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Potential Impacts of Climate Change on the Egyptian Economy

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Potential Impacts of Climate Change on the Egyptian Economy

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Disclaimer

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The analysis and policy recommendations of this report do not necessarily reflect the views of the Government of Egypt and/or UNDP. The authors hold responsibility for the opinions expressed in this publication.

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Glossary

ARC	Agricultural Research Center
ASME	Agriculture Sector Model of Egypt
CAPMAS	Central Agency for Public Mobilisation and Statistics
CCRMP	Climate Change Risk Management Project
CO_2	carbon dioxide
CoRI	Coastal Research Institute (part of Ministry of Water Resources and Industry)
DALY	disability adjusted life year
EASM	Egypt Agriculture Sector Model
EGP	Egyptian pounds (currency; we assume that 1 USD = 5.5 EGP)
GCM	general circulation model
GDP	gross domestic product
GEF	Global Environment Facility
GIS	geographic information system
HAD	High Aswan Dam
HARITA	Horn of Africa Risk Transfer for Adaptation
ICZM	Integrated Coastal Zone Management
IDSC	Egyptian Cabinet Information and Decision Support Center
IPCC	Intergovernmental Panel on Climate Change
MALR	Ministry of Agriculture and Land Reclamation
MENA	Middle East and North Africa
M&I	municipal and industrial
MWRI	Ministry of Water Resources & Irrigation
NARSS	National Authority for Remote Sensing and Space Sciences
NEEDS	National Environmental, Economic and Development Study
NFC	Nile Forecast Center
Nile	Nile River
Nile Delta	Nile River Delta
NWRC	National Water Research Center
NWRP	National Water Resources Plan

PET	potential evapotranspiration
PM	particulate matter
R&D	research and development
SLR	sea level rise
SNC	Second National Communication (Egypt)
SRES	Special Report on Emissions Scenarios
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
USD	U.S. dollar
VSL	value of a statistical life
WWTP	wastewater treatment plant

Abstract

This study, conducted in collaboration with the Egyptian government, used estimates of change in water supplies, coastal inundation, and crop yields previously published by Egyptian researchers to estimate the potential impacts of climate change on Egypt's agriculture economy in 2030 and 2060. In addition, the value of property that could be damaged due to sea level rise (SLR), the increase in the number of deaths and valuation of such losses from climate change-induced decreases in air quality and increases in heat stress, and losses to tourism from increased heat and loss of coral reefs were estimated. Agricultural production is estimated to decrease by 8 to 47% by 2060, with reductions in agriculture-related employment of up to 39%, although in one scenario employment increases by 3% and food prices increase by 16 to 68%. Welfare losses in agriculture in 2060 are estimated to range from 40 to 234 billion Egyptian pounds (EGP). The value of property in the Nile River Delta threatened by SLR could be 7 to 16 billion EGP. Increased particulate matter concentrations and heat stress could result in approximately 2,000 to 5,000 more deaths per year, with an equivalent loss of 20 to 48 billion EGP per year. Higher temperatures could reduce annual tourist revenues by 90 to 110 billion EGP. The study, which is not comprehensive, estimates that hundreds of billions of Egyptian pounds, about 2 to 6% of future gross domestic product, could be lost from effects on water resources, agriculture, coastal resources, and tourism; thousands could die from air pollution and heat stress; and millions could lose jobs in agriculture as the result of climate change. Given the risks that climate change poses for Egypt, it is very important that adaptation risks that are already apparent and risks that will most likely become greater under climate change be promptly addressed. The key sectors for adaptation include water resources, agriculture, tourism, health, and coastal resources. Egypt should also develop a national adaptation plan.

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S. Executive Summary

S.1 Introduction

Egypt faces serious risks from climate change. With 88% of its water coming from the Nile River (the Nile) and 97% of its population living along the Nile River Delta (the Nile Delta), a substantial reduction in flow of the Nile would pose a serious risk to Egypt. In addition, sea level rise (SLR) threatens settlements and agriculture in the Nile Delta and also in the Red Sea. Egypt is already hot and dry. Higher temperatures alone threaten to evaporate more water, increase the need for water supplies, create more heat stress, exacerbate already high levels of air pollution, and drive away tourists.

This study, undertaken in collaboration with the Egyptian government, is based on estimates of biophysical impacts of climate change developed by Egyptian researchers. Estimates of changes in water supply and potential inundation of agricultural land from the Ministry of Water Resources & Irrigation were combined with estimates of change in crop yields from Egypt's Second National Communication (SNC) to the United Nations Framework Convention on Climate Change. These inputs were used in a model of Egypt's agriculture economy in order to estimate the potential impact on agricultural production, employment, prices, and water use. The number and value of housing units as well as the length of roads at risk from SLR were estimated. In addition, the consequences of increased air pollution for human health and the impacts of excess heat and loss of coral reefs on tourism were examined.

S.2 Study Structure

This study estimates climate change impacts in 2030 and 2060. To be sure, climate change is virtually certain not to stop by mid-century and, in all likelihood, will continue for decades to centuries.

The structure for this study, displayed in Figure S.1, follows:

- *Population and economic scenarios.* These scenarios were based on published sources. The population scenarios were drawn from the SNC for the next few decades, the United Nations out to mid-century, and extrapolation by the authors to 2060. Income projections from the Intergovernmental Panel on Climate Change were used. A pessimistic socioeconomic scenario assumed no reduction in fertility rates and a relatively slow increase in income. An optimistic scenario assumed a stable population by mid-century and a relatively large growth in income.

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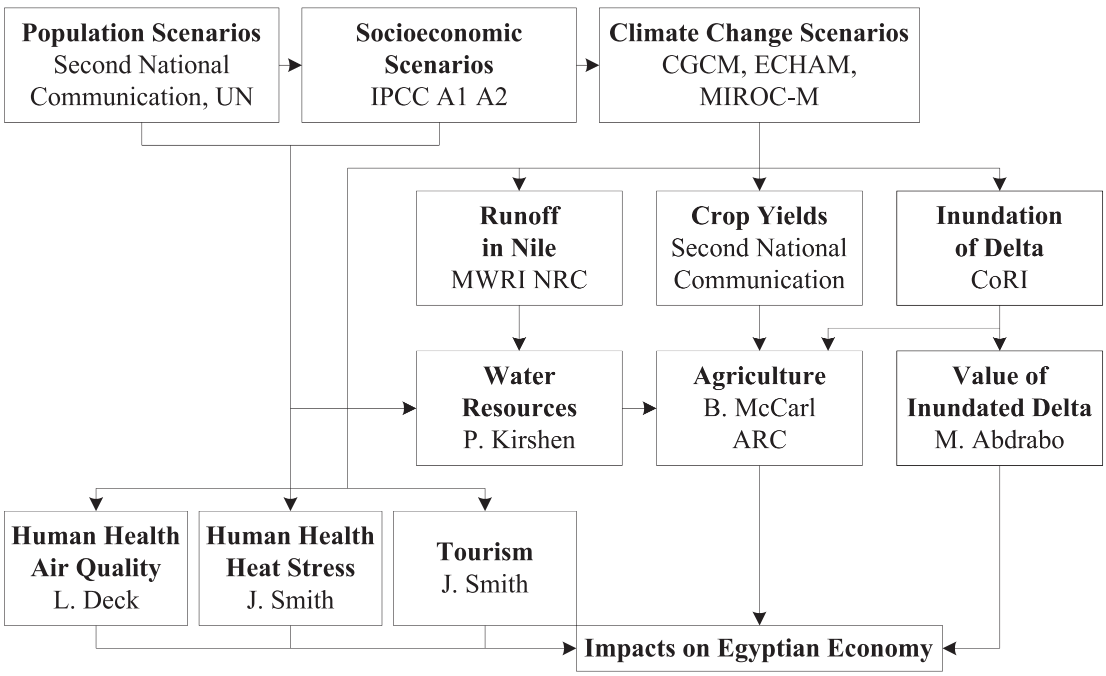

Figure S.1. Structure of the study.

- *Climate change scenarios*. The selection of climate models was based on results from Elshamy et al. (2009). We selected climate models that yield the largest increases and decreases in flow. The driest model is CGCM630 and the wettest model is MIROC-M. We also selected a model that gives change in flow that is close to the average of all of the climate models, ECHAM.

- *Water resources*. Changes in Nile flow were taken from Elshamy et al. (2009), who estimated change in flow in the Blue Nile. We assumed the same changes would happen for the entire Nile Basin and used temperature increases for the same climate models to estimate the change in evaporation from the High Aswan Dam (HAD).

- *Inundation of the Nile Delta*. SLR scenarios were taken from previously published work by the Coastal Research Institute (Elshinnawy, 2008). The rates of SLR were used to estimate the amount and value of agriculture, housing units, and roads at risk of inundation from SLR.

- *Agricultural production*. Changes in crop yields were taken from the Egypt SNC. Changes in Nile flow and inundation of agricultural land in the Nile Delta were used along with the crop yield changes as inputs into a model of the Egyptian agricultural economy. The model was used to estimate change in agricultural production, employment, prices, water use, and other factors.

- *Human health air quality*. The study built upon a study of current pollution by the World Bank (2002). Relationships between climate change and pollution levels from the published literature were used to estimate the health impacts of decreased air quality in greater Cairo through increases in particulate matter (PM) levels on projected future population levels. This was essentially a sensitivity analysis because air quality for Cairo was not modeled.

- *Human health heat stress*. Building on the work of Kalkstein and Tan (1995), increased heat stress mortality in greater Cairo was estimated. Cases of heat stress mortality are projected to increase linearly with higher temperatures. The study used the relationship that existed when the original research was conducted and thus does not examine how changes such as the increased use of air conditioning might affect the results.

- *Tourism*. Tourism revenues from the Egyptian Office of Tourism were used to estimate future tourism levels. Results from Bigano et al. (2007), a global of study of potential changes in tourism from climate change, were used to estimate the effect of climate change on tourism demand. In addition, estimates of loss of coral reefs in the Red Sea were used to estimate potential additional impacts on tourism.

A number of key impacts and sectors were not studied. The study did not include potential impacts of climate on fisheries. In addition, consequences of climate change for water quality and ecosystems, other than coral reefs, were not studied. There was limited analysis of the effectiveness and potential costs of adaptation. Also, the study did not include the examination of potential climate change impacts outside of Egypt. Nonetheless, the results indicate the magnitude of risks faced by Egypt from climate change.

S.3 Socioeconomic and Climate Change Scenarios

Pessimistic and optimistic population and income scenarios are displayed in Tables S.1 and S.2.

The selection of climate models was based on the Elshamy et al. (2009) analysis and uses scenarios that capture the range of potential changes in the Nile flow. The models selected are:

- Large Decreased Flow: Canadian Centre for Climate Modeling and Analysis (Canada; CGCM63)

- Small Decreased Flow: Max Planck Institute for Meteorology (Germany; ECHAM)

- Increased Flow: National Institute for Environmental Studies Medium Resolution (Japan; MIROC-M).

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Table S.1. Population scenarios for Egypt (millions of people)

	2009	2030	2060
Optimistic	80	104	113
Pessimistic	80	117	162

Table S.2. Income scenarios for Egypt

	2009	2030	2060
GDP (billion EGP)			
Optimistic	990	2,993	9,299
Pessimistic	990	2,287	5,907
GDP/capita (EGP)			
Optimistic	12,378	28,781	82,292
Pessimistic	12,378	19,548	36,464

Note that we assume 5.5 EGP/1 U.S. dollar.

GDP: gross domestic product.
EGP: Egyptian pounds.

The estimated changes in temperature and precipitation in Cairo in 2030 and 2060 are displayed in Table S.3.

Table S.3. Estimated change in temperature and precipitation for Cairo

	2030			2060		
	CGCM63	ECHAM	MIROC-M	CGCM63	ECHAM	MIROC-M
Annual temperature °C	0.9	0.9	1.0	2.0	1.9	2.2
Annual precipitation (% change)	-4	0	-5	-10	0	-10

Scenarios of SLR for different locations in the Nile Delta are presented in Table S.4. These estimates include subsidence and rise in global sea levels. Port Said is subsiding more than the other locations and thus has the largest “relative” rise in sea level. The low scenario has a global SLR of about 20 cm by 2060 and over 50 cm by 2060.

Table S.4. SLR (cm) scenarios used in this study relative to 2000

City	Scenario	2030	2060
Port Said	Low SLR	18.12	64.3
	High SLR	27.9	109.6
Al-Burullus	Low SLR	8.75	32.25
	High SLR	14.75	60.3
Alexandria	Low SLR	7.0	27.0
	High SLR	13.0	55.0

S.4 Results

S.4.1 Water resources

Projected changes in flow of the Nile as it enters the HAD are presented in Table S.5. MIROC-medium is the wettest model, with a flow increase of one-fourth, and CGCM63 is the driest, reducing flow by more than one-third. The ECHAM model is close to the average of all the models used by Elshamy et al. (2009) and projects a decrease of about 10% by 2060. The climate models tend to show a reduction in flow of the Nile, and some studies suggest that even larger reductions are possible. But, with a number of models projecting wetter conditions, an increase in flow cannot be ruled out.

Table S.5. Projected change in mean annual flow into the HAD

General circulation model	Egypt allocation 2000 (BCM)	2030 (BCM)	2060 (BCM)
Increased flow	55.5	63.1 (14)	70.6 (27)
Small decreased flow	55.5	52.3 (-6)	49.1 (-12)
Large decreased flow	55.5	45.5 (-18)	35.6 (-36)
Value in parentheses is % change in flow.			

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S.4.2 Coastal resources

Table S.6 displays the amount and percentage of agricultural land in the Nile Delta that would be inundated by 2060 when the Nile Delta is unprotected and protected from SLR. In the northeast Nile Delta, relative SLR in the high scenario increases the amount of land risk from inundation by 300 km^2, or more than one-fifth of total agricultural land in the northeast Nile Delta, while Figure S.2 displays agricultural land in the Delta at risk of inundation. Half of the agricultural land in the northeast is threatened by a high rate of SLR. Protection reduces potential losses to close to zero.

Table S.6. Amount and percentage loss of agricultural lands in the northern Nile Delta in 2060

	Northeast Nile Delta		North-Middle Nile Delta		West Nile Delta	
Climate scenarios for SLR	**km^2**	**%**	**km^2**	**%**	**km^2**	**%**
High SLR 2060 protected	25.8	1.8	137.2	2.7	15.0	0.3
High SLR 2060 unprotected	774.3	52.7	523.9	10.4	625.6	13.2
Low SLR 2060 protected	4.8	0.4	31.2	0.6	0.0	0.0
Low SLR 2060 unprotected	449.3	30.6	129.5	2.5	10.6	0.2

Table S.7 displays the value of housing units and roads at risk from SLR. One-quarter million to one million housing units would be at risk from SLR, assuming that there is no more housing construction in the low-lying Nile Delta regions. Assuming the values of housing units and roads would increase along with per capita income, the annual loss in property values would be about 7 to 16 billion EGP by 2060 under the SLR scenarios. This estimate does not include commercial property or public lands.

Table S.7. Annual value of housing units and roads in the Nile Delta at risk from SLR (billion EGP)

	Housing units		Roads	
	2030	**2060**	**2030**	**2060**
SLR scenario	**Pessimistic**		**Optimistic**	
Low	1.0	1.9	1.4	4.4
Middle	1.0	2.4	1.5	5.5
High	1.1	7.2	1.6	16.3

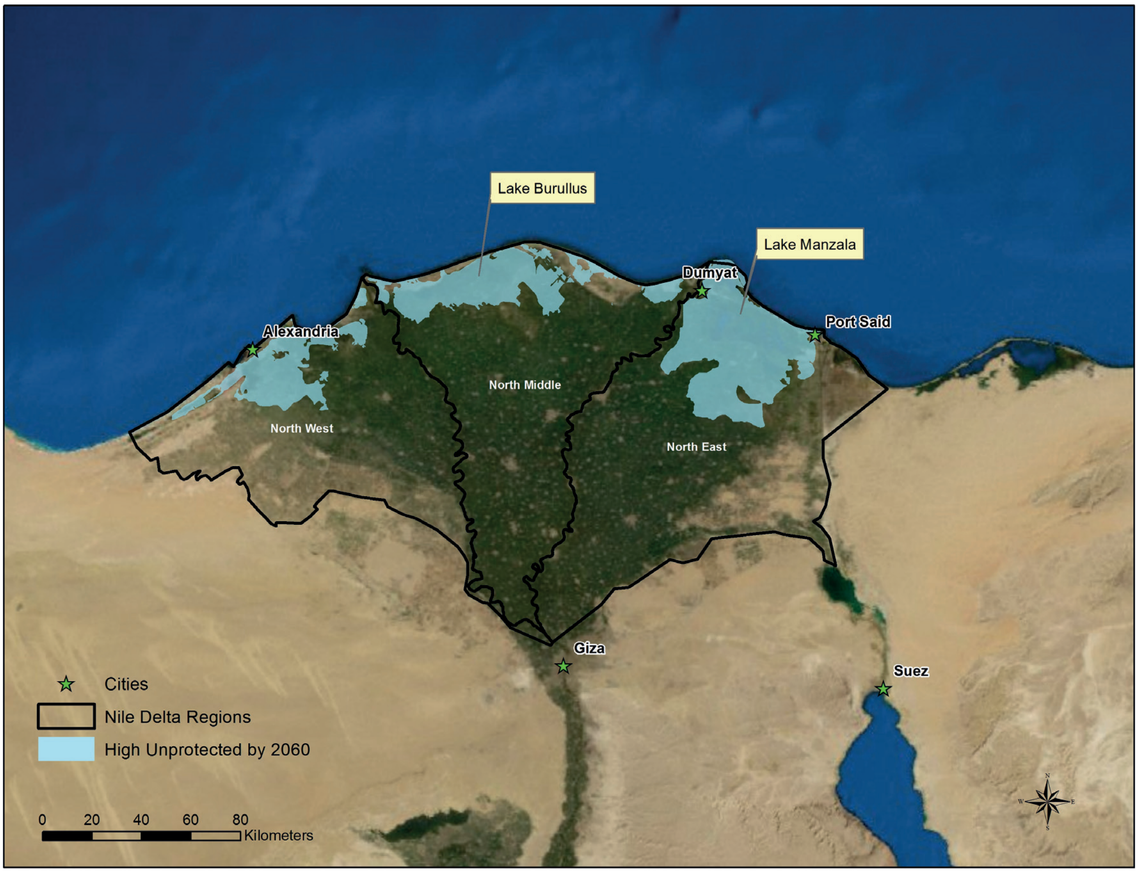

Figure S.2. Potential inundation of Nile Delta from high SLR in 2060.

S.4.3 Agriculture

Estimated changes in crop yields and water use for selected crops in 2060, based on Egypt's SNC, are displayed in Table S.8. All crops are projected to have a decrease in yields and an increase in irrigation needs. Some crops only decrease a few percent while others have a reduction of more than one-fourth.

Selected results for 2060 from the agriculture model are displayed in Table S.9. Estimated agricultural production decreases under all three scenarios, even when the flow of the Nile increases. In all cases, food prices rise by a larger percentage than the reduction in yields. Employment in the agriculture sector is estimated to decrease because of climate change.

Table S.8. Estimated change in yield and water use for selected crops by 2060 A1 scenario (% change)

Crop	Season	Yield	Water use
Citrus	Annual	-15.2	6.6
Cotton	Summer	19.8	7.2
Lentil	Winter	-28	7.28
Maize	Summer	-15.2	6.6
Onion	Winter	-1.53	7.84
Rice	Summer	-11	6.6
Sorghum	Nili[a]	-15.2	6.6
Soybeans	Summer	-28	7.28
Sugarcane	Annual	-15.2	6.6
Tomato	Winter	-28	8.16
Vegetables	Summer	-28	7.28
Wheat	Winter	-19.2	7.2

a. Nili is during fall months between summer and winter.

Agricultural production (the total amount of food produced) decreases in all scenarios, even when water supplies are projected to increase. This is apparently because crop yields (how much is grown per feddan) are lower in all of the scenarios, which must outweigh the gains from increased water supplies. When Nile flow decreases 12%, production drops by more than one-fourth; when flow decreases by one-third, production is cut in half. Total welfare[1] is reduced by tens of billions of EGP by 2030 and by tens to hundreds of billions of EGP by 2060. By 2060, the change in welfare is quite sensitive to changes in Nile flow and baseline socioeconomic conditions (with the optimistic socioeconomic scenario resulting in a much lower reduction in welfare than under the pessimistic scenario). Employment in agriculture also drops, even when the Nile flow increases; it decreases by more than one-third in the driest scenario. Prices increase by a greater percentage than the reduction in production. The model allows imports to increase up to five times current levels. Without increased imports, prices would rise even more. With higher prices and decreased employment, the number of people with insufficient food is likely to increase, perhaps considerably over baseline conditions. Agricultural production is quite sensitive to changes in crop yields and water supplies. It does not appear to be very sensitive to loss of land from SLR. Lower population growth and higher income appear to help make the agriculture economy somewhat less sensitive to climate change than a scenario with higher population growth and lower income levels.

1. “Welfare” means the income to producers above their costs of production and the value to consumers beyond what they pay for a product or service.

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Table S.9. Estimated impacts of climate change on Egyptian agriculture

Socioeconomic scenario	**Baseline value (2030)**	**Pessimistic**	**Pessimistic**	**Pessimistic**	**Optimistic**[a]
Nile flow	**55 BCM**	**Small decreased flow (52.5)**	**Large decreased flow (45.5)**	**Increased flow (62.5)**	**Small decreased flow (52.5)**
SRES (SLR + crops)		**A1**	**A1**	**A1**	**A1**
Protection from SLR		**Unprotected**	**Unprotected**	**Unprotected**	**Unprotected**
Agriculture results for 2030 (expressed as % change from base 2030)					
Production	Pessimistic: 211 Optimistic: 199 (billion EGP)	-11	-17	-4	-12
Agriculture consumption by consumers		-6	-8	-3	-2
Agriculture GDP	Pessimistic: 211.4 Optimistic: 198.5 (billion EGP)	17.9	23.09	9.7	0.3
Consumer prices (optimistic prices are 3% lower than pessimistic prices in baseline conditions)		+26	+38	+13	+7
Change in welfare (billions EGP)	Pessimistic: 1,354 Optimistic: 1,217	-25	-26	-14	-20
Agriculture labor hours	Pessimistic: 2.7 Optimistic: 2.5 (billion)	-3.9	-5.7	5.8	-6.5

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Table S.9. Estimated impacts of climate change on Egyptian agriculture (cont.)

Socioeconomic scenario	Baseline value (2060)	Pessimistic	Pessimistic	Pessimistic	Optimistic[a]
Nile flow	**55 BCM**	**Small decreased flow (49)**	**Large decreased flow (35)**	**Increased flow (71)**	**Small decreased flow (49)**
SRES (SLR + crops)		**A1**	**A1**	**A1**	**A1**
Protection from SLR		**Unprotected**	**Unprotected**	**Unprotected**	**Unprotected**
Agriculture results for 2060 (expressed as % change from base 2060)					
Production	Pessimistic: 374 Optimistic: 205 (billion EGP)	-27	-47	-8	-20
Agriculture consumption by consumers		-15	-30	-5	-7
Agriculture GDP	Pessimistic: 374 Optimistic: 205 (billion EGP)	15.6	9.0	13.8	14.1
Consumer prices (optimistic prices are 39% lower than pessimistic)		41	68	16	32
Change in welfare	Pessimistic: 1,845 Optimistic: 1,237 (billion EGP)	-112	-234	-38	-41
Agriculture labor hours	Pessimistic: 3.2 Optimistic: 2.8 (billion)	-20.1	-39.2	3.1	-5.4

SRES: Special Report on Emissions Scenarios.

a. Optimistic change is relative to optimistic baseline values.

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S.5 Air Quality

The health study examined how a presumed 1-µg/m^3 increase in PM could affect human health. Increased mortality estimates and the valuation of the impacts are displayed in Table S.10. Annual mortality is estimated to increase by a few hundred to a few thousand. Using a technique called value of a statistical life (VSL), which estimates economic and welfare losses from premature deaths, the equivalent economic loss to Egypt would be 10 to 34 billion EGP per year.

Table S.10. Increase in mortality from a 1-µg/m^3 change in PM levels in greater Cairo

Health effect	2060	Economic value (billion EGP)
Optimistic socioeconomic scenario		
Low $PM_{2.5}$ estimate (adults)	708	10.7
High $PM_{2.5}$ estimate (adults)	1,610	24.2
Pessimistic socioeconomic scenario		
Low $PM_{2.5}$ estimate (adults)	1,015	6.3
High $PM_{2.5}$ estimate (adults)	2,308	14.2

Analysis assumes a value of $1.1 million (pessimistic) and $2.7 million (optimistic). Value in 2010 is estimated to be about $400,000 per statistic life.

S.6 Heat Stress

The estimated increase in heat stress mortality from higher temperatures in greater Cairo are presented in Table S.11. These estimates do not account for the likely effect of higher per capita income enabling more use of air conditioning in Cairo.

Table S.11. Estimated increase in annual mortality in greater Cairo from increased heat stress

Socioeconomic scenario/climate change scenario	2030			2060		
	0.9/-4%	0.9/0	1.0/-5	2.0/-10	1.9/0	2.2/-10
Low population/ high GDP	662	662	736	1,662	1,579	1,924
High population/ low GDP	722	722	802	2,302	2,187	2,665

The first number in the climate change scenarios cells is the estimated °C increase in temperature. The second number is the percentage change in precipitation.

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The economic damages associated with the loss of life to heat stress are displayed in Table S.12. The estimated annual economic damages from increased heat stress mortality are in the tens of billions of EGP by 2060. The welfare loss in the "optimistic" scenario are higher than the "pessimistic" scenario because the VSL in the optimistic case is much higher than in the pessimistic case because the GDP/capita levels in the optimistic scenario are much higher than in the pessimistic scenario.

Table S.12. Estimated annual welfare loss from increased heat stress in greater Cairo (billions EGP)

Socioeconomic scenario/climate change scenario	2030			2060		
	0.9/-4%	0.9/0	1.0/-5	2.0/-10	1.9/0	2.2/-10
Low population/ high GDP	3.3	3.3	3.7	25.0	23.7	28.9
High population/ low GDP	2.4	2.4	2.7	14.2	13.5	16.4

The first number in the climate change scenarios cells is the estimated °C increase in temperature. The second number is the percentage change in precipitation.

S.7 Tourism

Climate change could affect tourism in Egypt in two ways. One is from higher temperatures. As temperatures rise, higher-latitude locations may become more attractive. Assuming that tourists will switch destinations based on changes in temperature, Bigano et al. (2007) estimated that tourism in Egypt would drop by 20%. We extrapolated the increase in tourism expenditures in the last few years to estimate potential tourism levels in 2030 and 2060. Assuming a 20% decrease in tourism, revenues in 2060 would decrease by 13 to 17 billion EGP per year.

The second way that tourism could be affected is through a loss of coral reefs. Coral reefs in the Red Sea are already declining because of higher temperatures and are estimated to stop growing by 2070 (Cantin et al., 2010). Table S.13 displays the estimated annual financial loss to the tourism industry from change in tourist preferences because of higher temperatures and loss of coral reefs in the Red Sea. Total financial losses are in the range of 100 billion EGP/year by 2060.

Table S.13. Annual total losses in tourism due to climate change

	Climate change losses (billion EGP)	
	Optimistic	**Pessimistic**
2030	22.2	19.3
2060	103.0	84.7

S.8 Summary of Impacts

Table S.14 lists the potential economic impacts of climate change on Egypt and Figure S.3 displays the results for the scenario assuming low reduction in Nile flow combined with the pessimistic socioeconomic scenario and no protection for SLR.

Egypt could face reduced crop yields, less water, a significant reduction in agricultural production, either losses of property or higher coastal protection costs, higher mortality from air pollution, and a loss in tourism revenues. Malnutrition and unemployment would increase and total economic losses by 2060 could be several hundred billion EGP per year. These estimates do not account for potential adverse impacts of higher temperatures and lower flows on fisheries, hydropower, and transportation. In addition, other ecosystems besides coral reefs could be harmed, water quality could deteriorate, and there could be other risks to human health besides reduced air quality. In summary, Egypt could face significant risks from climate change. Thus, under projected changes in climate, Egypt would be poorer and less healthy than it would otherwise be.

S.9 Adaptation

Adaptations will need to be made over the coming decades if Egypt wishes to reduce its risks from climate change. A national adaptation plan should be developed. Such a plan will send a clear signal to the government and throughout the country that adaptation is a priority.

