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Guidance Materials on Spatially Distributed Socio-Economic Projections of Population and GDP per unit area

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Abstract

Spatial distributions for current population density (population/unit area) and GDP density (GDP/unit area) have been developed at Columbia University (CIESIN) and Harvard University (Center for International Development), respectively. These distributions exist in high-resolution grids - on the order of kilometer scales. We have projected these grids forward in time to 2100, at $1/4^{\circ}$ resolution (~30 kilometers a side at the equator), using regional projection data from the United Nations (UN), International Institute for Applied Systems Analysis (IIASA) and the IPCC Special Report on Emissions Scenarios (SRES). This paper describes the methodology and initial results obtained for two of the four scenario families in the SRES report (named "A2" and "B2"). Additional projections will be forthcoming for the remaining SRES scenarios A1 and B1, and using a hierarchy of techniques to model distributional changes.

The overall strategy is to combine three distinct elements: (1) national and regional population projections over the next century from the United Nations (UN), the International Institute of Applied Systems Analysis (IIASA) and sub-national US projections from the US Census Bureau; (2) economic growth projections for 9-11+ regions of the globe over the next century, from the six economic modeling groups that participated in the IPCC SRES report and; (3) the high resolution gridded maps for population and income distribution developed at Columbia University and Harvard University, respectively. Our first projections are straightforward linear scalings. Later approaches will be stochastic, scenario and trend-based.

Although many studies project population and economic growth for nations and regions, our projections offer these in a high-resolution format, albeit with static distribution assumptions needing further work. We are producing the maps *annually* for the next century, including a visual 'film' over time. We expect analyses of both human vulnerability and human impact on ecosystems to make use of such data. Similarly we expect analysts who make aggregated national and regional projections of population and economic growth over the next century will benefit from visualizing their projections in a high-resolution gridded map. Earliest environmental applications could, for example, be to analyses of coastal vulnerability to sea level rise. Latter applications could include anticipating future land use patterns and air and water quality concerns. The projections will need to confront important questions on how to model future distributions of socio-economic data.

Background

Many high-resolution spatial distribution maps have been developed for different environments, ecosystems and indicators of human activity. Some examples include vegetation (Kineman and Hastings, 1998), night-time anthropogenic light distributions (Elvidge et al, 1997a,b; Sutton et al, 1997), emissions of greenhouse gases and air pollutants (Naki_enovi_ et al, 2000 ; Olivier et al, 1996), ecosystems (Olson et al, 1985), animal methane emissions (Lerner et al, 1988), soil type (Staub and Rosenzweig, 1986) and elevation (Cuming and Hawkins, 1981). Many other examples could be cited.[1] These maps provide important spatial information on natural and altered environments and human activities that are used in a variety of ways by analysts.

Spatial distributions are also available for the present day population density and GDP density of the world (CEISIN et al, 2000; Sachs et al, 200, Landscan, 2000; Dobson et al, 2000). Theses maps are global in scale and have high spatial resolution, ranging to as small as 1 kilometer and 4.5 kilometer grid sizes in the case of population (Landscan, 2000; CIESIN et al, 2000).

Interest has been growing in projecting these present day distributions forward in time. In addition to the projections discussed herein, at least one other gridded projection effort is underway at the UK Hadley Center, (M. Livermore, pers. comm.), using a 1^o x 1^o baseline population grid (Li, 1996).

A related development for such projections is that the IPCC Third Assessment Report (TAR) has published a new set of emissions scenarios called the Special Report on Emissions Scenarios (SRES) (Naki_enovi_ et al, 2000). The SRES scenarios span the 21st century and model the major greenhouse gases emissions and land use changes that will drive climate change. These scenarios incorporate vastly more information than just greenhouse gas emissions, as each scenario articulates a plausible future world state, including socio-economic, cultural, technological and energy resource changes. Following their use in the TAR, the SRES framework has increasingly become a new "standard" for the human dimensions component of climate impacts assessment (Parry, 2000; Lim & Moss, 2001).

The publication of the SRES scenarios provides a timely opportunity to advance the science of *projections* of socio-economic data because the SRES included a thorough review of existing projections for population and economic growth as well as a host of other social and technological forces. Our goal is to link the development of the SRES to increasingly diverse GIS applications for socio-economic spatial distributions. Doing so will advance the research on projecting future distributions, and help anticipate a number of long-term environmental issues. Initially these environmental problems may relate best

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[1] A list of global spatial datasets and associated metadata is being complied at CIESIN and currently includes 100 entries (C. Giri, pers. comm.)

to climate change impacts but a host of other environmental impacts related to air, water and land use can be envisioned.

The current work is being undertaken in partial support of the IPCC's Task Group on Climate Impact Analysis (TGCIA). The mission of the TGCIA is to facilitate research that will be important to forthcoming IPCC climate assessment reports. Projections of spatial distributions of population and income have been deemed an important research goal by the TGCIA.[2]

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[2] TGCIA meeting, Amsterdam, Netherlands, June 31-July1, 2001.

Baseline Spatial Distribution Data

Description of Gridded Population of the World (GPW)

Demographic information is often provided on a national basis, but global environmental and other cross-disciplinary studies often require data that are referenced by geographic coordinates, such as latitude and longitude, rather than by political or administrative units. This was a motivation behind development of the Grid-d Population of the World (GPW) map (CIESIN et al, 2000). In the GPW data set, the distribution of human population has been converted from national and sub-national units to a series of geo-referenced quadrilateral grids. Version 2 of GPW provides estimates of the population of the world in 1990 and 1995. Both population counts and densities (per square kilometer) have been estimated. Adjusted population counts and densities, based on data that have been reconciled to be consistent with United Nations population estimates, have also been produced. Figure 1 displays the 1995 GPW.

