Working Paper

An Assessment of Integrated Climate Change Impacts on Egypt

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INTRODUCTION

The waters of the river will dry up,
and the riverbed will be parched and dry.
The canals will stink;
the streams of Egypt will dwindle and dry up.
The reeds and rushes will wither,
also the plants along the Nile,
at the mouth of the river.
Every sown field along the Nile will become parched,
will blow away and be no more.
The fishermen will groan and lament,
all who cast hooks into the Nile;
those who throw nets on the water will pine away.
Those who work with combed flax will despair,
the weavers of fine linen will lose hope.
The workers in cloth will be dejected,
and all the wage earners will be sick at heart.

ISAIAH 19:5-10
(Holy Bible, New International Version, 1984)

This text, from the prophet Isaiah, describes the potential impact of a climatic fluctuation in the Nile Basin on Egypt and the impact of this fluctuation on water resources (reduction in Nile flow) and agriculture. It then describes an integrated impact assessment, not only on direct water users, such as farmers and fisherman, but also on industries dependent upon agricultural output, such as the agro-industries of flax, weaving and the clothing industry. Finally, it looks beyond the first and second order impacts and addresses the impacts on the entire economy ("all wage earners") and upon society: "(they)... will lose hope," "... will be dejected," and "...will be sick at heart."

This integrated economic analysis of the impact of a prolonged drought on Egypt, described by the Old Testament prophet over 2700 years ago, is amazingly similar in structure and framework to the work reported on in this chapter. Surprisingly, the prophecies of Isaiah are very similar to the results of the integrated assessment for one of the GCM climate change scenarios analyzed in the book. Old Testament scholars (Alexander, 1994) suggest that Isaiah's prophecy describes a long but not permanent drought as a punishment to Egypt, which will be followed by a time of blessing that has yet to occur. The significance to us of this passage is that (1) a climate fluctuation would be the means of punishment upon the whole nation, (2) for Egypt, with its unique water resources and riverine economy and society, climatic fluctuations can have a catastrophic impact upon the entire economy and society, and (3) it clearly shows the vulnerability of Egypt to climatic changes, related especially to the impacts upon the Nile River.

The insight we gain from Isaiah's words is that climate change impacts can affect all of a society, and the total impact on society must be investigated systematically. This chapter discusses a study that is just such an attempt to look not at first-order effects of climate change on individual sectors, but on the integrated impacts of all the sectors on the nation as a whole.

AN INTEGRATED IMPACT STUDY

Why do an Integrated Study?

In the preceding chapters, analysis was given of the potential impacts of climate change on a variety of natural and human-based systems or sectors. For each sector, the analysis focused only on the direct impacts of a "changed climate" (temperature and precipitation changes) on the particular sector. For example, the River Basin Study (Chapter 3) did not address increased water demands due to increased irrigation or municipal water use as a result of a changing climate. The Agriculture Study (Chapter 2) did not take into account the increase or decrease in the availability of water resources as a result of climatic change. The Sea-level-rise study (Chapter 4) did not address the changing land-use patterns in the vulnerable areas that may result from changes in crop yields, agricultural economics, or water resources, due to a changing climate.

While examining all of these indirect or feedback mechanisms is beyond the scope of each of the studies, the question remains: how will impacts on different, related sectors interact? For example, if agriculture in a region was less profitable due to climate change, the economic impacts of land loss due to sea-level rise may be significantly reduced. Or, if increased temperatures lead to increased water demands for irrigated agriculture, but decreased precipitation results in reduced water resource availability, then there will be an even greater decrease in agricultural production than the agricultural or water resource impact assessments would suggest.

Performing such a study requires an interdisciplinary effort that integrates information and assumptions across many disciplines and uses a consistent and systematic analytic framework. This chapter will discuss such an undertaking.

Examples of other integrated studies include: the MINK Study of climate change impacts on Missouri, Iowa, Nebraska, and Kansas (Bowes and Crosson, 1993; Crosson and Rosenberg, 1993); the Great Lakes-St. Lawrence Basin Project (Mortsch et al. 1993); and Southeast Asia (Parry et al. 1992).

Why do an Integrated Study of Egypt?

Previous climate change impact studies that focused on Egypt in some detail point to Egypt as being extremely vulnerable to climatic change. Broadus et al. (1986) and El-Raey (1991) suggest land losses of 12 to 15 percent of Egypt's current arable land for a one-meter sea-level rise. Gleick (1991), in an aggregated study of the Nile Basin, suggested that it is extremely sensitive to changes in temperature and precipitation.

The issues presented above and the implications that they posed for climate change impact assessment led the U.S. Environmental Protection Agency to initiate an integrated study. Egypt was chosen because detailed sectoral studies were being developed for it involving the Agricultural Study, the Sea-level-Rise Study, the River Basin Study and the Human Health Study, all of which enabled an integrated study of impacts on Egypt.

In addition, the Egyptian Ministry of Public Works and Water Resources and USAID/US Bureau of Reclamation were jointly extending a model of Egyptian agriculture, EASM (Egyptian Agricultural Sector Model) (Humphries, 1991). EASM provides a systematic assessment of national agricultural economic impacts with detailed modeling of agronomic, economic, land and water resources, and technology. The model could be modified to accept as inputs the results of the agricultural, river-basin, and sea-level-rise studies to provide an integrated assessment.

Despite the difficulties in undertaking an integrated study after all the sectoral studies were essentially complete, the project leadership felt there was much to be gained from the analysis.

EGYPT : A BACKGROUND SKETCH

Egypt Today

Geography and Climate

Egypt occupies the northeastern corner of Africa (Figure 1) from 22° to 31° North latitude and 24° to 36° East longitude. It is bounded in the east by the Red Sea, in the west by Libya, in the north by the Mediterranean Sea, and in the south by Sudan. The total land area is 997,688 square kilometers that comprise five major geographical regions: the Nile Valley (upper Egypt, lower Egypt), the Nile Delta, the Eastern Desert, Sinai, and the Western Desert. These geographical areas are divided into 26 administrative units or governorates that are grouped into four regions: Urban Egypt, Lower Egypt, Upper Egypt, and Frontier Egypt.

Figure 2 is a map of Egypt which shows that agricultural activity is located in the narrow corridor of the Nile valley and Delta. The Nile vally winds approximately 1000 kilometers from the High Aswan Dam in the south to the Nile Delta in the north. The figure shows that major cities and industries are concentrated in this corridor.

The Nile Delta is an important economic region. It makes up 60 percent of current agricultural land and is home to over 60 percent of the population. It is the focal point for industry and commerce, bounded by Alexandria in the west, the Suez Canal in the east, and Cairo in the south. Its coastline is currently subsiding due to the loss of Nile sediments to the High Aswan Dam. This results in the potential loss of agricultural land and reduced productivity in coastal lands due to waterlogging and salinity (Nicholls, 1991).

Figure 3a shows the annual rainfall distribution. Egypt is an arid country with only trace rainfall from the southern border to just south of Cairo, limited rainfall in the Delta, and up to 200 mm/yr in a narrow strip along the Mediterranean Coast. Figure 3b shows potential evapotranspiration estimates from the Penman equation for Egypt. When Figures 3a and 3b are compared, it is clear that Egypt is, effectively, desert, except for a very narrow strip along the coast, with the Nile Valley actually a long oasis in the desert.

Table 1 presents values of three climatological variables for key points in Egypt: Central Nile Delta, Cairo, and Aswan, while Figure 4 shows the mean monthly distribution of precipitation and potential evapotranspiration for the agriculturally important Nile Delta region. Figures 3 and 4 and Table 1 describe a hot, dry region capable of agriculture year-round, but with very high potential evapotranspiration, especially in the summer months.

Population

Egypt's population in 1990 was 52.4 million, of which 27.9 million lived in rural areas and 24.5 million lived in urban centers (FAO, 1993). Almost the entire population is located in the area of cultivation of the Nile Valley and Delta. This area represents only 3 percent of the total land area (Figure 2), providing an effective population density of over 5000 persons per square kilometer. Figure 5 shows population trends in Egypt from 1966 to 1992. Egypt's gross population density in 1990 of 55.4 persons per square kilometer is one of the most dense in the world (Onyeji, 1992).

Table 1. Climatological parameters for Egypt

Location	Mean Annual Precipitation (mm)	Mean Annual Potential Evapotranspiration (mm)	Mean Annual Temperature (°C)
Mid Delta	48	1,390	19.8
Cairo	25.5	1,780	20.8
Aswan	1	2,480	25.8

Source: Shahin, 1985.

Table 2 shows the distribution of population, income, and household size by region. Rural population accounts for 56 percent of the population but only 42 percent of the income. The annual rate of population growth in Egypt is currently 2.39 percent (WRI et al., 1992). The rapid growth of population has been accompanied by strong rural-urban migration. One result is that Cairo is estimated to have 12 to 15 million inhabitants, or approximately 25 percent of the population.

Table 2. Socio-economic indicators for Egypt in 1990

Region	% Population	Per-Capita Income (Egyptian pounds)	Average Household Size
Total Egypt	100	1,540	4.9
Urban	44	2,036	4.5
Rural	56	1,151	5.1

Source: Onyeji, 1992.

Standard of Living

An overview of the Standard of Living Indicators for Egypt in 1960 and 1985 (Table 3) shows a country that has undergone dramatic changes. Egypt's standard of living has increased significantly in the last generation. For example, income per capita has more than doubled. How were these changes accomplished, are they sustainable, and how could a changing climate affect them? To examine these questions in detail, the following sections will describe key factors affecting Egyptian society and economy.

The Economy

From the 1880s until Nasser's taking control in the 1950s, private enterprise and relatively free trade were the main features of the economy. Development was driven by public investment in agriculture, and, from 1930, limited protection for industry and some protection for a few agricultural products. From Nasser's program of Arab Socialism until the late 1980s, public ownership of the modern sector, major trade restrictions, and import substitutions predominated (Hansen, 1991). Governmental policies of the 50s, 60s, and 70s were quite successful in improving the standard of living as discussed above. Much of this success was due to the liberalization and open-door policies of 1974 that resulted in annual real economic growth of 9 percent and an inflation rate of 10 percent. Balance of payments improved from foreign exchange earnings that accrued from expatriate worker remittances, tourism, and foreign aid. (Zeineldin, 1986). However, following the subsequent collapse of oil prices and dwindling worker remittances, industrial growth began to lag behind the rapidly growing domestic demand which was fueled by the growing population and government policy. Since 1985, economic growth has declined, and unemployment and inflation have increased (Onyeji, 1992).

Table 3. Standard of Life Indicators for Egypt

Indicator	1960	1985
GNP per capita (1985 $)	275	610
Daily caloric supply (per capita)	2,435	3,203
Life expectancy (at birth)	46	61
Crude death rate (per 1000 population)	19	10
Infant mortality (per 1000 live births)	109	93
Crude birth rate (per 1000 population)	44	36
Urbanization (per cent of population)	38	46
Physicians (persons per physician)	2,560	760

Source: Hansen, 1991

The growth in living standard has not been evenly distributed across the population, and the cost has been high. To achieve such progress, Egypt spent more than it earned. Average annual expenditure growth was 1 percent greater than average annual income growth. This income deficit was made up with foreign loans, leaving Egypt as one of the most indebted nations in the world (Hansen, 1991).

