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Adaptive Management of Climate Change Risks

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Executive summary

The UK Department for Environment, Food and Rural Affairs (DEFRA) has sponsored several state-of-the-art assessments of future impacts of climate change on various climate-sensitive threats such as malaria, hunger, water shortage, coastal flooding, habitat loss, lowered carbon-sink capacity, and diminished coastal wetlands. The results, based on IPCC emission scenarios, figure prominently in the international debate about climate change, and formed the basis of the Stern Review's pronouncements that climate change would be dire, if not catastrophic.

Synthesis of the results shows that through the end of this century, the contribution of climate change to these threats is generally smaller than the contribution of factors unrelated to climate change. Specifically, under the scenario with the richest but warmest world, which is projected to increase global temperatures 4.0°C by 2085, climate change would be responsible for 28 million of the 133 million people at risk of hunger (21%). Corresponding figures for coastal flooding are 10 to 42 million out of 11 to 45 million (92%), but climate change would reduce the number of people at risk of water shortage by 1,200 million. For malaria, climate change would be responsible for 300 million (3%) of the 9,100 million people at risk of malaria. Translating these estimates into mortality estimates, climate change would be responsible for less than 224,000 (8%) of the 2.86 million deaths due to hunger, malaria, and coastal flooding in 2085.

Environmental well-being shows a similar profile. Global carbon-sink capacity in 2100 is higher than under the 1990 baseline under all scenarios, despite any global warming. Habitat loss, as measured by global cropland area, is least under the richest but warmest scenario. Moreover, factors unrelated to climate change will make a much greater contribution to the loss of coastal wetlands.

These results also show that even the impossible task of *halting* climate change, the costs of which would dwarf the annual \$165 billion (in 2010) estimated for achieving the Kyoto Protocol, would at best reduce the number of people at risk for hunger by 21%, malaria by 3%, and coastal flooding by 92%, while increasing the number of people at risk from water shortages by 72%. But results from the World Health Organization, the UN Millennium Project, and the IPCC show that hunger, malaria, and coastal flooding could be reduced by 50% to 75% at an annual cost of only \$22 billion. Alternatively, the pursuit of economic and technological development would deliver these benefits and more—reducing poverty, illiteracy, and child and maternal mortality by 50% or more—at an annual cost of \$145 billion.

Thus, with respect to both human and environmental well-being, the claim that climate change is the world's most important environmental problem of this century fails to hold up under scrutiny. Second, human and environmental well-being is probably highest in the richest but warmest world, and lowest in the poorest but coolest world. Third, through the next few decades, reduction of climate-related risks can be achieved most cost-effectively by reducing vulnerability to climate-sensitive threats that might be exacerbated by climate change rather than through any significant emission reduction.

Accordingly, in the near to medium term, we should focus on the following policies that, together, constitute an adaptive-management approach to addressing climate change.

Reduce vulnerabilities to climate-sensitive problems that are urgent today and might be exacerbated by future climate change.

Reducing barriers to economic growth, advancing human capital, and technological change, the lack of which is the major reason that developing countries are most vulnerable to climate change and to adversity in general.

Adopt “no-regret” measures to reduce emissions that would be justified in the absence of the threat of climate change, while at the same time expanding these options through research and development of cleaner and more affordable technologies.

Develop a more robust understanding of the science and impacts of climate change, and of the policies effective in dealing with it.

Monitor the impacts of climate change to give advance warning of “dangerous” impacts and, if necessary, to rearrange priorities for mitigation and adaptation should the adverse impacts of warming on human and environmental well-being occur faster or threaten to be more severe or more likely than is currently projected. Such monitoring is, therefore, key to the adaptive management of climate change risks.

Priorities for Canada

Efforts should first be devoted to reducing the vulnerability of climate-sensitive sectors such as agriculture, timber, water resources, fishery and tourism, while at the same time enhancing their ability to capitalize on new opportunities such as longer growing seasons. The government should also implement policies that would be justifiable even in the absence of climate change, such as the reduction or elimination of subsidies for natural resource extraction and energy consumption. Finally, Canada should continue to participate in national and international efforts to monitor and research the science and impact of climate change, and should aim to develop more cost-effective technologies for mitigation and adaptation.

Such adaptive management of the risks from climate change would help solve today's urgent problems while bolstering our ability to address tomorrow's climate-change challenge. It would advance human and environmental well-being further and faster than costly but ineffective policies such as the Kyoto Protocol and even costlier policies directed towards stabilizing concentrations of greenhouse gases in the atmosphere in the coming decades.

Adaptive Management of Climate Change Risks

Indur M. Goklany

1 Introduction

Under most scenarios of the future world, including those developed by the Intergovernmental Panel on Climate Change (IPCC) in its *Special Report on Emission Scenarios* (SRES) (IPCC, 2000), the world should be getting more populated and wealthier during this century. While this ought to advance human well-being, it should also increase greenhouse gas emissions, which may cause climate changes that may have negative consequences, with the potential to at least partly offset the advances in human and environmental well-being. The IPCC reports in its assessment of 2001 that modest global warming (of the order of 1° to 2° C over 1990 levels) could increase global economic product with gains in developed areas such as Canada and Northern Europe that are situated in the higher latitudes more than offsetting losses in developing countries (IPCC, 2001b: 943–48). However, global temperature increases beyond that could reduce global economic product and wreak substantial environmental damage.

Implicit in calls for aggressive reductions in greenhouse gases is the premise that a richer and more populous world will have lower human and environmental well-being because it would lead to greater climate change. These calls are further strengthened by repeated claims by highly regarded policy-makers ranging from President Chirac, Prime Minister Blair, and ex-

President Clinton that climate change is the most important environmental challenge facing the globe this century (Clinton, 1999; Cordis News, 2004). Joining in this chorus, Canada's National Round Table on the Environment and the Economy (NRTEE) recently "concluded that climate change is the most significant threat we face as we enter this century."¹

Based on analyses of the global impacts of climate change through the year 2085 on various threats to human and environmental well-being, this chapter will investigate whether climate change is, indeed, likely to be the world's most important environmental problem over the foreseeable future, and whether richer-but-warmer worlds will necessarily have lower human and environmental well-being than poorer-but-cooler worlds. It will then compare the global benefits and costs of reducing the impacts of climate change either through mitigation strategies (i.e., reductions in greenhouse gas emissions) or through strategies to reduce society's vulnerability to these impacts (i.e., adaptation). This comparison will show that in the near-to-medium term, reduction of vulnerability, appropriately focused, will provide greater benefits at lower costs than mitigation. In the longer term, however, mitigation may be inevitable, depending on the emissions path we find ourselves on and what is learned in the future about the social, economic, and environmental impacts of climatic changes induced by greenhouse gases. Finally, the chapter will offer a set of policies that will allow adaptation and mitigation strategies to evolve and be integrated over the different time scales to manage, effectively and efficiently, the future global risks from climate change despite uncertainties about the magnitude and timing of these risks.

2 Wealth, technology, well-being, and adaptive capacity

Economic growth broadly increases human well-being by increasing wealth, technological development, and human capital. These factors enable society to address virtually any kind of adversity, whether it is related to climate or not, and increase society's capacity to reduce damages from climate change through either adaptation or mitigation (Goklany, 1995, 2006; Yohe, 2001; Smit et al., 2001). It is well-established that many determinants of human well-being—hunger, malnutrition, mortality rates, life expectancy, the level of education, and spending on health care and on research and development—improve along with the level of economic development, as measured by GDP per capita (Goklany, 2002).

¹ Glenn Murray, Chair, and Alexander Wood, Acting President and CEO, National Round Table on the Environment and the Economy, personal communication, August 16, 2006, to Mark Mullins, Executive Director, The Fraser Institute.

Increasing wealth also improves some, though not necessarily all, indicators of environmental well-being. Wealthier nations have higher cereal yield (an important determinant of cropland, which is inversely related to habitat conversion), greater access to safe water and sanitation, and lower birth rates (Goklany, 2006).² Notably, access to safe water and access to sanitation double as indicators of both human and environmental well-being, as does cereal yield since higher yield not only means more food and lower hunger but also lowers pressure on habitat (Goklany, 1998; Green et al., 2005). Cross-country data also indicate that, for a fixed level of economic development, these indicators of human and environmental well-being (e.g., malnutrition, mortality rates, life expectancy, access to safe water, crop yields, and so forth) improve with time, indicating the likely beneficial effect of technological advances (Goklany, 2002).

In other words, for any given level of per-capita income, human well-being as measured by either life expectancy or infant mortality improves with time because of new technologies and broader diffusion of existing technologies. Similarly one should expect, all else being equal, that society's ability to cope with any adversity, including climate change, should also increase with the passage of time. That is, over time, society's adaptive capacity should increase and this, barring inadvertent maladaptation, should reduce the future impacts of climate change (Goklany, 2006).