Based on the results of this study and placing emphasis on the estimated economic impacts of climate change to Egypt, we rank the following sectors based on their relative vulnerability to climate change:

1. Water resources and agriculture
2. Tourism
3. Human health
4. Coastal resources.

Table S.14. Selected economic losses in Egypt from climate change (billion EGP)

	2030			2060		
Socioeconomic scenario	**High population; low GDP**	**High population; low GDP**	**Low population; high GDP**	**High population; low GDP**	**High population; low GDP**	**Low population; high GDP**
Nile flow scenario	**Large reduction**	**Small reduction**	**Small reduction**	**Large reduction**	**Small reduction**	**Small reduction**
Annual climate change in Cairo (temperature °C/% change in precipitation)	**0.9/-4%**	**0.9/0**	**0.9/0**	**2/-10%**	**1.9/0**	**1.9/0**
SLR	**High unprotected**	**High unprotected**	**High unprotected**	**High unprotected**	**High unprotected**	**High unprotected**
Welfare loss in agriculture	26	25	20	234	112	41
Annual coastal property losses (excluding agriculture)	1	1	2	7	7	16
Value of deaths from air pollution (using VSL)	3–6	3–6	3–7	6–14	6–14	11–24
Value of deaths from heat stress (using VSL)	2–3	2–3	3	14	14	24
Reduction in annual tourism revenues	19	19	22	85	85	103
Total of selected impacts	51–55	50–54	50–54	346–354	224–232	195–208
Percent of GDP	2.2–2.4	2.2–2.4	1.6–1.8	5.9–6.0	3.8–3.9	2.1–2.2

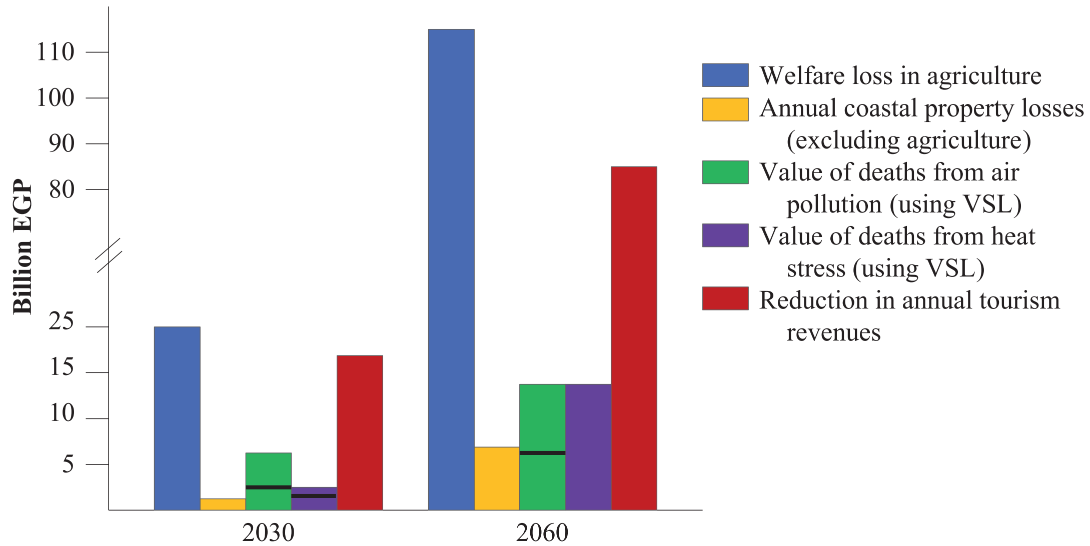

Figure S.3. Estimated economic impacts by sector in 2030 and 2060 assuming low reduction in Nile flow, a pessimistic socioeconomic scenario, unprotected coastal areas, and high SLR.

Adaptations needed to reduce the risks from climate change on the Egyptian economy and well-being could include:

Water resources

- *Enhance use of market mechanisms to reduce demand*. Market mechanisms such as charging users for their use of water can increase efficiency and reduce demand. Minimal or no charges should be applied for water to meet basic human needs.

- *Development of new supplies of water.* Desalination and reuse are among the technologies and management techniques that increase water supplies. We estimate that the benefits of reusing municipal and industrial (M&I) water can greatly exceed costs. Rainwater harvesting should be encouraged near the Mediterranean, which is where Egypt gets most of its precipitation.

Agriculture

- *Development of heat-resistant, drought-resistant, and salinity-resistant crops.* Development of varieties that can maintain yields under higher temperatures or use more heat- or drought-tolerant varieties or crops could help narrow the reduction in crop yields and agricultural output.

- *More efficient use of water resources.* Using more efficient irrigation techniques, planting crops that demand less water, and reducing M&I water use through adoption of more water-efficient technologies can limit the demand for water resources.

Tourism

- *The tourist industry should consider potential risks from climate change and work with the government to develop strategies for reducing vulnerability to climate change.* Given the uncertainties about how tourism could be affected by climate change but the potential for large losses, it would be prudent for the industry to monitor tourist behavior.

- *The government should consider the importance of tourism in allocating water resources and in coastal planning.* Tourism is of such high economic value, adequate water supplies for future tourism need to be secured. Coastal planning should consider the critical importance of protecting tourism facilities from SLR and change in coastal storms. This should be done in a manner that protects the attractiveness of tourism facilities.

Human health

- *Reduce air and water pollution.* Even today it is imperative that Egypt limit air and water pollution in order to reduce harm to human health and the environment. Climate change may mean that even stricter controls would be needed to meet the same levels of air and water pollution.

- *Heat watch warning systems and access to cooling centers* have proven to reduce risks to human health from heat waves.

- *Ensure that surveillance systems that can detect and warn about the emergence and spread of diseases are adequate*. If current systems are inadequate for monitoring current or future risks, they should be enhanced. In addition to surveillance systems, the public health system needs to be able to respond to outbreaks of disease.

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Coastal resources

- Egypt is engaged in the *development of an Integrated Coastal Zone Management (ICZM) Plan*. The plan should be regularly updated to reflect changes in conditions and new science. Planning for at least one meter of SLR by 2100 and possibly two meters would be prudent.

- *Implement recommendations from the Egyptian Second National Assessment on projecting coastal resources*, including:
    - Create wetlands in vulnerable areas
    - Reinforce hard structures such as the Muhammad Ali Wall and coastal roads.
    - Enhance the work of the Coastal Zone Management Committee to formulate an ICZM plan.

Cross cutting adaptations

A number of adaptations are cut across individual sectors.

Egypt should also plan for the potential for increased migration from rural to urban areas. Should water supplies and crop yields decrease, so would employment in agriculture. Displaced workers may migrate to urban areas.

There are many reasons for supporting policies to increase per capita income and limit population growth. Climate change is yet another reason. This study found the economic losses under a high population and low economic growth scenario would be larger in absolute and relative terms than under a low population and high economic growth scenario.

Finally, Egypt should prepare a national adaptation plan or strategy. Government adaptation appears to be most successful when there is a strong and coherent call for action by a chief executive. A call for action sends a clear signal across the government that adaptation is important and that cooperation is needed. If done well, a national plan can send a clear signal that adaptation to climate change is a priority of the government. It can also help foster needed coordination on management of resources vulnerable to climate change across ministries, across different levels of government, and with nongovernmental organizations.

We expect that current development needs will take priority over those related to climate change. However, the risks from climate change should not be overlooked. Eventually, Egypt will have to cope with climate change. Many of the adaptations mentioned above may take years to decades to develop and implement. Furthermore, these adaptations may be justified even under current climate. Thus, there seems little reason to delay adaptation.

In general, Egypt faces a wide array of serious risks from climate change including risks to its water supplies, agricultural production, human health, and tourist industry. Adaptation can help ameliorate some of these risks, but mitigation (reduction in greenhouse gas emissions) will also be needed through global efforts to avoid the most harmful effects of climate change.

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1. Introduction

When one thinks of countries that face the most significant threats from climate change, the first thing that comes to mind is small island countries, such as the Maldives. Some of these island countries are within a few meters of sea level and eventually could be inundated by sea level rise (SLR). Other small island countries may lose significant portions of their land.

Bangladesh is a continent-based country that could lose a substantial portion of its land to SLR and faces flood risks across the country from increased cyclone intensity and melting of Himalayan glaciers.

Another country that essentially faces a serious threat from climate change is Egypt. In part, Egypt is vulnerable to SLR, which threatens the fertile Nile River Delta (the Nile Delta). Perhaps more significant for Egypt are potential changes in water supplies. The Nile River (the Nile) is Egypt's life source. The vast majority of Egypt's water supply comes from the Nile and 97% of the country's population lives along the river or in the Nile Delta. Per capita water use is currently only 750 m^3/capita and is expected to significantly decline as the population continues to grow. A reduction in average flow of the Nile could seriously threaten Egypt's water supplies and the well-being of its citizens.

In addition to a change in water resources, SLR could threaten valuable lands in the Nile Delta with inundation. Higher temperatures could reduce yields of some key crops, while a decrease in water supplies could threaten the availability of irrigation. In addition, climate change could worsen Egypt's severe air pollution. The combination of higher temperatures and SLR could reduce tourism by making the climate less inviting and threatening ecological tourist attractions such as coral reefs. As Egypt's Second National Communication (SNC) to the United Nations Framework Convention on Climate Change (UNFCCC) stated, "Egypt is one of the most vulnerable countries to the potential impacts and risks of climate change…" (EEAA, 2010a, p. 69).

Thus, a key question to be answered is:

- Does climate change threaten Egypt's future?

Other key questions are:

- Would higher temperatures, SLR, and lower runoff in the Nile threaten the availability of water supplies for domestic, industrial, and agricultural uses?

- Would inundation of low-lying agricultural areas and increases in air pollution drive tourists elsewhere?
- What strategies exist to reduce the country's vulnerability to climate change?

In this report, we seek to provide answers to these questions. Our focus is on providing an estimate of the potential economic impacts of climate on Egypt in 2030 and 2060. We examine the implications of higher temperatures, changing water supplies, and SLR on:

- Uses of water resources
- Agricultural production
- Value of threatened property in the Nile Delta
- Human health
- Tourism.

These are not all the affected sectors in the Egyptian economy. However, climate change impacts on the sectors listed above could pose significant risks to Egypt's future.

This report is the result of a collaborative effort among the Egyptian government, the United Nations Development Programme, and the U.S. consulting team consisting of Stratus Consulting and Drs. Kirshen and McCarl. Stratus Consulting synthesized the results of the team's analyses to create this report. The specific contributions were as follows:

- *Climate change scenarios*: Joel Smith, Stratus Consulting, using climate models based on the analysis by the Egyptian Ministry of Water Resources & Irrigation (MWRI)
- *Population and economy*: Joel Smith, with support from the Center for Future Studies, Egyptian Cabinet Information and Decision Support Center (IDSC)
- *Water resources*: Dr. Paul Kirshen, University of New Hampshire, in collaboration with the MWRI, Nile Forecasting Center
- *Coastal resources*: Coastal Research Institute (CoRI) in the MWRI, Adaptation of the Nile Delta to Climatic Changes and SLR through the Integrated Coastal Zone Management (ICZM) project, with Stratus Consulting assisting in estimation of potential land loss
- *Coastal resources property*: Dr. Mohamed A. Abdrabo, University of Alexandria
- *Agriculture*: Dr. Bruce McCarl, Texas A&M University, in cooperation with the Agricultural Research Centre of Egyptian Ministry of Agriculture and Land Reclamation

- *Air pollution*: Dr. Leland Deck, Stratus Consulting
- *Heat stress*: Joel Smith and David Mills, Stratus Consulting
- *Tourism*: Joel Smith, Stratus Consulting
- *Synthesis*: Joel Smith, Stratus Consulting.

This report is organized as follows. The background on current climate, trends, and socioeconomic conditions in Egypt is given in Chapter 2. The literature on climate change impacts in Egypt is reviewed in Chapter 3. Chapter 4 presents the methods used in the study. Socioeconomic and climate change scenarios are discussed in Chapter 5. Results are presented in Chapter 6, Chapter 7 discusses adaptation, and Chapter 8 presents research ideas to follow up on this study.

Readers should note that most of the effort involved in this project was on estimating the economic consequences of climate change for Egypt. Chapter 7 contains a preliminary analysis of adaptation to climate change in Egypt. The chapter suggests priorities for adaptation based on results of this analysis, discusses potential adaptation strategies, reviews published estimates of the total cost of adaptation for the country, and offers some new preliminary estimates of costs on increasing desalination and water reuse. The chapter should be viewed as an initial analysis of adaptation issues and needs in Egypt. More research on adaptation needs and the effectiveness, costs, and feasibility of specific adaptations is needed.

2. Background: Current Climate, Trends, and Socioeconomic Conditions

This chapter provides a background on Egypt's geography, climate, climate trends, and socioeconomic conditions and trends. It is important to note that socioeconomic and environmental conditions in Egypt are changing rapidly. This report attempts to provide an estimate of the economic consequences of climate change in 2030 and 2060. As the events of 2011 demonstrate, it is not possible to project many political, economic, and societal changes. This is also true for projecting Egypt's socioeconomic conditions for those future years. Suffice it to say that changes in socioeconomic conditions are likely to have a greater impact on Egypt's economy and standard of living than climate change. Nonetheless, climate change could have very important implications for the country's well-being.

2.1 Geography

Located between 22 to about 33°N and 36 to about 24°E, Egypt lies in northeast Africa. It borders Libya, Sudan, Israel, and the Gaza Strip. About one-third of Egypt's coast is on the Mediterranean and the rest is on the Red Sea. Egypt's land area is larger than 995,000 km^2 and its coastline is 3,500-km long.

2.2 Climate

Egypt's climate is hot and dry. The average daily temperature ranges from 17 to 20°C along the Mediterranean to more than 25°C in Upper Egypt along the Nile (EEAA, 2010a). Figure 2.1 displays average annual temperatures across Egypt.

Precipitation is generally very low. It is highest along the Mediterranean where it averages more than 200 mm/yr. Precipitation rates drop quickly as one moves away from the coast. Most of Egypt receives about 2 mm of precipitation per year. Figure 2.2 shows average annual precipitation across the country. Thus, most of Egypt is a desert and can be classified as arid. The exception is the slightly wetter Mediterranean coast, which can be considered semi-arid. Generally, the small amount of rain that does fall comes in the winter, and hence Egypt has a Mediterranean climate.

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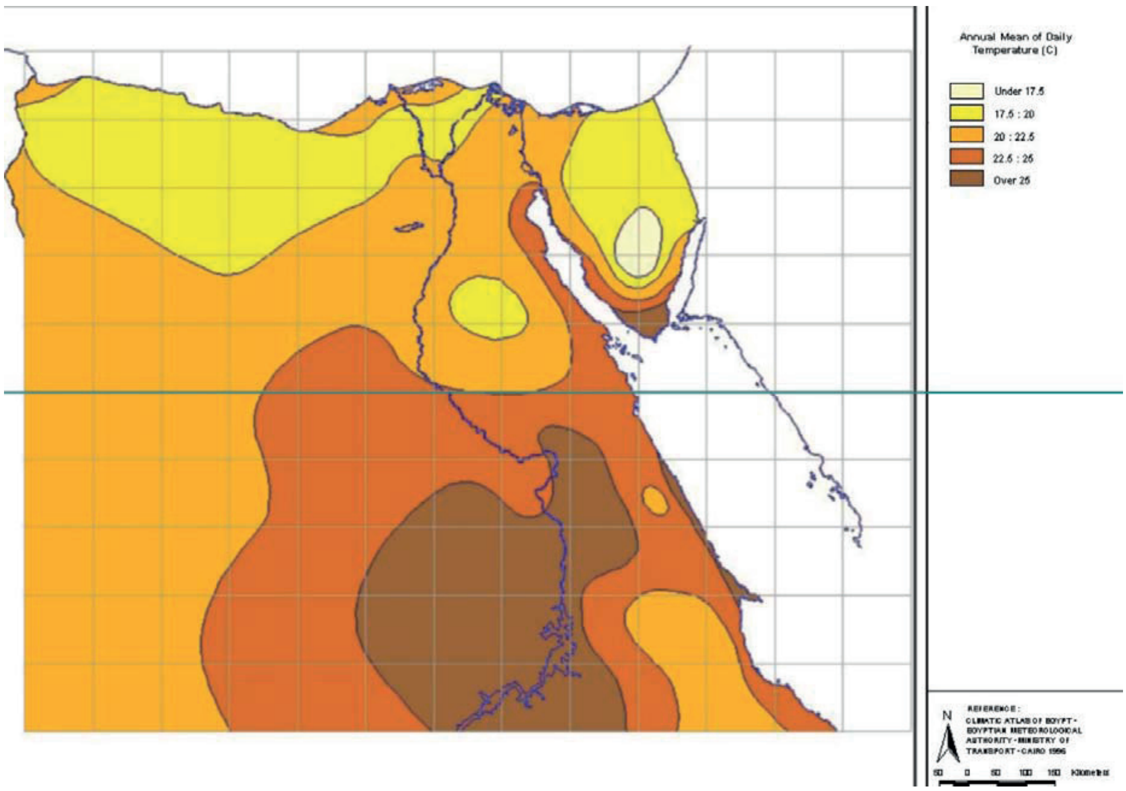

Figure 2.1. Average annual temperatures (°C) in Egypt.

Source: EEAA, 2010a.

2.3 Observed and Projected Climate Trends

Egypt is getting warmer. From 1961 to 2000, the mean maximum air temperature increased 0.34°C/decade, while the mean minimum air temperature increased 0.31°C/decade (EEAA, 2010a). Domroes and El-Tantawi (2005) report that there was a slight cooling trend across northern Egypt and a warming trend in the south from 1941 to 2000, but from 1971 to 2000 there was a clear warming trend in all stations. Temperature data from Aswan, Luxor, and Kharga show much variability but a long-term increase in temperature. Data from Alexandria, Port Said, and Asyut show that temperatures in the 1950s and 1960s were higher than in the 2000s but temperatures appear to rising slightly in recent decades.

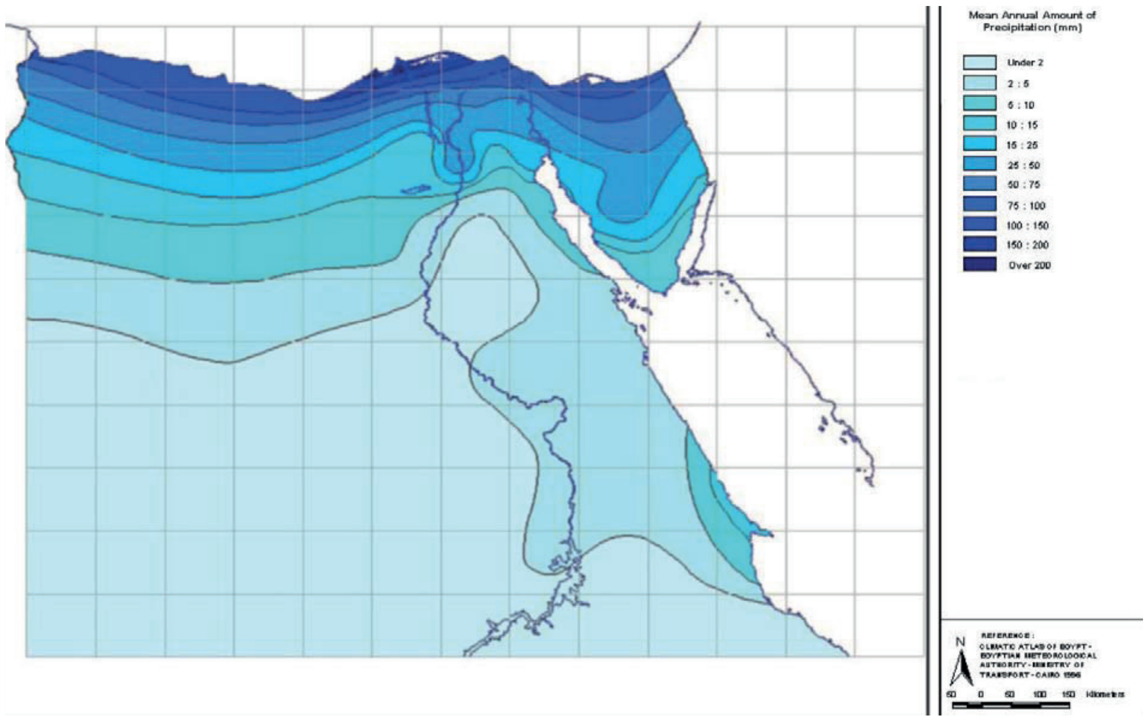

Figure 2.2. Average annual precipitation in Egypt (mm/yr).

Source: EEAA, 2010a.

Precipitation trends for Egypt are unavailable. However, Xoplaki et al. (2004) found that wet-season precipitation in the Mediterranean has generally decreased since the mid-1960s. Hoerling et al. (2011) find that human causes – higher greenhouse gas concentrations and aerosols – explain about half of the decrease in precipitation across the Mediterranean region. This suggests that observed drying of the region is at least partly due to changes in the atmosphere caused by humanity.

Relative sea levels are increasing, which is the result of at least two factors. The first is that global (eustatic) sea levels are rising (Bindoff et al., 2007). The second is that the Nile Delta is subsiding. This is partly the result of dams along the Nile, which limit natural sediment flow to the Nile Delta and, in turn, cause different observed rates of SLR along Egypt's coast. In Alexandria, the observed rate, which includes subsidence and eustatic SLR, is 1.6 mm/yr, in Al-Burrullus it is 2.3 mm/yr, and in Port Said it is 5.3 mm/yr. The difference between these three locations is the rate of subsidence (Elshinnawy, 2008). The rate of subsidence is reported as 0.4 mm/year in Alexandria, but appears to be as much as 4.1 mm/year in Port Said [based on Elshinnawy (2008)].

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The Intergovernmental Panel on Climate Change (IPCC) concluded that Egypt will probably get hotter and drier. Christensen et al. (2007) stated that it is very likely that not only will Africa become warmer, but also that the rise in temperatures in Africa will be greater than the rise of average global temperatures. They also concluded that precipitation is likely to decrease in the Mediterranean region, which includes Egypt. In contrast, the IPCC asserted that East Africa, which contains the sources of the Nile, is likely to get wetter. Roughly two-thirds of the general circulation models (GCMs) project an increase in precipitation in East Africa.

There is some disagreement about whether East Africa will get wetter. For example, Funk et al. (2008) state that precipitation during the growing season (March, April, and May) in East Africa has decreased by approximately 15% since about 1980. They also state that warmer surface temperatures in the Indian Ocean are disrupting the flow of moisture from the ocean to this region, and conclude that the IPCC projection of a wetter East Africa is wrong.

We are unable to judge who is “right” or “wrong” in this disagreement over future climate changes in East Africa. One thing is virtually certain: the Nile Basin has become warmer and the warming will in all likelihood continue. In addition, it seems likely that the Mediterranean region will continue to get drier. Whether East Africa will get wetter or drier is less clear. Many models project an increase in precipitation, but drier conditions cannot be ruled out. Furthermore, observed precipitation trends in the region do not appear to be consistent with projections of wetter conditions. Recent research suggests that in the past, warmer conditions in East Africa had more intense interannual variability in precipitation (Wolff et al., 2011).

2.4 Socioeconomic Conditions

Egypt’s population in 2010 was approximately 80 million and had increased 2.3% per year over the last 10 years (EEAA, 2010a).[1] Egypt is a developing country with a growing population and a growing economy. Its real economy (adjusted for inflation) has grown an average of 5.1% per year since 2000 (World Bank, 2011a). Thus, per capita income has increased by more than 3% per year. If sustained, such a level of growth would result in a doubling of average per capita income in less than a quarter century (note that we do not have data on the effect of the February 2011 revolution on economic growth; Handoussa, 2010).

Although incomes on average have increased, there is widespread poverty in Egypt. Egypt has reduced extreme poverty, but total poverty has increased in recent years. The extreme poverty rate of the population (which is close to $1.25/day in personal income) decreased from 8.2% in 1990 to 3.4% in 2008–2009. However, all of those in poverty (which is income less than $2/day)

1. The World Bank (2011a) reports that Egypt’s current population is 84 million.

went from 24.2% in 1990 to 21.6% in 2008–2009. The upper poverty line ($2.50/day) remained at around 40% of the population. So, it is not surprising that the Gini coefficient, which measures income inequality, increased by 2 percentage points from 2005 to 30.46 in 2008 (Handoussa, 2010, p. 51). UNDP (2011) reports that the Gini coefficient had increased again to 32.1 in 2010. Nonetheless, Egypt's Human Development Index, which considers income, health, and education, rose from the same level as all Arab countries in 1990 to the world average in 2000 and has continued to increase.

Egypt is still mostly rural, with 57% of its population living in rural areas. Seven of 10 in poverty live in rural areas. Even within rural areas there are geographic disparities, with two-thirds of the extreme poor living in Upper Egypt (Handoussa, 2010).

Thus, although Egypt is growing economically and poverty is being reduced, it is not across the board. Income in urban areas appears to be increasing faster than in rural areas, and overall income inequality is increasing. Climate change risks, which are often borne disproportionately by the poor, could exacerbate the inequality.

In the following sections, we briefly review events in sectors that will be affected by climate change: food, water resources, tourism, and human health.

2.4.1 Food

Agriculture is one of the largest sectors of the economy, comprising 13.7% of gross domestic product (GDP; CAPMAS, 2010). Agriculture employs more Egyptians than any other sector, providing 30% of all employment (CAPMAS, 2010; Handoussa, 2010). Although manufacturing is a slightly larger share of GDP, it employs far fewer people than agriculture. With virtually all agriculture jobs located in rural areas, agriculture employs about half the working population in those rural areas.

Total land dedicated to agriculture has increased in recent decades. Cropped areas have increased from 11.1 million feddans[2] in 1980 to 15.2 million feddans in 2007. In addition, Handoussa (2010) reports that the quality of this land has decreased.

The increase in the number of people employed in agriculture has led to the unfortunate consequence of average landholdings for agriculture shrinking, even with the increase in total cropped land. Average agriculture holdings have gone from 6.3 feddans in 1950 to 2.1 feddans today, with 43% of farmers farming 1 feddan or less. This was an increase from 1950 when 24% of the farms were that small. This increase in the number of small farms will likely result in a

2. One feddan is equal to 0.42 hectares or 1.038 acres.

decrease in the capacity of agriculture to adapt to climate change. It is generally thought that larger, well-capitalized farms will have a higher capacity to adapt to climate change than smaller, less well-capitalized farms.

Agricultural production in Egypt could be slowing. Handoussa (2010) reports that crop yields slowed significantly after the 1980s. From 1990 to 2000, yields increased 1% per year for maize and rice and 0.5% per year for wheat. Although there was a doubling of production for these three crops, the increase was primarily the result of expanding agricultural land.

The share of food consumption that comes from food produced in Egypt is decreasing. Abu-Abu-Ismail et al. (2009) report that Egypt's self-sufficiency (the share of food production that is produced domestically) of wheat decreased from about 60% in 2006 to about 50% in 2008.

Egyptian fish production has almost quintupled in the last three decades, rising from 243,000 MT in 1980 to 970,000 MT in 2007. Three-fifths of fish production is from aquaculture, with a majority of fish production located in the northern Nile Delta. Handoussa (2010) reports that total fish production is expected to rise to 1.5 million MT by 2015.

2.4.2 Water resources

Egypt is heavily dependent on the Nile for its water supplies. Egypt is particularly vulnerable to climate change because the Nile's sources are more than 1,000 km south of Egypt's border. Figure 2.3 shows the entire Nile Basin. Three-fifths of the Nile's flow is from the Blue Nile, which originates in the Ethiopian Highlands. The White Nile originates in the Equatorial Lakes region of East Africa.

Egypt's present water budget is given in Table 2.1. The 10 BCM evaporation loss from the surface of the High Aswan Dam (HAD) does not count against Egypt's net allocation of 55.5 BCM/yr to HAD from the 1959 Agreement. Water currently available for agricultural consumption is 44.7 BCM/yr. The actual withdrawal for agriculture water is approximately 63 BCM/yr (MWRI, 2005). This value exceeds the natural inflows because of return flows from municipal and industrial (M&I) users and reuse of irrigation drainage water. As the IPCC noted, Egypt and Libya are the only countries in Africa that consume more than 90% of their total available water resources (Boko et al., 2007). Most M&I returns or wastewater flows are untreated. Figure 4-10 in MWRI (2005) shows only 1.4 BCM/yr of municipal wastewater treatment. This analysis assumes that such treated and untreated flows remain suitable for irrigation in the future. Chapter 7 analyzes the costs of treating M&I wastewater from areas along the Mediterranean.