In May 1987, the Egyptian government and the International Monetary Fund concluded a stabilization and structural adjustment agreement purportedly to revitalize economic growth. This included a gradual move back to private enterprise and relatively free trade, particularly in agriculture. The full impact of the new policies was not in place in 1990, the base year for our analysis, but it has been observed in subsequent years (O'Mara and Hawary, 1992). For example, cotton and wheat cultivation have responded dramatically to new pricing policies (El-Din, 1993).

Table 4 presents a highly aggregated view of the Egyptian economy in 1984 and 1987. Agriculture is a major sector at 20 percent of GDP. Industry and mining, without petroleum, declined from 1984 to 1987. Petroleum is not seen as a long-term resource, as new major reserves have not been found. The rapidly increasing trade and finance sector, combined with a declining manufacturing sector, indicates a basic weakness in the Egyptian economy (Hansen, 1991). Table 5 presents employment by sector for 1990. It should be noted that agriculture is the dominant employer at 38 percent, with service next at 20 percent.

The Egyptian industrial structure is dominated by basic consumer goods (textiles, shoes, food, beverages, and cigarettes) and essential intermediate goods (building materials, fertilizer, chemicals, paper, petroleum products, and some metals) sold primarily on the domestic market. The capital goods industry (machinery, tools, implements) is small (Onyeji, 1992).

Table 6 is a list of the major exported agricultural commodities for 1984. While petroleum is the major export revenue source, agriculture was responsible for over 70 percent of the remaining exports. From the standpoint of employment, trade, and intermediate inputs to industry, agriculture is a key economic sector. The next section will take a detailed look at the agricultural sector.

Table 4. Economic Structure of Egypt

	1984	1987
Total value of GDP (millions Egyptian pounds)	25,961	43,685
Sector	**Percent of GDP**	
Agriculture	20.0	20.1
Industry, mining & petroleum	33.1	28.7
Other Sectors	46.9	51.2

Source: Hansen, 1991

Table 5. Employment figures for Egypt in 1990[a]

Sector	1000s	Percent
Agriculture	4,797	38.7
Mining	45	0.4
Manufacturing	1,540	12.4
Electricity, gas, water	98	0.8
Construction	900	7.3
Commerce and hotels	882	7.1
Transport and communication	671	5.4
Trade and Finance	243	2.0
Services	2,702	21.8
Other	505	4.1
Total	12,386	100.0

[a]These figures underestimate female employment.
Source: Onyeji, 1992

Table 6. Exports in 1984 as Percent of GNP

Commodity	Percent of GNP
Cotton	1.5
Rice	0.1
Fruits and vegetables	0.5
Cotton textiles	0.7
Petroleum	16.4
Industrial goods	1.0
Total	20.2

Source: Hansen, 1991

Agriculture Sector

With its very arid climate, Egypt has a unique agricultural system. Because there is effectively no rainfall, almost all of the agricultural land is irrigated. The water supply for this irrigation comes solely from the Nile River waters stored in Lake Nasser behind the High Aswan Dam. (See Chapter 3 for a detailed discussion of the effect of climate change on the Nile Basin.)

Currently, agriculture is practiced on 3 million hectares (5.892 million *feddans*[1]), or only 3 percent of the area of Egypt. It is limited to 9,300 square kilometers of the very fertile lands in the narrow Nile valley from Aswan to Cairo and the Nile Delta north of Cairo. New, less fertile lands on the fringe of the Delta and in the Sinai are being developed. Table 7 shows the distribution of agricultural land within Egypt. Over three-fifths of the land used for agriculture is in the Delta (Humphries, 1991).

Table 7. Agricultural Land In Egypt 1990

Agro-Climatic Zone	Area (10^3 *feddans*)	Percentage
Upper Egypt	1076	18
Middle Egypt	1192	20
Delta	3624	62
Total	5892	100

Source: Humphries, 1991

The agricultural year has three crop seasons. The winter season starts between October and December and ends between April and June. Its main crops are wheat and barley, berseem[2] and lentils, winter onions, and vegetables. The summer crops--cotton, rice, maize, sorghum, sesame, groundnuts, summer onions, and vegetables--are sown from March to June and harvested from August to November. A third growing season known as "*nili*" is a delayed summer season, when rice, sorghum, berseem, and some vegetables are grown. Since *nili* and summer cropping seasons overlap, a piece of land cannot be planted with both summer and *nili* crops in any one year. To prevent soil degradation and pest-induced losses, an elaborate crop rotation is practiced in Egypt. This leads to many small plots with multiple crops and a general three-year crop rotation to preserve soil fertility. There are significant perennial crops such as sugarcane in Upper and Middle Egypt and citrus, grapes, bananas, mangoes, olives, and dates (USU, 1986). Table 8 is a summary of the 1990 observed cropping pattern.

In 1990, agriculture (including livestock) accounted for nearly 20 percent of the gross domestic product (GDP) and employed 37 percent of the labor force. These figures do not include agro-industries such as textiles or food processing (Onyeji, 1992) Agricultural exports accounted for approximately 20 percent of export earnings. Even with some of the most productive agricultural land in the world and a plentiful water supply, Egypt is currently importing over two-thirds of its wheat and vegetable oils and one-third of its corn. Agricultural imports have increased three-fold since 1975, resulting in annual agricultural import costs of over $3 billion (FAO, 1993). This is partly due to governmental policy,

1 A *feddan* is the Egyptian unit of land measurement. It is equal to 1.04 acres, 0.42 hectares and 0.004 square kilometers.

2 Berseem is an Egyptian clover used for fodder.

international commodity prices, and foreign food aid and population growth. While annual agricultural production has increased by 46 percent over the period from 1978 to 1990, the population has grown 28 percent, resulting in a per capita increase of only 14 percent over this period.

Table 8. Egyptian Agricultural Production 1990

Crop	Production (ton x 1000)
Barley	175
Citrus	2734
Cotton Lint	219
Cotton Seed Oil	115
Eggs	156
Flax fiber	1138
Groundnut	24
Horse Bean	528
Legumes	26
Lentils	100
Maize	4606
Meat	340
Milk	2370
Onion	728
Potato	1937
Poultry	203
Rice	2093
Sesame	32
Sorghum	610
Soybeans	176
Sugar	872
Tomato	1657
Vegetable Oil	615
Vegetables	2166
Wheat	4218

Source: FAO, 1993

The net growth of agricultural lands is slowed to 20,000 *feddans* per year by the loss of highly productive lands to housing and urban construction around population centers. Highly productive agricultural land is limited, and land reclamation is slow and costly. The reclaimed lands are primarily desert, with lower productivity than the Nile Valley or Delta lands. Figure 6 plots the growth of agricultural land from 1961 to 1991. The rate of increase of land utilization is greater than the rate of increase in production, since most growth is in reclaimed desert lands. Even with the growth of agricultural production, the demand for food outstrips these gains, again driven mainly by population growth.

Egypt's Future Without Climate Change

Based on World Bank estimates, an Egyptian population of 115 million, i.e. 2.2 times that in 1990, is forecast for 2060. This is derived from a forecast of annual population growth rates of 1.66 percent from 1990 to 2020, 0.95 percent from 2020 to 2040, and 0.58 percent from 2040 to 2060; a long-term average annual growth rate over 70 years of 1 percent. The growing population will put enormous stress on efforts to increase agricultural production through land reclamation and technological improvement. Increasing agricultural production must be accomplished despite fixed water resources and harsh climatic and geographic features of the 97 percent of land that is undeveloped. The Central Planning Bureau of the Netherlands (1992) forecasts 2.1 to 3.6 percent annual GDP growth for middle eastern economies over the period from 1990 to 2015. Egypt's future depends on the sign and magnitude of difference in these two growth rates.

There are two quite opposite views about Egypt's long-range economic development (Yates, Strzepek, and O'Mara, forthcoming). The pessimists see that Egypt has dug itself into a deep economic hole. With its growing population, large foreign debt, continuing tendencies of debt increase and low investments, they forecast that, rather than getting out of it, the hole will actually get deeper. This group sees very low growth in the agricultural as well as the non-agricultural sectors and the prospect of unchecked population growth and slow changes in government policies leading to short-term consumption rather than long-term investments.

The optimists believe that, in spite of its current debt and low-technology industries, Egypt will invest in new, effective technologies in the mid- and long-term and will actually surpass some countries with aging, less productive technologies. This group sees Egypt as the South Korea of the twenty-first century. One economic modeling effort (Fischer et al., 1994; Chapter 2, this volume), which was based on optimistic growth parameters, projects a doubling of the 1990 per capita GDP in Egypt by the year 2060, fueled by six-fold and three-fold increases in non-agricultural and agricultural GDP, respectively. This is all accomplished while accommodating a population that has more than doubled.

While we cannot estimate the probability of these scenarios, the assumptions about the future are crucial to any analysis that attempts to assess climatic change impacts on a future economy. Given the structure of the economy, the impact may vary greatly. We look at Egypt's vulnerability to climatic change in the next section.

Egypt's Changed Climate

GCM results for doubled CO_2 uniformly estimate an increase of slightly over 4°C in average annual temperature for Cairo (Table 9). This increase will lead to higher potential evapotranspiration. These results suggest that Cairo and the Delta region would have a climate similar to that currently found in Aswan (see Table 1). Humphries (1991) found that there is a significant difference in crop water requirement between Upper Egypt and the Nile Delta. With only trace amounts of rainfall in the current climate, the precipitation changes estimated by the GCM are insignificant.

Almost all of Egypt's water supply comes from the Nile River, so climatic change over the entire Nile basin, as far south as Lake Victoria--some 5000 kilometers south of Aswan--will have an impact on Egypt. Table 9 presents the GCM results averaged over the

10 to 16 grid cells that cover the approximately 2,000,000 square kilometers of the Nile Basin upstream of the High Aswan Dam (see Figure 1). Annual average temperature increases of 3.1°C to 4.7°C and precipitation increases from 5 to 31 percent are estimated. A hydrologic model of the Nile River estimates the GCM-based climate changes will lead to impacts on flow at Aswan varying from an increase of 30 percent to a decrease of 77 percent (Chapter 3).

Table 9. Annual changes in temperature and precipitation for Cairo and the Nile Basin with three climate change scenarios

	Cairo			Nile Basin		
	UKMO	GISS	GFDL	UKMO	GISS	GFDL
Change in Temp. (°C) ($2xCO_2$-$1xCO_2$)	4.43	4.16	4.20	4.70	3.4	3.1
Precipitation Ratio ($2xCO_2/1xCO_2$)	0.86	1.56	0.85	1.22	1.31	1.05

Egypt's Vulnerability to Climate Change

Egypt is very dependent on natural resources that are vulnerable to climate change. The land used for growing crops is mainly in the Nile Delta, a low-lying area vulnerable to sea-level rise. Agriculture needs water from the Nile for irrigation. Climate change will likely impact water supply. In addition, crop yields and water use will also be directly affected by climate change.

The prospect of a climate-change-induced sea-level rise should be of serious concern to Egypt, since a majority of its population, agriculture, and industrial activity is located in the low-lying Nile Delta. Aside from the low elevation of the Nile Delta, Egypt's vulnerability to sea-level rise is further heightened by the damming of the Nile by the High Aswan Dam. Under natural conditions, sediments reaching the Mediterranean coast would accumulate and compensate for delta subsidence. However, with the High Aswan Dam in place, sediment laden Nile waters are no longer able to reach the Mediterranean Sea, effectively starving the delta of fluvial deposition. The lack of freshwater influx has led to subsidence of the Delta, an increase in soil salinization and a loss of cultivable land.