Figure 1 Gridded Population of the World (GPW)

GPW version 2, 1995 UN adjusted population density

http://sedac.ciesin.columbia.edu/plue/gpw

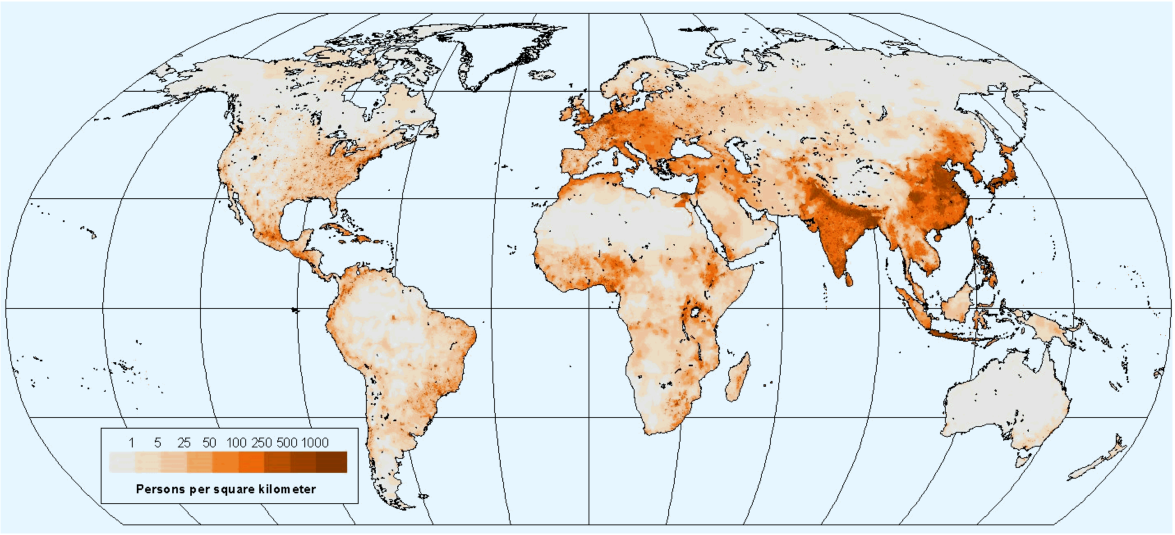

Figure 1. Gridded population of the world, in units of people/unit area (CIESIN et al, 2001). Our projections use this baseline population distribution and project it forward in time using more aggregated population projections from the UN (1998) and IIASA (Lutz, 1996).

To create GPW, population estimates for national and sub-national units were linked to the best available vector boundary data. The borders and coastlines of the spatial data were matched to the Digital Chart of the World (2000) where appropriate, and lakes from the Digital Chart of the World were added. The population of the units was then allocated over a grid with a spatial resolution of 2.5 arc-minutes of latitude and longitude (approximately 20 square kilometers in size at the equator). The actual area of land (net of ice and water) was also calculated for each grid cell and used to derive the population density grids.

In total, GPW employs assembled boundaries for 127,082 administrative units; 60,911 of these units are census tracts in the United States. Even without the very detailed information for the USA, however, the database provides significantly higher resolution than the previous version of GPW, which was based on about 19,000 units (Tobler et al., 1997). The administrative resolution also far surpasses that of other global gridded databases, such as LandScan (Dobson, 2000). Resolution (area) of the administrative units varies by country. A full description of GPW can be found at: http://sedac.ciesin.org/plue/gpw

Since the SRES Regions data do not exactly match the GPW countries (e.g. a number of GPW countries for which there are data are not listed in the SRES regions), the GPW data are not adjusted to match the population totals of the regions. Rather, as described below the *rates* of population change are used to project the existing GPW totals. If national-level population projections are used, the GPW totals could be adjusted to match the SRES totals before projecting forward in time.

Description of GDP/unit area ("GDP density") Map

The common economic indicator of prosperity is gross domestic product (GDP) per capita_the total value of a country's economic output, divided by its population. Among other indicators, GDP per capita reveals the vast gap between rich and poor nations.

A spatial distribution of GDP per unit area (GDP "density"), has been developed and published by Sachs et al (2001). One of the original purposes for deriving this map was to study the role of geography in economic development. As described in Sachs et al (2001), one finding is that the great majority of the poorest countries lie in the geographical tropics_the area between the tropic of Cancer and the tropic of Capricorn. In contrast, most of the richest countries lie in the temperate zones as well as along coastal areas. Reasons for this geographical and differences are discussed by the authors.

The GDP density map, shown in figure 2, forms a baseline for our economic projections.

Figure 2 GDP density

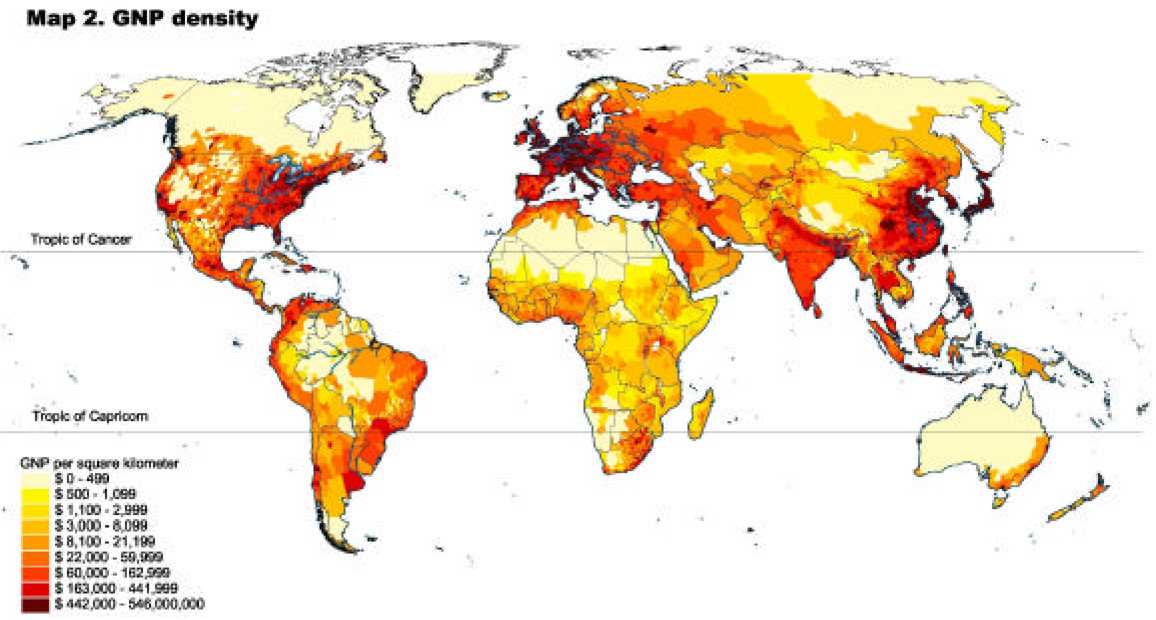

Figure 2: GDP/unit area map developed by Sachs et al, 2001. Our projections use this, and an underlying national/subnational GDP grid, and project them forward in time using economic growth rate and population scenarios for between 9-11+ regions from the recent IPCC SRES emissions scenarios report (Nakicenovic et al, 2000).

In the Sachs et al (2001) study, gross national product (GDP) per capita was measured at standardized purchasing power parity (PPP) at both the national and sub-national level for 1995. To capture intra-country variance in income distribution, sub-national (first level state/province divisions or non-administrative regions) per capita GDP data was gathered for 19 of 152 countries in a GIS, including most of the large economies. Since the sub-national data of these countries was collected in local currency rather than in a comparable $US purchasing power parity basis, the local-currency measures were adjusted to create internationally comparable sub-national measures. The countries for which sub-national data were obtained are:

First level division characteristics.