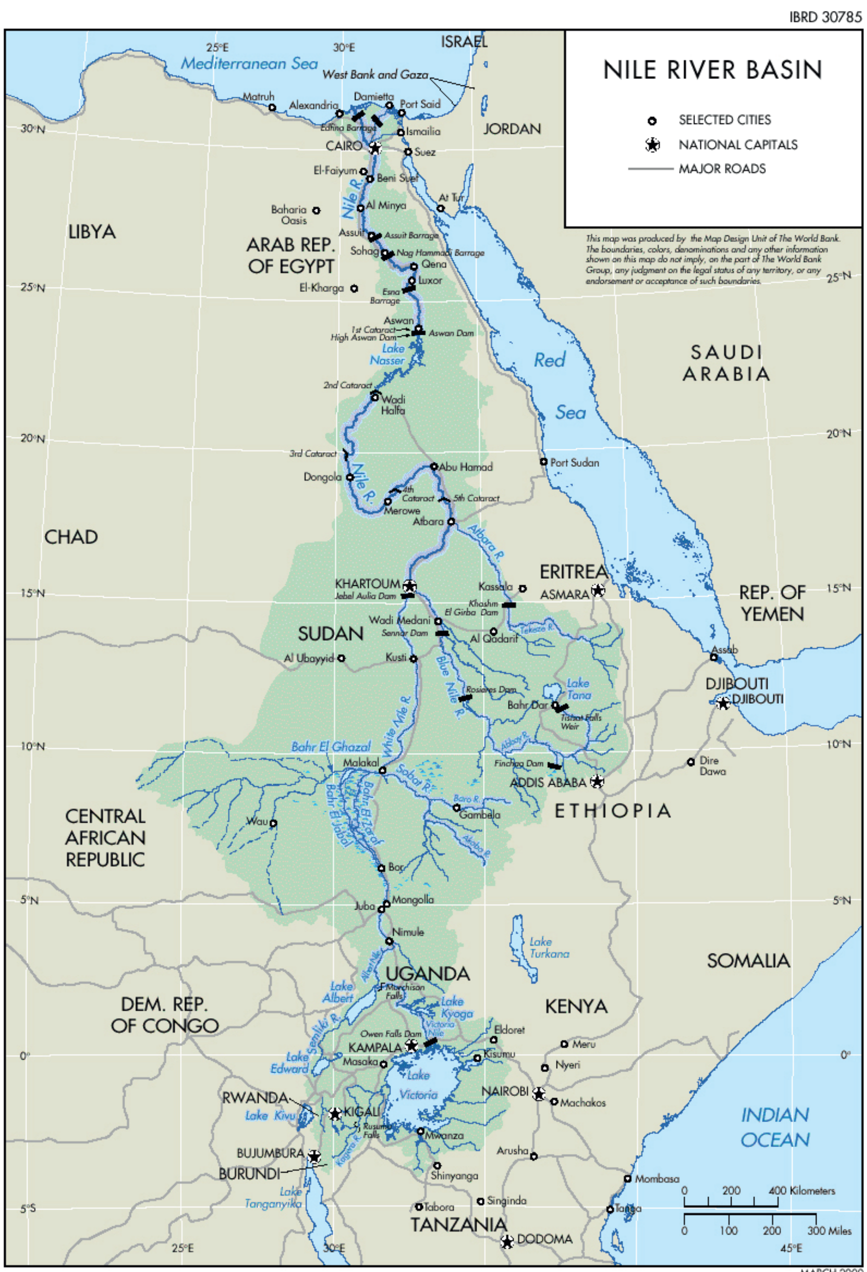

Figure 2.3. Map of the Nile River Basin.

Source: World Bank, 2011b.

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Table 2.1. Current sources of water in Egypt

2000–2010 supplies	BCM/yr	
HAD	55.5	National communication
Non-recharged groundwater	5.8	National communication
Recharged groundwater	0.2	National communication
Effective rainfall	1.3	Figure 4-10, MWR
Total	62.8	
2000–2010 evaporation and consumption (not withdrawals)		
Downstream surface evaporation	2	Calculations for this study
Industrial consumption	1.4	MWRI communication (2011)
Municipal consumption	1.62	Withdrawal from MWRI communication (2011) adjusted for consumption
Total	5.02	
Present outflow to sea	13.1	From Table 4-11, MWRI, if use 70 MCM/day, this is 25.5 BCM/year
Available for agriculture	44.68	
Sources: MWRI (2005), EEAA (2010a), and calculations by Bruce McCarl.		

Egypt's water supplies are extremely limited and projected to become even more limited. Water use per capita has decreased from 2,500 m^3/capita/yr in the 1950s to 750 m^3/capita/yr today. Water use per capita is projected to be only 250 m^3/capita/yr in 2050. Handoussa (2010) reports that countries with less than 1,000 m^3/capita/yr are considered to be in water poverty.

The government is seeking ways to improve water supply and, in particular, to increase access to potable water. Since about 2005, the government has completed 1,669 water sanitation projects. The goal is to have all inhabitants within a 15-minute walk of clean water. Drinking water supplies have increased by 8 million m^3/day to 27 million m^3/day. The number of people receiving sanitary drinking water increased from 75% in 2006 to 88% in 2010. Handoussa (2010) reports that there will be 100% coverage when Egypt's current projects are completed.

2.4.3 Tourism

Tourism is a growing sector of Egypt's economy. Handoussa (2010) reports that in 2009, tourism accounted for 11.3% of GDP and 21.4% of foreign currency. About one in eight (12%) Egyptian workers are employed in tourism. Of these, 1.2 million are employed in hotels and 1.5 million in travel and related services. Europeans make up three-fourths of the tourism market. The Ministry of Tourism is projecting 14 million visitors in 2011 and 25 million tourists in 2020.

Unfortunately, environmental conditions in many tourist areas are degrading. Handoussa (2010) reports that coastal habitat is being lost because of urbanization, pollution, landfilling, tourism, and flash flooding. In addition, higher ocean temperatures are linked to degradation of coral reefs in the Red Sea (Cantin et al., 2010).

2.4.4 Human health

The life expectancy of the typical Egyptian is 70 years, an increase of 10 years over the last 25 years. This suggests that the standard of living and health care in particular have been improving in Egypt. One indicator of improved health is the country's death rate, which has been reduced by more than 40% since 1985 (World Bank, 2011a). Another measure is infant mortality, which has been reduced by almost 80% in the same period. Child mortality rates fell from 240 per 1,000 in 1967 to 28 per 1,000 in 2008 (World Bank, 2011a).

Yet, health problems remain. Air and water pollution levels in Egypt are high and contribute to many premature deaths and morbidity. About 17,000 children per year, one-fifth of all childhood deaths, are estimated to result from poor water quality, inadequate hygiene, and poor sanitation. These conditions also contribute to high levels of infectious disease among children and adults, particularly diseases caused by worms and other parasites. This results in a yearly loss of 615,000 disability adjusted life years (DALYs; World Bank, 2002).

Air pollution also poses significant risks to Egyptians. A network of 17 $PM_{2.5}$ (particulate matter less than 2.5 microns in diameter) monitors in Greater Cairo (which includes the Governorates of Cairo, Giza, and 6th of October) measured the 2002 annual average of $PM_{2.5}$ to be between 77 and 100 $\mu g/m^3$ (Zakey et al., 2008), with the highest concentrations in industrial areas. The urban center level was 82.6 $\mu g/m^3$. The World Health Organization standard for $PM_{2.5}$ is 10 $\mu g/m^3$.

The World Bank (2002) estimates that high air pollution levels in Cairo and Alexandria contribute to 20,000 premature deaths each year. This and morbidity from pollution translates into about 450,000 DALYs per year. In general, the World Bank (2002) estimates that pollution causes an economic loss equivalent to 3 to 6% of GDP, with 4.8% being the median estimate.[3] Of this, air pollution contributes to a loss of 1.1 to 3.2% of GDP and water pollution to a loss of 0.7 to 1.2% of GDP.

Egypt's SNC reports that Egypt has a few cases of malaria and that the climate is suitable for spread of the disease. In addition, lymphatic filariasis is endemic in the Nile Delta region (EEAA, 2010a).

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3. Note that this loss is not entirely financial. The financial portion includes lost wages and medical costs. Most of the estimated value is a measure of welfare.

Malnutrition data are incomplete but show a decrease from more than 10% for children before 2000 to between 5 and 10% in the last decade (World Bank, 2011a). The data show a reduction in malnutrition but that it still exists in Egypt.

3. Literature Review

This chapter briefly reviews the literature on potential climate change impacts on Egypt. In creating this review, we relied on Egypt's SNC to the UNFCCC (EEAA, 2010a) because it is a recent and thorough compilation of the literature. We summarize findings on potential climate change impacts on water resources, food production, coastal resources, tourism, human health, and transportation. Note that all of these impacts except for transportation are addressed in the analyses presented in subsequent chapters.

Egypt has been the subject of climate change studies for more than two decades, including work by Milliman et al. (1989) and El-Raey et al. (1995) on vulnerability of coastal resources, as well as work by Strzepek et al. (1995, 2001) on vulnerability of agriculture to changes in climate, water supply, and coastal resources.

3.1 Water Resources

Most of the research on climate change and water resources has focused on the potential effects on water supply and, in particular, the effects on flow of the Nile. The focus on the Nile makes sense given the critical importance of the river to Egypt's water supply.

An important finding is how highly sensitive the Nile's flow is to changes in climate. The result is not surprising given the well-known variability of Nile flow (e.g., Krom et al., 2002). The Nile flows primarily through arid and semi-arid climate zones. In such areas, runoff is typically very sensitive to changes in climate. The SNC notes that a 10% decrease in precipitation over the sources of the Nile can result in a 31% decrease in flow of the river at Khartoum, whereas a 10% increase in precipitation is estimated to result in a 36% increase in flow at the same location. Flow is also very sensitive to changes in temperature. A 4% increase in evapotranspiration, which can occur with a temperature increase of less than 1°C, would decrease flow of the Blue Nile by 8% and flow out of Lake Victoria by 11%.

Studies on climate change impacts have shown the potential for very significant changes in the flow of the Nile. Conway and Hulme (1996) estimate that flow in the Blue Nile in 2025 could range from an increase of 15% to a decrease of 9%. Strzepek et al. (2001) estimate that by 2020, the flow coming into the HAD could decrease by 10 to 50%. More recently, Elshamy et al. (2009) used bias-corrected statistical downscaling of 17 GCMs to estimate an average reduction in flow of the Blue Nile of 15% by the end of the century, and a range of change from a decrease of 60% to an increase of 45% (Mohamed Elshamy, Nile Forecast Center, personal communication, March 15, 2011). These results are displayed in Table 3.1. Beyene et al. (2009)

Table 3.1 Model-simulated flow of the Blue Nile at Diem (BCM)

GCM	1961–1990	2081–2100	% change
BCM	48.96	37.34	-24
CGCM	50.57	20.70	-59
CGCM63	50.82	20.38	-60
CNRM	52.24	44.80	-14
CSIRO30	47.99	34.96	-27
CSIRO35	46.66	34.96	-25
CM20	46.45	28.85	-38
CM21	47.46	34.31	-28
AOM	48.44	49.33	2
GOAL	47.65	50.86	7
INMCM	42.82	56.45	32
MIROCH	47.74	47.74	0
MIROCM	46.93	68.25	45
ECHAM	44.18	35.74	-19
MRI	50.30	33.00	-34
CCSM	32.84	40.15	22
PCM	48.60	35.38	-27
Mean	47.10	39.82	-15

Source: Mohamed Elshamy, Nile Forecast Center, personal communication, March 15, 2011.

also used bias-corrected statistical downscaling of 11 GCMs and found a change in flow at the HAD ranging from a decrease of 32% to an increase of 15%. These researchers used the estimates of change in flow from Elshamy et al. (2009) in their calculations of change in water supplies.

The SNC notes that lower flows in the Nile would negatively affect Egypt's economy through impacts on agriculture, industry, tourism, hydropower generation, navigation, fish farming, and the environment. High flows, while increasing the total supply of water resources, would also necessitate more expenditures on infrastructure for increased water storage and conveyance and to control flooding.

3.2 Food Production

We identified three main domestic sources of food in Egypt: crop production, livestock, and fisheries. The literature on climate change and these three food sources are briefly reviewed below.

3.2.1 Crop production

Crop production in Egypt will be affected in at least three ways by climate change. First, higher temperatures will change yields and water demand. Table 3.2 from EEAA (2010a) displays projected changes in crop yields, all of which are projected to decrease except cotton. This is mainly the result of higher temperatures because all crops are irrigated. The IPCC stated that by 2050, rice yields in Egypt could decrease by 11% and soybean yields by 28% (Boko et al., 2007).

Table 3.2. Projected changes in crop production of some major crops in Egypt under climate change conditions

	Change %		
Crop	2050s	2100s	Reference[a]
Wheat	-15[b]	-36[c]	Abou-Hadid, 2006 (as cited in EEAA, 2010a)
Rice	-11		Eid and El-Marsafawy, 2002 (as cited in EEAA, 2010a; full reference not provided)
Maize	-19		Eid et al., 1997 (as cited in EEAA, 2010a)
	-14	-20	Hassanein and Medany, 2007 (as cited in EEAA, 2010a)
Soybeans	-28		Eid and El-Marsafawy, 2002 (as cited in EEAA, 2010a; full reference not provided)
Barley	-20		Eid et al., 1997 (as cited in EEAA, 2010a)
Cotton	+17[b]	+31[b]	Eid et al., 1997 (as cited in EEAA, 2010a)
Potato	-0.9 to -2.3	+0.2 to +2.3	Medany and Hassanein, 2006 (as cited in EEAA, 2010a)

a. Information on these studies can be found in EEAA, 2010a.
b. Temperature increase by 2°C.
c. Temperature increase by 4°C.

Source: EEAA, 2010a.

Change in irrigation is the second way climate change may affect crop yields. Higher temperatures will likely increase demand for water by crops [although higher atmospheric concentrations of carbon dioxide (CO_2) without a change in climate will reduce water demand by crops]. The SNC cited several studies that project a 5 to 13% increase in irrigation needs by Egyptian crops (EEAA, 2010a). If flows into the Nile decrease, it is possible that, in the long-term, deliveries of water for irrigation could be reduced. Even if the Nile's flow does not change, higher population levels could result in a shift of available water supplies from agriculture to personal and industrial uses.

The third way climate change could affect agriculture is through SLR. A rise in sea levels could inundate low-lying and unprotected agricultural lands along the Mediterranean coast. The low-lying Nile Delta is Egypt's most productive agricultural region.

There are other direct and indirect ways that climate change could affect crop production in Egypt. A change in climate could affect pests and disease. For example, a warmer climate may enable some pests and diseases to migrate into Egypt, but a warmer climate may also make it too warm for some pests and diseases to survive. Wetter conditions could enhance migration of pests and disease, whereas drier conditions could limit migration of some pests and disease but perhaps make it possible for others to migrate into agricultural areas in Egypt (Easterling et al., 2007).

Change in global supply and demand for certain crops could also affect production in Egypt. On average, warmer temperatures will increase relative yields of grain crops such as wheat in higher latitudes and will decrease relative yields in lower latitudes. This should shift the competitive advantage to growing areas at higher latitude (Easterling et al., 2007), putting Egypt at a competitive disadvantage and decreasing exports and increasing imports.

3.2.2 Livestock

There is limited information on how livestock in Egypt could be affected by climate change. Higher temperatures can decrease livestock productivity, and extreme hot and dry conditions can be fatal to livestock. The SNC notes that bluetongue and Rift Valley fever have recently emerged in Egypt and this emergence may be related to climate factors. Another risk to livestock from climate change is decreased fodder production.

3.2.3 Fisheries

In general, higher water temperatures will affect fish production. In addition, higher salinity levels could limit the production of freshwater fish.

3.3 Coastal Resources

Egypt's long coasts, particularly the Nile Delta, are exposed and vulnerable to SLR. Table 3.3 displays the potential loss of land due to SLR in 2025 and 2075 as reported in the SNC. The presence of the Mohamed Ali Sea Wall reduces potential losses near Alexandria to SLR (El Raey, 2010). These estimates are based on the IPCC's (Trenberth et al., 2007) projections of SLR. Some studies have found that those projections are low because they do not adequately account for the risk of accelerated SLR from the melting of major ice sheets such as those in Greenland and Antarctica (e.g., Oppenheimer et al., 2007; Vermeer and Rahmstorf, 2009).

Table 3.3. Areas vulnerable to SLR in the Nile Delta

	With Mohamed Ali Sea Wall	Without Mohamed Ali Sea Wall
Area (km^2) 2025	152.9	701.0
% of Nile Delta	0.6	2.8
Area (km^2) 2075	450.0	3,010.6
% of Nile Delta	1.9	12.0
Source: EEAA, 2010a.		

SLR would threaten coastal development, agriculture in the Nile Delta, and other areas. The IPCC cited a 1997 study by El-Raey (1997) that a 50-cm SLR would threaten 2 million people in Alexandria alone (Nicholls et al., 2007).

3.4 Tourism

As noted in Chapter 2, tourism is a major part of Egypt's economy and is projected to increase significantly in coming years. As of this writing, we do not have information on how the February 2011 revolution in Egypt affected tourism. However, even if tourism decreased in 2011, it is reasonable to expect that tourism in Egypt will continue to increase over the long-term.

Climate change poses some risks to tourism. SLR could threaten tourist areas and antiquities along the Mediterranean and Red seas. Higher temperatures, which are projected to increase heat waves in Egypt (Tebaldi et al., 2006), could reduce travel by tourists to low-latitude areas (Bigano et al., 2007; Handoussa, 2010). Indeed, Bigano et al. (2007) project a significant shift of tourism away from low-latitude areas to high-latitude areas, which are likely to have more favorable temperatures.

Decreased water supplies could pose challenges for tourism in Egypt, although it seems reasonable that allocation of water supplies to tourism-related areas would be a high priority. Areas along Egypt's coasts may increasingly rely on desalination for their water supplies. Handoussa (2010) states that there may be environmental limits to desalination and notes that domestic tourism could be affected by climate change. Many middle- and lower-income Egyptians take vacations in the Nile Delta, areas that could be threatened by SLR (Handoussa, 2010).

Finally, harm to coral reefs in the Red Sea caused by higher sea-surface temperatures and ocean acidification is projected to continue. Indeed, Cantin et al. (2010) project that coral reefs in the Red Sea will cease growing by 2070.[1]

3.5 Human Health

EEAA (2010a) suggests that many current health issues in Egypt could be exacerbated by climate change. Higher temperatures could increase heat stress, particularly in urban areas such as Cairo and Alexandria. Higher temperatures and changes in precipitation could also affect the distribution of diseases such as malaria. To be sure, if the climate gets hotter and drier, the range of many diseases could be restricted (Confalonieri et al., 2007).

A decrease in crop production, which could result from climate change, could result in an increase in malnutrition. If the use of irrigation increases, there could be more breeding ground for infectious and waterborne diseases. EEAA (2010a) notes that increased irrigation could result in more cases of schistosomiasis.

EEAA (2010a) points out that cardiovascular and respiratory diseases are already a major concern in Egypt. As noted by the World Bank (2002), this may be the result of high air pollution levels. Increased temperatures and drier conditions could increase pollution levels even more. In addition, an increase in particulate matter (PM) may be of concern.

Higher temperatures can also reduce water quality by, for example, reducing dissolved oxygen levels. A decrease in precipitation can result in lower flow in rivers, which can concentrate pollutants. An overall drier climate punctuated by less frequent, but more intense rain events, as projected by Tebaldi et al. (2006), could result in more runoff of pollutants into water bodies. Finally, SLR will increase salinity levels and degrade water supplies in coastal areas.

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1. Cantin et al. (2010) state that only an increase in temperature has affected coral reefs in the Red Sea to date. Nonetheless it seems plausible that an increase in ocean acidity will also contribute to loss of Red Sea coral reefs.

3.6 Transportation

Although not a focus of this study, various aspects of Egypt's transportation system are likely to be affected by climate change. If minimum flow levels in the Nile and various branches of the Nile in the Nile Delta are not maintained, river-based transportation could be limited.

EEAA (2010a) points out that, on the other hand, more intense precipitation events could flood roads and possibly threaten some bridges. The report notes that the risk of flooding will be highest in April and October. SLR is also a concern. Roadways along the coast in the Nile Delta will face risks of inundation or erosion.

Heat is also a risk to paved roadways. EEAA (2010a) notes that asphalt roads in Egypt can become deformed at temperatures above 45°C.

3.7 Conclusion

The literature indicates that Egypt faces many serious risks from climate change. Perhaps of greatest concern is the potential for a significant decrease in flow of the Nile. Also of major concern are SLR and higher temperatures. Reduced water supplies, loss of land, and higher temperatures could adversely impact many sectors of Egypt's economy, human health, and ecosystems. The literature clearly shows that Egypt is vulnerable to climate change. Thus, it is critical for Egypt to increase its understanding of the potential risks from climate change and to reduce its vulnerability to these effects.

4. Methods Description

This chapter describes the methods used to evaluate the following sectors in terms of climate change impacts: water resources, coastal resources, agriculture, air quality and human health, and tourism. We also describe how the scenarios of socioeconomic and climate change developed for this study and the individual study elements are linked to each other. Figure 4.1 displays the study components and how they fit together to generate estimates of how Egypt's economy could be affected by climate change.

The general climate models for this study were selected based on results of Elshamy et al. (2009). We selected climate models that yield the largest changes in flow (increase and decrease) and models that give changes in flow close to the average of all the climate models. Output from these same models was used to develop climate change scenarios for Egypt. SLR scenarios were taken from published work by CoRI (Elshinnawy, 2008). Many of the study elements rely on previous studies and, in particular, on studies conducted by the Egyptian government or reported by Egypt's SNC to the UNFCCC (EEAA, 2010a). The specific studies are described in the discussion of each sector. Chapter 5 describes the selection of socioeconomic and climate change scenarios.

4.1 Socioeconomic and Climate Change Scenarios

We developed two sets of socioeconomic and climate change scenarios for 2030 and 2060 to be used in this study. Since changes in population and economic growth are uncertain, we developed optimistic and pessimistic projections to reflect a range of future conditions. Population scenarios were developed using SNC (EEAA, 2010a) projections out to 2030 and World Bank (2008) population projections out to 2050. We extrapolated the projections to 2060.

We used IPCC's Special Report on Emissions Scenarios (SRES) projections (Nakićenovic et al., 2000) as a basis for socioeconomic and climate change scenarios. The scenarios begin with different assumptions about population and economic growth, changes in technology, and even governance. Table 4.1 lists the main SRES scenarios used in this report.

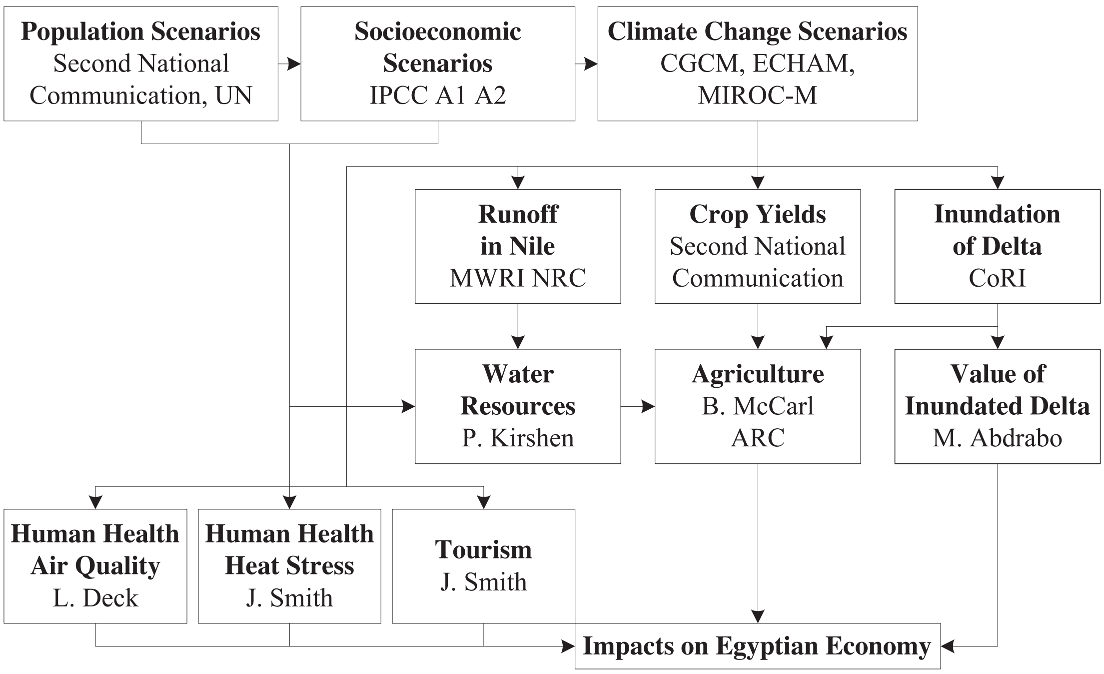

Figure 4.1. Study of climate change impacts on Egyptian economy.

Table 4.1. SRES socioeconomic scenarios

SRES scenario	Key assumptions
A1FI	Very high rates of growth in global income, moderate population growth, and very high fossil fuel
A2	Moderate rates of economic growth, but very high rates of population growth
A1B	Same economic and population assumptions as the A1FI scenario, but assumes more use of low-carbon emitting power sources and clean technologies
B1	Same population growth as A1FI and A1B, but assumes a more service-oriented economy and much greater use of low-carbon emitting power sources and clean technologies

We used the SRES estimates of change in per capita income. The optimistic scenario (A1) assumes that real per capita income increases by about 3.8% per year, a high rate to sustain over 50 years. The pessimistic scenario (A2) assumes that real per capita income increases by 2.2% per year.[1] Combining per capita income changes and population projections yielded projections of total income.

As discussed in the next section, we selected three climate models based on results from Elshamy et al. (2009). The three models cover the projected wettest and driest conditions in the Blue Nile basin and intermediate conditions. We used the tool "SimCLIM" (CLIMSystems, 2011) to develop estimates of changes in temperature and precipitation for Cairo and the HAD.

The SLR analyses used estimates of SLR based on the A1FI and B1 emissions scenarios as well as current SLR trends.

4.1.1 Limitations

The population projections used in this study are quite pessimistic and optimistic. The pessimistic projection assumes no reduction in fertility. However, fertility rates in Egypt have decreased. In the 1950s, a typical woman in Egypt would have six children. By the end of the last decade, a typical Egyptian woman would have fewer than three children (United Nations, 2012). The low population scenario was based on an optimistic assumption that Egypt would substantially reduce its fertility rate and have a stable population by mid-century. As discussed in Chapter 5, the "medium" variant, as developed by the United Nations, is between the high and low estimates of future population used in this study (United Nations, 2012).

The climate change scenarios used in this study are not consistent across all the study components. As discussed below, this study relied on published literature and the Egyptian SNC for estimates of biophysical impacts of climate change. This included estimated changes in runoff of Nile water, crop yields, demand for water, and potential inundation of coastal areas by SLR. We selected climate models based on the Elshamy et al. (2009) estimate of change in runoff in the Blue Nile. We used one of the climate models to develop scenarios of changes in temperature and precipitation in Cairo. Those projections were used to estimate impacts on air quality, heat stress, and tourism. We used crop yield projections from studies reported in the Egypt SNC and were unable to determine what climate change scenarios were used in those studies. The SLR estimates used different greenhouse gas emissions scenarios than the other analyses did. The sea level analysis used the A1FI and B1 emissions scenarios, while the Nile air quality, heat stress, and tourism analyses used the A1B scenario. The change in climate projected

1. Real GDP grew about 13% from 2008 to 2009 (CAPMAS, 2010). Subtracting the population growth of 1.8% (United Nations, 2012) yields a real increase of per capita income of about 11%.

by these emissions scenarios differs little in 2030 but there are some noticeable differences by 2060 (Nakićenovic et al., 2000).

On the whole, some of the projected changes in biophysical conditions may be internally inconsistent. Specific quantitative results should therefore be interpreted with caution. Nonetheless, we feel that the results do demonstrate the sensitivity of different parts of the Egyptian economy and society to climate change.

4.2 Water Resources

For the water resources sector, we used change in population and income as well as change in Nile flow (Elshamy et al., 2009) to estimate change in deliveries of water for municipal (e.g., drinking water), industry, and agriculture uses, and instream flows. Assumptions provided by MWRI were used to estimate how the availability of water would change and, in particular, how supplies for agriculture would change. In addition, MWRI supplied a model of agriculture in Egypt, which includes allocation of water resources. We estimated the increase in evaporation downstream from the HAD.

Elshamy et al. (2009) developed estimates of changes in flow of the Blue Nile at Diem (same station as El Diem) based on several GCMs and the A1B SRES (Nakićenovic et al., 2000). Because the Blue Nile contributes 60% of the Nile's flow at Dongola (near the inlet of the reservoir of the HAD) and derives its precipitation from the same climate systems that affects the White Nile, we used the same relative changes in flow at the HAD as the relative changes in the Blue Nile. The reasonableness of this approach is reinforced by Beyene et al. (2009; Tables 10 and 11). They show that under a range of GCMs and SRES scenarios, the percent changes in mean annual flow at the HAD are, for the most part, only slightly greater than the changes in the Blue Nile discharge.

We estimated change in flow in 2030 and 2060 by linearly interpolating between the Elshamy et al. (2009) estimate of change in runoff from the year 2000 to the 2081–2100 period.

By treaty, Egypt is given an allocation of 55.5 BCM/yr, and there are other water allocations to upstream nations. Consequently, it is assumed that any shortages or surpluses under climate change will be equally shared among Nile Basin states.

