
12 determinants. (Gething *et al.*, 2010) There is also growing appreciation of the social upheaval and damage to
13 population health that may arise from the interaction of large-scale food insecurity, population dislocation, and
14 conflict. (US EPA, 2007)

11.2.   Major Climate-Sensitive Health Outcomes

11.2.1.   Introduction

21 In this section we review work done since the last Assessment on the links between climate and significant health
22 outcomes. We concentrate on research that enlarges our understanding of the ways in which human health can be
23 affected by variability in the climate, as shown in Figure 11-4. Discussion of the effects of climate change, up until
24 the present and in the future, is placed later in the chapter (see Sections 11.4 and 11.5).

26 [INSERT FIGURE 11-4 HERE
27 Figure 11-4: Ways in which climate, climate variability, and climate change may influence human health.]

11.2.2.   Disease and Injury due to Heat and Cold Extremes

31 A great deal has been written on the links between outdoor temperatures and morbidity and mortality. (Basu and
32 Samet, 2002; Ye *et al.*, 2012)**.**All-cause mortality is frequently used as the principal outcome of interest, because
33 individual causes of death (such as heat stroke and hypothermia) do not capture the full impact of temperature
34 extremes. The temperature at which mortality is lowest on the typically U, V, or J-shaped dose-response curve
35 between daily mortality and the range of year-round outdoor temperatures (the so-called optimum, or minimum
36 mortality, temperature) is area dependent; warmer areas have higher optimum temperature and colder areas have
37 lower optimum temperature. (Curriero *et al.*, 2002) In a Japanese study, the optimum temperature was not related to
38 long-term average temperature; instead it was highly correlated with the 80 to 85th percentile value of daily
39 maximum temperature. (Honda *et al.*, 2007)

41 It is physiologically plausible that mortality and morbidity of circulatory diseases increase along with an increase in
42 the ambient temperature; for instance, displacement of blood to skin surface may lead to cardiac pump failure.
43 Biological mechanisms are less evident for other causes of death that have been related to weather. For instance,
44 some studies indicate an association of ambient temperature with suicide (Kim *et al.*, 2011; Likhvar *et al.*, 2011;
45 Page *et al.*, 2007) and accidents (Bai *et al.*, 1995; Honda *et al.*, 1995; Ishigami *et al.*, 2008).

47 Some investigators have reported that mortality increases more during heat waves than would be anticipated on the
48 basis of physiologic tolerance to temperature alone,(Anderson and Bell, 2011; D'Ippoliti *et al.*, 2010), although the
49 added effect is relatively small in some series, and apparent only with prolonged heat waves. (Gasparrini and
50 Armstrong, 2011) Also, in extreme conditions, excess deaths have been noted in younger age groups than are
51 normally affected by heat. (Rocklov *et al.*, 2011) One explanation may be that duration of extreme heat exposures
52 compounds the cumulative stress and health risks. Some studies have shown larger effects of heat and heat waves
53 earlier in the hot season (Anderson and Bell, 2011; Rocklov *et al.*, 2011).This may be testament to the importance of

1   acclimatisation and adaptive measures, or may result from a large group in the population that is genuinely
2   susceptible to heat early in the season (Rocklov *et al.*, 2009; Rocklov *et al.*, 2011).
3
4   The extreme heat wave in Europe in 2003 led to numerous epidemiological studies. The initial reports from France
5   (Fouillet *et al.*, 2008) included age-specific rates, and concluded that a very large proportion of the extra deaths
6   occurred in elderly people (80% above age 75). It is notable, however, that the extra heat wave-related mortality in
7   younger ages was also substantial (approximately 3,000 deaths), and among younger people more men than women
8   died, unlike the older age groups. One explanation may be that men were working outdoors or in other very hot
9   circumstances. Questions were raised at the time as to why this event had such a devastating effect (Kosatsky,
10 2005). It is still not clear, but one contributing factor may have been the relatively mild influenza season the year
11 before. Recent studies have found that when the previous year's winter mortality is low, the effect of summer heat is
12 increased. This intrinsic relationship between risk factors in winter and summer time may complicate the attribution
13 of heat and cold effects (e.g. with climate change), given their inter-dependence.
14
15 Most analyses have focused on mortality and morbidity in relation to heat in high-income countries, but recent
16 studies have investigated the relation in low- and middle-income countries, suggesting heterogeneity in vulnerability
17 by age groups and socio-economic factors similar to that seen in higher-income settings. (Bell *et al.*, 2008;
18 McMichael *et al.*, 2008)
19
20 Studies of temperature-related morbidity, most commonly based on hospital admission or emergency presentations,
21 find that cardio-vascular, respiratory and kidney diseases often are more strongly associated with temperature than
22 other conditions not specifically coded as temperature-related. (Bayentin *et al.*, 2010; Hansen *et al.*, 2008; Knowlton
23 *et al.*, 2009; Lin and Chan, 2009; Nitschke *et al.*, 2011)
24
25 Health risks during heat extremes are greater in people carrying out physical activity. The intra-body surplus heat
26 created by physical activity (only 20% ends up as external "work"; (Parsons, 2003) causes particular vulnerability to
27 heat effects in these population groups. This has importance for public health promotion of outdoor physical activity
28 and it is of special relevance to analysis of the impacts of climate change on occupational health (see separate
29 section below).
30
31 Cold weather is related to hypothermia, accidents due to slipping on snow or ice, and carbon monoxide poisoning.
32 (Parsons, 2003) Carbon monoxide poisonings may be considered as indirect effect of cold, due to improper use of
33 heating devices that involve indoor burning. Another example of the indirect effect of cold would be snow-
34 shovelers' myocardial infarction in heavy snow areas. (Janardhanan *et al.*, 2010) It is still unclear precisely how
35 much of the winter excess in mortality is due to seasonal factors, other than temperature variations. In some studies,
36 it was reported that although deaths were more common in the winter months, within these months there was no
37 relation between mortality and temperature.(Honda and Ono, 2009), Kinney et al. in press.
38
39 Cold and heat extremes can be prevented by air-conditioning, but this adaptation depends on a secure power supply.
40 Recent work reports that power outages are themselves associated with excess mortality, and this relation may be
41 due in part to temperature variations indoors (Anderson and Bell, 2012).
42
43 The literature on health impacts of temperature extremes reveals heterogeneity in response in various subgroups of
44 the population, classified by age, sex, underlying disease status, location of residence, and socio-economic factors.
45 The interplay among these factors is complex, since lower-income groups may, for example, have a higher
46 prevalence of certain diseases associated with susceptibility, and have less protection from ambient temperatures due
47 to poorer-quality housing. The comparability of studies is often limited due to differences in measurement
48 approaches and availability of variables, although certain common variables related to vulnerability—ranging from
49 access to air conditioning, vegetative cover of an area, age, and community structure- have emerged and are being
50 explored in efforts to map vulnerability to temperature exposure. (Reid *et al.*, 2009)
51
52
53

1 *11.2.3. Injury and Disease Resulting from Storms and Floods*
2
3 In the IPCC Fourth Assessment Report, floods were reported to be the most frequent natural weather disaster. This
4 is still true; in 2010, the ten most important disasters, judged by the number of people affected, included six floods
5 and these floods accounted for more than 90 percent of the total number of victims, i.e., 175 million people. Most of
6 the losses occurred in mid- to low-income countries such as China, Pakistan (Dar *et al.*, 2011), Thailand, Cambodia,
7 India, and Colombia. However, as exemplified by flooding in Eastern Australia in 2010, developed countries are not
8 immune.
9
10 The direct impacts of storms and floods include drowning, injuries, hypothermia and infectious diseases, whereas
11 indirect health effects result from damage to infrastructure, water supplies, displacement and disruption to people's
12 lives (Jonkman and Kelman, 2005); WHO/HPA, 2012). Over the last 10 years, floods in Europe have killed more
13 than 1,000 people and affected over 3.4 million (Jakubicka*et al.*, 2010). Worldwide, it is estimated that two thirds of
14 flood deaths are due to drowning, and 70% of flood-related deaths are male (Jonkman and Kelman, 2005).
15
16 The attribution of deaths to flood events has been found to be complex with immediate traumatic deaths being most
17 easily recorded (WHO/HPA, 2012). There is some uncertainty as to whether flood events are associated with a
18 longer-term effect on mortality in the flooded population (e.g. 6-18 months after the flood). A study of the Bristol
19 floods of 1968 reported a 50% increase in mortality rates among those flooded compared to those not flooded during
20 the 12 months following the event (Bennet, 1970). Although others have sought such an effect, the Bristol finding
21 has not been repeated. Understanding the effects of population displacement after a flood is challenging, since it
22 requires the long-term follow up of individual households. A study of mortality patterns in flooded areas in England
23 and Wales from 1994-2005 found a relative reduction in mortality of 10% in years following flooding. It is not clear
24 whether this finding is real or artefactual (for instance, due to missing information on populations from flooded
25 postcodes (Milojevic *et al.*, 2011).
26
27 Flood-related injuries have been caused when people are evacuating from flood waters, attempting to save family or
28 valuables, or during the clean-up process (Jakubicka*et al.,* 2010). Following the 2002 floods in Germany, contact
29 with floodwaters was identified as a risk factor for injuries (Schnitzler *et al.*, 2007). Infectious diseases may also be
30 affected. In many countries, heavy rainfall and flooding have led to outbreaks of leptospirosis (caused by contact
31 with bacteria of the genus *Leptospira*, an organism which circulates in a wide variety of animal hosts, including
32 rats). (Lau *et al.*, 2010) Drinking water can become contaminated by bacteria, sewage, agricultural waste or
33 chemicals (CDC, 2011). Floods commonly damage water storage and reticulation systems, and this means that
34 emergency supplies are required. For instance, flooding in Cork, Ireland in 2009 resulted in 18,000 homes being cut
35 off from main water supply; in total, approximately 300,000 litres of bottled water were distributed (Gavin, 2009).
36 The 2006 flooding of an underground aquifer in Hungary, which served 174,000 people, resulted in provision of
37 safe drinking water to consumers (Dura *et al.*, 2010).
38
39 Flooding can have profound effects on peoples' mental health and psychosocial resilience that may continue over
40 extended periods of time. However, methodological complexities in analysing and comparing data make it hard to
41 compare and understand these impacts (Murray *et al.,* 2011). A study of the aftermath of the 2007 England and
42 Wales floods found that the prevalence of all mental health symptoms (psychological distress, probable anxiety,
43 probable depression and probable PTSD) was two to five times higher among individuals who reported flood water
44 in the home compared to individuals who did not (Paranjothy *et al.*, 2011). A study of the psychological impacts of
45 flooding found that, among flood-affected adults, 27.9% met criteria for symptoms associated with post-traumatic
46 stress disorder (PTSD), 24.5% for anxiety and 35.1% for depression (Mason *et al.*, 2010). Several factors were
47 associated with greater psychological distress, including: vacating homes following a flood, previous experience of
48 flooding and poor health at time of flood. A longitudinal study (follow up of persons affected by 1998 flood in
49 Oxfordshire) found participants reported continuing psychological effects that they attributed to the experience of
50 being flooded (Tapsell and Tunstall, 2008). The provision of emergency and longer-term mental health care in
51 planning, response and recovery is an important component of flood management (Murray *et al.,* 2011).
52
53
54

1   *11.2.4.   Vector-Borne and Other Infectious Diseases*
2
3   11.2.4.1. Vector-Borne Diseases
4
5   Vector-borne diseases (VBDs) are infections transmitted by the bite of infected arthropod species, such as
6   mosquitoes, ticks, triatomine bugs, sandflies and blackflies. VBDs are among the most well-studied of the diseases
7   associated with climate change, due to their widespread occurrence and sensitivity to climatic factors. In general,
8   range shifts of a variety of VBDs and their hosts and vectors in response to rising temperatures have been observed.
9   These range shifts have generally been poleward and upward (toward higher elevations) (Hickling *et al.*, 2006). For
10 example, altitudinal and latitudinal range shifts have occurred for *Ixodesricinus*, the vector of the agents of Lyme
11 disease and tick-borne encephalitis (TBE) in Europe (Gage *et al.*, 2008), while shifts, contractions and expansions
12 have been reported in sub-Sahara Africa where the tick is a vector for East Coast fever (Olwoch JM, Reyers B,
13 Engelbrecht FA,Erasmus BFN, 2008; Olwoch JM, Reyers B,Jaarsveld ASV, 2009). Northerly range shifts also have
14 been observed for *Ixodesscapularis*, a vector of Lyme disease, human granulocytic anaplasmosis, and babesiosis in
15 Canada. In Canada endemic areas for Borreliaburgdorferi, the etiological agent of *Lyme borreliosis* (LB) in North
16 America, are increasing (Ogden *et al.*, 2008).
17
18 Many studies have reported that the incidence of vector-borne diseases is temperature-related (Bangs *et al.*, 2006; Bi
19 *et al.*, 2007; Halide and Ridd, 2008; Wu *et al.*, 2009) but this is not true in every case. For example, *S. mansoni*, a
20 parasite leading to sparganosismansoni, is not responsive to increased temperatures according to one report (Mangal
21 *et al.*, 2008). Moreover, the distribution of VBDs is influenced by many factors other than climate (examples include
22 land use, population movement, housing quality and urbanization (Vittor *et al.*, 2006)).
23
24
25 *11.2.4.1.1.   Malaria*
26
27 Malaria is caused by four distinct species of plasmodium parasite, transmitted between individuals by Anopheline
28 mosquitoes. There were an estimated 247 million malaria cases among 3.3 billion people at risk in 2006, causing
29 nearly a million deaths, mostly of children under 5 years. (WHO, 2008) World-wide, there have been significant
30 advances made in malaria control in the last 20 years (Feachem, 2011), but the disease remains a significant
31 challenge in some locations, particularly in Africa. For example, large outbreaks have occurred in several highland
32 regions in East Africa, and these may be promoted, at least in part, by rising temperatures locally (Chaves and
33 Koenraadt, 2010). Studies of disease trends in Africa, however, emphasize that the relative importance of climate
34 compared to other factors needs further elaboration (Omumbo *et al.*, 2011).The influence of temperature on malaria
35 development appears to be highly non-linear, and is vector-specific (Alonso *et al.*, 2011). Daily temperature
36 fluctuation around low mean temperatures acts to speed up parasite development, whereas daily fluctuation around
37 high mean temperatures tends to slow processes down. Analysis of environmental factors associated with the
38 malaria vectors *Anopheles gambiae* and *Anopheles funestus* in Kenya found that the abundance, distribution and
39 disease transmission are affected in different ways by precipitation and temperature (Kelly-Hope *et al.*, 2009).
40
41
42 *11.2.4.1.2.   Dengue*
43
44 Dengue fever is currently a threat in more than 100 countries, and about 70% of the 2.5 billion people presently at
45 risk live in the Asia-Pacific region (see Box 11-3). There is evidence that the disease is associated with climate on
46 spatial (Beebe *et al.*, 2009; Li *et al.*, 2011; Russell *et al.*, 2009), temporal (Descloux *et al.*, 2012; Earnest *et al.*,
47 2011; Gharbi *et al.*, 2011; Herrera-Martinez and Rodriguez-Morales, 2010; Hii *et al.*, 2009; Hsieh and Chen, 2009;
48 Pham *et al.*, 2011) and spatiotemporal (Chowell *et al.*, 2008; Chowell *et al.*, 2011; Lai, 2011) scales. But the
49 findings are not entirely consistent. Although some report that high rainfall and humidity are strong environmental
50 influences on dengue transmission (Pham *et al.*, 2011; Rohani *et al.*, 2011; Su, 2008), others have found that there
51 were no, or only weak associations between dengue incidence and the two climatic variables. (Chowell *et al.*, 2011;
52 Gharbi *et al.*, 2011; Jury, 2008). In some circumstances, heavy precipitation favours the spread of dengue fever, but
53 drought can also be a cause if household water storage increases the number of suitable mosquito breeding sites
54 (Beebe *et al.*, 2009; Padmanabha *et al.*, 2010).Other factors than climate have a powerful effect on the spread of

1   dengue. In subtropical Taiwan, for example, the degree of urbanization was found to be positively associated with
2   increasing risk of dengue fever incidence at township level (Wu *et al.*, 2009). Shang et al. (Shang *et al.*,
3   2010)emphasized that the conjunction of imported cases and favorable climate conditions was important in the
4   initiation of dengue epidemics.
5
6   _____ START BOX 11-3 HERE _____
7
8   **Box 11-3. Case Study: Dengue Fever**
9
10   Dengue Fever (DF) and its haemorrhagic manifestations are caused by four antigenically distinct serotypes (1 to 4)
11   belonging to the Flaviviridae family. Each year within the "dengue belt" (35ºN and 35ºS latitude) an estimated 50-
12   100 million cases of Dengue Fever and approximately 500,000 cases of Dengue Haemorrhagic Fever (DHF) and
13   Dengue Shock Syndrome (DSS) cases are reported (Chadee *et al.*, 2007; Gubler and Kuno, 1997). The risk factors
14   for DF transmission are summarized in the "epidemiological triad"- the vectors (*Aedes aegypti* and
15   *Aedesalbopictus*), the virus (dengue serotypes 1, 2, 3, and 4) and the susceptible human population (Chadee, 2009).
16   Prior to 2006, no consistent patterns had been reported on the seasonal distribution of DF and *Ae. aegypti* adult
17   populations within the Americas (Gubler and Kuno, 1997), but seasonal dengue transmission patterns have recently
18   been reported in the Caribbean region. However, seasonality in dengue transmission is well known in South East
19   Asia, with transmission occurring during the wettest months of the year (Chadee *et al.*, 2007; Gubler and Kuno,
20   1997).
21
22   Figure 11-5 shows most DF cases (80%) were recorded during the wet season when the *Aedes aegypti* mosquito
23   population density was four to nine times higher than the dengue transmission threshold (Macdonald, 1956). The
24   observation of dengue transmission during the wet season was recently used to develop a pre-seasonal treatment
25   strategy which reduces the mosquito population before the onset of the rains. Studies conducted in Trinidad
26   demonstrated proof of concept by the application of insecticides (temephos) into water drums, the primary breeding
27   sites of *Ae. aegypti* in the Caribbean region, prior to the onset of the rainy season. This strategy effectively
28   controlled the mosquito populations for almost 12 weeks (Figure 11-6) after which the mosquito populations
29   reverted to levels observed in the untreated control areas.
30
31   [INSERT FIGURE 11-5 HERE
32   Figure 11-5: Rainfall, temperature, Breteau index, and dengue cases, Trinidad (2002-2004). Source: Chadee *et al*.
33   (2007).]
34
35   [INSERT FIGURE 11-6 HERE
36   Figure 11-6: Efficacy of pre-seasonal treatment with temephos on Aedes aegypti ovitrap egg counts in Curepe
37   (treatment) and St. Joseph (control), Trinidad (2003). Source: Chadee (2009).]
38
39   Studies conducted on global climate models for the Caribbean region reported consistent patterns, with no marked
40   changes in the "timing of the rainfall seasonality" (J and L, 2010). Therefore with consistency in the timing of the
41   onset of the rainfall season pre-seasonal treatment strategies can continue to be implemented. However, recent
42   climate change scenarios for the period 2071-2100 project altered dynamic circulation patterns in both dry and wet
43   seasons, therefore changing the intensity and frequency of rainfall events (Campbell *et al.*, 2011) In addition, there is
44   evidence to support greater variability in rainfall patterns during November to January, with the northern Caribbean
45   region receiving more rainfall than in the southern Caribbean (Campbell *et al.*, 2011) .There may be both water
46   shortages during drought periods and flooding during heavy rainfall episodes thus influencing the breeding habitats
47   of *Ae. aegypti* and *Ae. albopictus* mosquitoes. In view of these scenarios, vector control strategies will have to be
48   planned and managed astutely to systematically reduce vector populations.
49
50   _____ END BOX 11-3 HERE _____
51
52
53

1   *11.2.4.1.3.   Tick-borne diseases*
2
3   Tick-borne diseases are long known and frequently underappreciated threats to public health. Examples are tick-
4   borne encephalitis (TBE) and *Lyme borreliosis* (LB). TBE is endemic from Alsace-Lorraine in the west to
5   Vladivostok and north-eastern regions of China in the east, and from Scandinavia to Italy, Greece and Crimea in the
6   south. Lyme disease is an acute infectious disease caused by the spirochaete bacteria Borreliaburgdorferi. There are
7   foci of Lyme borreliosis in forested areas of Asia, north-western, central and eastern Europe, and the
8   USA.Themainvector is the Ixodesricinus tick in Europe and I. persulcatus in Euroasia and Asia.Many studies have
9   found that climate may have an influence on the distribution of tick-borne diseases (Lukan *et al.*, 2010; Okuthe and
10   Buyu, 2006; Tokarevich *et al.*, 2011). In southern Sweden, the incidence of LB incidence was positively associated
11   with mild winters and warm, humid summers (Bennet *et al.*, 2006). The many socioeconomic changes that occurred
12   at the end of the Soviet era acted synergistically with climate factors to increase TBE incidence in northern Europe
13   (Sumilo *et al.*, 2007). However, the complex ecology and epidemiology of tick-borne diseases such as Lyme
14   borreliosis and tick-borne encephalitis make it difficult to attribute changes in disease frequency and distribution to
15   specific environmental factors such as climate (Gray *et al.*, 2009).
16
17
18   11.2.4.1.4.   Other vector-borne diseases
19
20   Hemorrhagic fever with renal syndromeis a zoonosis caused by the hantavirus, and leads to approximately 150,000
21   to 200,000 hospitalized cases each year globally. The incidence of this disease has been associated with climatic
22   factors including local temperature, precipitation, and relative humidity (Fang *et al.*, 2010). Plague, one of the oldest
23   identifiable diseases, remains endemic in many natural foci around the world. Outbreaks have been linked to
24   seasonal and inter-annual variability in climate, via the effects of precipitation and temperature on plague hosts and
25   vectors. (Holt *et al.*, 2009; Nakazawa *et al.*, 2007; Stenseth *et al.*, 2006; Xu *et al.*, 2011).
26
27
28   *11.2.4.2.Other Infectious Diseases*
29
30   Significantly higher rates of gram-negative infections among hospitalized patients have been reported during the
31   summer months, compared with other seasons (Perencevich et al., 2008).In enclosed hospital environments with
32   inadequate ventilation, hot and humid conditions can enhance transmission of aerosol droplets from other ill patients
33   and hasten food spoilage. It is well know that the growth of bacterial, viral and fungal pathogens varies with
34   temperature (Burge, 2006; Danaher et al., 1999; Nelson, 1943), but the role of temperature in the proliferation and
35   spread of resistant strains such as methicillin-resistant Staphylococcus aureus (MRSA), is uncertain.
36
37   Influenza outbreaks follow a seasonal pattern (Dushoff et al., 2006) (Mahoney 2010) but the underlying mechanism
38   determining the periodicity is still unknown (Tamerius et al., 2011). The modes of transmission are person to person
39   contact (including contact with contaminated hosts and surfaces) and through large respiratory droplets.
40   Overcrowding at indoor sites during the winter (Lofgren et al., 2007)and during heavy rains in tropical regions
41   (Graham and McCurdy, 2004) provide suitable conditions for airborne spread. In addition, temperature and humidity
42   may affect host immunity (Tamerius et al., 2011) and antigenic drift and waning immunity may also contribute to
43   seasonal outbreaks. Temperature and humidity, the El Nino Southern Oscillation (ENSO) (Viboud et al., 2004)and
44   solar radiation (Sagripanti and Lytle, 2007)have been implicated in influenza transmission in temperate climes but
45   the role of climate on influenza in the tropics is not well studied.(Soebiyanto et al., 2010). There is some evidence in
46   the tropics of a high incidence of influenza during the rainy season especially in India, Vietnam and Brazil
47   (Soebiyanto et al., 2010).but this pattern does not occur in other tropical locations like Singapore, Thailand and
48   Philippines (Hampson, 1999; Soebiyanto et al., 2010).
49
50   Illness caused by infection with the rotavirus caused about 450,000 deaths in children under 5 years old in 2008(Tate
51   *et al.*, 2012). There are seasonal peaks in the number of cases in temperate and subtropical regions but less distinct
52   patterns are seen within 10° latitude of the equator (Cook *et al.*, 1990). Variations in the timing of peak outbreaks
53   between countries or regions (Turcios *et al.*, 2006) (Atchison *et al* 2010) and variations with time in the same
54   country (Dey *et al.*, 2010) have been attributed to fluctuations in the number and seasonality of births (Pitzer*et al*