Country	**1st Level**	**Number of Units**	**Country**	**1st Level**	**Number of Units**
Australia	States	8	India	State	31
Belgium	Region	3	Italy	Regioni	11
Brazil	Unidade de Federacao	31	Japan	Regions*	9
Canada	Province	12	Mexico	State	32
Chile	Region	13	Netherlands	Region	4

China	Province	31	Spain	Region	7
Colombia	Departamento	33	United Kingdom	Province	4
France	Region	8	United States	State**	52
Germany	Region	16	Uruguay	Departamento	19
Greece	Region	4			

* In Japan, the first level administrative districts are regions, so the GNP data do represent first level administrative divisions. Where the term “Region” is used elsewhere in Table 1, it refers to non-political reporting units.
** The US data include Puerto Rico and Washington, DC as state equivalents.

The country-level $US PPP-adjusted GDP is used for each country for 1995 (GDPc below), available from the World Bank (1998) World Development Indicators, supplemented by CIA World Factbook (1996) estimates. For each sub-national region i, the $US PPP GDPi is calculated accord to the following formula:

$$\$\text{US PPP GDPi} = \text{GDPc x (GDPi/GDPa)} \qquad (1)$$

GDPi is the GDP per capita of region i in local currency, and GDPa is the country-average per capita GDP in local currency. GDPa is calculated as Σ(GDPi x Popi)/Σ(Popi). Sub-national regional GDP was collected from national sources, mainly government statistical yearbooks. Therefore, provincial populations and provincial income data are used to calculate a country’s average GDP per capita, and then used to calculate the ratio of each province’s per capita GDP to the national average. That ratio is then multiplied by the $US PPP GDP, to calculate a GDP on a PPP basis for each region. This calculation assumes that the ratio of the regional GDP per capita to national GDP per capita in local currency equals the ratio of the regional GDP to national GDP on a PPP basis.

The map of GDP density is calculated within a geographic information system (GIS) by multiplying GDP per capita (measured at PPP) by the gridded population of the world (Sachs et al, 2001; CIESIN et al, 2000). This multiplication converts the units of “GDP per capita into GDP per unit area, because GPW is in units of population/unit area.

Aggregated Population and Economic Growth Projections

Population Projections

Currently, and at the time of the SRES report, world population projections are generated by the following organizations:

- The US Census Bureau (USCB)
- The World Bank (WB)
- The United Nations (UN)
- The International Institute for Applied Systems Analysis (IIASA)

Tables 1 and 2 provide a comparison of the main characteristics of the individual projections (Gaffin, 1998). A more extensive survey of population projections is given in O'Neill et al, 2001. All the projections employ the age-cohort methodology, the root of which depends on projections of fertility, mortality and migration rates at various levels of aggregation and over various timeframes (O'Neill et al, 2001; Frejka, 1996; Hollmann et al, 2000). A brief summary of the various methodologies and assumptions employed is given in Appendix 1.

The projections described in Tables 1 and 2 were those studied and used in the SRES report. Even though they are not the most recent projections, they are intentionally shown here for consistency with the SRES report.

With respect to the most recent 2000 UN Revision (UN, 2001), world population reached 6.1 billion in mid 2000 and is currently growing at a rate of 1.2 per cent annually, implying a net addition of 77 million people per year. Six countries account for half of that annual increment: India for 21 per cent; China for 12 per cent; Pakistan for 5 per cent; Nigeria for 4 per cent; Bangladesh for 4 per cent, and Indonesia for 3 per cent. By 2050, world population is expected to be between 7.9 billion (low variant) and 10.9 billion (high variant), with the medium variant producing 9.3 billion people.

The population of more developed regions, currently estimated at 1.2 billion, is anticipated to change little during the next 50 years, although fertility levels are expected to remain below the replacement level. However, by mid century the populations of 39 countries are projected to be smaller than they are today (e.g., Russian Federation, Georgia and Ukraine, between 28 and 40 per cent smaller; Italy and Hungary, 25 per cent smaller; Japan and Germany, 14 per cent smaller). The population of the less developed regions is projected to rise steadily, from 4.9 billion in 2000 to 8.2 billion in 2050 (medium variant). This projection assumes continuing declines in fertility. In the absence of such declines, the population of the less developed regions could reach 11.9 billion. Particularly rapid growth is expected in the group of 48 countries classified as the least developed. Their population is expected nearly to triple between 2000 and 2050, passing from 658 million to 1.8 billion, despite the fact that their fertility is projected to decline markedly.

Table 2 shows good agreement between the central projections from the four demographic organizations over the next 100 years (with the possible exception of the IIASA projection whose 'overshoot' is related to higher near term total fertility rates than recent UN data has indicated). In general the good agreement should not be construed as implying accuracy. Rather it reflects similar methodologies, databases, the dominance of population momentum associated with a young population age structure, and the assumption of replacement level fertility in the long term. The central projections indicate that a further expansion of global population to about 10.4 billion persons in 2100 is being forecast by all the major demographic organizations that perform long-range projections.

The reasons for this expansion are well-known (Bongaarts, 1998): (i) "population momentum" is associated with the present young age structure in developing countries, ensuring significant population growth over the next few decades; (ii) further increases in life expectancy will take place; (iii) a continued near-term fertility preference of about 3 children per woman world-wide exists, which is 50% above the two-child level that is needed for population stabilization.

Table 1: Features of Population Projections by UN, IIASA, World Bank & USCB*

	United States Census Bureau (USCB)	World Bank (WB)	United Nations Revision (UN)	United Nations Long Range	IIASA
Last issue date before SRES report	1996	1996	1996	1998	1996
Results published?	No - internet only	No	Yes	Yes	Yes
Update cycle [years]	2	1	2	6 ?	2 ?
Forecast period	2050	2150	2050	2150	2100
No. of regions	Country level	Country level	Country level	9	13
No. of variants	1	1	3	5	27+
Fertility variants	1	1	3	5	3
Long-range fertility (central)	Below 2.1	2.1	2.1	2.1	1.9
Mortality variants	1	1	1	1	3
Migration variants	1	1	1	1	3
Migration cutoff year	?	2025	2025	2025	2100? (central)
2050 population (central case)	9.4	9.2	9.4	9.4	9.9
2100 population (central case)	-	10.32	-	10.4	10.35

* These features applied *at the time of the SRES report, 1996-1998 (Gaffin, 1998)*. Some characteristics may have changed in more recent projections (UN, 2001).