M&I use of water is projected to increase with population growth and to be further affected by climate change. Based on a study done in the Edwards aquifer area of Texas (Chen et al., 2001), we assumed that M&I use of water would increase by 2.5% under climate change. The same assumption was used for all scenarios. To be sure, outdoor water use in Egypt is currently less

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than that in the United States. We do not know if this might change with the presumed higher income levels in the socioeconomic scenarios.

4.2.1 Limitations

Elshamy et al. (2009) modeled the Blue Nile and we assumed that there would be equal percentage changes in flow of the White Nile and Atbara rivers. Beyene et al. (2009) found slightly larger magnitude changes in the White Nile than the Blue Nile. So, our analysis may slightly underestimate both the potential decrease and increase in flow of the Nile into Aswan.

The analysis assumes that Egypt will get a share of the Nile in the same proportion as current deliveries. Thus, a percentage increase or decrease in the flow of the Nile is assumed to result in the same percentage increase or decrease in flow of water into the HAD. The analysis does not account for changes in upstream use of Nile water. In addition, the analysis did not account for the effect of higher temperatures on evaporation from the HAD or elsewhere in Egypt.

4.3 Coastal Resources

Estimations of potential loss of coastal resources were used to estimate relative SLR, as described in Chapter 5.

The analysis of coastal resources was done in two parts. One part conducted by CoRI used Elshinnawy (2008) to estimate potential inundation of the Nile Delta from SLR. The second part of the analysis, which was conducted by Dr. Mohamed Abdrabo and Dr. Mohamed Borhan, involved mapping land use and estimating the current value of property in the Nile Delta that could be threatened by SLR.

4.3.1 Agricultural land lost

To estimate the amount of agricultural land inundated under each SLR scenario, we overlaid various inundation scenarios with agricultural datasets within the geographic information system (GIS). CoRI provided several GIS outputs of projected inundation from SLR. These included two IPCC SRES emissions scenarios (A1FI and B1); the years 2025, 2050, 2075, and 2100; and two “protection” scenarios (protected and unprotected). Estimates for 2025 were used to represent results in 2030, and 2075 estimates were used for 2060. To ensure that the unprotected scenarios captured the maximum spatial extent of inundation, the unprotected dataset combined the unprotected and protected datasets provided for each SRES and time period above. Estimates of impacts on agricultural land from CoRI were also used. The resulting final agricultural layer was then overlaid with each inundation layer to estimate the spatial extent of agricultural lands inundated under each emissions scenario, time period, and protection scenario.

The resulting inundated agricultural layers were split into three regions of the Nile Delta (east, central, and west) based on a layer developed by digitizing the regions from satellite imagery. The percentage of inundated agricultural land was calculated based on the total agricultural land layer provided by CoRI with sand, water, and urban areas removed.

After the elevation data were processed, areas of vulnerability to inundation and erosion for each of the land use layers was quantified by 0.25-m increments for elevations from shoreline to 2.0 m, and 0.5-m increments from 2.0 m to 3.0 m. Elevation zones were then split into the three Nile Delta regions. The elevation datasets were then used as inputs for SLR analysis. Two inundation modules, representing "business as usual" (module 1) and "actual situation" (module 2) were run in the analysis. Each module was then run for years 2025, 2050, 2075, and 2100 under the following emission-based SLR scenarios:

- Projected impact of SLR on the coastal zone according to tide gauge measurements carried out by CoRI over the last three decades (the CoRI scenario assumed the same increase rate of air temperature until 2100)
- Projected impact of SLR according to the B1 emissions scenario
- Projected impact of SLR according to the A1FI scenario.

4.3.2 Property value

The property value was estimated by gathering data on population size, number of housing units, manpower and unemployment rates, and current price of housing units and agricultural land in five governorates on the Nile Delta: Damietta, Dakahlyia, Kafr El Sheikh, Behaira, and Alexandria. Note that the estimated effect of climate change on agricultural land value is part of the agriculture modeling.

The analysis was done at the local level. Data were collected from CoRI, the Central Agency for Public Mobilisation and Statistics (CAPMAS), and information centers from different governorates. Field work was then done to collect data on the number of housing units and land values.

While the number of housing units was assumed not to change, the housing value was assumed to increase at the same rate as the increase in per capita income in the socioeconomic scenarios for Egypt.[2]

4.3.3 Limitations

All the layers of land use and inundation were calculated by CoRI (Elshinnawy, 2008). The protection and no-protection scenarios were modeled, but we are unable to determine which scenario is more likely. We only analyzed a northern region of the Nile Delta. Some of the SLR scenarios showed that areas outside this region could become inundated.

The number of housing units was estimated to be unchanged from current levels, which is probably an optimistic assumption. With population growth, particularly under the pessimistic scenario, it is possible that there would be more housing in the Nile Delta. The increase could be the result of building multi-story housing structures. Since this is speculative, we assumed no change in the number of units.

4.4 Agriculture

Agriculture integrates a number of inputs. Population projections were used to estimate change in demand for food and labor. The water resources study (Section 4.2) was used to estimate change in availability of water for irrigation. The study of Nile Delta inundation was used to estimate loss of agricultural land to SLR. The Agriculture Research Centre provided a wide array of data on current agriculture conditions in Egypt. Changes in crop yields, which were taken from the Egypt SNC and adjusted to be consistent with the climate change scenarios through expert judgment, were used to estimate change in agricultural output for a variety of crops that were not individually modeled. The expert judgment and extrapolation introduce additional uncertainty into the results. The agriculture model also calculates change in demand for irrigation as a result of population growth and climate change. All the elements were integrated to estimate change in agricultural production.

The agriculture analysis used a model of the agriculture sector of the Egyptian economy. This is referred to as a partial equilibrium analysis because it allows for economic adjustments within

2 The assumption that the percentage increase in housing value is the same as the percentage increase in per capita income is based on analysis of the increase in per capita income in the United States compared to the increase in mortgage spending from 1985 to 2005. Income before taxes increased 234% while spending on mortgages increased 240% (U.S. Census Bureau, 2011). To be sure, change in mortgages is not only a function of the price of homes, but also of the interest rate.

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the agriculture sector (e.g., allowing consumers to change food consumption as prices change), but holds the rest of the economy constant. This type of modeling has been used by Adams et al. (1990) and Reilly et al. (2003). The original model developed by Bruce McCarl is called the Egypt Agriculture Sector Model (EASM; McCarl et al., 1989). This assessment built upon a number of subsequent efforts, including a redevelopment of the EASM, which was previously called EASM89. The most recent model was developed by the MWRI and is called Agriculture Sector Model of Egypt (ASME). This model was unified with an earlier version developed by Mohamed (2001) and modified to include a more detailed hydrological component. MWRI gave the updated version of the model to Dr. McCarl in 2011 for use in this study.

The EASM model accounts for the following:

- Crop and fodder yields (including technological progress)
- Water use by irrigated crop
- Surface and groundwater supply including climate change effects on precipitation
- Land loss induced by SLR
- Livestock productivity
- M&I water demand.

The population projections were used to estimate changes in food demand and changes in demand for M&I water. The analysis did not consider the effect of the assumed increase in per capita income on demand.

Estimated changes in crop yields were based on EEAA (2010a). Because most crops in Egypt were not reported in EEAA (2010a), we assigned proxy crops to the crops that were not modeled. Table 4.2 displays the crops with data on climate change and the proxy crops.

Two scenarios were defined for technological improvements in crop yields. The base scenario was based on discussions with the Ministry of Agriculture and assumed a relatively slower rate of increase in crop yields. The other (faster change) scenario was based on estimation results drawn from the U.S. National Agricultural Research, Extension, Education, and Economics Advisory Board (2011), which estimated rates of yield for many regions including a 2.1% rate of yield for grains in northern Africa. The slow scenario assumed that yields of all crops increase 1% per year through 2060, but that berseem increases at a rate of 2.1% per year. The faster change scenario assumed the rate of increase in yield for all crops to be 2.1% per year. Note that Handoussa (2010) reports a 1.0% per year increase in yields of maize and rice and only a 0.5% per year increase for wheat from 1990 to 2000. We assumed that a 1% increase in yield stimulated a 0.4% increase in all purchased input use (e.g., fertilizers, seeds, pesticides, but not in water, land, and labor) for all crops except berseem. No change in input use is assumed for that crop. Note that this is assumed to be an average across farms. We expect individual farms to have varying results.

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Table 4.2. Assignment of unmodeled crops to proxy crops

Crop without data	Proxy crop
Berseem long	Maize
Berseem short	
Citrus	
Sesame	
Sorghum	
Sugarcane	
Rice	
Rice short season	
Fava bean	Soybeans
Lentil	
Other legume	
Tomato	
Vegetables	
Flax	Wheat
Barley	
Cotton	
Onion	Potato
Peanut	
Sugar beets	

Additional assumptions for the agriculture model follow:

- *Crop yields*. Changes in crop yields were taken from the Egypt SNC (EEAA, 2010a). The underlying climate scenario was not specified. Crop yields in 2030 were assumed to be 60% of reported yield changes in 2050 for the respective SRES scenario. Crop yields in 2060 were assumed to be a combination of 80% of the reported yield changes in 2050 and 20% of the reported yield changes in 2100 (an interpolation between the two estimates).

- *Water resources*. Changes in Nile flow are specified in terms of releases ranging from a base case of 55.5 BCM up to 62.5 BCM (equivalent to MIROC-M 2030) and 71.0 BCM (MIROC-M 2060), and down to 52.5 (ECHAM 2030), 49 (ECHAM 2060), 45.5 (CGCM63 2030), and 35.5 BCM (CGCM63 2060), based on Elshamy et al. (2009).

- *Inundation of the Nile Delta*. SLR scenarios were developed by CoRI and computed by the Stratus Consulting team in terms of land lost.

- *Livestock yields*. The productivity of cattle in terms of final slaughter weight was altered based on data from the U.S. National Assessment in the southwest region.
- *Imports*. Imports are allowed to increase up to five times current levels.

4.4.1 Limitations

The major limitation on the agriculture study was the use of changes in biophysical conditions based on published literature or studies cited in the Egypt SNC. As noted above, these studies used different greenhouse gas emissions scenarios and probably used different climate models. The SNC did not report what climate models were used (if any) in the crop yield studies it reported.

It is unclear if the agriculture studies incorporated carbon fertilization. CO_2 can increase crop yields, particularly for crops such as wheat, and can decrease water needs. This "carbon fertilization effect" can be substantial, although there is disagreement in the literature on the magnitude of the effect (e.g., Tubiello et al., 2007).

The agriculture analysis did not account for farm-level adaptations such as changing planting dates. It did account for increased irrigation use.

The study did not account for changes in global food prices as a result of climate change, changes in global demand and supply of food resulting from population and economic growth, and changes in technology. In recent years, food prices have increased substantially (FAO, 2011). It is unclear if such increases are temporary or a harbinger of future changes in food prices.

The limits on imports contribute to higher prices and reduced welfare. The assumption of a limit on increase of imports to five times current levels is arbitrary. It is possible that Egypt would allow more agricultural goods to be imported in response to decreased production. To be sure, it is not possible to predict what future government policy would be on this matter. As discussed in Chapter 7, we tested the effect of allowing imports to increase up to ten-fold above current levels in 2030. This reduced the welfare loss by 2 billion Egyptian pounds (EGP) per year if there is no climate change.

The agriculture study did not address impacts on fisheries or examine the effects of changes in air quality, water quality, pests, or diseases on agriculture.

4.5 Air Quality

Climate change can worsen air quality by increasing levels of PM as well as other pollutants. Higher PM levels can increase human mortality and morbidity (Confalonieri et al., 2007). The higher temperatures and drier conditions that are projected for Egypt could result in even higher levels of pollutants such as PM, with increased risk to human health. Cairo currently is the most polluted city and the city with the largest population in Egypt. Consequently, the study focused on Cairo, including outlying areas (Greater Cairo).

A detailed study of how air pollution in Cairo could change would require running complex models of climate and air pollution. Such an effort was beyond the scope of this study. Since a change in air pollution and its implications for human health are potentially quite serious, we conducted a sensitivity analysis. We used what is known about the adverse effects of air pollution on health, current air quality in Greater Cairo, the size and age composition from our scenarios of future population, and public health information to estimate the impact of a small increase in future air pollution levels. For illustrative purposes, this sensitivity analysis focused on changes in only PM. We examined two types of PM: $PM_{2.5}$ and PM_{10}. The numbers refer to the size of particles measured in microns (one-millionth of a meter), which are tiny particles. The smaller the particles, the deeper they can penetrate into lungs and potentially other organs. PM can cause asthma, cardiovascular problems, and premature death.

The purpose of the analysis was to indicate how serious an increase in air pollution in Cairo could be. Given the complex relationship between climate change and air quality and the reliance on expert judgment used in this analysis, the results should be interpreted with caution. At best, they are indicative of the approximate order of magnitude of potential impacts of climate change on Cairo's air quality and consequences for human health. More detailed analyses may be needed to generate more accurate estimates of how air quality in Cairo could change.

Population projections were used to estimate the number of people exposed to air pollution. The literature on air pollution was used to estimate mortality and morbidity impacts and to obtain statistical value of human life estimates (which were then adjusted for projected levels of Egyptian GDP/capita).

The study on human health built upon methods reported by the World Bank (2002). The study combined Egyptian public health statistics, the scenarios of population increase, and the literature on effects of climate change on pollution levels to estimate the health impacts of climate change in Greater Cairo.

Population data for Cairo were obtained from CAPMAS and current pollution levels were obtained from EEAA (2009). Based on CAPMAS, the current population of Greater Cairo (not the city limits of Cairo) is 19.6 million, including the governorates of Cairo, Giza, and Qualyubia, and the former governorates of Helwan and 6th of October. We assumed that Cairo's population will increase at the same rate as the national population. To be sure, with increased urbanization, this may be a conservative assumption.

We used World Bank (2002) data on air pollution levels and consequent mortality and morbidity rates. We developed high and low estimates of pollution effects on health based on Katsouyanni et al. (1997), the Health Effects Institute (2004), and WHO (2005). We also used WHO (2011) age-specific mortality rates for Egypt in 2009.

We used modeling studies of how air quality in the United States might change under climate change to estimate how air quality of Cairo might change. Since the southwestern United States is like Egypt, hot and dry, we focused on projected changes in air quality in one of the largest inland metropolitan areas in the Southwest: Phoenix, Arizona.

Current and future $PM_{2.5}$ levels in the semi-arid southwestern United States are substantially lower compared to current conditions in Cairo. Because the significantly higher precursor emissions in Greater Cairo are causing the current levels of high PM, it is likely that the impact of a similar change in climate (e.g., temperature, humidity, precipitation) in Greater Cairo will have a larger impact on $PM_{2.5}$ levels than was estimated for the southwestern United States.

Tagaris et al. (2009, 2010) estimated increases in $PM_{2.5}$ concentrations by 2080 in the southwestern United States will range from 0.3 $\mu g/m^3$ to 0.7 $\mu g/m^3$. These estimated changes were due to climate change alone because other factors were held constant. Since Cairo will still probably have higher PM concentrations then Phoenix, we assumed that by 2030 the Greater Cairo area may have a $PM_{2.5}$ increase of 0.5 $\mu g/m^3$ and an increase of 1.0 $\mu g/m^3$ by 2060. We believe that these PM increases due to climate change are more likely to be underestimates rather than overestimates of climate effects. Note that changes in ozone levels, which are also projected to increase with higher temperatures (Confalonieri et al., 2007), are not included in this analysis.

We used two methods to estimate the value of health. One estimates the effect of mortality on GDP, and basically assumes that about 10 years' worth of per capita income would be lost for each death. Hospital admissions were valued at 2.6% of GDP/capita (equivalent to a 10-day hospital stay per year). The health effects measured in days of having symptoms were valued at 0.3% of GDP/capita (equivalent to 1-day hospital stay per year).

The second (and higher) estimate was derived from an economic concept known as the value of a statistical life (VSL). This value reflects not only the loss of productivity but also the pain and suffering to the individual and his or her family. This is a widely established practice for estimating what society should be willing to pay to protect human life (e.g., Viscusi and Aldy, 2003). The VSL-based value used by the World Bank (2002) was based on available VSL estimates from studies in Europe and the United States. The current VSL used by the U.S. Environmental Protection Agency (EEAA, 2010a) is $7.9 million (in 2008 dollars and income levels). Since we are unaware of a published estimate of VSL for Egypt, we used the relative difference in current per capita income between the United States and Egypt to derive a VSL estimate for Egypt. Adjusting VSL for different countries based on differences in per capita income is a standard practice. Adjusting the U.S. VSL by the ratio of Egyptian 2009 GDP/capita [$2,250 U.S. dollars (USD)] to U.S. 2009 GDP/capita ($45,745; from World Bank, 2011a), the estimated Egyptian 2009 VSL is $388,650. Future-year VSL estimates were calculated assuming that the Egyptian VSL grows at the same rate as we assumed the Egyptian GDP/capita would increase.

4.5.1 Limitations

As noted above, the analysis of change in air quality relied on expert judgment, not a model of changes in air quality for Cairo. Indeed the analysis is based on estimates of change in air quality for the southwestern United States using different climate change scenarios. Both the southwestern United States and Egypt are generally projected to become warmer and drier (Christensen et al., 2007), but specific changes could vary considerably between the regions. Therefore, the effects on air quality could also differ quite considerably.

A further key limitation is that we did not assume any behavioral or technological changes in Egypt that could substantially improve air quality. Should Egypt develop as projected in the socioeconomic scenarios, it is quite plausible that substantial measures would be taken to improve Cairo's air quality through technological controls on vehicle emissions and greater use of mass transit. This would likely be most evident in the optimistic scenario. The substantial increases in per capita wealth would in all likelihood enable Egypt to afford to install pollution control measures to reduce pollution levels.

4.6 Heat Stress

The estimation of the effect of climate change on heat stress mortality focuses on heat stress in Cairo. The analysis relied on estimates made by Kalkstein and Tan (1995), who analyzed summertime daily mortality and weather data in Cairo from 1981 to 1985. Kalkstein and Tan (1995) found that mortality in Cairo increases as maximum daily temperatures rise. They used the relationship of heat stress and maximum temperature to estimate how the frequency of heat stress cases could change with higher temperatures.

Interestingly, Kalkstein and Tan (1995) did not find a "threshold" in the Cairo data. In most cities analyzed by Kalkstein (see, e.g., Kalkstein and Greene, 1997), there is a level of maximum daily temperatures below which daily mortality does not appear to be affected by maximum temperatures. This suggests that in those cities, populations are adapted to maximum temperatures up to a threshold. Temperatures above the threshold result in increased mortality from heat stress.

Kalkstein and Tan (1995) reported that in their observed dataset, the heat stress mortality rate was 4.45/100,000. They estimated that a 2°C increase in maximum temperatures would increase the mortality rate to 10.23/100,000. This implies that the mortality rate increases by 2.89/100,000/°C increase in peak temperature. As discussed in Chapter 5, as Cairo temperatures are projected to rise by less than 2°C by 2060 in two of the three scenarios, we use the estimated increase in mortality rate between current temperatures and 2°C to estimate the change in heat stress mortality. Kalkstein and Tan (1995) estimate that heat stress mortality in Cairo at 4°C would be 19.32/100,000. The mortality rate between 2°C and 4°C is therefore 4.55/100,000/°C increase in peak temperature, which is a rate 50% higher than the increase up to 2°C. This suggests that heat stress mortality would rise more rapidly with higher temperatures. We estimate the increase in heat stress for the scenario with a greater than 2°C increase in temperature by applying the 4.55/100,000 rate to the share of warming in that scenario above 2°C.

The results from Kalkstein and Tan (1995) appear to be similar to a more recent study on heat stress and climate change (Takahashi et al., 2007). Takahashi et al. (2007) apparently did not study Cairo alone, and report that heat stress mortality in Egypt is projected to increase about 300% by 2100, assuming an increase in average global temperatures of 3°C. Using MAGICC/SCENGEN (Wigley et al., 2009), a 3°C increase in mean global temperature would result in almost a 4°C increase in Cairo. Kalkstein and Tan (1995) estimate that the mortality rate in Cairo would increase by approximately 300% at 4°C above their baseline climate. So, the estimates of increase in heat stress across the two studies appear to be consistent.

This analysis assumed that maximum temperatures increase at the same rate as average temperatures. We multiplied the estimated increase in summer temperatures, as reported in Chapter 5: Scenarios, by the rate of increase in mortality between current temperatures and 2°C. This result was then multiplied by the same estimated population of Greater Cairo in 2030 and 2060 to estimate increases in mortality from heat stress that was assumed for the air quality analysis. The same statistical monetary value of life estimates that were used in the air quality analysis were applied to the estimated changes in heat stress mortality.

4.6.1 Limitations

There are several important limitations to the analysis of heat stress. These limitations suggest that the estimated increase in heat stress mortality in Cairo may he high. Indeed the future increase in mortality could be substantially lower for several reasons.

Kalkstein and Tan (1995) based their results on data from the early 1980s. As discussed in Chapter 5, we estimate that per capita income in Egypt will increase substantially through 2060, which will more than double the pessimistic scenario and increase six-fold the optimistic scenario. With increasing per capita income, it seems quite likely that in a hot climate such as in Egypt there will be a commensurate increase in air-conditioning use. With more air conditioning, the population of Cairo will be less vulnerable to higher temperatures. Also, governments have developed heat warning programs and established cooling centers (U.S. EPA, 2006), which have reduced risks from excessive heat events. However, we are unable to estimate how much the increase in income or adaptation measures such as heat-watch warning systems or cooling centers would reduce vulnerability in Cairo.

Thus, the results reported in Chapter 7: Results should be interpreted as a high estimate of increased heat stress mortality for Cairo.

4.7 Tourism

The estimates of changes in tourism levels were based on extrapolation of recent trends because the study focused on foreign tourism. We assumed that revenues from foreign tourists are affected by the income of tourists, not the income of Egyptians. Tourism revenues from the Egyptian Office of Tourism were extrapolated to 2030 and 2060 to estimate future tourism levels. Results from Bigano et al. (2007) were used to estimate the effect of climate change on tourism demand. We estimated potential changes in tourist visits as a result of increased temperatures and loss of coral reefs.

4.7.1 Tourist expenditures

Bigano et al. (2007) estimated changes in tourist visits and expenditures by country as a result of changes in average temperatures. Their results were supplied by Dr. Richard Tol (Richard Tol, Economic and Social Research Institute, Dublin, Ireland, personal communication, December 3, 2010). We also used the literature on potential impacts of climate change on coral reefs in the Red Sea (Cantin et al., 2010) and valuation of the coral for recreation purposes (Cesar, 2003) to estimate potential additional tourism losses.

Note that estimating the potential impacts of climate change on future tourism is fraught with uncertainty for several important reasons. First, it is difficult to project future tourism levels. Although Egypt will most likely always be a tourist destination because of its history and resorts, it is difficult to estimate tourism levels with confidence. Second, it is also difficult to project how climate change will affect tourism. Whether tourism to Egypt decreases depends not just on what happens in Egypt but also on whether alternative destinations are attractive to tourists. The choice of a destination is not a biophysical or deterministic process. Thus, it is impossible to project how preferences may change in the future. Consequently, this analysis should be interpreted as preliminary and indicative of possible changes in tourism levels.

We estimated future baseline tourism levels (i.e., levels that could be reached without climate change) by extrapolating from recent trends. Tourism grew from 2004 to 2008 but dropped in 2009. Preliminary data for 2010 suggested some recovery. We do not have data for 2011, but understand that levels may have dropped considerably. This is probably a temporary deviation.

We developed an optimistic projection of future tourism levels based on extrapolation of the 2004–2008 trend and a pessimistic projection based on extrapolation from the 2004–2010 trend. The extrapolations are shown in Table 4.3.

Table 4.3. Recorded and estimated tourism revenues

Year	Expenditures (millions EGP)	
2004	34,804	
2005	39,633	
2006	44,732	
2007	56,799	
2008	66,572	
2009	59,400	
2010 (estimated)	69,850	
Extrapolations	**Optimistic**	**Pessimistic**
2030	242,413	189,430
2060	484,517	367,844

As a percentage of projected national income, these values are close to 6% of GDP, particularly in 2060. Because the projections for 2030 are around 8% of GDP, they could be somewhat high.

Accounting for recreation share

Not all visits to Egypt are for purposes that would be affected by a change in climate. Some people come for business, to visit families, to see antiquities, and other purposes. Table 4.4 includes the number of visits to Egypt by purpose from 2000 to 2009.

We assume that 84.5% of future visits to Egypt are for leisure and recreation and would change as estimated by Bigano et al. (2007).

Table 4.4. Purpose of tourist arrivals in Egypt in 2010

Purpose of visit	%
Leisure and recreation	84.5
Culture tourism	0.6
Religious tourism	0.8
Visiting friends	4.8
Business	4.1
Health treatment	2
Others	3.2
Total	**100**

Source: Dr. Adla Ragab, Economic Advisor to the Minister, Ministry of Tourism, personal communication, January 12, 2012.

4.7.2 Coral reefs

Cantin et al. (2010) found that warming and increased acidification of seawater will slow coral reef growth in the Red Sea. They estimated that ocean acidification will increase the frequency of coral bleaching by 80% when atmospheric CO_2 concentrations reach 550 ppm – around 2060 under the A1B scenario. They also projected that coral reef growth will decline by 5% for each 0.2°C increase in water temperature above 30.5°C, and that growth has already decreased by 30%. This suggests that coral reef loss would be at least 50% assuming an approximate 2°C warming above 1990 levels by around 2060. Based on this, we assumed a 20 to 35% loss in 2030 (assuming a linear increase in coral reef loss since 1990) and a 50 to 80% decrease in coral reef by 2060.

Cesar (2003) reported that recreational expenditures on Red Sea coral were $472 million (2.6 billion EGP) in 2000. We assumed the same level of expenditures in 2004 and allowed for increases at the same rate as projected increases in tourism revenues. We then subtracted estimated losses in total revenues from higher temperatures based on Bigano et al. (2007).[3]

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3. Cesar (2003) also reported that the value of fisheries from coral reef was $40 million (220 million EGP) in 2000. This value would probably not increase over time. However, an 80% reduction in coral reefs could result in reduction in the fishery value of $32 million (165 million EGP). Because this amount is only about 1% of the estimated losses in tourist revenues, it was not included in the analysis.

We assumed that recreation expenditures decrease proportionately with loss of coral reef. It is possible that this assumption is too pessimistic because tourists could recreate among the remaining coral. This might be true for small reductions in reef productivity. It is reasonable to assume a proportional reduction in tourist expenditures as losses become significant. Indeed, as corals continue to diminish, it is possible that expenditures on recreation could completely cease.

4.7.3 Limitations

The tourism analysis used many simplified assumptions about future tourism levels and how tourists would respond to climate change. It is very difficult to know how demand for tourism will change as a result of domestic conditions in Egypt or changes in global population, income, and tourism preferences. News reports and personal discussions show that tourism decreased substantially following the uprisings in 2011. It is difficult to project whether and when tourism will return to its pre-uprising levels and growth trends.

The Bigano et al. (2007) analysis applied simple assumptions about how tourists will respond to changing temperatures. It is possible that higher temperatures will make more northern locations more attractive, but such an outcome is difficult to project with much confidence.

The tourism results should be interpreted with a substantial level of caution.

4.8 General Limitations

This study is a collaboration among the United Nations Development Programme, the Government of Egypt, researchers in Egypt, and researchers in the United States. The intent of this study was to build as much as practical on previous research. This avoided devoting limited resources to re-estimating changes in Nile flow, crop yields, and inundation from SLR. There are many published studies that have estimated these changes. By building on existing research, this project was able to go further in exploring the socioeconomic consequences of climate change such as impacts on the agriculture economy, water users, property, human health, and tourism.

The limitation that comes from building on existing research is that the studies that we drew from used a number of different assumptions. Some assumed different greenhouse gas emissions scenarios and different climate models from other studies. Many of the studies did not account for changes in socioeconomic conditions such as changes in population, income, and technologies. Therefore the results are not fully internally consistent.

Nonetheless, we think this study adds value to the understanding of the risks Egypt faces from climate change. The results indicate the sensitivity of different sectors to climate change and some of the relative risks that different sectors of the economy and society may face.

In any case, it is simply not possible to *forecast* how Egypt will be affected by climate change. Although it is certain the climate is changing and it is very likely that humans are the primary cause of the change (Solomon et al., 2007), there are still substantial uncertainties about exactly how climate will change. We do not know how much future emissions of greenhouse gases will increase. In addition, there are uncertainties about exactly how much the atmosphere will warm in response to increased greenhouse gases. This means that at best we can forecast the direction of change (e.g., sea levels and temperatures will rise and this can threaten coastal areas, reduce crop yields, and increase risks to human health) but we cannot forecast the exact amount of change.

Beyond these uncertainties about the climate, there are also substantial uncertainties about future socioeconomic conditions in Egypt. The work on this report began shortly before the January 2011 revolution started and uncertainty remains about Egypt's future political path. Beyond that, there are substantial uncertainties about future population growth, economic development, societal changes, and changes in lifestyle and technology. These changes will have a major effect on how Egypt is affected by climate change. We are no more able to forecast these socioeconomic changes than we are able to forecast exactly how Egypt's climate will change.

