

# Is a richer-but-warmer world better than poorer-but-cooler worlds?

Indur M. Goklany<sup>1</sup>

Assistant Director, Science & Technology Policy  
Office of Policy Analysis  
U.S. Department of the Interior  
Washington, DC 20240  
Ph: 202-208-4951; Fax: 202-208-4867  
E-mail: [Igoklany@ios.doi.gov](mailto:Igoklany@ios.doi.gov)

*Greater economic growth could lead to greater greenhouse gas emissions, while simultaneously enhancing various aspects of human well-being and the capacity to adapt to climate change. This begs the question as to whether and, if so, for how long would a richer-but-warmer world be better for well-being than poorer-but-cooler worlds. To shed light on this issue, this paper draws upon results of the “Fast Track” assessment (FTA) reported in a special issue of Global Environmental Change: Part A 14(1): 1-99 (2004), which employed the IPCC’s emissions scenarios to project future climate change and its global impacts on various determinants of human and environmental well-being. Results suggest that notwithstanding climate change, through much of this century, human well-being is likely to be highest in the richest-but-warmest (AIF1) world and lower in poorer-but-cooler worlds. With respect to environmental well-being, matters may be best under the AIF1 world for some critical environmental indicators through 2085-2100, but not necessarily for others.*

## 1. INTRODUCTION<sup>2</sup>

One of the conundrums facing the world, which should be addressed in the course of developing climate change policies, is whether, and, if so, for how long, would a richer-but-warmer world be better for human and environmental well-being than a poorer-but-cooler world. This conundrum arises because, unless climate change is modest (IPCC, 2001; Hitz and Smith, 2004), greater economic growth could, by increasing greenhouse gas (GHG) emissions, lead to greater damages

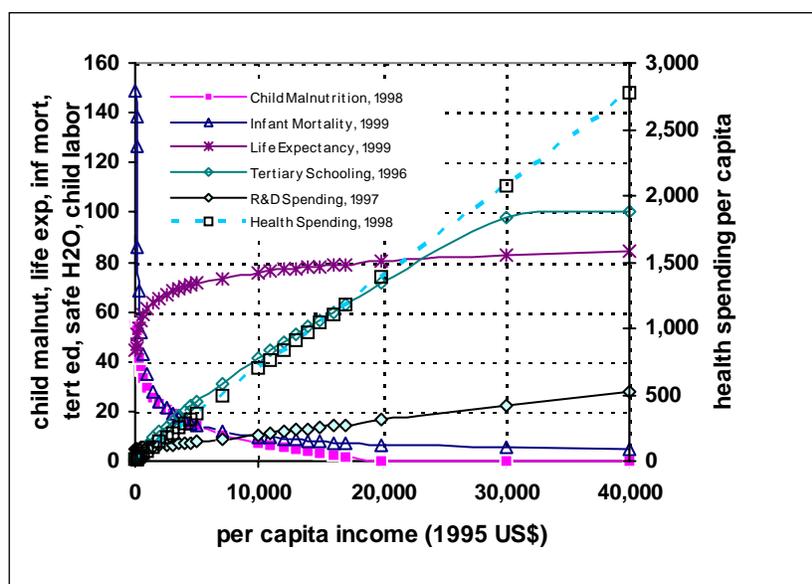
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<sup>1</sup> Views expressed in this paper are the author’s, and not necessarily those of any unit of the U.S. government.

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from climate change. On the other hand, by increasing wealth, technological development and human capital, economic growth would broadly increase human well-being (Goklany, 2002a), and society's capacity to reduce climate change damages via adaptation or mitigation (Goklany, 1995, 2005a; Yohe, 2001; Smit et al., 2001).