3 The IPCC's scenarios for the future

The information in this chapter is drawn for the most part from the "Fast Track Assessment" (FTA) of the global impacts of climate change sponsored by the UK Department of Environment, Forests and Rural Affairs (DEFRA) and reported in a special issue of *Global Environmental Change* edited by Dr. Martin Parry (Parry, 2004), and supplemented, as necessary, by other DEFRA-sponsored studies. Many, if not most, of the authors of the papers in that special issue have served as coordinating lead authors, lead authors, or contributing authors of the IPCC's Third and Fourth Assessment Reports. Dr. Martin Parry is, moreover, the current Chairman of the IPCC's Work Group II, which oversees the impacts, adaptation and vulnerability sections of Assessments.

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- 2 One indicator that, so far at least, has not shown an improvement with wealth is total CO₂ emissions. Also, some environmental indicators (e.g., air pollutants such as sulfur dioxide and particulate matter) generally worsen initially as incomes increase before declining at higher income levels (Shafik, 1994; Grossman and Krueger, 1995; Dasgupta et al., 2006).

Like all estimates of the impacts of climate change, the results of the FTA are plagued with uncertainties resulting from, among other things, the fact that such estimates are based on a series of linked models with the uncertain output of each model serving as the input for the next model. Socio-economic assumptions are used by emission models to generate emission scenarios extending 100 or more years into the future. These scenarios are then used to drive yet other models to estimate future trends in atmospheric concentrations of greenhouse gases. This information is then fed into coupled atmosphere-ocean general circulation models (GCMs) to estimate spatial and temporal changes in climatic variables. These are used as inputs to simplified and often inadequate biophysical models that project location-specific biophysical changes (e.g., crop or timber yields). Next, depending on the human or natural system under consideration, the outputs of these biophysical models may have to be fed into additional models to calculate the social, economic, and environmental impacts on those systems.

Despite the resulting cascade of uncertainties associated with such impacts assessments, for the purposes of this chapter I will, for the most part, take the results of the FTA at face value, because it has figured prominently in the international debate about global warming.³ Like the FTA, this chapter does not consider low-probability but potentially high-consequence outcomes such as a shut down of the thermohaline circulation. They are deemed unlikely to occur during this century (see, e.g., DEFRA 2004; Gregory, 2005; Wunsch, 2004).

The FTA employed scenarios developed by the IPCC's *Special Report on Emissions Scenarios* (IPCC, 2000) to project future climate change. The dominant characteristics of the "storylines" used in the SRES are shown in table 1. These characteristics describe the demographic, technological, economic, and social trajectories driving emissions in the four scenarios that were used by the FTA. This table also provides corresponding estimates of atmospheric CO₂ concentrations in 2085, and climate change (as represented

³ For example, results of the FTA's results for the impacts of climate change on food, agriculture, water resources, and coastal flooding were a prominent part of a symposium, *Avoiding Dangerous Climate Change*, sponsored in 2005 by the UK Government as part of the run up to the 2005 Gleneagles Summit of the G-8 (DEFRA, 2005), and which also informed the more recent Stern Review of the Economics of Climate Change. Prior to that, the claim by Her Majesty's Government's Chief Science Advisor Sir David King's (2004) that "climate change is the most severe problem that we are facing today—more serious even than the threat of terrorism" was based, in part, on older FTA estimates that were published in another special issue of *Global Environmental Change* (Parry and Livermore, 1999; Arnell et al., 2002; see Goklany and King, 2004).

Table 1: Characteristics and assumptions for the various scenarios

	A1FI	A2	B2	B1
Population in 2085 (billions)	7.9	14.2	10.2	7.9
GDP growth factor, 1990–2100 (1990 \$US)	525 to 550	243	235	328
GDP/capita in 2085, global average (1990 \$US)	\$52,600	\$13,000	\$20,000	\$36,600
GDP/capita in 2100 (1990 \$US)				
<i>Industrialized countries</i>	\$107,300	\$46,200	\$54,400	\$72,800
<i>Developing countries</i>	\$66,500	\$11,000	\$18,000	\$40,200
Technological change	rapid	slow	medium	medium
Energy use	very high	high	medium	low
Energy technologies	fossil intensive	regionally diverse	"dynamics as usual"	high efficiency
Land use change	low-medium	medium-high	medium	high
CO₂ concentration (ppm) in 2085	810	709	561	527
Global temp change (°C) in 2085	4.0	3.3	2.4	2.1
Sea level rise (cm)	34	28	25	22

Note: Global temperature change is based on the HadCM3 model. The columns in this table are arranged by scenario in the order of decreasing global temperature changes. Using the labels provided by the IPCC, these scenarios from left to right are A1FI (warmest), A2, B2 and B1 (coolest).
Sources: Arnell et al., 2004: tables 1, 6, 7; Arnell, 2004: table 1; Nicholls, 2004: tables 2, 3.

by increases in globally averaged temperature) and sea-level rise between 1990 and 2085 (Arnell et al., 2004). The columns in this, and most subsequent, tables are arranged by scenario in the order of decreasing change in global temperatures. Using the labels provided by the IPCC, these scenarios from left to right are A1FI (warmest), A2, B2 and B1 (coolest).

The FTA used these climate-change projections (Arnell et al., 2004) to estimate the global impacts on various climate-sensitive threats that also serve as determinants of human and environmental well-being. The FTA analyzed hunger (Parry et al., 2004), water stress (Arnell, 2004), coastal flooding (Nicholls 2004), and malaria (van Lieshout et al., 2004) as threats affecting human well-being; and projected net biome productivity (a measure of the strength of the terrestrial biosphere as a carbon sink) and the global extent of coastal wetlands and croplands (Levy et al., 2004) as threats to environmental well-being. In this chapter, I will use the FTA's climate-change impact estimates for 2085 or 2100 while noting that 2085 is at the outer limit of the foreseeable future since socioeconomic scenarios are not deemed credible beyond that (Arnell et al., 2002).

Examination of table 1 suggests that, on one hand, the impacts of climate change should decrease as one goes from scenario A1FI on the left to B1 on the right (in accordance with the pattern of declining climate change, other things being equal).⁴ On the other hand, economic and technological development—both critical determinants of adaptive capacity (Goklany, 1995, 2006; Smit et al., 2001; Yohe, 2001)—ought to attenuate the impacts through a combination of autonomous and proactive adaptations. Considering future levels of economic and technological development this attenuation should be greatest for the A1FI scenario, followed by the B1, B2, and A2 scenarios, in that order. Thus, even though the A1FI scenario has the highest climate change it would not necessarily have the worst outcomes, because it should also have the highest adaptive capacity, since it leads to the richest world.

The threats to human and environmental well-being examined by the FTA—hunger, water stress, malaria, coastal flooding, and loss of habitat and carbon sinks—are not unique to climate change. Factors unrelated to climate change also contribute to these threats. In the following, the magnitude of the threat or problem in the absence of climate change will be denoted by P_o , while the magnitude of the problem due to climate change will be indicated by ΔP . Thus, the magnitude of the total problem [P_T] with climate change equals $P_o + \Delta P$.

4 The "FI" in "A1FI" indicates that this scenario is fossil-fuel intensive.

In consonance with the FTA, the magnitude of the problem (P) due to each climate-sensitive threat affecting human well-being, namely, malaria, hunger, water stress, and coastal flooding, will be measured by the global population at risk (PAR) or suffering from the specific climate-sensitive threat. For these threats, P will henceforth be used interchangeably with PAR, as will ΔP with ΔPAR . With respect to environmental well-being, P will be measured by various indicators of habitat loss, which is generally acknowledged to be the most important threat to global terrestrial biodiversity (e.g., Green et al., 2005; Goklany, 1998), and by the global terrestrial-sink capacity (i.e., the capacity of the earth to absorb carbon dioxide from the atmosphere).

4 Population at risk for various climate-sensitive threats, with and without climate change

In this section, I present the FTA's estimates of the populations at risk in 2085 with and without climate change (i.e., ΔPAR and P_o , respectively) for four climate-sensitive threats to human well-being, namely, hunger, water stress, coastal flooding, and malaria, under each scenario summarized in table 1.

In comparing P_o and ΔPAR under the various scenarios, it should be noted that, first, the A1FI and B1 scenarios are assumed to have the same population in 2085 (see table 1). In fact, in the real world, lower total fertility rates are generally associated with higher levels of economic development. Arguably, therefore, the A1FI world should have a lower population in 2085 than the B1 world. Accordingly, the emissions and climate change for the A1FI scenario are probably overestimated relative to the B1 scenario, as are P_o and ΔPAR .

Second, while the FTA studies assume that no new governmental policies and measures will be implemented to reduce damages from climate change, some of them (e.g., the studies for hunger and coastal flooding) allow for some "spontaneous" adaptive responses because it should be expected that, even in the absence of new governmental policies, people would employ existing technologies to protect themselves from economic or bodily harm under a "business-as-usual" world. However, even where the FTA studies allow for such adaptation, they limit the range of available technological options to currently available technologies (see, e.g., Parry et al., 2004: 57). But we should expect that the menu of technological options would be much broader, more cost-effective, and more affordable in the future under any SRES scenario because: (a) the world will be wealthier under any of the scenarios (table 1) and, therefore, better able to develop, afford, and adopt new as well as improved technologies; (b) technology will advance even if society

does not become wealthier through the accretion of knowledge; and (c) even in the absence of specific policy changes, new and improved technologies will inevitably be developed to cope specifically with the negative impacts of climate change. Thus, the FTA studies tend to overestimate both P_o and ΔPAR , with the upward bias increasing with the future level of economic development: that is, the overestimates are greatest for the A1FI scenario, followed by B1, B2 and A2, in that order.