Egypt has been granted an annual yield of 55 billion cubic meters of Nile water from Lake Nasser via the Nile Waters agreement with Sudan. Annual per capita water availability in 1990 was 1005 m^3 and is projected to drop to 452 m^3 in the year 2060 based on World Bank forecasts (Fischer, 1993). Kulshreshtha (1993) suggests that a nation with less that 1000 cubic meters per person per year results in a water-scarcity condition. With few economically feasible alternative water supply options, Egypt must rely solely on the Nile. Climate change could affect the flow of the Nile and the availability of water for Egypt.

GCM results for Egypt show substantial warming. An increase in temperature will lead to increased evapotranspiration by crops. This translates into increased crop water requirements and lower yields (Eid and Saleh, 1992).

The description of the Egyptian economy in 1990 would suggest that it might be sensitive to the type of climatic change suggested for Egypt. With 20 percent of GDP and 38 percent of the labor forces involved directly in agriculture, any impact will be felt throughout the economy. In addition, loss of land and infrastructure due to sea-level rise or major investments to mitigate impacts will take away from more productive investments. Because of the importance of this sector, this study focuses on the agricultural economy.

SECTORAL IMPACTS OF CLIMATE CHANGE

Sea-Level Rise

Analysis performed as part of the sea-level-rise study reported in Chapter 4 estimates that by 2060, the mean impact of a global sea-level rise of 1 meter by 2100 would produce a 0.37 meter sea-level rise at the Nile Delta. This effect, combined with a non-climate induced subsidence of the Nile Delta of 0.38 meters, is estimated to result in the movement of the shoreline to the current 0.75-meter contour by 2060 (Figure 6). El-Raey (1991) and others assume that agriculture cannot take place within a 1 meter buffer zone from sea level to the 1-meter contour. Currently, irrigation takes place in this buffer zone and Egyptian government plans call for reclamation of delta lands well below the current 0.75-meter contour, including large areas of inland salt lakes and sand dunes. However, due to salinization and sea-water intrusion, agriculture below an elevation of one meter is very difficult and requires careful water management (Rosenzweig and Hillel, forthcoming). A 0.75-meter net rise based on agriculture in the buffer zone will result in a direct loss of 4 percent of Egyptian agricultural land in 2060. If, in fact, irrigation is not sustainable within the 1-meter buffer, then sea-level rise in 2060 will mean the loss of land between the current 1.00-meter and 1.75-meter contours (Strzepek and Saidin, 1994).

Water Resources

The GCM-based results do not agree on the direction of change of Nile River flow. Chapter 3 presents a full discussion of climate change impacts on the Nile Basin and Egyptian water resources at Aswan. Table 10 is a summary of the impacts. The UKMO scenario suggests a 12 percent decrease in the flow of the Nile at Aswan. The GISS and LOWEND scenarios suggest increases in the flow of the Nile at Aswan that would become only 18 percent and 14 percent increases, respectively, in water supply for Egypt[3]. This is due to increased evaporation at Aswan and the nature of the Nile Waters Treaty with Sudan, which evenly shares any increase in flow at Aswan. Finally, the GFDL results show a catastrophic decline of 77 percent of the Nile flow at Aswan.

Agriculture

The study of the agriculture sector, described in Chapter 2, had two components: agricultural (crop yields) and economic (world food trade study). Both of these were used for the integration analysis. The crop-yield analysis also considered the direct effects of increased CO_2 on plant growth and water requirements. The agricultural impacts were studied in depth for wheat, maize, soybean, and rice. In general, crop yields decrease at a minimum of 20 percent without direct effects of CO_2 and, on average, the direct effects lessen this decrease by 5 percent. Water requirements of crops increase about 7 percent in the Delta and 15

[3] There currently exists an agreement between Egypt and the Sudan on the allocation of Nile River flows. This allocation is based on the current annual mean flow at Aswan of 84 MCM, taking into account losses, evaporation, and seepage caused by storing the water in Lake Nasser. However, there are formal procedures for dealing with any increases to the Nile flow due to the Upper Nile projects which call for an equal sharing between the Sudan and Egypt of any flow above the current 84. For the GISS scenario, which projects 30 percent increase in Nile flow, both Sudan and Egypt would get 11.5 MCM of additional allowable annual withdrawals after accounting for the increased evaporation due to warming over the reservoir area.

percent in upper and middle Egypt. Tables 11 and 12 report on the results of the climate change scenarios on crop yield and water use (Eid and Saleh, 1992).

Table 10. Climate change impacts on Nile River flow at Aswan and High Aswan Dam yield as percent of current conditions

Scenario	Nile Yield	Egypt Yield
UKMO	88	87
GISS	130	118
GFDL	23	17
LOWEND	118	114

Table 11. Egyptian Crop Yield Impacts under climate change. (Units are ton/ha except where noted.)

Scenario	REF	GISS	GFDL	UKMO	LOWEND
CO_2 (ppm)	330	555	555	555	555
Wheat	4.92	3.59	3.82	1.49	4.72
Maize	10.60	8.63	8.28	8.71	8.30
Rice	6.93	6.88	6.70	6.58	--
Soybean	2.98	2.28	2.08	2.00	--

Source: Eid and Saleh, 1992

Table 12. Egyptian Crop Water Use Impacts under climate change. (Units are mm/yr except where noted.)

Scenario	REF	GISS	GFDL	UKMO	LOWEND
CO_2 (ppm)	330	555	555	555	555
Wheat	557	454	499	515	476
Maize	571	480	516	569	515
Rice	1,062	1,073	1,131	1,195	--
Soybean	816	910	981	1,018	--

Source: Eid and Saleh, 1992

The results in Tables 11 and 12 show rather dramatic impacts on Egyptian agricultural production and water demand. It is likely, though, that Egyptian farmers will respond to changing conditions by changing agricultural practices and water use.

To examine the combined impacts of local and global crop yield and economic changes, a world food trade analysis was performed. The Basic Linked System (BLS) (Fischer et al. 1988) was used to forecast Egyptian domestic demand and net exports for each future scenario (see Chapter 2). Table 13 shows the national domestic consumption in absolute terms for the year 2060 base scenario. The results of the GCM scenario are presented as percentage changes from the reference scenario.

Table 13. BLS results for Egypt under climate change

	2060 Base	GISS	GFDL	UKMO	LOWEND
	Domestic Consumption				
Commodity	(million tons)	(percentage change from Base)			
wheat	13.8	-1.0	-0.7	-5.2	0.6
rice	3.5	-0.6	-0.4	-2.7	-0.2
coarse grains	6.5	-0.8	-2.1	-2.4	0.3
protein feed	0.2	8.4	-3.1	1.6	18.4
other food	7.5	-0.6	0.1	-1.2	-0.2
non food ag	0.9	-0.8	-0.4	-4.8	1.0
bovine & ovine	2.1	-1.2	0.0	-1.3	-1.1
dairy products	7.6	-0.6	-0.1	-1.0	-0.4
other animal	0.1	-0.8	-0.2	-1.3	-0.5

Source: Fischer, 1993

The BLS projects relatively small changes in national demand (consumption) for most agricultural commodities. The largest reduction in any category is a 5.2 percent decrease in wheat consumption for the UKMO scenario. The UKMO scenario projects the greatest overall impact on domestic consumption, while the GFDL scenario has the least impact.

While total domestic consumption is not greatly affected, the agricultural trade balance is significantly impacted with all scenarios showing, on average, a 10 to 20 percent increase in imports with a 120 to 237 percent increase in the import of rice. The net exports in non-food agricultural products (Egyptian cotton and flax) range from a 455 percent increase to a 722 percent decrease. The BLS is a collection of applied general equilibrium models, with Egypt as one of the country models. For the economy to be in equilibrium, the model projects increases in non-agricultural net exports to fund the increases of the import of agricultural commodities. In all the scenarios, the non-agricultural sector expands and provides the national income to maintain domestic food demand, and provides non-agricultural exports to make up for the negative agricultural balance of trade. These results follow the "optimistic" economic future projections for Egypt as discussed in the section on Egypt's future.

APPROACH AND METHODOLOGY TO MODELING THE INTEGRATED CLIMATE CHANGE EFFECTS

A Forward-Linkage Impact Integration

The analytical framework under which this study was done is shown in Figure 8. The applied approach for integrated assessment takes the individual sectoral impacts on Egypt as inputs to the EASM model. There are no feedback linkages in the analysis. BLS modeled demands and domestic agricultural production do not reflect the direct impacts of the water supply, water requirements, or sea-level rise. Neglecting these impacts could lead the BLS to under- or overestimate the impacts of climate change on domestic demand and production. This lack of feedback is referred to as a forward-linkage analysis.

The schematic representation in Figure 8 gives an outline of the major elements of the study. Climate scenarios based on an effective doubling of CO_2 came from GCM runs. These scenarios were used to model hydrologic and agronomic impacts (see Nile River flow, Chapter 3, and global and Egyptian crop yields and water use, Chapter 2, respectively). Only the crop yields were input into the IIASA Basic Linked System (BLS) for modeling world food supply and trade to the year 2060, when full CO_2 effects were assumed to be realized. Egypt's economy and its linkage to the rest of the world is specifically modeled in the BLS up to the year 2060 using World Bank forecasts of population growth. Egyptian domestic and foreign commodity demands are generated by the BLS and input, along with Nile flow, land availability (based on a 37-cm sea-level rise in 2060), crop yield, and water use, to a modified Egyptian Agricultural Sector Model (EASM-CC).

EASM-CC models the economics of the agricultural sector as well as the water, land, crop, livestock, and labor components on a sub-national scale. EASM models economic behavior by maximizing the consumer-producer surplus (CPS) over an annual cycle (Yates, Strzepek, and O'Mara, forthcoming).

A Consistent 2060 Base Scenario

A consistent 2060 base scenario was needed in order to create a plausible scheme for Egyptian agriculture in 2060.

Adaptation of Costs, Prices, and Demand

For the 2060 base scenario, restrictive taxes and subsidies were removed from the marketing costs. Marketing costs were assumed to be true markups between domestic prices and farm gate prices. Export marketing prices were assumed to be 20 percent greater than the domestic marketing costs. International import and export prices were taken from the BLS and are referenced as percentage changes from the 1990 base.

To derive a demand curve for 2060, it was assumed that a parallel shift of 1990 demand would take place. For the 2060 base scenario, it was assumed that the slope of the demand curve did not change from 1990; only the intercept of the demand curve was recomputed based on the price and demand equilibrium from the BLS.

Technology

Technology changes in agriculture primarily affect crop yield responses. Endogenously-calculated 2060-base crop yields were taken from the BLS, based on exogenous technological growth rates and production functions of inputs. Crops in 2060 were assumed to require more water as yields increase and more inputs are applied. Crop water requirements were assumed to be 25 percent of the yield change based on experimental data from the southwestern USA (Hexem and Heady, 1978). Inputs such as mechanization, fertilizer, etc., were taken from the BLS as percent increases or decreases from 1990 data. Technological inputs affect the utilization of labor, capital, and fertilizer in EASM-CC.

