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Constructing “not implausible” climate and economic scenarios for Egypt

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A space of “not-implausible” scenarios for Egypt’s future under climate change is defined along two dimensions. One depicts representative climate change and climate variability scenarios that span the realm of possibility. Some would not be very threatening. Others portend dramatic reductions in average flows into Lake Nassar and associated increases in the likelihood of year to year shortfalls below critical coping thresholds; these would be extremely troublesome, especially if they were cast in the context of increased political instability across the entire Nile Basin. Still others depict futures along which relatively routine and relatively inexpensive adaptation might be anticipated. The ability to adapt to change and to cope with more severe extremes would, however, be linked inexorably to the second set of social–political–economic scenarios. The second dimension, defined as “anthropogenic” social/economic/political scenarios describe the holistic environment within which the determinants of adaptive capacity for water management, agriculture, and coastal zone management must be assessed.

Keywords: not-implausible scenarios, climate change, adaptive capacity

1. Introduction

Vulnerability analysis has progressed to the point where simple methods, designed specifically to help the research community come to grips with assessing the vulnerability of systems, can be applied to analyses of how these systems might adapt to a wide range of futures that cannot presently be ruled-out. Indeed, the next step should begin to focus attention on building representative collections of futures that are “not-implausible”. This attention will, of course, be informed by “first generation” impact *cum* adaptation analyses that reveal how various sources of cascading uncertainty might influence systems beyond baseline scenarios. It is in these preliminary analyses that we have identified the critical sectors whose adaptive capacities must be thoroughly modeled in the next round of analyses.

This paper is methodological in nature. It is designed to demonstrate how this next step might be accomplished by documenting the creation of a set of “not implausible” impact scenarios for Egypt. It will, more specifically, report the results of applying a vulnerability indexing scheme recently developed by Schimmelpfennig and Yohe [13] to vulnerable subsystems in Egypt. It will, as well, complement these climate scenarios with a set of “not-implausible” social–political–economic scenarios. The point of doing both is to show how vulnerabilities to climate might be evaluated within a diverse set of possible futures whose evolution would largely be the result of human activity, human decisions, and a plethora of non-climatic stresses.

The work presented here clearly accepts the notion that existing studies of Egypt have identified critical impact variables that are the sources of stress and which frame the associated adaptation questions. Strzepek and Yates (1995), for example, tracked several of these variables along a few selected climate scenarios; their results serve as the “first generation” foundation for this broadening exercise. Ranges of climate impacts drawn from COSMIC [see [14]] will be employed to sample across a wider range of “not-implausible” climate futures that from 14 different general circulation models (GCM’s), different climate sensitivities, different emissions trajectories, and different sulfate forcings. Yohe et al. [27] have already applied the method to traditional maize agriculture in Mexico where summer precipitation was the critical impact variable. The methodological development chronicled here will supply the foundation for a more integrated and multi-dimensional application to the coastal and agricultural zones of Egypt based on flows in the Nile, temperature in Egypt, and sea level rise along the northern coastline. The approach will offer the potential for good and bad news, depending upon how the future might unfold. It will offer insight into the timing of each. It will indicate which GCM supports which type of news along what type of emissions scenario. It will identify where careful exploration of the degree to which vulnerability might be diminished by autonomous or planned adaptation can pay the largest and most timely dividends. And it will suggest which set of social–political–economic scenarios might bring the best and the worst news.

Section 2 begins the presentation with a quick review of the earlier single variable application by Yohe et al. [27] to traditional maize agriculture in Mexico. Section 3 extends

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their methodology to handle a three variable case for Egypt. Internally consistent scenarios that track

(1) water flow into Lake Nassar from the upper Nile (derived from inserting COSMIC output into a reduced form hydraulic model of the entire basin),

(2) monthly temperature scenarios for Egypt (also drawn from COSMIC), and

(3) sea level rise only the northern coastline (correlated with mean annual temperatures in Egypt)

are derived and reported. Similarly diverse social-economic-political scenarios for Egypt are then described in section 4. Each is the product of contemplating the determinants of adaptive capacity – a notion that has evolved in the development Chapter 18 (Working Group II) of the Third Assessment Report (TAR) for the Intergovernmental Panel on Climate Change (IPCC). Smit et al. [16] laid the groundwork of adaptive capacity, and Yohe and Moss [28] offered the first suggestive list of discrete determinants. A concluding section finally suggests how representative climate and "anthropogenic" scenarios might all be combined to support a more comprehensive collection of integrated assessments of climate change in Egypt over the next century across a wide range of "not-implausible" futures.

It must be emphasized from the start that the methodological development described here has a practical motivation that cannot be ignored. The COSMIC program is capable of producing literally thousands of "not-implausible" climate scenarios that are internally consistent; but it would surely be imprudent if not impossible to conduct integrated analyses along each one. There is, in short, a fundamental need to limit the number of scenarios under study while still spanning the range of "not-implausibility". Nine scenarios will therefore be chosen and dubbed "representative", therefore; but care must be taken in interpreting this adjective. They will not be chosen to be representative in any statistically significant sense. They will, instead, be chosen so that they represent the diversity displayed by the multitude of internally consistent "not-implausible" climate futures that published climate models can produce. In this regard, the methodological development will be to show that this representative set of scenarios can be selected to display diversity along three critical variables for Egypt. Two will be specific to Egypt, but one will derived from a hydrolic model that takes inputs from precipitation and temperature scenarios for ten other countries in the Nile Basin.

2. Background – An earlier application to traditional agriculture in Mexico

Eakin [4] reported the results of a carefully crafted analysis of the potential impact of climate change on maize agriculture in Tlaxcala, Mexico. She noted, quite succinctly, that shortfalls in summer precipitation in excess of 50% of the mean for July and August spell trouble for the traditional maize agricultural sector of the area. Indeed, Eakin reported that associated yields below 2000 kilograms per hectar severely impact the communities that rely on this crop; and her work indicated that this coping threshold is crossed under present climate about 30% of the time. In summary, her work defined the limit of the coping range for this style of maize agriculture at a 50% reduction in rainfall below the historical, but not very reliable mean.

Yohe et al. [27] investigated changes in the relative likelihood of this severe event along 1134 "not implausible" scenarios of climate change dawn from 14 different GCM's along three alternative emissions scenarios with three different associated sulfate profiles, three different climate forcings, and three different sulfate forcings. These scenarios were drawn from the Schlesinger and Williams [14] COSMIC program. The mean trajectory of summer precipitation stayed above the 50% precipitation threshold for at least 50 years along more than 70% of these "not-implausible" scenarios. By then, however, the likelihood that precipitation in any one year would have fallen below the 50% coping threshold would rise from the current 30–35% by the year 2050 along the median precipitation trajectory. The same year-to-year likelihood would rise to 57% along a trajectory that would put mean precipitation at 50% of current levels by 2050 and to 90% along a trajectory that would put the mean at 30% of current levels.

Eakin also identified changes in the way maize could be grown in that are currently being encouraged by the Mexican government because making the change would make maize agricultural more drought resistant in the present climate. It would, as well, make growing maize more sustainable in future climates. Indeed, adopting these measures would lower the coping threshold, and thereby lower the likelihood of suffering a crisis along the three representative trajectories identified above to 20%, 33% and 50%, respectively. The correct way to read these results, of course, is not to conclude that community based maize agriculture will be sustained over the next half century across most of the "not-implausible" scenarios generated by COSMIC. It is, instead, to suggest that social, economic, and/or cultural stresses are more likely than climate to be the cause of fundamental change in the way maize is grown in Mexico. It should be noted that Downing et al. [3], Miller et al. [10] and Tol and Langen [22] reach the same conclusion.

For present purposes, then, there are two lessons to be drawn from this analysis of maize agriculture in Mexico. First of all, the technique of spanning "not-implausible" climate futures drawn from COSMIC is tractable, at least when these futures can be described in terms of change in one critical variable. Secondly, underlying social–political–economic scenarios can play a significant role in defining exactly how climate change might ultimately affect a society. These non-climate scenarios can, quite simply, go a long way in determining a society's adaptive capacity. The results reported here for Egypt take both of these lessons seriously. On the one hand, they are the product of extending the descriptions of "not-implausible" futures from one dimension to three. On the other, they carefully describe at least the broad outlines of a range of anthropogenic scenarios within which the vulnerability to the climate scenarios will be judged in terms of exposure to change and adaptive capacity.

3. Climate scenarios

Yates and Strzepek [25] identified flow in the Nile, local temperature in selected months, and sea level rise as the critical variables for tracking future climate change in Egypt. A variety of statistical and modeling approaches allowed COSMIC results to define a range of consistent "not-implausible" climate scenarios for each of these essential dimensions. This section describes each of these approaches in turn.