Given these uncertainties, it is better to understand how systems will be affected by climate change rather than try to forecast a specific amount of change. Understanding whether the water resources system, agriculture, or coastal systems can absorb and adapt in the face of climate change and socioeconomic changes or whether they could be substantially harmed is very important information to provide to decision-makers and the public in Egypt.

5. Scenarios of Socioeconomic and Climate Change

This chapter presents the scenarios of future socioeconomic and climate change conditions in Egypt used in the study. Egypt's population and income have been increasing for many years, and both are likely to continue growing. What is uncertain is the future rate of population growth. In addition, the world's climate has been changing and this change is affecting Egypt. We expect climate change to continue and most likely accelerate (Solomon et al., 2007). A key uncertainty is the extent to which climate continues to change, not whether the climate will continue to change.

It is simply not possible to forecast future socioeconomic conditions because we do not know how population, income, greenhouse gas emissions, climate, and many other important factors will change. In assessments such as this it is critical to communicate that there many uncertainties about future conditions. This is often done through the use of scenarios. A scenario is a plausible combination of circumstances that reflect our current understanding of possible future conditions. A set of scenarios should capture a reasonably wide range of future conditions, which is done for two reasons. One is to show how conditions can change and to communicate what is known and not known about future conditions. When all scenarios show a variable such as population or temperature increasing, it is likely that the variable will increase in the future. When all scenarios show different positive or negative changes, that is, some scenarios show an increase in a variable and others show a decrease, there is uncertainty about whether the variable will increase or decrease.

Differences in the magnitude of change can demonstrate uncertainty about how a variable will change. For example, uncertainties about how much population will increase in the future can be shown by scenarios with different levels of increase in population.

The second reason for using scenarios is to gain an understanding of how systems will be affected by future changes in conditions. For example, we could use different estimates of population increase to examine what might happen to agriculture production or water consumption.

This chapter presents the timeframe of the analysis, the socioeconomic scenarios, and the climate change and SLR scenarios. None of these scenarios should be interpreted as predictions. All are intended to be plausible possibilities of future conditions. We do not assign any probabilities to these scenarios and therefore do not combine the scenarios into one outcome.

5.1 Timeframe

Two years in the future were selected for analysis: 2030 and 2060. The year 2030 generally fits within planning horizons and is less than 20 years from now. One important caveat is that climate change scenarios for 20 years into the future should be treated with caution. We expect that climate variability may have a stronger signal than average change in climate. Thus, the weather that will exist in 2030 may not be significantly different from current weather.

The year 2060 was selected to incorporate significant climate change. It is expected that by 2060 Egypt's climate will be substantially different from today's climate and the average change (signal) from increased greenhouse gases will exceed natural climate variability. Although 2060 is almost 50 years from now, it is close enough that the projections for impacts could be considered in long-term planning.

To be sure, climate change is on a long-term trajectory. The IPCC projects a continued increase in temperature through at least 2100 (Solomon et al., 2007), and sea level is projected to continue rising for centuries. In addition, Solomon et al. (2009) argue that CO_2 emissions "are largely irreversible for 1,000 years."

5.2 Socioeconomic Scenarios

The socioeconomic scenarios used in this study consist of population and income growth projections. There is substantial uncertainty about how these variables might change over the next 50 years. To capture a range of potential changes, we developed "optimistic" and "pessimistic" scenarios. An optimistic scenario would be one with relatively low-population growth and a relatively high increase in per capita income. The pessimistic scenario would have high-population growth and a low increase in per capita income. None of the scenarios assume a decrease in either population or income because we could find no support for such assumptions.

5.2.1 Population scenarios

Population projections out to 2030 were made based on the Egyptian SNC (EEAA, 2010a). The report noted that population in 2010 was 82 million and had been increasing by 2.3% per year. This population estimate may be conservative because the World Bank (2011a) states that the population of Egypt in 2010 was more than 84 million. Note that EEAA (2010a) states that several million Egyptians are currently living abroad.

The SNC posited two scenarios for population growth in Egypt. If fertility rates in Egypt stay unchanged, Egypt's population would reach 119 million by 2030. The second scenario was based on the assumption that a concerted effort would be made to reduce fertility rates. Under that scenario, Egypt's population would grow to only 104 million.

The population projections for Egypt out to 2050 are from the United Nations (2008). The United Nations projections for high- and low-population variants were close to the SNC's no change in fertility and population control scenarios. The pessimistic population number, 117 million in 2030, was taken from the United Nations high variant to maintain consistency with projections beyond 2030.

These trends were extrapolated in order to develop population estimates for 2060. The rate of population growth is estimated to slow through 2050. The scenario for 2060 assumes the slowdown continues. By 2060 under the optimistic assumption, population levels will have just about reached stability. Under the pessimistic scenario, population levels will still be growing considerably in the 2050s, almost 9% for the decade, but at a slower rate than in previous decades.

The population projections are displayed in Table 5.1.

Table 5.1. Optimistic and pessimistic population assumptions

	2009	2020	2030	2040	2050	2060
Optimistic	80	92	104	110	112	113
Pessimistic	80	98	117	134	149	162

Note that the pessimistic scenario is lower than the United Nations' projection of Egyptian population assuming constant fertility: 169 million. The optimistic scenario is higher than the United Nations "Low Variant" scenario for 2060: 104 million. The United Nations' "Medium Variant" projection for Egypt's population in 2060 is 128 million.

The analyses of increased air pollution and heat stress were conducted only for Cairo. We estimated that Cairo's population would increase at the same rate as national population.

The estimated population of Cairo in 2030 and 2060 is displayed in Table 5.2.

Table 5.2. Estimated population of Cairo

Cairo population (millions)	2030	2060
Optimistic	25.5	28.8
Pessimistic	27.8	39.9

5.2.2 Income scenarios

We developed optimistic and pessimistic projections of per capita and total income in Egypt out to 2060. Projecting future income levels is an exercise fraught with great uncertainty, with much greater uncertainty than projecting future population levels. The IPCC's SRES give a wide range of potential future socioeconomic conditions (Nakićenovic et al., 2000). We used two socioeconomic scenarios that have the widest range of projections for future income. The A1 scenario assumes high economic growth, with particularly high rates of economic growth in developing countries.[1] It also assumes that global population levels peak about mid-century and then decline. The A2 scenario assumes a much lower rate of economic growth,[2] with a much smaller increase in per capita income. It assumes very high global population levels with no stabilization in the 21st century. Thus, the A1 scenario is consistent with our optimistic scenario and A2 is consistent with the pessimistic scenario. We used published IPCC projections for the Africa Latin America region for the A1 and A2 scenarios (IPCC, 2001).

IPCC projects per capita income for 1990, 2050, and 2100. We calculated the annual increase in per capita income between these years and then applied those growth rates to current per capita income in Egypt. Egyptian GDP in 2009 was taken from CAPMAS and then divided by 80 million (Egypt's population). We then calculated income per capita in 2030 and 2060 for the optimistic and pessimistic scenarios. The IPCC estimates for 1990 to 2050 rates of income growth were used to calculate income for 2030 and 2050. Beyond 2050, we used the IPCC estimates for 2050 to 2100 rates of income growth. Total GDP was calculated by multiplying optimistic and pessimistic income per capita estimates by the population estimates for 2030 and 2060.

The projections of GDP and GDP per capita are displayed in Table 5.3. The calculations assume an exchange rate of 5.5 EGP per 1 USD (Yahoo Finance, 2011). *This exchange rate, 5.5 EGP/USD, is assumed throughout the report*.

5.3 Climate Change Scenarios

We relied on Elshamy et al. (2009) for projections of change in flow in the Nile. They applied a technique call bias-corrected statistical downscaling (Maurer et al., 2007) to 17 GCMs that were reviewed by the IPCC (Randall et al., 2007).

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1. In Africa, Latin America, and the Middle East, the A1 scenario assumes real per capita income increases at an annual rate of 4.1% through 2050 and 2.5% thereafter.

2 In Africa, Latin America, and the Middle East, the A2 scenario has an annual increase in real per capita income of 2.2% through 2050 and 1.9% thereafter.

Table 5.3. Projections of GDP and GDP per capita

	2009	2030	2050	2060
GDP in EGP (millions)				
Optimistic	$990,212	$2,993,208	$7,200,060	$9,298,978
Pessimistic	$990,212	$2,287,141	$4,501,023	$5,907,201
GDP in USD (millions)				
Optimistic	$178,417	$539,317	$1,297,308	$1,675,491
Pessimistic	$178,417	$412,097	$ 810,995	$1,064,361
GDP/capita in EGP				
Optimistic	$12,378	$28,781	$64,286	$82,292
Pessimistic	$12,378	$19,548	$30,208	$36,464
GDP/capita in USD				
Optimistic	$2,250	$5,233	$11,688	$14,962
Pessimistic	$2,250	$3,554	$5,492	$6,630

Elshamy (Mohamed Elshamy, Nile Forecast Center, Cairo, personal communications, March 17 and April 20, 2011) shared the quantitative estimates of change in Blue Nile flow from his 2009 article. We chose three GCMs to capture a range of results: large decreased flow, small decreased flow, and increased flow. The models selected for high and low flow simulated the highest and lowest flows of all GCMs. The median model is closest to the estimated change in flow of the average of all 17 GCMs.

The models selected are:

- Large decreased flow: Canadian Centre for Climate Modeling and Analysis (Canada; CGCM63)
- Small decreased flow: Max Planck Institute for Meteorology (Germany; ECHAM)
- Increased flow: National Institute for Environmental Studies Medium Resolution (Japan; MIROC-M).

We used the tool MAGICC/SCENGEN (Wigley et al., 2009) to examine how well the three models simulate current precipitation patterns in the Nile Basin (1.3°S to 31.3°N; 28.8°E to 33.8°E). The pattern correlations are expressed on a scale from 0 to 1, with 1 being a perfect match. Scores above 0.7 to 0.8 are generally considered to be strong. The pattern correlations for the three GCMs are displayed in Table 5.4.

Table 5.4. Pattern correlations on observed precipitation for three GCMs

GCM	Pattern correlation
CGCM63	0.923
ECHAM	0.863
MIROC-M	0.912

All three models were well above the 0.7 to 0.8 score considered to be an indication of good performance.

Elshamy (Mohamed Elshamy, Nile Forecast Center, Cairo, personal communication, March 17, 2011) reported the changes in potential evapotranspiration (PET; which is correlated with temperature) and precipitation for 17 GCMs. We used his PET and precipitation changes for the three GCMs we selected. These were taken from the change between each model's estimate of the base period (1910–1990) and each model's simulation of the end of the 21st century (2081–2098). See Table 5.5.

Table 5.5. GCM estimated changes in PET and precipitation for the Blue Nile

GCM	PET % change	Precipitation % change
Large decreased flow (CGCM63)	14	-15
Small decreased flow (ECHAM)	14	2
Increased flow (MIROC-M)	6	14

CGCM63 is clearly the driest model because it estimates the same increase in PET as ECHAM, but simulates a decrease in precipitation. MIROC-M is the wettest because it projects the smallest increase in PET and the largest increase in precipitation of the three models. ECHAM estimates a slight increase in precipitation. The higher temperature in ECHAM would probably evaporate more water (and cause vegetation to consume more water) than the increase in precipitation and likely cause a decrease in runoff.

We used the tool SimCLIM (CLIMSystems, 2011) to derive projected change in temperature and precipitation for Cairo for the three GCMs (see Table 5.6). The model projects warmer and drier conditions for Cairo.

Table 5.6. Estimated change in temperature and precipitation for Cairo

	2030			2060		
	CGCM63	ECHAM	MIROC-M	CGCM63	ECHAM	MIROC-M
Annual temperature °C	0.9	0.9	1.0	2.0	1.9	2.2
Temperature November–April	0.9	0.8	0.9	1.9	1.8	2.0
Temperature May–October	0.9	0.9	1.1	2.1	2.0	2.4
Annual precipitation % change	-4	0	-5	-10	0	-10
November–April precipitation % change	-5	-12	-11	-10	-26	-25
May–October precipitation % change	-4	18	6	-9	41	13

All three models project almost exactly the same amount of increase in temperature for Cairo: about 1°C in 2030 and about 2°C in 2060. To be sure, MIROC-M projects slightly more warming than the other two models. Two of the models project a decrease in annual precipitation and one (the one that projects a small reduction in flow of the Nile) estimates no change in precipitation over Cairo. All the models project a decrease in cooler season precipitation (November to April), while the models disagree on whether precipitation from May to October will increase or decrease.[3] It is interesting that the MIROC-N model, which has the lowest temperature increase and increase in precipitation over the Blue Nile, is the hottest and driest scenario for Cairo. This shows how projections of change by individual models can vary in different regions.

5.4 SLR Scenarios

We used SLR scenarios from the CoRI (Elshinnawy, 2008). As noted in Chapter 2, relative SLR in the Nile Delta is affected by global (eustatic) SLR and subsidence.

Elshinnawy (2008) used current SLR trends and estimates of accelerated eustatic SLR from the IPCC (Solomon et al., 2007). Bindoff et al. (2007) report that from 1961 to 2003 average global sea level rose at a rate of 1.8 +/- 0.5 mm/year.[4] The rate of approximately 2 mm/year will be

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3. These results are consistent with other climate models. Moretti et al. (2008) report that the climate models used by the IPCC in the Fourth Assessment, on average, project an 8% decrease in precipitation in the Mediterranean region by the 2040s and tend to project a larger decrease in November–April precipitation than during May–October.

4. Bindoff et al. (2007) also report that from 1993 to 2003 the rate was approximately 3 mm/year, but they could not determine if this was an acceleration in the rate of SLR or the result of decadal variability.

referred to as the "Low SLR scenario." Elshinnawy (2008) also used different SRES emissions scenarios (A1FI and B1) to capture a range of changes in sea level. The IPCC's estimate for the A1FI scenario is 0.26 to 0.59 m by 2100 relative to 1980–1999. The estimate for the B1 scenario is 0.18–0.38 m over the same period. We refer to the A1FI scenario as the "High SLR scenario" and the B1 scenario as a "Middle SLR scenario."

Recent literature has found that SLR in the 21st century could be significantly higher than the IPCC estimate because of accelerated melting of the major ice sheets in Greenland and Antarctica (e.g., Oppenheimer et al., 2007). Vermeer and Rahmstorf (2009) found that SLR could be as high as 1.9 m by 2100. Pfeffer et al. (2008) concluded that SLR will be no higher than 2 m by 2100, and their best estimate is that it will increase by 0.8 m by 2100.

Elshinnawy estimates, listed in Table 5.7, show both subsidence and SLR rates at three locations that span the Nile Delta.[5] Relative SLR is much higher in the eastern Delta, that is, where Port Said is located, than in the middle or western Delta.

Table 5.7. Observed SLR and subsidence rates in selected Nile Delta locations

Region	Alexandria	Al-Burullus	Port Said
Subsidence (mm/yr)	0.4	1.1	4.10
SLR (mm/yr)	1.2	1.2	1.2
Tidal trend (mm/yr; 1 + 2)	1.6	2.3	5.3

Sources: Elshinnawy, 2008; Mohamed Elshinnawy, Nile Forecast Center, Cairo, personal communication, August 24, 2011.

Table 5.7 also includes Elshinnawy's (2008) projected rates for SLR for the Low, Middle, and High SLR scenarios using the IPCC (Solomon et al., 2007) projections.

The projected relative rates of SLR for the Nile Delta vary considerably, differing by a factor of 5 (from the B1 projection in Alexandria in 2100 to the A1FI projection for Port Said).

Because this study is providing estimates of impacts in the years 2030 and 2060, we needed to select the years listed in Table 5.8 that best represent impacts in the years we are using. As discussed in Chapter 3, CoRI provided maps for these scenarios, making it unfeasible to interpolate results. We considered that SLR may be higher than projected by the IPCC.

5. The observed SLR and subsidence rates for Port Said were adjusted based on personal communication with Dr. Elshinnawy (CoRI, Cairo, August 23, 2011).

Table 5.8. Projected low (current rates), middle (B1 scenario), and high (A1FI scenario) average annual SLR (cm) relative to year 2000 sea level

City	Scenario	2025	2050	2075	2100
Port Said	Low SLR	13.25	26.5	39.75	53.0
	Middle SLR	18.12	39.5	64.3	72.5
	High SLR	27.9	68.8	109.6	144.0
Al-Burullus	Low SLR	5.75	11.5	16.25	23.0
	Middle SLR	8.75	19.5	32.25	35.0
	High SLR	14.75	37.5	60.3	79.0
Alexandria	Low SLR	4.0	8.0	12.0	16.0
	Middle SLR	7.0	16.0	27.0	28.0
	High SLR	13.0	34.0	55.0	72.0

Source: Elshinnawy, 2008.

In our judgment, for 2030, the 2025 projections were the most reasonable. Indeed, a difference of five years in climate change projections is trivial. Selection of a year to represent 2060 presented a greater challenge. The year 2050 is closer to 2060 than to 2075, but again, the difference in years is small. If subsidence through 2075 is subtracted from the results in Table 5.7, the rate of SLR is 0.5 m in Alexandria and Al-Burullus (and 0.7 m in Port Said). A SLR of 0.5 m by 2060 is consistent with slightly more than 1 m by 2100. Although this is above IPCC's projections, we think it is well below the upper end of more recent projections. So, we selected the year 2075 coastal results, as estimated by CoRI, to represent the year 2060 in our analysis.

Table 5.9 displays the SLR assumptions used in this study for 2030 and 2060.

Table 5.9. SLR scenarios used in this study (cm) relative to 2000

City	Scenario	2030	2060
Port Said	Low SLR	13.25	39.75
	Middle SLR	18.12	64.3
	High SLR	27.9	109.6
Al-Burullus	Low SLR	5.75	16.25
	Middle SLR	8.75	32.25
	High SLR	14.75	60.3
Alexandria	Low SLR	4.0	12.0
	Middle SLR	7.0	27.0
	High SLR	13.0	55.0

6. Results

This chapter reviews estimated climate change impacts on water resources, coastal resources, agriculture, air quality, heat stress, and tourism.

6.1 Water Resources

Table 6.1 displays the projected change in mean annual flow into the HAD. The estimated changes in flow are large in both the wetter and drier directions. The results are of a similar magnitude as those estimated by Strzepek et al. (1995, 2001) but are of a larger magnitude than those of Beyene et al. (2009). As noted in Chapter 5, we label the three scenarios based on their relative change in flow.

Baseline (assuming no climate change) M&I use is projected to increase 30% (optimistic population) to 46% (pessimistic population) by 2030, and to increase 41% (optimistic) to 102% (pessimistic) by 2060.

6.2 Coastal Resources

Figure 6.1 displays land areas in the Nile Delta at risk from SLR. The estimated loss of low-lying agricultural lands in the northern Nile Delta for the middle and high SLR scenarios is displayed in Table 6.2. The loss of agriculture land under the low (CoRI) scenario was not calculated.

In many cases, the percentage of land lost is low. Indeed, as a percentage of all agricultural land in the Nile Delta, land loss is often 1% or less. In some cases, there are more significant risks, as is the case in the northeast Delta for the higher SLR and unprotected scenarios. The SLR scenarios in the eastern Delta revealed a greater relative SLR than in the central and western areas. It is also notable that the A1FI scenario in 2060 had significantly higher risks in the central and western regions than elsewhere. The relative SLR for the central and western regions is estimated to be about 0.5 m by 2060. In the eastern region, the relative SLR is estimated to be just over 1 m by 2060.

Many housing units would be at risk of inundation from SLR. Table 6.3 lists the current estimated number of housing units at risk from SLR and the estimated increase under the pessimistic scenario. The latter assumes that the number of housing units at risk from SLR increases with population growth.

Table 6.1. Projected change in mean annual flow into the HAD

GCM	Egypt allocation (BCM) 2000	2030 (BCM)	2060 (BCM)
Increased flow (MIROC-medium)	55.5	63.1	70.6
Small decreased flow (ECHAM)	55.5	52.3	49.1
Large decreased flow (CGCM63)	55.5	45.5	35.6

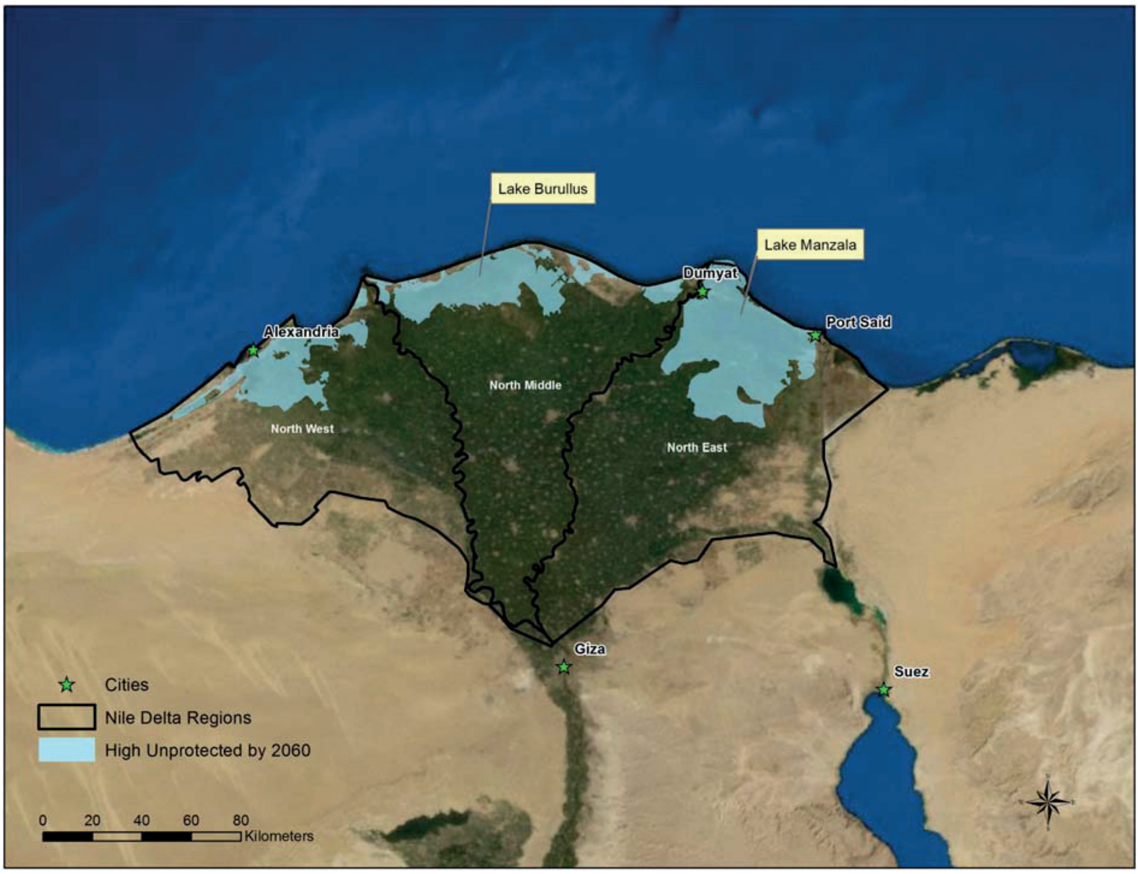

Figure 6.1. Potential inundation of Nile Delta from high SLR in 2060.

Table 6.2. Percentage loss of agricultural lands in the northern Nile Delta

	Northeast Delta		North Middle Delta		West Delta		Total Delta	
Scenario sea level	**km^2**	**%**	**km^2**	**%**	**km^2**	**%**	**km^2**	**%**
High SLR 2030 protected	11.4	0.7	13.4	0.2	0.0	0.0	24.8	0.2
High SLR 2060 protected	25.8	1.8	137.2	2.7	15.0	0.3	178	1.6
High SLR 2030 unprotected	379.3	25.7	84.3	1.6	6.0	0.1	469.6	4.2
High SLR 2060 unprotected	774.3	52.7	523.9	10.4	625.6	13.2	1,923.8	17.1
Middle SLR 2030 protected	2.6	0.0	7.8	0.2	0.0	0.0	10.4	0.1
Middle SLR 2060 protected	4.8	0.4	31.2	0.6	0.0	0.0	36	0.3
Middle SLR 2030 unprotected	2.6	0.0	7.8	0.2	0.0	0.0	10.4	0.1
Middle SLR 2060 unprotected	449.3	30.6	129.5	2.5	10.6	0.2	589.4	5.2

Table 6.3. Number of housing units vulnerable to SLR

SLR scenario	2030	2060
Low	260,505	273,118
Middle	276,748	338,178
High	281,905	1,110,793

Table 6.4 lists the value of housing units and roads at risk from SLR. The first section of the table displays current values. The second and third sections show increased values based on the pessimistic and optimistic scenarios for change in per capita income. The final section calculates an annual impact assuming all the housing units and roads are inundated and the value is completely amortized over 30 years. The losses would be approximately between 1 and 2 billion EGP in 2030 and between 2 and 16 billion EGP in 2060. To be sure, this assumes that the housing units and roads would not be protected from a rise in sea level, which is a pessimistic assumption.

6.3 Agriculture

Three types of impacts are discussed: change in crop yields, impacts on the Egyptian agriculture economy, and the value of agriculture impacts.

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Table 6.4. Current value of lost housing units and roads (billion EGP)

	Housing units		Roads		Total	
SLR scenario	**2030**	**2060**	**2030**	**2060**	**2030**	**2060**
Low	16.4	17.5	2.2	2.3	18.6	19.7
Middle	17.5	22.2	2.4	2.6	19.9	24.8
High	18.0	65.6	2.4	8.0	20.4	73.5
Adjusted for increase in per capita income (pessimistic)						
Low	25.9	51.4	3.5	6.7	29.3	58.2
Middle	27.7	65.4	3.7	7.7	31.4	73.1
High	28.4	193.2	3.8	23.5	32.2	216.7
Adjusted for increase in per capita income (optimistic)						
Low	38.1	116.0	5.1	15.2	43.2	131.3
Middle	40.8	147.6	5.5	17.4	46.3	165.0
High	41.8	436.0	5.6	53.0	47.4	489.0
Annual impacts	**Pessimistic**		**Optimistic**			
Low	1.0	1.9	1.4	4.4		
Middle	1.0	2.4	1.5	5.5		
High	1.1	7.2	1.6	16.3		

6.3.1 Crop yields

Changes in crop yields and water demand are displayed in Table 6.5.

Yields are projected to decrease for all crops included in the analysis, and water needs are projected to increase. (Whether water use increases or not depends on the availability of water supplies.)

6.3.2 Impacts on the Egyptian agriculture economy

Tables 6.6 and 6.7 display results from the economic modeling of the impacts of climate change on Egyptian agriculture. The results are complicated and may seem to be a paradox, in part because of how the agricultural economy can be affected by climate change. If production is reduced, prices can increase quite significantly. Indeed, this can result in an increase in the total value of agricultural production. Yet, Egyptian consumers would be worse off because agricultural production would be lower and prices higher. However, farmers who are able to produce a crop would gain because the increase they receive per unit crop produced would be larger than the reduction in yield (see, e.g., Hertel et al., 2010, for analysis of differential impacts of climate change on agriculture production).