Constraints and Assumptions

Several constraints and assumptions made for 1990 conditions were removed or adapted for 2060. Changes include:

- Removing the upper limits on sugar processing and on citrus, cotton, and vegetable cultivation;

- Removing the exogenous herds of camels, donkeys, and goats;
- Utilizing only 50 percent of 1990 crop by-product fodder (assumption of specialization);
- Increasing labor availability linearly with total population;
- Adding new lands in the Upper Valley and the Nile Delta comprising 2 million *feddans* (distributed equally) with a limited cropping pattern (USU, 1986);
- Removing 124,000 *feddans* of agricultural area due to land subsidence in the Nile Delta;
- Removing the navigational requirement;
- Removing bounds on imports and exports;
- Keeping industrial water use at 1990 levels;
- Keeping domestic water use per capita at 1990 levels, resulting in a 120 percent increase of domestic water use.

The Model Runs

To assess the integrated impacts of climatic change, a primary set of model runs was made using EASM-CC. These runs are listed below.

B1990 (Base 1990) is based on the 1990 observed population, land and water resources, and technology, but with a free market economy with no trade restrictions as postulated for 2060. This run was made using current climate conditions to provide a comparison between a 1990 hypothetical situation (removal of trade restrictions) and the 2060 scenario postulated by the BLS.

B2060 (Base 2060) is based on a consistent scenario for 2060, with population, economic growth, agricultural production, and commodity demands from the BLS, with land and water resources based on the current climate, and with water use based on agricultural production and technology postulated for 2060.

GCMs: The four GCM scenarios discussed in the introductory chapter were run to analyze the integrated impacts on the Egyptian agricultural economic sector due to climatic change.

All of these runs were performed with the standard EASM-CC objective to maximize consumer-producer surplus. Additional runs were made to assess possible adaptations to mitigate the impacts of climate change. These adaptations are described below.

Adaptations

Adaptations were examined for land resources, water resources, and irrigation and agricultural technology.

Land Resources: In addition to runs assuming land loss to sea-level rise, each of the climate change scenarios was run assuming no land lost due to global sea-level rise, because some form of coastal protection would be constructed. The land lost from natural subsidence remains, however.

There are hundreds of possible adaptation combinations that could be examined. It was not practical to consider them all. To provide some focus, the following adaptations were applied only to the UKMO scenario:

Water Resources: There are plans (most notably the Jonglei Canal Project) to develop major water projects in the Upper Nile Basin (the Sudd Swamps) to divert runoff before it enters the swamps and evapotranspires. These projects would provide Egypt with an additional 10 MCM of water, or 20 percent of its current water supply. It is assumed that the projects will be realized and still be effective under climate change conditions.

Irrigation Technology: A 5 percent increase in irrigation system efficiency was assumed.

Agricultural Technology: The low-cost adaptations discussed in the agricultural chapter as adaptation Level I were used (see Chapter 2). These adaptations affect crop yield, water use, and commodity demand.

Adaptation scenario I (ADI) includes the improvement in irrigation technology, the Level I agricultural adaptations, and protection against sea-level rise. Adaptation scenario II (ADII) is the same as ADI with an additional 20 percent increase in Egyptian water availability.

Policy Adaptations: Maximizing social welfare by way of maximizing economic performance makes sense to an economist, but doing so might involve reduced agricultural output and increased agricultural imports. The 2060 base scenario that maximizes social welfare for Egypt would have only a 10 percent food self-sufficiency value. An alternative policy, which many countries follow based on national security grounds, is to maximize food self-sufficiency. This policy could have substantial economic costs. Most governments adopt a policy somewhere between the free-market economy and the maximizing of food self-sufficiency. Since we will examine a policy of maximizing social welfare defined by the consumer-producer surplus, an alternative food self-sufficiency policy was developed. The EASM-CC objective function was changed to maximize domestic production of calories to increase food self-sufficiency while meeting the BLS estimated domestic demands.

Measures of Climate Change Impacts

The objective function of EASM-CC is to maximize Consumer-Producer Surplus [CPS], in addition to this integrative economic measure of social welfare, other economic and societal welfare measures are recorded for each run. They include the following:

Economic Measures

- Consumer Surplus [CS]
- Producer surplus [PS]; exports are considered as positive and imports as negative
- Agricultural Trade Balance [ATB] in Egyptian Pounds, calculated as exports minus imports
- Exports in Egyptian Pounds [EXP]
- Imports in Egyptian Pounds [IMP]
- Marginal Value of Water [MVW]
- Marginal Value of Land [MVL]

Societal Welfare Measures

- Calories per person per day exogenously determined by BLS and 1990 consumption patterns [CAL]
- Food Self-sufficiency-Calories [FSS-CAL]: ratio of domestically-produced calories to total demanded calories per year

These specific measures provide insight into the nature of the economic impacts as well as providing some measure of the impact upon direct societal welfare.

THE INTEGRATED ASSESSMENT

Model Results

The Base Scenarios

While the Base 2060 scenario is not intended to be a prediction of Egypt's future, it is a self-consistent and plausible scenario considered optimistic by our definition. In this scenario the BLS Egyptian economic model suggests a 5.2-fold increase in GDP, made up of 3.1- and 5.6-fold increases in the agricultural and non-agricultural sectors, respectively. This growth is fueled by a 2.2-fold increase in population and 3.4- and 7.1-fold increases in the agricultural and non-agricultural capital, respectively (Onyeji and Fischer, 1993). The first analysis to be presented is a comparison of the Egyptian agricultural economic sector between 1990 and 2060 from the viewpoint of an integrated analysis, with the current climate.

Tables 14a-b present the set of economic measures recorded for each of the model runs. Comparing the 1990 base (B1990) with the 2060 base (B2060), four results stand out:

- Food consumption (calories per capita per day) decreases from 1990 to 2060. In 1990, Egyptian food consumption was well above what the economy could afford, due to foreign food aid (principally wheat and grain) and heavy government subsidies funded by foreign aid and loans. Food consumption in 2060 is more in line with per capita income.

- The agricultural trade balance for 1990 is negative, and food self-sufficiency is close to sixty percent. This is the result of trade restrictions, pricing policies that affect the domestic farmer, and consumer policies.

- In 1990, water has a zero marginal value[4] while land has a positive value. This means that in 1990, land is the limiting resource to agricultural production under the observed economic conditions, while in 2060 both land and water are limiting resources.

- For the base 2060 case, food self-sufficiency plummets to 10 percent, but agricultural trade balance is 40 percent of CPS and exports outnumber imports by 3 to 1. This shows a nation using its comparative agricultural advantage to export high valued crops and importing inexpensive grains and feeds that can be grown elsewhere more

[4] Marginal value or shadow price is the change of the model objective function at the margin to the addition or subtraction of an additional unit of the resource. If a resource is in *surplus* at the optimal solution, the marginal value is zero. If the marginal value is positive it means that the resource is *limiting* and the objective will increase by the marginal value if an additional unit of the resource can be supplied or will decrease if a unit is removed.

efficiently. Egypt benefits economically from free trade, but becomes quite vulnerable to international markets.

Table 14a. Economic measures of integrated impact assessment results under climate change (absolute numbers). (Units are Egyptian pounds except where noted.)

	B 1990	B 2060	UKMO	GISS	GFDL*	LOWEND
Consumer-Producer Surplus	36,039	222,554	171,998	208,822	106,114	199,318
Consumer Surplus	27,673	140,999	132,426	138,820	139,746	141,391
Producer Surplus	8,366	81,555	39,571	70,003	-33,631	57,928
Agricultural Trade Balance	-926	83,280	4,681	67,783	-82,013	46,295
Food Consumption (cal/day)	3,519	3,261	3,159	3,235	3,238	3,263
Food Self-Sufficiency (%)	53	10	9	12	4	16
Imports	4,244	43,116	69,488	44,430	102,760	34,250
Exports	3,318	126,396	74,169	112,213	20,747	80,545
Marginal Value of Water	0.00	0.53	1.29	0.32	6.58	0.00
Marginal Value of Land	0.30	0.49	0.59	1.09	0.00	2.54

* GFDL results only feasible with imports of W, S, N vegetables, S+N tomato, and Sorghum allowed

Table 14b. Economic measures of integrated impact assessment results under climate change (relative numbers)

	B1990	B2060	UKMO	GISS	GFDL*	LOWEND
Consumer-Producer Surplus	0.16	1	0.77	0.94	0.48	0.90
Consumer Surplus	0.20	1	0.94	0.98	0.99	1.00
Producer Surplus	0.10	1	0.49	0.86	-0.41	0.71
Agricultural Trade Balance	-0.01	1	0.06	0.81	-0.98	0.56
Food Consumption	1.08	1	0.97	0.99	0.99	1.00
Food Self-Sufficiency	5.30	1	0.90	1.20	0.40	1.60
Imports	0.10	1	1.61	1.03	2.38	0.79
Exports	0.03	1	0.59	0.89	0.16	0.64
Marginal Value of Water	0.00	1	2.43	0.60	12.42	0.00
Marginal Value of Land	0.62	1	1.21	2.23	0.00	5.20

* GFDL results only feasible with imports of W, S, N vegetables, S+N tomato, and Sorghum allowed

The Climate Change Scenarios

A summary of the sectoral climate change impacts follows.

- Under all scenarios crop yields decline and crop water requirements increase;
- Agricultural land is lost to sea-level rise;
- Domestic commodity demands decrease only slightly with a slight increase under the LOWEND scenario;
- Nile water resources decline under UKMO and GFDL, and increase under GISS and LOWEND scenarios.

Chapters 2, 3, and 4 provide details of the sectoral impacts. Below, a discussion of the differences between integrative results and the sectoral results will be presented.

Tables 14a-b present the set of model results for the four climate change scenarios used for this study. Table 15 and Figure 9 provide a summary of the relative impact of climate change on four agro-economic measures. The four measures provided are indicators of climate change impact on the sector as a whole (consumer-producer surplus), the consumer (consumer surplus), the producer (producer surplus), and balance of payments (agricultural trade balance).

Table 15. Summary of integrated impacts as measure as changes from the base scenario (percent)

	UKMO	GISS	GFDL	LOWEND
Consumer-Producer Surplus	-23	-6	-52	-10
Consumer Surplus	94	98	99	100
Producer Surplus	49	86	-41	71
Agricultural Trade Balance	-94	-19	-198	-44
Food Consumption	-3	-1	-1	0

The summaries show that while consumer-producer surplus decreases from 6 to 52 percent from the 2060 Base Run, the consumer surplus ranges from a slight increase in the LOWEND scenario to a decrease of 6 percent in UKMO. Consumer-surplus is driven by domestic commodity demands that come from the BLS. The BLS determines commodity demands based on prices and income. The non-agricultural sector is modeled as being unaffected by climate change. The BLS base 2060 and climate change scenarios show the non-agricultural sector accounting for approximately 90 percent of Egyptian GDP (Onyeji and Fischer, 1993). Thus, under climate change scenarios, national income as well as food consumption and commodity demands remains relatively unaffected.

Agricultural production, which is modeled in great detail in EASM-CC, is most directly affected by climate change, and the results reflect this fact with decreases in producer surplus from 14 to 141 percent[5]. Decreased domestic production leads to changes in the agricultural trade balance with decreases from 19 to 198 percent. The GFDL results are extremely dramatic and lead to a negative agricultural trade balance.

The impact of climate change on the marginal values of land and water is an important measure. Tables 14a-b show these values, which are discussed below.