1 2009, 2011). While vaccination against rotavirus is expected to reduce the total burden of disease, it may also
2 increase seasonal variation (Pitzer *et al*., 2011; Tate *et al*., 2009)
3
4 Over one-third of the world population is infected with the *Mycobacterium tuberculosis* (TB) bacillus, and 5-10% of
5 this number may become sick or infectious at some time during their lifetime. It is estimated that 1.7 million people
6 died from TB in 2009 and many regions report seasonal variations in TB notifications (Luquero et al., 2008;
7 Nagayama and Ohmori, 2006). TB incidence increased during winter months in China, Mongolia, and South Africa
8 (Douglas et al. 1996, Naranbat et al. 2009); in contrast in the UK and Hong Kong outbreaks peaked during the
9 summer months(Douglas et al., 1996). In the tropics, higher prevalence rates were reported during the wet season in
10 Cameroon and Thailand (Ane-Anyangwe et al., 2006) (Kongchouv et al. 2010). During heavy rains in tropical
11 regions people congregate indoors and this may provide suitable conditions for airborne spread of TB.There is also
12 an indirect link between climate and TB, via effects on agriculture, food production and nutritional status (Cegielski
13 and McMurray, 2004).
14
15

16 *11.2.5. Food and Water-Borne Infections*
17
18 Human exposure to climate-sensitive pathogens occurs by ingestion of contaminated water or food, incidental
19 ingestion during swimming or by direct contact with eyes, ears or open wounds. Pathogens in water also can be
20 concentrated by bivalve shellfish (e.g., oysters) or pathogens in irrigation water can be deposited on produce; both
21 food sources can then serve as a vehicle for water-associated bacteria and viruses. Pathogens of concern for
22 waterborne exposure may be either enteric and transmitted by the fecal oral route (enteric viruses, bacteria and
23 protozoa) or may occur naturally in aquatic systems (bacteria and protozoa), where they may cause a range of
24 diseases. Climate may act on these pathogens directly by influencing growth, survival, persistence, transmission or
25 virulence; changing climate or environments may likewise alter or facilitate transmission of the pathogens or affect
26 the ecology and/or habitat of zoonotic reservoirs.
27
28

29 *11.2.5.1.Vibrio*
30
31 Vibrio is a genus of native marine bacteria that includes a number of human pathogens, most notably V. cholerae
32 which causes cholera. Although cholera is unique in that it can be transmitted both by drinking water and by
33 environmental exposure in seawater and seafood, other Vibrio species are solely linked to seawater and shellfish.
34 These primarily include V. parahaemolyticus and V. vulnificus, with V. alginolyticus emerging in importance
35 (Weis, 2011). Risk of infection is influenced by temperature, precipitation (and accompanying changes in salinity
36 with freshwater run off, addition of organic carbon or other nutrients or changes in pH), and sea level rise. These
37 factors, in turn, affect the geographic and temporal range of Vibrio risk and illness and likewise affect exposure
38 routes (direct [e.g., swimming] or via seafood).In countries with endemic cholera,temperature-based models have
39 been developed that suggest a robust relationship between the disease and temperature (e.g., (Islam, 2009; Paz,
40 2009; Reyburn *et al*., 2011)).
41
42 Martinez-Urtaa et al. (Martinez-Urtaza *et al*., 2010) suggest that climate anomalies have already resulted in
43 geographic range expansion, particularly among V. parahaemolyticus. The influx of V. parahaemolyticusinto the
44 north Pacific (Alaska) in 2004 and Chile and Peru in the southern Pacific in 1997 was strongly correlated with
45 unusually high water temperatures and ocean circulation. Similar expansions were seen in Europe (Martinez-Urtaza
46 *et al*., 2010) and there has also been a range expansion among marine zooplankton (Martinez-Urtaza *et al*., 2010;
47 Vezzulli *et al*., 2012) documented rising proportions of Vibrio, including V. cholerae, among microbial communities
48 in the North Sea following sea surface temperature elevation and shifts in plankton abundance beginning in 1987. In
49 addition to geographic range expansion, recent reports show a seasonal expansion of V. vulnificus and V.
50 parahaemolyticus infections associated with shellfish from US Gulf of Mexico, with an expanding number of cases
51 in spring and fall months (Martinez-Urtaza *et al*., 2010).
52
53
54

1   *11.2.5.2.Enteric Bacteria and Viruses*
2
3   There is a general trend for rising rates of gastrointestinal illness (diarrhea) with increasing temperature (Kolstad and
4   Johansson, 2011; Onozuka, 2010) but these estimates often do not take into account specific disease etiology.
5   Salmonella and Campylobacter are among the most common zoonotic food and waterborne bacterial pathogens
6   worldwide and both show distinct seasonality in infection with highest rates at warmer temperatures. The
7   association between climate (especially temperature) and Salmonella may, in part, explainseasonal and latitudinal
8   trends; although some have reported that the link to climatic conditions is stronger for non-outbreak cases than it is
9   for those that occur as part of outbreaks (Lake, 2009).
10
11   Among the enteric viruses, there are distinct seasonal patterns in infection and shedding (e.g., feces) that can be
12   related indirectly to temperature. Enterovirus infections in the U.S. peak in summer and fall months (Khetsuriani,
13   2006). Hand, foot and mouth disease (caused by coxsackievirus A16 and enterovirus 71), shows a linear relationship
14   with temperature in Singapore with a rapid rise in incidence when the temperature exceeds 32°C (Hii *et al.*, 2011).
15   However, it is not clear what the underlying driver is and if temperature is simply reflecting the disease season.
16   Other studies have shown that when released into the environment, enterovirus persistence is negatively correlated
17   with temperature (e.g., (Wetz, 2004)).
18
19   Temperature may have a clear mechanistic link with enteric disease risk in Arctic communities, where rising
20   temperatures and loss of permafrost may result in transport of sewage (which is often captured in shallow lagoons)
21   into groundwater or drinking water sources (Martin, D., B. Belanger, P Gosselin, J Brazeau,C.Furgal and S.Dery,
22   2007). Additionally, thawing may damage drinking water intake systems (for those communities with such
23   infrastructure) (Hess, 2008).
24
25   Rainfall has also been associated with enteric infections. Salmonella shows a higher likelihood of uptake by produce
26   crops (lettuce) under both flooding and drought periods (Ge *et al.*, 2012). Studies suggest that drought
27   (Bandyopadhyay *et al.*, 2012) as well as flooding can lead to increased risk of illness. Higher levels of enteric
28   viruses have been noted in drinking water (surface and ground) and recreational water following heavy rainfall
29   events or during the rainy season (e.g., (Futch, 2010; Jofre *et al.*, 2010)). Likewise, cases of hand, foot and mouth
30   disease (echovirus 71 or coxsackievirus A16) in Singapore increase linearly with cumulative rainfall of up to 75 mm
31   per week (Hii *et al.*, 2011).
32
33
34   **11.2.6.   Nutrition**
35
36   Population nutrition can be considered as a system involving the interaction of three main elements: agricultural
37   production (including post-harvest wastes and storage), governance including prices, and consumption (see Figure
38   11-7). Many of the factors which constitute these elements are climate-sensitive.
39
40   [INSERT FIGURE 11-7 HERE
41   Figure 11-7: Nutrition, health, social, environmental interactions: Population and nutrition can be conceptualized as
42   a synthetic state arising from the interaction of social, health and environmental factors, in a complex system. Many
43   relationships are bidirectional. For example, poor population health status can impair social function (e.g. by
44   impaired education). Source (Colin Butler, 2012?).]
45
46   Many studies have examined the relations between crop production, climate variability and extreme weather events,
47   and these are described in detail in chapter xx of this report. The effects of higher temperatures and variations in
48   rainfall patterns vary by time, region and crop. To date, the magnitude of changes in land-based agricultural
49   production due to increasing temperatures and changes in rainfall is small compared to increased harvests due to
50   improved farming knowledge and technology (Lobell *et al.*, 2011). The changes are also small in comparison to the
51   amount of food fed to livestock, used for biofuels, consumed beyond baseline needs by over-nourished populations
52   and wasted in other ways (Foley *et al.*, 2011).
53

1   Social and environmental factors that result in a locally available crop and livestock abundance do not necessarily
2   mean that the food is consumed locally. Moreover whether food that is ingested provides adequate nutrition is
3   influenced by other factors, such as the level of physical activity and by conditions that lower appetite (Mangili *et*
4   *al*., 2006), nutrient absorption and metabolic rates. People with febrile illnesses, for instance, require more calories
5   just to maintain body weight(Weisz *et al*., 2011). Elevations in food price can also lead to a deterioration in ingested
6   nutritional quality among the poor, as populations "trade off" more expensive micronutrients for less expensive
7   calories, such as in cooking oil (Hoddinott *et al*., 2008).
8
9   Probably of even more importance than fevers and appetite suppressing illnesses are "nutrient bypass" conditions,
10   such as infections with hookworm and other gastrointestinal helminths. These can prevent ingested nutrients from
11   being absorbed, and in some cases also cause microscopic bleeding that depletes nutrient stores, such as of iron.
12   Chronic bacterial intestinal infections can also limit nutrient absorption, even if food is ingested, and can be
13   complicated by chronic post infective malabsorptive states (Humphrey, 2009).
14
15
16   *11.2.7. Occupational Health*
17
18   Since the AR4 substantial new evidence has accumulated on the effects ofheat on working people (Kjellstrom *et al*.,
19   2009a) and other climate-related health risks for occupational groups (Bennett and McMichael, 2010)
20
21
22   *11.2.7.1.Heat Strain and Heat Stroke*
23
24   One important feature of human biology is the maintenance of core body temperature (Tc) close to 37 °C, the
25   temperature at which different biochemical and physiological systems function at their optimum. Climate-related
26   factors that influence heat stress are air temperature, humidity, wind speed, and heat radiation (outdoors usually
27   from the sun). In addition, body temperature is also affected by the metabolic rate at which a person is working and
28   the clothing worn (Parsons, 2003).
29
30   A working person creates internal body heat that needs to be emitted via the skin. In a hot and humid tropical
31   environment, sweating may be insufficient to prevent body temperature from rising. If the body temperature goes
32   beyond 38°C, there may be symptoms of sluggishness and lack of concentration. Temperature above 39°C, risks
33   more serious symptoms of organ damage, eventual unconsciousness (heat stroke), and even death. Pre-existing
34   disease or malnutrition increases vulnerability. In addition, a hard-working person may sweat more than 5 litres per
35   work shift, which has to be replaced to avoid dehydration, another serious hazard in hot working environments. A
36   net water loss of more than 2-3 litres during a day risk damage to kidneys and other organs (Ramsey, J.D.,
37   Bernard,T.E., 2000).
38
39   Experimental and field studies have documented the risks of heat strain and heat stroke (Parsons, 2003; Ramsey,
40   J.D., Bernard,T.E., 2000)and detailed exposure response relationships were described long ago (Wyndham, 1969).
41   Heat remains an occupational health issue even in a high-income country like the USA (Luginbuhl *et al*., 2008).
42   Moreover, for health in hot working conditions work pace should be reduced, which leads to potential conflict
43   between health protection and economic productivity (Kjellstrom, T., Lemke, B., Hyatt,O., 2011): as workers take
44   longer rests to prevent heat stroke, hourly productivity goes down.
45
46
47   *11.2.7.2.Heat Exhaustion and Work Capacity Loss*
48
49   Sensitivity to heat varies considerably (Parsons, 2003), and acclimatization, which takes approximately 1-2 weeks,
50   reduces the sensitivity, but there is still a limit and international standards of maximum recommended workplace
51   heat exposure exist for either acclimatized or non-acclimatized people. In hot countries during the hot season, large
52   proportions of the workforce are affected by the heat exposures, and the economic impacts of reduced work capacity
53   can be serious (Kjellstrom, T., Lemke, B., Hyatt,O., 2011; Kjellstrom *et al*., 2009a). When heat exposure is high

1   enough to reduce the effective daily working hours,: the productivity of labour is lowered, while the number of
2   mouths to feed remains the same, potentially placing additional stress on the population. (Lecocq and Shalizi, 2007)
3
4
5   *11.2.7.3. Other Occupational Health Concerns*
6
7   Exposure to heat affects psychological performance with a risk of increased mistakes in daily activities and
8   increased accidental injuries in workplaces (Ramsey *et al.*, 1983; Ramsey, 1995). In areas where vector-borne
9   diseases, such as malaria and dengue fever, are common, people working in farm fields without effective protection
10   may experience a higher incidence of these diseases when climatic conditions favour mosquito breeding. (Bennett
11   and McMichael, 2010) Increasing heat exposure in farm fields during the middle of the day in many places during
12   the planting and harvesting seasons may also lead to more work during dawn and dusk when some of the vectors are
13   biting humans more actively.
14
15   Another risk factor is increased chemical poisoning where solvents are used, because higher temperatures make the
16   solvents evaporate faster and may lead to higher occupational exposures (Bennett and McMichael, 2010). An
17   epidemic of chronic kidney disease in Central America has been considered as at least partly linked to daily
18   dehydration among sugar cane harvesting workers, due to the insufficient drinking water supplied to replace liquid
19   lost due to sweating (Garcia-Trabanino, 2005). In the Arctic, the part of the world that is now experiencing the
20   fastest increase of temperatures, traditional hunting and fishing activities are affected by reduction in sea ice and
21   there is a greater risk of drowning. (Ford *et al.*, 2008)
22
23
24   ***11.2.8.   Air Quality***
25
26   *11.2.8.1. Chronic Air Pollution*
27
28   Tropospheric ozone is formed through photochemical reactions that involve nitrogen oxides (NO_x), carbon
29   monoxide (CO), and volatile organic compounds (VOCs) in the presence of sunlight and elevated temperatures (US
30   EPA, 2007).Therefore, if temperatures rise, many air pollution models (Chang *et al.*, 2010; Ebi and McGregor,
31   2008; Polvani *et al.*, 2011; Tsai *et al.*, 2008) project increased ozone production especially within and surrounding
32   urban areas (Hesterberg *et al.*, 2009). Even small increases in atmospheric concentrations of ground-level ozone
33   may affect health. (Bell *et al.*, 2006; Ebi and McGregor, 2008; Jerrett *et al.*, 2009) For instance, Bell et al. (Bell *et*
34   *al.*, 2006) found that even levels that meet the US EPA 8-hour regulation (0.08 ppm over 8 hours) were associated
35   with increased risk of premature mortality. There is a lack of association between ozone and premature mortality
36   only at very low concentrations (from 0 to ~10 ppb) but the association becomes positive and approximately linear
37   at higher concentrations (Bell *et al.*, 2006; Ebi and McGregor, 2008; Jerrett *et al.*, 2009).An analysis of 66 United
38   States cities with 18 years of follow-up (1982-2000), ozone was found to be significantly associated with
39   cardiopulmonary mortality(Smith *et al.*, 2009).See also section 11.5.5.
40
41
42   *11.2.8.2. Acute Air Pollution Episodes*
43
44   Among all air pollutants, literature sources provided most detailed accounts on the relationship between forest fires
45   and PM_{10} levels. For example, during a fire near Denver (USA) in June 2009, 1-hour concentrations of PM_{10} and
46   $PM_{2.5}$ reached 370μg/m3 and 200μg/m3, and 24-hour average concentrations reached 91 μg/m3 and 44 μg/m3,
47   compared to the 24-hour WHO air quality guidelines for these pollutants of 50 μg/m3 and 25 μg/m3, respectively
48   (Vedal and Dutton, 2006). One study of world-wide premature mortality attributable to air pollution from forest fires
49   estimated there were 339,000 deaths per year (range 260,000 to 600,000). (Johnston et al 2012)
50
51   Extremely high levels of PM_{10} were observed in Moscow due to fires caused by a heat wave in 2010.Daily mean
52   temperatures in Moscow exceeded the respective long-term averages by 5°C or more for 45 days and 10 new
53   temperature records were established in July and 9 in August, based on measurements since 1885, and an anti-
54   cyclone in the Moscow region prevented dispersion of air pollutants. The highest 24-h levels recorded in Moscow

1   during these conditions of high atmospheric pressure and temperature inversion were between 430 and 900 μg/m3
2   PM10 most days but occasionally reached 1500 μg/m3. The highest 24-h CO concentration was 30 mg/m3, and the
3   levels of formaldehyde, ethyl benzene, benzene, toluene and styrene were also increased (WHO, 2010a).
4
5
6   *11.2.9.   Mental Health*
7
8   There are three main pathways through which climate may affect mental health (Berry *et al.*, 2010). The first is
9   direct, resulting from traumatic experiences associated with extreme events such as storms, fires and floods.
10   Manifestations include severe anxiety reactions (such as post-traumatic stress) and longer-term impacts such as
11   generalised anxiety, depression, aggression and complex psychopathology (Ahern *et al.*, 2005; Norris *et al.*,
12   2004).For slow-developing events such as prolonged droughts, impacts include chronic psychological distress and
13   increased incidence ofsuicide (O'Brien et al., in prep; Alston, 2008). People tend to feel a distressing sense of loss,
14   known as solastalgia (Albrecht *et al.*, 2007), on witnessing land degrade and they also lose amenity and opportunity.
15
16   The remaining two pathways are indirect. Firstly, mental health may suffer as a consequence of impacts on physical
17   health. Heat stress, communicable and vector-borne disease, for example, are potential risk factors for psychiatric
18   morbidity. Finally community functioning may be disrupted by impacts on agricultural productivity, fishing,
19   forestry, tourism, mining, subsistence farming and other economic endeavours reliant on the land. Where access to
20   and productivity of land are compromised, so too are these industries, businesses and households; and when these
21   fail, livelihoods can fail, families can fail and eventually whole communities can come under pressure. To the extent
22   that deteriorating community functioning involves loss of social capital (and it tends to), mental health will be at
23   risk. (Almedom, 2005; Berry *et al.*, 2010; De Silva *et al.*, 2005; Kawachi *et al.*, 2008)(Veenstra, 2005; Yip, 2007).
24   (Figure11-8).
25
26   [INSERT FIGURE 11-8 HERE
27   Figure 11-8: Links between climate change, social capital, and mental health.]
28
29
30   *11.2.10. Violence*
31
32   A study examining the impact of extreme heat on morbidity in Milwaukee, Wisconsin reported a significant and
33   positive correlation between hot temperatures and accidents and self-harm at a threshold of 27.2°C (Li, T., Horton,
34   R., Kinney,P., 2011). Another found that assault-related injuries among 15–64 year-olds increased significantly
35   during heat waves (Nitschke *et al.*, 2007), and yet another suggested a relationship between high temperatures and
36   increased risk of suicide, with a threshold effect at 18°C (Page *et al.*, 2007). Changes in behavior in times of extreme
37   heat and cold, however, may reduce the risks of some forms of injury. For example, a significant decrease in
38   automobile accidents was found during heat waves in the 75+ age group (Nitschke *et al.*, 2007)
39
40   Soil degradation, freshwater scarcity, population pressures and other forces that are related to climate are all
41   potential causes of conflict. A study of internal conflict in African countries from 1981-2002 found a positive
42   correlation between country-level temperature increases and probability of armed conflict and suggested that the
43   effects of temperature change on agriculture might be a significant factor (Burke *et al.*, 2010). The relationships are
44   not straightforward, however. A study drawing on data from 1960-99, including more than 160 countries, found that
45   poverty, low economic growth and high dependence on primary commodity exports were strongly associated with
46   civil war, while ethnic and religious diversity as well as democracy were not (Collier and Hoeffler, 2004). Another
47   found that economic and political factors were the strongest predictors of conflict, and environmental and
48   demographic factors were less prominent (Hauge and Ellingsen, 1998). The resultant ambiguity has recently led to
49   more highly specified models of the causal patterns between demography, environment and conflict (e.g. (Kahl,
50   2001)). These take account of variables such as social networks, indigenous knowledge and family cohesion that
51   reduce vulnerability to climate disasters (Adger et al., 2004) In Sub-Saharan Africa, a study found that climates that
52   are more suitable for agriculture are associated with a lower risk of conflict (Hendrix and Glaser, 2007). Another
53   study argues that environmentally induced migration can increase the risk of conflict, particularly in less-developed