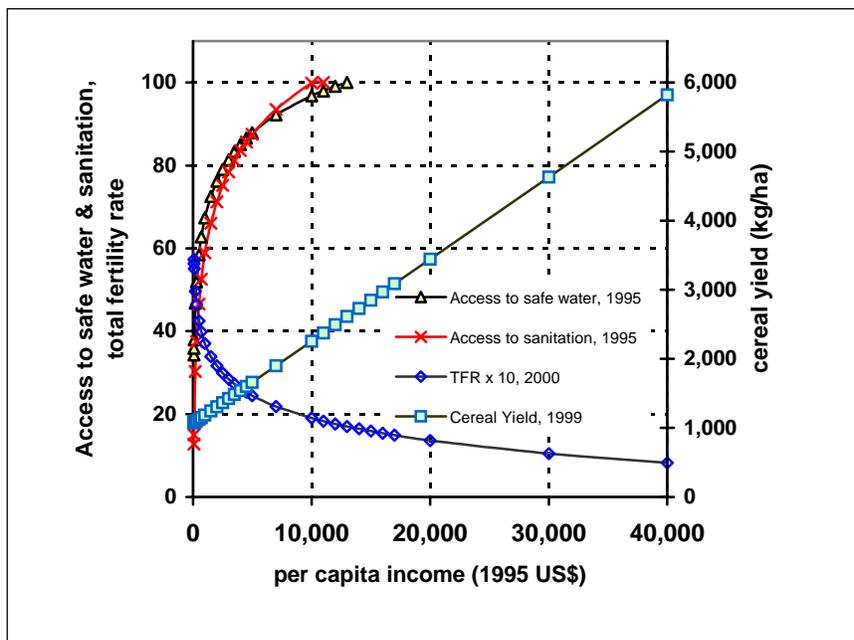
Specifically, many determinants of human well-being — hunger, malnutrition, mortality rates, life expectancy, the level of education, and spending on health care and on research and development — improve along with the level of economic development, as measured by GDP per capita, a surrogate for both per capita income and wealth (or “affluence”) (see Figure 1; Goklany, 2002a). Improvements in these determinants are associated with increased human capital and should aid technological diffusion.



**Figure 1. Dependence of various indicators of human well-being on per capita income for the late 1990s.** Child malnutrition measured as % of children < 5 years with subnormal height, infant mortality is in deaths per 1,000 live births, life expectancy is in years, “tert ed” measures enrollment in tertiary schools (as % of eligible population), R&D spending is in terms of % of GDP, health spending is in 1998 US\$ per capita. Sources: Goklany (2002a, 2005a), based on data from various years of the World Bank’s *World Development Indicators*.

Increasing wealth would also improve some, though not necessarily all, indicators of environmental well-being, e.g., 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 (see Figure 2; Goklany, 2002a, 2005a).<sup>3</sup> 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 means more food and lower hunger (in addition to lower pressure on habitat; Goklany, 1998; Green et al., 2005).



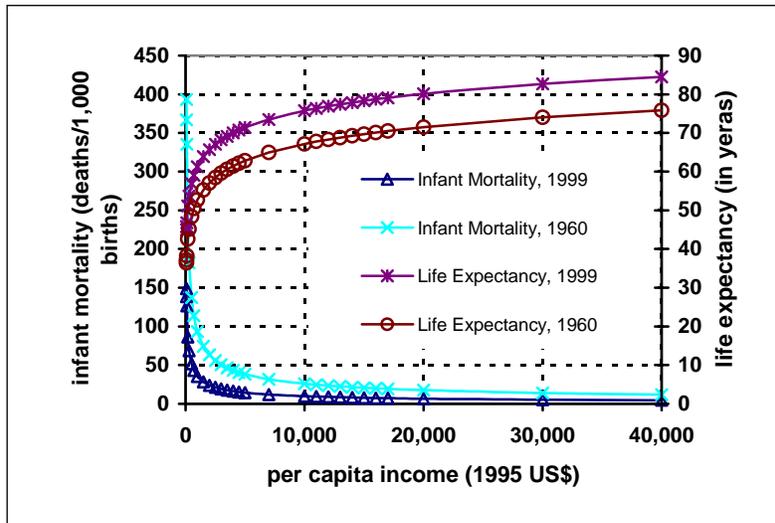
**Figure 2: Dependence of various indicators of environmental well-being on the level of economic development (for the late 1990s).** Sources: Goklany (2002a, 2005a), based on data from various years of the World Bank's *World Development Indicators* and WRI (2000).

Cross country data also indicate that at any given level of economic development, the previously-noted 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, which itself is a surrogate for advances in, and diffusion of, technology (Goklany, 2002a, 2005a).