Hunger

The FTA's estimates of PAR for hunger in 2085 both with and without climate change for the various scenarios are shown in table 2 in terms of both millions of people and the percent of global population. These estimates, taken from Parry et al. (2004), show that whether or not climate changes beyond 1990 levels, no matter which scenario we choose, through 2085 the future world will be better off with respect to hunger than it was in 1990. In 2085, the warmest scenario might actually result in lower levels of hunger than some cooler scenarios. Hunger in 2085 will be lowest in the B1 scenario, followed by A1FI, B2, and A2 (in that order). Thus, the warmest scenario (A1FI) does not lead to the lowest level of well-being, despite the tendency to overestimate its impacts. For some scenarios (A2 and, possibly, B2), climate change might, in fact, reduce the incidence of hunger at least through 2085. Finally, for each scenario, ΔPAR is smaller than P_o , which shows that through 2085 at least, the impact of climate change is secondary to the impact of other environmental factors that are unrelated to climate change.

The estimates shown in table 2 are based on the assumption that direct CO_2 effects on crop yields would be realized. If, however, these direct effects are not realized, then Parry et al.'s analysis indicates that climate change would exacerbate the total population at risk (TPAR) under all scenarios while ΔPAR would still be less than P_o for all but the A1FI scenario. But such outcomes are unlikely. First, the probability that direct CO_2 effects on crop growth are zero or negative is virtually non-existent, particularly since future societies should have a greater capacity to adapt (IPCC, 2001b: 254–56; see, also, Long et al., 2006). As noted, the FTA most likely systematically overestimates P_o and ΔPAR for tomorrow's wealthier and more technologically advanced societies, especially for the A1FI world, which has the highest level of wealth, because yields generally increase with greater wealth (Goklany, 2000). Moreover, the population of the A1FI world might be an overestimate relative to the B1 world. Had these factors been given their due, the A1FI scenario might have resulted in the lowest overall levels of hunger.

Table 2: Population at risk (PAR) in 2085 for hunger, with and without further climate change

Baseline 1990	A1FI 2085	A2 2085	B2 2085	B1 2085
Population at risk in the absence of climate change (P_0) (millions)				
798 to 872 (15.1% to 16.5%)	105 (1.3%)	767 (5.4%)	233 (2.3%)	90 (1.1%)
Additional population at risk because of climate change (ΔPAR) (millions)				
N/A	28 (0.4%)	-28 to -9 (-0.2% to -0.1%)	-11 to +5 (-0.1% to 0.05%)	10 (0.1%)
Total population at risk (TPAR = P_0 + ΔPAR) (millions)				
798 to 872 (15.1% to 16.5%)	133 (1.7%)	739 to 758 (5.2% to 5.3%)	222 to 238 (2.2% to 2.3%)	100 (1.3%)

Note: Figures in parentheses are in percent of global population.

Source: Parry et al., 2004.

Finally, the estimates provided in table 2 indicate that, in order to compare the consequences of various scenarios, it is insufficient to examine only the impacts of climate change. One should look at the total level of hunger. Otherwise, based merely on an examination of Δ PAR, one could conclude, erroneously, that, with respect to hunger, A2 is the best of the four scenarios. But, based on total PAR, A2 would be the worst. This also illustrates that efforts focused on minimizing the consequences of climate change to the exclusion of other societal objectives might actually reduce overall human welfare.

Water stress

The FTA's estimates of PARs for water stress in 2085 with and without climate change are shown for each scenario in table 3 in both millions of people and the percent of global population (Arnell, 2004).⁵ A population is deemed to be at risk if its available water supplies fall below 1,000 m³ per capita per year. The Δ PARs in table 3 account for the fact that because of climate change some populations will move in and out of the water-stressed category.

5 Arnell (2004) also uses the "10-year return period minimum annual runoff" as a measure of water availability. Even under this variation, climate change relieves water stress in 2085 (compared to the "no climate change" condition). Hence, those results are not shown.

Table 3: Population at risk (PAR) in 2085 for water shortage, with and without further climate change

	Baseline 1990	A1FI 2085	A2 2085	B2 2085	B1 2085
Population at risk in the absence of climate change (P_0) (millions)					
	1,368 (25.8%)	2,859 (36.2%)	8,066 (56.8%)	4,530 (44.4%)	2,859 (36.2%)
Additional population at risk because of climate change (ΔPAR) (millions)					
	NA	-1,192 (-15.1%)	-2,100 to 0 (-14.8% to 0%)	-937 to 104 (-9.2% to 1.0%)	-634 (-8.0%)
Total population at risk (TPAR = P_0 + ΔPAR) (millions)					
	1,368 (25.8%)	1,667 (21.1%)	5,966 to 8,066 (42.0% to 56.8%)	3,593 to 4,634 (35.2% to 45.4%)	2,225 (28.2%)

Note: Figures in parentheses are in percent of global population.

Source: Arnell, 2004: 41, table 8.

Information in table 3 indicates that, for each scenario, P_0 exceeds Δ PAR in 2085. In other words, with respect to water stress, factors unrelated to climate change are more important than climate change under each scenario, at least through the foreseeable future. As with hunger, climate change by itself might, in fact, *reduce* the total PAR for water stress. In the absence of climate change, A1FI and B1 have the smallest PAR in 2085, while A2 generally has the highest. This is true in terms of both absolute numbers and the percent of total population for the relevant scenario. In the absence of climate change, the A1FI and B1 scenarios have identical PARs due to the population assumptions built into the story lines. With climate change, the A1FI world continues to have the lowest PAR but that for B1 falls to second place.

Notably, Arnell's analysis totally ignores any adaptation despite the ready availability of time-tested adaptive responses on both the supply and demand side: e.g., water storage facilities to augment water supplies during drier periods, or water pricing and other conservation measures (Goklany, 2005). Thus it overestimates both P_0 and Δ PAR. These overestimates are greatest for the A1FI (richest) scenario and lowest for the A2 (poorest) scenario and, although the ranking among the scenarios would not change, the differences in both P_0 and PAR among the various scenarios would have been magnified.

Coastal flooding

The FTA's estimates of the PAR for coastal flooding with and without any rise in sea levels induced by climate change between 1990 and 2085 are shown in table 4. Note that sea level will rise relative to the land not only because of climate change but also because the land may subside for a variety of reasons not related to climate change: e.g., extraction of water, gas, or oil under the coastline. In this table, PAR is measured by the average number of people who would experience coastal flooding by storm surge in 2085 with and without climate change, assuming that populations would be attracted preferentially to the coast,⁶ and "evolving" protection with a 30-year lag time. The low and high end of the ranges for PAR for each entry in table 4 assume low and high subsidence due to human causes unrelated to climate change.

Nicholls (2004) makes a creditable effort to incorporate improvements in adaptive capacity due to increasing wealth. Nonetheless, some of its assumptions are questionable. For instance, it allows societies to implement measures to reduce the risk of coastal flooding in response to 1990 surge conditions but ignores conditions caused by subsequent rises in sea level (Nicholls, 2004: 74). But one would expect that whenever any measures are implemented, society would consider the latest available data and information on the surge situation at the time the measures are initiated. That is, if the measure is initiated in, say, 2050, the measure's design would at least consider both the sea level and *trends* in the sea level as of 2050, rather than merely the 1990 level. Nicholls also allows for a constant lag time between a rise in sea level and a society's initiating protection. But one should expect that if sea level continues to rise, the lag between upgrading protection standards and higher GDP per capita will be reduced over time. Moreover, it is conceivable that the richer a society, the faster this reduction. In fact, if future empirical data confirms that trends in the rise in sea level are robust, it is possible that protective measures may be taken in advance, i.e., that lag times may even become negative, even under a "business-as-usual" world.

In addition, Nicholls (2004) does not allow for any deceleration in the preferential migration of the population to coastal areas, which is not unlikely if coastal flooding becomes more frequent and costly. Alternatively, if the preferential migration continues unabated, a country's expenditures on coastal protection might increase because its coastal population increases relative to its total population, an outcome that would be consistent with democratic governance.

6 The scenario of high growth in coastal populations assumes that coastal population grows twice as fast as the general population or, if populations are projected to drop, it drops at half the pace of the general population (Nicholls, 2004: table 6).