Table 2: World Population Projections (billions) *Used By The SRES Report**

Year	UN 96 low	UN 96 med	UN 96 high	IIASA 96 rapid	IIASA 96 med	IIASA 96 slow	World Bank 96	U.S. Cen. Bur. 96	UN 98 LR lo	UN 98 LR med-low	UN 98 LR med	UN 98 LR med-high	UN 98 LR high
1995	5.687	5.687	5.687	5.702	5.702	5.702		5.691	5.7	5.7	5.7	5.7	5.7
2000	6.062	6.091	6.123	6.110	6.140	6.170	6.065	6.090	6.062	6.062	6.091	6.123	6.123
2005	6.409	6.491	6.581	6.480	6.573	6.665		6.479	6.409		6.491		6.581
2010	6.726	6.891	7.060	6.850	7.012	7.168		6.859	6.726		6.891		7.060
2015	6.062	7.286	7.554	7.211	7.451	7.678		7.233	6.062		7.286		7.554
2020	7.265	7.672	8.062	7.547	7.879	8.191		7.593	7.265		7.672		8.062
2025	7.474	8.039	8.581	7.838	8.289	8.715	7.926	7.938	7.474		8.039		8.581
2030	7.625	8.372	9.100	8.072	8.672	9.247		8.266	7.625		8.372		9.100
2035	7.715	8.670	9.614	8.239	9.019	9.779		8.577	7.715		8.670		9.614
2040	7.746	8.930	10.12	8.371	9.341	10.300		8.865	7.746		8.930		10.12
2045	7.725	9.159	10.63	8.456	9.627	10.800		9.126	7.725		9.159		10.63
2050	7.662	9.367	11.16	8.488	9.874	11.300	9.199	9.356	7.662	8.0	9.367	10.8	11.16
2055				8.465	10.08	11.780							
2060				8.391	10.25	12.250							
2065				8.275	10.39	12.710							
2070				8.121	10.49	13.140							
2075				7.933	10.56	13.540	9.929						
2080				7.714	10.59	13.900							
2085				7.466	10.58	14.220							
2090				7.174	10.53	14.530							
2095				6.850	10.46	14.810							
2100				6.507	10.35	15.070	10.32		5.6	7.2	10.4	14.6	17.5
2150							10.77		3.6	6.4	10.8	18.3	27.0

* These projections were those available *at the time of the SRES report, 1996-1998*. More recent projections will have differences (UN, 2001).

The IPCC SRES Scenarios & the Exogenous Assumptions on Population and Economic Growth

The mandate for the new IPCC SRES emissions scenarios originated within the IPCC in 1997. One motivation was the need for an updated emissions series over the previous IPCC "IS92" series. The SRES was completed and published in 2000 (Naki_enovi_ et al, 2000). These scenarios form the basis for global warming and sea level rise projections over the next 100 years. The final emissions results of the SRES report are available online from CIESIN at: http://sres.ciesin.org/final_data.html. A complete online text of the SRES report is available at: http://www.grida.no/climate/ipcc/emission/

The SRES scenarios go well beyond being emissions scenarios because they represent an extensive 3-year review of essentially all major driving forces behind development including economic, demographic, social and technological change. This review was essential because all these factors play a role in energy consumption, land use patterns and emissions. A collateral benefit of such a review is that the SRES scenarios may be useful for other research purposes on sustainable development.[3]

Four scenario "storylines" were developed in the SRES report and labeled A1, A2, B1, B2. These storylines were the result of analyzing different viewpoints on possible future development pathways by the members of the writing team. They have been discussed at length elsewhere (Parry, 2000, Naki_enovi_ et al, 2000) and will be described in briefest terms here.

Briefly, storyline A1 characterizes a market-based, technology driven world with high economic growth rates (global GDP reaches $550 trillion in 2100) and strong globalization. There is a rapid diffusion of people, ideas and technologies globally. Population growth was assumed to be low (~ 6.5 billion in 2100) because of the importance of development in bringing about the demographic transition from high to low fertility in developing countries with fertility currently above replacement level. Low mortality is assumed to correlate with the low fertility. For these and related reasons, the scenario assumes the IIASA "rapid demographic transition" (Table 2 and Appendix 1)

Storyline A2, in contrast, is a world of lower economic development (GDP reaches $250 trillion in 2100) and weak globalization. It is more prone to clashes between cultures and ideas. Population growth in A2 is high (15 billion by 2100) because of the reduced financial resources available to address human welfare, child and reproductive health and education. The relatively higher fertility rates in this scenario are assumed to correlate

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[3] Although we focus on the SRES scenarios in this report, it is worth noting there are many alternative scenario studies, independent of the IPCC, that are equally plausible and perhaps more suited to various regional climate impact studies (Strzepek et al, 2001; DeVries et al, 1994).

with higher mortality rates and so this scenario employs the IIASA “slow demographic transition” scenario (Table 2 and Appendix 1). Per capita incomes are low.

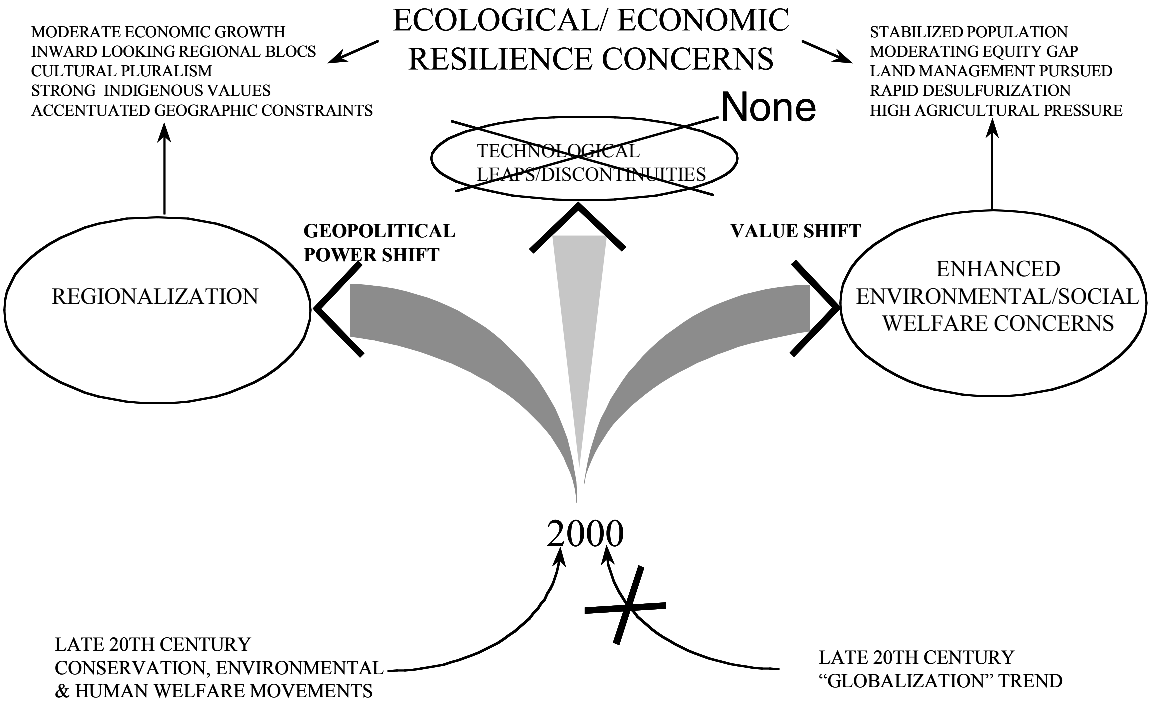
Storyline B1 comes closest to a “sustainable development” future where economic growth and environmental protection are considered compatible. It too has high economic growth (GDP $350 trillion in 2100) although not as rapid as A1. B1 is a world where the emphasis could be on education, equity and social welfare rather than on technological growth. Environmental protection worldwide is considered a shared priority by most nations and population growth is again low (IIASA “rapid” scenario; Table 2 and Appendix 1).