3.1. A stylized hydrologic model of the Nile Basin

The Nile River Basin covers roughly 2.9 million km^2, or almost one-tenth the area of Africa. It traverses some 6500 kilometers from south to north as it winds its way across the boundaries of ten different countries – Eritrea, Tanzania, Uganda, Rwanda, Burundi, Zaire, Kenya, Ethiopia, Sudan, and Egypt. The Nile is unique among the world's larger river basins, having one of the lowest specific discharges (average annual discharge divided by drainage area) of any of the major river basins of the world. In fact, the Congo Basin, which shares a common border with the Nile, has a specific discharge that is 10 times greater [12]. Only 1.6 million km^2 of the basin located below the confluence of the Atbara River and the Nile in northern Sudan contributes to streamflow due to the extremely arid conditions in the northern portion of the basin.

Climate fluctuations have dramatically changed both the structure and the regime of the River Nile, and it is only within "recent" times that the Nile has taken on its current hydrologic characteristics and its connectivity between Equatorial Africa and the Mediterranean Sea [12]. During the Holocene (Nabtian) Wet Phase (approximately 10,000 years ago), the flow regime of the Nile was many times greater than the present day discharge, and it is believed that this situation lasted about 6500 years and was the major force in carving the current basin configuration. As this period ended (3500 years ago), the rain front shifted south and the Sahara desert became the vast region that it is today. In more recent times (the past 120 years), climatological and Nile flow records have supported the correlation between the position of the Sahelian rain front and discharge from the Highland Plateau region of Ethiopia (the Blue Nile and Atbara Basins). Discharges have tended to increase when this front moves northward and decrease as the front retreats to the south [12].

The equatorial lakes region in the southern portion of the basin (the White Nile) is not highly correlated to the Sahelian front and is more influenced by equatorial circulation patterns [15]. There is no correlation in either precipitation or runoff between the White Nile and Blue Nile regions. However the unique hydro-climatic characteristics of the equatorial African region make it sensitive to climate variability. This region has exhibited particular sensitivity to marginal changes in precipitation [9,19,20].

The runoff across many regions of the Nile Basin is very sensitive to climate variations related to global circulation patterns. Increased atmospheric concentrations of greenhouse gases may change these global circulation patterns, so anthropogenically climatic change could cause significant variation in Nile flows. Several studies have been done to assess the impact of climate change on the River Nile. Gleick [5] evaluated the vulnerability of runoff of the Blue Nile Basin to climatic change using three General Circulation Models (GCMs). Two of the GCMs gave increases in runoff, while the third gave a decrease. Gleick [5] concluded that future climatic changes in the Nile Basin cannot be predicted with confidence, but there are indications that any changes would be significant and possibly severe. Hulme [6] studied current and future precipitation changes of the Nile Basin. During the period 1880–1989, the upper White Nile catchment, the upper Blue Nile catchment, and the Middle Nile showed a decline in total precipitation. A GCM scenario analysis for 1861–1988 showed overall warming of about 0.5°C. Conway and Hulme [1] also evaluated climate change impacts within the Nile Basin by directly applying three GCM scenarios. Their results showed changes in runoff of -0.2, -4.0, and $+12.2$ billion cubic meters (-0.2%, -5%, and $+15\%$, respectively). Conway and Hulme [1] concluded that the effects of future climate change on Nile discharge will further increase the uncertainties in Nile water planning and management, especially in Egypt. Strzepek et al. [18] used a spatially aggregated monthly water balance model along with the Thornthwaite method for computing potential evapotranspiration and reported that the Nile is very sensitive to climate change. Four GCM simulations showed two increases and two decreases in runoff, with one of the decreases greater than 70 percent of the annual flow! Yates and Strzepek [25], using a monthly water balance model, reported that five of six GCMs showed for doubled CO_2 levels increased flows at Aswan, with increases as much as 137% (UKMO). Only one GCM (GFDLT) showed a decline in annual discharge at Aswan (-15%).

3.1.1. An annual water balance approach to runoff modeling

It is important to keep in mind the difference between *precision* and *accuracy* in modeling when assessing methods for analyzing climate change impacts on hydrology. Models with very detailed spatial and temporal representations require much data resolved at detailed scale. These models provide very *precise* results of climate change impacts on the state of the hydrology of the basin. However, the COSMIC scenarios that describe the potential change in temperature and precipitation provide very coarse data at a national scale. These data are not very *precise*. If one uses this coarse national scale data to drive *precise* process models, the results maybe precise but will not be accurate, because the exact changes of climatic variables at the level of detail of the process model is not known. Therefore, a methodology for modeling hydrologic impacts of climate change was developed that matches the precision of the COSMIC generated climatic data.

Dooge [2] suggests using the lumped form of the continuity equation (1) for climate change impacts assessments at large hydrologic scales. When looking at the long-term water balance of a large catchment or region, an appropriate assumption is that the change in storage can be assumed to be zero. Therefore the water balance equation can be written as:

$$P_\mathrm{a} = Et_\mathrm{a} + Q_\mathrm{a}. \tag{1}$$

Given as annual long-term averages, P_a is the precipitation, Et_a is the evapotranspiration, and Q_a is basin runoff. Dooge [2] points out that, "any estimate of the effect of climate change on water resources depends on the ability to relate change in actual evapotranspiration to the predicted changes in precipitation and potential evapotranspiration."

Turc [7] attempted to relate precipitation and temperature to annual runoff. E.M. Ol'dekop developed a model in 1911 which relates precipitation, evapotranspiration, and potential evapotranspiration to runoff [2]. Pike extended the Turc model to a quasi "physically based" annual model using precipitation and potential evapotranspitation to estimate actual evaportranspitation. The Turc–Pike model holds that

$$\frac{Et_\mathrm{a}}{PET_\mathrm{a}} = \frac{P_\mathrm{a}/PET_\mathrm{a}}{\sqrt{1 + (P_\mathrm{a}/PET_\mathrm{a})^2}}, \tag{2}$$

where PET_a represents annual potential evapotranspiration. Using Turc–Pike together with the water balance equation (1), one is able to determine annual runoff volume. PET in this work is estimated using the empirical based Thornthwaite temperature model [21]. The methodology of the Turc–Pike and Thornwaithe models provide a relationship between annual runoff and precipitation and temperature, $R = f(P, T)$, the two climate variable provided from the COSMIC scenario generation tool. Yates [24] used this methodology for estimating climate change impacts on continental scale runoff for South America. Although developed within the context of specific hydro-climatic regions, the model does contain a calibration coefficient and can therefore be applied, with caution, to different basins on an annual basis.

Runoff is generated by the physical processes of precipitation, soil moisture, and evaportranspitation at the timescale of weather events, hours and days. Annual runoff is the difference between annual P and annual Et. Runoff occurs when ET_a is less than P_a. The Turc–Pike model is illustrated in figure 1a and shows that Et_a does not equal P_a even when PET_a is greater than P_a as the climate becomes semi-arid, thus generating runoff. Thus the Turc–Pike model is able to captures sub-annual runoff generating processes while using annual climate data. This is an important feature of the model that qualifies it to be used for large scale hydrologic analyses of climate change impacts.

3.1.2. A swamp model

One of the unique hydrologic features of the Nile Basin in southern Sudan is the massive wetlands and swamps known as the Sudd. The Sudd is made up three swamp regions, Bahr-El-Jebel, Bahr-El-Gazal, and Sobat. In the stylized hydrologic approach of this research the three regions are modeled as a single swamp. An annual model based on the approach of Sutcliffe and Parks [20] has been developed. Represented formally, their model holds that

$$Q_\mathrm{s} = Q_\mathrm{u} + Q_\mathrm{t} - \left[\alpha \times PET \times \left\{\frac{V_\mathrm{s}}{D_\mathrm{s}}\right\}\right], \tag{3}$$

where V_s represents water volume in the swamp, D_s reflects its depth, and Q_s, Q_u, and Q_t, describes runoff of the swamp basis, tributaries, and any upstream basins, respectively.

3.1.3. Modeling runoff from the Nile Basin under climate change

A Nile hydrologic model was developed and calibrated applying the methodology described above with the climatic data from COSMIC. The Nile Basin was divided into 5 hydrologic regions: The Equatorial Lakes, Sudd Swamp Region, White Nile, Ethiopian Highlands, and the Desert Reach. Figure 2 shows the regionalization. The first region contains the tributaries to the Equatorial Lakes, and so it includes the countries of Burundi, Kenya, Rwanda, Tanzania and Uganda. Moving northward, the Nile flows out of the lake region, past Mongala and into the vast Sudd swamp region – the second hydro-climatic zone. At Malakal, the Nile flow represents the net quantity of water coming from the equatorial lakes, as well as the Bahr-el-Ghazal and the Sobat Rivers and represents 30% of the flow reaching Aswan. This flow is almost evenly distributed over the entire year. In this stretch from Malakal to Atbara, the White Nile flows northward through the Sudan plains where it loses water to the aquifer system. The Sudan and Ethiopian Highlands, which comprise the Blue Nile and Atbara catchments where 70% of the flow reaching Aswan originates lie to the west of the Sudan Plains. The flow here is concentrated during the three months of the summer monsoon. Finally, and below the confluence of the Atbara, the climate becomes a hot, desert environment with little rainfall. From Atbara to Aswan, the Nile loses almost seven percent of its flow to seepage to groundwater. For this analysis this fifth region extends from the mouth of the Atbara Basin in the north-central area of Sudan to Dongala in Northern Sudan the southern most part of the Lake Nasser, the reservoir behind the High Aswan Dam in Egypt. Lake Nasser has a storage capacity of three times the average annual flow of the Nile.