1 countries, and the risk is compounded by rapid population growth and limited migration opportunities (Reuveny,
2 2007).
3
4   Although the relationship between climate and armed conflict should not be overstated, in view of other social,
5 cultural, political and economic factors that play a part, there is ample evidence that the depletion and altered
6 distribution of natural resources may heighten the risk of violent conflict (Brauch, 2002; Tanzler, D., Carius,A.,
7 2002).Using data from 1950 to 2004 from the tropics, Solomon et al (2010)found that the probability of new civil
8 conflicts arising doubles during El Niño years relative to La Niña years. A study of a thousand years of violent
9 conflict in Europe and various reconstructions of temperature and precipitation, found that conflict was exacerbated
10 during cold periods that were associated with crop failures and food shortages(Tol and Wagner, 2010). Similar
11 findings have been reported in China(Zhang *et al.*, 2006), and indeed the links between rapid climate change,
12 starvation and civil disorder and collapse are apparent as far back as the first agricultural settlements roughly 10,000
13 years before the present. (McMichael, 2012)
14
15

16 *11.2.11. Aeroallergens and Diseases*
17

18 Warmer conditions generally favour production and release of air-borne allergens (such as plant pollen and
19 mushroom spores) and, consequently, there may be an effect on asthma and other allergic respiratory diseases,
20 allergic rhinitis, conjunctivitis and dermatitis. Children are particularly susceptible to problems of this kind (Schmier
21 and Ebi, 2009). These trends will be strengthened if higher CO_2 levels stimulate plant growth. Visual monitoring and
22 experiments have shown that increases in air temperature cause earlier flowering of prairie tallgrass (Sherry *et al.*,
23 2007). Temperature increases stimulate production of allergens not only by plants but also by trees, e.g., birch and
24 sycamore. Changes in local climate may also bring dust which contains pollen and spores to new regions. For
25 example, Holland expects to receive new allergens such as pollen of ambrosia and olive trees (de Weger and
26 Hiemstra , 2009).
27

28 Time series analysis was used to uncover the relationship between increase in concentrations of grass pollen and
29 increase in the number of ambulance calls with asthma symptoms, with a time lag of 3-5 days(Heguy *et al.*, 2008).
30 The relationship between pollen levels and hospital visits with rhinitis symptoms has also been reported (Breton *et*
31 *al.*, 2006). A cross-sectional study in the three climatic regions of Spain documented a positive correlation between
32 the rate of child eczema and humidity, and negative correlation between child eczema and air temperature or the
33 number of sunshine hours (Suarez-Varela *et al.*, 2008).
34

35 The incidence of bronchial asthma attacks increases during thunderstorms and hurricanes, possibly due to emission
36 of small-size pollen particles which penetrate into lower airways.(D'Amato *et al.*, 2007). Numbers of *Alternaria* and
37 *Cladosporium* spores in the air also increase during thunderstorms (Pulimood *et al.*, 2007). Such phenomena were
38 described also during heavy rainfalls in Atlanta, USA (Grundstein *et al.*, 2008), and during severe flooding in New
39 Orleans in 2005. Physicians in New Orleans hospitals reported an increase in the number of visits of allergic
40 patients, and even coined a new term "Katrina cough" (Manuel, 2006; Ratard *et al.*, 2006; Solomon *et al.*, 2006;
41 Wilson, 2006).
42

43 There are complex interactions between climate variability, air pollution and airborne allergens, and these inter-
44 dependencies make it difficult to project the health effects of changes in ambient temperatures and rainfall. Some
45 studies showed that combined effects of air pollutants (PM and NO_2) and airborne allergens led to an increase in the
46 number of emergency department visits with bronchial asthma (Erbas *et al.*, 2007). Yet, other authors did not
47 identify such interactions (Dales *et al.*, 2008; Galán *et al.*, 2003; Villeneuve *et al.*, 2007). Specific types of pollen,
48 air pollutants, geographic location and local climate may also play a role. (D'Amato and Cecchi, 2008)
49
50

51 *11.2.12. Ozone, UV, and Skin Cancer*
52

53 Epidemiological studies have reported relationships between UV levels, maximum summertime day temperatures
54 and the prevalence of non-melanoma skin cancers. In one study in the United States, the number of cases of

1   squamous cell carcinoma was 5.5% higher for every 1°C increment in average temperatures, and basal cell
2   carcinoma was 2.9% more common with every 1°C increase. These values correspond to an increase in the effective
3   UV dose by 2% for each 1°C (van der Leun *et al.*, 2008). Higher temperatures in the northern countries and
4   countries with temperate climates may result in an increase in the time which people spend outdoors and, thus in
5   additional UV-induced-adverse effects. Notably, however, skin cancer rates are rising already in many countries, for
6   other reasons, such as changes in travel and recreation (Diffey, 2004).
7
8
9   **11.3.   Vulnerability to Disease and Injury due to Climate Variability and Climate Change**
10
11 In the IPCC assessments, vulnerability is said to be "the degree to which geophysical, biological and socio-
12 economic systems are susceptible to, and unable to cope with, adverse impacts of climate change" (Schneider SH,
13 Semenov S , Patwardhan A, Burton I, Magadza C, Oppenheimer M, Pittock B, Rahman A, Smith JB, Suarez A,
14 Yamin F, 2007). This means vulnerability encompasses both exposure to a hazard, and the response to this exposure.
15
16
17 ***11.3.1.   Current Sources of Vulnerability***
18
19 *11.3.1.1.Geographic Causes of Vulnerability*
20
21 Location has an important influence on the potential for losses caused by climate change. (Samson *et al.*, 2011) The
22 inhabitants of low-lying coral atolls are exquisitely sensitive to flooding, contamination of fresh water reservoirs due
23 to sea level rise, and salination of soil, all of which may have significant effects on health. (Nunn, 2009) Those
24 living in inland cities at mid- and low latitudes are more severely affected by heat waves than people living in rural
25 and coastal settlements. Rural populations that rely on subsistence farming in low rainfall areas are at high risk of
26 under-nutrition and water-related diseases in future drought, although this vulnerability may be modified strongly by
27 local factors, such as access to markets and irrigation facilities. (Acosta-Michlik *et al.*, 2008) In high-income
28 countries, location remains an important measure of susceptibility to the adverse effects of climate change. For
29 example, living within 100- and 500-year flood zones, or within 5 km of coasts subject to sea level rise have been
30 proposed, in the United States, as indicators of vulnerability to climate change. (Acosta-Michlik *et al.*, 2008; English
31 *et al.*, 2009) Regional factors also modulate risk. In the tropics, human populations are often living with
32 temperatures that are close to tolerable thresholds.In the Arctic, where temperatures are rising more rapidly than any
33 other region, the changes in sea ice and northern ecosystems may jeopardize food security and increase injury and
34 drowning (Ford *et al.*, 2008).
35
36
37 *11.3.1.2.Age*
38
39 Children and the elderly are both at increased risk, though for different reasons. (Perera, 2008). This is evidenced by
40 the existing health status for important climate-related diseases, particularly malaria, diarrhea, and malnutrition in
41 children. Thus modest increases in risk for these diseases from climate change lead to relatively large burdens. As a
42 result, 88% of the total burden of disease from climate change estimated in the 2004 CRA occurred in children
43 under 5 (McMichael, 2004) . It is also expected that children will be more vulnerable to heat-related illnesses, due to
44 their small body mass to surface area ratio. Evidence of excess heat-related mortality in this age group is mixed,
45 however. In California, a study of summer mortality records for 1999-2003 reported a stronger association of heat
46 and mortality among infants (aged less than 1 year) and those aged 65 years and over than other age groups. (Basu
47 and Ostro, 2008) Other studies have sought, but not detected, such an association. (Kovats and Hajat, 2008)
48 Children are more severely affected by many infectious diseases that may be encouraged under climate change.
49 Malaria is one of the most important – parasite loads are greater and mortality rates higher in childhood (from about
50 6 months to 3 years) due to less well-developed immune responses to infection with the plasmodium. (Michon *et al.*,
51 2007; Reyburn *et al.*, 2005; Rowe *et al.*, 2006) Children also dehydrate more rapidly than adults when affected by
52 diarrhoeal diseases, and case-fatality rates are correspondingly higher. In some circumstances, children may be
53 protected from climate-related diseases. For instance, maternal antibodies lower the risk of dengue fever in children
54 in the first year of life. Studies of populations affected by storms, floods and other climate extremes indicate that

1   children may be affected with psychological problems, such as anxiety and behavioural disturbances, although it is
2   not clear whether these effects are more severe than in other age groups. (Ahern *et al.*, 2005; Durkin *et al.*, 1993;
3   Price, 1978) Children are generally at greater risk when food supplies are restricted. Although families in many
4   cultures give priority to feeding children, households with children tend to have lower than average incomes, and
5   childhood is a particularly sensitive period for health and development. (Cook and Frank, 2008)
6
7   Older people are at greater risk from storms, floods and other extreme events, in part because they tend to be less
8   mobile than younger adults and so find it more difficult to avoid hazardous situations and also more likely to live
9   alone in some cultures. Older people are also more likely to suffer from health conditions that limit the body's
10   ability to respond to stressful events. Chronic diseases such as diabetes and ischemic heart disease, for example,
11   magnify the risk of death or severe illness associated with high ambient temperatures. (Basu and Ostro, 2008;
12   Sokolnicki *et al.*, 2009) People over 65 years are also more strongly affected by air pollution due to ozone and other
13   photochemical oxidants. (Medina-Ramon and Schwartz, 2008)
14
15
16   *11.3.1.3. Gender*[2]
17
18   [FOOTNOTE 2: WHO has a review of climate change, gender, and health:
19   http://www.who.int/globalchange/publications/reports/gender_climate_change/en/]
20
21   Vulnerability is associated with gender but the relationship is complex (World Health Organization, 2011a) In the
22   United States, it is reported that men are at greater risk of death following flooding, perhaps because in this setting
23   men are more commonly exposed to risk (e.g. many of the flood drownings in the US are motor-vehicle related, and
24   on average, men drive more than women do). (Jonkman and Kelman, 2005) A study of the health effects of flooding
25   in Hunan province, China, also found an excess of flood deaths among men, often related to rural farming. (Abuaku
26   *et al.*, 2009) In Canada's Inuit population men are exposed to dangers associated with insecure sea ice, while women
27   may be more vulnerable to the effects of diminished food supplies. (Pearce *et al.*, 2011),In the Paris 2003 heatwave,
28   women were more affected than men in every age group except those aged 25-64. In this instance, the male
29   dominance in the working age group may be related to differential exposures to heat in occupational settings. In
30   Bangladesh, women are more affected than men by a range of climate hazards, at least in part because a greater
31   proportion suffers from poverty and poor nutrition, and women are more frequently exposed to water-logged
32   environments. (Neelormi *et al.*, 2009) There may also be physiological differences in reserve and resilience. After
33   controlling for differences in age and co-morbidities, it appears that women are more strongly affected than men by
34   high temperatures (Yu *et al.*, 2010) and ozone air pollution (Medina-Ramon and Schwartz, 2008). There are signs
35   also that the effect of food insecurity on growth and development in childhood may be more damaging for girls than
36   boys. (Cook and Frank, 2008)
37
38   Pregnancy is a period of increased vulnerability to a wide range of environmental hazards, including infectious
39   diseases (such as malaria and foodborne infections) (Jamieson *et al.*, 2006) and illness and injury resulting from
40   climate disasters. For example, an increase in spontaneous abortions was recorded in counties in New York State
41   that had been affected the year before by severe flooding caused by Hurricane Agnes. (Janerich *et al.*, 1981)
42
43
44   *11.3.1.4. Race and Ethnicity*
45
46   In many countries, race and ethnicity are powerful markers of health status and social disadvantage. Black
47   Americans have been reported to be more vulnerable to heat-related deaths than other racial groups in the United
48   States. (Basu and Ostro, 2008) This may be due to a higher prevalence of chronic conditions such as over-weight
49   and diabetes, (Lutsey *et al.*, 2010) financial circumstances (lower incomes may restrict access to health-protecting
50   air conditioning),(Ostro *et al.*, 2010) or to community-level characteristics (such as local crime rates or disrupted
51   social networks).Indigenous peoples who depend heavily on local resources, and live in parts of the world where
52   climates are changing quickly, are generally at greater risk of economic losses and poor health. Studies of the Inuit
53   people, for example, show that rapid warming of the Canadian Arctic is jeopardizing hunting activities which many
54   in these communities rely on for food. (Ford, 2009) In Australia, indigenous peoples experience higher rates of

1   diarrheal diseases and other climate-sensitive conditions than the remainder of the national population and their
2   general health status is poorer and puts them at additional risk of climate stressors such as heat-waves. (Green *et al.*,
3   2010)
4
5
6   *11.3.1.5. Socioeconomic Status*
7
8   Socioeconomic status typically reflects, and may be measured by, educational attainment, occupational prestige and
9   personal income. At a national level, the poorest countries are most susceptible to damage caused by climate change,
10   including health effects. Likewise, individuals and households most vulnerable to climate hazards are those with
11   relatively low socioeconomic status. A review of global trends in tropical cyclones found that mortality risk
12   depended on storm intensity, effective governance, and levels of poverty. (Peduzzi *et al.*, 2012) A study of the
13   impacts of flooding in Bangladesh found that household risk reduced with increases in both average income and
14   number of income sources. Poorer households were not only more severely affected by flooding, but they took
15   preventive action less often, and received assistance after flooding less frequently than did more affluent households.
16   This was explained partly by financial obstacles to relocation and other coping strategies, but there were differences
17   also in knowledge of hazards and in beliefs about the preventability of flooding. (Brouwer *et al.*, 2007) Occupation
18   is also directly related to vulnerability to climate variability and extremes. For instance, outdoor occupations have
19   been linked with disease and injury caused by flooding in China (Abuaku *et al.*, 2009) and heat-waves in the United
20   States (Centers for Disease Control and Prevention, 2008).(The effects of heat on working lives are described in
21   detail elsewhere in this chapter.) But a link with socioeconomic status is not always present. In Brisbane, Australia,
22   heat-wave mortality was related to age and gender, but not to small area measures of social disadvantage. (Yu *et al.*,
23   2010) This null finding, contrary to what has been observed elsewhere with individual-level measures of SES,
24   (Medina-Ramon *et al.*, 2006) may be due to the much greater variability in housing quality in Australia within
25   neighbourhoods than exists between neighbourhoods, or the relatively flat social gradient in access to protective
26   factors such as air conditioning and private transport.
27
28
29   *11.3.1.6. Neighborhoods*
30
31   The physical environments around where people live and work can influence the health risks due to climate
32   variability and climate change. In Cuba, a country with a well-developed public health system, dengue fever has
33   been a persistent problem in the larger cities, due in part to the lack of a constant supply of drinking water in many
34   neighbourhoods (leading to people storing water in containers that are suitable breeding sites for the disease vector,
35   *A. aegypti*). (Bulto *et al.*, 2006) A study of the city of Phoenix, in the US, found the number of heat distress calls
36   during heat waves was higher in areas affected by the urban heat island effect (which was measured by the
37   proportion of impervious surfaces and minimum night time temperatures). (Uejio *et al.*, 2011)
38
39   Climate extremes may promote the transmission of certain infectious diseases and the vulnerability of populations to
40   these diseases will depend on the baseline levels of pathogen and vector. In the United States, as one example,
41   arboviral diseases such as dengue and the encephalitides are rarely seen after flooding, compared with the
42   experience in other parts of the Americas. The explanation lies in the scarcity of dengue and other viruses circulating
43   in the population, pre-flooding. (Keim, 2008) Schistosomiasis was present in parts of Portugal in the 1950s.
44   However, disease control efforts have eliminated the microbe from local snail populations so that although there is a
45   competent vector and climate projections indicate that both parasite survival and vector survival will be favoured by
46   rising temperatures, the risk of schistosomiasis returning to Portugal is low. (Casimiro *et al.*, 2006) On the other
47   hand, the high prevalence of HIV infection in many populations in Sub-Saharan Africa multiplies the health risks of
48   prolonged drought, which may lead to migration, family disruption, deepening poverty, and increased exposure to
49   unsafe sex.
50
51
52

1   *11.3.1.7. Summary*
2
3   We have divided the causes of vulnerability into sections for convenience. In practice, these factors combine, often
4   in complex and place-specific manner. For example, a study of the spatial distribution of vulnerability to heat in the
5   United States found the strongest contributions were made by neighbourhood green space, personal education and
6   income, the prevalence of diabetes, social isolation and access to air conditioning. (Reid *et al.*, 2009) However there
7   was substantial spatial variation within the US, with greatest vulnerability to heat in the northeast and Pacific coast,
8   and least in the southeast of the country.
9
10   There are some factors (such as education, income, health status and responsiveness of government) that might be
11   described as generic causes of vulnerability. Low levels of parental education, for example, are consistently
12   associated with higher child mortality in times of stress, whether it is military conflict, famine, or other natural
13   disasters. (Kiros and Hogan, 2001) But the precise causes of vulnerability, and therefore the most relevant coping
14   capacities, vary greatly from one setting to another. Vulnerability to heat, for example, varies spatially: the factors
15   that are important in rural areas differ from those that put people at risk in cities. (Reid *et al.*, 2009) The lag between
16   high ambient temperatures and increased incidence of salmonella food poisoning varies from one country to another,
17   suggesting that the mechanisms differ (deficiencies in food storage may be the critical link in some places, food
18   handling problems elsewhere). (Kovats *et al.*, 2004)
19
20   The 2010 World Development Report concluded that all developing regions are vulnerable to economic and social
21   damage resulting from climate change – but for different reasons. (The World Bank, 2010) The critical factors for
22   Sub-Saharan Africa, for example, are the current climate stresses (in particular, droughts and floods) that are
23   projected to worsen with climate change, sparse infrastructure and high dependence on natural resources. East Asia
24   and the Pacific, on the other hand, are distinguished by the very large number of people living in low-lying areas
25   prone to flooding (this includes roughly half the population of Vietnam).
26
27
28   **11.3.2.   *Projections for Vulnerability***
29
30   Population growth is likely to be one of the strongest influences on vulnerability to the health effects of climate
31   change. Increasing numbers of people, particularly in environments that are already resource-stretched, will magnify
32   harmful impacts. For instance, it is estimated that about 150 million people currently live in cities affected by
33   chronic water shortages (< 100 L per person per day of sustainable freshwater flows). In 50 years, unless there are
34   rapid improvements in urban environments, demographic growth will push the number affected by chronic water
35   shortages to around a billion (and climate change may add another 100 million). (McDonald *et al.*, 2011) Under a
36   "business as usual" scenario, the OECD projects that about 1.4 billion people will be without access to basic
37   sanitation in 2050. (OECD, 2012) The age structure of the population also has implications for vulnerability. The
38   proportion aged over 60 is projected to increase everywhere (rising from about 10% presently to 32% by the end of
39   the century). (Lutz *et al.*, 2008) In some regions, this change will occur much faster (going from 10% to over 40% in
40   China, for example). It is expected that mortality rates will continue to fall, with profound implications. For
41   instance, under relatively conservative assumptions the average years of life remaining globally (a product of
42   average age in the population and prevailing mortality rates) is projected to fall only slightly (43.8 years at present,
43   41.2 years in 2100). (Lutz *et al.*, 2008) Historically, as populations live longer, age-related disability has reduced,
44   (Vaupel, 2010) but it is uncertain whether older populations in the future will be more robust than at present. A
45   particular concern is the rising prevalence of conditions such as cancer, heart disease and diabetes in many parts of
46   the world.
47
48   Future trends in social and economic development are relevant to vulnerability. For instance, it has been observed
49   that the countries with higher Human Development Indices (a composite of life expectancy, education and literacy
50   and GDP per capita) are less affected by floods, droughts and cyclones. (Patt *et al.*, 2010) Therefore policies that
51   improve such measures are likely to reduce future vulnerability. But these relationships are not linear.In the early
52   stages of economic development, historically, health statistics tend to deteriorate as the detrimental effects of rapid
53   social and technological change predominate. (Szreter and Woolcock, 2004)) It is important to note also that the
54   relation between national wealth and health is roughly log linear – an extra dollar brings much more health gain in

1   low income countries than in medium and high income settings. This suggests that trends in the distribution of
2   wealth as be as important as changes in average incomes, with greater equity tending to improve health anad reduce
3   vulnerability. Last, the protective effects of national wealth are most marked for less severe climate extremes. For
4   instance, Peduzzi (Peduzzi *et al.*, 2012) found "that poverty levels are less significant when facing very intense
5   tropical cyclones, whereas at the lower intensities only the poorest suffer heavy losses". Finally, it is not clear that
6   current patterns of consumption (on which measures of GDP per capita are based) are compatible, long term, either
7   with environmental protection (Dietz *et al.*, 2012) or low carbon emissions (Steinberger *et al.*, 2012).
8
9   Other global trends that may impact on future vulnerability include the distribution of wealth and resources
10 (inequalities within and between countries), urbanization and changes in the nature and location of work. The flow
11 of people and goods internationally is an important influence on the risk of some climate-sensitive infections, such
12 as those caused by the dengue and chikungunya viruses. (Randolph and Rogers, 2010) For this reason, future trends
13 in trade and migration will affect the susceptibility of many populations to diseases associated with climate change.
14
15 Mal-adaptation may be a source of vulnerability – steps taken to cope with challenges in the present or the near
16 future may make the situation worse, not better, if more extreme conditions occur. For instance, in Victoria,
17 Australia, preparation for bushfires was historically based on the message "Prepare, stay and defend, or leave early".
18 In February 2009, many householders decided to "stay and defend" but were overwhelmed by unprecedentedly
19 intense fires that caused 173 deaths. (Parliament of Victoria, 2010)
20
21
22 **11.4.   Current Impacts of Climate Change on Health**
23
24 Although there is strong evidence for the effects of variation in weather and season on a range of health outcomes
25 (section 11.2), assessment of the health impacts of long-term climate change is much more challenging. Over the
26 multi-decadal time scales that are necessary to measure climate change, human disease systems are also strongly
27 affected by a range of other social and environmental factors. This means that robust studies require not only long
28 time series of data on climate and disease rates, but also on all other established or potential causative factors,
29 coupled with statistical analysis to apportion changes in health states to the various contributing factors. In addition,
30 wherever risks are identified, health agencies are mandated to intervene immediately, confounding long-term
31 analyses. Finally, there is no clear consensus on appropriate methods and standards for studies correlating long-term
32 time trends in environmental variables and health outcomes. Such studies are therefore relatively rare, and often
33 inconclusive.
34
35
36 *11.4.1. Effects of Climate Change on Meteorological Hazards to Health*
37
38 Since AR4, there is stronger evidence both for increases in some meteorological exposures that are hazardous to
39 human health, and of attribution of these changes to anthropogenic influences. The IPCC Special Report on Extreme
40 Events SREX [to be updated with data from WG1 of AR5] concludes that it is very likely that there has been an
41 overall decrease in the number of cold days and nights, and an overall increase in the number of warm days and
42 nights, at the global scale. The report also identifies statistically significant trends in the number of heavy
43 precipitation events in some regions, and judges that it is likely that more of these regions have experienced
44 increases than decreases. It assesses that it is likely that anthropogenic influences have led to increases in extreme
45 daily minimum and maximum temperatures at the global scale, and that there is medium confidence that
46 anthropogenic influences have contributed to intensification of extreme precipitation at the global scale.
47
48 The association between very hot days and increases in mortality in temperate populations is very robust (see studies
49 reviewed in section 11.2.2 above). It is therefore very likely that the observed increase in very hot days will have
50 been associated with an increase in the number of heat-related deaths in mid-latitude populations, and similarly a
51 decline in cold-related deaths. In contrast, due to data scarcity and confounding there is only low confidence in the
52 evidence that increases in extreme precipitation have increased human exposure to floods to date.
53
54