- UKMO: Both land and water are limiting constraints, with water at 2.43 and land at 1.21 times the base 2060 marginal value. The 1.21 factor for land reflects the seasonal limitation on land, as the model simulates planting more winter crops when crop consumptive water use per output value is lowest.

- GISS: With an 18 percent increase in Nile water there is still a marginal value on water due to reductions in agricultural water productivity from reduced crop yields and increased water requirements. With increased water availability, land will become the limiting resource, leading to a 2.23-fold increase in marginal value.

[5] Producer surplus includes imports as negative and exports as positive. So, if imports far exceed exports, as in the case in the GFDL scenario, then the producer surplus can become negative.

- GFDL: With so little water, land is in surplus and marginal value is zero, but water has a very high marginal value.

- LOWEND: With a 14 percent increase in Nile water and a decrease in average water use per ton of agricultural production, the marginal value on water is zero and land is the only limiting resource.

Adaptation Results

Sea-level Rise

All the above scenarios were run assuming a land loss from a 37-cm sea-level rise in 2060. Runs were made to examine the net impact to Egypt of mitigating sea-level rise. Table 16 reveals that the land loss due to 37 cm of sea-level rise has very little economic impact on the agricultural economic sector. This results from high-valued, higher water-use crops being substituted for some lower water-use crops. Thus, water is spread less thin over fewer areas, but the economic yields are only slightly less.

Table 16. Sea-level-rise effects on integrated impacts under climate change

	UKMO	GISS	GFDL	LOWEND
Percentage change in Consumer-Producer Surplus	99	99	100	99

Integrated Adaptations: Water, Irrigation and Agriculture

To examine the effects of a series of integrated adaptations to mitigate climate change impacts, two adaptation runs were made. Each run has adaptations for land resources, water resources, and agricultural and irrigation technology. The UKMO scenario was chosen as the climate change scenario upon which to measure the impacts of the adaptations. The only difference between ADI and ADII is that ADII has an additional 20 percent increase in available water due to the upper Nile projects. Tables 17a-b present the results in absolute and relative numbers, respectively.

The model results (Table 17b) show only modest increases in the CPS of 7 and 8 percent for ADI and ADII, respectively. However, there are significant increases in the ATB of 3.5-fold for ADI and 4-fold for ADII.

The UKMO scenario has a 13 percent decrease in water resources. ADI, with improved irrigation efficiencies and decreases in crop water use, shows the marginal value of water decreasing by 75 percent, while the marginal value of land increases 3-fold even with an increase in land resources. This is because water supply has been increased. The result of ADII, however, shows that a 20 percent increase of water provides for only a minor improvement in the CPS and moderate improvement in the ATB.

Food Self-Sufficiency

All the previous results were based on maximizing economic welfare. Table 18 provides the results for a model run that maximizes food self-sufficiency under the UKMO scenario. For this model run, the effect of climate change is to reduce food self-sufficiency by 42 percent and economic welfare by 56 percent. By comparison, the UKMO scenario for maximizing economic welfare has food self-sufficiency dropping 10 percent and economic welfare dropping 23 percent. It appears that economic welfare maximizing policy is less vulnerable to climate change.

Table 17a. Integrated impacts results for adaptation to the UKMO scenario. (Units are Egyptian pounds except where noted.)

	UKMO	**ADI***	**ADII***
Consumer-Producer Surplus	171,998	184,238	185,063
Consumer Surplus	132,426	134,205	134,205
Producer Surplus	39,571	50,033	50,858
Agricultural Trade Balance	4,681	20,863	23,550
Food Consumption (cal/day)	3,159	3,184	3,184
Food Self-Sufficiency (%)	9	9	9
Imports	69,488	42,417	42,364
Exports	74,169	63,280	65,915
Marginal Value of Water	1.29	0.30	0.28
Marginal Value of Land	0.59	1.87	2.00

* I No Upper Lakes Projects
II Upper Lakes Projects

Table 17b. Adaptation results measured as percentage changes to the UKMO scenario results

	ADI*	**ADII***
Consumer-Producer Surplus	+7.1	+7.6
Consumer Surplus	+1.3	+1.3
Producer Surplus	+26.4	+28.5
Agricultural Trade Balance	+346	+403
Food Consumption (cal/day)	+0.8	+0.8
Food Self-Sufficiency (%)	0	0
Imports	-39.0	-39.0
Exports	-14.7	-11.1
Marginal Value of Water	-76.7	-78.3
Marginal Value of Land	+217	+239

* I No Upper Lakes Projects
II Upper Lakes Projects

Table 18. UKMO climate change impacts on food self-sufficiency policy

	Percentage change from base
Consumer-Producer Surplus	44
Consumer Surplus	94
Producer Surplus	-2244
Agricultural Trade Balance	-234
Food Consumption (cal/day)	97
Food Self-Sufficiency (%)	58
Imports	234
Exports	--
Marginal Value of Water	--
Marginal Value of Land	15

Summary

The integrated climate change impacts upon the agricultural economic sector of Egypt result in decreases of consumer-producer surplus from 6 to 52 percent from the Base 2060. Under all scenarios, the consumers do relatively well with consumer-surplus impacts ranging from a 0.3 percent increase to a 6 percent decrease from the base 2060. The producers and the balance of trade are the parts of the agricultural sector that are affected the most by climate change.

Producer surplus drops 14 to 141 percent from the 2060 base, while the agricultural trade balance decreases by 19 to 198 percent. These impacts are the results of strong agricultural commodity demands fueled by income from the non-agricultural sector, which is not directly impacted by climate change.

Dramatic declines of 141 percent and 198 percent in producer surplus and agricultural trade balance are found for the GFDL scenario. From a water resource and agro-economic perspective, the GFDL scenario is a catastrophe. Such a decline in water resources leading to a major reduction in agricultural production and massive imports will most likely result in major social-economic impacts.

Land loss from a 0.37 meter sea-level rise by 2060 has little impact on economic performance. However, a full 1 meter or more of sea-level rise on top of continued subsidence may present more significant agro-economic impacts in addition to major social impacts.

Adaptations in the water resources, irrigation and agricultural technology, as well as protection against sea-level rise, provide for a modest 7 to 8 percent increase in the agricultural sector performance above the no-adaptation results. The adaptation results are still 17 percent below the base 2060 results. These extremely expensive adaptations are unable to mitigate the climate change impacts, but investments in improving irrigation efficiency appear to be a robust policy that would be beneficial regardless of whether the climate changes.

The analysis of a food self-sufficiency policy alternative shows that the climate change impacts are more severe when compared to a 2060 food self-sufficiency base than to the impacts of maximizing agricultural sector consumer-producer surplus.

If food consumption is not significantly impacted, should Egypt worry about climate change impacts? This food consumption outlook is based on an "optimistic" view of future non-agricultural performance as modeled as a single sector in the BLS.

As Onyeji (1992) points out, in Egypt the close link between the agricultural and non-agricultural sectors means that any change in agricultural output or its composition will, in turn, affect the level of industrial activity, which will extend to different socioeconomic groups. How these climate changes affect government control and markets will undoubtedly directly affect all socio-economic groups. Thus, the primary impact of global climatic change on people is measured by how the change affects the people's entitlement to food (income), and the ability to import the food.

Lessons from an Integrated Assessment

Table 19 provides a summary of the impacts of climate change on Egypt as measured by the biophysical impacts of each sector together with the integrated economic welfare measure. To provide an aggregate biophysical measure of climate change impacts on Egyptian agriculture, the Agricultural Water Productivity Index [tons/m³] was developed. The index is defined as total agricultural production [tons] divided by total agricultural water use [m³]. It is calculated by taking the cropping pattern from the base 2060 model run, multiplying the cropped acreage by its yield, and summing over all crops to provide total agricultural production. The next step is multiplying the cropped acreage by its water use and summing over all crops to provide total water use, then dividing total agricultural production by total water use. These steps are then repeated for each of the climate change scenarios, but with using the crop yields and water use determined by the crop modeling described in Chapter 2.

Table 19

A Comparison of Integrated and Sectoral Impacts to Climate Change

Percentage Change from Base 2060 Results

Scenario	**Sea-level** (land)	**Food Demand** (kcal)	**Ag Water Productivity** (ton/m³)	**Water Resources** (Aswan)	**Integrate** (CPS)
UKMO	**-5**	**-3**	**-45**	**-13**	**-23**
GISS	**-5**	**-1**	**-13**	**+18**	**-6**
GFDL	**-5**	**-1**	**-36**	**-78**	**-52**
LOWEND	**-5**	**0**	**+10**	**+14**	**-10**

There are two main conclusions to be drawn about the integrated analysis. First, the interactions and importance of the sectoral impacts depend very much on the collective impact of all sectors. For example, under the GFDL scenario where water resources are greatly reduced, the impact of sea-level rise is zero. In the GISS scenario, where water resources increased by 18 percent, the 4 percent loss of land and the 13 percent reduction in agricultural water productivity leads to a 6 percent reduction in economic welfare. Under the UKMO scenario, sectoral reductions of 4 percent in land, 13 percent in water, and 3 percent reduction in food intake result in a 23 percent reduction of economic welfare due to the 45 percent reduction in agricultural water productivity.

Second, integrated analysis shows a substantially different picture about climate change impacts than if each individual sectoral impact had been studied. For example, in

Table 19, food intake reductions are 0 to 3 percent, due to the climatic change, while the reductions in economic welfare are on the order of 6 to 50 percent. The LOWEND scenario is the best example for this point. Figure 10 presents, graphically, the last row of Table 19. For the LOWEND scenario, each sector, except sea-level rise, shows significant increases over current climate conditions.[6] However, there is a 10 percent decline in economic welfare. This result is because the rest of the world does even better under the LOWEND scenario and Egypt therefore loses some of its competitive advantage for exports, and the trade balance declines. This result could be found only via an integrated (and global) analysis. Sectoral results point to a positive impact, but when using the BLS results with global impacts and their implications for Egypt, this negative impact appears. Even the BLS alone would not have shown this result so clearly.

While much can be learned about climate change impacts from separate bio-geophysical sectoral impacts, a much better measure of the economic and societal impacts is an integrated impacts approach.

Lessons for Egypt about Vulnerability to Climate Change

The analysis presented in this chapter has identified a number of insights or lessons about Egypt's vulnerability to climate change. Some of the important lessons are listed below.

1. Population is a dominant factor in all future scenarios with or without climate change.

2. Water resources availability and crop water use are important factors in assessing the vulnerability of Egyptian agriculture and must be accounted for in any analysis.

3. Investments in improving irrigation efficiency appear to be a robust policy that would be beneficial regardless of whether the climate changes.

4. Land loss due to sea-level rise in 2060 is not a major factor, since water is the more limiting resource. In addition, most of the land loss occurs on the lands that are or will be reclaimed over the next 70 years that are not as productive as existing arable lands.

5. Loss of existing highly productive agricultural lands to urbanization is a crucial problem that will become more acute, should the sea level rise more than 0.5 meters.

6. For three of the four GCM scenarios the upper Nile projects do not significantly mitigate climate change impacts. Given the uncertainty of the performance of these projects under climate change, it appears that they are not a robust hedge against potential climatic change.

7. High food consumption, even in the base scenario, is based on incomes generated from significant growth in the non-agriculture sector of the economy, which is very uncertain.

8. The most efficient agro-economic strategy for feeding the future populations is to develop high-valued export crops and to import low-cost staples.