The Turc–Pike model was calibrated for the Equatorial Lakes, Ethiopian Highlands, and the Sudd Swamp Tributaries catchments. The temperature and precipitation used

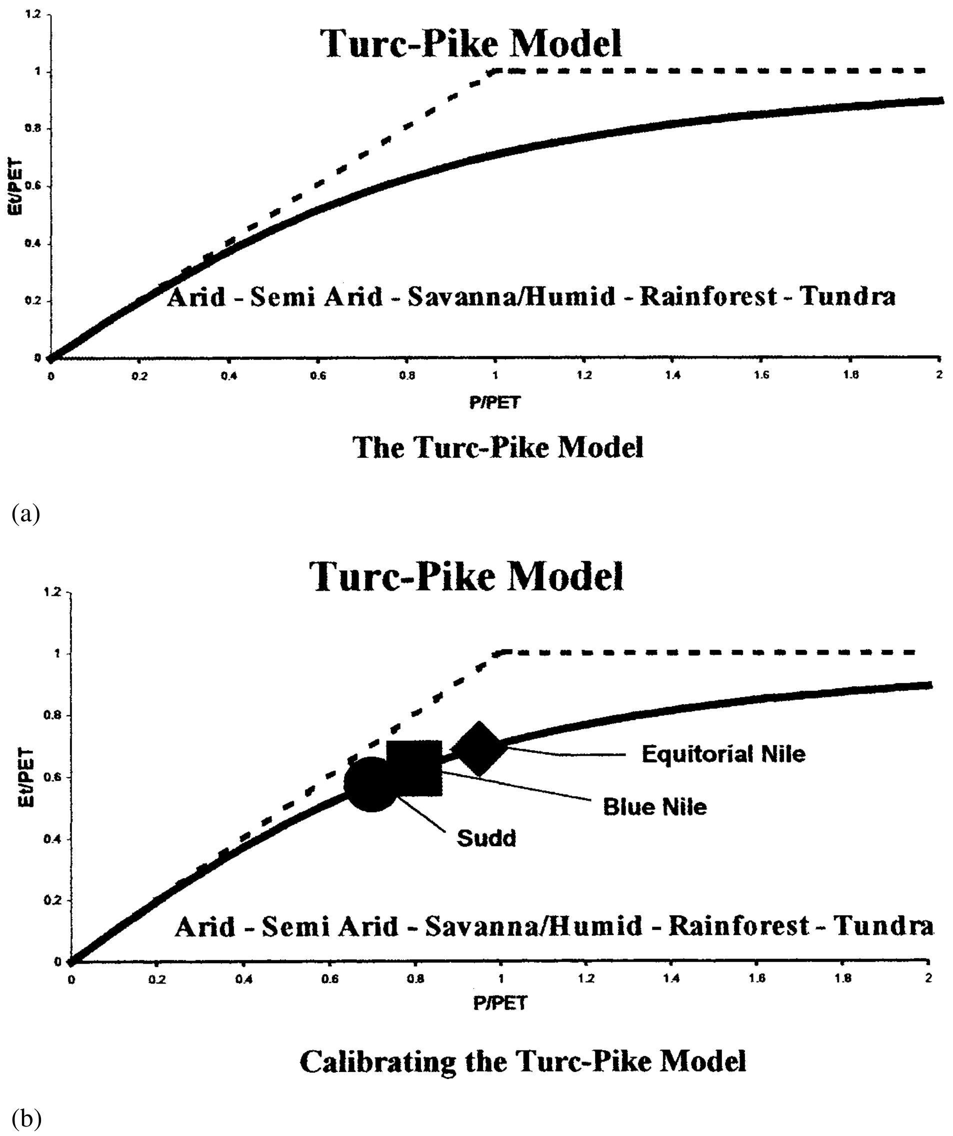

Figure 1. The Turc–Pike model.

for each catchment came from weighted averages of COSMIC bases national climatic data. Figure 1b displays the calibration, and table 1 presents the mapping of COSMIC national data into catchments for the model.

The outflow of the Sudd Swamp region was calibrated to the outflow of the Swamp Model. The total swamp area closely matched the observed historic total for the three subregions area [12]. For the White Nile and Desert Reaches, regression relationships were used to route flows between gauging stations along the main stem of the Nile. Along these portions of the Nile River, there is a net loss in flow due to seepage and evaporative losses.

Detailed results are presented in the following section. This modeling exercise supports previous findings that change in precipitation and to a lesser extent temperature over the Nile Basin could have serious consequences on regional water resources throughout this large African Basin. The hydrologic model showed the strong response of the Nile to climate variability and pointed to the real issue: *runoff is a by-product of two larger processes – precipitation and evapotranspiration and understanding the nature of these two climate variables is critical.* Should long-term average precipitation and temperature patterns change over Equatorial Africa, there would be considerable change in the

Table 1
Mapping of cosmic climate data to runoff model basins.

Runoff model basin	Cosmic national data	
	Temperature	Precipitation
Equatorial lakes	Uganda Rwanda Kenya Zaire Burundi	Uganda
Sudd swamps	Sudan Uganda	Uganda
White Nile	NA	NA
Ethiopian highlands	Ethiopia	Ethiopia
Desert reach	NA	NA

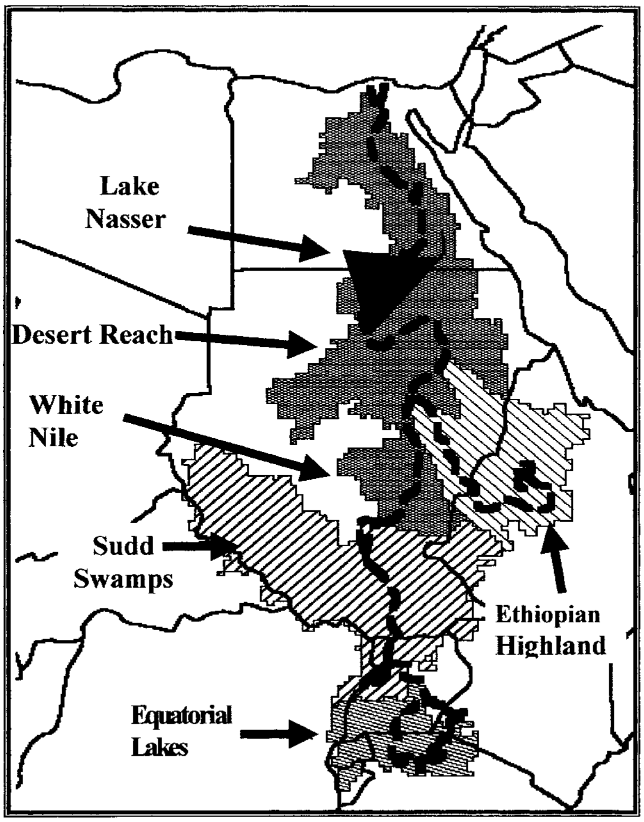

Figure 2. The Nile Basin.

hydrologic regime of the River Nile and the physical characteristics of the lakes and surrounding regions. These changes would in turn affect the hydrologic and ecological regimes of the Sudd swamp region – potentially affecting thousands of square kilometers of land and disrupting millions of lives.

The Ethiopian Highlands are a climatologically sensitive region, exhibiting considerable sensitivity to local, regional, and global phenomenon. The complex interaction of all the different driving forces on the hydrologic cycle of this region is yet to be fully understood. Orbital changes, the Inter-tropical Convergence Zone (ITCZ), the El Niño Southern Osciliation (ENSO), the northern polar front, land cover changes, and anthropogenic green house gases all act on different time and space scales but are not independent processes. How these different forces interact to affect the short and long-term climate variability of this region will be critical in understanding the future hydrologic response of the Nile basins.

3.2. Representative not-implausible climate scenarios

Figure 3 displays ordered pairs of Nile flow and mean annual temperature for Egypt as a fraction of current levels. Each point is identified on the figure by the global greenhouse gas emissions scenario from which it was drawn. These details of these scenarios are described in Yohe and Schlesinger [26]; but it is sufficient for present purposes to point out that they cover the range of IS92 scenarios from low (S1) to high (S7) with (S3) tracking the old IS92a scenario quite closely. Indeed, the expanse of their range runs from the 5th percentile through the 95th percentile of the most recent RICE runs authored by Nordhaus [11]; and their range also dwarfs the variability captured in the new IPCC SRES story lines. Each pair plotted in figure 3 is also differentiated, in the background, by associated sulfate emissions trajectories, assumed sulfate forcing, and assumed climate sensitivity (in terms of the increase in the global mean temperature that would be associated with an effective doubling of atmospheric concentrations of greenhouse gases).

Table 2
Representative scenarios.