1 *11.4.2. Effects of Climate Change on Exposures to Health Risks*
2
3 Consistent with observed climate change effects on tree and plant species, further studies have confirmed observed
4 changes to seasonality in pollen production in mid to high latitudes. Studies have shown an earlier onset but not an
5 extension of the *Betula* pollen season in Finland (e.g. (Yli-Panula *et al.*, 2009)) and earlier onset of grass pollen
6 season in Spain (García-Mozo *et al.*, 2010). A study of several data series in North America, indicated an extension
7 of the ragweed (*Ambrosia* spp.) pollen season at high latitudes (Ziska *et al.*, 2011). An increase in the length of the
8 season by 13-27 days since 1995 was observed at latitudes above 44N. One published study reported changes in
9 allergic sensitization in humans (Ariano *et al.*, 2010). An increase in the percentages of patients sensitized to five
10 specific pollens over 25 year period in Italy was observed, but the attribution to observed warming remains unclear.
11
12 Several studies have reported changes in the latitudinal and altitudinal distribution of ticks in Europe consistent with
13 observed warming trends (see (Confalonieri, U., B. Menne, R. Akhtar, K.L. Ebi, M. Hauengue, R.S.
14 Kovats,B.Revich and A.Woodward, 2007; Gray *et al.*, 2009)), however, there is no evidence so far of any associated
15 changes in the *distribution* of human cases of tick-borne diseases. In North America, there is good evidence of
16 northward expansion of the distribution of the tick vector (*Ixodesscapularis*) in the period 1996 to 2004based on an
17 analysis of active and passive surveillance data (N.H. Ogden *et al.*, 2010).
18
19
20 *11.4.3. Effects of Climate Change on Human Disease*
21
22 Climate change effects will be experienced in the context of rapid changes in disease incidence, distribution, and the
23 emergence of new diseases (Jones *et al.*, 2008). Disease systems are strongly affected by local conditions, and few
24 have been investigated intensively to elucidate the role (if any) of decadal temperature changes. Owing to the
25 multiple causes of disease, the contemporaneous increase in temperature (or any other climate variable) preceding a
26 change in incidence or distribution is a necessary but not sufficient criterion for attribution to observed climate
27 change (Omumbo *et al.*, 2011; Pascual *et al.*, 2009; Randolph, 2010),Two disease systems where high quality data
28 are available, and changes in incidence have occurred after observed warming periods are and tick-borne
29 encephalitis cases in central and eastern Europe, and malaria cases in Kericho, Kenya.
30
31 Sumilo (Sumilo *et al.*, 2008; Sumilo *et al.*, 2009) conclude that socio-economic factors rather than temperature were
32 the main cause of the upsurge in TBE in the 1980-90s in central and eastern Europe. Spring-time maximum daily
33 temperatures rose in the late 1980s, sufficient to encourage transmission of the TBE virus. But the variations in
34 illness rates across the region suggest the most important influences were greater human-tick contact caused by
35 changes in human behaviour (such as increased foraging), changes in agricultural practices, and increased
36 unemployment. Changes in the observed incidence of TBE in central Sweden remain unexplained (Randolph, 2010).
37
38 Further studies have tried to elucidate the role of local warming on malaria transmission in Kericho region of Kenya
39 but these are limited by lack of time series data on non-temperature causes (e.g. drug resistance, vector control
40 measures). Data from local weather stations showed a warming trend (Omumbo *et al.*, 2011). A study using a
41 mosquito-human model showed that predicted malaria cases exhibited a strongly non-linear response to observed
42 warming (Alonso *et al.*, 2011). A detailed review by Chaves and Koenraadt (Chaves and Koenraadt, 2010)
43 concluded that there is robust evidence that decadal temperature changes have played a role in changing malaria
44 incidence but temperature trends should not be considered the main or sole cause of such changes in the east African
45 highland region
46
47 At the global level, Gething et al. (Gething *et al.*, 2010) compared the distribution of malaria in 1900 with the
48 current distribution of *Plasmodium falciparum* malaria. The study supports previous work that shows that although
49 there has been modest warming over the last century, the current distribution of disease world-wide is much
50 restricted, largely due to control of P. vivax malaria in moderate climates with low transmission intensity. This
51 indicates that the protective effects of non-climatic factors, including economic and social development and control
52 interventions were larger than any negative effects of warming on the global malaria distribution during this period.
53
54

1   *11.4.4.   Estimation of Current Impacts based on Modeling*
2
3   As reported in AR4, in 2004 the World Health Organization published the first Comparative Risk Assessment
4   (CRA), which used common methods, rule of evidence, and databases for estimating aggregate disease burdens
5   attributable to different risk factors (McMichael, 2004). In addition to other environmental, nutritional, infectious,
6   and behavioral risk factors, these were applied to published and newly developed models for a range of climate-
7   sensitive diseases in order to estimate the effect of global climate change on current disease burdens and likely
8   proportional changes in the future (McMichael, 2004). The approach places climate change within the same criteria
9   for epidemiologic assessment as other health risks and takes into account the size of the burden of climate-sensitive
10 diseases rather than just proportional change, which highlights the importance of small proportional changes in
11 diseases such as diarrhea and malnutrition that cause a large burden (Campbell-Lendrum and Woodruff, 2006).
12
13 In 2009, an updated burden of disease assessment of climate change was published by the Global Humanitarian
14 Forum based on the same methods as the WHO CRA,, and concluded that about 300,000 premature deaths per year
15 were attributable to climate change at the end of the decade, roughly twice the number reported in the WHO CRA
16 for 2000 (GHF, 2009).
17
18 These exercises help clarify important knowledge gaps such as a relatively poor understanding of the role of non-
19 climatic factors (socioeconomic and other) that may modify future climatic influences. We also lack empiric
20 evidence and methods for quantifying more complex climate–health relationships, which consequently are often
21 excluded from consideration. These exercises highlight the need for risk assessment frameworks that not only make
22 the best use of traditional epidemiologic methods but also take into account the specific characteristics of climate
23 change. These include the long-term and uncertain nature of the exposure and the effects on multiple physical and
24 biotic systems that have the potential for diverse and widespread effects, including high-impact events.
25
26
27 **11.5.   Future Risks**
28
29 This section focuses exclusively on literature that assesses future risks to various time horizons, most typically to
30 2050. The literature on biological plausibility and empirical evidence of the link between meteorological variables
31 and adverse health outcomes is assessed earlier in the chapter (see Section 4.2).
32
33 A few projections of specific health impacts attributable to climate change have been published since AR4, but they
34 do not include all potential impacts, e.g. little has been written on non-communicable diseases, including mental
35 disorders. (Hosking and Campbell-Lendrum, 2012) There is a particular dearth of studies in low and middle-income
36 countries, except in the areas of some infectious diseases. Unfortunately, investigators have used different climate
37 models, time horizons,model assumptions, and scenarios, which makes policy-relevant comparative assessment
38 difficult.
39
40
41 *11.5.1.   Malnutrition*
42
43 Lloyd et al. (Lloyd *et al.*, 2011) built a model for estimating future undernourishment (too little food) and child
44 malnutrition, defined as growth retardation (stunting) under two climate change scenarios and a reference scenario
45 without climate change. While the estimates of the proportion of undernourished children were based on food
46 availability projections from Nelson et al. (Nelson *et al.*, 2009), stunting was modeled using "food" and "non-food
47 causes". The percent increase in severe stunting attributable to climate change in 2050 ranged from 31% in central
48 Sub-Saharan Africa to 61% in South Asia. The comparison was the reference scenario i.e. the world without climate
49 change. In such a world, the trend would be an overall reduction in both undernourished <u>and</u> stunted children.
50
51 Nelson et al. (Nelson *et al.*, 2009) compared the number of malnourished children in 2000 with projections to 2050
52 under three different assumptions: (i) no climate change, (ii) climate change with technological improvement in
53 developing countries only, and (iii) climate change with technological improvements in both developing and
54 developed countries. Table 11-1 provides the data for the NCAR model (the other model used, CSIRO, generates

1   essentially similar projections). Lloyd et al. (Lloyd *et al.*, 2011) estimated that there would be, in addition, a shift to
2   more severe forms of malnutrition. Unsurprisingly, various degrees of adaptation policies are expected to
3   moderately reduce the predicted impact of climate change on malnutrition (two last lines in Table 11-1).
4
5   [INSERT TABLE 11-1 HERE
6   Table 11-1: Number of malnourished children in 2000 and under the NCAR climate model till 2050 using different
7   assumptions for investment in agricultural productivity: + only in developing countries; ++ both in Dev. and
8   developed countries. Adapted from (Nelson *et al.*, 2009).]
9
10 In a subsequent paper, Lloyd et al. (Lloyd, S.J., Kovats, R.S., Chalabi,Z., 2011) went further and estimated the
11 number of malnutrition-attributable childhood deaths from all causes. The relationship between the severity of
12 stunting and mortality was drawn from Black et al.(Black *et al.*, 2008). They calculated odds ratios for subsequent
13 death, given malnutrition, of 1.6 (1.3-2.2) and 4.1 (2.6-6.4) for moderate and severe stunting respectively. For 2030,
14 their model predicted 108,028 malnutrition-related childhood deaths from climate change (8.0% out of a total of
15 1,256,440 malnutrition-related deaths). For 2050, they estimated this number to be 96,460 out of 614,361 (15.7%)[3].
16 Hence, while the <u>absolute</u> number of children dying from malnutrition would fall by half between 2030 and 2050
17 due to socioeconomic factors worldwide, the <u>relative</u> proportion attributable to climate change would double.
18
19 [FOOTNOTE 3: The data were calculated from Table 5, 4a, Lloyd et al. (2011).]
20
21 In summary, it is anticipated that climate change alone will have a substantial negative impact on childhood
22 malnutrition and on malnutrition–related child deaths. Optimistic assumptions of economic growth and future
23 adaptation efforts are likely to counter-act the climate impact on child malnutrition, without eliminating it. Sub-
24 Saharan Africa and South Asia will be affected most.
25
26
27 *11.5.2.   Malaria*
28
29 Since AR4, the World Malaria Map Project has added considerably to our knowledge of the global epidemiology of
30 malaria (Gething *et al.*, 2011b; Guerra *et al.*, 2008; Hay *et al.*, 2009). Based on comprehensive survey information
31 (for *Pl. falciparum*, 7,953 surveys were analyzed) and reported cases, it projects major parameters of malaria
32 epidemiology to a world map based on 2007 data (Hay *et al.*, 2009), after due standardization of, for example, the
33 definitions of malaria and parasitemia (Smith *et al.*, 2007). Contrary to previous world maps of malaria, the process
34 of image generation is not based on climate or geographical features. This malaria map was updated for 2010
35 (Gething *et al.*, 2011a) and it will be revised in the future, as new surveys and data on entomology, malaria
36 transmission and human infection are generated.
37
38 Most of the research has focused on the conundrum of "fringe malaria". The question is, whether malaria will
39 expand its current geographical limits latitudinally and altitudinally in a warmer world. Gething (Gething *et al.*,
40 2010) compared the distribution of malaria in 1900 with today's much smaller expanse of the globe covered by
41 malaria. He argued that this contraction of the space occupied by malaria had occurred in spite of a warming climate
42 in the past century and inferred that non-climatic factors, such as economic and social development and control
43 interventions were overwhelmingly more important for the contraction of the "malaria space" than climate change.
44 There is wide agreement that the area on the globe, within which malaria has been transmitted, has shrunk by more
45 than half in the past century. However, the view that therefore climate change does not play a role in malaria has
46 been challenged. Economic development and effective health systems have made it relatively easy to control
47 malaria, and it should not be assumed (some say) that these favourable conditions will continue in the future. Further
48 more, it is much easier to control *P.vivax* malaria and its vectors in moderate climates with low transmission
49 intensity than *P. falciparum* malaria and its extremely efficient vectors in optimally warm tropical settings.
50
51 Using the IPCC AR 5 A1B scenario, Béguin et al. (Béguin *et al.*, 2011) projected differences in the population at
52 risk to 2030 and 2050 using the A1B scenario. Keeping economic growth constant, the model projected 5.2 billion
53 people at risk in 2050, out of a predicted global population of 8.5 billion. The additional malaria transmission areas
54 are shown in red in Figure 11-9. On the other hand, keeping climate constant, and assuming the effect of strong and

1   equitable economic growth on malaria, would lead to a projection of 1.74 billion people at risk. Hence the area of
2   malaria transmission would shrink by the blue shaded zone in the left panel of Figure 11-9.The combined effect of
3   climate and economic growth would lead to only 1.95 billion people estimated to be at risk of malaria, a substantial
4   reduction from the present day 3.5 billion estimated at risk by WHO. As we will see in the projections of many
5   health impacts, the potential impact of climate change can be reduced or even reversed by many health systems,
6   biological and social factors, the most prominent being sustained, equitable economic and social development (e.g.
7   Lafferty 2009). It is far from obvious that the latter condition will be achieved in the medium term, particularly in
8   Sub-Saharan Africa.

10 [INSERT FIGURE 11-9 HERE
11 Figure 11-9: Contraction of the area of malaria transmission through economic development offsets expansion
12 through higher temperatures. Based on IPCC scenario A1B, projections to 2050. Source: (Béguin *et al.*, 2011).]

14 Another aspect of fringe malaria concerns highland malaria, which has remained a controversial issue since AR4.
15 There is now widespread agreement that the strength of epidemic malaria and the number of malaria cases have
16 increased in the past decades in the Kenyan Highlands. What portion of the increase can be ascribed to climate
17 change, however, continues to be fiercely debated (Alonso *et al.*, 2011; Bouma *et al.*, 2011; Pascual *et al.*, 2006;
18 Pascual *et al.*, 2008; Pascual *et al.*, 2009; Stern *et al.*, 2011).

20 Given that the overwhelming majority of malaria transmission, new cases and deaths occur within the confines of
21 the areas in which transmission is possible, it is surprising how little research has been directed to model and predict
22 transmission changes in the "heartland" of malaria. Rainfall and air humidity are thought to be the major
23 meteorological drivers of malaria transmission in the core transmission area, as opposed to the "fringes", where
24 temperature and its diurnal variations are key. We could identify only two papers which look at rainfall AND
25 temperature as predictors of malaria transmission in the present transmission area ((Parham and Michael, 2010) for
26 modeling the Reproductive Number Ro and (Ye *et al.*, 2009) for seasonal prediction).

28 There has been no prediction of a future sustained introduction of malaria in Northern America or Europe, where it
29 was once prevalent. Although suitable vectors for *P. vivax* malaria transmission abound in these parts of the world,
30 the risk of re-introduction is thought to be very low, barring civil strife or a breakdown of health services.

33 ### *11.5.3.   Dengue Fever*

35 The Dengue literature since 2006 abounds in time series analyses looking at time lags of days up to several
36 months(e.g. (Gharbi *et al.*, 2011)) or for inter-annual anomalies, such as the El Nino/la Nina phenomena (Descloux
37 *et al.*, 2012). However, we could identify only one single study since 2006 modeling future risk of dengue under
38 climate change. Åström et al. (2012) estimated the changes of the population at risk to the year 2050.The authors
39 used as the outcome variable the presence or absence of any type of dengue fever in each grid cell of 0.5° x 0.5° of
40 the globe. The data were based on national routine reporting and scientific surveys as part of the global burden of
41 disease projections of WHO. The authors used the detailed information on population, GDP growth and greenhouse
42 gas emissions of the A1B scenario. These data were linked with three different global circulation models run out to
43 2050. By this time, 4.86 billion people billion were projected to live in areas at risk of dengue, 6.1% or 280million
44 more than would have been expected otherwise. If the impact of GDP growth on Dengue is included in the model,
45 120 million people would no longer be exposed to Dengue in 2050. There is broad agreement between this study
46 and that by Hales et al. (Hales *et al.*, 2002) reported in AR4, as to (i) the influence of climate alone on the
47 geographic expansion of the area at risk of Dengue and (ii) an opposite trend from economic growth. Both studies
48 only looked at the margins of the geographic distribution and did not consider changes in intensity of transmission
49 where Dengue currently is present. As with malaria and health impacts in general economic growth is a strong
50 confounding factor (Tang *et al.*, 2009), as it is associated with emissions and climate change, and has an
51 independent effect on health (generally positive).

53 Kearny (Kearny *et al.*, 2009) used biophysical models to predict the geographical extension of vector range in
54 Australia. He predicted, "Climate change will directly increase habitat suitability throughout much of Australia."

1   Changes in water storage as a response to a drier climate may be an indirect pathway, through which climate change
2   affects mosquito breeding. (Beebe *et al.*, 2009)
3
4
5   *11.5.4.   Schistosomiasis*
6
7   Studies confirming the influence of meteorological and other environmental variables on the snail and the aquatic
8   stages of the parasite abound (e.g. (Remais *et al.*, 2008)). However, we are only aware of one published study,
9   which models future changes in the area at risk of schistosomiasis (Zhou *et al.*, 2008). The authors modeled the
10   transmission index of schistosomiasis due to *S. japonicum* for China based on anticipated changes in the mean
11   January temperatures for 2030 (not shown in the figure below) and 2050. They concluded that an additional 784
12   thousand km^2 would become suitable for schistosomiasis transmission in China by 2050 (Figure 11-10).
13
14   [INSERT FIGURE 11-10 HERE
15   Figure 11-10: Predicted risk map of schisosomiasis*(S. japonicum)* transmission in China in 2050. For comparison
16   the current risk map in 2000. Green area denotes the range of schistosomiasis in 2000. The blue area shows the
17   geographic expansion. Adapted from (Zhou *et al.*, 2008).]
18
19   Mangal et al. (Mangal *et al.*, 2008) constructed a mechanistic model of the transmission cycle of another species, *S.*
20   *mansoni* and reported a peak in the worm burden in humans at an ambient temperature of 30°C, falling sharply as
21   temperature rises to 35°C. The authors attribute this to the increasing mortality of both the snails and the water-
22   borne intermediate forms of the parasite, and noted that worm burden is not directly linked to the prevalence of
23   schistosomiasis.
24
25
26   *11.5.5.   Air Pollution*
27
28   It is projected that climate change could affect future air quality, including levels of photochemical oxidants and fine
29   particles (PM2.5), and if this occurs there will be consequences for human health. (Bell *et al.*, 2007; Chang *et al.*,
30   2012; Dong *et al.*, 2011; Lepeule *et al.*, 2012; Meister *et al.*, 2012) High temperatures may magnify the effects of air
31   pollutants like ozone to increase morbidity and mortality, although findings have been inconsistent (Jackson, J.E.,
32   Yost, M.G., Karr, C., Fitzpatrick, C., Lamb, B.K., Chung, S.H., Chen, J., Avise, J., Rosenblatt, R.A., Fenske,R.A.,
33   2010) (Ren et al 2008). Increasing urbanization, the continued use of solid biomass fuels and industrial development
34   in the absence of emission controls could also lead to increases in ozone chemical precursors (Selin *et al.*, 2009;
35   Wilkinson *et al.*, 2009) Changes in regional weather patterns could likewise increase exposure to PM$_{2.5}$, although
36   future projections are very uncertain (Ebi and McGregor, 2008).
37
38   The number of studies modeling the projected impacts of future climate change on air pollution-related morbidity
39   and mortality has increased since 2006 (see Table 11-2). Most have focused on exposure to ozone (Bell *et al.*, 2007;
40   Jackson, J.E., Yost, M.G., Karr, C., Fitzpatrick, C., Lamb, B.K., Chung, S.H., Chen, J., Avise, J., Rosenblatt, R.A.,
41   Fenske,R.A., 2010; Selin *et al.*, 2009; Tagaris *et al.*, 2009)and there are fewer studies that have examined effects of
42   particulate matter(Tagaris *et al.*, 2009) or other air pollutants (Cheng *et al.*, 2011). The majority of studies also focus
43   on future ozone-related mortality in only a few geographical regions, including the U.S. and Canada. Projections are
44   lacking for other areas of the world, especially developing countries, where air pollutant burdens are increasing.
45
46   [INSERT TABLE 11-2 HERE
47   Table 11-2: Projected future health impacts of climate change through air pollution.]
48
49   Ozone-related mortality is expected to increase in the US and Canada (Bell *et al.*, 2007; Cheng *et al.*, 2011; Jackson,
50   J.E., Yost, M.G., Karr, C., Fitzpatrick, C., Lamb, B.K., Chung, S.H., Chen, J., Avise, J., Rosenblatt, R.A.,
51   Fenske,R.A., 2010; Tagaris *et al.*, 2009), although the projected effects are not consistent across studies (Selin *et al.*,
52   2009). Ozone-related cardiopulmonary and respiratory mortality is also projected to increase in the U.S. (Bell *et al.*,
53   2007; Jackson, J.E., Yost, M.G., Karr, C., Fitzpatrick, C., Lamb, B.K., Chung, S.H., Chen, J., Avise, J., Rosenblatt,
54   R.A., Fenske,R.A., 2010), Globally, ozone-related mortality is projected to increase by the 2050s. Under a scenario