Figure 3 illustrates this time-dependent (or secular) improvement for two of the most important

<sup>3</sup> One indicator that, so far at least, has not shown an improvement with wealth is CO<sub>2</sub> 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 (see Goklany, 2002a, and references therein).

indicators of human well-being, namely, life expectancy and infant mortality. Thus one should expect, *ceteris paribus*, that society's adaptive capacity should also increase with the passage of time which, barring inadvertent maladaptation, should reduce the future impacts of climate change (Goklany, 2005a).



**Figure 3: Secular (time-dependent) improvements in life expectancy & infant mortality due to technological change (from 1960 to 1999).** Sources: Goklany (2002a, 2005a), based on World Bank (2001).

Thus, the question must be asked: at what point in the future would the benefits of a richer and more technologically advanced world be cancelled out by the costs of a warmer world?

This paper attempts to shed light on this issue, while recognizing that given the current state of knowledge, a definitive answer is unlikely at this time. It draws upon results of the “Fast Track” assessment (FTA) of the global impacts of climate change sponsored by the U.K. Department of Environment, Forests and Rural Affairs (DEFRA) and reported in a special issue of *Global Environmental Change: Part A* (volume 14, issue 1, pp. 1-99, 2004). Like the FTA, this paper 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).

The FTA employed scenarios developed by the IPCC's Special Report on Emissions Scenarios (SRES 2000) to project future climate change. Table 1 summarizes the dominant characteristics of the "storylines" associated with the scenarios used by the FTA, and corresponding estimates in 2085 of atmospheric CO<sub>2</sub> concentrations and climate change — the latter represented by increases in globally averaged temperature (Arnell et al., 2004). The columns in this, and subsequent, tables are arranged from left to right in the order of decreasing CO<sub>2</sub> concentrations (and global temperature changes), that is, A1F1, A2, B2 and B1.

**Table 1**  
**Characteristics and assumptions for the various scenarios**

	Scenario			
	A1F1	A2	B2	B1
Population in 2085 (billions)	7.9	14.2	10.2	7.9
GDP growth factor, 1990-2100	525-550	243	235	328
GDP/capita in 2100				
Industrialized countries	\$107,300	\$46,200	\$54,400	\$72,800
Developing countries	\$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
CO <sub>2</sub> concentration in 2085	810	709	561	527
Global temp change (°C) in 2085	4.0	3.3	2.4	2.1

Sources: Arnell et al. (2004), Tables 1, 6, 7; Arnell (2004), Table 1.

The FTA used these climate change projections (Arnell et al., 2004) to estimate the global impacts on various climate-sensitive hazards and threats which also serve as determinants of human and environmental well-being. Specifically, with respect to hazards affecting human 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). With respect to environmental well-being, the FTA 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). For the most part, climate change impacts were estimated through 2085 or 2100. 2085 is probably at the outer limit of the foreseeable future since socioeconomic scenarios are not deemed credible beyond that (Arnell et al., 2002). It also assumed no new policies and measures to reduce damages from climate change, but it included some, but not all, “spontaneous” adaptations that could be reasonably assumed to occur (IPCC, 2001) — see below.

Table 1 suggests that, on one hand, the impacts of climate change should decrease as one goes from scenario A1F1 on the left to B1 on the right (in accordance with the pattern of declining climate change, *ceteris paribus*). On the other hand, since economic development and the rate of technological change are both critical determinants of adaptive capacity (Goklany, 1995, 2005a; Smit et al. 2001; Yohe 2001), these impacts ought to be attenuated through a combination of autonomous and pro-active adaptations. Considering future levels of economic and technological development (see Table 1), this attenuation should be greatest for the A1F1 scenario, followed by the B1, B2 and A2 scenarios, in that order. Thus, it is not obvious that although the A1F1 scenario has the highest climate change, it would necessarily have the highest damages from climate change (because A1F1 should also have the highest adaptive capacity).

More important, climate change is only one factor impinging on future human and environmental well-being. Consequently, to answer the question posed in the title of this paper, it is insufficient to examine just the incremental problems caused by climate change (denoted by  $\Delta P$ ) for each of the above-noted climate-sensitive hazards and threats to well-being. To these incremental problems we should add the problems that would exist in the absence of climate change (denoted by  $P_0$ ). Hence, the total problem [ $P_T$ ] with climate change equals  $P_0 + \Delta P$  (Goklany, 2000, 2003).