Table 4: Population at risk (PAR) in 2085 for coastal flooding with and without further sea-level rise (SLR) induced by climate change

Baseline 1990	A1FI 2085	A2 2085	B2 2085	B1 2085
Population at risk in the absence of climate change (P_0) (millions)				
10 (0.2%)	1 to 3 (0.0% to 0.0%)	30 to 74 (0.2% to 0.5%)	5 to 35 (0.0% to 0.3%)	2 to 5 (0.0% to 0.1%)
Additional population at risk because of climate change (ΔPAR) (millions)				
NA	10 to 42 (0.1% to 0.5%)	50 to 277 (0.4% to 2.0%)	27 to 66 (0.3% to 0.6%)	3 to 34 (0.0% to 0.5%)
Total population at risk (TPAR = P_0 + ΔPAR) (millions)				
10 (0.2%)	11 to 45 (0.1% to 0.6%)	80 to 351 (0.6% to 2.5%)	32 to 101 (0.3% to 1.0%)	5 to 39 (0.0% to 0.5%)

Note: For coastal flooding, PAR is measured as the average number of people who experience flooding each year by storm surge or “average annual people flooded” (AAPF). The low (high) end numbers are based on an assumption of low (high) subsidence. Figures in parentheses are in percent of global population.

Source: Nicholls, 2004.

Nicholls (2004: table 7) also suggests that subsidence is more likely under the A1FI and A2 worlds than the B1 and B2 worlds. Although this assumption conforms with the SRES's storylines regarding the priority given to environmental issues, it contradicts real-world experience, which indicates that once richer countries are convinced of a problem, whether it is environment or related to health, they generally respond quicker to remedy the problem, spend more, and have greater environmental protection than poorer ones, especially at the high levels of development that are projected (table 1) to exist virtually everywhere later this century under all the IPCC's scenarios (see also Goklany, 2002). Hence, one should expect that the richest (A1FI) world would spend more and be better protected from whatever subsidence occurs, than would the B1 (and A1 and B2) worlds.

Putting aside these shortcomings, the information in table 4 shows that in the absence of climate change, the PAR for coastal flooding in 2085 under the A1FI and B1 worlds would be lower than what it was in 1990, but it would be higher under the A2 world; and it may or may not be higher under the B2 world. With climate change, the PARs would increase under each scenario, with A2 having the highest total PAR by far, followed, in decreasing order, by B2, and perhaps A1FI and B1. Notably, the difference in PAR between A1FI and B1 scenarios is not very large, despite the several assumptions that downplay the adaptive effects of wealth.

Malaria

The report by van Lieshout et al. (2004) on the FTA's analysis for malaria only provides estimates for changes in global PAR due to climate change (i.e., Δ PAR) but not for PARs in the absence of climate change or for total PARs with climate change.⁷ But we saw in table 2 that the scenario with the highest Δ PAR does not always have the highest total PAR and that the latter is a more relevant measure of human well-being. Thus, the analysis by van Lieshout et al. sheds no light on whether well-being (as measured by the total PAR for malaria) would be greater in a richer but warmer world than in poorer but cooler worlds.

Accordingly, to compare the relative contributions to PAR from climate change and factors unrelated to climate change, I use the results of an earlier (pre-SRES) version of the Fast Track Assessment of the global impact of climate change (Martens et al., 1999; Arnell et al., 2002) that was also sponsored by DEFRA. That earlier analysis used a "business-as-usual" scenario, the so-called IS92a scenario, which was developed for the 1995 IPCC impact assessment. It neither included any additional greenhouse-gas controls nor allowed for any adaptation. Under this scenario, the global population and average GDP per capita in 2085 were projected at 10.7 billion and \$17,700 (in 1990 US\$). The UK Meteorological Office's HadCM2 model projected that, under this scenario, the globally averaged temperature would increase by 3.2° C between 1990 and 2085 (Parry et al., 2001), which approximates the temperature increase using HadCM3 under the A2 scenario (see table 1).⁸

The results from the study by Arnell et al. (2002) for malaria are summarized in table 5. It indicates that the global population at risk of malaria transmission in the absence of climate change (P_0) would double from 4,410 million in 1990 to 8,820 million in 2085, while Δ PAR in 2085 would be between 256 million and 323 million.⁹ In other words, climate change would contribute only a small portion (no greater than 3.5%) of the total PAR for malaria in 2085 (Goklany, 2005).

7 The author contacted various co-authors of the paper by van Lieshout et al. to obtain their results for PAR with and without climate change, but to no avail.

8 HadCM2 and HadCM3 are general circulation models used to project climate under different concentrations of CO₂. These models were developed at UK's Hadley Centre, Bracknell, England; the latter is an update of the former. Further details on these can be obtained from the IPCC Data Distribution Center at http://www.ipcc-data.org/is92/hadcm2_info.html and http://cera-www.dkrz.de/IPCC_DDC/IS92a/HadleyCM3/hadcm3.html.

9 While these estimates for the numbers of people at risk from malaria (with and without climate change) are taken directly from Arnell et al., 2002, they seem excessive given that they imply that 83% to 85% of all inhabitants on the globe are at risk.

Table 5: Population at risk (PAR) in 2085 for malaria, with and without further climate change

	Baseline 1990	2085
Population at risk in the absence of climate change (P_0) (millions)	4,410	8,820
Additional population at risk because of climate change (ΔPAR) (millions)	NA	256 to 323
Total population at risk (TPAR = P_0 + ΔPAR) (millions)	4,410	9,076 to 9,143

Note: This table is based on a pre-SRES scenario. HadCM2 estimates that, under this scenario, globally averaged temperature will increase about 3.2° C. between 1990 and 2085.

Source: Arnell et al., 2002.

Note that the current range of malaria is dictated less by climate than by human adaptability. Despite any global warming that might have occurred so far, malaria has been eradicated in richer countries although it was once prevalent there in earlier centuries, and sometimes extended into Canada and as far north as the Arctic Circle (Reiter, 2000; Fallis, 1984; Watson 2006). This is because wealthier societies have better nutrition, better general health, and greater access to public health measures and technologies targeted at controlling diseases in general and malaria in particular. In other words, today's wealthier and more technologically advanced societies have greater adaptive capacity and that is manifested in the current geographic distribution of malaria around the globe (Goklany, 2006). This reaffirms the importance of incorporating adaptive capacity—and changes in adaptive capacity due to economic growth and technological change—into impact assessments. In fact, analysis by Tol and Dowlatabadi (2001) suggests that malaria is functionally eliminated in a society whose annual per-capita income reaches \$3,100. But as shown in table 1, even under the poorest (A2) scenario, the average GDP per capita for developing countries is projected to be \$11,000. Hence, few, if any, countries ought to be below the \$3,100 threshold in 2085. In addition, given the rapid expansion in our knowledge of diseases and development of the institutions devoted to health and medical research, the \$3,100 threshold will almost certainly drop in the next several decades as public-health measures and technologies continue to improve and become more cost effective.

5 Ecological changes from 2085 to 2100, with and without climate change

In table 6, I provide information on the variation in three specific ecological indicators across the different scenarios: net biome productivity (a measure of the terrestrial biosphere's net carbon sink capacity); the area of cropland, a crude measure of the amount of habitat converted to agricultural uses (perhaps the single largest threat to global terrestrial biodiversity) (Goklany, 1998); and the global loss of coastal wetlands relative to 1990. Under each scenario the biosphere's sink capacity is higher in 2100 than in 1990 mainly because, according to the projections, the positive effect of carbon fertilization will not be offset by the negative effects of higher temperatures. Sink capacities under the A1FI and A2 scenarios are approximately the same in 2100, and greater than the sink strengths under the B1 and B2 scenarios. Partly for the same reason and also because of its low population, the amount of cropland is lowest for the A1FI world, followed by the B1 and B2 worlds (estimates of cropland were not provided for the A2 scenario). Thus, through the foreseeable future, the A1FI scenario would have the least habitat loss and, therefore, pose the smallest risk to terrestrial biodiversity from this particular threat, while the B2 scenario would have the highest habitat loss.

The estimated losses of coastal wetlands due to sea-level rise (SLR) for each scenario are substantial but the contribution of climate change to total losses in 2085 are smaller than losses due to subsidence from other man-made causes, confirming the results of earlier studies (Nicholls, 1999). Table 6 shows that total wetland losses are much higher for the A1FI and A2 scenarios than for the B1 and B2 scenarios but this is due mainly to the assumption that the first two scenarios would have higher subsidence unrelated to climate change (Nicholls 2004: 76), an assumption that, as noted, is suspect.

6 Is climate change the most important environmental problem for the foreseeable future?

A recent review paper in *Nature* claims that global warming may have been responsible for about 0.17 million deaths worldwide in 2000. This estimate is based on an analysis by McMichael et al. (2004) put out under the auspices of the World Health Organization. However, its authors themselves acknowledge that

climate change occurs against a background of substantial natural climate variability, and its health effects are confounded by simultaneous changes in many other influences on population health ... Empirical

Table 6: Ecological indicators under different scenarios, 2085–2100

Baseline 1990	A1FI	A2	B2	B1
CO₂ concentration (in 2100) (ppm)				
353	970	856	621	549
Net biome productivity with climate change (in 2100) (Pg C/yr)				
0.7	5.8	5.9	3.1	2.4
Area of cropland with climate change (in 2100) (% of global land area)				
11.6%	5.0%	NA	13.7%	7.8%
Global losses of coastal wetlands in 2085				
<i>Losses due to SLR alone (% of current area)</i>				
N/A	5 to 20%	3 to 14%	3 to 15%	4 to 16%
<i>Losses due to other causes (% of current area)</i>				
N/A	32 to 62%	32 to 62%	11 to 32%	11 to 32%
<i>Combined losses (% of current area)</i>				
N/A	35 to 70%	35 to 68%	14 to 42%	14 to 42%

Sources: Arnell et al., 2004; Nicholls, 2004; Levy et al., 2004.

observation of the health consequences of long-term climate change, followed by formulation, testing and then modification of hypotheses would therefore require long time-series (probably several decades) of careful monitoring. *While this process may accord with the canons of empirical science, it would not provide the timely information needed to inform current policy decisions on GHG emission abatement, so as to offset possible health consequences in the future.* (McMichael et al., 2004: 1546, emphasis added).