1   in which present air quality legislation is rolled out everywhere, projected premature ozone-related mortality could
2   decrease, particularly in Africa, South Asia and East Asia. Under a maximum feasible reduction A2 scenario, it is
3   projected that 460,000 premature ozone-related deaths could be avoided in 2030, mostly in South Asia, from a
4   substantial decrease in ozone levels in these areas (West *et al.*, 2007).
5
6   A study that investigated regional air quality in the United States in 2050, using down-scaled climate models,
7   concluded there would be about 4000 additional annual premature deaths due to exposures to PM2.5 (Tagaris *et al.*,
8   2009). Air pollutant-related mortality increases are also projected for Canada but in this case are largely driven by
9   the effects of ozone (Cheng *et al.*, 2011). Both ozone and particulate matter-related health impacts vary greatly from
10 one location to another, within any country (Selin *et al.*, 2009; Tagaris *et al.*, 2009).
11
12 A study of the interaction between CO_2, ozone, and PM and compared pre-industrial levels of ozone and PM to
13 those of the present day. Increasing concentrations of CO_2 were associated with higher concentrations of ozone and
14 PM on the local level, leading to an estimated 1.1% increase in mortality per degree temperature increase over the
15 baseline rate (Jacobson, 2008). Approximately 40% of the increase in mortality was attributable to ozone and 60%
16 to PM, with impacts most apparent in locations with poorer air quality and higher population densities (Jacobson,
17 2008)..The study concluded that restrictions of local and global CO_2 emissions may reduce exposure of local and
18 regional populations to elevated levels of PM, ozone, and other health-damaging co-pollutants.
19
20
21 ***11.5.6.   Diarrheal Diseases***
22
23 Since 2006, there has been only one major study estimating future climate-related diarrhea risk (Kolstad and
24 Johansson, 2011) (see Table 11-3). For the period to 2030, the authors project an increase of the risk of diarrhea of
25 8-11%, which is consistent with the estimate of 8-9% of WHO (World Health Organization, 2008). For the periods
26 2040-69 and 2070-99, Kolstad and Johansson projected risk increases of 15-20% and 22-29% respectively.
27
28 [INSERT TABLE 11-3 HERE
29 Table 11-3: Projected relative risk of diarrhea relative to the baseline period of 1961-1990, SRES A1B, the
30 information of 19 climate models was combined. Source: (Kolstad and Johansson, 2011).]
31
32
33 ***11.5.7.   Heat and Cold***
34
35 Health effects related to changes in temperature are expected be both detrimental and beneficial (see summary Table
36 11-5). Under predicted climate change scenarios, heat waves will likely increase in frequency and intensity and
37 worsen heat-related exposures, although acclimatization and improvements in energy efficiency may mitigate some
38 of these effects(Bi and Parton, 2008; Hanna *et al.*; Wilkinson *et al.*, 2007; Wilkinson *et al.*, 2007). In Australia, the
39 number of "dangerously hot" days, when core body temperatures may increase by $\geq$ 2ºC and outdoor activity is
40 hazardous, is forecast to rise from the current 4 to 6 days per year to 33-45 days per year by 2070 for non-
41 acclimatized people. Among acclimatized people, an increase from 1-5 days per year to 5-14 days per year is
42 expected (Hanna *et al.*). If the proportion of elderly increases, as expected in most countries, this will add to
43 vulnerability to extreme heat (Luber and Hess, 2007).
44
45 Cold-related mortality is expected to drop in temperate regions but the increase in heat-related mortality may
46 outweigh these gains, especially in developing countries with limited adaptive capacities and much larger exposed
47 populations (Wilkinson *et al.*, 2007) . Model predictions in three Quebec cities predict an increase in summer
48 mortality of 2% and an annual overall mortality rise of 0.5% by 2020. By 2080, summer mortality is predicted to
49 rise to 10% and annual mortality to 3% compared to current rates, which will outweigh predicted fall and winter
50 decreases (Doyon *et al.*, 2008). Another study, using years of life lost as the outcome, and located in Brisbane,
51 Australia, found the gains associated with fewer cold days were outweighed by the effects of more hot days when
52 warming exceeded 2 degrees. (Huang *et al.*, 2012) The same trend is echoed in a study modeling heat-related
53 premature mortality in the New York City Metropolitan region. By the 2050's, an increase in premature mortality
54 between 47-95% with a mean increase of 70% is expected, compared to the 1990's (Knowlton *et al.*, 2007).

1   Acclimatization may reduce the expected number of summer heat-related premature mortality regionally by up to
2   25%. Urban areas are expected to show greater numbers of deaths due to population density but an overall smaller
3   percentage increase than less-urbanized counties (Knowlton *et al.*, 2007). Socioeconomic status may also play a role
4   in the uneven distribution of heat-related deaths as households that live in poverty or in older residential
5   neighborhoods in New York City often do not have air conditioning, which can increase mortality risk. Thus,
6   despite the uncertainty associated with forecasts regarding climate and future health vulnerability, as well as the
7   expected reduction in mortality estimates from acclimatization, research still suggests an overall net increase in heat-
8   related premature mortality (Knowlton *et al.*, 2007).
9
10   [INSERT TABLE 11-4 HERE
11   Table 11-4: Studies projecting heat mortality due to climate change since 2006: Authors, scenarios and climate
12   models used, time period for model baseline (turquoise) and date or period of projection. Modified from (Huang *et*
13   *al.*, 2011).]
14
15   Goslin et al. (Gosling *et al.*, 2009)refined this modeling approach by including not only changes of the annual mean
16   temperatures but also of its variability, which certainly comes closer to the physiological impact of heat which is
17   dependent not only on absolute temperature, but also on the acuity and duration of heat-waves.
18
19   [INSERT TABLE 11-5 HERE
20   Table 11-5: Projected future health impact of climate change through cold and health.]
21
22   For all the six cities the authors examined-Boston, Budapest, Dallas, Lisbon, London and Sidney-, two conclusions
23   can be drawn (i) projections of heat mortality is very much influenced by the choice of the scenario, A2 consistently
24   generating a higher death toll; (ii) Adding variability to level of temperature increases heat-related mortality
25   substantially: underlying the A2 scenario increases estimates for heat-related mortality attributed to climate change
26   from the present (1961-90) 35.8/100,000 to 140.5/100,000 in the future (2070-2099).
27
28
29   ***11.5.8.   Work-Related Heat Stress***
30
31   Climate change is projected to increase the health burden for those working in hot environments (Kjellstrom et al,
32   2009). Mapping of future heat exposures in Northern Africa, for instance, indicates the very difficult work
33   conditions that will emerge in the hot afternoons of the hottest months (Kjellstrom and Crowe, 2011). Maps of
34   occupational heat based on future WBGT increases by 3 degree C (Hyatt *et al.*, 2010) offer a guide to adaptation
35   measures.
36
37   Estimates of the effects in the 2050s on work productivity (Kjellstrom *et al.*, 2009a) found that in all of the 21 global
38   regions there would be an annual loss of fully productive work hours due to heat stress if the workforce distribution
39   and occupational health programs remained at current levels. The proportion of work days lost due to heat was as
40   high as 15-18 % in South-East Asia, West and Central Africa and Central America (Kjellstrom *et al.*, 2009a) . If
41   workforce distributions include fewer people in agriculture and more in services, the estimated work days lost will
42   be less, in the range 3-4 % in most of these regions (Kjellstrom *et al.*, 2009a) . A more detailed regional analysis of
43   occupational heat stress health and productivity impacts until 2030 and 2050 was recently completed (Kjellstrom et
44   al., 2012, in press). It is based on global grid cell (0.5 x 0.5 degrees, 90,000 cells) climate analysis and newly
45   assessed exposure-response relationships for clinical heat stroke effects as well as heat induced work capacity
46   losses. Even after taking likely changes in workforce distributions into account, the likely additional numbers of
47   occupational heat stress fatalities may be 12,000 – 30,000 in 2030 and 26,000 – 54,000 in 2050 (Kjellstrom et al.,
48   2012, in press). Non-fatal heat strokes at work may be twice these numbers. People in heavy labor jobs outdoors in
49   the hot sun are most affected (from 10% work days lost due to heat, increasing to 20% lost in 2050), highlighting the
50   negative effect on health and well-being equity that these trends in occupational heat stress will have.
51
52   In summary, recent analysis of future occupational risks due to excessive workplace heat exposure linked to climate
53   change projects substantial impacts on both occupational heat stroke numbers and work productivity in the hottest
54   regions of the world.

1
2
3   *11.5.9.   UV-Induced Skin Cancers*
4
5   Other health effects that might be associated with future climate changes are a rise in chronic disease incidence and
6   severity. Sun-induced skin cancers have been predicted to rise from mice experiments when the combined effects of
7   ozone depletion, climate change and a rise in ambient temperature are taken into account (van der Leun *et al*., 2008)
8   .This effect may slow down the progress in reducing carcinogenic UV-B radiation in the wake of the Montreal
9   protocol (West *et al*., 2007) .
10
11
12   *11.5.10. Conclusion*
13
14   There are few studies modeling the health impacts of climate change, particularly in low and middle income
15   countries, and greater efforts are required to improve the research base for policy makers. Future work should
16   examine closely the roles of economic growth as confounding factor and effect modifier in the climate change and
17   health relation. The relative attribution of the burden of disease to climatic and non-climatic drivers is likely to
18   remain a challenge. A promising complementary approach to tease out the relative importance of climate change to
19   disease burden would be using large population cohorts, particularly in low and middle-income countries.
20
21
22   **11.6.   Adaptation to Protect Health**
23
24   Adaptation is modification of natural or human systems in response to actual or expected climate changes and their
25   effects. It may be deliberate, "planned adaptation", or result from autonomous feedbacks that involve no explicit,
26   human decision-making.
27
28   The importance of adaptation is demonstrated by the recent history of natural disasters, and their impacts on
29   population health. For example, when cyclone Bhola (category 3 in severity) hit East Pakistan (present day
30   Bangladesh) in 1970, more than 500,000 people died. Then in 1991 a cyclone of similar severity caused about
31   140,000 deaths. In November 2007, cyclone Sidr (category 4) resulted in 5-10,000 deaths, although the population
32   of the country had grown by more than 30 million in the intervening period. (Mallick *et al*., 2005) Bangladesh
33   achieved this remarkable reduction in disaster mortality through effective collaborations between government, local
34   communities and non-governmental organizations. (Khan, 2008) Alongside improving the general education of the
35   population (which has been greatly assisted by rising literacy rates, especially among women), the country deployed
36   early warning systems and built a network of cyclone shelters. Early warning systems included both high technology
37   information systems and relatively simple measures such as training volunteers who could distribute warning
38   messages by bicycle.
39
40   The scientific literature on adaptation to climate change has expanded greatly since AR4, but investment in specific
41   health protection activities is growing less rapidly. A review by the World Health Organization in 2012 estimated
42   that commitments to health adaptation internationally amount to less than 1% of the annual health costs attributable
43   to climate change by 2030. (World Health Organization, 2012) In this section we will concentrate on planned
44   adaptations, including what might be described as "generic" adaptation, and interventions designed specifically to
45   reduce the adverse impacts of climate change.
46
47
48   *11.6.1.   General Adaptations*
49
50   Climate change acts as a multiplier of risk – in most instances, changes in temperature, rainfall and extreme events
51   compound health problems that are already present. Where rates of diarrheal disease among children are already
52   high, for instance, rising temperatures will have much greater effects than in populations where children are seldom
53   affected. One recent review concluded that the baseline health status of a population is probably the single most
54   important predictor of both the future health impacts of climate change, and the costs for that country of adapting.

1   (Pandey, 2010) This means that reducing background rates of disease and injury is an important step to improving
2   population resilience and minimizing poor health outcomes resulting from climate change.
3
4   Improvements in basic public health functions such as disease surveillance, monitoring of risky exposures, and
5   coordination between health and other sectors also constitute adaptation. (Woodward *et al.*, 2011) A United States
6   review picked out ten "essential public health services" of this kind that underpin coping with the risks associated
7   with climate change (Frumkin H., Hess J., Luber G., Malilay J.,McGeehin M., 2008) For example, food safety in a
8   time of rising temperatures and extremes in rainfall depends on well-functioning links between human health and
9   veterinary authorities, integrated monitoring of food-borne and animal diseases and improved detection methods to
10 pick up pathogens and contaminants in food. (Tirado *et al.*, 2010) In Lusaka, Zambia the incidence of cholera rises
11 sharply following heavy rainfall, but the risk is much less in parts of the city with effective drainage networks.
12 (Sasaki *et al.*, 2009)
13
14 Better access to health care is another example of "generic" adaptation. In Benin, one of the measures that is
15 proposed as part of the response to sea level rise and floods is expanded health insurance arrangements, so that
16 diseases that may be aggravated by climate change (malaria, enteric infections) can be treated promptly and
17 effectively. (Dossou and Glehouenou-Dossou, 2007)
18
19 Other sectors than health care play an important part in protecting against disease and injury resulting from climate
20 change. EuroHEAT, a European review of public health responses to extreme heat, reported that transport policies,
21 building design and urban land use are all important elements of national and municipal heat-health action plans.
22 (World Health Organization, 2009a) In the United States, a study examined well-established interventions to reduce
23 the urban heat island effect (replacing bitumen and concrete with more heat-reflective surfaces, and introducing
24 more green spaces to the city) and estimated these would reduce heat-related emergency calls for medical assistance
25 by almost 50%. (Silva *et al.*, 2010) (Adaptation priorities may depend on the location – a study in London, UK,
26 found that built forma and other dwelling characteristics had a stronger influence on indoor temperatures during heat
27 waves than the urban health island effect. (Oikonomou and Wilkinson, 2012)) But in general, urban green spaces
28 lower ambient temperatures, and also improve air quality, provide shade and may be good for mental health. (van
29 den Berg *et al.*, 2010) A more variable climate is expected to increase the risk of child under-nutrition in some parts
30 of the world, but a review of food aid programmes indicates that a rapid response, targeted to those in greatest need,
31 with flexible financing and the capacity to rapidly scale-up depending on need, may reduce damaging health
32 consequences. (Alderman, 2010)
33
34 Migration is a common coping strategy in the face of adverse changes in climate, and may itself have significant
35 effects on health, both positive and negative. Within the Pacific there has been migration from outer islands to urban
36 centres, in part at least due to environmental pressures, and this has improved economic and educational
37 opportunities for some. But there is a cost in infectious diseases and other health problems caused by crowding
38 associated with a lack of adequate water supplies, waste disposal and housing. (Locke, 2009) Large numbers of
39 Pacific islanders have also moved to countries around the Pacific rim and comparisons of the health of migrants and
40 peers in the islands show mixed effects (higher levels of risk factors such as raised blood pressure and cigarette
41 smoking among migrants, but also lower mortality rates overall and higher life expectancies). Climate-related
42 migration includes both the movements of population between countries, and within-country shifts, such as flows to
43 cities from drought and heat affected rural areas. (Acosta-Michlik *et al.*, 2008) Where people choose to live may
44 reflect a complex balancing of risks and benefits. A study in Indore in India found that low-income households were
45 willing to live in flood-prone areas because of other advantages provided by these sites, including access to health
46 care (and low-cost housing). (United Nations Human Settlements Programme, 2011)
47
48 There are many effects of community organization that are pertinent to climate change adaptation. In the
49 Philippines, for example, interventions in low-income urban settings include savings schemes, small-scale loans,
50 hygiene education, local control and maintenance of water supplies, and neighbourhood level solid waste
51 management strategies. (Dodman *et al.*, 2010) All these have the potential to reduce harmful effects of climate
52 extremes on health.
53
54

1   *11.6.2. Specific Adaptations*
2
3   *11.6.2.1. Early Warning Systems*
4
5   Early warning systems have been developed in many areas as a means of alerting public health authorities to
6   climate-related health risks.
7
8   Heat-health warning systems (HHWS) are instruments to prevent negative impacts of the thermal environment on
9   health during heat waves. Weather forecasts are used to predict situations that are associated with an increase in
10   mortality or morbidity. The essential and common components of HHWS are identifying weather situations that
11   adversely affect human health, monitoring weather forecasts and activating mechanisms for issuing warnings. Ebi et
12   al (Ebi *et al.*, 2004) estimate that the Philadelphia Hot Weather Health Watch Warning System saved about 177
13   deaths in 3 years, at a cost of approximately $210,000. Few papers have been published since 2006 on the
14   effectiveness of HHWS on mortality or morbidity – the most informative are listed in Table 11-6. Heat warning
15   systems appear to be effective in raising awareness of the risks associated with heat waves, although whether this
16   extends to behavioral changes is less certain. However, when combined with other elements of a health protection
17   plan, as in France after the 2003 heat wave (Fouillet *et al.*, 2008), it is apparent that the impacts of extreme heat can
18   be greatly reduced by deliberate and focused interventions.
19
20   [INSERT TABLE 11-6 HERE
21   Table 11-6: Studies of the effectiveness of heat-health warning systems.]
22
23   Early warning systems have also been developed on the basis of predictive models for vector-borne and food-borne
24   infections. In Botswana, forecasts of malaria incidence up to 4 months ahead have been made on the basis of
25   observed rainfall, on the basis of evidence that inter-annual and seasonal variations in climate are associated with
26   outbreaks of malaria in this part of Africa. The outputs from the model include probability distributions of disease
27   risk and measures of the uncertainty associated with the forecasts. (Thomson *et al.*, 2006) The incidence of several
28   bacterial enteric infections is known to vary with ambient temperature, (Fleury *et al.*, 2006) and this information has
29   been used to develop health alerts based on projected temperatures. A study of campylobacteriosis in the United
30   States developed models of monthly disease risk that showed a very good fit in validation data sets (R^2 up to 80%).
31   (Weisent *et al.*, 2010)
32
33
34   *11.6.2.2. Vulnerability Mapping*
35
36   Remote sensing applications are now sufficiently fine-grained to allow mapping of local factors associated with
37   vulnerability to climate, and guide the allocation of interventions to reduce exposures and/or impacts. For instance,
38   these technologies can be used to map surface temperatures and urban heat island effects at the neighbourhood scale,
39   indicating where city greening and other urban cooling measures should be concentrated, and alerting public health
40   authorities to populations that may be at greatest risk of heatwaves. (Luber and McGeehin, 2008) Mapping at a
41   coarser level, for instance regionally, may also be useful to guide adaptation. In Portugal, modelling of Lyme
42   disease, spread by ticks that are sensitive to ambient temperatures and soil moisture, indicates that future conditions
43   will be less favourable for disease transmission in the south, but more favourable in the centre and northern parts of
44   the country. (Casimiro *et al.*, 2006) Ideally, mapping exercises of this kind might also take account of climate
45   sensitivity and adaptation capacity, in addition to climate exposures, to capture a complete picture of vulnerability.
46   An example of this approach is an assessment of climate change and risk of poverty in Africa. (Thornton *et al.*,
47   2008)
48
49
50   *11.6.2.3. Public Education*
51
52   Much of the adaptation to climate change to protect health happens at the neighbourhood and community levels.
53   Information, education and engagement of populations is essential to mobilizing community resources and
54   responding appropriately to natural disasters. For example, the 1997-98 El Nino event resulted in severe drought

1   across much of the Pacific. In some islands, this caused serious health problems (diarrhoeal diseases, malnutrition).
2   However it was noted in Pohnpei in the Federated States of Micronesia that admissions of children to hospital for
3   diarrhoeal disease did not rise. It is thought this may be due in part to an effective public education campaign to alert
4   families to the risks of water-borne diseases. (Ebi *et al*., 2006) In the summer of 2006, France was affected by the
5   most severe high temperatures that had occurred since the serious heat-wave of 2003. About 2000 excess deaths
6   were recorded in the 2006 heat-wave, but this was about 4000 less than was anticipated, on the basis of the
7   experience in 2003. A national assessment attributed the lower than expected death toll to greater public awareness
8   of the health risks due to heat, as well improved health care facilities and the introduction, in 2004, of a heat health
9   watch warning system. (Fouillet *et al*., 2008),
10
11
12   *11.6.2.4. Health Care*
13
14   Health care interventions aimed at primary prevention may reduce harm caused by climate and other environmental
15   stressors. As one example, following the introduction of vaccination programmes in the US, seasonal outbreaks of
16   illness caused by rotavirus, a common climate-sensitive pathogen, have been delayed and diminished in magnitude.
17   (Tate *et al*., 2009) Post-disaster initiatives are important also. Studies of the severe European heat-waves of the early
18   2000s showed that there were serious deficiencies in many countries in care of those affected by extreme
19   temperatures. The EuroHEAT assessment has since recommended a number of practical steps that health services
20   can take to reduce morbidity and deaths caused by heat. Examples include staff planning over the summer period,
21   cooling of health care facilities, training of staff in recognition and treatment of heat strain, and monitoring of those
22   in the highest risk population groups. (World Health Organization, 2009a) In a similar vein, there have been many
23   studies carried out on the effects of Hurricane Katrina in the US, and what improvements need to be made in order
24   to deal more effectively with large-scale floods and storms in the future. Diabetes care, for example, was
25   compromised following Katrina by a lack of blood glucose testing kits, insulin and other diabetes medications, and
26   calls have been made for these, and similar essential medical supplies for care of individuals with chronic
27   conditions, to be better stockpiled and more rapidly and appropriately distributed post-disaster. (Cefalu *et al*., 2006)
28   The costs of these, and other health adaptation strategies, are not well described. Ebi (Ebi, 2008) estimated that the
29   costs in 2030 of treating additional cases of diarrheal diseases, stunting and wasting, and malaria, if emissions were
30   stabilized at 750 ppm CO2-equivalent, would be between $4 and $12 billion.
31
32
33   **11.7.   Health Co-Benefits**
34
35   Essentially every human activity affects (and is affected by) climate and health in some way, but not all are strongly
36   linked to either and even fewer to both. Some measures to mitigate the atmospheric concentration of warming CAPs
37   (climate active pollutants), however, also hold the potential to significantly benefit human health ((Apsimon *et al*.,
38   2009; Haines *et al*., 2007; Shindell *et al*., 2012; Smith and Balakrishnan, 2009; UNEP, 2011)).The health co-
39   benefits associated with climate change mitigation strategies fall into five categories (Smith *et al*., 2009; Smith and
40   Balakrishnan, 2009): (1) Reduction of health-damaging co-pollutants; (2) Increases in active transport from
41   modifications to the built environment; (3) Increases in urban green-space; (4) Decreases in ruminant meat
42   consumption; (5) Increased access to reproductive services. In addition, there are also side effects of mitigation
43   measures including geoengineering that are potentially deleterious for human health, which are addressed in WGIII,
44   chapter x and y.
45
46   In Table 11-7, we summarize publications in all five categories, and below provide some additional detail for three
47   categories.
48
49   [INSERT TABLE 11-7 HERE
50   Table 11-7: Summary of recent research on co-benefits of climate change mitigation.]
51
52
53