	Model	Emissions trajectory	Sulfate forcing	Climate sensitivity
Scenario 1	GISS	S5	-1.0 w/m^2	4.5°C
Scenario 2	UKMO	S1	-1.0 w/m^2	4.5°C
Scenario 3	WASH	S3	-1.0 w/m^2	4.5°C
Scenario 4	POLLD	S3	-1.0 w/m^2	2.5°C
Scenario 5	GFQF	S5	-1.0 w/m^2	2.5°C
Scenario 6	HEND	S1	-1.0 w/m^2	4.5°C
Scenario 7	CCC	S3	-1.0 w/m^2	4.5°C
Scenario 8	POLLD	S5	-1.0 w/m^2	2.5°C
Scenario 9	UIUC	S5	-1.0 w/m^2	4.5°C

It would, of course, be impossible to use each scenario as a basis for a thorough assessment of its potential impact on Egypt. As a result, nine representative scenarios were selected to span their range in terms of flow and temperature without regard to the relative likelihood that they might actually describe the future. Table 2 identifies these representative scenarios in terms of not only the source GCM, but also the underlying greenhouse gas emissions trajectory, the sulfate forcing applied to corresponding sulfate emissions trajectories, and assumed degree of climate forcing. Each representative is, as well, identified as an ordered pair in figure 3. Recall, though, that these scenarios are not the result of applying a statistically-based selection criterion to the full range of possible scenarios. They were, instead, chosen to work together as a set of scenarios that are representative of the diversity of possibility of internally consistent climate futures. They do not include, therefore, combinations of critical variables that were not derived from a specific GCM; and so they preclude the possibility of looking at a combination that would, given complicated climate interactions, be deemed implausible by the current science.

Figures 4 and 5 display transient trajectories for the Nile flow and the associated area of the essential swamp-land buffer upstream. Scenario 1 shows modest increases in flow from the GISS model with high emissions and high climate sensitivity. This model corresponds to the model that produced extraordinary flow increases in the earlier Strzepek and Yates (1995) work. The earlier GISS-based scenario did not, however, include the effect of reducing sulfate emissions – a reduction assumed here to proceed over the next half-century in response to local air pollution problems at their source. Several of the other scenarios display modest reductions in flow, but some depict dramatic reductions. In-

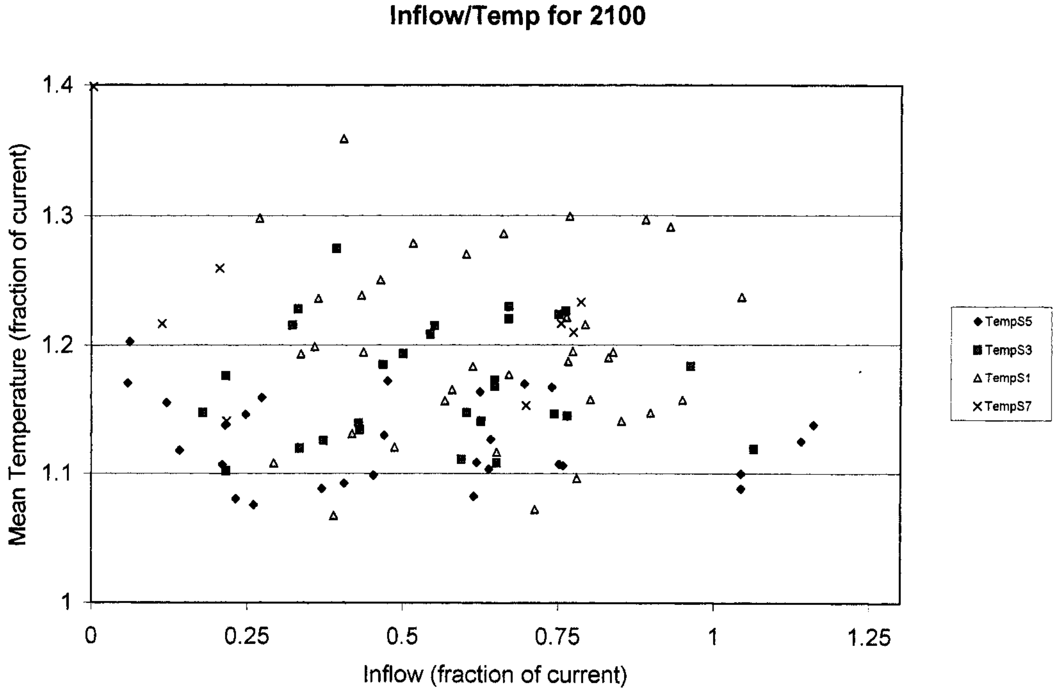

Figure 3. Temperature – Nile flow pairs from selected COSMIC representations of global circulation output.

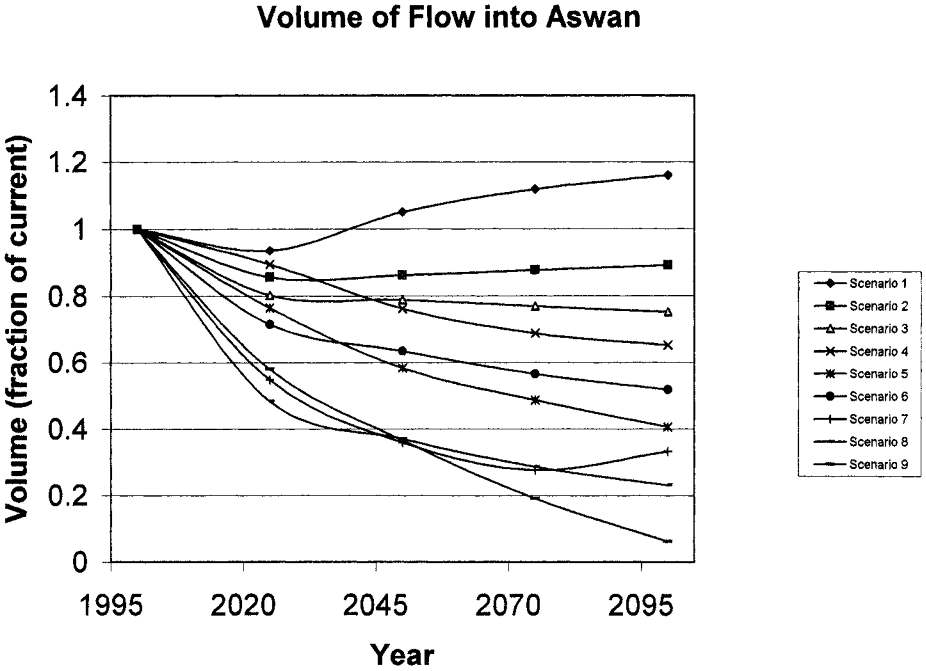

Figure 4. Flow trajectories along selected scenarios that represent the range of not-implausibility.

deed, Scenarios 7 and 9 portray reductions of more than 75% by the year 2100. Meanwhile, all of the scenarios involve dramatic reductions in the area of the upstream swamp.

Figure 6a displays associated trajectories of average temperatures in the month of July as each of the nine scenarios unfolds over time. Figure 6b displays the same information in terms of average decadal rates of change over four 25 year intervals between the year 2000 and the year 2100. The highest rate of change is 2.54% per decade along Scenario 2 between 2025 and 2050. The careful reader will notice that several of the scenarios depicted in figure 6a project temperature increases that exceed the range reported for the global mean by the Intergovernmental Panel on Climate Change (IPCC) in the Second Assessment Report. Nonetheless, the maximum rate of change depicted in figure 6b is well below the maximum reported for the next century by the IPCC in its Third Assessment Report for Northern Africa and Southern Europe (figure TS-3 of the Technical Summary for the Work-

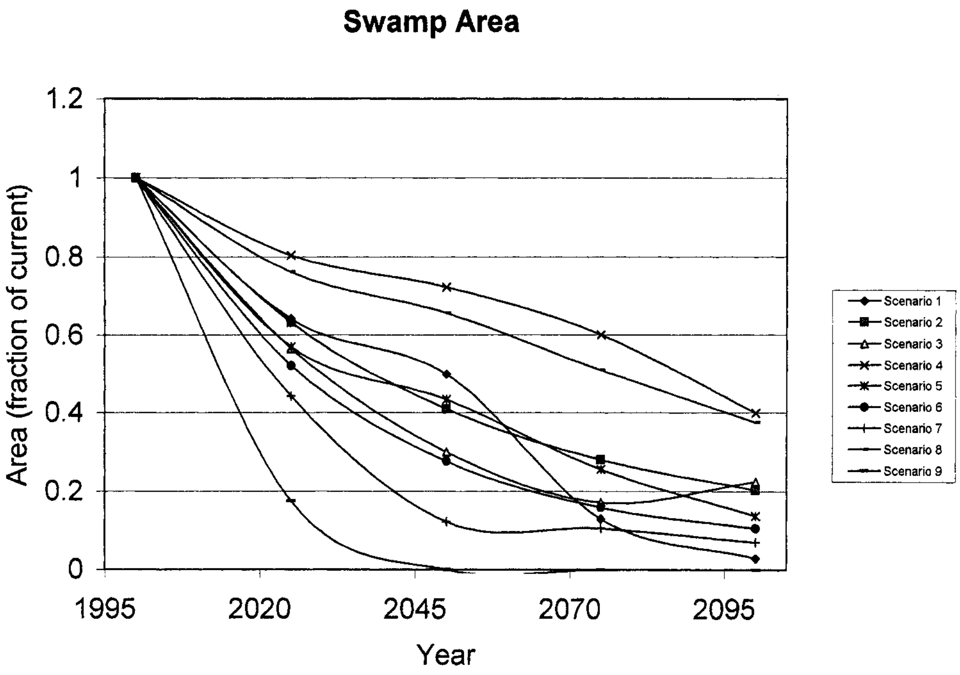

Figure 5. Trajectories of upstream swamp area along selected scenarios that represent the range of not-implausibility.

ing Group II Report). These high temperature increases are, though, the source of flow estimates in figures 4 and 5 that are lower than reported in earlier studies.