In other words, the estimate of 0.17 million deaths should be taken with a large dollop of salt since science was admittedly sacrificed in hot pursuit of a pre-determined policy objective. But, absent serendipity, one cannot base sound policy on poor science.

Nevertheless, for the purposes of this chapter, I will accept this problematic estimate at face value. Notably, 0.17 million deaths per year would constitute 0.28% of global mortality, according to the *World Health Report 2002* (WHO, 2002). The same report indicates that climate change is not even among the top 10 global health-risk factors related to food, nutrition, and

environmental and occupational exposure. Specifically, it attributes 1.12 million deaths in 2001 to malaria; an additional 3.24 million deaths to malnutrition;¹⁰ 1.73 million deaths due to unsafe water, and inadequate sanitation and hygiene; 1.62 million deaths due to indoor air pollution from indoor heating and cooking with wood, coal, and dung; 0.8 million to urban air pollution; and 0.23 million to lead exposure. Climate change is clearly not the most important environmental problem facing the world today.

Is it possible, however, that in the foreseeable future, the impact of climate change on public health could outweigh that of other factors? To shed light on this question, I will translate the PAR and Δ PAR in 2085 shown in tables 2, 4, and 5 for hunger, coastal flooding, and malaria into “ball park” estimates for mortality, assuming that mortality due to the various threats scales linearly with PAR between 1990 and 2085 and that there has been no change in mortality for these threats between 1990 and 2001.¹¹ The results are shown in table 7.

In this table M_0 is the mortality in the absence of climate change, while ΔM is the incremental change in mortality due to climate change. This table shows that, *for each scenario*, hunger is responsible for a greater burden of mortality than coastal flooding and the total burden due to factors unrelated to climate change substantially exceeds that due to climate change.

These results, in conjunction with those from table 6, indicate that climate change is unlikely to be the most important environmental problem confronting human or environmental well-being, at least through the foreseeable future.

10 This estimate excludes an estimated 0.51 million people who died from malaria but whose deaths were attributed in the report to their being underweight (WHO, 2002).

11 This assumption is necessary because data on mortality from hunger and malaria are not readily available for 1990. According to FAO (2004), the number of people suffering from chronic undernourishment in the developing countries was virtually unchanged between 1990/1992 and 2000/2002 (going from 824 million to 815 million in developing countries between these two periods). According to WHO (1995), malaria killed 2 million in 1993 (compared to 1.12 million in 2001). Thus, to the extent that the ratio of deaths-to-PAR may have declined between 1990 and 2001, future deaths due to malaria would be underestimated. Finally, according to EM-DAT (2005), there were 7,100 fatalities due to floods, windstorms, and waves/surges in 1990 and an average of 7,500 for the period from 2000 to 2004 (excluding deaths due to the Christmas tsunami of 2004). Table 7 assumes: (a) an estimate of 8,000 deaths in 1990 due to these extreme weather event categories, and (b) that all deaths for these categories are due to coastal flooding. Thus table 7 underestimates the relative importance of malaria compared to the other threats, while overestimating future deaths as a result of coastal flooding.

Table 7: Deaths (in thousands) in 2085 due to various climate-sensitive threats, with and without further climate change

	Baseline 1990	A1FI 2085	A2 2085	B2 2085	B1 2085	IS92a 2085
Hunger						
M_0	3240	404	2845	892	364	
ΔM	N/A	108	-104 to -33	-42 to 19	40	
<i>Total mortality</i>	3,240	512	2,741 to 2,812	850 to 911	404	
Coastal flooding						
M_0	8	1 to 2	24 to 59	4 to 28	2 to 4	
ΔM	N/A	8 to 34	40 to 222	22 to 53	2 to 27	
<i>Total mortality</i>	8	9 to 36	64 to 281	26 to 81	4 to 31	
Malaria						
M_0	1120					2240
ΔM						82
<i>Total mortality</i>						2322

M_0 = mortality in the absence of climate change; ΔM = change in mortality due to climate change.

Hunger: 1990 baseline mortality based on WHO, 2002; M_0 and ΔM calculated from table 2.

Coastal flooding: 1990 baseline from EM-DAT; M_0 and ΔM calculated from table 4.

Malaria: 1990 baseline from WHO, 2002; M_0 and ΔM calculated from table 5.

7 Is a richer but warmer world worse off than poorer but cooler worlds?

In table 8, I rank the four SRES scenarios for the year 2085 using the various indicators of human and environmental well-being that were addressed above. Rankings shown in the top portion of the table are based on indicators of human well-being, namely, wealth (for which GDP per capita is a surrogate), hunger, water stress, and coastal flooding, using data from tables 1 to 4. Rankings are provided separately for the scenarios both without and with climate change.

Table 8: Ranking of scenarios in order of future well-being per each indicator, 2085–2100

	Without climate change				With climate change			
	A1FI	A2	B2	B1	A1FI	A2	B2	B1
Indicators of human well-being								
<i>GDP/capita</i>								
	1	4	3	2	1	4	3	2
<i>Hunger (PAR in 2085)</i>								
	2	4	3	1	2	4	3	1
<i>Water stress (PAR in 2085)</i>								
	1.5	4	3	1.5	1	4	3	2
<i>Coastal flooding (PAR in 2085)</i>								
	1	4	3	2	2	4	3	1
Indicators of environmental quality								
<i>Terrestrial carbon sink capacity (in 2100)</i>								
					1.5	1.5	3	4
<i>Cropland area (in 2100)</i>								
					1	N/A	3	2
<i>Coastal wetland area (in 2085)</i>								
					3.5	3.5	1.5	1.5

Note: “1” indicates the best level of well-being while “4” indicates the worst. If two scenarios show the same level of well-being, then they share the same ranking. For example, in the absence of climate change, scenarios A1FI and B1 are both ranked at the top with respect to water stress in 2085. Accordingly, they split the number one and two rankings, and their joint ranking is indicated as 1.5. Sources: Tables 1 through 7

In the ranking scheme used in table 8, “1” indicates the best level of well-being while “4” indicates the worst. If two scenarios show the same level of well-being, then they share the same ranking. For example, in the absence of climate change, scenarios A1FI and B1 are both ranked at the top with respect to water stress in 2085 (because they both have the same low population in 2085). Accordingly, they split the number one and two rankings, and their joint ranking is indicated as 1.5.

In constructing table 8, I assume that the relative ranking of the scenarios with respect to GDP per capita will be maintained despite any climate change. This is likely because the gaps in GDP per capita from one scenario to the next are quite large (see table 1) and the impacts of climate change are relatively small from 2085 to 2100. Consider that under the A1FI scenario, the

average GDP per capita for developing countries in 2100 is 65% higher than under the B1 scenario (that with the next highest GDP per capita). It is unlikely that any drop in income levels by 2100 due to climate change will close this gap (IPCC, 2001). Moreover, the other entries in table 8 suggest that the drop in GDP per capita due to climate change will be largest for the A2 world and least for the A1FI world (because these scenarios are likely to result in climate change having the smallest and largest impact on human well-being, respectively). Hence, if there is any re-ordering of the rankings for GDP per capita, it would probably be due to B2 and B1 trading places (because B1 is wealthier and, therefore, likely to have greater adaptive capacity; see table 1)

Table 8 suggests that human well-being in 2085 would, in the aggregate, be highest for the A1FI scenario and lowest for A2. Reinforcing this conclusion is the possibility that compared to the B1 scenario populations at risk for the A1FI scenario might be overestimated (as might the amount of climate change). Applying the same logic and considerations, it would seem that human well-being should be better under B1 than B2. These findings are based on the assumptions that: (a) GDP per capita—or more accurately, the logarithm of GDP per capita (Goklany, 2002, 2006)—should be given greater weight because it is a surrogate for numerous, and more appropriate, indicators of human well-being (e.g., life expectancy, mortality rates, access to safe water and sanitation, and level of educational attainment), and (b) impacts analyses have a general tendency (discussed previously) to underestimate changes in adaptive capacity as a function of both economic development and technological progress (or time). These aggregate rankings would stay the same whether or not climate changes, or whether they are based on PAR in terms of absolute numbers or the proportion of global population (see tables 1 to 4).