In the following, in consonance with the FTA, the magnitude of the problem ( $P$ ) due to each climate-sensitive hazard 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 hazard. For these hazards,  $P$  and  $PAR$  will, henceforth, be used interchangeably, as will  $\Delta P$  and  $\Delta PAR$ . With respect to environmental well-being,  $P$  will be measured by three indicators: (a) global cropland area (an indicator of habitat loss, the most important threat to global terrestrial biodiversity, see, e.g., Green et al., 2005; Goklany, 1998 and references therein), (b) losses in coastal wetlands, and (c) the negative of net biome productivity (a measure of the terrestrial carbon sink capacity).

## **2. POPULATION AT RISK FOR VARIOUS CLIMATE-SENSITIVE HAZARDS, WITH AND WITHOUT CLIMATE CHANGE**

This section examines risks associated with four climate-sensitive risks to human well-being, namely, hunger, water shortage, coastal flooding and malaria, in 2085 under each of the four scenarios summarized in Table 1.

Hunger. Tables 2 and 3 show the FTA's estimates of PAR for hunger in 2085 both with and without climate change for the various scenarios. Table 2 gives PAR in absolute numbers, while Table 3 provides it as a proportion of the specific scenario's 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 both in terms of absolute numbers and as a proportion of total population. Second, in 2085, some of the warmer scenarios might actually result in lower levels of hunger, than some cooler scenarios. Third, hunger in 2085 will be lowest in the B2 scenario, followed by A1F1, B1 and A2 (in that order). Thus, the warmest scenario (A1F1) does not lead to the lowest level of well-being. Note, however, that this is not just the consequence of wealth-related adaptive capacity, but also higher CO<sub>2</sub> levels (and, at least in some areas, greater soil moisture). Equally important, the coolest scenario (B1) does not lead to the lowest level of hunger. Finally, for some scenarios (A2 and, possibly, B2), climate change might, in fact, reduce the PAR for hunger at least through 2085.

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

		<b>Baseline 1990</b>	<b>A1F1 2085</b>	<b>A2 2085</b>	<b>B2 2085</b>	<b>B1 2085</b>
PAR, no climate change (CC)	millions	798-872	105	767	90	233
ΔPAR, because of CC only	millions	NA	28	-28 to -9	-11 to +5	10
<i>Total PAR with climate change</i>	<i>millions</i>	798 to 872	133	739 to 758	79 to 95	243

Source: Parry et al. (2004).

**Table 3**  
**Population at risk (PAR) in 2085 for hunger with and without further climate change, as percent of total population**

	<b>Baseline 1990</b>	<b>A1F1 2085</b>	<b>A2 2085</b>	<b>B2 2085</b>	<b>B1 2085</b>
PAR, no climate change (CC)	15.1% to 16.5%	1.3%	5.4%	0.9%	2.9%
$\Delta$ PAR, because of CC only	NA	0.4%	-0.2% to - 0.1%	-0.1% to 0.0%	0.1%
<i>Total PAR with climate change</i>	NA	1.7%	5.2% to 5.3%	0.8% to 0.9%	3.1%

Notably, Parry et al.'s analysis allows for some secular (time-dependent) increases in agricultural productivity, increases in crop yield with economic growth due to greater application of fertilizer and irrigation in richer countries, decreases in hunger due to economic growth, and for some adaptive responses at the farm level to deal with climate change. However, as that study itself acknowledged, these adaptive responses are based on currently available technologies, not on technologies that would be available in the future or any technologies developed to specifically cope with the negative impacts of climate change (Parry et al., 2004, p. 57). The potential for future technologies to cope with climate change is large, especially if one considers bioengineered crops (Goklany, 2001b, 2003).<sup>4</sup> Thus the projections of  $\Delta$ PAR in Tables 2 and 3 are probably overestimates, especially for the A1F1 world, which has the highest level of wealth, because yields generally increase with greater wealth (see Figure 2; Goklany, 1998, 2001a, 2002a). Had that been considered, the A1F1 scenario might have resulted in the lowest levels of hunger.