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[6]Agricultural water productivity is greater than current climate conditions due to the CO_2 effects that reduce water requirements, so that even though yields decline, water requirements decline slightly more to give a 10 percent increase in agricultural water productivity.

9. Government economic, trade, and social policies greatly affect the potential integrated impacts of climate change.

10. Egypt is vulnerable, not only to its own direct climate change impacts, but to effects of climate change on the rest of the world as well.

General Lessons Learned

The results of this analysis not only provide lessons for Egypt, but provide for more general insights that may be applicable to analyzing climate change effects on nations or regions of the world. These are as follows:

- **Consistent scenario and assumptions**
  In performing integrated analysis, it is absolutely essential that all scenarios and assumptions are consistent across the sectoral analysis, or integrated results will be meaningless.

- **Macro-economic measure of impact**
  The level of impact of climate change on an economy can vary greatly, depending on which measure or criterion is chosen to measure the impact. The level of economic development of a country should be taken into account when choosing a macro-economic measure.

- **The distribution of impacts across socio-economic levels**
  When examining socio-economic impacts, a single macro-economic measure may not reflect the situation when the impacts are not being felt equally across the population; and in many cases, the population, already struggling, is being burdened on the lower levels.

- **The impact on food entitlement**
  In many cases the amount of food available to the population at large may not be greatly reduced, but certain sectors of the population may be significantly affected in terms of entitlement to food, either by reduced income or lack of resources for subsistence agriculture.

- **Adaptations may not be justified**
  Some of the easier adaptations that appear justifiable from a sector standpoint (e.g. increased water supply) may turn out not to be justifiable under an integrated assessment (e.g. sea-level rise may reduce land, reducing need for water supply).

- **Need to have feedback, population/consumption**
  The economic and population growth must be analyzed with feedback of resource and economic impacts due to climate change over a dynamic time horizon.

- **Flexible systems/policy**
  Government social and economic policies can result in a system that is relatively flexible and more easily adaptable to climatic change or produce a rigid system which is more vulnerable to climate change (e.g., food self-sufficiency policies).

Conclusions and Recommendations

Egypt is highly vulnerable to the warming and changes in precipitation and river runoff that are forecast to accompany greenhouse-gas-induced climate change. It has been shown that water is an important element in the agricultural economy and must be explicitly included in any analysis of climate change impacts. Finally, this study has shown that in addressing climate change impacts on an economy or nation, the entire economy must be analyzed. The linkage of the sectors directly affected by climate change must be analyzed in concert with the other sectors of the economy in sufficient detail so that feedback can be part of the analysis.

Future research must include the development of more crop models that include CO_2 effects, incorporation of crop water use, irrigation and water resources directly into the macro-economic policy models. The development of a better understanding of potential agricultural/water adaptations to climate change and sea-level-rise impacts on deltaic agricultural lands is needed. Better macro- and sectoral economic understanding and models of bio-geophysical resources, particularly those impacted by climate change, and their role in the economy need to be developed.

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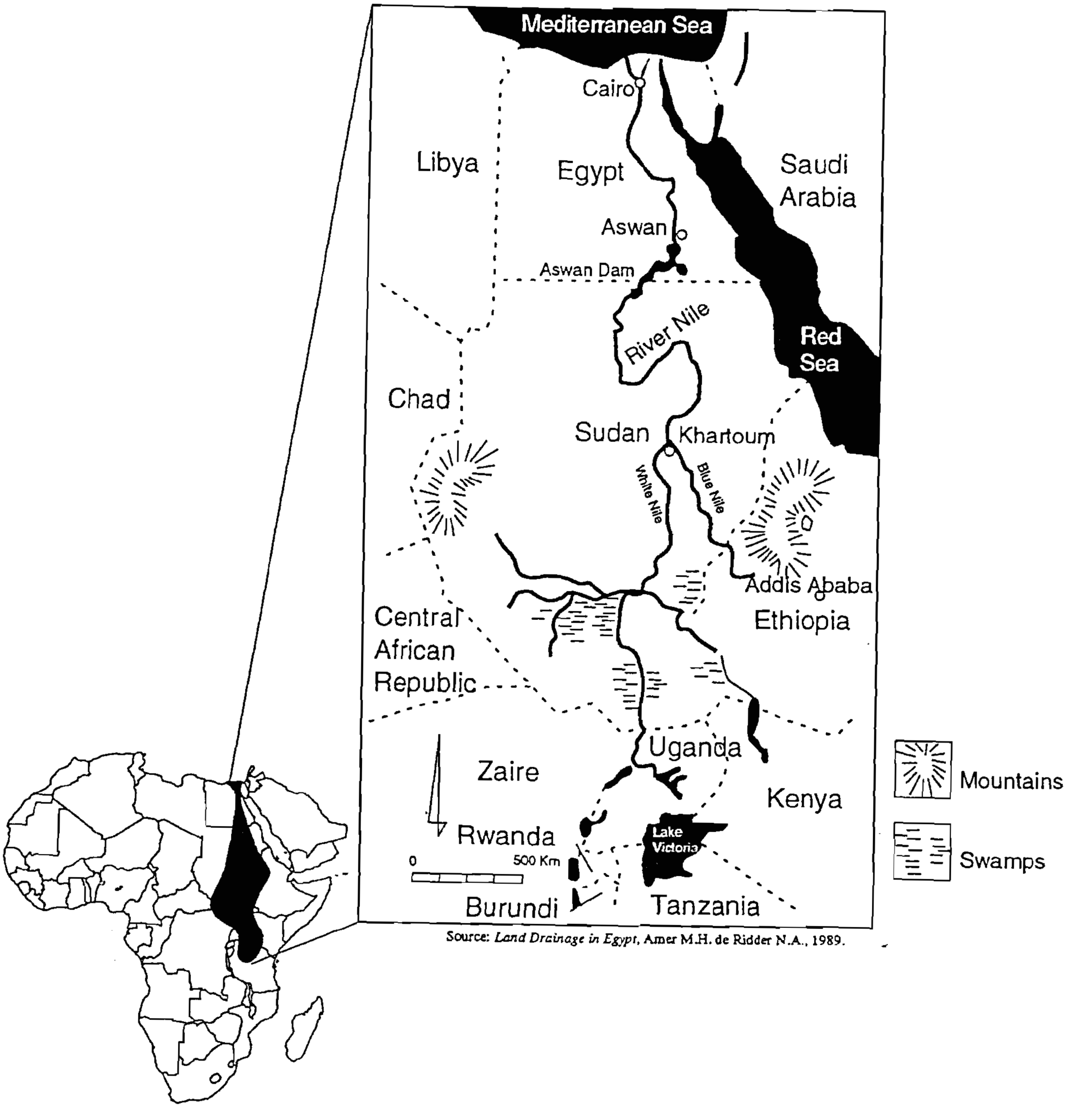


Source: *Land Drainage in Egypt*, Amer M.H. de Ridder N.A., 1989.

Figure 1. The Nile Basin in relations to Africa and Egypt.

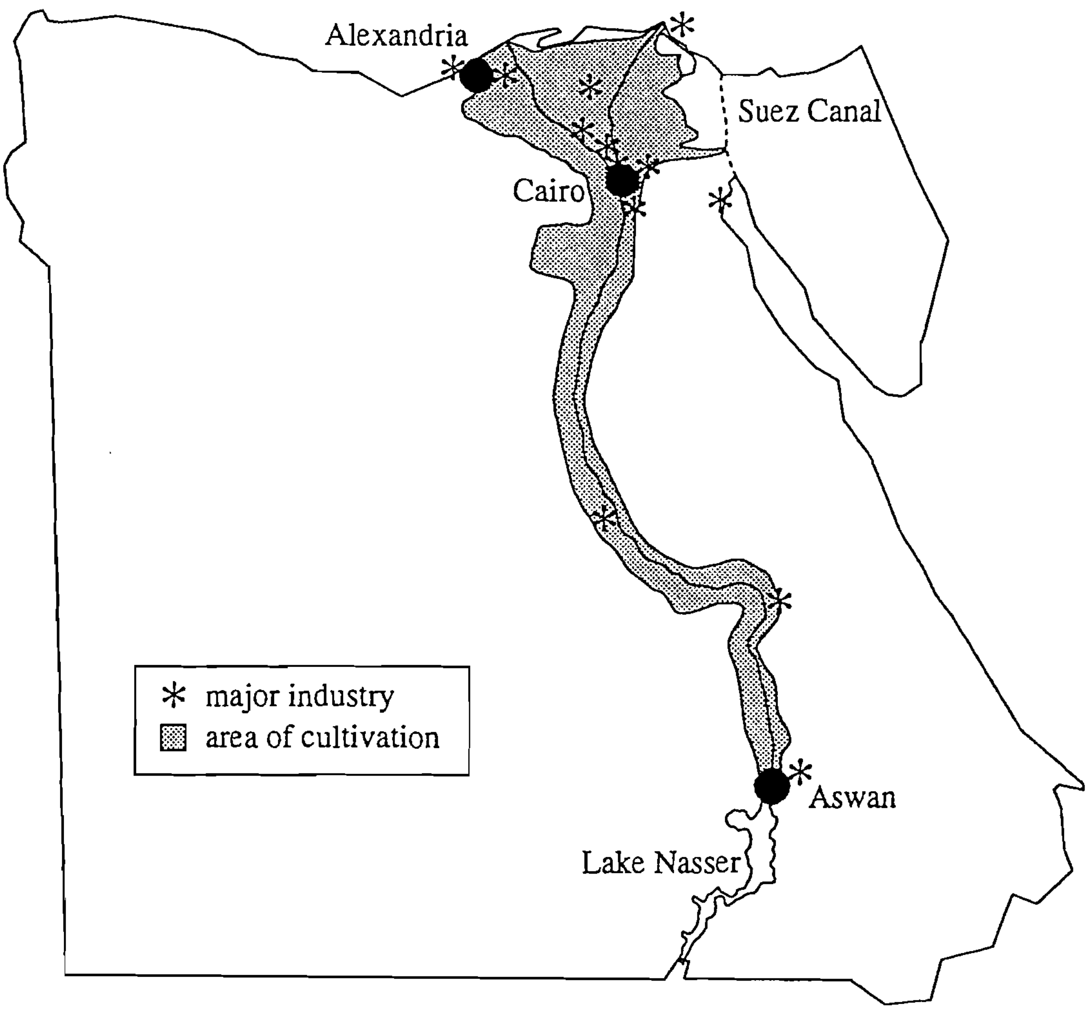


Figure 2. Map of Egypt showing agriculture, population, and economic activity confined to Nile Valley and Delta.