In the last three rows of table 8, I rank scenarios based on the three environmental indicators addressed previously (see table 6). Based on the capacity of the terrestrial carbon sink and cropland area, environmental quality would be superior under the A1FI scenario than under either the B1 or B2 scenarios through 2100, but these rankings would apparently be reversed for coastal wetlands, at least through 2085—“apparently” because, as noted, that could be an artifact of the assumption that subsidence should or would be lower under the B1 and B2 scenarios than the A1FI scenario.

To summarize, the SRES scenario that the IPCC projects will lead to the greatest risk of climate change over the coming century is also the one that leads to the greatest gains in human welfare over that period. And the gains in human welfare from increasing wealth are sufficiently large compared to the FTA's assessment of the risks of climate change that the ranking of scenarios in terms of human well-being does not change by adding in the

impacts of climate change. Notwithstanding climate change, through much of this century human well-being is likely to be highest in the richest but warmest (A1FI) world and lower in poorer but cooler worlds. Consequently, even if proponents of aggressive controls on greenhouse gases are correct in their view of the environmental impact of greenhouse gases, human welfare could be worsened by policies that would sacrifice economic growth over the next several decades in order to pursue poorer but cooler worlds. With respect to environmental well-being, matters may be best under the richest but warmest world for some critical environmental indicators through 2100, though not necessarily for all.

8 Comparing the costs and benefits of mitigation against those of adaptation

The foregoing assumes that climate change does not create major new classes of problems but rather mostly exacerbates existing ones, such as malaria, hunger, coastal flooding, water stress, and various threats to biodiversity. Hence, the magnitude of the total problem ($P_o + \Delta P$) will generally exceed the contribution of climate change to that problem (ΔP). Consequently, policies that would reduce the total problem itself are more likely to enhance human well-being than policies that would try to mitigate climate change. Equally important, measures that would reduce the vulnerability to the portion of the problem unrelated to climate change (P_o) could also reduce the component due to climate change (ΔP).

For example, a strategy to reduce society's vulnerability to malaria through, say, the development of a malaria vaccine, would reduce the risk faced by the entire population at risk for malaria in 2085, which is estimated to be 9,143 million (table 5). On the other hand, a policy to mitigate climate change would at most reduce risks to 323 million people (i.e., ΔP) or 3.5% of the total problem in 2085. Thus strategies that would reduce the total problem are more likely to advance human well-being with regard to malaria than any mitigation policy, regardless of how deep the mitigation efforts (Goklany, 2005).

8.1 Mitigation

In table 9, I show the decreases in total populations at risk (TPAR) from malaria, hunger, water stress, and coastal flooding, as well as decreases in global average temperature and in sea-level rise that would be obtained under the A1FI, A2, and the IS92a scenarios in 2085 using two mitigation scenarios at either end of the spectrum in terms of stringency, namely, the Kyoto Protocol at

Table 9: Decline in total population at risk, temperature, and sea level rise in 2085 under the Kyoto Protocol and no-climate-change scenarios using A1FI, A2, and IS92a emission scenarios

	A1FI		A2		IS92a	
	Kyoto Protocol	No climate change after 1990	Kyoto Protocol	No climate change after 1990	Kyoto Protocol	No climate change after 1990
Decline in total population at risk						
<i>Malaria</i>					0.2%	3.5%
<i>Hunger</i>	1.5%	21%	-0.1% to -0.3%	-1.2% to -3.8%	1.5%	21%
<i>Water stress</i>	-5.0%	-72%	-2.5% to 0%	-35% to 0	-4.1% to 0.8%	-59% to -12%
<i>Coastal flooding</i>	19% to 20%	91% to 93%	13% to 17%	63% to 79%	18%	86%
Decline in ΔT (°C)						
	0.3°	4.0°	0.2°	3.3°	0.2°	3.2°
Decline in sea level rise (cm)						
	2	34	2	28	3	41

Note: ΔT is the globally averaged temperature rise between 1990 and 2085, assuming no mitigation. SLR is the sea level rise induced by climate change between 1990 and 2085, assuming no mitigation. Sources: Tables 1 to 5; Goklany, 2005.

the low end of effectiveness and cost and, at the high end, a scenario that would ensure no climate change beyond 1990 levels. These decreases are shown relative to the unmitigated case, that is, no emission controls whatsoever.

Information on the two SRES scenarios is derived from tables 2 to 4, while that for IS92a is based on Arnell et al. (2002). To construct this table, I optimistically assume that by 2085 the Kyoto Protocol would reduce climate change, as represented by the changes in global temperature and sea level, by 7%, which would then reduce the impacts of climate change on malaria, hunger, and water stress by a like amount, and the impacts of coastal flooding by 21% (Goklany, 2005).¹²

¹² This is based on Wigley (1998) which estimates that if the Kyoto Protocol were to be fully implemented that would reduce the amount of warming in the 2080s by no more than 7%, which, then, should also reduce ΔPAR for hunger, malaria and water stress by approximately

In the following discussion, I will assume that the Kyoto Protocol will cost \$165 billion per year in 2010.¹³ On the other hand, the cost of the no-climate-change scenario, assuming that it is even feasible, would be astronomical.

Malaria

In 2085, even the most drastic reduction in emissions (i.e., the no-climate-change scenario) would not reduce total PAR for malaria by more than 3.5%. Reductions under the Kyoto Protocol would be marginal at 0.2%, despite its considerable cost.

Hunger

The maximum reduction possible in total PAR for hunger through mitigation would be 21% under both the A1FI and IS92a scenarios; however, under the A2 scenario, mitigation might, perversely, increase the total PAR. Again, changes, whether positive or negative, would be minimal under the Kyoto Protocol. But while the contribution of climate change to total PAR seems large, it results from a small (1.9%) climate-change-related drop in future global food production between 1990 and 2085 (Parry et al., 2004). In other words, unmitigated warming would reduce the annual growth in food productivity from 0.84% per year to 0.82% per year.

Water stress

Mitigation would, more likely than not, increase the total PAR for water stress because, as table 3 shows, climate change may reduce the PAR. This also illustrates one of the major shortcomings of mitigation, namely, that it is indiscriminate, reducing all impacts, whether they are positive or negative.

7%, and by thrice that (21%) for coastal flooding. The latter two assumptions are derived from a visual inspection of Figure 1 in Parry et al. (2001), which is based on an earlier version of the FTA (see Goklany, 2003). That figure suggests that the dependence of Δ PAR on the increase in temperature is linear or less-than-linear for each of the risk factors except coastal flooding, for which the dependence is closer to quadratic or even cubic. The 21percent change in Δ PAR for coastal flooding owing to a 7% change in temperature (Δ T) assumes that the dependence is cubic. As will become evident, the precise functional form does not affect the validity of the arguments or conclusions in this paper.

- 13 IPCC (2001) estimates that in 2010 the Protocol could cost between 0.1% and 2.0% of the GDP of Annex I countries. I will assume that its cost is 0.5% of their cumulative GDP, which is at the lower end of this range. This translates to \$165 billion (in 2003 dollars). See Goklany, 2005.

Coastal flooding

In contrast with the other threats listed on table 9, mitigation would substantially reduce the total PAR for coastal flooding—by as much as 93% under the no-climate-change scenario and 19% to 20% under Kyoto Protocol.

8.2 Reducing current vulnerabilities via focused adaptation

Measures that are focused on reducing current vulnerabilities to these climate-sensitive threats—or “focused adaptation,” for short—would provide greater aggregate benefits than halting climate change—a practically impossible task—at a fraction of the cost even of the inconsequential Kyoto Protocol.

Malaria

At an additional cost of \$3 billion per year, malaria's current global death toll of about one million per year can be reduced by 75%, according to the UN Millennium Project (UNMP). These expenditures may have to be doubled by 2085 to keep pace with the projected increase in the global population at risk in the absence of climate change (see table 5).

Adaptations focused on reducing current vulnerabilities to malaria include measures targeted specifically at malaria as well as measures that would generally enhance the capacity to respond to public-health problems and deliver public-health services more effectively and efficiently. Measures targeted specifically at malaria include indoor residual (home) spraying with insecticides, insecticide-treated bednets, improved case management, more comprehensive antenatal care, and development of safe, effective, and cheap vaccine(s) and therapies (WHO, 1999; UNMP, 2005b). Moreover, if these measures are even partly successful, they could further reduce the likelihood of outbreaks because the risk of exposure would be lower.

Hunger

An additional \$5 billion annual investment in agricultural R&D—approximately 15% of global funding of agricultural research and development during the 1990s (Goklany, 2005)—should raise productivity sufficiently to more than compensate for the 0.02% annual shortfall in productivity caused by climate change. This should reduce total PAR by significantly more than the largest estimate under any scenario for Δ PAR of 21% (see table 2), particularly if the additional investment is targeted toward solving developing countries' current agricultural problems that might be further exacerbated by warming.

An alternative cost estimate can be derived from the work of the UN Millennium Project, which estimates that somewhere between 5% and 8%

of the extra funding needed to realize the Millennium Development Goals would be required to reduce global hunger by 50% in 2015 (UNMP, 2005c: 18). This works out to less than \$12 billion in 2010 and about \$15 billion in 2015 (calculated using UNMP, 2005c and UNMP, 2005a: 57). I will for purposes of this discussion assume \$15 billion per year.