<sup>4</sup> It is also unclear how well it accounts for potential increases in overall productivity of the food and agricultural sector that might occur as technologies that are underutilized today become more affordable and are, therefore, likely to be used more broadly with rising incomes. These include technologies that would, for instance, reduce post-harvest and end-use losses that have been estimated at 47 percent worldwide (Goklany 1998, and references therein).

These tables also confirm that in comparing the consequences of various scenarios, it is not sufficient to examine only the impacts of climate change. One should also look at the total level of hunger. Otherwise, based merely on an examination of  $\Delta$ PAR, one could conclude, erroneously, that, with respect to hunger, A2 is the best of the four scenarios. But, in fact, 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 terms of absolute numbers in Table 4, and in terms of the proportion of global population in Table 5 (Arnell, 2004).<sup>5</sup> [A population is deemed to be under water stress if its available water supplies fall below 1,000 m<sup>3</sup> per capita per year.] By contrast to the case of hunger, these estimates exclude any spontaneous or proactive adaptations that might be undertaken, albeit at some cost, to alleviate future water shortages. Thus these estimates do not adjust adaptive capacity as a function of economic progress or secular (i.e., time dependent) technological development. Nevertheless, both tables indicate that for each scenario, climate change by itself might, in fact, *reduce* the total PAR for water shortage.

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<sup>5</sup> 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 (compared to the "no climate change" condition). However, his paper does not provide estimates using this measure of the population in 2085 living in countries where water availability would fall below 1,000 m<sup>3</sup>/capita/year assuming climate change. Hence, those results are not shown in Tables 4 or 5.

**Table 4**  
**Population at risk (PAR) in 2085 for water shortage, with and without further climate change**

		<b>Baseline 1990</b>	<b>A1F1 2085</b>	<b>A2 2085</b>	<b>B2 2085</b>	<b>B1 2085</b>
PAR, no climate change	millions	1,368	2,859	8,066	4,530	2,859
$\Delta$ PAR due to climate change		NA	-1,192	- 2,100 to 0	- 937 to 104	-634
<i>Total PAR with climate change</i>	<i>millions</i>	<i>NA</i>	<i>1,667</i>	<i>5,966-8,066</i>	<i>3,593-4,634</i>	<i>2,225</i>

PAR measured as the number of people inhabiting countries where available water supplies are less than 1,000 m<sup>3</sup> per person per year. Source: Arnell (2004).

Second, in the absence of climate change, A1F1 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 fraction of total population for the relevant scenario. Third, with climate change, the A1F1 world continues to have the lowest PAR but that for B1 falls to second place (both in terms of absolute numbers, and a fraction of the global population).

**Table 5**  
**Population at risk (PAR) in 2085 for water shortage with and without further climate change, as percent of total population**

	<b>Baseline 1990</b>	<b>A1F1 2085</b>	<b>A2 2085</b>	<b>B2 2085</b>	<b>B1 2085</b>
PAR, no climate change	25.8%	36.2%	56.8%	44.4%	36.2%
$\Delta$ PAR, because of CC only	NA	-15.1%	-14.8% to 0.0%	-9.2% to 1.0%	-8.0%
<i>Total PAR with climate change</i>	<i>NA</i>	<i>21.1%</i>	<i>42.0% to 56.8%</i>	<i>35.2% to 45.4%</i>	<i>28.2%</i>

Although they were not considered, there are several supply side and demand side adaptations that would reduce PAR for water shortage whether or not climate changes (see, e.g., Goklany, 1998, 2002a). One should expect that the wealthier societies of 2085 will be better able to afford — and, therefore, would be more likely — to employ such adaptation technologies than are

today's relatively poorer societies, particularly if, in the meantime, water shortages are heightened, as indicated in Tables 4 and 5. Therefore, had Arnell's (2004) analysis considered adaptations, the PAR estimates would have been reduced for each scenario. These reductions would have been greatest for the A1F1 (richest) scenario and lowest for the A2 (poorest) scenario and, although the ranking among the scenarios would not change, the differences in PAR between the various scenarios would have been magnified.