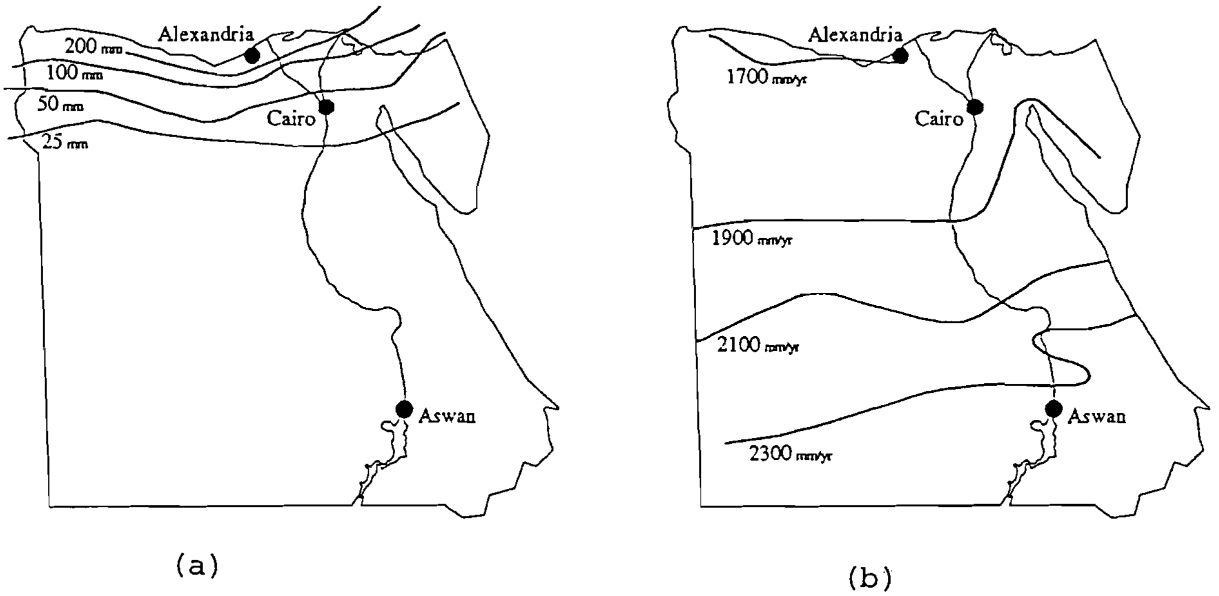


Figure 3. Distributions over Egypt of (a) mean annual precipitation and (b) mean annual potential evapotranspiration (Penman).

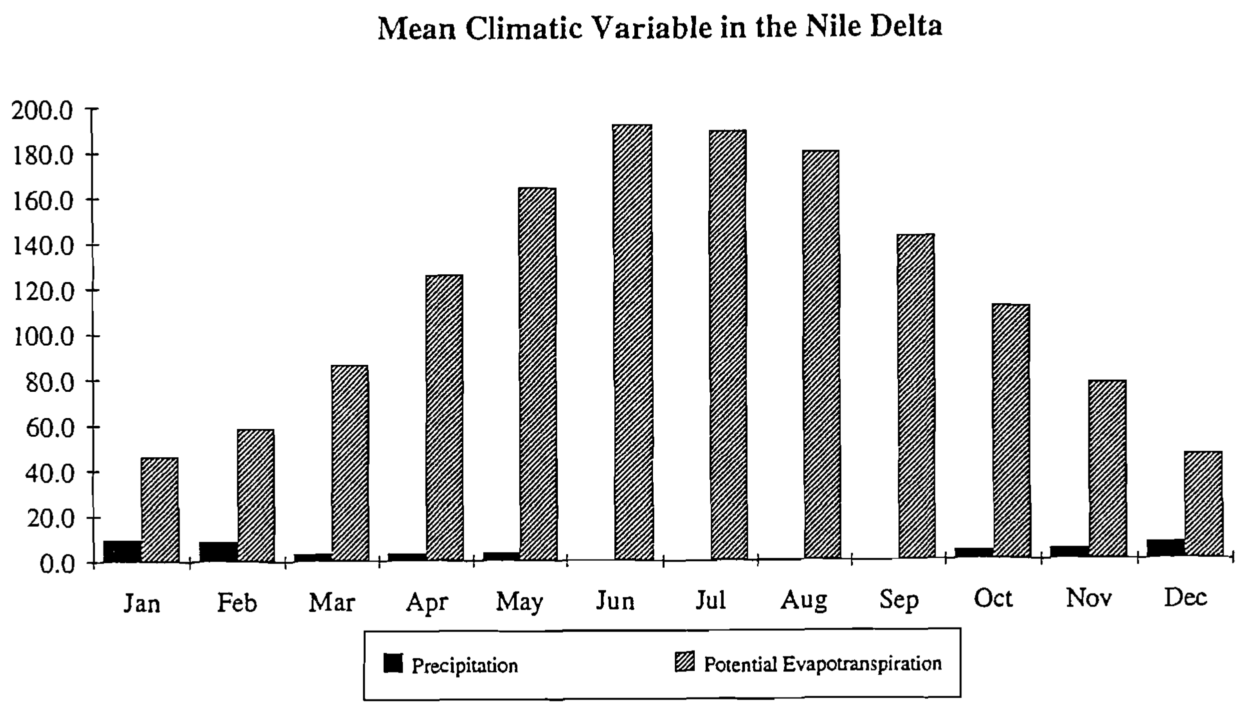


Figure 4. Mean monthly distribution of precipitation and potential evapotranspiration (Penman) for a location in the Nile Delta showing the extreme aridity of the region.

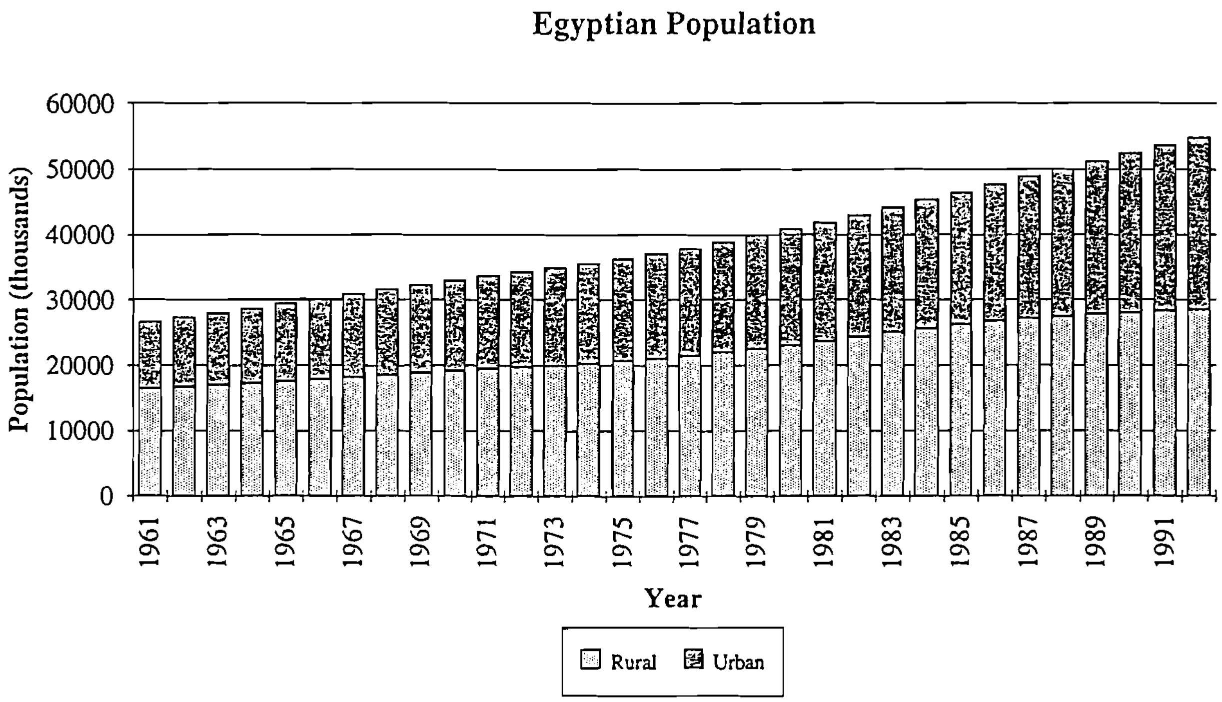


Figure 5. Egyptian population growth from 1961 to 1992 with urban/rural distribution.

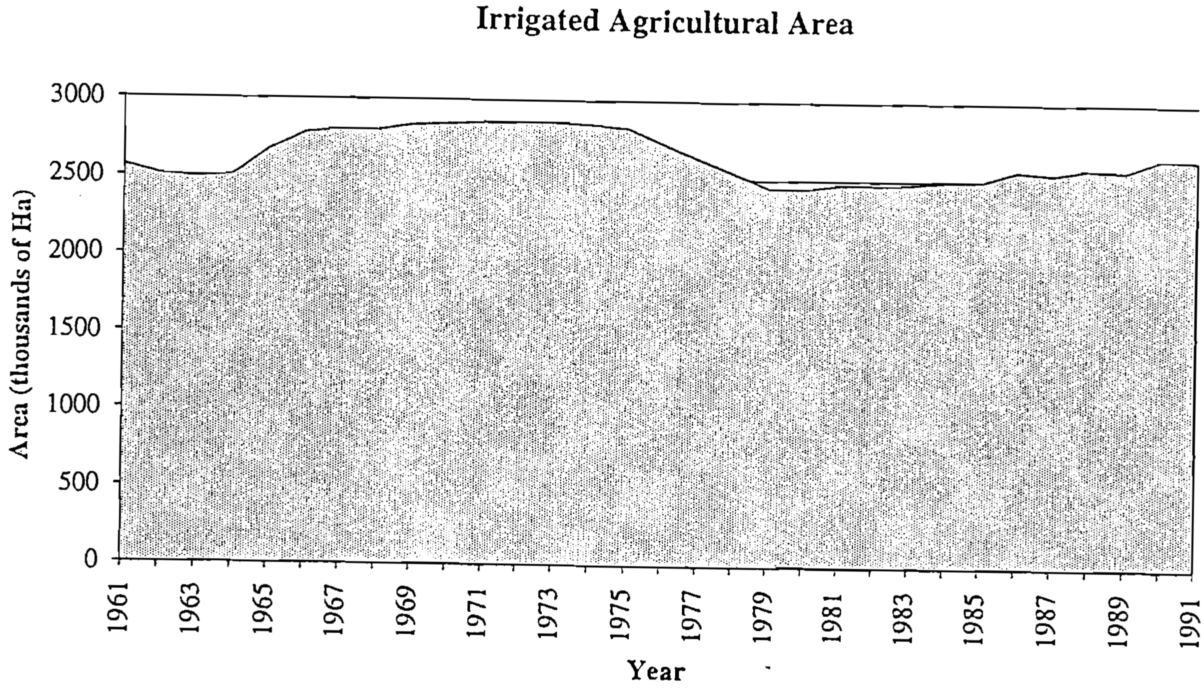
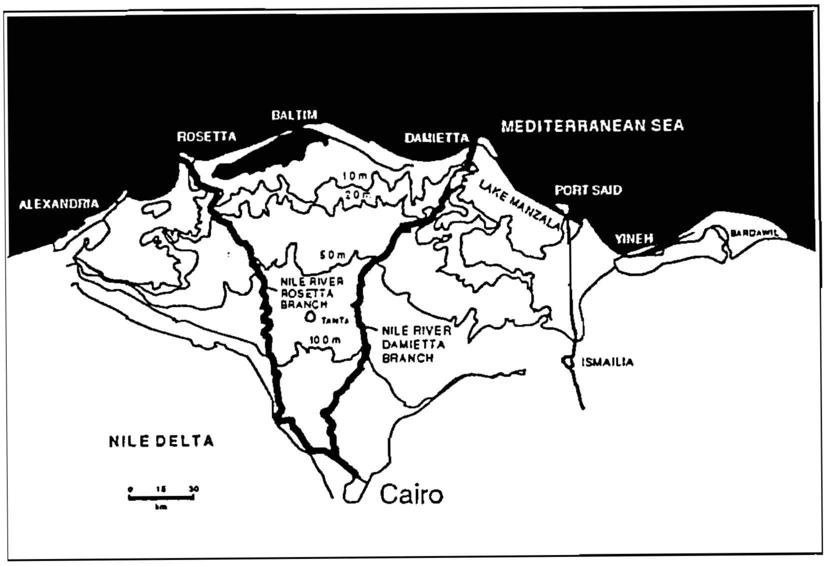


Figure 6. Egyptian cultivated land under irrigation from 1961 to 1991.