Table 6.5. Estimated change (%) in crop yield and water use for Egyptian crops

		2030 A1		2030 B1		2060 A1		2060 B1	
Crop	**Season**	**Yield**	**Water demand**	**Yield**	**Water demand**	**Yield**	**Water demand**	**Yield**	**Water demand**
Barley	Winter	-12	3.6	-12	2.64	-20	7.2	-20	4.58
Berseem (long)	Winter	-8.4	3.3	-8.4	3.12	-15.2	6.6	-15.2	5.2
Berseem (short)	Winter	-8.4	3.3	-8.4	3.12	-15.2	6.6	-15.2	5.2
Citrus	Annual	-8.4	3.3	-8.4	3.12	-15.2	6.6	-15.2	5.2
Cotton	Summer	10.2	3.6	10.2	2.64	19.8	7.2	19.8	4.58
Fava bean	Winter	-16.8	4.02	-16.8	2.88	-28	7.82	-28	4.96
Flax	Winter	-9	3.6	-9	2.64	-19.2	7.2	-19.2	4.58
Lentil	Winter	-16.8	3.48	-16.8	2.52	-28	7.28	-28	4.44
Maize	Summer	-8.4	3.3	-8.4	3.12	-15.2	6.6	-15.2	5.2
	Nili	-8.4	3.3	-8.4	3.12	-15.2	6.6	-15.2	5.2
Onion	Summer	-0.96	4.32	-0.96	3	-1.53	7.84	-1.53	5
	Winter	-0.96	4.32	-0.96	3	-1.53	7.84	-1.53	5
Other (legume)	Winter	-16.8	3.48	-16.8	2.52	-28	7.28	-28	4.44
Peanut	Summer	-0.96	4.32	-0.96	3	-1.53	7.84	-1.53	5
Potato	Summer	-0.96	4.32	-0.96	3	-1.53	7.84	-1.53	5
	Nili	-0.96	3.36	-0.96	2.88	-1.53	7.26	-1.53	4.92
Rice	Summer	-6.6	3.3	-6.6	3.12	-11	6.6	-11	5.2
Rice (short season)	Nili	-6.6	3.3	-6.6	3.12	-11	6.6	-11	5.2
Sesame	Summer	-8.4	3.3	-8.4	3.12	-15.2	6.6	-15.2	5.2
Sorghum	Summer	-8.4	3.3	-8.4	3.12	-15.2	6.6	-15.2	5.2
	Nili	-8.4	3.3	-8.4	3.12	-15.2	6.6	-15.2	5.2
Soybeans	Summer	-16.8	3.48	-16.8	2.52	-28	7.28	-28	4.44
Sugar beets	Winter	-0.96	4.32	-0.96	3	-1.53	7.84	-1.53	5
Sugarcane	Annual	-8.4	3.3	-8.4	3.12	-15.2	6.6	-15.2	5.2
Tomato	Summer	-16.8	3.48	-16.8	2.52	-28	7.28	-28	4.44
	Nili	-16.8	3.54	-16.8	2.88	-28	7.18	-28	5.04
	Winter	-16.8	4.2	-16.8	3.06	-28	8.16	-28	5.28
Vegetables	Summer	-16.8	3.48	-16.8	2.52	-28	7.28	-28	4.44
	Nili	-16.8	3.48	-16.8	2.52	-28	7.28	-28	4.44
	Winter	-16.8	3.48	-16.8	2.52	-28	7.28	-28	4.44
Wheat	Winter	-9	3.6	-9	2.64	-19.2	7.2	-19.2	4.58

Table 6.6. Agriculture results for 2030 (expressed as % change from base 2030)

Socioeconomic scenario	Baseline value (2030)	Pessimistic	Pessimistic	Pessimistic	Optimistic[a]	Pessimistic	Pessimistic
Nile flow	**55 BCM**	**Small decreased flow (52.5)**	**Large decreased flow (45.5)**	**Small decreased flow (52.5)**	**Small decreased flow (52.5)**	**Small decreased flow (52.5)**	**Increased flow (62.5)**
SRES (SLR + crops)		**A1**	**A1**	**A1**	**A1**	**B1**	**A1**
Protection from SLR		**Unprotected**	**Unprotected**	**Protected**	**Unprotected**	**Unprotected**	**Unprotected**
Production	Pessimistic: 211 Optimistic: 199 (billion EGP)	-11	-17	-11	-12	-12	-4
Agriculture consumption by consumers		-6	-8	-6	-2	-12	-3
Agriculture GDP	Pessimistic: 211.4 Optimistic: 198.5 (billion EGP)	17.9	23.09	18.4	0.3	-7.4	9.7
Consumer prices (optimistic prices are 3% lower than pessimistic prices in baseline conditions)		+26	+38	+24	+7	+10	+13
Agriculture water use	Pessimistic: 33.6 Optimistic: 34.8 (BCM)	-5.9	-18.3	-6.7	-3.4	-3.5	13.9
M&I consumption of surface water	Pessimistic: 6.8 Optimistic: 6.0 (BCM)	-4.3	-7.2	-5.3	-10.7	-10.8	6.1
Flow to sea	Pessimistic: 18.8 Optimistic: 17.9 (BCM)	+0.7	-4.3	+1.3	-6.9	-6.8	4.4

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Table 6.6. Agriculture results for 2030 (expressed as % change from base 2030) (cont.)

Socioeconomic scenario	**Baseline value (2030)**	**Pessimistic**	**Pessimistic**	**Pessimistic**	**Optimistic[a]**	**Pessimistic**	**Pessimistic**
Nile flow	**55 BCM**	**Small decreased flow (52.5)**	**Large decreased flow (45.5)**	**Small decreased flow (52.5)**	**Small decreased flow (52.5)**	**Small decreased flow (52.5)**	**Increased flow (62.5)**
SRES (SLR + crops)		**A1**	**A1**	**A1**	**A1**	**B1**	**A1**
Protection from SLR		**Unprotected**	**Unprotected**	**Protected**	**Unprotected**	**Unprotected**	**Unprotected**
Agriculture land use	Pessimistic: 19.2 Optimistic: 19.5 (million feddans)	-3.6	-9.7	-1.0	-6.0	-1.7	-5.9
Agriculture labor hours	Pessimistic: 2.7 Optimistic: 2.5 (billion)	-3.9	-5.7	-3.6	-6.5	-6.7	5.8

a. Optimistic percentage change is relative to optimistic baseline values.

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Table 6.7. Agriculture results for 2060 (expressed as % change from base 2060)

Socioeconomic scenario	**Baseline value in 2060**	**Pessimistic**	**Pessimistic**	**Pessimistic**	**Optimistic[a]**	**Pessimistic**	**Pessimistic**
Nile flow	**55 BCM**	**Small decreased flow (49)**	**Large decreased flow (35)**	**Small decreased flow (49)**	**Small decreased flow (49)**	**Small decreased flow (49)**	**Increased flow (71)**
SRES (SLR + crops)		**A1**	**A1**	**A1**	**A1**	**B1**	**A1**
Protection from SLR		**Unprotected**	**Unprotected**	**Protected**	**Unprotected**	**Unprotected**	**Unprotected**
Production	Pessimistic: 374 Optimistic: 205 (billion EGP)	-27	-47	-26	-20	-26	-8
Agriculture consumption by consumers		-15	-30	-15	-7	-14	-5
Agriculture GDP	Pessimistic: 374 Optimistic: 205 (billion EGP)	15.6	9.0	16.8	14.1	16.1	13.8
Consumer prices (optimistic prices are 39% lower than pessimistic)		41	68	41	32	41	16
Agriculture water use	Pessimistic: 31.4 Optimistic: 33.8 (BCM)	-14.9	-51.4	-14.8	-15.8	-15.1	35.5
M&I consumption of surface water	Pessimistic: 9.0 Optimistic: 6.5 (BCM)	0	3.6	0.1	0.4	-5.6	8.4
Flow to sea	Pessimistic: 23.1 Optimistic: 18.8 (BCM)	-3.5	-17.3	-3.3	-3.1	-3.3	9.3

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Table 6.7. Agriculture results for 2060 (expressed as % change from base 2060) (cont.)

Socioeconomic scenario	Baseline value in 2060	Pessimistic	Pessimistic	Pessimistic	Optimistic[a]	Pessimistic	Pessimistic
Nile flow	**55 BCM**	**Small decreased flow (49)**	**Large decreased flow (35)**	**Small decreased flow (49)**	**Small decreased flow (49)**	**Small decreased flow (49)**	**Increased flow (71)**
SRES (SLR + crops)		**A1**	**A1**	**A1**	**A1**	**B1**	**A1**
Protection from SLR		**Unprotected**	**Unprotected**	**Protected**	**Unprotected**	**Unprotected**	**Unprotected**
Agriculture land use	Pessimistic: 17.1 Optimistic: 17.9 (million feddans)	-10.2	-24.9	-10.0	-5.3	0	0
Agriculture labor hours	Pessimistic: 3.2 Optimistic: 2.8 (billion)	-20.1	-39.2	-19.2	-5.4	-19.4	3.1

a. Optimistic percentage change is relative to optimistic baseline values.

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In this analysis, we assumed that exports and imports of agricultural goods are no greater than five times the levels of 2007, which leads to higher food prices when production decreases. In the adaptation analysis (Chapter 7), we assumed that import restrictions are 10 times above 2007 levels, which reduces the price increase by about one-half.

We present a number of indicators of climate change impacts that broadly represent how Egypt can be affected by climate change. Changes in agricultural production, prices, water consumption by agriculture, land dedicated to agriculture, and labor hours in agriculture give a truer indication of the extent to which Egypt will gain or lose from climate change, although we also report changes in GDP and welfare. “Welfare” is an economics term that means the income to producers above their costs of production and the value to consumers beyond what they pay for a product or service. In this case, producers gain because prices rise and consumers lose because they have to pay more for goods.

We focus on a single scenario for reporting results. The scenario assumes a pessimistic population and economic growth, the low reduction (ECHAM) in Nile flow (a decrease of just over 10% by 2060), the high (A1) crop and SLR scenarios, and no protection from SLR. To be sure, some of these assumptions are more likely to actually occur than others. Under this scenario, by 2030, agriculture production decreases 11% and prices rise 26%; ultimately, Egyptian consumers would pay more for fewer goods. Furthermore, they would consume fewer agricultural products (which include cotton as well as food) as consumption would decrease by 6%. Consumers’ welfare, a measure of the value received from consumption above what consumers pay, drops by 5%. Meanwhile, the amount of land dedicated to agriculture is reduced by 3.6% and there are 3.9% fewer labor hours. Currently, agriculture employs almost 9 million people in Egypt (CIA, 2012), which means that more than 350,000 jobs could be at risk. Note, however, that farmers who are able to plant a crop may gain from higher prices. Agriculture value of production, as measured by GDP, rises by almost 18%, but welfare is reduced by 2%, primarily because consumers have to spend more for food and divert income from other consumption and investment. In summary, agricultural output is reduced, fewer people are employed in agriculture, and consumers pay more for food. Such a scenario would almost certainly cause increased malnutrition and poverty. The non-agricultural populace in Egypt would be worse off because of the reduction in agricultural production. While farmers would gain more income from higher prices, they also would pay more for food. Even though there would be increases in farm income, on the whole, Egypt would be worse off because of the decrease in agricultural production.

By 2060 under the same socioeconomic and climate change scenarios, conditions would be significantly worse. Production drops 27% and imports of agricultural goods rise by 49%. Nonetheless, prices increase by 41%, which also leads to a reduction in consumption of agricultural goods by 15%. That is, there would be more than a one-seventh in the amount of agricultural goods Egyptian consumers are able to purchase. By this time, land dedicated to

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agriculture is down 10% and the level of employment is reduced by 20%. Assuming current agriculture employment, this would result in the loss of 1.8 million jobs. Agriculture GDP rises by more than 15%, but total welfare drops by 6% and consumer surplus drops by 11%.

It is difficult to project what these results mean for malnutrition in Egypt. Income per capita would be substantially higher in 2060 compared to today. If there is more income equality, the risk of malnutrition would be lower than if significant inequities in income remain or increase. But if income equality is the same or increases, there will still be many poor people. With such large increases in the cost of food and a large decrease in consumption, it is likely that the poor would face a much greater risk of malnutrition than they would otherwise.

Two factors appear to have a very significant effect on agriculture. One is change in yields. Under the climate change scenarios, yields of all crops would decrease. This would result in decreased production, even if the flow of the Nile increases. For example, under the increased flow scenario, flow of the Nile increases to 62 BCM in 2030 and to 71 BCM in 2060. Yet, in 2030, agricultural production would be reduced by 4% and prices would rise by 13% (assuming limitations on imports). While agriculture land decreases by 6%, labor rises by about the same percentage. By 2060 under this scenario, production decreases by 8% and prices rise 16% (assuming limitations on imports). Land use remains unchanged and labor hours are estimated to increase by 3%. So the results are complex. Agricultural production drops even with more water, probably because yields are down. But, apparently a little more labor is needed to try to produce more output. This is probably the result of having more water available for irrigation.

The second factor is water supply. The results above show how increased water supplies can moderate the losses from reduced crop yields. In contrast, the low-flow scenario reduces flow to 45 BCM by 2030 and about 35 BCM by 2060. This results in a 17% reduction in agricultural output in 2030 and a 47% reduction in 2060. Prices rise 38% in 2030 and 658% in 2060 (assuming restrictions on imports). This could have a dramatic effect on the poor and malnutrition rates. To make matters worse, agriculture labor hours are projected to decrease by almost 6% in 2030 and 39% in 2060, which would mean a substantial reduction in employment in the agriculture sector.

Other factors have less of an effect on agriculture. The reduction in agricultural production is virtually the same under the optimistic socioeconomic conditions compared to the same scenario but assuming pessimistic socioeconomic conditions.[1] By 2060, the optimistic scenario results in less of a reduction in agricultural production (20%) than does the pessimistic scenario (27% reduction). The loss in welfare is smaller in absolute and percentage terms in the optimistic case

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1. The reduction is 11.3% under the pessimistic scenario and 11.7% under the optimistic scenario. The results reported in Table 6.6 are the result of rounding to the nearest whole number.

than in the pessimistic case. So, in general, a lower population growth and higher per capita income would make Egypt less vulnerable to potential climate change impacts on agriculture.

Protection of coastal areas has a limited effect on national agricultural output. Agricultural production is estimated to be 0.65% higher with protection than without in 2060. Even though the percentage difference is small, protecting vulnerable agriculture areas in the Nile Delta from SLR would increase agriculture production in 2060 by 6.1 billion EGP per year. In addition, there are many other benefits to protecting coastal resources including protecting cities such as Alexandria and Port Said and protecting antiquities. This study did not examine the risks of SLR to coastal areas other than agriculture. (This topic is revisited in Chapter 7.)

The lower greenhouse gas emissions scenario, which has less of a rise in sea level and a less negative effect on crop yields, has a positive effect on agricultural production in the time period studied. Under the lower greenhouse gas scenario (B1), agriculture production is reduced by 22% rather than the 27% under the higher emissions (A1) scenario, an absolute difference of 2 billion EGP per year. We would expect that further into the future, the differences between lower and higher emissions scenarios will become more distinct.

Chapter 7 addresses how subsidies for sugar and wheat could be affected by climate change.

6.3.3 Value of agriculture impacts

The term "welfare" is used by economist to measure well-being. In the context of agriculture, welfare essentially consists of the value that consumers gain from the consumption of agriculture goods above what they pay for the goods and the gains to producers above their costs of production. A change in welfare is an economic indication of the net gains and losses to consumers and producers. With prices rising, consumers will lose because they will pay more for to consume goods whose value does not change (i.e., consumers get the same benefit from eating bread, but have to pay more for it). Producers will see a rise in price. Unless the costs to them rise, they will make more profit.

We also measure trade surplus, which is the difference between the costs of imported goods if there were no trade restrictions and the costs of imported goods with restrictions.

Tables 6.8 and 6.9 display the changes in agriculture welfare in 2030 and 2060, respectively.

Table 6.8. Change in agriculture welfare in 2030 (billion EGP)

Socioeconomic scenario	Baseline value in 2060	Pessimistic	Pessimistic	Pessimistic	Optimistic[a]	Pessimistic
Nile flow	**55 BCM**	**Small decreased flow (52.5)**	**Large decreased flow (45.5)**	**Small decreased flow (52.5)**	**Small decreased flow (52.5)**	**Increased flow (62.5)**
SRES (SLR + crops)		**A1**	**A1**	**A1**	**A1**	**A1**
Protection from SLR		**Unprotected**	**Unprotected**	**Protected**	**Unprotected**	**Unprotected**
Consumer surplus	Pessimistic: 1,248 Optimistic: 1,117	-55	-65	-54	-18	-27
Producer surplus	Pessimistic: 106 Optimistic: 100	29	37	29	-3	13
Trade surplus	Pessimistic: 0.8 Optimistic: 0.5	1	1	1	0.3	0
Total welfare (consumer and producer surplus)	Pessimistic: 1,354 Optimistic: 1,217	-25	-26	-25[a]	-20	-14

a. Welfare loss in the unprotected scenario is 0.6 billion EGP greater than in the protected scenario.

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Table 6.9. Change in agriculture welfare in 2060 (billion EGP)

Socioeconomic scenario	Baseline value in 2060	Pessimistic	Pessimistic	Pessimistic	Optimistic[a]	Pessimistic	Pessimistic
Nile flow	**55 BCM**	**Small decreased flow (49)**	**Large decreased flow (35)**	**Small decreased flow (49)**	**Small decreased flow (49)**	**Small decreased flow (49)**	**Increased flow (71)**
SRES (SLR + crops)		**A1**	**A1**	**A1**	**A1**	**B1**	**A1**
Protection from SLR		**Unprotected**	**Unprotected**	**Protected**	**Unprotected**	**Unprotected**	**Unprotected**
Consumer surplus	Pessimistic: 1,602 Optimistic: 1,221 (billion EGP)	-181	-293	-183	-85	-180	-71
Producer surplus	Pessimistic: 238 Optimistic: 206 (billion EGP)	62	45	66	42	64	32
Trade surplus	Pessimistic: 5 Optimistic: 0.7 (billion EGP)	7	15	7	2	6	1
Total welfare (consumer and producer surplus)	Pessimistic: 1,845 Optimistic: 1,237 (billion EGP)	-112	-234	-110	-41	-110	-38

The welfare effects are fairly consistent in 2030: annual losses in the 20–26 billion EGP range if the Nile flow drops and about 15 billion EGP if the flow increases. Losses to consumers are much higher ranging from 18 billion per year in the optimistic scenario to 65 billion EGP per year by 2030 in the low-flow scenario. Agriculture producers gain except in the optimistic scenario, where the assumed increase in crop yields from improved technology outpaces the effect of climate change.

By 2060, the welfare impacts are substantially larger. The reduction in total surplus ranges from about 40 billion EGP per year under the increased-flow scenario and under the optimistic scenario to 100 to more than 200 billion EGP per year under the pessimistic and reduced-flow scenarios. Consumers lose welfare while producers gain, but the magnitude of the loss to consumers is two to six times greater than the magnitude of the gain to producers. In the small decrease in flow scenario with pessimistic assumptions, consumers lose over 180 billion EGP per year; in the scenario with a large decrease in flow, consumers lose 300 billion EGP per year.

6.4 Air Quality

We examine the effect of an increase in Cairo's $PM_{2.5}$ concentrations of 1 $\mu g/m^3$ on mortality. Table 6.10 presents the future estimates in Greater Cairo for a 1-$\mu g/m^3$ change in ambient PM levels. We assumed a 0.5-$\mu g/m^3$ increase in $PM_{2.5}$ in 2030 and that the impacts would be one-half of those estimated for 2060.

Table 6.10. Estimated population and changes in deaths from a 1-$\mu g/m^3$ change in PM levels in Greater Cairo

	Population scenario	**2010**	**2030**	**2060**
Greater Cairo population (millions)	Optimistic scenario	19.7	25.5	27.8
	Pessimistic scenario	19.7	28.8	39.9
Change in number of deaths from a 1-$\mu g/m^3$ change in PM in Greater Cairo				
	Optimistic population	**2010**	**2030**	**2060**
$PM_{2.5}$ – Low (Pope) estimate (adult only)		501	649	708
$PM_{2.5}$ – High (Laden) estimate (adult only)		1,140	1,477	1,610
	Pessimistic population	**2010**	**2030**	**2060**
$PM_{2.5}$ – Low estimate (adult only)		501	733	1,015
$PM_{2.5}$ – High estimate (adult only)		1,140	1,667	2,308

As noted in Chapter 2, the World Health Organization standard for $PM_{2.5}$ is 10 µg/m^3 and measurements of air quality in Cairo in 2002 found levels 8 to 10 times above this standard. Thus, a 0.5- to 1.0-µg/m^3 change in $PM_{2.5}$ levels is quite small relative to the amount by which current air quality standards are being exceeded.

Since Egypt's population under the pessimistic scenario increases more than under the optimistic scenario, we find that there would be more deaths under the pessimistic scenario.

Using assumed increases in per capita income (see Chapter 5), we estimated the future value of statistical life in Egypt as shown in Table 6.11.

Table 6.11. Estimated VSL for increased PM (millions EGP)

	2030	2060
Optimistic	5.0	15.0
Pessimistic	3.8	6.2

Table 6.12 combines the estimated change in mortality and morbidity with the estimated value of the impacts in Egypt. The equivalent value of the increase in mortality from higher $PM_{2.5}$ levels is estimated to be tens of billions of EGP per year by 2060. It may seem ironic that the optimistic scenario has higher values than the pessimistic scenario. The result is because the VSL is estimated to be much higher under the optimistic (high GDP/capita) scenario compared to the pessimistic (low GDP/capita) scenario.

Table 6.12. Estimated value of increased mortality using VSL (million EGP)

	2030	2060
Optimistic	3,226–7,341	10,651–24,220
Pessimistic	2,475–5,628	6,254–14,221

6.5 Heat Stress

The estimated increases in heat stress mortality from higher temperatures in Greater Cairo are presented in Table 6.13. The optimistic and pessimistic results reflect the different assumptions about population growth. Basically, hundreds of additional heat stress cases per year are projected by 2030 and one to two thousand additional annual heat stress cases are projected by 2060. As noted in Chapter 4, however, these estimates do not account for the likely effect of higher per capita income enabling more use of air conditioning in Cairo. This would in all likelihood reduce cases of heat stress. Therefore, these estimates are likely to be high.

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Table 6.13. Estimated increase in annual mortality in Greater Cairo from increased heat stress

	2030			2060		
	CGCM63	ECHAM	MIROC-M	CGCM63	ECHAM	MIROC-M
Optimistic	662	662	736	1,662	1,579	1,924
Pessimistic	722	722	802	2,302	2,187	2,665

We combined the estimated increase in annual mortality from heat stress with the increased VSL. The results are displayed in Table 6.14. The estimated annual economic damages from increased heat stress mortality are in the billions of EGP by 2030 and in the tens of billions of pounds by 2060. The welfare losses in the "optimistic" scenario are higher than the "pessimistic" scenario because the VSL in the optimistic case is much higher than in the pessimistic case because the GDP/capita levels in the optimistic scenario are much higher than in the pessimistic scenario. That difference far outweighs the higher estimated number of deaths in the pessimistic scenario.

Table 6.14. Annual welfare loss from increased heat stress in Greater Cairo (million EGP)

	2030			2060		
	CGCM63	ECHAM	MIROC-M	CGCM63	ECHAM	MIROC-M
Optimistic	3,291	3,291	3,657	24,999	23,749	28,937
Pessimistic	2,437	2,437	2,708	14,186	13,476	16,420

6.6 Tourism

Bigano et al. (2007) estimate that climate change reduced revenue by 3.6% from 1990 to 2010. This is relative to where it would be if there were no climate change. Based on the estimate for tourism levels in 2010 of 70 billion EGP, assuming that 84.5% of those tourists came for recreation and leisure, approximately 2 billion EGP has been lost as a result of climate change. Given the fluctuations in tourism, it would be very difficult to verify that this much revenue was affected by climate change.

The impacts of higher temperatures on future tourist revenues are taken from Bigano et al. (2007). For the A1B SRES scenario (no climate models are mentioned), they estimate that tourism revenues in Egypt will decrease 8.4% in 2030 relative to 1990 and 19.7% by 2060 relative to 1990. We applied the percentage losses from climate change to the estimated levels of tourism revenues in Egypt to estimate impacts of climate change.

The results are listed in Table 6.15. Estimated revenue losses from climate change are estimated to be 15 to 19 billion EGP by 2030 and 67 to 88 billion EGP by 2060.

Table 6.15. Estimated effect of climate change on annual tourism revenues

	Climate change losses (million EGP)	
	Optimistic	Pessimistic
2030	18,856	14,735
2060	88,386	67,103

The results should be interpreted with caution. Tourist destinations can be very difficult to predict, especially 50 years into the future. Factors such as how much disposable income is available, the relative attractiveness of different tourist sites, and travel and resort costs all factor into travel decisions. The Bigano et al. (2007) analysis is based on changes in income and changes in the relative temperatures of different tourist destinations. The presumption is that as climate continues to warm, relatively cooler locations will become more attractive and relatively warmer locations will become less attractive.

Climate change is also projected to harm coral reefs in the Red Sea. This could directly affect tourism as many tourists come to dive or snorkel to view the corals. The coral reefs are estimated to be reduced by 20 to 80% by 2060. Table 6.16 lists the potential reductions in recreation expenditures related to coral reefs in 2030 and 2060.

Table 6.16. Reduction in annual coral reef recreation expenditures related to climate change (million EGP)

	Optimistic, 20–50%	Pessimistic, 35–80%
2030	3,312	4,530
2060	14,510	17,626

We combine losses from increases in temperature with losses of coral reef. We used the lower tourist revenues after accounting for higher temperatures. However, in calculating change in coral reef expenditures, it is possible that there is some double-counting when these two estimates are combined. We assume that tourist expenditures are further reduced because of loss of coral reefs. In other words, those who are driven away by higher temperatures clearly do not recreate in the Red Sea coral reefs. Those who continue to come to Egypt are projected to have a reduction in recreation at the Red Sea coral reefs because of the decline in coral reefs. The total losses to tourist revenues are listed in Table 6.17.

Table 6.17. Annual total losses in tourism due to climate change

	Climate change losses (million EGP)	
	Optimistic	**Pessimistic**
2030	22,168	19,265
2060	102,897	84,729

We estimate that climate change could reduce tourist revenues by 19 to 22 billion EGP by 2030. By 2060, the revenue loss is projected to be 85 to 103 billion EGP, which would amount to more than 1% of GDP.

6.7 Summary of Impacts

A summary of impacts for the sectors covered is provided in Tables 6.18 and 6.19. The results include low, middle, and high estimates. Note that the middle estimate is not necessarily the most likely result and that ranges were not developed for the tourism estimates.

We estimated impacts of climate change on some of Egypt's vulnerable sectors. Egypt faces significant vulnerabilities from climate change. Perhaps the most significant finding was that most climate models project decreased flow in the Nile Basin, even though under some climate models flow is estimated to increase. Egypt's water supplies are already very limited, and population growth alone will make those supplies even more limited. A reduction in flow of the Nile would put additional stress on water resources throughout Egypt. Such a reduction would have the most serious consequences for agriculture, which is currently responsible for the consumption of 85% of all water consumed. Thus, any reduction in water supplies will, unless supplies are increased to offset the loss, limit irrigation water.

Projected change in flow of the Nile by 2030 ranges from an increase of more than 10% to a decrease of almost 20%. A middle projection is for a reduction in flow of about 5%. Agriculture is also projected to be negatively affected by lower crop yields resulting from higher temperatures and loss of some agricultural lands in the Nile Delta. Yields of major crops are estimated to decrease by 1 to 17%. In addition, a small percentage of agricultural land in the Nile Delta is at risk of inundation.

Table 6.18. Summary of results for 2030

Scenario	**1**	**2**	**3**	**4**
Socioeconomic scenario	**High population; low GDP**	**High population; low GDP**	**High population; low GDP**	**Low population; high GDP**
Nile flow scenario (flow in BCM)	**Large reduction (45.5)**	**Small reduction (52.5)**	**Increase (62.5)**	**Small reduction (52.5)**
Annual climate change in Cairo (temperature °C/% change in precipitation)	**0.9/-4%**	**0.9/0**	**1.0/-5%**	**0.9/0**
SLR	**High unprotected**	**High unprotected**	**High unprotected**	**High unprotected**
Agricultural production (% change)	-17	-11	-4	-12
Total welfare (% change)	-3	-2	N/A	-2
Consumer surplus (% change)	-11	-5	N/A	-12
Food prices (% change)	38	26	13	7
Reduction in consumption of agriculture (% change)	-8	-6	-3	-2
Agriculture employment (% change)	-6	-4	6	-7
Annual coastal property losses (excluding agriculture; billion EGP)[a]	1.1	1.1	1.1	1.6
Increase in annual deaths from air pollution ($PM_{2.5}$)	733–1,667	733–1,667	733–1,667	649–1,447
Value of deaths from air pollution (billion EGP using VSL)	2.5–5.6	2.5–5.6	2.5–5.6	3.2–7.3
Increase in annual deaths from heat stress	722	722	802	662
Value of deaths from heat stress (billion EGP using VSL)	2.4	2.4	2.7	3.3
Reduction in annual tourism revenues (billion EGP)	19.3	19.3	19.3	22.2

a. Values are displayed for a high SLR scenario. Annual losses for the pessimistic scenario assuming low and middle SLR projections are 1.0 billion in 2030. For the optimistic scenario, the annual losses for the low and middle SLR scenarios are 1.5 and 1.5 billion EGP, respectively.

Table 6.19. Summary of results for 2060

Scenario	1	2	3	4
Socioeconomic scenario	**High population; low GDP**	**High population; low GDP**	**High population; low GDP**	**Low population; high GDP**
Nile flow scenario	**Large reduction (CGCM63)**	**Small reduction (ECHAM)**	**Increase (MIROC-M)**	**Small reduction (ECHAM)**
Annual climate change in Cairo (temperature °C/% change in precipitation)	**2/-10%**	**1.9/0**	**2.2/-10**	**1.9/0**
SLR	**High unprotected**	**High unprotected**	**High unprotected**	**High unprotected**
Agricultural production (% change)	-47	-27	-8	-20
Food prices (% change)	68	41	16	32
Reduction in consumption of agriculture (% change)	-30	-15	-5	-7
Total welfare (% change)	-12	-6	-2	-2
Consumer surplus (% change)	-18	-11	-4	-7
Agriculture employment (% change)	-39	-20	3	-5
Coastal property losses (excluding agriculture; billion EGP)[a]	7.2	7.2	7.2	16.3
Increase in annual deaths from air pollution ($PM_{2.5}$)	1,105–2,308	1,105–2,308	1,105–2,308	708–1,610
Value of deaths from air pollution (billion EGP)	6.3–14.2.7	6.3–14.2	6.3–14.2	10.7–24.2
Increase in annual deaths from heat stress	2,302	2,187	2,665	1,579
Value of deaths from heat stress (billion EGP using VSL)	14.2	13.5	16.4	23.7
Reduction in annual tourism revenues (billion EGP)	84.7	84.7	84.7	102.9

a. Values are displayed for high SLR scenario. Annual losses for low and middle SLR scenarios, assuming the pessimistic socioeconomic scenario, are respectively, 1.9 and 2.4 billion EGP. Annual losses for the low and middle SLR scenarios, assuming the optimistic socioeconomic scenario are 4.4 and 5.5 billion EGP, respectively.