Coastal flooding. The Fast Track assessment of the impacts of climate change on coastal flooding reported in Nicholls (2004) makes a valiant effort to incorporate improvements in adaptive capacity due to increasing wealth. Nonetheless some of its assumptions are questionable. For instance, Nicholls allows societies to implement measures to reduce the risk of coastal flooding in response to 1990 surge conditions, but they ignore subsequent sea level rise (Nicholls, 2004, p. 74). But one would expect that whenever any measures are implemented, they would consider the latest available data which would include surge conditions 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 sea level and sea level trends as of 2050, rather than merely the 1990 level. Nicholls also allows for a constant lag time between initiating protection and sea level rise. 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, and that the richer a society the faster this reduction. In fact, if the trend in sea level rise proves to be robust, it is not inconceivable that protective measures may be taken in advance, i.e., the lag times may even become negative.

In addition, Nicholls (2004) makes no adjustments for a country's expenditures on coastal protection as its coastal population increases relative to its total population. A plausible

adjustment that could be made would be to increase such expenditures on a per-GDP basis as the fraction of the population in coastal areas rises. Such an outcome would not be inconsistent with democratic governance.

Table 6 provides Nicholls' (2004) estimates of PAR as measured by the average number of people who would experience coastal flooding by storm surge in 2085 with and without climate change, assuming that the 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), and "evolving" protection with a 30-year lag time. The low and high end of the ranges for PAR for each entry in Table 6 assume low and high subsidence due to non-climate change related human causes, respectively.

**Table 6**

**Population at risk (PAR) in 2085 for coastal flooding, with and without further climate change**

		<b>Baseline 1990</b>	<b>A1F1 2085</b>	<b>A2 2085</b>	<b>B2 2085</b>	<b>B1 2085</b>
PAR, no sea level rise (SLR)	millions	10	1-3	30-74	5-35	2-5
$\Delta$ PAR because of SLR alone	millions	NA	10-42	50-277	27-66	3-34
<i>TOTAL</i> <i>PAR</i>		<i>10</i>	<i>11-45</i>	<i>80-351</i>	<i>32-101</i>	<i>5-39</i>

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. Source: Nicholls (2004).

Table 7 provides the same information as in Table 6, but as a proportion of the global population in 2085 for each scenario.

**Table 7**  
**Population at risk (PAR) in 2085 for coastal flooding with and without further climate change, as percent of total population**

	<b>Baseline 1990</b>	<b>A1F1 2085</b>	<b>A2 2085</b>	<b>B2 2085</b>	<b>B1 2085</b>
PAR, no climate change	0.2%	0.0% to 0.0%	0.2% to 0.5%	0.0% to 0.3%	0.0% to 0.1%
$\Delta$ PAR, because of CC only	NA	0.1% to 0.5%	0.4% to 2.0%	0.3% to 0.6%	0.0% to 0.5%
<i>Total PAR with climate change</i>	NA	<i>0.1% to 0.6%</i>	<i>0.6% to 2.5%</i>	<i>0.3% to 1.0%</i>	<i>0.0% to 0.5%</i>

Nicholls (2004, Table 7) suggests that subsidence is more likely under the A1F1 and A2 worlds than the B1 and B2 worlds. Although this assumption conforms with the SRES's narratives 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 health related, 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, as indicated in Table 1, are projected to exist virtually everywhere later this century under all the IPCC's scenarios (see also Goklany, 2002a). Hence, one should expect that the richest (A1F1) world would spend more and be better protected from subsidence, than would the B1 or B2 worlds. If greater concern for the environment, in fact, translates into a higher fraction of GDP spent on the environment then, despite spending a smaller fraction under A1F1, total spending on — and the amount of — coastal protection could be higher under that scenario than, say, the B1/B2 scenarios, given the wide gaps in GDP per capita between these scenarios.

Putting aside these qualms and shortcomings, Tables 6 and 7 show that in the absence of climate change, the PAR for coastal flooding in 2085 under the A1F1 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 order, by B2, and perhaps A1F1 and B1. Notably, the difference in PAR between A1F1 and B1 scenarios is not very large, considering the several assumptions, noted above, that tend to downplay the adaptive effects of wealth.