Current agricultural problems that could be exacerbated by warming and should be the focus of vulnerability-reduction measures include growing crops in poor climatic or soil conditions (e.g., low soil moisture in some areas, too much water in others, or soils with high salinity, alkalinity, or acidity). Because of warming, such conditions could become more prevalent, agriculture might have to expand into areas with poorer soils, or both. Thus actions focused on increasing agricultural productivity under current marginal conditions would alleviate hunger in the future whether or not climate changes. Similarly, since both CO₂ and temperatures will, like it or not, increase, crop varieties should be developed to take advantage of such conditions as, and when, they come to pass. Notably, in the initial stages at least, progress on these approaches does not depend on improving our skill in forecasting details of the impact of climate change in particular locations. These measures of focused adaptation should be complemented by development of crop varieties and agronomic practices giving higher yields with lower impact so that more food is produced and used by consumers per unit of land or water devoted to food production. This would help reduce hunger while providing numerous ancillary benefits for biodiversity and sustainable development (see below).

Water stress

Although climate change could relieve water stress (table 9), there are, nevertheless, many measures that would help societies cope with present and future water stress regardless of their cause. These include institutional reforms to treat water as an economic commodity by allowing market pricing and transferable property rights to water. This should stimulate widespread adoption of existing but underused conservation technologies and lead to more private-sector investment in R&D that would reduce the demand for water by all sectors. For example, new or improved crops and techniques for more efficient use of water in agriculture would enhance agricultural productivity and reduce the risk of hunger.

Improvements in water conservation following such reforms are likely to be most pronounced for the agricultural sector, which is responsible for 85% of global water consumption. A reduction of 18% in agricultural water consumption would, on average, double the amount of water available for all other uses, including household, industry, and in-stream uses (such as rec-

reation and conservation of aquatic species). The last would reduce pressures on freshwater biodiversity as a result of water diversion, which is the greatest threat to freshwater biodiversity (Goklany, 2005).

Coastal flooding

According to estimates provided in IPCC (1996), an annual investment of \$1 billion per year is sufficient to adapt to a sea-level rise of 0.5 meter in 2100. Considering that the sea-level rise under the various SRES scenarios is estimated at between 0.22 and 0.34 meter for 2085, this ought to reduce the total PAR by more than Δ PAR regardless of the specific scenario (table 1). Governments could, moreover, discourage maladaptation by refusing to subsidize insurance and protective measures that allow individuals to off-load private risks to the broader public.

The benefits of focused adaptation

Thus, at a cost of less than \$22 billion per year, focused adaptation could deliver far greater benefits than would halting climate change, at less than a seventh of the cost of the Kyoto Protocol. And it will not only reduce present-day, climate-sensitive problems, it will also help reduce these problems in the future, whether they are caused by climate change or other factors. This is because the technologies, practices, systems, and human and social capital devised to cope with these problems today will aid societies in coping with these problems in the future. Such focused adaptation can be implemented without detailed knowledge of the impacts of climate change. Cases in point are the development of malaria vaccines, drought resistant crops, or transferable property rights for water resources, or development of early warning systems for climate-sensitive events ranging from storms to potential epidemics of various kinds.

Further, focused adaptation will start to provide a steady stream of benefits in the very near term while, because of the inertia of the climate system, the benefits of mitigation will not be significant until decades have elapsed. One might, nevertheless, argue that under the precautionary principle it would be appropriate to pursue mitigation. Such an argument would be valid but for the fact that there are plenty of unsolved problems that afflict current generations that could use the economic and human resources that might otherwise be diverted toward aggressive mitigation (in contrast to “no-regret” mitigation measures¹⁴ that would help solve current urgent

14 “No-regret” actions are cost-beneficial actions that would or should be undertaken for economic or environmental reasons unrelated to climate change. Examples of no-regret actions

problems while also limiting greenhouse emissions). In fact, focused adaptation can itself be viewed as a no-regret action since, as we have seen, it can substantially reduce existing problems such as hunger and malaria that currently beset the developing world while simultaneously helping ensure that the world prepares to cope with the future impacts of climate change.

The indiscriminate effect of mitigation and the ancillary benefits of adaptation

Mitigation has the additional problem that it indiscriminately reduces all impacts of climate change, whether they are positive or negative. But adaptation can selectively capture the positive aspects of climate change while reducing the negative. And while the impacts of global warming are uncertain, there is no doubt that malaria, hunger, water stress, and coastal flooding are real and urgent problems here and now. Thus, focused adaptation is far more likely to deliver benefits than is mitigation, and to deliver those benefits sooner rather than later.

Co-benefits (or ancillary benefits) of adaptation focused on reducing vulnerability to malaria and hunger include better health, increased economic growth, and greater human capital, which should advance human well-being and the capacity to address a much wider variety of problems, in addition to climate change (Goklany, 2000, 2006; UNMP, 2005a). These co-benefits, in fact, are among the goals and purposes of sustainable development, as explicitly articulated in the Millennium Development Goals.

Several measures to reduce current hunger and water stress would also provide co-benefits by enhancing agricultural productivity per unit of land and water. In turn, that would reduce human demand for agricultural land and water, which is the greatest current threat to both terrestrial and freshwater biodiversity, and is likely to remain so through the foreseeable future (Goklany, 1998, 2000). It would also aid mitigation by limiting land under cultivation, thereby reducing losses of carbon stores and sinks, and reduce the socioeconomic costs of reserving land for conservation or carbon sequestration. These co-benefits would, moreover, advance sustainable development in their own right.

Finally, the conclusion that focused adaptation is for the foreseeable future superior in terms of both global benefits and global costs is robust to the choice of

include elimination of subsidies, replacement of inefficient processes or appliances for business reasons, or replacement of coal with natural gas in order to reduce air pollution. Note that the suite of no-regret actions is constantly expanding as societies' technological options increase due to greater wealth and technological change. Thus, an action that does not fit that description today may appropriately be classified as a no-regret action tomorrow.

discount rates,¹⁵ including a zero discount rate. This is because the benefits of focused adaptation will generally follow relatively soon after its costs are incurred. On the other hand, the climate system's inertia ensures that costs of emission reductions will have to be borne for decades before any benefits accrue.

9 Integrating mitigation, adaptation, and sustainable development

The foregoing examined two approaches to address warming through the foreseeable future. The first, mitigation, would reduce impacts—positive and negative—across the board. This entails significant near-term costs and the pay-off, if any, will be delayed far into the future. The second approach, focused adaptation, would reduce vulnerability to climate-sensitive effects now and to 2085 by focusing on the individual threats and attacking these threats simultaneously.

Developing countries are most vulnerable to warming, not because they will experience greater climate change, but rather because they lack adaptive capacity to cope with its impacts. Hence, a third approach to addressing climate change would be to enhance their adaptive capacity by promoting economic development and the formation of human capital, which, of course, is the point of sustainable development. Moreover, since the determinants of adaptive and mitigative capacity (IPCC, 2001; Yohe 2001) are largely the same, enhancing the former should also boost the latter (Goklany, 1995, 2006). Thus, pursuit of sustainable development would simultaneously advance the capacity to adapt to, or mitigate, climate change. Perhaps more important, that would also advance society's ability to cope with all other manners of threats, whether it is related to climate or not.

One approach to estimating the costs and benefits of sustainable development is to examine the literature on the Millennium Development Goals, which were devised explicitly to advance sustainable development in developing countries. The benefits associated with these goals—halving global poverty, hunger, lack of access to safe water and sanitation; reducing child and maternal mortality by 66% or more; universal primary education; and reversing growth

15 Discount rates are used to compare costs and benefits that might occur in the future to costs and benefits that occur now. The premise behind discounting is that the value of costs and benefits are worth more if they occur now as opposed to some time in the future. The discount rate reflects the time value of money. The higher the discount rate, the lower is the present value of future costs and benefits. Frequently costs are concentrated in early periods of a program while benefits follow later. There is much debate regarding the appropriate choice of discount rates since its magnitude influences whether or not early costs will be outweighed by future benefits.

in malaria, AIDS/HIV, and other major diseases—would generally exceed the benefits flowing from focused adaptation or even the deepest mitigation (see table 10). Yet, according to the UN Millennium Project (2005), the additional annual cost to the richest countries of attaining the Millennium Development Goals by 2015 is pegged at about 0.5% of their GDP. That is approximately the same cost as that of the ineffectual Kyoto Protocol.¹⁶

Moreover, since measures to advance sustainable development would address urgent problems that developing nations currently face (e.g., malaria, hunger, HIV/AIDS, and poor access to safe water and sanitation), while mitigation would only address future and less certain damages due to climate change, the benefits associated with sustainable development would be obtained sooner and more certainly than through mitigation alone. In addition, increased adaptive capacity would either raise the level at which GHGs would need to be stabilized to forestall warming from becoming “dangerous” or allow mitigation to be postponed, or both. In any case, costs associated with any eventual stabilization of greenhouse gas concentrations could be reduced, particularly if, in the interim, resources are expended to improve the cost-effectiveness of mitigation options. Advancing sustainable development would also advance mitigative capacity so that mitigation, if it becomes necessary, is more affordable or more effective. In fact, such an approach would be entirely consistent with the objectives outlined in Article 2 of the UN Framework Convention on Climate Change: “to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened, and to enable economic development to proceed in a sustainable manner” (United Nations, 1992: 4).