The July transient is offered only as an illustration of a monthly temperature series that can be deduced from annual averages by regressing monthly COSMIC temperature data on the annual mean. Adding a time factor improved the fit, though, so the actual regression employed in producing figure 6 was

$$\begin{aligned}\mathrm{Temp}_{\mathrm{monthly}}(\mathrm{Year}) = {} & \beta_1 \mathrm{T}_{\mathrm{annual\ average}} \\ & + \beta_2(\mathrm{Year} - 2000) + \varepsilon_{\mathrm{Year}}.\end{aligned}$$

Table 3 displays the results for 1120 COSMIC "observations" for all twelve months. T-statistics for all of the coefficients are indicated in parentheses; each is wildly significant. Notice, though, that the time coefficients indicate a smoothing of the anticipated annual temperature cycle in Egypt. In particular, note that all monthly temperatures climb with annual averages, but that summer temperatures climb more slowly; i.e., all of the time coefficients are all negative in the summer months.

Figure 7 finally portrays sea level rise transients for the nine representative scenarios. It is important to note that these represent only the effect of rising water along the northern coastline computed as a linear function of annual mean temperature in Egypt. They do not, in particular, reflect local subsidence along that coastline; and so they underestimate effective sea level rise. Subsidence will, of course, be correlated with Nile flows that reach the Mediterranean sea; but it will also be correlated with local land-use and water-use decisions. Care will have to be taken, therefore, to include these decisions and associated adaptations before the trends depicted in figure 7 can be translated into actual exposure along the coast.

Table 3
Regression results for monthly temperature series.

	Annual temp.	(Year – 2000)	Adj R^2
January	0.579	0.008	0.612524
	(193.365)	(6.931)	
Februray	0.644	0.009	0.884125
	(470.097)	(17.991)	
March	0.803	0.008	0.836702
	(431.502)	(11.144)	
April	0.995	–0.002	0.907058
	(786.157)	–(4.090)	
May	1.181	–0.005	0.908229
	(929.944)	–(9.556)	
June	1.295	–0.009	0.900817
	(962.599)	–(18.257)	
July	1.325	–0.010	0.914647
	(1031.493)	–(20.429)	
August	1.336	–0.010	0.892092
	(894.367)	–(16.942)	
September	1.227	–0.007	0.912427
	(967.315)	–(13.582)	
October	1.086	–0.003	0.880176
	(739.860)	–(4.712)	
November	0.864	0.006	0.941471
	(818.925)	(13.957)	
December	0.664	0.014	0.905264
	(485.384)	(26.811)	

3.3. Variability and Nile flows along representative scenarios

Climate variability along any of the representative scenarios will play an enormous role in determining Egypt's exposure to climate change as the future unfolds. Strzepek

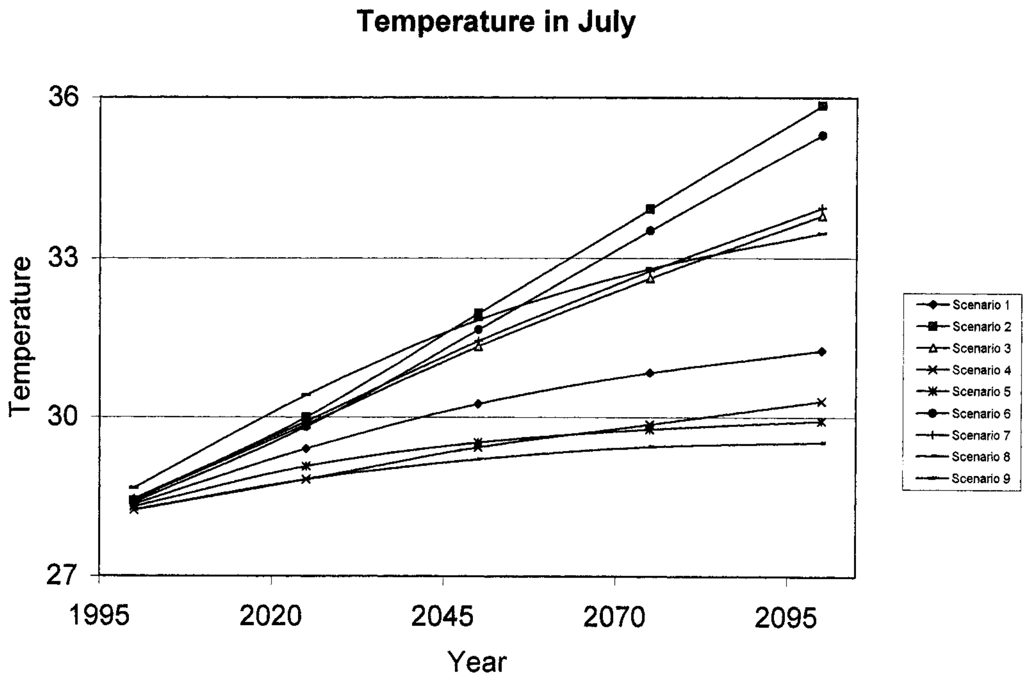

Figure 6a. Trajectories for July temperature in Egypt along selected scenarios that represent the range of not-implausibility.

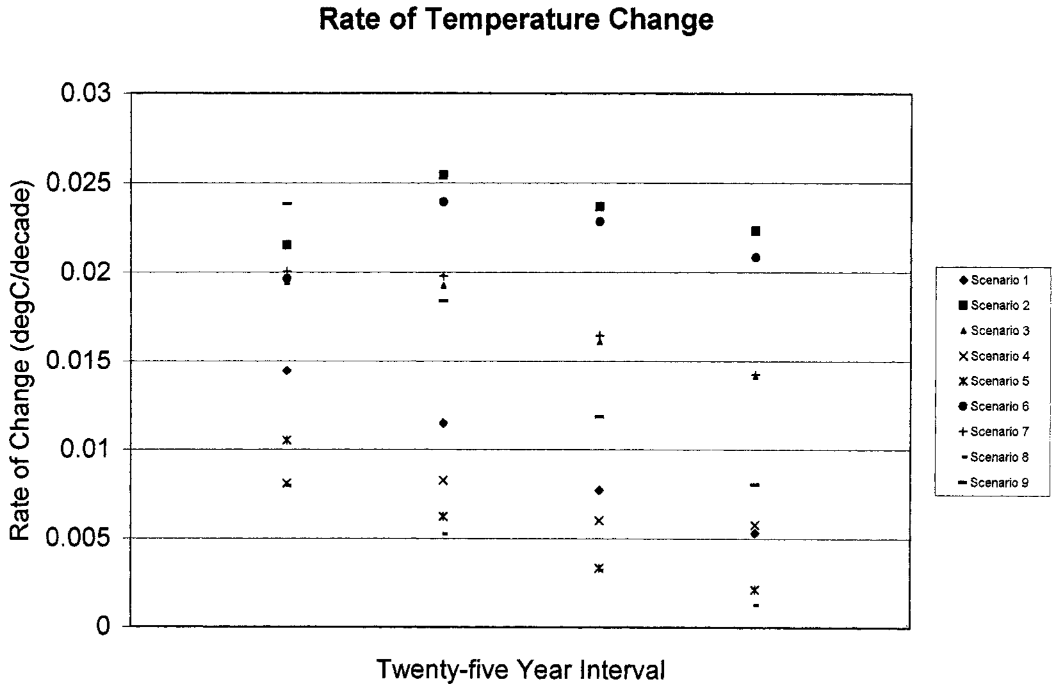

Figure 6b. Rates of temperature change in Egypt for four time intervals along selected scenarios that represent the range of not-implausibility.