Malaria. Van Lieshout et al. (2004) reported on the FTA's analysis for malaria. However, they only provide numerical estimates for changes in global PAR due to climate change (i.e.,  $\Delta$ PAR) under the various scenarios, but not for PARs in the absence of climate change, or for total PARs with climate change.<sup>6</sup> But, as noted, the scenario with the highest  $\Delta$ PAR does not always have the highest total PAR, a much more relevant measure of human well-being. Moreover, although van Lieshout et al. (2004) attempt to include adaptive capacity as it was in 1990, they do not adjust for changes in adaptive capacity over time, i.e., with advances in economic and technological development, as ought to occur between 1990 and 2085. Thus, their analysis sheds no light on the issue of whether well-being (as measured by the population at risk for malaria) would be greater in a richer-but-warmer world as compared to a poorer-but-cooler world.

### **3. ECOLOGICAL CHANGES IN 2085-2100, WITH AND WITHOUT CLIMATE CHANGE**

Table 8, based on Levy et al. (2004) and Nicholls (2004), provides information on the variation in three specific ecological indicators across the different scenarios. One indicator is the net

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<sup>6</sup> This author contacted various co-authors of the van Lieshout et al. paper to obtain their results for PAR with and without climate change, but to no avail.

biome productivity (a measure of the terrestrial biosphere's net carbon sink capacity). The second indicator is the area of cropland (a crude measure of the amount of habitat converted to human use). Notably, land conversion to agricultural uses is perhaps the single largest threat to global terrestrial biodiversity (Goklany, 1998). The third indicator is the global loss of coastal wetlands relative to 1990 levels.

**Table 8**  
Ecological indicators under different scenarios, 2085-2100

		<i>Baseline 1990</i>	<b>A1F1</b>	<b>A2</b>	<b>B2</b>	<b>B1</b>
Global temperature increase ( $\Delta T$ ) (in 2085)	$^{\circ}C$	0	4.0	3.3	2.4	2.1
Global population (in 2085)	billions	5.3	7.9	14.2	10.2	7.9
GDP/capita, global average (in 2085)	\$/cap	3.8	52.6	13.0	20.0	36.6
CO <sub>2</sub> 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%
<i>Global losses of coastal wetlands in 2085</i>						
Losses due SLR alone	% of current area	NA	5 - 20%	3 - 14%	3 - 15%	4 - 16%
Losses due to other causes	% of current area	NA	32 - 62%	32 - 62%	11 - 32%	11 - 32%
Combined losses	% of current area	NA	35 - 70%	35 - 68%	14 - 42%	14 - 42%

Sources: Arnell et al. (2004); Nicholls (2004); Levy et al. (2004)

The biosphere's sink capacities under the A1F1 and A2 scenarios are approximately the same, at least through 2100. Largely because they result in higher CO<sub>2</sub> concentrations, their sink

strengths are greater compared to the B1 and B2 scenarios and, at least through 2100, the positive effect of carbon fertilization under the A1F1 scenario was not projected to be reversed by the negative effects of higher temperatures. Partly for the same reason and also because of its low population, the amount of cropland is lowest for the A1F1 world, followed by the B1 and B2 worlds. (Cropland estimates were not provided for the A2 scenario.) Thus, through 2085, the A1F1 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.

With regard to the loss of coastal wetlands, the estimated loss due to sea level rise (SLR) for each scenario is quite 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; see also Goklany, 2003). According to Table 8, wetland losses are much higher for the A1F1 and A2 scenarios than for the B1 and B2 scenarios. This is due mainly to the assumption that the first two scenarios would have higher non-climate change related subsidence (Nicholls 2004, p. 76), but as noted, this assumption is suspect.

#### **4. DISCUSSION**

For each indicator for which data were provided in the foregoing, Table 9 ranks the four scenarios according to the level of human or environmental well-being per that indicator for both the climate change and the non-climate change cases. In this ranking scheme, “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 A1F1 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.