Finally storyline B2 is a less prosperous version of B1 with slower economic growth (GDP $250 trillion in 2100). Regional governance is more inward looking rather than global. Cultural pluralism is strong along with environmental protection. Technological changes diffuse slowly. Population growth is considered to be medium in this scenario (10.3 billion in 2100). For this case the SRES used the UN 1998 medium long-range projection as described in Table 2 and Appendix 1. This is the only SRES scenario using a medium population growth projection with replacement level fertility in the long-run.

More detailed quantification of these population and economic growth scenarios was made in the SRES report (Naki_enovi_ et al, 2000). However, as an example of a richer picture that can be developed for each scenario, figure 3 illustrates some of the thinking behind the B2 scenario using a “grand logic” diagram. Similar grand logic diagrams were developed for the other scenarios, but not published. Impact studies might benefit from more work on richer scenario storylines derived from the SRES global scenarios.

Figure 3: A ‘Grand Logic’ Diagram for the B2 Scenario

“REGIONAL STEWARDSHIP”
B2 SCENARIO GRAND LOGIC

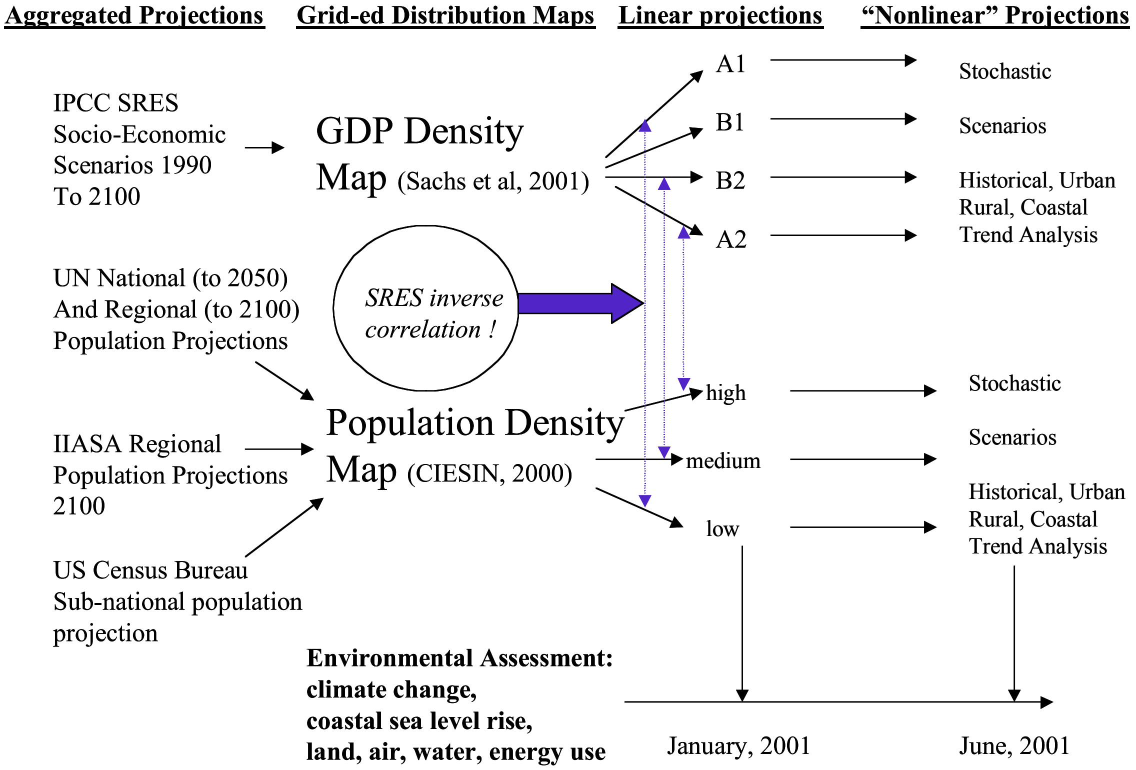


The SRES report concluded that none of the scenarios was ‘most likely’ and, when possible, the full set should be used by analysts. The implication of this for projecting baseline economic and population maps forward in time is that we should make use of a range of plausible population and economic growth rates. A debate on whether probabilities can be assigned to the SRES scenarios has taken place (Schneider, 2001; Grübler and Naki_enovi_, 2001; Lempert and Schlesinger, 2001). However, the authors of the SRES report maintain that probabilities cannot be usefully applied to the scenarios, largely because they are not ‘independent observations,’ but were instead developed as contrasts to each other (Grübler and Naki_enovi_, 2001).

Economic growth rates in the six SRES models were more or less exogenously applied based in part on the long term (2100) target GDP’s listed above. The full details about how such economic growth rates were determined is best left to a review of the supporting literature on the SRES models (e.g. Roehrl and Riahi, 2000; Riahi and Roehrl, 2000; Edmonds et al, 1996).

The regional population and economic growth rates in our projections are the same as those used in the SRES report, including the inverse correlation between population and income described above. In other words, when generating the income maps we correlate the economic growth rates and population growth rates in the same way as SRES. Thus when using the A1 high economic growth rates we, at the same time, use the low population projections (figure 4). For the A2 income maps, we correlate lower economic growth with the high population projections. Analogous correlations will hold for B1 and B2 as well.