1   *11.7.1. Reduction of Co-Pollutants*
2
3   Most of the publications related to CAPs and health-damaging pollutants relate to fuel combustion and fall into two
4   major categories: 1) improvement in energy efficiency will reduce emissions of CO_2 and health-damaging pollutants
5   if the energy is derived from combustion of fossil fuels or non-renewable biomass fuels, either directly or through
6   the electric power system; in addition, 2) increases of combustion efficiency (decreasing emission of incomplete
7   combustion products) will have both climate and health benefits, even if there is no change in energy efficiency
8   and/or fuel itself is renewable, i.e. carbon neutral. This is because a number of the products of incomplete
9   combustion are climate active and nearly all are damaging to health (Smith and Balakrishnan, 2009).
10
11 Studies of the health co-benefits of reduction in air pollutants include sources that produce outdoor air pollution
12 (Bell *et al.*, 2008) and household sources (Po *et al.*, 2011) where much of the pollution exposure occurs indoors. In
13 recent years, however, it has become clear that in many parts of the world, household fuel (poorly combusted
14 biomass and coal) is responsible for a substantial percent of primary outdoor fine particle pollution as well, perhaps
15 a third to a half in China and India, for example (Chafe et al. submitted) indicating that reductions in emissions from
16 household sources could yield co-benefits through the outdoor pollution pathway as well.
17
18
19 *11.7.1.1. Outdoor Sources*
20
21 Outdoors, health-damaging pollutants can be separated into two categories -- primary and secondary. Primary co-
22 pollutants, such as particulate matter (PM) and carbon monoxide (CO) are those released at the point of combustion,
23 while secondary co-pollutants, such as tropospheric ozone and sulphate particles, are formed downwind from the
24 combustion source via atmospheric chemical interactions (Jerrett *et al.*, 2009). As noted in Section 11.2, outdoors,
25 the production and distribution of some secondary co-pollutants is exacerbated by temperature-associated attributes
26 of climate change itself, thus posing a positive feedback effect.
27
28 The burden of disease from outdoor exposures in a country may often be greater in populations with low
29 socioeconomic status, both because of living in areas with higher exposures and because these populations often
30 have greater pre-existing ill-health and are often subjected to multiple additional negative environmental and social
31 exposures (Morello-Frosch *et al.*, 2011).
32
33
34 *11.7.1.2. Household Sources*
35
36 Globally, the largest exposures from the pollutants from poor fuel combustion occur in the poorest populations. This
37 is because household use of biomass for cooking is distributed nearly inversely with income. Essentially, no poor
38 family can afford gas or electricity for cooking and very few families who can afford to do so, do not. Thus, the
39 approximate 41% of all world households using solid fuels for cooking are all among the poor in developing
40 countries (Adair, submitted).
41
42
43 *11.7.1.3. Primary Co-Pollutants*
44
45 Outdoor exposure to PM, especially to particles with diameters less than 2.5 μm ($PM_{2.5}$), contributes significantly to
46 ill-health including cardio- and cerebrovascular disease, chronic and acute respiratory illnesses, lung cancer, and
47 possibly other diseases.The WHO Comparative Risk Assessment for outdoor air pollution found xx [to be updated
48 with new results in 2012].Importantly, reductions in ambient PM concentrations have also been shown to decrease
49 morbidity and premature mortality (Boldo *et al.*, 2010).
50
51 Because of higher exposures, an additional set of diseases has been associated with combustion products in
52 households burning biomass and/or coal for cooking and heating. Thus, in addition to the diseases noted above,
53 cataracts, low birth weight, and stillbirth have been associated strongly with exposures to incomplete combustion
54 products, such as PM and CO. CO has impacts on unborn children in utero through exposures to their pregnant

1   mothers (WHO, 2010b) .There is also growing evidence of exacerbation of tuberculosis (Pokhrel *et al.*, 2010) in
2   adults and cognitive effects in children (Dix-Cooper *et al.*, 2012). The WHO Comparative Risk Assessment found
3   xxx [to be updated with new results in 2012]. Importantly, there are also studies showing health benefits of
4   household interventions, including child pneumonia (Smith *et al.*, 2011), blood pressure (Baumgartner *et al.*, 2011;
5   McCracken *et al.*, 2007), lung cancer (Lan *et al.*, 2002), and chronic obstructive pulmonary disease (Chapman *et al.*,
6   2005).
7
8   Black carbon (BC), a primary product of incomplete combustion, is both a strong CAP and health-damaging (IPCC,
9   2007; Ramanathan and Carmichael, 2008). A systematic review, meta-analysis, and the largest cohort study to date
10   of the health effects of BC found that there were probably stronger effects on mortality from exposure to EC than for
11   undifferentiated fine particles (PM$_{2.5}$) (Smith *et al.*, 2009).The conclusion is that BC abatement represents an
12   opportunity to achieve both climate mitigation and health benefits, a conclusion shared by other recent reviews as
13   well (UNEP, 2011).
14
15
16   *11.7.1.4.Secondary Co-Pollutants*
17
18   Small increases in tropospheric ozone can cause ill-health (see 11.2.8). In addition to being a strong CAP, methane
19   (CH$_4$) is also a significant precursor to regional anthropogenic tropospheric ozone production, which itself is a CAP.
20   Thus, reductions in CH$_4$could lead to reductions in ambient tropospheric ozone concentrations, which in turn could
21   result in reductions in population morbidity and premature mortality and climate forcing (Figure 11-11).
22
23   [INSERT FIGURE 11-11 HERE
24   Figure 11-11: Avoided global premature mortalities from a 65 mt-yr^{-1} CH$_4$ emission reduction, beginning in 2010.
25   Cited from (West *et al.*, 2006).]
26
27   One study found that a reduction of global anthropogenic CH$_4$ emissions by 20% beginning in 2010 could decrease
28   the average daily maximum 8-h surface ozone by 1 ppb by volume, globally (West *et al.*, 2006).When they applied
29   epidemiologic ozone mortality relationships, a reduction of 1 ppb ozone was estimated to prevent 30,000 premature
30   all-cause mortalities globally in 2030, and 370,000 between 2010 and 2030.When they considered only
31   cardiovascular and respiratory mortalities, 17,000 deaths globally were found to be avoidable in 2030 (West *et al.*,
32   2006). CH$_4$ emissions are generally accepted as the primary source of tropospheric ozone concentrations above other
33   ozone precursors (West *et al.*, 2007) and thus, the indirect health co-benefits of CH$_4$ reductions are
34   epidemiologically significant.
35
36   In an analysis of ozone trends from 1998-2008 in the United States, Lefohn et al. (Lefohn *et al.*, 2010) found that 1-
37   hour and 8-hour ambient ozone averages have either decreased or failed to increase due to successful regulations of
38   ozone precursors, predominantly NO$_x$ and CH4 (Lefohn *et al.*, 2010).This analysis agrees with the US EPA (US
39   EPA, 2009) conclusions that in the US, for the period 1980-2008, emissions of nitrogen oxides and volatile organic
40   compounds fell by 40% and 47%, respectively (Lefohn *et al.*, 2010; US EPA, 2009).These results point to the
41   effectiveness of reducing ambient ozone concentrations through regulatory tools that reduce the emissions of ozone
42   precursors, some of which, like CH$_4$, are GHGs.
43
44
45   *11.7.1.5.Case Studies of Co-Benefits of Air Pollution Reductions*
46
47   A recent UNEP- and WMO-led study of black carbon and tropospheric ozone found that, if all of 400 proposed BC
48   and CH4 mitigation measures were implemented on a global scale, the estimated benefits to health would come
49   predominately from reducing PM2.5 (0.7 – 4.6 million avoided premature deaths; 5.3 – 37.4 million avoided years
50   of life lost) compared to tropospheric ozone (0.04 – 0.52 million avoided premature deaths; 0.35 – 4.7 million
51   avoided years of life lost) based on 2030 population figures (UNEP, 2011). An estimated 98% of the estimated
52   avoided deaths would come from reducing PM2.5, with 80% of the estimated health benefits occurring in Asia
53   (Anenberg *et al.*, 2012).
54

1   A study of the benefits of a hypothetical 10-year program to introduce advanced combustion cookstoves in India
2   found that in addition to reducing premature mortality by about 2 million and DALYs by 55 million over that
3   period, there would be reduction of 0.5-1.0 billion tons CO2-eq (Wilkinson *et al.*, 2009).
4
5   In their estimation of effects of hypothetical physical and behavior modifications in UK housing, Wilkinson and
6   colleagues (Wilkinson *et al.*, 2009) found that the magnitude and direction of implications for health depended
7   heavily on the details of the intervention. However, the interventions were found to be generally positive for health.
8   In a strategy of housing modification that included combined fabric, ventilation, and fuel switching, along with
9   behavioral changes, it was estimated that 850 fewer DALYs, and a savings of 0.6 megatonnes of CO_2 per million
10   population in one year could be achieved. These calculations were made by comparing the health of the 2010
11   population with and without the specified physical and behavioral modifications (Wilkinson *et al.*, 2009).
12
13   Markandya *et al.*,(Markandya *et al.*, 2009) assessed the changes in emissions of $PM_{2.5}$ and subsequent effects on
14   population health that could result from climate change mitigation measures aimed to reduce GHG emissions by
15   50% by 2050 (compared with 1990 emissions) from the electricity generation sector in the EU, China, and India
16   (Markandya *et al.*, 2009). In all three regions, changes in modes of production of electricity to reduce CO_2 emissions
17   were found to reduce $PM_{2.5}$ and associated mortality. The greatest effect was found in India and the smallest in the
18   EU. The analysis also found that health benefits greatly offset the cost of GHG emission reductions, especially in the
19   Indian context where emissions are high but costs of implementing the measures are low (Markandya *et al.*, 2009).
20
21
22   ***11.7.2.   Ruminant Meat Consumption***
23
24   Livestock production systems are responsible for approximately one-fifth of all human-caused CAP emissions
25   (Eshel and Martin, 2006; FAO, 2006; McMichael *et al.*, 2007) with four-fifths of those emissions being generated
26   by the agricultural sector (Friel *et al.*, 2009). These CAP emissions are predominantly in the form of CH_4 emissions
27   from the animals or indirectly through growing the animal feed and processing/shipping the livestock products. Red
28   meat consumption from ruminants (cows, sheep, goats) in turn is associated with higher rates of cancers (including
29   bowel cancer) and cardiovascular disease(Pan *et al.*, 2012; Sinha *et al.*, 2009). It is also associated with obesity and
30   other cancers (WHO/FAO, 2003AO 2003). On the other hand, lack of protein and the micronutrients in meat (e.g.,
31   iron) are still problems in many poor countries (UN, 2008).
32
33   McMichael et al. (McMichael *et al.*, 2007) found that policies to reach a per capita convergence on 90 grams of
34   meat with not more than 50 grams of red meat per day from ruminants (i.e., cattle, sheep, goats, and other digastric
35   grazers) could achieve major health benefits globally, in both developed and developing countries, while
36   significantly reducing CAP emissions. As of 2007, the global average for meat consumption was 100 g per person
37   per day, with about a ten-fold variation between developed (200-250 g/day) and developing (25-50 g/day) countries
38   (McMichael *et al.*, 2007). The proposed shift would be approximately halve global red meat consumption and
39   distribute it more evenly. Among more developed countries where red meat consumption is especially high,
40   reductions to 90 g/day might reduce the risk of heart disease, stroke, colorectal cancer, breast cancer and
41   overweight/obesity (McMichael *et al.*, 2007). In addition, in poor populations, an increase in meat protein
42   consumption would have health benefits.
43
44   Friel et al. (Friel *et al.*, 2009) analyzed the red meat consumption target recommended by the UK Committee on
45   Climate Change to reduce UK GHG emissions by 80% by 2050 compared to 1990, which would require a 50%
46   reduction by 2030. One component of this climate change mitigation portfolio was a 30% reduction in livestock
47   production through a decrease in meat consumption. Assuming these reductions, the UK and in Sao Paulo, Brazil
48   were compared using data to model the potential benefits of reduced consumption of livestock products on the
49   burden of ischaemic heart disease. The burden of IHD would be expected to decrease by approximately 15% in the
50   UK (equivalent to 2,850 DALYs per million population over one year) and 16% in Sao Paulo city (equivalent to
51   2,180 DALYs per million population over one year) (Friel *et al.*, 2009).
52
53
54

1   *11.7.3.   Access to Reproductive Services*
2
3   Population growth is another factor involved in the consumption of resources and emissions of CAPs. Although
4   population growth rates and total population size do not alone determine emissions (WG1), population size is an
5   important factor. One study showed that CO_2 emissions could be lower by 30% by 2100 if access to contraception
6   were provided to those women expressing a need for it (O'Neill *et al.*, 2010). Slowing population growth through
7   lowering fertility, as might be achieved by increasing access to family planning has been associated with improved
8   maternal and child health in two main ways: increased birth spacing and reducing births by very young and old
9   mothers.
10
11
12   *11.7.3.1.Birth and Pregnancy Intervals*
13
14   Current evidence supports, with moderate confidence, that short birth intervals (defined as birth intervals between
15   <19 and <25 months and inter-pregnancy intervals <6 months) are associated with increased risks of uterine rupture
16   in women attempting a vaginal birth after previous cesarean delivery and uteroplacental bleeding disorders
17   (placental abruption and placenta previa (Bujold *et al.*, 2002; Conde-Agudelo *et al.*, 2007; Huang *et al.*, 2002; Shipp
18   *et al.*, 2001)). Bujold and colleagues (Bujold *et al.*, 2002) reported, in a high quality observational cohort study, a
19   possible dose-response relationship between increased risks of uterine rupture in women with short intervals
20   between births (4.8% for intervals <13 months; 2.7% for intervals 13-24 months; and 0.9% for intervals >24
21   months) (Bujold *et al.*, 2002).
22
23   Several studies indicate correlations between short birth intervals and elevated risk of low-birth-weight ((Adams *et*
24   *al.*, 1997; Basso *et al.*, 1998; Kallan, 1997; Khoshnood *et al.*, 1998; Rawlings *et al.*, 1995). Zhu et al. (Zhu, 2005)
25   found, in a review of three studies performed in the United States that a J-shaped relationship existed between inter-
26   pregnancy spacing in that the lowest risk of adverse birth outcomes (i.e., low birth weight, existed between 18-23
27   months and risk increased as it departed, in either direction (Zhu, 2005). This J-shaped relationship is reported in
28   other studies as well (Rousso *et al.*, 2002).
29
30   Although an ecological analysis, a review across 17 countries shows a strikingly coherent picture of the relationship
31   between birth spacing (as preceding birth intervals), malnutrition, and reductions in child, infant and neonatal
32   mortality (Figure 11-12) with risk of child malnutrition and mortality both increasing with shorter birth intervals
33   (Rutstein, 2005). One study estimated, for example, that shifting birth spacing from current patterns in the world to a
34   minimum of 24 months would reduce by 20% (~2 million) the current excess child mortality in the world (Gribble *et*
35   *al.*, 2009; Rutstein, 2005).
36
37   [INSERT FIGURE 11-12 HERE
38   Figure 11-12: Reduction in child mortality due to increasing spacing of birth based on studies in 17 countries. Cited
39   from (Rutstein, 2005).]
40
41   On the other hand, long inter-pregnancy intervals (between 48 and 60+ months) are independently associated with
42   an increased risk of preeclampsia. In the largest systematic review to date on birth spacing and maternal morbidity
43   and mortality (Conde-Agudelo *et al.*, 2007), the majority of studies reported a likely dose-response relationship with
44   odds ratios increasing with increasing inter-pregnancy or birth interval(Basso *et al.*, 2001; Conde-Agudelo and
45   Belizan, 2000; Mostello *et al.*, 2002).
46
47
48   *11.7.3.2.Maternal Age at Birth*
49
50   Risk of death during delivery is highest in very young and very old mothers, which are also the age groups most
51   wishing to control their fertility (Engelman, 2010).Women who begin child bearing under the age of 20 years are at
52   an increased risk of developing pregnancy complications such as cephalopelvic disproportion, obstructed labor,
53   preterm delivery, toxemia, bleeding, and death (Tsui *et al.*, 2007) Additionally, children born to women under the
54   age of 20 are at an increased with of fetal growth retardation and low birth weight, which can both lead to long term

physical and mental developmental problems. (Tsui *et al.*, 2007) Childbearing at later ages (>35 years) is associated with increased risks for the child of miscarriage, perinatal mortality, preterm birth, low birth weight, congenital and chromosomal abnormalities, and increased risks for the mother of placental previa, gestational diabetes, cesarean delivery and maternal death (Cleary-Goldman *et al.*, 2005; Ujah *et al.*, 2005)

Thus, providing access to family planning saves women's lives by reducing the total number of births and, in particular, through the reduction of births in high-risk groups (Prata, 2009). Studies have found that when women have access to family planning, it is the highest risk age groups (youngest and oldest women) who reduce their fertility most, in other words, family planning has a differential impact on maternal mortality reduction through reducing births in the highest risk groups (Diamond-Smith and Potts, 2011).

11.8.   Conclusions
[here just repeating executive summary]

The health of human populations is sensitive to shifts in weather patterns and other aspects of climate change (very high confidence).
These effects occur directly, due to changing incidence in temperature and humidity extremes and occurrence of floods, storms, droughts, and fires. Indirectly, health may be damaged by ecological disruptions brought on by climate change (crop failures, shifting patterns of disease vectors), or social responses to climate change (such as displacement of populations following prolonged drought). Variability is a risk factor in its own right – it is more difficult to protect human health in a highly variable climate than one that is more stable. There is emerging evidence of non-linearities in response (such as mortality due to heat waves) as climates become more extreme.

To date, climate change has contributed to global burden of disease (highly likely) though the global health effects are relatively small compared with other stressors and not well quantified.
Changes in temperature, rainfall and sea-level have altered distribution of some disease vectors, increased heat wave casualties, and reduced food production for vulnerable populations.

If climate change occurs in the future as projected in scenarios xxx, the major effects on health will be:
- increased risk of under-nutrition resulting from diminished food production
- greater incidence of injury and disease due to more intense heat waves, storms, floods and fires
- some reductions in cold-related injury and disease, but it is not clear how substantial these savings will be, in a more variable climate, and it appears likely that positive outcomes will be exceeded by negative effects of climate change
- increased pressure on disease control systems due to more favourable conditions in many parts of the world for food- and water-borne diseases, and dengue and other vector-borne infections

The most important effect of climate change is to multiply current risks to health.
Although new infections and other conditions may emerge under climate change, the largest risks by far apply to health problems that already exist. This means the most vulnerable populations to climate change impacts, world-wide, are those that currently carry the heaviest burden of disease. In these settings, improvements in public health and health care are important elements of adaptation for climate change.

There are opportunities to mitigate against climate change, and improve health at the same time. These co-benefit actions include:
- Reducing local pollution and emissions of climate altering pollutants (CAPs)from energy production through better combustion, energy efficiency, and shifting to renewables
- Reducing rising trends of livestock production, particularly of ruminants, by shifting diets in rich countries to less red meat and dairy products.
- Reducing CAP emissions by redesigning communities to rely on more public transport and promote physical activity
- Providing access to reproductive services reducing population growth over time and improving child and maternal health through increased birth spacing.

11.9.   Key Uncertainties and Research Recommendations

[to be developed]

Frequently Asked Questions

FAQ 11.1: How is climate change thought to affect human health?
There are three major routes by which changes in climate change are thought to affect health 1) by direct impacts, such as heat stress and floods; 2) by indirect impacts mediated through the natural environment, such as shifts in patterns of disease-carrying mosquitoes and waterborne diseases; and 3) impacts mediated through societal systems, such as malnutrition from altered agricultural production and stress from population displacement due to sea-level rise.

FAQ 11.2: Are there also benefits for health?
Yes, some populations in temperate areas may be at less risk from extreme cold and some populations may benefit from greater agricultural productivity, but the overall impact for nearly all populations and for the world as a whole is expected to be much more negative than beneficial.

FAQ 11.3: Who is most affected?
As climate change mainly acts to exacerbate existing disease patterns and does not create significant new ones, those populations already under stress from disease are likely to be most affected. Thus, most assessments indicate that it is poor and disenfranchised groups everywhere that will bear the most risk and, globally, the greatest burden will fall on poor countries, particularly on poor children, who are most affected today by such climate-related diseases as malaria, malnutrition, and diarrhea.

FAQ 11.4: What is the most important adaptation strategy to reduce the health impacts?
Accelerating current public health and medical interventions directed toward reducing existing disease in the world, particularly for climate-related diseases in poor countries, is the single most important step that can be taken to reduce the health impacts of climate change.

FAQ 11.5: What are health "co-benefits" of climate mitigation measures?
A number of mitigation measures to reduce emissions of climate-altering pollutants (CAPs) seem to have important direct health benefits in addition to reducing the risk of climate change, a relationship called "co-benefits." For example, increasing energy efficiency reduces health-damaging air pollution from fuel combustion; reducing red meat consumption reduces both CAPs and the risk of chronic disease such as cancer; and providing access to reproductive health services slows population and energy demand growth and reduces risks of child and maternal mortality.

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Table 11-1: Number of malnourished children in 2000 and under the NCAR climate model till 2050 using different assumptions for investment in agricultural productivity: + only in developing countries; ++ both in Dev. and developed countries. Adapted from (Nelson *et al.*, 2009).

Scenario	South Asia	East Asia/ Pacific	Eu + Centr. Asia	LA & Carrib.	Middle East/ N.Africa	Sub2-Sah. Africa	Devel. Countr.
2000	75.6	23.8	4.1	7.7	3,5	32.7	147.9
2050							
No climate change	52.3	10.1	2.7	5.0	1.1	41.7	113.3
NCAR	59.1	14.5	3.7	6.4	2.1	52.2	138.5
NCAR + adaptation	54.2	10.1	3.0	4.9	1.4	44.1	118.9
NCAR ++adaptat'n	53.7	10.5	3.0	4.8	1.3	43.5	117.2

Table 11-2: Projected future health impacts of climate change through air pollution.