**Table 9:**  
**Ranking of scenarios in order of future well-being per each indicator, 2085-2100**

Indicator	Without climate change				With climate change			
	A1F1	A2	B2	B1	A1F1	A2	B2	B1
<b>Indicators of human well-being</b>								
GDP/capita	1	4	3	2	NA	NA	NA	NA
Hunger (PAR in 2085)	2	4	1	3	2	4	1	3
Water stress (PAR in 2085)	1.5	4	3	1.5	1	4	3	2
Coastal flooding (PAR in 2085)	1	4	3	2	2	4	3	1
<b>Indicators of environmental quality</b>								
Terrestrial carbon sink strength (in 2100)					1.5	1.5	3	4
Cropland area (in 2100)					1	NA	3	2
Coastal wetland area (in 2085)					3.5	3.5	1.5	1.5

Remarkably, the rankings are the same whether one uses absolute numbers or the proportion of global population as the measure of the impact of climate change.

The top part of Table 9 provides rankings for various indicators of human well-being (HWB) in 2085, namely, wealth (for which GDP per capita is a surrogate), hunger, water stress, and coastal flooding. If one considers that: (a) GDP per capita — or perhaps more accurately, the logarithm of GDP per capita (Goklany, 2002a, 2005a; Figures 1-3) — should arguably be given greater weight because it is a surrogate for numerous, and more appropriate, HWB indicators (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), then Table 9 suggests that HWB in 2085 would, in the aggregate, be highest for the A1F1 scenario and lowest for A2.

Applying the same logic and considerations, it would seem that HWB should be somewhat better under B1 than B2. 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.

The last three rows of Table 9 rank scenarios based on the three environmental indicators addressed in Section 3 (and Table 8). Based on the strength of the terrestrial carbon sink and cropland area, environmental quality would be superior under the A1F1 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/would be lower under the B1 and B2 scenarios than the A1F1 scenario.

## 5. CONCLUSION

Strictly from the perspective of human well-being, the richest-but-warmest world characterized by the A1F1 scenario would probably be superior to the poorer-but-cooler worlds at least through 2085, particularly if one considers the numerous ways GDP per capita advances human well-being. Human well-being would likely be the lowest for the poorest (A2) world. With respect to environmental well-being, matters may be best in the A1F1 world for some critical environmental indicators through 2100, but not necessarily for others.

This conclusion casts doubt on a key premise implicit in all calls to take actions now that would go beyond “no-regret” policies in order to reduce GHG emissions in the near term, namely, a richer-but-warmer world will, before too long, necessarily be worse for the globe than a poorer-but-cooler world. But the above analysis suggests this is unlikely, at least until after the 2085-2100 period. Assuming that it takes 50 years to replace the energy infrastructure, that means we have at least 30 years (= 2085-50-2005) before embarking on a GHG reduction program that goes beyond “no-regrets” provided, in the interim, we focus on:

- Increasing adaptive capacity, particularly of developing countries, by investing in efforts now to reduce vulnerability to today’s urgent climate-sensitive problems — malaria, hunger, water shortage, flooding and other extreme events — that might be exacerbated by climate change (Goklany, 1995, 2003, 2005b). The technologies, human capital and institutions that will need to be strengthened or developed to accomplish this will also be critical in addressing these very problems in the future if and when 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.<sup>7</sup> Alternatively, it could postpone the deadline for stabilization. In either case, it could reduce the costs of meeting the ultimate objective;
- Strengthening or, where needed, developing the institutions necessary to advance and/or reduce barriers to economic growth, human capital and the propensity for technological change. These factors underpin both adaptive and mitigative capacities, as well as

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<sup>7</sup> 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.”

sustainable development (Goklany, 1995, 2000, 2005a). This can be achieved, among other things, through efforts to meet the Millennium Development Goals in 2015, which were, in fact, designed to advance sustainable development by alleviating poverty, disease and illiteracy;

- Expanding the range of no-regret options through R&D to improve existing —and develop new — technologies that would reduce atmospheric greenhouse gas concentrations more cost-effectively than currently possible so that future emission reductions might be cheaper, even if they have to be deeper to compensate for the delay in a more aggressive response in the short term;
- Allowing the market to run its course in implementing 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;
- Developing a more robust understanding of the science, impacts and policies of climate change in order to develop 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; and
- Monitoring the impacts of climate change to spot “dangerous” impacts before they become imminent.

Such an approach would allow us to solve today’s urgent problems while bolstering our ability to address tomorrow’s climate change challenge.

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