Figure 4: Outline of CIESIN Gridded Population and GDP Density Projections



Gridded Population and Economic Growth Projections

The GPW Projections for A2 and B2

The process of projecting GPW forward in time is straightforward under the linear scaling approach. Using the aggregated regional growth rates from UN and IIASA, the current population for a given geographic region is simply multiplied by the annual growth rate for that region to obtain the next year's population.

For the B2 scenario, we use the regional aggregation of the MESSAGE model from IIASA (Naki_enovi_ et al, 2000; Roehrl and Riahi, 2000; Riahi and Roehrl, 2000). It consists of 11 regions: North America, Western Europe, Pacific OECD (Australia, Japan and New Zealand), Central and Eastern Europe, newly independent states of the former

Soviet Union, centrally planned Asia and China, South Asia, other Pacific Asia, Middle East and North Africa, Latin America and the Caribbean, Sub-Saharan Africa.

For the A2 scenario, we use the regional aggregation of the MiniCAM model from Batelle (Edmonds et al, 1996). This consists of 9 regions: Centrally Planned Europe, OECD Europe, Canada, USA, Oceania, Japan, South East Asia, Centrally Planned Asia, Middle East + Africa + Latin America.

The formula used to determine the *annual* growth rates, r, between population projections separated by more than 1 year in time is (5 year time separation is typical for the UN and IIASA projections):

$$r = \frac{\ln[\frac{P_2}{P_1}]}{t_2 - t_1} \tag{2}$$

P_1 and P_2 are the population totals for the first and second reference years, t_1 and t_2 are the years of the two census enumerations and ln is the natural logarithm. The log formula accounts for the fact that the annual growth rates are applied to a continuously changing population base. Additional technical notes on the geographic aspects of the population projection are given in Appendix 2.

Figure 5 shows time slices for the initial gridded population projections for the B2 scenario (A2 will be forthcoming for the Barbados meeting). As described above, the A2 projection is based on the IIASA 1996 “slow” demographic transition. The B2 projection is based on the UN 1998 Long Range medium projection. Discussion of this figure will be deferred to the forthcoming TGCIA Barbados meeting.

Figure 5: Projected population density grids for the B2 scenario

(OPEN ATTACHED FILE “gpw-gnp2000-2080.doc” to view)

The GDP Density Projections for A2 and B2

The GDP Density projection is dependent on the corresponding GPW projection described above. The ‘flowchart’ in figure 6 summarizes the steps.

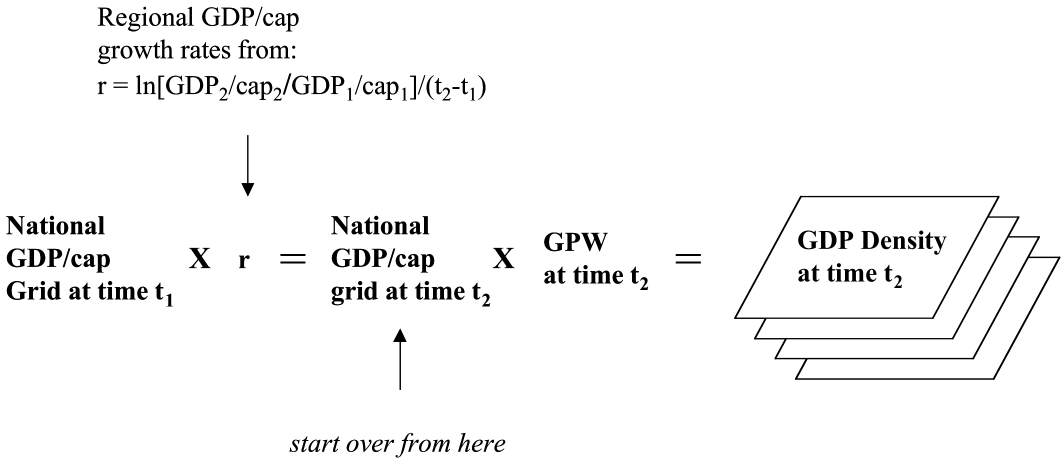


Figure 6: ‘Flowchart’ depicting generation of GDP density grids

We start with a grid of national GDP/capita at time t_1 and multiply it by the growth rates in GDP/capita from the disaggregated SRES modeling data, for the respective scenario. This generates a national GDP/capita grid at time t_2. This is then multiplied by the corresponding GPW grid at time t_2, to produce a GDP density map at time t_2. The process is repeated starting at time t_2.

Figure 7 shows time slices for the initial results for the B2 GDP density projection using economic growth data for the 11 regions of the IIASA MESSAGE model (Naki_enovi_ et al, 2000). (A2 will be forthcoming at the Barbados meeting). Discussion of this figure will be deferred to the forthcoming TGCIA meeting.

Figure 7: Projected GDP density grids for the B2 scenario

(OPEN ATTACHED FILE “gpw-gnp2000-2080.doc” to view)

ISSUES FOR DISCUSSION

This section provides a preliminary discussion of some issues that need to be addressed. It is a sketched discussion and will be expanded following the TGCIA meeting in Barbados, November 26-29, 2001.

A simple taxonomy of the issues for the next phase of work is:

(1) Baseline errors and distributional problems associated with the 2000 maps for population and GDP density.

(2) Near-term (<2020), Mid-term (2020 –2050) and Long- term (2050-2100) projection errors and fallacies associated with projecting population and GDP density using aggregated projections and linear scaling only.

Preliminary thoughts are given below.

Baseline issues:

There are errors and uncertainties associated with the baseline maps. For example, the GPW population map has been referenced to the year 1995, which is also the base year for the UN 1996 Revision data used in the B2 scenario. However, small differences exist between the national populations obtained for GPW map when compared to the UN data. One option here is to correct such discrepancies by scaling GPW data so that the national figures are the same as the UN figures. This has not been done for the results shown in figure 5.

One geographic issue is that grid cells on the borders between nations have a mix of population numbers from the border nations. The GPW map currently does not supply the percentage contribution of each bordering nation to the cell. A question has been raised whether such information may be useful for climate impact analysis (M. Livermore, pers. comm.). We will evaluate this and, if such percentages are important, appropriate information can be created for GPW.

On the GDP density map, it is noted that the main source of the distributional 'texture' is derived from the distribution of people in the GPW map. The only other economic distribution data that go into the map are the national and 19 sub-national GDP values that were used to develop the baseline GDP map (Sachs et al, 2001). Therefore the GDP density map is based on the premise that economic activity is largely associated with the distribution of people – the validity of which can be questioned (Sutton et al, 1997). For example, 2 billion people are estimated to lie outside of formal economies, mostly in rural areas of developing countries (UNDP, 1997). Additionally, areas such as airports, industrial zones and commercial centers have generally low population density but high levels of economic activity. Conversely, some residential areas may have high population density but are not necessarily the primary zones of economic activity (e.g. low income areas of large urban centers).