Source: *Land Drainage in Egypt*, Amer M.H. de Ridder N.A., 1989.

Figure 7. Topographical map of the Nile Delta.

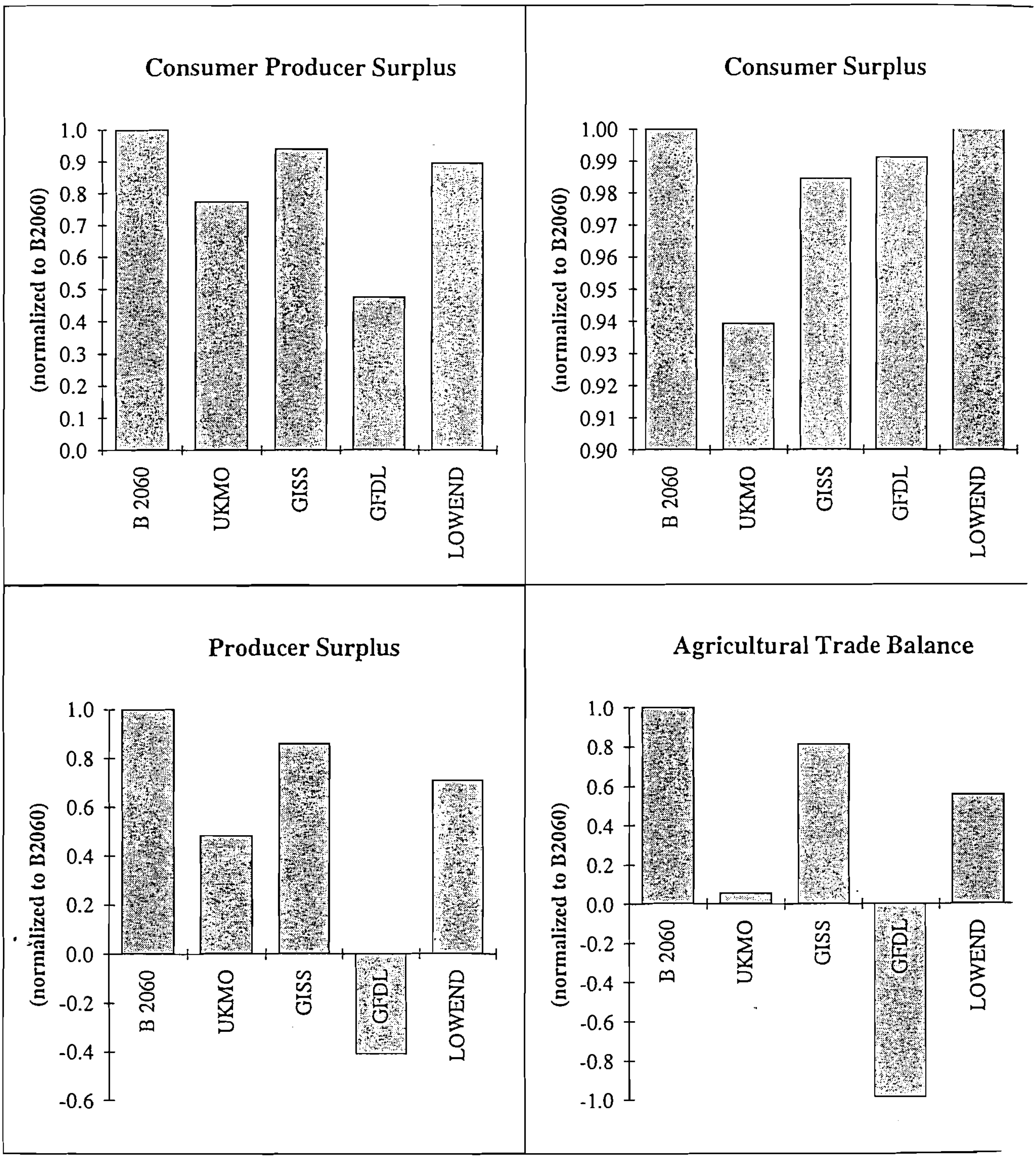


Figure 8. Schematic of integrated assessment framework showing sectoral model linkages.

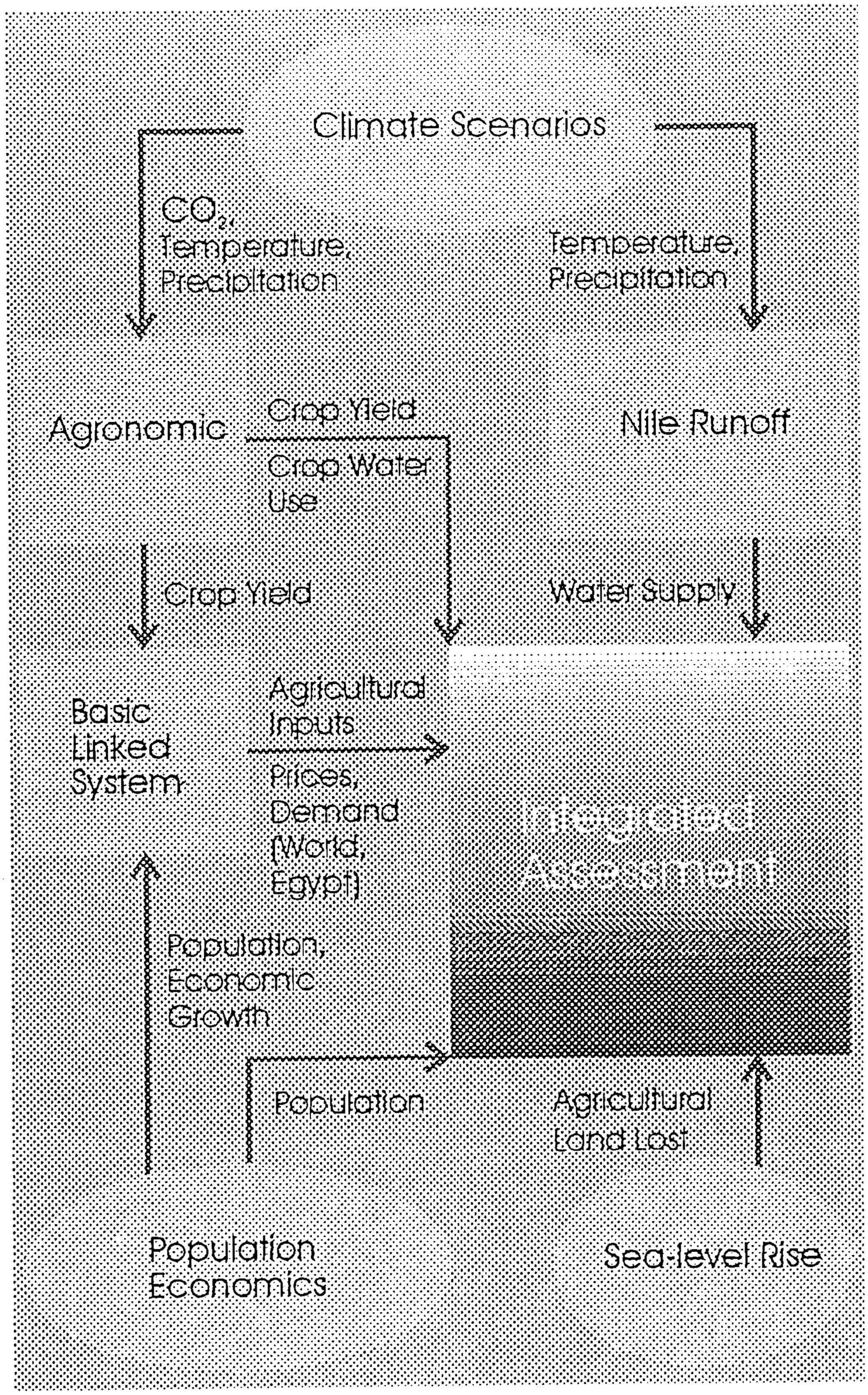


Figure 9. Integrated assessment results for climate change impacts on four economic welfare measures.

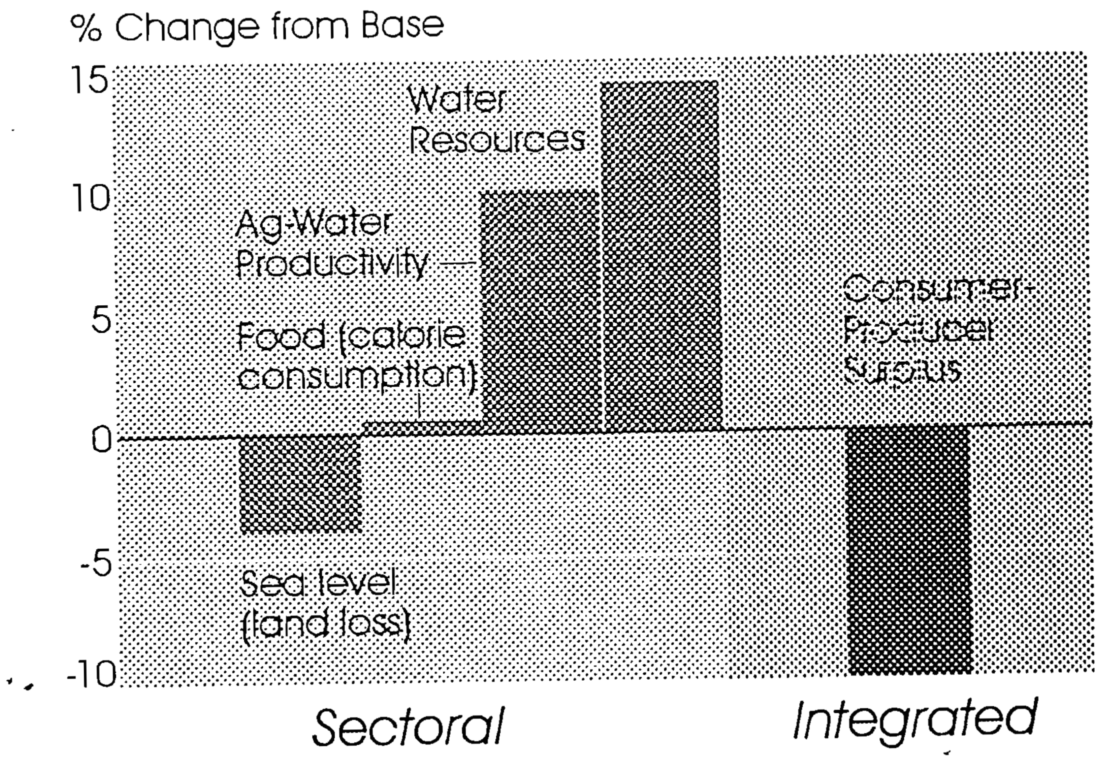


Figure 10. Comparison of sectoral versus integrated impacts for the LOWEND scenario.