These factors combine to result in a projected 12% reduction in agriculture output by 2030, with a 16% increase in prices, but only a 2% decrease in employment. Should the Nile flow decrease as the most pessimistic climate model suggests, then by 2030, agricultural production would fall by 23% with a commensurate reduction in employment and an increase in prices. Even an increase in Nile flow of almost 20% would still result in a small reduction in agricultural

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production. This is likely to be mainly the effect of the projected decreases in crop yields. While those farmers able to grow crops would benefit by higher prices, their gains would be outweighed by the losses to consumers. Indeed, higher prices and increased unemployment would likely result in more poverty and malnutrition than if the climate did not change.

By 2030, levels of PM that harm human health could increase, causing an annual increase in deaths of about one thousand people. Higher temperatures and loss of coral reefs could reduce tourism revenues by about 20 to 23 billion EGP per year. Coastal property losses from housing units in the Nile Delta could amount to 1 billion EGP per year if those housing units are not protected. Indeed, annual economic losses just from SLR, heat stress, and tourism are estimated to be more than 30 billion EGP per year by 2030.

By 2060, the effects of climate change are projected to be more negative. The estimated change in flow of the Nile in the middle model is over 10%. The wettest climate model results in an increase of almost 30%, but the driest model results in a decrease in flow of 37%. Crop yields are projected to decrease by 2 to almost 30% as a result of higher temperatures.

These effects combine to further decrease agriculture production and drive up prices. Under the middle scenario, production drops by 27% and employment by 18%. Meanwhile, prices rise 40%. The driest scenario would be even more dire. Agricultural output would decline 47%, with a decrease in agriculture employment of 37% and a rise in prices of 65%. Some of the shortfall could be alleviated through allowing more imports, which would reduce the price increase. But, this would further reduce agriculture production and employment. Even under the wettest climate model, agriculture production drops 9% and employment 5%, while prices rise 12%.

Harmful PM concentrations would be even higher by 2060 and annual deaths would increase to 1,000 to 2,300. The value of that loss is equivalent to 12 to 34 billion EGP per year. Higher temperatures and loss of coral reefs could reduce tourism revenues by about 90 to 110 billion EGP per year. Coastal property losses from housing units in the Nile Delta could amount to 2 to 16 billion EGP per year if those housing units are not protected. The total estimated loss from the sectors estimated, which does not include agriculture and many other potential adverse impacts, is well over 160 billion EGP per year. As noted earlier, there are expected to be many other adverse impacts of climate change. Thus the estimate of damages is not comprehensive and is likely to underestimate the total economic costs of climate change.

Table 6.20 displays estimated economic impacts in 2030 and 2060 from analyzed sectors for scenarios 2 and 4: a small decrease in Nile flow with the Nile Delta unprotected from high SLR. Scenario 2 assumes the pessimistic socioeconomic changes and Scenario 4 assumes the optimistic socioeconomic changes. Figure 6.2 displays economic impacts in 2030 and 2060 under scenario 2.

Table 6.20. Selected economic losses in Egypt from climate change (billion EGP)

	2030			2060		
Scenario	**1**	**2**	**4**	**1**	**2**	**4**
Welfare loss in agriculture	26	25	20	234	112	41
Annual coastal property losses (excluding agriculture)	1	1	2	7	7	16
Value of deaths from air pollution (using VSL)	3–6	3–6	3–7	6–14	6–14	11–24
Value of deaths from heat stress (using VSL)	2–3	2–3	3	14	14	24
Reduction in annual tourism revenues	19	19	22	85	85	103
Total of selected impacts	51–55	50–54	50–54	346–354	224–232	195–208
Percent of GDP	2.2–2.4	2.2–2.4	1.6–1.8	5.9–6.0	3.8–3.9	2.1–2.2

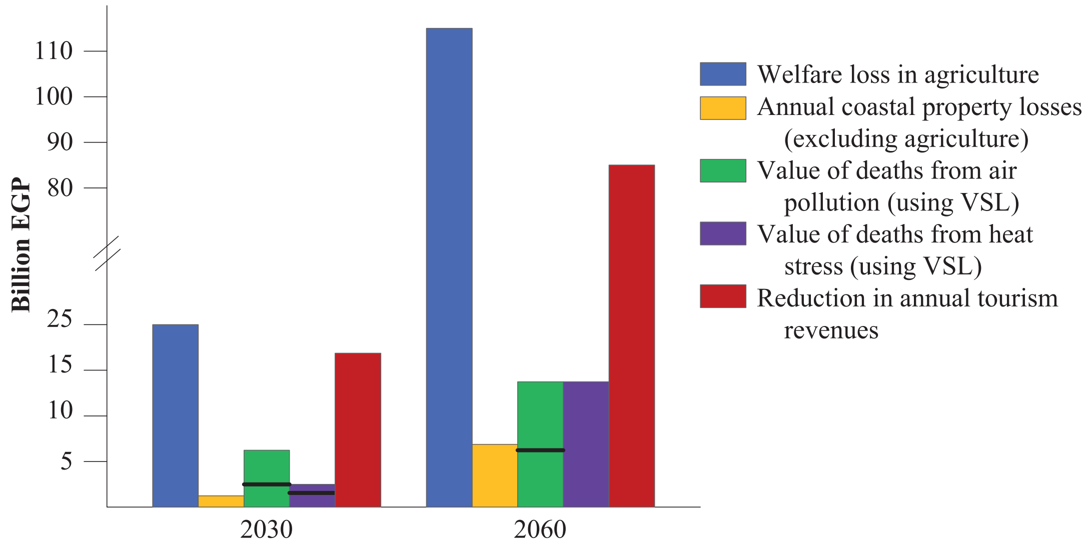

Figure 6.2. Estimated economic impacts by sector in 2030 and 2060.

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Total losses by 2030 do not differ much by scenario as they are about 50 billion EGP per year. This ranges from under 2% of GDP in the optimistic scenario to over 2% in the pessimistic scenario.

The absolute and relative size of the economic impact is substantially higher by 2060. Total economic losses range from 200 to 350 billion EGP per year. In the optimistic scenario, the percentage impact only increases slightly from 2030 and reaches just over 2% per year. But in the pessimistic scenario, the welfare loss represents almost 4% of GDP in the small Nile reduction scenario and about 6% in the large reduction scenario. In both time periods, agriculture has the largest economic losses with tourism second. Note that these losses are not all the economic impacts that could result from climate change. Other forms of air pollution, water pollution, SLR impacts on cities and adverse impacts of lower water flows, higher water temperatures and SLR on fisheries, loss of biodiversity, and many other impacts would also result in economic losses.

7. Adaptation Discussion

This chapter identifies and discusses *some* adaptation options for Egypt in the sectors that are the subject of this report: water resources, coastal resources, agriculture, human health, and tourism. It also addresses cross-cutting adaptation. The focus of this report is mainly on the analysis of potential economic impacts of climate change. The adaptations identified here have not been analyzed in detail in the context of Egypt. More work is needed to analyze and evaluate the potential effectiveness of these adaptations, costs, consequences for other sectors, and feasibility.

7.1 Setting Priorities

This report identified potentially negative impacts to water resources, agriculture, human health, tourism, and coastal resources in Egypt. Based on the magnitude of the risk, the certainty of the risks, and how soon the risks could become significant, we use our judgment to rank these risks. To be sure, the rankings below are subjective.

Water and agriculture appear to be the highest priority for Egypt. The flow of the Nile is projected to decrease by one-tenth in the middle scenario and by more than one-third in the lowest-flow scenario. Agriculture is projected to face risks from higher temperatures and a potential reduction in water supplies. Projected decreases in crop yields range from a few percent to almost 30%, although cotton yields are projected to increase. All the studies reported in the SNC project that climate change will decrease yields. This is consistent with published literature that generally finds that agriculture production in lower latitudes is projected to decrease as a result of climate change (e.g., Nelson et al., 2009). Even under the scenario of increased water supplies, we project a decrease in agriculture production in Egypt. Therefore it will also be important to reduce the vulnerability of crop yields to changes in climate.

The combination of lower crop yields and reduced water for irrigation results in an estimated decrease in agriculture production of one-quarter for the middle scenario and almost one-half for the low-flow scenario. Food prices would rise 40 to 65% and employment in agriculture would decrease by roughly 20 to over 35%. Annual reductions in total welfare are estimated to be 100 to 200 million EGP, larger than the impacts on other sectors, except tourism in some scenarios. A reduction in water supplies would also harm human welfare by potentially reducing water for drinking and sanitation (although domestic use of water is the highest priority for Egypt), industry, navigation, and ecosystems.

To be sure, a reduction in water supplies is not certain. Six of the 17 GCMs used by Elshamy et al. (2009) resulted in projections of increased flow in the Blue Nile. While there is much uncertainty about how rains in East Africa may change (e.g., Funk et al., 2008) based on the

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literature we reviewed, there appears to be a better chance that flow in the Nile will decrease. The consequences of a decrease in Nile flow appear to be so great that Egypt needs to prepare for at least the potential of a reduction in flow. Based on this risk, improving the efficiency of water use and increasing water supplies should be a high priority for Egypt.

Tourism is a critical component of Egypt's economic growth. Keeping tourism in Egypt attractive is therefore vitally important. As we have noted, while the study projects a potentially large reduction in tourism because of climate change – roughly 100 billion EGP per year – there is significant uncertainty surrounding this finding. Nonetheless, the importance of this sector leads one to conclude that reducing vulnerability of the tourism sector to climate change is important.

The effect of climate change on human health in Egypt is a topic that is often overlooked. This study suggests that there could be significant and important risks to health from climate change. The analyses estimate 3,000 to 5,000 additional deaths per year from increased air pollution and heat stress. To be sure, a critical uncertainty in projecting health impacts from climate change is not knowing the degree to which pollution will be controlled in the future. Population growth and continued reliance on automobiles and power from fossil fuels can worsen Cairo's air quality (as well as air quality in other cities such as Alexandria). Growth of urban populations, particularly poor urban populations, will most likely place more people at risk of heat stress. Climate change impacts on vector and waterborne disease could also increase. On the other hand, if Egypt controls emissions from power plants and vehicles and relies more on mass transit, then air pollution could be curbed. So, too, Egypt's vulnerability to climate change impacts on air quality would also be reduced. Increased penetration of air conditioning, although it will increase energy use and quite possibly carbon emissions, can also reduce vulnerability to heat stress. These are important components of development and can reduce vulnerability to climate change.

Finally coastal resources are also at risk from SLR. This study did not investigate the most critical SLR risks facing cities and cultural sites. The risks to agriculture are not large on a national scale but would likely be of importance on a local scale. For most of the scenario, only a small percentage of agricultural land in the Nile Delta is at risk from SLR through 2060. Also, whether the land becomes inundated or is protected generally had a very small impact on national agricultural production. On the whole, the risks SLR poses to Egyptian agriculture appear to be much smaller than the risks agriculture faces from a decrease in water resources and a hotter and drier climate.

Based on the results of this study and placing emphasis on the estimated economic impacts of climate change to Egypt, we rank the following sectors based on their relative vulnerability to climate change:

1. Water resources and agriculture
2. Tourism
3. Human health
4. Coastal resources.

This chapter identifies specific adaptations by sector and cross-sector. Most of the adaptations are described qualitatively. In a few cases, we were able to estimate adaptation costs. The potential total costs of adaptation are briefly analyzed toward the end of this chapter, based on published studies.

7.2 Water Resources

As discussed in previous chapters, there is the potential for a very significant reduction in Egypt's water supplies from climate change. Across many studies, median or average results suggest a decrease in flow of the Nile. While it is possible that the flow of the Nile can increase under climate change, prudent planning should incorporate the risks of lower flows of the Nile. These projections of decreased flow come on top of projections of higher population and economic growth for Egypt, both of which could result in increased demand for water.

Projected population growth alone is already a strong reason to encourage more efficient use of Egypt's water supplies and development of new supplies.

There are three main issues for adaptation of Egypt's water resources: water management, enhancement of supplies, and a reduction in demand. Reducing water demand in agriculture is discussed below.

7.2.1 Demand reduction

Agriculture currently uses about 85% of water resources in Egypt (CAPMAS, 2010), so demand reduction needs to address agricultural water use. In addition, population is projected to increase substantially so reducing water demand in the domestic sector is also important. Climate change adds the risk of reduced water supplies. Indeed, the term "maladaptation" can mean increasing use of or dependency on climate-sensitive resources that may themselves be diminished or degraded by climate change (UNDP-UNEP, 2011). Among the options that can be considered are:

- *Enhance use of market mechanisms to reduce demand*. Charging users a fee based on their use of water typically results in increased efficiency. This can be done for municipal, industrial, and agricultural uses. Markets require mechanisms for measuring use and collecting fees. M&I water use is not metered so users do not pay more if they consume more water. Equity issues are also a concern. Minimal or no charges should be applied for water to meet basic human needs, as is done in South Africa. One option is to first meter private sector water consumers. There are probably far fewer businesses than households and businesses can probably better afford to pay the cost of metering than households. Household metering could wait until per capita income increases enough to make metering affordable or could begin in relatively wealthy communities.

- *Enable water to be traded*. An additional market mechanism is to allow users to trade water. This tends to make sense where water is allocated to specific users. Users should be enabled to sell their water or rights to water to others. This enables water to be reallocated to higher-value uses.

Note that improving the efficiency of irrigation and developing less water-demanding crops is a need not unique to Egypt. Virtually all arid and semi-arid states need to increase the efficiency of water use to cope with rising populations, economic growth, and climate change. This is virtually a global need. Therefore, Egypt does not need to pursue solutions on its own. *Rather Egypt should collaborate with other arid and semi-arid states on research to develop technologies and practices that would improve irrigation efficiency and reduce water demand for crops*. Since climate change can put much more pressure on water resources, the advance of technologies and practices could be supported by the UNFCCC. Funding could be provided through the newly established Green Fund. Egypt could work with other developing countries to request the UNFCCC provide financial and technical support on improving efficiency of water use. Such funding could support research in Egypt by such organizations as the MWRI, the National Water Research Center (NWRC), the Agricultural Research Center (ARC), and the Ministry of Agriculture and Land Reclamation (MALR).

7.2.2 Enhancement of supplies

With population growth and the potential for reduced flow in the Nile, cost-effective options for enhancing supplies should be pursued. These options do not need to be developed immediately, unless they are already needed, but they should be kept open as options if they are needed in the future. This may involve research and development (R&D), keeping land use options open (e.g., to build a desalination plant or reuse facility), removing regulatory and institutional barriers to such options, and having financing available.

- *Desalination* is an option that is already being pursued in Egypt and may need to be enhanced because of climate change. Costs of desalination have been decreasing, thus making it more competitive. But desalination requires more energy and probably only is justifiable for providing water to coastal areas.

- *Reuse* is another option for enabling more to be done with existing supplies. Water applied to irrigation need not meet the same standards as drinking water. Water that has been used for municipal, industrial, or even agriculture uses can be treated to certain levels and used for internal uses, irrigation, or to maintain instream flow (although it should be treated to a level that supports aquatic ecosystems). We ran the agriculture analysis assuming a 1% increase in reuse from M&I discharges under the 2060 small flow reduction, no protection A1 scenario, and found that total welfare would increase by 1.5 billion EGP. A rule-of-thumb is that reuse can be applied for \$0.30/m^3 (1.65 LE/m^3; World Bank, 2009). Assuming 10 BCM are for M&I uses in 2060 under this scenario, then increasing reuse by 1% would cost 165 million EGP. Box 7.1 examines one option in detail: reusing treated wastewater discharges from household and industry use in the Nile Delta to free up water for irrigation consumption in or upstream of the Nile Delta. The box also considers desalination to provide for the water consumed by M&I use in the Nile Delta.

- *Additional groundwater usage is in general not a sustainable strategy unless it is being recharged*. With precipitation already low in Egypt and with projections of reductions in precipitation, recharge of groundwater could be reduced. Additional use of groundwater would likely result in a quicker depletion of such supplies.

- The SNC mentions *additional rainwater harvesting*. This could help along the Mediterranean coast.

- *Line water distribution canals*. In Egypt, during the summer, the main irrigation canals are estimated to lose some 1,500 million m^3 of water through seepage every year – approximately 10% of the water available for irrigation. Over the entire irrigation system, losses to conveyance, seepage, and extravagance in water utilization amount to 17% of the water delivered (Goldsmith and Hildyard, 1984).

One general point that can be made about many, if not all of the adaptations on water resources and on other sectors, is that the adaptations identified above can be justified without consideration of climate change. The extremely tight water supplies in Egypt, combined with growing demand, make more efficient use of water and enhancement of supplies imperative. Climate change presents yet another reason for making such investments and may hasten the time when these investments need to be made.

Box 7.1. Reuse and household and industrial water and desalination for irrigation in the Nile Delta

We estimate costs of reusing and desalinating as much household and industrial (M&I) water as possible to free it up for agricultural consumption. Direct water reuse options, defined here as the treatment of wastewater to a quality that is suitable for potable use, for Middle and Upper Egypt, was not examined since reuse in cities along the Nile except at the mouth would not increase the overall water balance for the Nile. This is because we assume non-consumed water is returned to the Nile. Therefore, we only consider (1) replacing M&I water withdrawals as much as possible in the Nile Delta areas because we assume otherwise this water is lost to the Mediterranean, and (2) desalinating some water in the Nile Delta and piping it upstream. Our preliminary analysis found the latter to be very expensive. For example, piping 5 BCM/year upstream to Cairo would have a capital cost of $400 billion and annual operating costs of $82 billion (at $0.08/kWh). All costs are in 2012 USD, representative of construction costs in Egypt, and assume electricity costs $0.08/kWh. The capital and annual operating costs of the associated 5 BCM/year desalination plant would be $62 billion and $3 billion, respectively. Therefore, we only estimate the cost of supplying the Nile Delta region with reused M&I water and desalinated water.

According to the MWRI (2005), all urban areas are projected to have wastewater treatment plants (WWTPs) by 2017. We assume that in the Nile Delta cities, wastewater will be treated to secondary wastewater treatment standards and will be discharged into the Mediterranean Sea. Here, as an adaptation option, we estimate the cost of additionally treating all the Nile Delta wastewater to advanced WWTP levels, and then piping it 10 km upstream and discharging it into the Nile, where it would flow downstream and be used again by the downstream cities. We further assume that enough desalination is put in to provide an amount of water equivalent to the amount of water consumed by M&I. In this way, all the water currently withdrawn by Delta cities would be made available for upstream consumption.

The analysis uses estimated M&I use under Scenario 2 in 2060 (see Table 6.18), assuming the small reduction in Nile flow, the A1 scenario, and no protection against SLR. The Nile Delta M&I withdrawal is 17.2 BCM/year, consumption is 3.4 BCM/year, and wastewater is 13.8 BCM/year. We estimate the cost of advanced wastewater treatment for 13.8 BCM/year and pump it 10 km upstream for discharge into the Nile. We also estimate the cost of desalinating 3.4 BCM/year. Costs are included in Table 7.1. The level of accuracy of these cost estimates based upon the range of observed cost estimates for existing large-scale desalination facilities (0.14 BCM or larger) is +/- 50%. The level of accuracy of these cost estimates based upon the range of observed cost estimates for existing, extremely large water pipelines (0.2 BCM or larger) is an order of magnitude. The accuracy of these cost estimates based upon the actual 2012 cost ranges of water reuse facilities greater than 0.14 BCM is +/- 50%.

Table 7.1. Estimated costs for reuse of the Nile Delta M&I and desalination (billions USD)

	Fixed capital costs	Annual operating costs
Advanced wastewater treatment (13.8 BCM/yr)	$65	$6
Pipeline and pumping (13.8 BCM/yr)	$60	$7
Desalination (3.4 BCM/year)	$42	$2
Total costs	$167	$15

7.2.3 Water management

Among the important issues facing Egypt is management of the HAD. If flows appear to be decreasing, perhaps flood management margins could be decreased. If flows increase, then an issue is what should be done with the excess water. The SNC mentions further developing storage options in Egypt in locations such as Toshka and the Quattara Depressions. Another possibility that is often overlooked in the literature is increased variability. It is possible that flows could also fluctuate between higher and lower flow levels on seasonal and annual cycles. Since reservoirs are designed to manage the flow variability at a particular site, increased variability would lower the yield. Part of the present proposed Nile management strategy is to use seasonal river flow forecasts, which has the potential to partially recover the decreased yield. Adding storage at other sites or using the water conjunctively with groundwater could increase yield relatively inexpensively.

Water management can also involve improved planning for extreme and long-term changes in climate conditions. Egypt should have a drought management plan. If one already exists, it should account not only for increased demand, e.g., from population growth, but also for the possibility of more intense and frequent droughts if Egypt's climate becomes hotter and drier.

An integrated water management strategy for Egypt is needed. It should account for current risk and potential changes in those risks from climate change. As with a drought management plan, if a water management plan already exists, then it should be evaluated in light of climate change to see if adjustments, changes, or contingency plans are need to cope with climate change risks.

7.3 Agriculture

Two of the main adaptations for agriculture are discussed under water resources: improving irrigation efficiency and developing more drought-tolerant crops. There are other adaptations in the agriculture sector that are briefly discussed below.

In many respects, the role of government in adaptation of the agriculture sector is a role of facilitating change by what is basically a private sector activity. This is in contrast to sectors such as water resources, where the government builds and manages infrastructure and allocates supplies.

Among the possible government roles in facilitating agriculture adaptation are:

- *Enhanced efforts to improve irrigation efficiency*. With agriculture currently consuming about 85% of Egypt's total water use, the population growing, and substantial risk of reduced supplies, it is imperative that water be used more efficiently in Egyptian agriculture. This could involve more support for transfer of water-efficient technologies.

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Private or government financing may induce greater use of such technologies. Increased information on benefits of such technologies may spur more investment in irrigation efficiency. More R&D may be needed to develop better technologies and practices that would reduce irrigation demand. With regard to R&D, there is a global need for more efficient use of water resources. Egypt may wish to increase participation in regional and international R&D efforts.

- *Develop more heat- and salinity-resistant or tolerant crops*. Many crops such as grains have optimal temperatures for growth. Above these amounts, growth can decrease. The development of new varieties, potentially including genetic modification of crops, may be able to increase heat tolerance of crops. Another option is to use varieties from other locations. With SLR making aquifers more saline, increasing salt tolerance could also reduce yield losses in those parts of the Nile Delta that face risk of inundation. Note that even if coastal agriculture areas are defended through use of physical structures to block the sea, higher sea levels can still result in increased salinity in aquifers. Using fresh or reclaimed water to flush out the saline water could maintain the quality of the aquifers. Given how limited fresh water may be, this option may not be feasible. As with the development of new water technologies and practices, this also creates technological needs that are faced by many countries. Thus, it may be much more cost-effective for an international effort to take on the development of new crop varieties that are better adapted to climate change.

- *Enable or otherwise support crop insurance*. Insurance can help farmers cope with poor production years. As noted above in the coastal section, the insurance industry can also help improve practices. Private sector funding should be encouraged. There could be a role for the public sector in removing institutional barriers and possibly providing some financial support for insurance. There is an interesting public-private partnership in Ethiopia that increased farmers' access to crop insurance. The Horn of Africa Risk Transfer for Adaptation (HARITA) project was a joint effort by Oxfam America, Swiss Re, and others to develop a risk management package for farmers in Ethiopia (Oxfam America, 2009). The program includes a mix of risk reduction, insurance, and credit products to reduce vulnerability to weather and climate risks.

- *Increase yields*. Higher production would make it easier for Egypt to bear the crop reductions resulting from climate change. This is because the reductions would be coming off a higher base level of production. As noted below, if this is combined with lower population growth, the benefit is even greater. We tested two scenarios of change in crop yields. The "fast" scenario assumed that crop yields would increase by 2.1% per year. The "slow" scenario assumed that crop yields would increase by 1.0% per year. In 2060, a small decrease in Nile flow scenario and no protection against SLR, the fast scenario results in an annual gain to total welfare of 22 billion EGP or 1.3% above the slow scenario. We also tested the slow versus fast crop yield assumptions assuming no change in Nile flow, but changes in crop yields. In this case, the assumption of faster increase in crop yields results in a welfare gain of 71 billion EGP or 4%. This suggests that a reduction in the flow of the Nile reduces the gain from higher crop yields.

- *Allow more agriculture imports*. We tested the effect of allowing imports to increase by ten-fold as an adaptation to climate change. Allowing more imports into Egypt would result in more agricultural products being available and would lower prices. This would benefit consumers although farmers would face lower prices than with restrictions on imports. This would result in a net welfare improvement for Egypt. The higher import levels would reduce the estimated 25 billion EGP loss in total welfare in 2030 under the small Nile flow and pessimistic scenario by 2 billion EGP. By 2060, however, the higher import levels would reduce the estimated 112 billion EGP annual welfare loss by 40 billion EGP. To be sure, allowing more imports would most likely make Egypt more exposed to fluctuations in international agriculture prices.

- *Address food subsidies*. Egypt has been subsidizing these costs for more than six decades. The World Bank (2010a) estimates that in 2008/2009, food subsidies cost 21 billion EGP, about 2% of GDP. With population growth alone, we estimate that the size of the subsidy would increase by 32% in the optimistic scenario and by 49% in the pessimistic scenario by 2030. By 2060, the increases are estimated to be 50% and 77% in the optimistic and pessimistic scenarios, respectively. Climate change is estimated to reduce the subsidies because it reduces agriculture production and consumption. For the small Nile flow reduction scenario under pessimistic socioeconomic conditions, the reduction is 5% in 2030 and 18% in 2060. This is not necessarily good news because there will in all likelihood be more hungry people under these scenarios. Nonetheless, reducing or eliminating food subsidies would help the agriculture markets become more efficient and encourage more output by farmers. Such changes would improve the government's financial stability.

7.4 Tourism

The tourist industry should consider potential risks from climate change and work with the government to develop strategies for reducing vulnerability to climate change. As noted in Chapter 4 on methods, it is very difficult to project how tourism will be affected by climate change. This suggests that the industry should be aware of risks from climate change and develop appropriate contingency plans. Given the uncertainty, it may be prudent for the industry to monitor tourist behavior. *Surveys could be used to determine what factors affect tourist choices and whether climate-related factors, such as heat, beach erosion, or quality and quantity of water supplies, affect decisions on selection of destinations*.

The government should consider the importance of tourism in allocating water resources and in coastal planning. Tourism is of such high economic value that adequate water supplies for future tourism need to be secured. Coastal planning should consider the critical importance of protecting tourism facilities from SLR and changes in coastal storms. This should be done in a manner that protects the attractiveness of tourism facilities. So, pumping sand onto beaches would much better project the attractiveness of tourism facilities than would hard structures such as sea walls.

7.5 Human Health

This study only examined vulnerability of human health to deterioration of air quality. There are a number of human health risks from climate change that should be part of an adaptation effort.

What is generally recommended on adaptation to climate change risks to human health is to develop or maintain a strong a public health system (Frumkin et al., 2008; Ebi, 2009). A strong public health system can significantly improve a society's capacity to address current and future risks to public health.

Efforts to control air pollution emissions need to be enhanced. Egypt already has tremendous problems with air quality. Emissions of air pollutants and precursors will need greater controls along with encouragement of behavior such as use of mass transit. Such measures can be expensive, but the expenses should be compared to current and future costs of air pollution. As noted in Chapter 2, the World Bank (2002) estimates that 20,000 people per year die because of high air pollution levels and air pollution costs Egypt 1% to 3% of GDP. In addition, more reliance on mass transit would reduce time spent in traffic.

Water quality is also of concern and higher temperatures and reduced flows could further degrade water quality. *Proper treatment of effluent and efforts to control non-point sources such as runoff from farms are needed*.

With higher temperatures, heat stress will likely increase (e.g., Kalkstein and Tan, 1995). *Heat watch warning systems and access to cooling centers* have proven to reduce risks to human health from heat waves (Ebi et al., 2004).

Risks of increases in infectious disease such as malaria are possible from climate change. To be sure, hotter and drier conditions should in general reduce such risks. Adaptations such as increased use of irrigation can provide sources of water for breeding of mosquitoes that can spread malaria and other diseases or breeding of other hosts such as snails that can spread schistosomiasis. One adaptation is to *ensure that surveillance systems that can detect and warn about the emergence and spread of diseases are adequate*. If current systems are inadequate for monitoring current or future risks, they should be enhanced. In addition to surveillance systems, the public health system needs to be able to respond to outbreaks of disease. This requires sufficient training, communications, and access to necessary medicines.