Projection issues:

A first issue concerns the aggregation level available in the projections. The B2 scenario employs the UN 1998 Long Range projection for 11 geographic regions. However, as shown in Tables 1 and 2 and described in Appendix 1, the UN also undertakes a more refined country level projection out to 2050, the so-called *Revision*. The Revision data underlying the 1998 Long Range projection could be applied to our B2 projection out to 2050. Thereafter we need to rely on the 11 region Long-Range results.

A second refinement concerns the fact that the US Census Bureau undertakes a detailed US projection. The results shown in figure 5 for the US are based on the more aggregated North American projections by UN and IIASA, and largely maintain the current population distribution pattern. It would be preferable to incorporate the more refined USCB data for the US and this should be done in subsequent grids.

A third issue concerns the more recent projections by the UN and other population projection efforts. The results shown in figure 5 use the older projection estimates that were used in the SRES report. These same projections were used here for consistency with the SRES report and climate model projections. A question to be discussed is whether it would be preferable to use more recent UN and IIASA projections without, therefore, exact consistency with the SRES report.

The most important problem, obviously, has to do with the static distributions used in the projections over the next century. In a sense, the projections are just 'linear' scalings of the current distributions. Clearly this is being done as a first attempt at projecting the population and GDP grids.

On the other hand, some strengths of the approach are worth mentioning. For example, the UN (United Nations, 1998), IIASA (Lutz, 1996) and US Census Bureau (Hollmann et al, 2000) population projections include migration rate assumptions using current and recent migration patterns. Such migration assumptions are a first-order account for changes in regional distributions of population. Secondly, there is some 'inertia' to the current distribution of human populations, cities and other infrastructure so that the linear scaling approach has the advantage of having accuracy over the near term. Therefore the problem of a static distribution is obviously more serious for the latter half of the century and this is where alternative 'nonlinear' approaches are best considered. We outline ideas some ideas that could be investigated to achieve this:

Urbanization: Urbanization is a strongly anticipated demographic trend. Since 1970, most urban growth has taken place in developing countries. Its causes are both internal increases of the existing urban population and rural to urban migration (UN, 1997).

In addition to providing national population projections, the UN 1996 Revision also includes a projection of urban rural population changes out to 2030. Essentially, future urban growth and rural decline rates are assumed and applied to the projected population levels.[1] As a first correction to our linear projections, we might incorporate available urbanization data, ensuring that such data are consistent with the national projections. In

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[1] Basically the method involves extrapolating into the future the most recently observed urban/rural growth difference and including a dampening factor based on empirical evidence that the urban/rural growth difference declines as urban proportion rises.

addition, we will consider using any available sector-specific GDP projections in combination with urban/rural location data to change how GNP is allocated to population. For example, if a particular country's GNP is considered to be mostly

Scenarios: Other settlement trends are also important such as coastal population growth. Such growth is well known in the US and elsewhere (Gaffin, 1997), although this factor varies worldwide. Coastal population changes have an obvious importance to studies of the impacts of projected sea level rise on human societies as well as the converse impact of coastal populations on coastal ecosystems.

Such trends are best simulated using scenarios. We will investigate the usage of present coastal trends using high, medium and low variants on these trends and attempt near term corrections on our distribution maps. In some regions, such as the U.S., coastal census data and projections are available (e.g. National Planning Association Data Services, Inc., www.npadata.com).

Stochastic Modeling: A third approach that we will explore is stochastic modeling. This method has been applied to the distribution of anthropogenic night-lights data (Dietz et al, 2000). We will make an exploration of stochastic applications to the future distribution of population and per capita income. For example, one possibility may be to place a cap on the population density and increase neighboring grid cells as a way of distributing the population growth.

APPENDIX 1: Population Projection Methodologies

The following are brief descriptions of key features of the UN and IIASA projections *used in the SRES report, 1996-1998*. They are intentionally not the most recent projections for that reason.

(i) The UN 1996 Revision & 1998 Long Range Projections.

Availability and Update Schedule: At the time of the SRES report, the 1996 Revision was the latest in a series of projections that the UN undertakes every two years. Projections are made for a medium, high, and low variant, as well as a constant fertility scenario. Previously these revisions were carried out to the year 2025. Starting in 1994 the revisions were calculated out to 2050 and such is the case with the 1996 revision.

The 1996 Revision projection generated substantial press attention over the fact that the UN forecasted nearly half-a-billion fewer people in 2050 (9.36 billion) than it did in 1994 (9.83 billion). The base year of data for the UN 1996 Revision is 1995. In contrast, the base year for the 1994 Revision was 1990 so that 1995 vital rates (fertility, mortality, and migration) had been forecasted. The reduction in the population projection had largely to do with the more accurate data available for 1995 (UN, 1997a). World population in 1995 was 5.66 billion people whereas the 1994 Revision had projected 5.69

billion --- a difference of 29 million persons. (LDC population was 34 million persons lower than projected while MDC population was 5 million persons higher.)

The reduction in 1995 population was in turn due to lower than anticipated world average fertility of 2.96 children per woman during the period 1990-1995 as compared to 3.10 children per woman assumed in the 1994 Revision. The main factor causing this decline in fertility rates was a faster than anticipated decline in fertility in a number of countries in South -central Asia (Bangladesh and India) and Sub-Saharan Africa (Kenya and Rwanda) (UN, 1997b). Other important regional declines in fertility also took place in Brazil, former Soviet Republics and new independent states in Eastern and Southern Europe (Haub, 1997). Finally, higher than anticipated mortality rates in a number of countries afflicted by wars (Burundi, Iraq, Liberia and Rwanda) or the spread of AIDS (Eastern Africa) also contributed to the downward revision in projected population.

UN Long Range Projections: The UN also generates longer-term scenarios out to the year 2150. Projections are made for a medium, medium-high, high, medium-low, and low variant, as well as constant fertility and instant replacement level fertility scenarios. Two of the Long Range Projections from 1992 (medium high and medium low) were employed in the IPCC IS92 emissions scenarios. The SRES long range projections from the UN were published in 1998 and again extended out to the year 2150.

Methodology: The UN revisions use country level aggregation throughout the forecast period. Mortality rates change over time however the same mortality trend is used for each of the three variants.