and Yates (1995), informed by extensive conversation with water planners and administrators in Egypt, reported, for example, that reductions in annual Nile flows in excess of 20% would significantly effect agricultural productivity in Egypt by interrupting normal irrigation practices. This observation, confirmed in conversation with the Ministry of Water and Irrigation in May of 2000, suggests that 80% of current flows can be identified as the limit of a coping range for existing practices. The Ministry also indicated that the same threshold applies for determining when currently negotiated allocations of flow between Egypt and its southern neighbors would become intolerably stressed. Assume, for the sake of argument, that variability in flow in the Nile around its mean annual flow will not change with the climate (in the sense of preserving the coefficient of variation). The procedure outlined in Schimmelpfennig and Yohe [13] then makes it possible to track the likelihood that flow along any of the representative scenarios would fall below this threshold in any

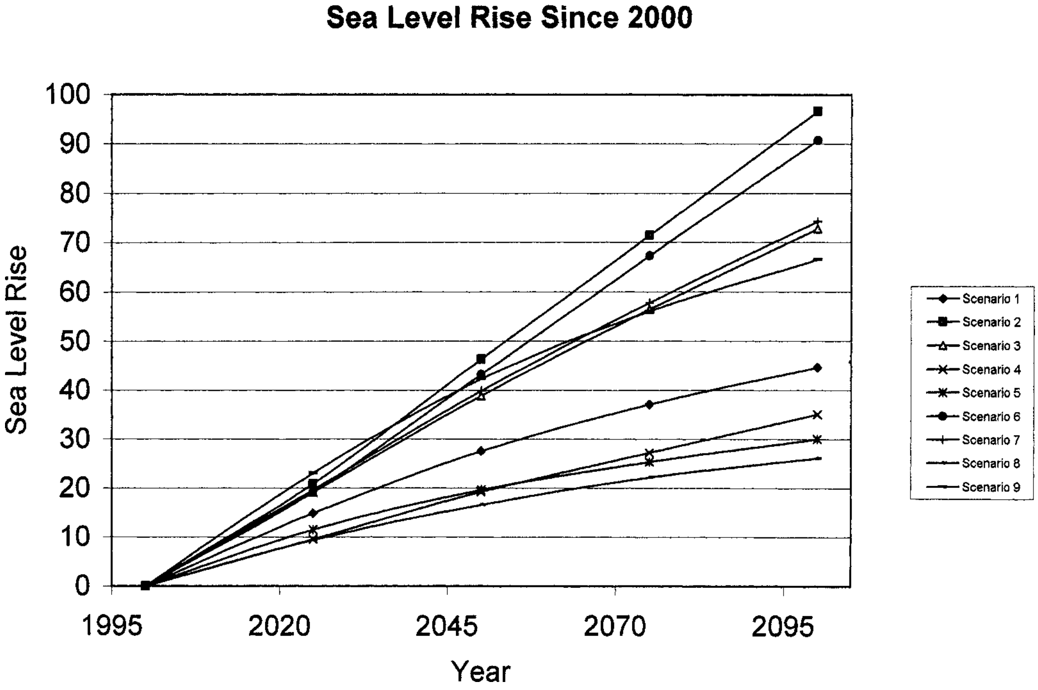

Figure 7. Sea level rise trajectories along selected scenarios that represent the range of not-implausibility.

given year. Figure 8 displays the results. The current likelihood of a critical shortfall Nile flow is slightly less than 0.15; but it climbs significantly and quickly for all but Scenarios 1, 2 and 4. The likelihood eventually falls along Scenario 1 and it converges to 0.30 along Scenario 2; but it climbs to more than 0.8 even along Scenario 4. Perhaps more importantly, though, the likelihood of serious interruption of current practices is greater than 50% by the year 2020 along five of the representative climate scenarios. Egypt's greatest exposure to climate change may, therefore, lie in the associated ramifications of climate variability, even in the unlikely event that that variability does not change.

Observations such as these will become increasingly important as the research community begins to turn in earnest to investigations of abrupt climate change. Much of the discussion at a two day Workshop on Abrupt Climate Change conducted by the U.S. National Academy of Science in late October of the year 2000 was, for example, devoted to what some might consider a semantic difference. Participants focused on the differences between sudden and widespread change in the climate, on the one hand, and sudden social, political or economic impact of even smooth climate change, on the other. They ultimately came to the conclusion that both were equally important as they offered advice to the Academy in its task of setting a coherent research agenda for the next decade or so. Certainly reductions in the flow of the Nile of the sort displayed in figure 4 hold the potential of creating sudden and significant stress between Egypt and its neighbors to the south. Indeed, the current allocation of water at Egypt's southern border, negotiated during periods of high flow, would become untenable if flows fell by 20% and cross, with any great regularity, the lower threshold upon which figure 8 was constructed. Figure 8 portrays, therefore, a collection of "not-implausible" futures along which abrupt change might be expected or even guaranteed.

4. Social–economic–political scenarios

The construction of social–economic–political scenarios for Egypt was informed by three workshops held in Egypt during May, 2000, an extended conversation with the Minister of Irrigation and Water, and by private conversations with Egyptian researchers. All of the participants in these discussions were privy to the range of "not-implausible" scenarios described above. All of the participants were also privy to a description of the list of determinants of adaptive capacity recorded in table 4; and concentrating on those determinants provided a means of leading these conversations to productive insights.

Adaptive capacity, of course, began to emerge during a Workshop on Adaptation, Climate Variability, and Change organized by the IPCC in San Jose, Costa Rica in April of 1998. Smit et al. (2000), for example, provided the participants of the workshop with a concise description of adaptation and how it might be evaluated in a multiplicity of contexts. Yohe and Moss [28] subsequently offered a synthesis of this and other work at an IPCC Expert Meeting on Climate Change at Its Linkages with Development, Equity, and Sustainability held in Colombo, Sri Lanka at the end of April in 1999. It was there that a tentative list of determinants of adaptive capacity much like the one depicted in table 4 was offered in support of the IPCC-TAR. Kane and Yohe [8] also used adaptive capacity as a unifying concept in the organization of a Special Issue of *Climatic Change* on Adaptation. In addition, Chapter 18 in the TAR (Working Group II)

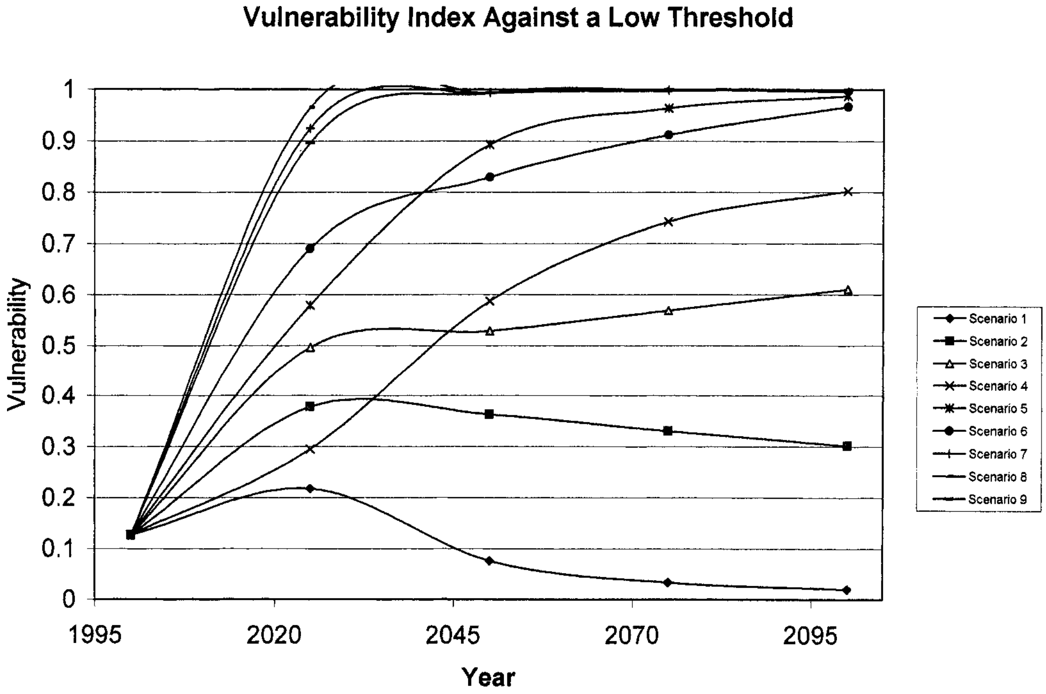

Figure 8. Vulnerability index against a 20% flow reduction threshold along selected scenarios that represent the range of not-implausibility.

Table 4
Preliminary determinants of adaptive capacity.

1. The range of available technological options for adaptation.
2. The availability of resources and their distribution across the population.
3. The structure of critical institutions and the derivative allocation of decision-making authority.
4. The stock of human capital, including education and personal security.
5. The stock of social capital including the definition of property rights.
6. The system's access to risk spreading processes.
7. The ability of decision-makers to manage information, the processes by which these decision-makers determine which information is credible, and the credibility of the decision-makers, themselves.

employed adaptive capacity as a central organizing theme in their assessment of the current literature on adaptation in the context of equity and sustainable development.