United States	Ozone-related morbidity and mortality	Multipollutant, multiscale air quality from Community Multiscale Air Quality (CMAQ) Modeling System	GISS-GCM driven by A1B SRES emissions scenario for the period 1950-2055 and downscaled to a 36-km resolution using Mesoscale Meteorological model version 5 (MM5)	Global temperature increase of 1.59°C in 2050, compared to 1990s	Population held constant at 2000 levels	Climate change-driven air quality-related health effects will adversely affect greater than 2/3 of the continental U.S	Potential Impact of Climate Change on Air Pollution-Related Human Health Effects (Tagaris et al. 2009)
	$PM_{2.5}$-related morbidity and mortality	Meteorological data from Goddard Institute for Space Studies (GISS) Global Climate Model (GCM)			Mortality rates held constant at 2000 levels	Approximately 4000 additional annual premature deaths due to climate change impacts on $PM_{2.5}$ compared to 300 due to climate change-induced ozone changes	
		Penn State/NCAR Meso scale Model (MM5 model) used to downscale GISS-GCM outputs to a regional scale			Disease incidence rates held constant at 2000 levels	$PM_{2.5}$ and ozone-related health impacts vary spatially	
		Health effect analysis conducted using U.S. EPA's Environmental Benefits Mapping and Analysis Program (BenMAP)				Increased premature mortality due to elevated ozone concentrations will be offset by lower mortality from reductions in $PM_{2.5}$ in 11 states	
South-central Canada (Montreal, Ottawa, Toronto, Windsor)	air pollution mortality	GCM	GCM downscaled using regression-based statistical method for the periods 2040-2059 and 2070-2089	Air temperature from SRES A2 and B2 scenarios	Population and age structure not directly taken into account	Air pollution-related mortality could increase about 20–30% by the 2050s and 30–45% by the 2080s, projected with climate change	Differential and combined impacts of extreme temperatures and air pollution on human mortality in south-central Canada. Part II: future estimates (Cheng et al. 2008)
						Increase in air pollution-related mortality would be largely driven by increases in ozone effects	
Africa, Middle East, South Asia, Southeast Asia, East Asia, Japan and Australia, Former Soviet Union, Europe, North America, Latin America	Premature ozone-related mortality	GCM	GCM and LMDz-INCA models driven by SRES A2 emissions scenario for 2030	Baseline simulation from 2000	World population of 9.17 billion by 2030	Under current legislation (CLE) scenario, estimated reduction in premature ozone-related human mortalities by 190,000 globally in 2030, mostly in Africa	Human mortality effects of future concentrations of tropospheric ozone (West et al. 2007)
		Laboratoire de Météorologie Dynamique (LMDz)-Interaction Chimie - Aérosols (INCA) chemistry-climate model			Spatial distribution by region based on 2003 population from Landscan database	Under maximum feasible reduction (MFR) scenario, estimated reduction in premature ozone-related human mortalities by 460,000 in 2030, with the greatest reductions in South Asia	
					Constant baseline mortality rates through 2030		

Table 11-3: Projected relative risk of diarrhea relative to the baseline period of 1961-1990, SRES A1B, the information of 19 climate models was combined. Source: (Kolstad and Johansson, 2011).

Region	Time period 2010–2039	2040–2069	2070–2099
A–South America	1.09 (0.04)	1.17 (0.07)	1.25 (0.11)
B–North Africa	1.10 (0.04)	1.19 (0.08)	1.27 (0.11)
C–Middle East	1.11 (0.05)	1.20 (0.08)	1.29 (0.12)
D–Equatorial Africa	1.08 (0.04)	1.15 (0.06)	1.23 (0.10)
E–Southern Africa	1.09 (0.04)	1.18 (0.07)	1.26 (0.11)
F–Southeast Asia	1.08 (0.03)	1.15 (0.06)	1.22 (0.09)

For each time period and each region, data is listed as the mean of the RR projection matrix.

Table 11-4: Studies projecting heat mortality due to climate change since 2006: Authors, scenarios and climate models used, time period for model baseline (turquoise) and date or period of projection. Modified from (Huang *et al.*, 2011).
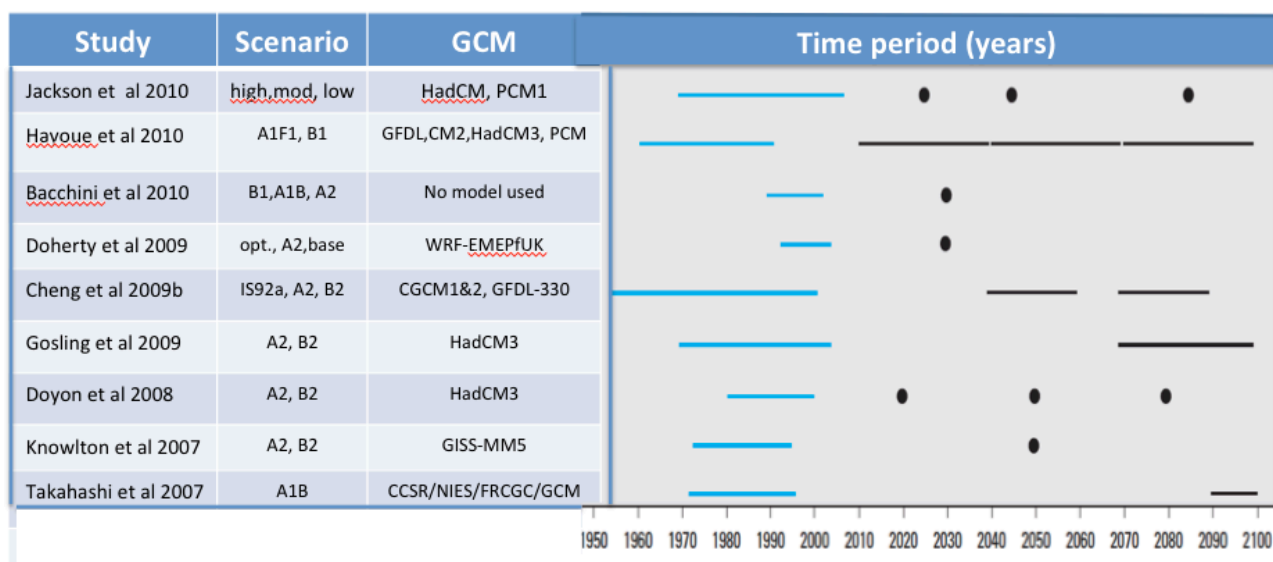

Study	Scenario	GCM	Time period (years)
Jackson et al 2010	high,mod, low	HadCM, PCM1	
Hayoue et al 2010	A1F1, B1	GFDL,CM2,HadCM3, PCM	
Bacchini et al 2010	B1,A1B, A2	No model used	
Doherty et al 2009	opt., A2,base	WRF-EMEPfUK	
Cheng et al 2009b	IS92a, A2, B2	CGCM1&2, GFDL-330	
Gosling et al 2009	A2, B2	HadCM3	
Doyon et al 2008	A2, B2	HadCM3	
Knowlton et al 2007	A2, B2	GISS-MM5	
Takahashi et al 2007	A1B	CCSR/NIES/FRCGC/GCM	

Table 11-5: Projected future health impact of climate change through cold and health.

Area	Health effect	Model	Climate scenario, time slices	Population projections and other assumptions	Reference
South-central Canada (Montreal, Ottawa, Toronto, Windsor)	Mortality	3 Canadian GCMs, 2 US GCMs downscaled	2040-2059 2070-2089	Based on population growth between 1954-200?	Differential and combined impacts of extreme temperatures and air pollution on human mortality in south-central Canada. Part II: Future estimates Cheng et al. 2008
Greater Seattle area in US	Mortalilty	PCMI-B1 HADCM-A1B Composite models	2025 2045 2085 A1B, B1	2005-2030 population projections from Washington Office of Financial Management Projections extended beyond 2030 Population from 2025 a constant in calculation of future excess deaths during extreme heat events	Public health impacts of climate change in Washington State: projected mortality risks due to heat events and air pollution (Jackson, J.E., Yost, M.G., Karr, C., Fitzpatrick, C., Lamb, B.K., Chung, S.H., Chen, J., Avise, J., Rosenblatt, R.A., Fenske,R.A., 2010)
Chicago, Illinois	Mortality	cccma.cgcm3.1 cnrm.cm3 csiro.mk3 gfal.cm2.0 miroc3.2medres mpi.echam5 mri.cgcm2.3.2a	2081-2100 A1, A2, B1		Toward a Quantitative Estimate of Future Heat Wave Mortality under Global Climate Change (Peng *et al.*, 2011)
Chicago	Mortality	GFDL CM2.1 HadCM3 PCM	2000-2099 A1F1, B1		Climate change, heat waves, and mortality projections for Chicago (Hayhoe *et al.*, 2010)
Montreal, Quebec City, Saguenay, Canada	Mortality	GCM	2010-2039 2040-2069 2070-2099 A2, B2		The potential impact of climate change on annual and seasonal mortality for three cities in Quebec, Canada (Doyon *et al.*, 2008)
Gulf contries (Yemen, Oman, UAE, Qatar, Bahrain)	All-cause mortality	HadCM3	2020-2050	Populaton estimates from Population Action International for 2025 and 2050.	Human health risk assessment due to global warming-A case study of the Gulf countries
		CGCM2	2070-2099	Population estimates for 2100 were extrapolated	(Husain and Chaudhary, 2008)
		NCAR-PCM	A2, B2		

California	Mortality		2025		Quantifying the health impacts of future changes in California
			2050		(Ostro *et al.*, 2011)
			A2, B1		
New York City	Mortality	GISS-MM5	2050	Population totals for each of 31 counties in NYC metropolitan region were from the US Census 2000 survey & were held constant throughout modeling period.	Projecting Heat-Related Mortality Impacts Under a Changing Climate in the New York City Region
			A2, B2		(Knowlton *et al.*, 2007)
Boston, Budapest, Dallas, Lisbon, London, Sydney	Mortality	HadCM3			Climate change and heat-related mortality in six cities Part 2: climate model evaluation and projected impacts from changes in the mean and variability of temperature with climate change
					(Gosling *et al.*, 2009)
40 cities in US	Mortalilty	coupled atmospheric-oceanic GCM	2020-2029		
			2045-2055		
			2090-2099		
3 cities in Alabama, US	mortality	CRCM	2041-2050		Estimating the health impact of climate change with calibrated model output
		CHCM3	A2		(Zhou, J., Chang, H.H., Fuentes,M., 2012)
15 Canadian cities	mortality	GLM	2040	1981-2000 population baseline	Climate change and future temperature-related mortality in 15 Canadian cities
		CRCM4	2060		(Martin *et al.*, 2011)
			2080		
			A2		

Table 11-6: Studies of the effectiveness of heat-health warning systems.

Effectiveness parameter	Location	Study design	Key findings on effectiveness	Commentary
Mortality	France	Regression analysis	Excess mortality during the 2006 heat wave in France was markedly less than expected (2,065 excess deaths versus 6,452 predicted). Reduction in mortality most pronounced in women and the elderly (Fouillet et al., 2008). The mortality reduction may be partly attributable to the differences in the intensity and geographical scope of the heat wave. Some decrease may be attributed to increased public awareness of the risk of heat, and the measures put in place after the 2004 heat wave (Fouillet et al., 2008; IPCC SREX., 2012 Ch9 9.2.1.5).	HHWS vary from those based solely on issuing of heat alerts through to comprehensive systems and responses (IPCC SREX., 2012 Ch9 9.2.1.5.1). The main features typical of a HHWS are timely accurate warnings, tailored communications, notification of adaptation actions to the most vulnerable populations and heat avoidance advice to general populations (Lowe et al., 2011). The number of studies looking at effectiveness is limited. There are methodological challenges in assessing the effectiveness of HHWS interventions. Most HHWS and associated response plans have been implemented relatively recently. Other challenges include heat waves being relatively rare events; meteorological variation between events; differential distribution of vulnerability; level of heat acclimatization; and that several public health interventions are often implemented simultaneously. Therefore attribution to one factor over another is difficult. (IPCC SREX., 2012; Bassil and Cole., 2010; WHO Regional Office for Europe., 2009).
	Philadelphia, US	Regression and economic analysis	Implementation of the Philadelphia HHWS is likely to have reduced daily mortality by 2.6 lives during heat events and could save 117 lives over 3 years (Ebi et al., 2004; IPCC SREX, 2012 Ch9 9.2.1.5.1). Net economic savings estimated at over US$450m.	
	Czech Republic	Regression analysis	Decrease in mortality in the 2003 European heat waves compared to heat waves in earlier years (Kysely and Kriz., 2008). Mortality decrease attributed in part to that the 2003 heat wave was less severe in central Europe compared to western Europe and night-time temperatures were not particularly elevated. Part of mortality decrease may be due to greater public awareness of heat-related risk, regular biometeorological forecasts and warnings, enhanced media coverage; as well as improvements in socioeconomic factors, general health, medical-technological changes and more widespread use of air conditioning. Stronger family and neighborhood ties in rural areas were also considered as possible protective factors.	
Public awareness of an extreme heat episode **and subsequent changes in behavior**	Phoenix, Arizona, U.S	Cross-sectional survey	Survey of general public on risk perception and warning response to heat episodes (Kalkstein and Sheridan., 2007). Majority of population were aware when a heat advisory warning had been issued. However, only about half the population actually changed behavior in response to a heat event. Variation in awareness across different demographic groups (greater awareness in women and those aged >65 years).	HHWS may be able to reduce mortality. However, the extent of mortality reduction attributable to HHWS interventions versus other factors such as meteorological factors or changes in population vulnerability is unclear (IPCC SREX., 2012; Bassil and Cole., 2010). Further testing, development and evaluation are required to assess the most effective HHWS approaches. Particular areas include efficacy of existing plans; timely and accurate forecasts and warnings; vulnerable groups; improving uptake of adaptation advice; and how to best communicate across diverse groups (SREX, 2012 Ch9 9.2.1.6; Bassil and Cole., 2010; Lowe et al., 2011)
	France	Cross-sectional survey	Survey of general public in 2005-2006 to assess awareness and practices during heat alerts (INPES., 2006 - Cited and discussed in Bassil and Cole., 2010) Recall of media heat alerts was high (74%). High proportion (73%) of respondents reported increased efforts to support vulnerable friends and family. However, only 63% of the elderly reported being helped and only 14% asked for help when they felt discomfort. In 2006, 63% of respondents took protective measures against the	

Effectiveness parameter	Location	Study design	Key findings on effectiveness	Commentary
			heat compared to 48% in 2005.	
	3 US cities and Toronto, Canada	Cross-sectional survey	Survey of people aged >65 years to assess knowledge of heat warnings (Sheridan., 2007). Knowledge of the heat warning system was high (90%) and likely due to extensive media coverage (particularly television). However, the details of the heat mitigation plans were less well understood and few people changed practices in response to the warnings. Many did not believe the messages were applicable to them or that they were vulnerable. Some confusion between heat precautions and ozone precautions.	
	UK	Cross-sectional survey	Study evaluated the component of the Heatwave Plan for England that focused on elderly people living in the community (Abrahamson et al., 2008). Survey assessed knowledge and perceptions of heat-related health risks, and protective behaviors. May be more effective to provide behavior modification advice to the whole population rather than targeting elderly people who may not perceive the advice is relevant to them. Few respondents considered themselves old or at risk from the effects of heat, despite many having a chronic illness. Most respondents had taken appropriate steps to reduce the effects of heat. Some respondents expressed practical concerns regarding the role and appropriateness of primary care for advice and support. No consensus on the effectiveness on the Heatwave Plan's media approach. Respondents suggested plausible and innovative ways to disseminate advice, as well as suggestions to harness existing community networks and resources to provide assistance.	
	Montreal, Canada	Cross-sectional survey	People aged 41-88 years with chronic cardiac and/or lung conditions were interviewed regarding heat awareness and response during a hot summer in 2005 (Kosatsky et al., 2009). Most recalled heat advisory warnings in the media, with television being the predominant source. Of those who recalled advisories, 85% named at least one recommended protective measure; and most judged the recommendations useful. High awareness about effects of heat on health, including that people with heart or lung disease are at greater risk. However, most were unaware that heat waves have a greater effect on health when they occur at the beginning of summer. Some confusion between extreme heat and smog. All respondents reported that they "always" or "often" employed at least one measure to protect themselves from extreme heat.	

Table 11-7: Summary of recent research on co-benefits of climate change mitigation.

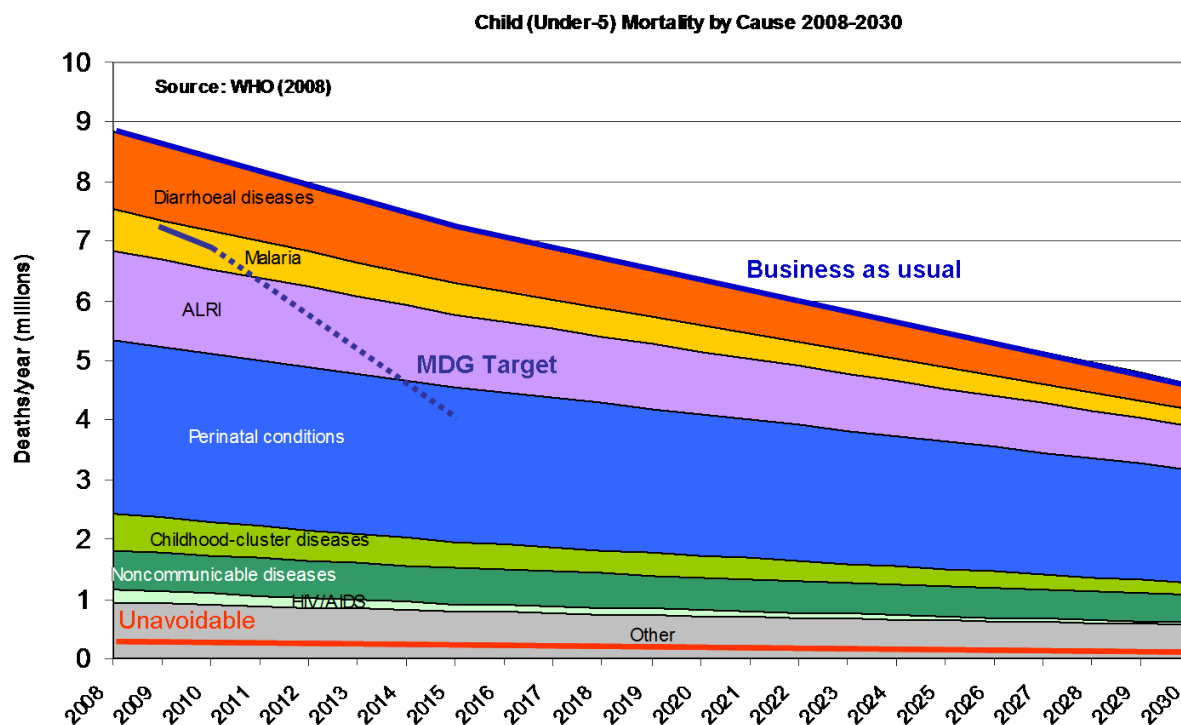| Co-benefit category	Benefits for health	Benefits for climate	Publications since 2006
Reduction of co-pollutants from outdoor and household sources	Can reduce cardio- and cerebrovascular disease, chronic and acute respiratory illnesses, lung cancer, premature mortality, incidences of low birthweight and stillbirths, and possibly tuberculosis; less money spent on energy costs; promotes healthy homes	Reduce CAP emissions associated with household fuel use	(McCracken *et al.*, 2007) (Markandya *et al.*, 2009) (Smith and Balakrishnan, 2009) (Smith *et al.*, 2009) (Wilkinson *et al.*, 2009) (Boldo *et al.*, 2010) (Pokhrel *et al.*, 2010) (Baumgartner *et al.*, 2011) (Smith *et al.*, 2011) (UNEP, 2011) (Anenberg *et al.*, 2012) (Dix-Cooper *et al.*, 2012)
Increases in active transport from modifications to the built environment, including smart growth	Increased physical activity; reduced obesity; reduced chronic disease; improved mental health; reduced exposure to air pollution; increased local access to essential services, including food stores; enhanced safety	Reduce CAP emissions associated with vehicle transport; possible mitigation of emissions through sequestration	(Woodcock *et al.*, 2009) (Grabow *et al.*, 2011) (Reed and Ainsworth, 2007) (Kaczynski and Henderson, 2008) (Casagrande *et al.*, 2009) (Rundle *et al.*, 2009) (Durand *et al.*, 2011) (McCormack and Shiell, 2011) (Babey *et al.*, 2007)
Increases in urban green space	Reduced temperatures and heat island effects; reduced noise; enhanced safety; psychological benefits; better self-perceived health status	Reduce air pollution; more carbon sequestration (through forests and soil)	(Mitchell and Popham, 2007) (Babey *et al.*, 2008) (Maas *et al.*, 2009) (van den Berg *et al.*, 2010) (van Dillen *et al.*, 2011) (McMichael *et al.*, 2007) (Friel *et al.*, 2009)
Less ruminant (red) meat consumption	May reduce (ischaemic) heart disease, stroke, colorectal cancer, breast cancer and prevalence of overweight/obese individuals	Less CH_4 emissions; lower energy intensity per calorie (?)	(Sinha *et al.*, 2009) (Jakszyn *et al.*, 2011) (Pan *et al.*, 2012) (Xu *et al.*, 2012) (Smith and Balakrishnan, 2009)
Increased access to reproductive health services	Lower child and maternal mortality from increased birth intervals and shfits in maternal age.	Potentially slower growth of energy consumption and related CAP emissions; less impact on land use change, etc.	(Conde-Agudelo *et al.*, 2007) (Engelman, 2010) (O'Neill *et al.*, 2010) (Diamond-Smith and Potts, 2011)