10 The adaptive management of the risks from climate change

Climate change is not now, nor is it likely to be through the foreseeable future, the most important environmental problem facing the world. As a factor affecting human well-being, it will continue to be outranked by pre-existing problems such as hunger and malaria and, with respect to environmental well-being, by habitat loss and other threats to biodiversity. Through 2085, human well-being is likely to be highest in the richest but warmest world (A1FI) and

¹⁶ Note that the conclusion that broadly and substantially advancing sustainable development would provide greater benefits at lesser costs than mitigation (at least through 2085) is independent of whether the Millennium Development Goals are, in fact, met by 2015. Even if the goals of the Millennium Development Goals were postponed, say, to 2085, as table 10 shows, their benefits would still outweigh those obtainable through mitigation and, presumably, at a lower cost than estimated by UN Millennium Project.

Table 10: Comparing benefits and costs for various risk factors associated with advancing sustainable development, mitigation, and focused adaptation

Dependent on climate change	Reduction in total problem ^a			
	Due to Kyoto Protocol (in 2085)	Due to halt in climate change (in 2085)	Focused adaptation (in 2015)	Due to sustainable development (in 2015) ^h
Malaria^{b, c}				
Yes	0.2%	3.5%	75% ^f	75%
Hunger^{b, c}				
Yes	2%	21%	50% ^d	50%
Water shortage				
Yes	-5%	-72%	+	Not addressed explicitly
Coastal flooding^c				
Yes	~ 20%	~ 92%	>92% ^g	+
Poverty^{b, c}				
Indirect	Unknown, but small	Unknown sign	++ ^{b, e}	50%
Child mortality rate^{b, c}				
Indirect	Small +	+ ^e	++ ^{b, e}	67%
Maternal mortality rate^{b, c}				
Indirect	Small +	+ ^e	++ ^{b, e}	75%
Lack of access to safe water^c				
No	No effect	No effect	No effect	50%
Lack of access to sanitation^c				
No	No effect	No effect	No effect	50%
Lack of primary education^{b, c}				
No	Minor + ^e	Small + ^e	+ ^{b, e}	100%
AIDS, TB^{b, c}				
No	No effect	Zero to small + ^e	+ ^{b, e}	++
Annual costs	~ \$165 billion in 2010	> \$165 billion	~ \$22 billion	~ \$145 billion in 2010

Notes: (a) + denotes a positive reduction in P, while ++ denotes a larger positive reduction. (b) Reductions in malaria and/or hunger should directly or indirectly reduce risks associated with each other, poverty, child and maternal mortality rates, educability, AIDS and TB. (c) Risks associated with these categories should decline with economic development. (d) Assumes same measures to reduce hunger as used to meet Millennium Development Goals. (e) Indirect improvements because hunger/malaria would be reduced under focused adaptation. (f) Assumes \$6 billion per year spent to reduce malaria mortality by 75%. (g) Assumes \$1 billion per year spent on protection (IPCC, 1996a). (h) Assumes costs and benefits match those estimated for the Millennium Development Goals.

Sources: For costs, IPCC, 2001; World Bank, 2005; and UN Millennium Project, 2005a, b, c; for reduction in risks due to mitigation, table 9 using the A1FI scenario for hunger, water stress, and coastal flooding and the IS92a scenario for malaria; for risk reduction due to adaptation and development, UNMP, 2005a, b, c.

lowest in the poorest world (A2). Matters may be best in the A1FI world for some critical environmental indicators through 2100, but not necessarily for others. Either focused adaptation or broad pursuit of sustainable development would provide far greater benefits than even the deepest mitigation—and at a cost less than that of the barely-effective Kyoto Protocol.

These conclusions cast doubt on key premises underlying calls to take aggressive actions now that would go beyond “no-regret” policies in order to reduce GHG emissions in the near term:¹⁷ namely, there is no greater environmental problem in the twenty-first century than climate change, that a richer but warmer world will soon be worse for the globe than a poorer but cooler world, and that the adverse impacts of climate change would be more efficiently and effectively reduced through mitigation rather than adaptation. The above analysis suggests these premises are unlikely to be valid before at least the period between 2085 and 2100. Even assuming that it takes 50 years to replace the energy infrastructure, that means we have a few decades before we need to commit to an aggressive GHG reduction program that goes beyond “no-regrets.”

Only if new information emerges suggesting that the adverse impacts of climate change induced by greenhouse gases are growing more rapidly or are likely to be greater than currently indicated would aggressive mitigation measures become justifiable. The issue is not whether adaptation or mitigation should be the sole approaches to addressing climate change. Clearly, the two approaches are not mutually exclusive. The issue, in fact, is one of the magnitude and relative balance of resources expended on these strategies, and how that balance might shift over time to ensure that well-being is optimized. Accordingly, in the near to medium term, we should focus on the following policies that, together, constitute an adaptive-management approach to addressing climate change. Such an approach would help solve today's urgent problems while bolstering our ability to address tomorrow's climate change challenge.

Increase adaptive capacity

Increase adaptive capacity, particularly of developing countries, by investing in efforts now to reduce vulnerability to today's urgent climate-sensitive problems—malaria, hunger, water stress, flooding, and other extreme events—that might be exacerbated by climate change (Goklany, 1995, 2005). The technologies, human capital, and institutions that will need to be strengthened or developed to accomplish this will also be critical in address-

¹⁷ See footnote 14.

ing these very problems in the future if they are aggravated by climate change. This might also increase the level at which GHG concentrations would need to be stabilized to “prevent dangerous anthropogenic interference with the climate system,” which is the stated “ultimate objective” of the UN Framework Convention on Climate Change.¹⁸ Alternatively, it could postpone the deadline for stabilization. In either case, it could reduce the costs of meeting the ultimate objective.

Strengthen institutions

Strengthen or, where needed, develop the institutions necessary to advance, or remove barriers to. economic growth, human capital and the propensity for technological change. These factors underpin both adaptive and mitigative capacities as well as sustainable development (Goklany, 1995, 2000, 2006).

Adopt “no-regret” mitigation measures

Adopt “no-regret” mitigation measures now while expanding the range and diversity of future no-regret options through research and development to improve existing —and develop new—technologies that would reduce atmospheric concentrations of greenhouse gases in a more cost effective manner than currently possible. Should new information indicate more aggressive mitigative action is necessary, future emission reductions might then be cheaper, even if they have to be deeper to compensate for a delay in a more aggressive response in the short term.

Allow the market to provide options

Allow the market to provide no-regret options as their range expands with improvements in cost effectiveness. Among other things, this implies reducing subsidies that directly or indirectly increase energy use, land clearance, use of fertilizers or other activities that contribute to greater greenhouse gas emissions, and reducing other perverse subsidies that encourage maladaptation. As part of this effort, OECD nations should also reduce, if not eliminate, agricultural subsidies and barriers to trade. Not only are such subsidies and

18 Article 2 of the UN Framework Convention on Climate Change (UNFCCC) specifies that its “ultimate objective ... is to achieve ... stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner” (United Nations, 1992: 4).

barriers expensive for consumers in these nations, they damage the economies and well-being of many developing nations whose economies and employment are dominated by the agricultural sector (Goklany, 1995, 2006).

Develop a more robust understanding of climate change

Develop a more robust understanding of the science and impacts of climate change, and of the policies proposed for dealing with it, in order to find response strategies that would forestall “dangerous” impacts of climate change (per the UNFCCC’s Article 2) while at the same time advancing human well-being.

Monitor the impacts of climate change

Monitor the impacts of climate change to give advance warning of “dangerous” impacts and, if necessary, to rearrange priorities for mitigation and adaptation should the adverse impacts of warming on human and environmental well-being occur faster or threaten to be more severe or more likely than is currently projected.

Priorities for Canada

Consistent with the adaptive-management framework outlined above, Canada should, first, focus on its climate-sensitive sectors like agriculture, timber, water resources, fisheries, and tourism, ensuring that their vulnerability to climate change is reduced even as their ability to take advantage of new opportunities created by climate change is enhanced. Canada should also be prepared to take advantage of new commercial opportunities in trade and natural resources that may arise should the Northwest Passage indeed open up although, given the vagaries of nature, it is probably premature to invest heavily on this in the short term. Second, it should implement “no-regret” policies, such as eliminating natural resource subsidies and other policies that can be justified without necessarily referring to climate change. Third, it should continue to participate in national and international efforts to (a) monitor and research climate, climate change, and their impacts, and (b) research and develop more cost-effective technologies for mitigation and adaptation. Finally, to the extent that Canada funds efforts in developing countries aimed at adapting to climate change, it should direct funds to projects that reduce the vulnerability of these populations to urgent, climate-sensitive problems that may be exacerbated by climate change.

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