Two initial workshops were held in Cairo. The first drew its participants primarily from the various research institutes of the Ministry of Irrigation and Water. After the participants described their work and the work of their Institutes, the discussion turned to the complexity of multiple socio-economic–political objectives within Egypt. It produced the list of adaptive options listed for water and agriculture in table 6. Participants were generally amenable to a objective that would see Egypt attain and sustain a 100% food security objective over the next century. This view supported one sub-scenario highlighted in table 5. Participants did, however, acknowledge the possibility that Egypt would move toward a free trade position in which it might trade for food – another sub-scenario in table 5. The third sub-scenario listed there identifies achieving a 50% level of food security; it was informed by comments offered by the Minister who stressed the importance of strategic food and water reserves, but acknowledged constraints that might inhibit the full realization of complete security.

Many other points were also emphasized as the workshop focused its attention on Egypt's future. Population growth was identified as a serious source of stress. Will it continue at 2.5% per year, or will it decline as economic growth brings higher standards of living? In any case, population growth will be a continuing source of stress on the water sector. The difficulty of charging for water use in Egypt was also emphasized. The population views water as an entitlement so that individuals seldom take responsibility for the social cost of their use. Water is implicitly paid for through land and other taxes, but individual consumption is disconnected from the price paid. As a result, water demand is seldom influenced by current circumstances even, for example, during a period of looming catastrophe when levels behind the High Aswan Dam fell to the point of nearly exposing the intake conduits. It follows that education and demonstration projects are and will continue to be critical for improving water efficiency and for bringing any pricing structure to water allocations. These and other considerations supported the consensus view that water problems (e.g., shortfalls in flows into Lake Nassar of the sort displayed in section 3) cannot be solved domestically; their solution will depend critically upon international cooperation and trust within the Nile Basin and beyond.

The second Cairo workshop invited participation from economists who teach at the University of Cairo. They presented the current state of the Egyptian economy and reported on the success (or lack thereof) of the recent initiatives on privatization. It must be emphasized, though,

Table 5
Qualitative descriptions of political/economic scenarios for Egypt[a].

Scenario I: General description: High capital – high growth:

A. The government allocates public capital efficiently in ways that complement private investment.
B. Business and industry is sufficiently privatized to foster domestic private investment.
C. Cultural changes that allow the population to accept responsibility for the social opportunity cost of their consumption (e.g., in water).
D. Attractive investment opportunities for foreign capital in tourism, trade zones, etc...
E. Perhaps Egypt's joining an international economic trade block within which the potential of free trade is enhanced (but Egypt still confronts the world as a price taker).

Scenario variants:

A. Complete integration into global markets according to comparative advantage.
B. Integration into global markets with a domestic preference toward specialization in agriculture.
C. Either or both of the above with sporadic water crises spawned by trouble in the upper Nile – stochastic or permanent interruptions of the Nile flow.

Scenario II: General description: Low capital – low growth:

A. The government continues to allocate public capital to "mega-projects" that pay off slowly if at all; the result is a crowding-out of private (and other public) domestic investment.
B. Privatized is hampered by cultural reluctance so that domestic private investment is further discouraged.
C. Cultural barriers continue so that the population declines responsibility for the social opportunity cost of their consumption (e.g., in water) and continues to be reluctant to move in response to anything but absolute necessity and/or crisis.
D. Egypt confronts the world marketplace as a price taker.

Scenario variants:

A. Global integration with 100% food security as a domestic policy objective.
B. Global integration with 50% food security as a domestic policy objective.
C. Complete integration with international trade governed by comparative advantage.
D. The population views government policy as extremely uncertain from planning period to planning period and from planning to implementation within any single period.
E. Any or all of the above with sporadic water crises spawned by trouble in the upper Nile – stochastic or permanent interruptions of the Nile flow.

[a] High and low population growth might be assumed for each general scenario and selected variants.

that the government would still control 83% of the Egyptian economy even if all of the current initiatives were fully implemented. Participants in this, and other workshops, confirmed the dominant role of the government in the economy; they mimicked the population in the sense that they often looked at the government as the sole source of change. Participants here described two alternative futures for Egypt. One saw inefficient, misdirected and frequently redirected public investment (currently in eight "mega-projects") crowding-out private investment and discouraging international investment. These points are the genesis of the Low-Capital scenario outlined on the bottom of table 5 and elaborated in table 8. The second was an optimistic scenario driven either by private or foreign investment in tourism or perhaps private investment that would exploit a historical comparative advantage in agriculture, or perhaps education and research, to support robust levels of foreign trade. Either optimistic sub-scenario depends upon the efficient allocation of public investment into capital that would complement private capital; this is the source of the High-Capital scenario outlined on the top of table 5 and described in more detail in table 7. The economists agreed, though, that the welfare and efficiency implications of both the High- and Low-Capital scenarios would be sensitive to alternative assumptions about population growth.

These second set of discussions also reinforced the previously articulated impression that charging for water use would be extremely difficult; cultural perceptions and historical practices would fade only in the wake of education (and only very slowly as successive generations move into positions of decision-making authority). The same discussion also emphasized the need for demonstration projects that convince risk averse Egyptians that change is appropriate. Finally, the stories that the participants told about governmental planning and implementation struck a note of pessimism for a country in which planning is such an essential part of current and past experience. Indeed, even local taxi drivers told stories of the government failing to deliver on its promises. It is, for example, currently possible for private individuals or firms to build new power plants with the benefit of 10-years of tax foregiveness if their new power infrastructure were located in a remote area. It is, nonetheless, currently forbidden for these same individuals or firms to sell the power that these plants would produce. These sto-

Table 6
Adaptation options in major sectors.

Water sector	Agriculture	Coastal zones	Coastal fishing
Efficiency improvement Desalinization[a] Water recycling[a] Expansion in in the use of groundwater[b] Migration[b] Demonstration projects	Promote export crops Migration[b] Employ high yield – low water crops Demonstration projects	Protect developed coastline Protect tourist areas Protect agricultural lands from salt water intrusion (e.g., cultivate rice)[a] Demonstration projects	Adopt new technologies (for deeper waters) Invest in new methods Demonstration projects

[a] Technical and/or economic feasibility is very sensitive to the supply of energy as reflected in its price. It fllows that feasibility is vulnerable to mitigation policy.
[b] Social–economic–political feasibility is very sensitive to the acceptance of migration by the population at large in response to positive inducements in addition to crises and threats.

Table 7
Adaptive capacity under the high-capital scenario.

Determinant	Water	Agriculture	Coastal zones	Fishing
1. Options	Table 6	Table 6	Table 6	Table 6
2. Resource availability	Increased public, private & international (all anticipated)	Increased public, private & international (all anticipated)	Increased public, private & international (all anticipated)	Increased public, private & international (all anticipated)
3. Institutions	Adequate with evolution	Adequate with evolution	Adequate with evolution	Adequate with evolution
4. Human capital	Adequate	Adequate	Adequate	Adequate
5. Social capital	Adequate	Adequate at the state level; limited at the micro-level	Adequate at the state level; limited at the micro-level	Adequate at the state level; limited at the micro-level
6. Risk	Diversified	Resource-based	Adequate	Experience-based
7. Information & credibility	Adequate	Adequate at the state level; need education & demonstration at the micro-level	Adequate	Adequate at the state level; need education & demonstration at the micro-level

ries led to the stochastic government sub-scenario described on the bottom of table 5 – a scenario of extreme skepticism in the effectiveness and consistency of government planning from period to period and/or governmental implementation within a planning period.

Alexandria was the venue for a third workshop; coastal zone experts and veterans of the Country Studies Program participated. They briefly presented the results of their earlier work; but they also spent some time outlining recently composed development plans for a virgin coastal region west of Alexandria. Subsequent discussion worked from both the "not-implausible" scenarios and from their experience with adaptation to produce the list of adaptive options recorded in table 5 for coastal zones and fishing and the assessment of

Table 8
Adaptive capacity under the low-capital scenario.

Determinant	Water	Agriculture	Coastal zones	Fishing
1. Options	Table 6	Table 6	Table 6	Table 6
2. Resource availability	Stable public anticipated; small reactive private; little international in crises	Stable public anticipated; small reactive private; little international in crises	Low public anticipated; low private & international in crises	Low private and public in crises.
3. Institutions	Inadequate with evolution less likely	Inadequate with evolution less likely	Inadequate with evolution less likely	Inadequate with evolution less likely
4. Human capital	Adequate	Adequate	Adequate	Adequate
5. Social capital	Limited	Limited at the state level; more so at the micro-level	Limited at the state level; more so at the micro-level	Limited at the state level; more so at the micro-level
6. Risk	Limited	Limited	Limited	Extremely limited
7. Information & credibility	Adequate information management at the state level; limited credibility at micro-level	Limited even at the state level; very limited credibility at the micro-level	Adequate information management at the state level; very limited credibility at the micro-level	Adequate information management at the state level; almost no credibility at the micro-level

adaptive capacity recorded in tables 7 and 8. The critical role typically played by government in helping Egyptian communities and individuals respond to stress was a recurrent theme in these discussions. The view of the participants, informed by focused interaction with citizens threatened by sea level rise, held that individuals would react only when they were sure about what, why and when. This observation supported an evaluation of adaptive capacity that saw access to risk spreading processes as experience-based (and the lessons of experience disappear when people change techniques). It also envisioned a population that was skeptical of its government's plans. Education and demonstration projects were seen as possible responses to this functional aversion to new risk.