Figure 11-1: Projected Child Mortality, 2008-2030, Including Climate-Sensitive Causes. Sources: Mortality projections by cause from WHO. Population projections from UN DESA. Child mortality rates from IGME. (Interagency Group for Child Mortality Estimation, 2011; United Nations, Department of Economic and Social Affairs, Population Division., 2011; World Health Organization, 2008).
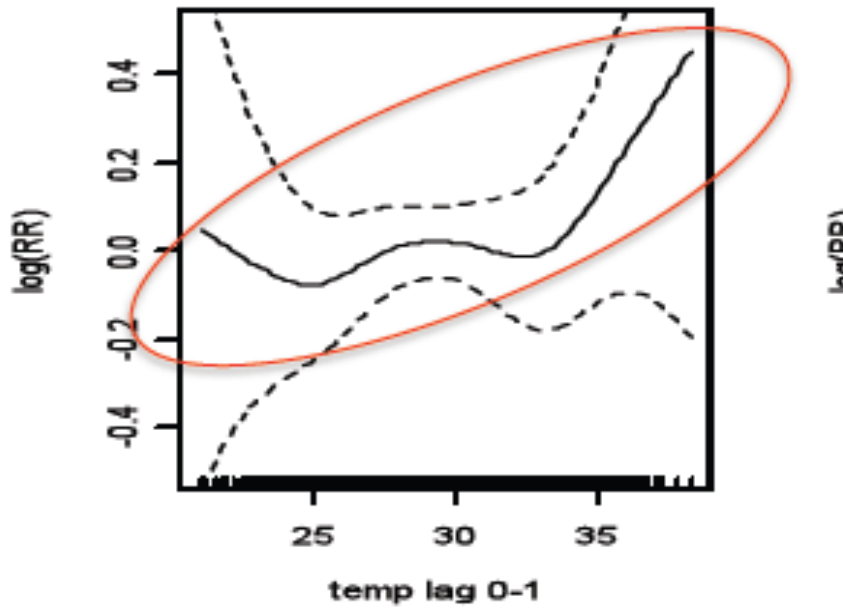
Figure 11-2: Relationship between the risk of dying and temperature on the preceding day. Y-axis: log(RR), XS-axis: Temp in °C, lagged by one day.
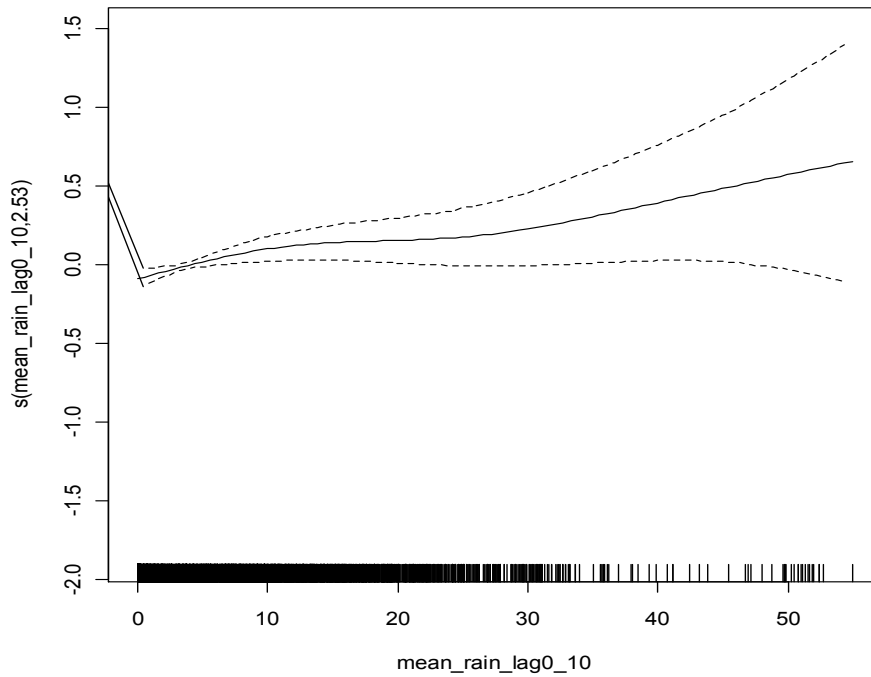
Figure 11-3: The effect of daily rainfall on daily mortality in diarrheal diseases in AMK HDSS, Bangladesh.
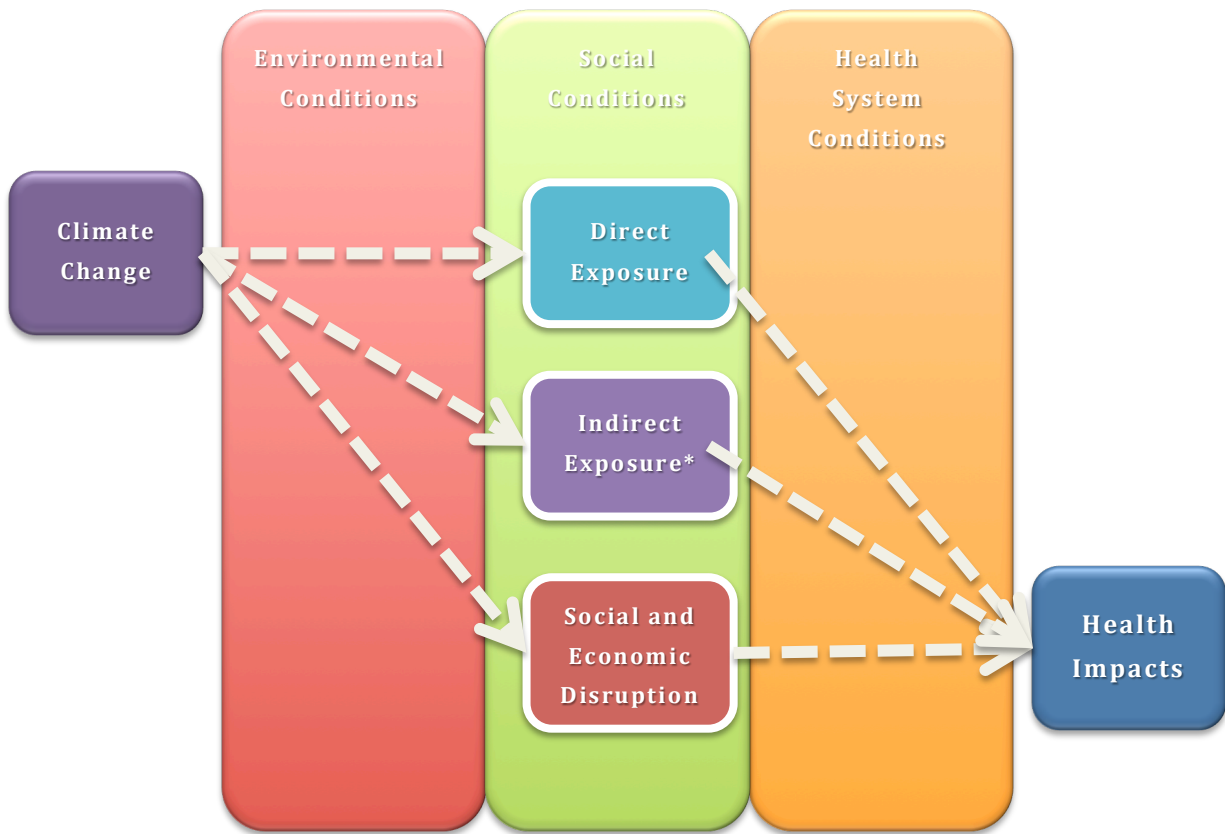
*Changes in water, air, food quality; vector ecology; ecosystems, agriculture, industry, and settlements
†Arrow inside 'condition' box indicates modifying influence

Figure 11-4: Ways in which climate, climate variability and climate change may influence human health. Source: E. Garcia (2011).
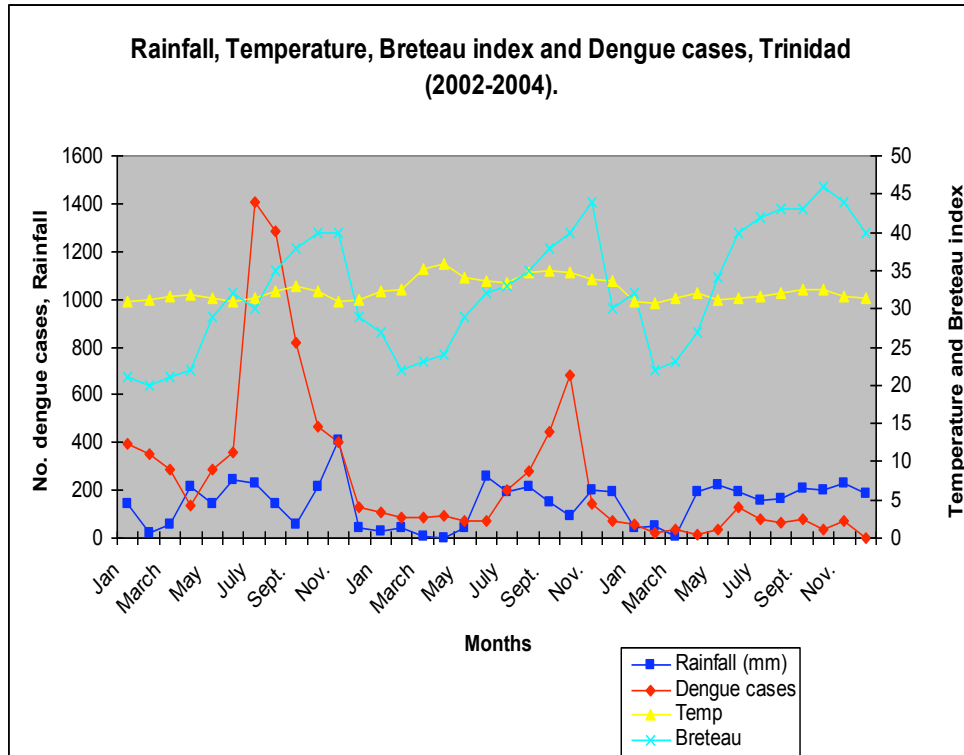
Figure 11-5: Rainfall, temperature, Breteau index, and dengue cases, Trinidad (2002-2004). Source: Chadee *et al.* (2007).
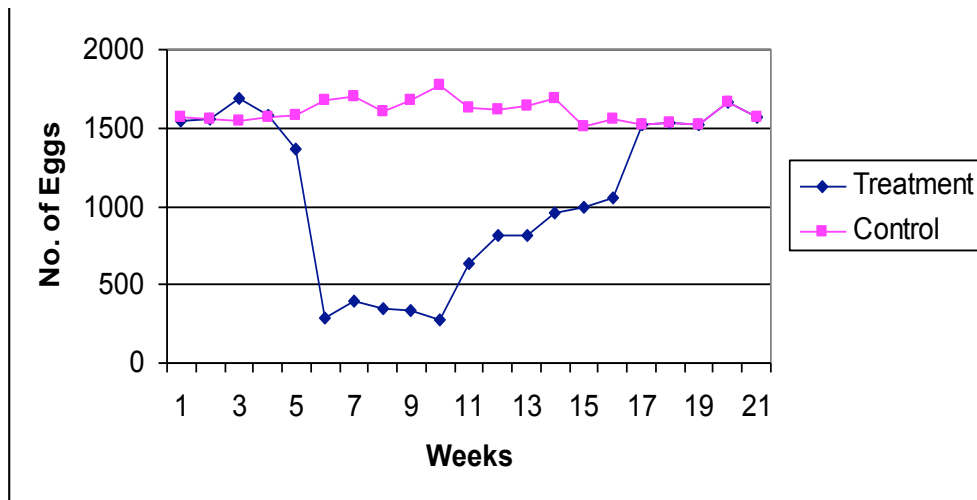
Fig. 3. Efficacy of pre-seasonal treatment with temephos on Aedes aegypti ovitrap egg counts in Curepe (treatment) and St. Joseph (control), Trinidad (2003)

Figure 11-6: Efficacy of pre-seasonal treatment with temephos on Aedes aegypti ovitrap egg counts in Curepe (treatment) and St. Joseph (control), Trinidad (2003). Source: Chadee (2009).
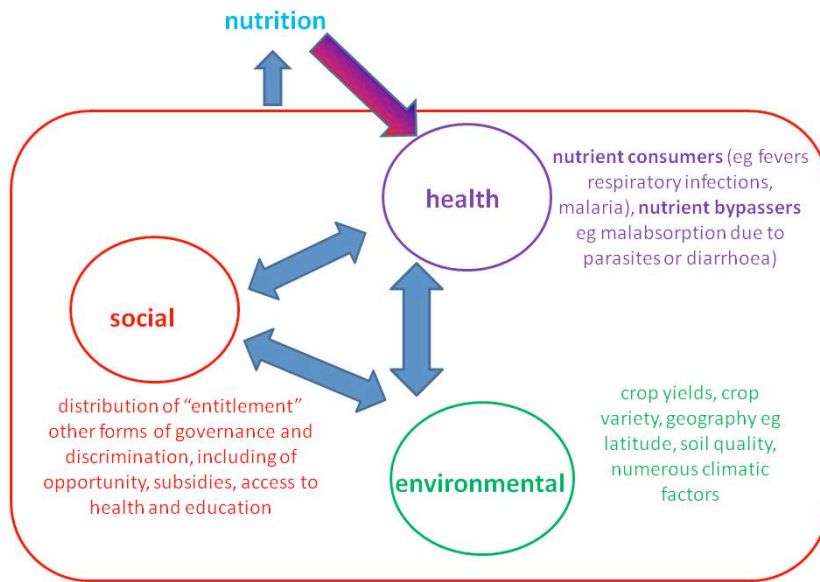
Figure 11-7: Nutrition, social, health, environmental interactions: Population and nutrition can be conceptualized as a synthetic state arising from the interaction of social, health and environmental factors, in a complex system. Many relationships are bidirectional. For example, poor population health status can impair social function (e.g. by impaired education). Source (Colin Butler, 2012?)
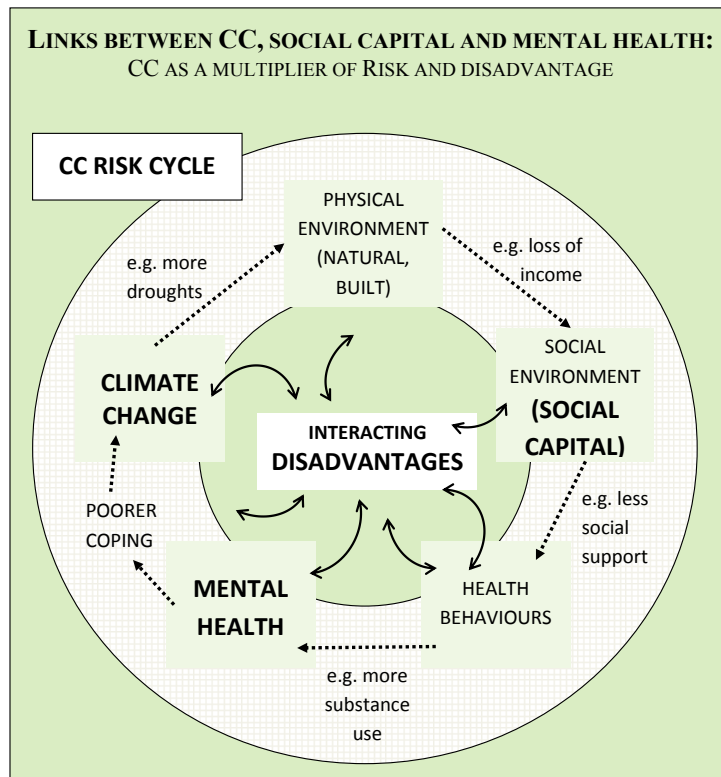
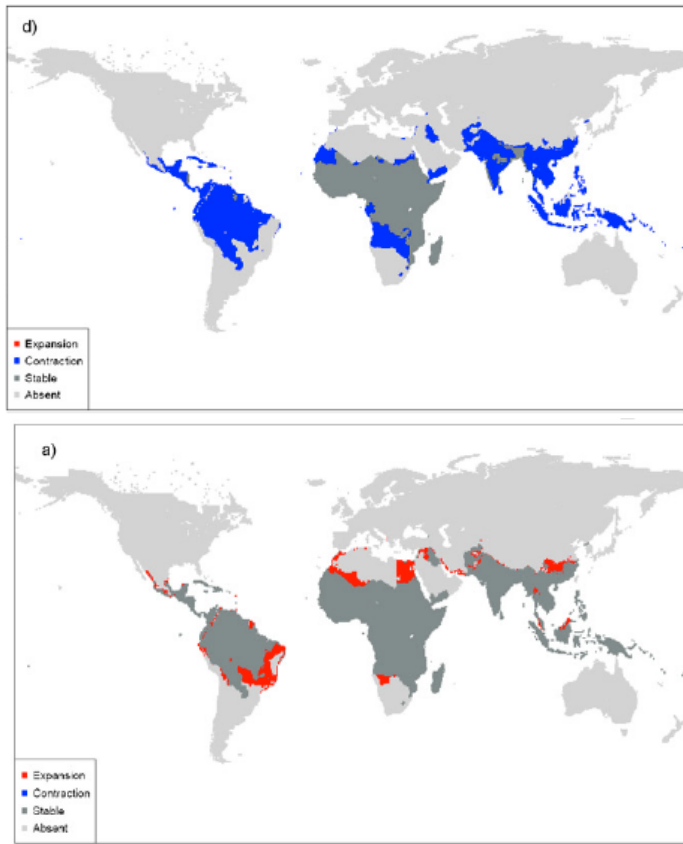Figure 11-8: Links between CC, social capital, and mental health. Source: (Colin Butler, 2012?).

Figure 11-9: Contraction of the area of malaria transmission through economic development offsets expansion through higher temperatures. Based on IPCC scenario A1B, projections to 2050. Source: Béguin *et al*. (2011).
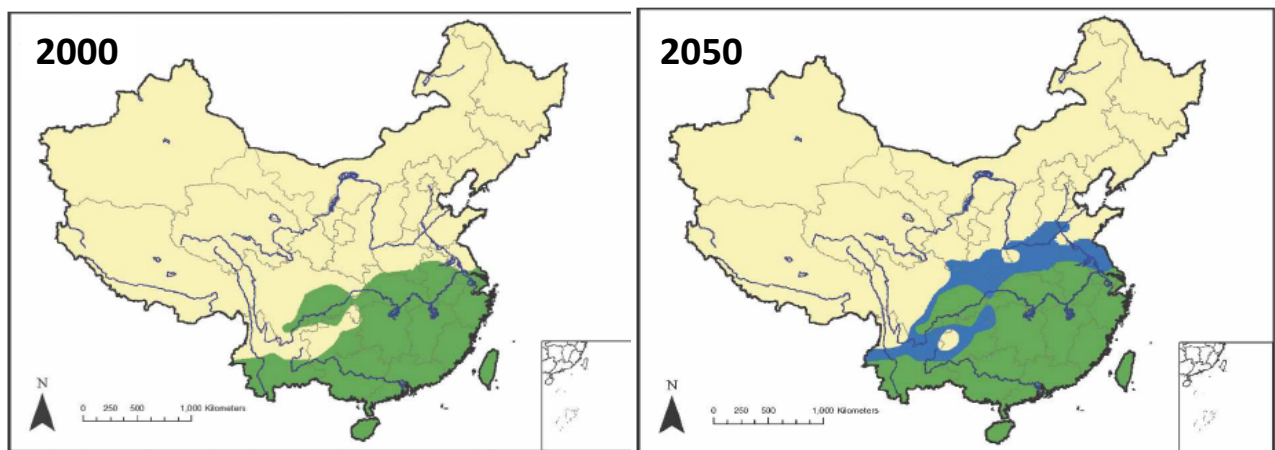

Figure 11-10: Predicted risk map of schisosomiasis*(S. japonicum)* transmission in China in 2050. For comparison the current risk map in 2000. Green area denotes the range of schistosomiasis in 2000. The blue area shows the geographic expansion. Adapted from (Zhou *et al*., 2008).
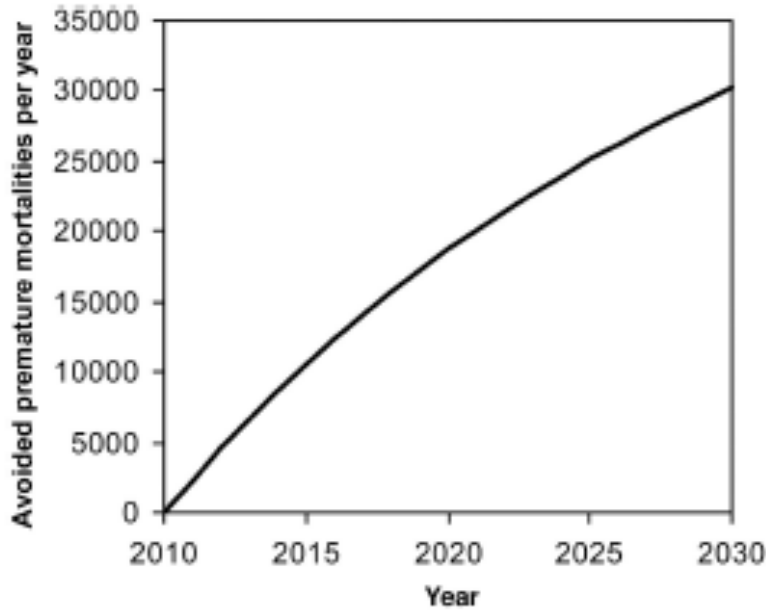
Figure 11-11: Avoided global premature mortalities from a 65 mt-yr^{-1} CH$_4$ emission reduction, beginning in 2010. Cited from (West *et al.*, 2006).
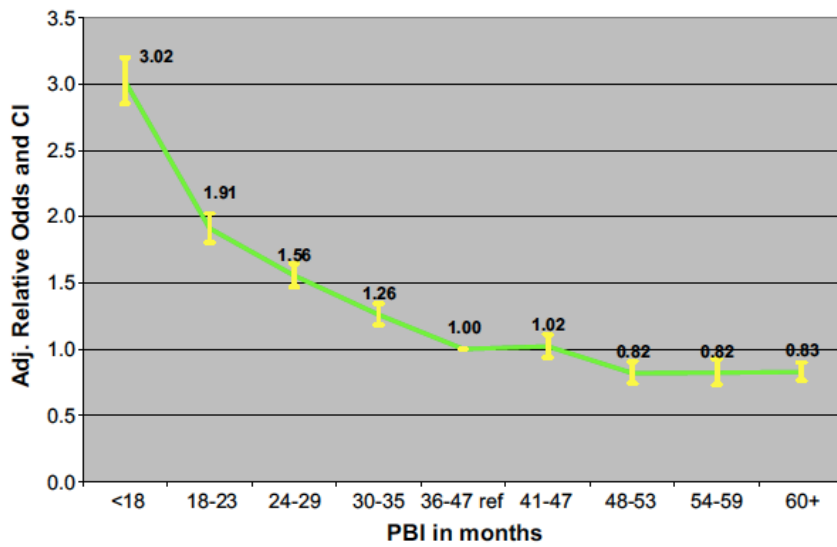

Figure 11-12: Reduction in child mortality due to increasing spacing of birth based on studies in 17 countries. Cited from (Rutstein, 2005).