7.6 Coastal Resources

SLR and consequent inundation and salination of surface and groundwater threaten Egypt's coastal areas. Sea level is going to continue rising; the uncertainty is how fast.

As with water resources, comprehensive planning can help identify needs and set priorities. Egypt is engaged in *development of an ICZM Plan*. As with all plans, they need to be regularly updated to reflect changes in conditions and new science. Coastal zone planning should consider the real possibility that SLR could greatly exceed the IPCC's 2007 projections. Planning for at least one meter of SLR by 2100 and possibly two meters may be prudent.

The risks of SLR to settlements and other uses of coastal areas need to be considered. Among the choices that need to be made are whether further development of low-lying coastal areas can be justified and whether such areas can be protected from SLR. In addition, for existing coastal development, one of the key choices is whether to protect such areas from SLR, accommodate SLR, or move settlements or other activities further inland. Within each of these choices, there are additional choices. If it makes sense to protect, how much should be spent on protection and what amount of risk of inundation or failure of the protection measure is acceptable?

Among the factors that can be taken into account in making such decisions are:

- What is the capacity of existing coastal protection infrastructure such as the Mohamed Ali Seawall to provide an acceptable level of protection from SLR? Such an analysis should consider not just mean sea level, but tidal fluctuations and storm surge.
- What is the value of existing (and potential future) development of the coast? This is an important, although controversial factor, because more valuable land uses can justify more expensive protection measures.
- What are the options for protecting vulnerable coastal areas? How effective would they be, how much would they cost, how feasible are they, and do they cause other problems? For example, hard structures can hasten erosion and harm wetlands and mangroves.

A comprehensive and consistent analysis of the risks from climate change and options for protecting all of Egypt's vulnerable coastlines can serve as the basis for the national plan on adapting to SLR.

The SNC also suggests consideration of the following options for adaptation in the coastal zone:

- Creation of wetlands in vulnerable areas. In general, use of natural measures such as wetlands or dunes should be examined as a way to provide protection from SLR.
- Reinforcing hard structures such as the Mohamed Ali Seawall and coastal roads. Although not mentioned by the SNC, we recommend also examining consequences of use of hard structure to protect coastal areas (e.g., increased erosion, harm to wetlands).
- Enhance the work of Coastal Zone Management Committee to formulate an ICZM plan.

Other options for adaptation include

- Expand marine protected areas
- Redirect growth away from vulnerable areas
- Develop strong monitoring and enforcement system to ensure implementation of adaptation measures.

Another measure that can promote adaptation is the enhanced use of private insurance. Insurance can provide protection to property owners against harm to coastal property and, in particular, structures. The insurance industry has an incentive to encourage behavior that reduces risk. If risk gets too high, the industry can withdraw coverage, which will discourage development in vulnerable areas.

7.7 Migration

The studies project that agricultural employment could decrease by 5 to 37% by 2060. By that time, assuming that agriculture employs about 9 million people, the same number currently employed in agriculture, several million people could lose their jobs in agriculture. To be sure, it is possible that agriculture becomes more efficient in coming decades and fewer people are employed.

This study did not analyze where the unemployed would go. It seems quite plausible that many unemployed might emigrate to urban areas or out of Egypt. Such a movement of people could stress urban systems, increase unemployment, or lead to a loss of labor from Egypt.

Migration from rural to urban areas is already a concern for Egypt. Climate change could accelerate the movement of people. *The government should plan for the potential of a higher amount of migration from rural to urban areas and the need to make new urban settlements sustainable*.

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7.8 Population and Income Growth

This study tested two rather extreme scenarios of population growth. One scenario, the pessimistic scenario, corresponded to the high scenario in the SNC and results in a doubling of population by 2060 to about 160 million people. The other scenario, the optimistic scenario, which corresponds to the low scenario in the SNC, stabilizes Egypt's population at below 115 million. The optimistic scenario assumed a much higher growth in per capita income than the pessimistic scenario. The result of these two different scenarios is that Egypt would be much less vulnerable to the effects of climate change should it develop under the optimistic scenario than the pessimistic scenario. The effects of climate change on agricultural production, prices, and consumer well-being are lower under the optimistic scenario than under the pessimistic scenario. As noted in Chapter 5, the United Nations "Medium Variant" projection for Egypt's population in 2060 is 128 million. If this is accompanied by income growth rates between the optimistic and pessimistic assumptions, then we can presume that impacts of climate change would also fall between the two more extreme scenarios. *This implies that policies that can lower population growth and increase per capita growth can reduce Egypt's vulnerability to climate change*.

7.9 Development of a National Adaptation Plan

This section discusses the development of a National Adaptation Plan, incorporating climate change into other plans, and briefly reviews Bangladesh's National Adaptation Plan.

7.9.1 Need for a National Adaptation Plan

While adaptation needs to be dealt with in sectors, an argument can also be made to try to address it comprehensively. Government adaptation appears to be most successful when there is a strong and coherent call for action by a chief executive (Smith et al., 2009). A call for action sends a clear signal across the government that adaptation is important and that cooperation is needed.

A National Adaptation Plan, while being more difficult to develop than plans at a ministry level or sector level, has the advantage of having all relevant ministries and departments participate. If done well, a national plan can send a clear signal that adaptation to climate change is a priority of the government. It can also help foster needed coordination on management of resources vulnerable to climate change across ministries, across different levels of government, and with nongovernmental organizations.

Another general point about adaptation is the importance of stakeholder involvement in adaptation planning. If adaptations are not developed and implemented with the active cooperation of stakeholders who are at risk from climate and whose involvement is needed to ensure success of adaptation, then adaptation efforts can fail. Stakeholder involvement in adaptation planning is needed at multiple levels including the community level, sub-Governorate level, Governorate level, and national level. Appropriate regional planning may be needed such as with Governorates in the Nile Delta and Governorates in greater Cairo.

In general, many of the adaptations discussed below are probably ones that could be justified even if the climate were not changing. With a growing population and income, Egypt clearly needs to improve the efficiency of its water management system. The Nile Delta has been subsiding for decades, thus making it imperative to examine whether coastal areas should be protected, and if so, how. With the size of land holdings in agriculture decreasing, helping farmers become more resilient to climate variability and other changes in market conditions has become more imperative over time. Air pollution already poses serious risks to human health. Maintaining the sustainability of tourism is very important for the future of Egypt's economy.

Nonetheless, climate change can accelerate the need for dealing with these current challenges. In addition, climate change may pose some new challenges such as loss of coral reefs.

7.9.2 Incorporating climate change into existing planning processes

Besides developing a National Adaptation Plan, consideration of climate change should also be incorporated into national and sector level plans. National plans address management of resources and development of areas and sectors that will be affected by climate change. Plans for sectors that can be affected by climate change should examine the potential consequences of climate change and adaptations.

Egypt's update of its Five Year Plan should discuss climate change adaptation and what it means for specific objectives and projects. In addition, Egypt should also be sure to fully incorporate climate change into appropriate sector plans such as those on:

- Water resources
- Agriculture
- Coastal resources
- Tourism
- Human health
- Biodiversity
- Fisheries.

7.9.3 National climate change adaptation plans in other countries

A number of other countries have prepared National Adaptation Plans. Bangladesh published theirs in 2008 (MoEF, 2008). Since most of Bangladesh lies in a coastal plain, it is quite vulnerable to SLR. Increased intensity of cyclones and melting of Himalayan glaciers also pose significant risks to the country.

Bangladesh's adaptation strategy has six focal areas:

1. Food security, social protection, and health
2. Comprehensive disaster management
3. Infrastructure development
4. Research and knowledge management
5. Mitigation and low-carbon development
6. Capacity building and institutional development.

The adaptation strategy states that Bangladesh, with the support of development partners, has already spent $10 billion on adaptation including projects on flood management, strengthening coastal defenses, building shelters, and raising roads and highways. The government estimates it will need about $5 billion over the next five years for such investments as disaster management, research, capacity building, public awareness, and improving drainage and evacuation infrastructure. The government started a National Climate Change Fund, with an initial funding of $45 million, which will focus mainly on adaptation. The fund can receive contributions from development partners. The plan states:

> Adaptation to climate change will place a massive burden on Bangladesh's development budget and international support will be essential to help us rise to the challenge…. Bangladesh is seeking the strong political commitment and support of the international community to assist in implementing its long-term climate-resilient strategy. We call on the international community to provide the resources needed to meet the additional costs of building climate resilience.

A National Steering Committee on Climate Change was created under the Prime Minister's office. The Ministry of Environment and Forests manages the Climate Change Secretariat, which supports the National Steering Committee.

7.10 Coordinate and Enhance Data Gathering and Monitoring

Developing and managing an integrated adaptation plan will more likely be successful if supporting activities such as data gathering and monitoring are coordinated. In this study, we used data from a number of sources within the Egyptian government, including CAPMAS, the

Agriculture Research Center, and MWRI. Successful implementation of adaptation measures such as improving the allocation and efficiency of use of water will require coordinated and effective data gathering and monitoring. Managing these activities out of different ministries and organizations makes it more likely that different standards will be applied to data gathering. Having a single data source would help ensure consistency of methods and data.

In addition, monitoring networks should be assessed with regard to their capacity to identify emerging trends or even surprises. For example, it will be important to carefully monitor trends in climate, particularly extreme events such as drought. Monitoring of emergence of pests and diseases, which can affect human health or agriculture, may be critically important.

7.11 What Will Adaptation Cost?

This study did not develop cost estimates for each adaptation identified above. We briefly examine other studies which have attempted to estimate total adaptation costs.

Two approaches have been taken to estimate adaptation costs for Egypt. One approach involves developing adaptation estimates specifically for Egypt. The second approach is a "top down" approach that builds on estimates of total annual adaptation costs in all developing countries or regions. We calculate Egypt's share of the total using population to allocate among countries.

We first review the estimate of adaptation costs developed by the Government of Egypt. Under the auspices of the UNFCCC, the Egypt Environmental Affairs Agency published, "National Environmental, Economic and Development Study (NEEDS) for Climate Change" (EEAA, 2010b), and estimated adaptation costs for the agriculture and coastal sectors. The conclusions are displayed in Table 7.2. The costs are estimated for 2020 and 2050. This results in an average annual cost of $100 to $270 million (with annual costs estimated to be higher through 2020 and then lower in the next three decades).

The Egypt NEEDS study only covers two sectors, although as noted above, addressing irrigation is a key component of the water resources sector as well as agriculture.

Adaptation in the irrigation sector is the highest cost component. Adaptation for M&I water use, human health, and tourism are not included.

We now turn to the "top down" estimates. Table 7.3 presents two recently published estimates of the total annual costs of adaptation in all developing countries, by the UNFCCC (2007) and the World Bank (2010b). To be sure, both estimates were derived using simplified assumptions about the impacts of climate change and the costs of adaptation. Thus, both estimates should be treated with a high level of caution. A very simple approach for using these studies to estimate adaptation costs in Egypt is to assume that the estimated annual costs of adaptation by 2030 are

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Table 7.2. Estimated adaptation costs from Egypt NEEDS study

	Cumulative finance needed (million USD)	
Program	**2020**	**2050**
Observation and control of climate change	90	210
Land and agriculture production	311	948
Irrigation	2,055	2,150
Socioeconomic studies	16	28
Capacity building, enlightenment, and training	17	51
Coasts and seashore regions	330	620
Total	**2,819**	**4,007**

Source: EEAA, 2010b.

Table 7.3. Comparison of published estimates of developing country adaptation costs (billions USD per year in 2030)

Sector	UNFCCC (2007)	World Bank (2010b)
Agriculture, forestry, fisheries	7	6
Water resources	9	11
Human health	5	3
Coastal zones	5	29
Infrastructure	2–41	29
Extreme events	–	7
Fisheries	–	2
Ecosystem	–	–
Total	28–67	80–90[a]

a. Range is from the World Bank (2010b) report. Estimates by sector are based on reported numbers for the 2020s and 2030s.

spread evenly across population in developing countries. There are about 6 billion people in the developed world. Assuming Egypt's approximately 80 million people receive the same share of adaptation funding as all other people, then annual adaptation costs in Egypt would be approximately $400 million to $1.2 billion.

To develop estimates that were used in the UNFCCC (2007) report, Kirshen (2007) estimated how much additional infrastructure would be Adaptation Options and Cost in Water Supply needed to meet water supply shortages of individual countries in 2050. The climate change

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scenario is not the same one used in our analysis of climate change. He also assumed that water use would increase with population and economic growth and more than triple by 2050. To be sure, we do not expect this to happen mainly because neither Nile treaty obligations nor flow of the Nile would accommodate this growth. He assumed that to meet the needs of population and economic growth and climate change, an addition 560 million m^3 of storage would need to be built. This is approximately 0.3% of the storage capacity in Lake Nasser.

In contrast, Nelson et al. (2009) estimate the potential effects of climate change on global agricultural production in 2050. They estimate the cost of adapting global agriculture to keep malnutrition from increasing. Their estimates of adaptation costs are included in Table 7.4. About $3 billion of the $7 billion global annual investment in agriculture would be needed in sub-Saharan Africa. But $240 to $270 million is estimated to be needed in the Middle East and North Africa (MENA) region. Egypt's population is about 24% of the total population of the MENA region (which includes Iran; World Bank, 2012). If the costs are divided evenly by population, Nelson et al. (2009) estimate that $57 to $65 million per year is needed for Egypt to adapt. This estimate appears to be quite a bit lower than the World Bank adaptation study and the NEEDS survey. Without more detailed analysis, it is difficult to tell which estimate is more accurate. Our initial judgment is that the Nelson et al. (2009) estimate may be too low.

Table 7.5 compares the estimated adaptation costs in the four studies examined here. In general, the table suggests that there is substantial uncertainty about how much adaptation will cost Egypt in the next few decades. The three top-down approaches to estimating costs [i.e., UNFCCC, World Bank, and Nelson et al. (2009)] are well below the costs estimated through the country-based NEEDS survey. To be sure, the NEEDS survey did not address important adaptation sectors such as tourism and human health. Thus the total cost for adapting in all affected sectors in Egypt using the NEEDS survey method would likely be higher than the $3 billion per year estimate in Table 7.5. The top-down methods suggest that adaptation in Egypt would cost hundreds of millions to about a billion USD by 2030 (although the Nelson et al., 2009, estimate is well below the others). More detailed studies should be done to better refine these estimates and to see if there is confidence in this range of estimates.

7.12 A Broader Perspective on Adaptation

Specific steps on adaptation are discussed above. These can be thought of as the "micro" view on adaptation. These steps are important but insufficient to address adaptation. In contrast to the "micro" perspective adaptation is the "macro" perspective. While the "micro" is about specific measures, the "macro" concerns the level of development. It is a general rule of thumb in the adaptation community that wealthier nations are typically less vulnerable to climate change than less-wealthy nations. This rule of thumb also applies to communities within nations, e.g., wealthier regions or populations as opposed to less wealthy regions or populations.

Table 7.4. Estimated global and regional costs for agriculture adaptation

Scenarios	South Asia	East Asia and the Pacific	Europe and Central Asia	Latin America and the Caribbean	Middle East and North Africa	Sub-Saharan Africa	Developing countries
NCAR with developing-country investments							
Agricultural research	172	151	84	426	169	314	1,316
Irrigation expansion	344	15	6	31	-26	537	907
Irrigation efficiency	999	686	99	129	59	187	2,158
Rural roads (area expansion)	8	73	0	573	37	1,980	2,671
Rural roads (yield increase)	9	9	10	3	1	35	66
Total	1,531	934	198	1,162	241	3,053	7,118
CSIRO with developing-country investments							
Agricultural research	185	172	110	392	190	326	1,373
Irrigation expansion	344	1	1	30	-22	529	882
Irrigation efficiency	1,006	648	101	128	58	186	2,128
Rural roads (area expansion)	16	147	0	763	44	1,911	2,881
Rural roads (yield increase)	13	9	11	3	1	36	74
Total	1,565	977	222	1,315	271	2,987	7,338

NCAR: National Center for Atmospheric Research.
CSIRO: Commonwealth Scientific and Industrial Research Organisation.

Note that total amounts may not be consistent with sector estimates because of rounding errors.

Source: Nelson et al., 2009.

Table 7.5. Comparison of estimated adaptation costs for Egypt ($ millions per year) in 2030

Study	General adaptation	Agriculture and irrigation	Coastal resources	Total adaptation
NEEDS	180	2,680	425	3,215
UNFCCC	N/A	74[a]	N/A	400–960
World Bank	N/A	N/A	N/A	1,065–1,200
Nelson et al. (2009)	N/A	57–65	N/A	N/A

a. Results are not published in UNFCCC (2007) and would leave Egypt short of water

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The reason for this difference is not because the wealthy countries are less exposed to climate change. Like poor countries, wealthy countries will be affected by SLR, increased droughts and storms, extreme temperatures, etc. The reason the vulnerability differs is because in general, wealthier countries have a greater *capacity to adapt* to climate change. They can better absorb and respond to climate change than can poorer countries. The IPCC identified six "determinants of adaptive capacity" (Smit et al., 2001):

1. Economic resources (wealth)
2. Technology
3. Information and skills
4. Infrastructure
5. Institutions
6. Equity.

The determinants of adaptive capacity tend to be correlated with development. The more developed a country is, the more it tends to have these determinants. More developed countries have more wealth, access to better technology, access to information, better skills in their workforce, more expansive infrastructure, and better working institutions. It is unclear that equity is correlated with development, but inequity can limit adaptation. With these attributes, more developed countries have greater financial resources to invest in infrastructure, technology, or other attributes that can reduce vulnerability. They have the access to information and skills to help develop effective adaptation responses. Their institutions are better developed to organize responses to climate changes and extremes or to facilitate changes in livelihoods or locations.

Handoussa (2010) notes on page 89:

> There is a strong correlation between economic growth and poverty. Countries without economic growth or even a decline of GDP per capita were not able to reduce the number of the malnourished in their country and often even faced a considerable increase.

Thus, a higher GDP growth will in all likelihood reduce Egypt's poverty far more than a low economic growth rate.

A more developed Egypt would on the whole be less vulnerable to climate change than a less developed Egypt. This report presents two rather extreme paths for development. The pessimistic path has very high population growth and more limited economic growth (although even the assumptions about economic growth in that scenario are still somewhat optimistic). The optimistic scenario has very low population growth and very high economic growth. With lower population growth, demand for water would be lower and there would be fewer people to feed. There also would be fewer people affected by heat waves and pollution. As discussed in Chapter 6, under the pessimistic scenario the estimated economic losses are equal to about 4% of the projected GDP for Egypt. Under the optimistic scenario, the loss in terms of total EGP is only slight lower at 2% of projected GDP. This is approximately one-half the relative impact of climate change on the pessimistic scenario. So the pessimistic scenario is estimated to result in Egypt having greater exposure to climate change risks than the optimistic scenario.

Although not explored in this study, a wealthier Egypt would probably be much less vulnerable to climate change for several reasons. A wealthier country would be able to invest in more efficient water use technologies, thus reducing demand for water. In addition, wealthier countries will have more access to air conditioning, which will reduce the risk of heat stress (although also increase greenhouse gas emissions). A wealthier country will have the financial and institutional capability to control pollution through treatment of emissions and use of mass transit. Finally, a wealthier country is more likely to have a lower population growth than a poorer country.

Thus, development is an adaptation strategy. But the question remains, How should Egypt develop? That is beyond the scope of this study. One outcome is likely: whether through industrialization or expansion of the service sector, development will likely provide jobs to people from urban and rural areas. These jobs will likely pay more than farming and will reduce the pressures of population growth and limited arable land. With such development and wealth, Egypt could better afford to import food, thus further limiting demand for water for irrigation.

Two visions are laid out in this chapter: a "micro" and a "macro" adaptation vision. These are not mutually exclusive choices. It is imperative that Egypt develops to alleviate poverty and lift its standard of living. But it is also imperative in face of a changing climate that Egypt develops in a climate-resilient manner. It needs to avoid paths that increase reliance on resources that will be strained by climate change such as water and low-lying land. Thus, Egypt needs to develop in a sustainable manner.

7.13 Conclusion

Egypt faces serious risks from climate change. Unfortunately, international efforts to control emissions of greenhouse gases have had limited success. Even an ambitious greenhouse gas control program will still not avoid significant climate change. Thus it is imperative that Egypt prepares for the inevitable risks that climate change is expected to bring.

With significant risks posed by climate change, it is important that Egypt develops an adaptation strategy. There should be a strong sectoral component to its adaptation planning and to implementation of the plan. In our view, a coordinated national effort will ultimately be more successful.

The potential risks from climate change suggest the following priorities for adaptation. These adaptations will need to be made over coming decades if Egypt wishes to reduce its risks from climate change. The adaptations include:

- *More efficient use of water resources*. With a growing population and the real possibility of reduced water supplies from climate change, Egypt will have to use water resources more efficiently or face curtailment of uses. More efficient irrigation techniques, planting of less water demanding crops, and reducing M&I water use through lead reduction and adoption of more water-efficient technologies are one way Egypt can limit demand for water resources. Also, Egypt needs to improve the efficiency of water use for domestic and commercial uses.

- *Development of heat-resistant, drought-resistant, and salinity-resistant crops*. Crop yields are projected to decrease even if water supplies increase. Development of varieties that can maintain yields under higher temperatures or use more heat- or drought-tolerant varieties or crops could help narrow the reduction in crop yields and agricultural output.

- *Development of new supplies of water*. Desalination and reuse are among the technologies and management techniques that can either increase supplies (desalination) or effectively increase supplies (reuse). Desalination costs are now about \$0.50–0.70/m^3 (Miller, 2003; Dore, 2005), while reuse is about 1.65 LE/m3 (about \$0.30). Rain water harvesting should be encouraged near the Mediterranean where Egypt gets most of its precipitation.

- *Reduction of air and water pollution*. Current pollution levels are estimated to cause losses to human health and productivity equivalent to 3 to 6% of GDP. Climate change can increase particulate concentrations, leading to further equivalent losses of billions of EGP per year. It is already imperative that Egypt limits air and water pollution to reduce harm to human health and the environment. Climate change may mean that even stricter controls would be needed to meet the same levels of air and water pollution.

- *Protection of tourism*. Water supplies for tourist areas may need to be guaranteed. This may need to be done through increased use of desalination. Beaches in coastal areas may need to be nourished to offset the effects of SLR. While there is little that can be done to directly protect coral reefs from the adverse effects of higher temperatures and acidification of the ocean, reducing harm to coral reefs from pollution and habitat destruction can strengthen corals. One study suggests that higher temperatures may reduce tourism. Advertising the unique attributes of tourism in Egypt may create demand that is more tolerant of a warmer climate.

We note that many of the adaptations can be justified even without consideration of climate change. Nonetheless, the risks from climate change add more urgency to adopting these adaptations.

We expect that current development needs will take priority over consideration of climate change. The risks from climate change should not be overlooked. Many of the adaptations mentioned above may take years to decades to develop and implement. Furthermore, these adaptations may be justified even under current climate. Thus, there seems little reason to delay adaptation.

List of adaptation recommendations

The following lists adaptations that are discussed in this chapter.

Water resources

- Increase the storage if flow variability or runoff increases
- Develop a drought management plan for Egypt
- Develop an integrated water management strategy for Egypt
- Enhance the use of water market mechanisms to encourage conservation
- Pursue research in collaboration with other countries.

Agriculture

- Improve irrigation efficiency (international cooperation)
- Develop and use less water demanding crops (international cooperation)
- Support crop insurance
- Increase crop yields (international cooperation)
- Allow more imports if necessary
- Address food subsidies.

Tourism

- The tourism industry should work with the government to reduce risks from climate change
- Study how sensitive tourism in Egypt will be to changes in climate and related environmental conditions
- Allocations of water supplies should recognize the importance of tourism for economic growth and development.

Human health

- Egypt's public health system should be strengthened
- Enhanced efforts are needed to reduce air pollution
- Heat watch warning systems and cooling centers are needed to reduce the risk of heat stress
- Surveillance systems for monitoring outbreak of infectious diseases need to be put in place or enhanced to ensure they can identify infectious diseases that may emerge with climate change.

Coastal resources

- Develop an ICZM Plan
- Implement recommendations from the Egyptian Second National Assessment on projecting coastal resources, including:
    - Create wetlands in vulnerable areas
    - Reinforce hard structures such as Mohamed Ali Seawall and coastal roads.
    - Enhance the work of the Coastal Zone Management Committee to formulate an ICZM plan
- Expand marine protected areas
- Redirect growth away from vulnerable areas
- Develop a strong monitoring and enforcement system to ensure implementation of adaptation measures.

Cross-cutting adaptation policies

- Develop a National Adaptation Plan with detailed costs, implementation, and metrics.
- Coordinate and enhance monitoring and data collection efforts in support of implementing adaptation measures.
- Plan for the potential for increased migration to urban areas from rural areas.

- Support development. In particular, support policies that limit population or increase per capita income while reducing the use of natural resources such as water and coastal lands that are threatened by climate change.
- Seek international cooperation and financing opportunities for adaptations.

8. Research Needs

This chapter briefly identifies research needs to better understand the potential impacts of climate change on Egypt and to improve the understanding of the benefits and costs of adaptation measures. The chapter first identifies research on vulnerability and then turns to adaptation.

8.1 Research on Vulnerability

Most of the research on climate change impacts on Egypt has focused on water resources, agriculture, and coastal resources. As has been shown in this analysis, climate change may have larger economic impacts on water resources and agriculture than on any other sector. While the impacts of SLR on agriculture were estimated to be small, the potential impacts on settlements, antiquities, and other resources and sectors such as tourism are likely to be quite substantial.

8.1.1 Water resources

Our study was based on an assessment of climate change impacts on the Blue Nile. Future research on the potential changes in Nile flow should also examine the White Nile and Atbara rivers. Such studies should also consider potential changes in demand throughout the entire Nile Basin.

The research has tended to focus on changes in mean conditions. The climate models also project changes in variability such as consecutive years of below normal flow. The consequences of changes in variability should also be studied.

The management of water resources is discussed in the adaptation section.

8.1.2 Agriculture

Research on impacts of climate change on agriculture needs to be sure to carefully account not only for the direct effects of climate but also carbon fertilization.

The potential impacts on many different types of crops and crop varieties should be analyzed.

Research should also address how changes in land use, e.g., conversion of agriculture to urban uses, affects water use.

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8.1.3 Coastal resources

There are a number of critical vulnerabilities in coastal resources to SLR. Studies to date have examined vulnerability to published IPCC projections of SLR. However, recent studies suggest that total SLR could be much higher by 2100 than the IPCC projected (e.g., Oppenheimer et al., 2007; Pfeffer et al., 2008; Vermeer and Rahmstorf, 2009). Egypt should examine the vulnerability of its coastal resources to SLR scenarios of up to 2 meters. Topics for studies on coastal resources include:

- Estimate the value of property and other resources in detail at risk from SLR
- Assess costs and benefits of protecting vulnerable coastal areas from SLR
- Examine the potential impacts of SLR on salinity of coastal aquifers, consequences for use of such waters, and costs and effectiveness of adaptation options
- Assess the impacts of SLR on coastal tourist resorts and the costs, effectiveness, and any adverse consequences of adaptation options.

In addition, an analysis should be done of use of natural systems, such as wetlands and dunes, to protect coastal resources from SLR.

8.1.4 Human health

Our estimates of potential health impacts are based on studies on heat stress conducted two decades ago and sensitivity analysis on air pollution impacts. Nonetheless, we estimated thousands of additional deaths per year, but the estimates are quite uncertain. So, more research is needed on such human health topics as:

- *Heat stress*. Work specifically on risks Egypt faces from increased heat stress should be done to update the older studies.
- *Air pollution*. Modeling of potential changes in air pollution and consequences for human health should be conducted. To be sure, such modeling can be expensive as it can require application of downscaling and use of air quality models. The analysis should consider a range of alternative future development scenarios, including increased pollution from higher population and more emissions and imposition of controls to reduce emissions.

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- *Water quality*. Water quality can be degraded by climate change and this can have important consequences for human and ecological health.

- *Vector-borne disease*. Hotter and drier conditions could impede the spread of vector-borne diseases, such as malaria, but studies should determine if this applies to Egypt.

8.2 Adaptation

Perhaps the most important research need on adaptation is for a comprehensive assessment of adaptation needs and costs. To be sure, there is a good foundation of research to build on, particularly from the NEEDS survey for Egypt (EEAA, 2010b). The estimation of adaptation costs should examine a variety of sectors including health (which will include air pollution, water pollution, heat stress, and disease control), tourism, fisheries, ecosystems and biodiversity, and other sectors. It is likely that such an analysis will identify many adaptation options that will have benefits even if climate does not change. For example, controlling air and water pollution will have substantial benefits for the health and well-being of Egyptians under current climate conditions. Climate change will most likely result in greater benefits. Therefore, the estimate of adaptation costs should to the extent possible, separate out adaptations that are mainly to address current problems and adaptations that are mainly to anticipate climate change.

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