The 1998 long-range projections are extensions of the 1996 revision, and "take off" from the 3 revision variants in 2050. The medium-low and low take off from the low variant of the revision, the medium-high and high from the high variant, etc. (In other words, the medium-low and low are identical through 2050.) Also, the long-term projections do not report country level results out to 2050. All results are reported for the same 9 regions [MDC regions (Europe, N. America, Oceania, USSR) and LDC regions (Africa, L. America, China, India, Asia)] through the entire period. Country level results are only available from the separate projections contained in the revisions. The UN constructs their fertility scenarios by picking an asymptotic target fertility (different in each scenario, and equal to replacement level in the central) that is identical for all regions, but is achieved at different times in each region. They then pick the year in which the target fertility level is achieved in each region. This target fertility/target year point, along with the fertility in 2050 derived from the appropriate revision variant, is used to create the time path of fertility. The mortality assumptions are created in a similar way by picking an ultimate life expectancy for men and women, identical in all regions, and then picking for each region a year in which that ultimate level is reached. This point, along with mortality in 2050 given in the underlying revision variant, is used to create the mortality path for each region (assumed identical in all scenarios).

(ii) IIASA 1996 Projections

Availability and Update Schedule: This set of projections is essentially an update on "The Future Population of the World: What Can We Assume Today?" by Wolfgang Lutz (ed) originally published in 1994 and now updated to 1996.

Methodology: The IIASA projections involve 13 world regions, not country level detail, and the same regional breakup is maintained throughout. The IIASA regions are: North America, Western Europe, Eastern Europe, European FSU, Pacific OECD, Latin America, Central Asia, Middle East, North Africa, Sub Saharan Africa, China and CPA, South Asia, Pacific Asia.

IIASA also employs significantly more degrees of freedom in the treatment of mortality and also migration than others. The main scenarios are labeled "central," "rapid transition," "slow transition," "high," and "low." In the two "transition" scenarios, mortality rates and fertility rates are correlated so that low/high mortality accompanies low/high fertility, in line with conventional wisdom by demographers that fertility declines are associated with mortality declines. This correlation has the effect of narrowing the range of projected population size as compared to an anti-correlation. The "high" and "low" scenarios, by contrast, anti-correlate mortality and fertility and are considered quite unlikely.

The fertility, mortality and migration rate assumptions were developed based on a Gaussian fit to a survey of "experts" who were asked to give a range of rates for each region that they considered to cover the 90th % probability range. Given the Gaussian curve fits to the expert data, a Monte Carlo simulation was run to generate 4000 scenarios, with 5 year timesteps, which have a probability distribution attached to them. The branch points in the fertility, mortality, and net migration rate curves, based on the expert data, were set in 1995, 2000, 2030 and 2080. The IIASA projections go out to 2100.

It is useful to note that the IIASA projections are also presented as a probability distribution in addition to the alternative projections named above. The middle 60th % of the projections fall in a fairly narrow band centered at 10.35 billion in 2100. The spread in this band is only about ± 1.5 billion people around the central number 10.35 billion.

In addition, migration is treated in the IIASA projections in a way that actually allows modelers to combine population scenarios for different regions differently. For example, a modeler may combine the IIASA "slow" scenario for Africa with the "fast" scenario for Europe and this won't be a contradiction as long as the same migration scenario is assumed in both cases.

Appendix 2: Notes on Projecting GPW & GDP Density Grids

Since the SRES Regions data do not exactly match the GPW countries (e.g. a number of GPW countries for which there are data are not listed in the SRES regions), the GPW data were not adjusted to match the population totals of the regions. Rather, the rates of population change were used to project the existing GPW totals. If national-level population projects are used, the GPW totals could be adjusted to match the SRES totals before projecting.

1. Matched countries to SRES World Regions. Some were guessed because they were not included in the list of regions (see gpwcodes.xls for a list of the ones guessed at).

2. A quarter-degree resolution grid of population (1990 UN-adjusted values) was created based on GPW using the following GRID command in ArcInfo:

```
GLP90AG25 = aggregate(../world/glp90ag,6,sum)
```

3. Reclassified the global country identifier grid for GPW (glcntryg) into 11 numbers representing each of the regions(grid SRES_CNTRY). For the MESSAGE model implementation of the B2 scenario these regions are as follows:

1-AFR Sub-Saharan Africa
2-CPA Centrally planned Asia and China
3-EEU Central and Eastern Europ
4-FSU newly independent states of the former Soviet Union
5-LAM Latin America and the Caribbean
6-MEA Middle East and North Africa
7-NAM North America
8-PAO Pacific OECD
9-PAS Other Pacific Asia
10-SAS South Asia
11-WEU Western Europe

This was completed with the GRID command: SRES_CNTRY = reclass(../ancillary/glcntryg,cntry_remap.txt)

A quarter-degree resolution version of this grid was created with the following GRID commands:

```
setcell glp90ag25
setwindow glp90ag25
SRES_CNTRY25 = SRES_CNTRY
```

4. Population change rates were calculated in the spreadsheet B2_pop_gdp.xls for each of the 11 regions described in step 2. The following formula was used:

r=(LN(P2/P1))/10 This is how the formula appears in excel, except that cell addresses are substituted for P2 and P1.
r= rate
LN = natural logarithm
P2 = population at interval two (latest)
P1 = population at interval one (earliest)

5. Rate factors (one rate per decade) were appended to the identifier grid by joining the population rates calculated in step 4 to the grid SRES_CNTRY25. The rates were exported as a text file from the spreadsheet (rates.txt), then converted to an INFO file

(RATES), which was then appended to the grid SRES_CNTRY25 with the following ARC commands:

```
JOINITEM SRES_CNTRY25.VAT RATES SRES_CNTRY25.VAT value
INDEXITEM SRES_CNTRY25.VAT value
```

By doing this, the rates were associated with the appropriate grid cells for each of the SRES regions.

6. The population projection grids for each year were created with the following command (just a few are given as an example!):

```
p1991 = exp(sres_cntry25.r90_2000) * p1990 /* p1990 is actually GLP90AG25
p1992 = exp(sres_cntry25.r90_2000) * p1991
p1993 = exp(sres_cntry25.r90_2000) * p1992
...
p2001 = exp(sres_cntry25.r00_2010) * p2000
p2002 = exp(sres_cntry25.r00_2010) * p2001
etc...
```

these are all listed in the AML step.aml

7. As a form of error checking, the grids were summed and the results written to a text file (poptotal.txt). See popcheck.aml for details.

7. As a form of error checking, the grids were summed and the results written to a text file (poptotal.txt). See popcheck.aml for details.

8. To save space, and given that the information is not needed, the grids were rounded to whole numbers. See the AML pop_round.aml for details.

9. The input pop grids were deleted (remove_int.aml)

10. For cartographic use, the rounded grids were divided by 1000. See popk.aml for details.

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