According to the consensus of this workshop, adaptation to climate change will occur only as part of adaptation to some other stress. As a result, it is unlikely that anticipatory adaptation to climate change that would involve changes in behavior or techniques that would not be contemplated in the absence of climate change would be forthcoming. Coastal protection to climate change involving decisions that would protect development from climate variability or agriculture from subsidence-induced saltwater intrusion could therefore be expected if the resources were available from the government (the High-Capital scenario). This sort of protection would also be a natural response to other stresses (like increasing population density and the continuing natural implications of the High Aswan Dam). Anticipatory investment in boats that would accommodate new fishing techniques in deeper water should not, however, be expected even in the High-Capital scenario (unless demonstration projects diminish cultural inertia). The meeting closed by producing the assessments of adaptive capacity in coastal zones and fishing recorded in tables 7 and 8 for the High- and Low-Capital Scenarios.

Finally, private meetings with experts at the National Water Research Center (NWRC) of the Ministry of Irrigation, located at Kanateer (approximately 30 kilometers from Cairo) underscored many of the lessons drawn from the workshops. Dr. Hussam Fahmy (Director of the Strategic Research Unit), for example, described the ongoing Toshka Canal Project in Upper Egypt. The Toshka Project is a capital-intensive initiative that is being supported at the highest levels. Large pumps draw Nile water directly from Lake Nasser, pump it into a large canal, and then transport it into the western desert for use as irrigation water. The hope of this major project is to entice Egyptians living in the Old lands along the Nile to migrate into the less populated desert regions. Challenges to the success of this project include social barriers to migration, lack of significant infrastructure (roads, hospitals, entertainment, etc.), poor soils for agriculture, and extreme climate conditions (particularly summer heat) that increase evaporative demand.

Tables 5–8 thus synthesize a preliminary impression of the diversity of "not-implausible" socio-economic–political scenarios for the future of Egypt. Table 5 summarizes the expectations voiced by participants in the scoping discussions described above. Table 6 lists adaptive options that emerged during these discussions, while tables 7 and 8 cast those options into the adaptive capacity context for the High- and Low-Capital scenarios, respectively. It is clear, even at this point, that low levels of capital and reticence to adapt in anticipation of climate change should be expected to increase the cost of adaptation and to reduce its efficiency. Some concern has been raised, in fact, that the economic implications of these obstacles might be so large that even the implementation of what should be an attractive adaptation option might be in question.

4.1. Synthesizing not-implausible social–political–economic futures

Section 3 identifies and describes nine representative climate scenarios (CS) that span adequately the range of "not-implausible" possibilities in terms of transient scenarios that track the flow into Lake Nassar, temperature in Egypt, and sea level rise along the northern coastline through the year 2100. This section describes the bases for similarly representative social/political/economic scenarios (SPE scenarios) that span a wide range of "not-implausibility". They are now summarized in table 9. Notice that table 9 differentiates across High- and Low-Capital futures as well as high or low population growth. Table 9 also discriminates between two domestic policy objectives:

(1) maintaining food security, or

(2) allowing unconstrained participation in world food markets

and two internationally defined economic circumstances:

(1) Egypt's joining a trading block to support some market power both as an importer and an exporter, or

(2) Egypt's confronting world markets as a price taker.

There are, however, only six alternatives for each of the two capital scenarios because adopting a domestic objective of food security would preclude fully exploiting the comparative advantages that that would be required to sustain participation in a trading block.

4.2. A preliminary quantification

Scenarios of Egypt's population, income, and agriculture were developed based on simple, yet informed extrapolation

Table 9
Quantifying social/political/economic scenarios.

High capital scenario:

1. The government allocates public capital efficiently in ways that complement private investment.
2. Business and industry is sufficiently privatized to foster domestic private investment.
3. Cultural changes that allow the population to accept responsibility for the social opportunity cost of their consumption (e.g., in water).
4. Attractive investment opportunities for foreign capital in tourism, trade zones, etc. . .

Low capital scenario:

1. The government continues to allocate public capital to "mega-projects" that pay off slowly if at all; the result is a crowding-out of private (and other public) domestic investment.
2. Privatized is hampered by cultural reluctance so that domestic private investment is further discouraged.
3. Cultural barriers continue so that the population declines responsibility for the social opportunity cost of their consumption (e.g., in water) and continues to be reluctant to move in response to anything but absolute necessity and/or crisis.

	Population		Food objective		Trade position	
	High	Low	Security	Open	Trade block	Price taker
High capital						
Scenario A	x			x		x
Scenario B	x			x	x	
Scenario C	x		x			x
Scenario D		x		x		x
Scenario E		x		x	x	
Scenario F		x	x			x
Low capital						
Scenario G	x			x		x
Scenario H	x			x	x	
Scenario I	x		x			x
Scenario J		x		x		x
Scenario K		x	x		x	
Scenario L		x	x			x

Note: Adopting a food security objective is assumed to imply a price-taking trade position.

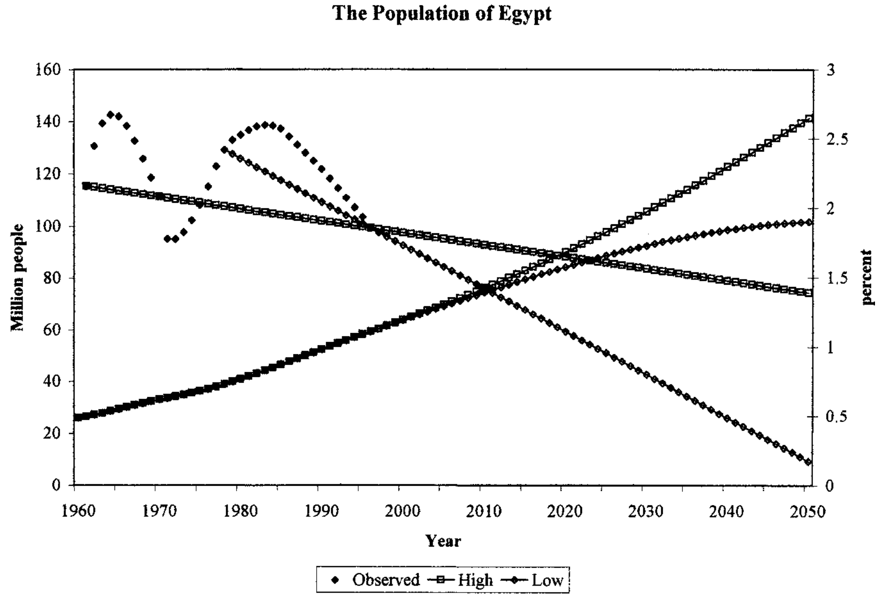

Figure 9. The population of Egypt and its growth rate as observed (1960–1996) and as projected (1997–2050) according to two alternative scenarios. Annual growth is on the right axis, annual income on the left axis.

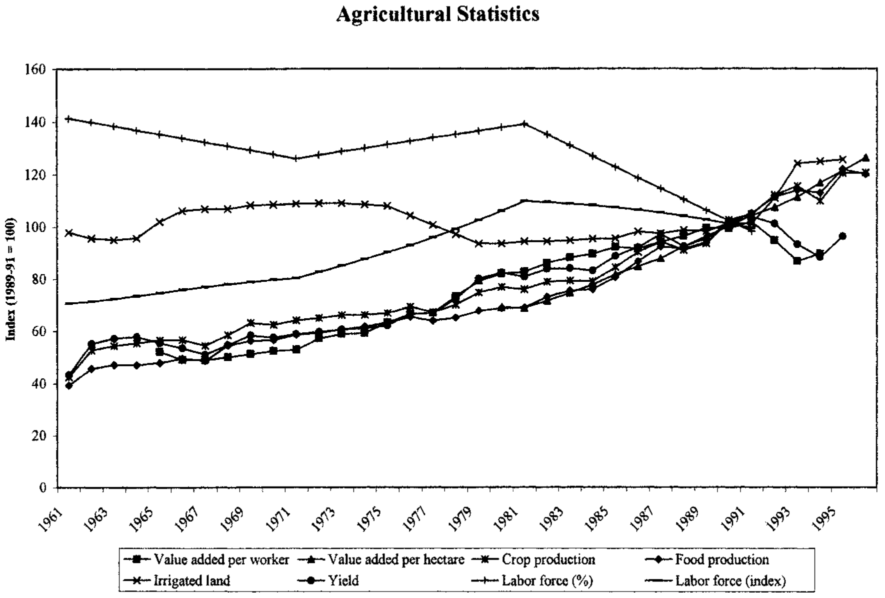

Figure 10. Agricultural statistics for the period 1960–1996; 1990 = 100.

of observed trends in the last 35 years. Data were taken from the World Resource Database. Trends were identified using standard line-fitting techniques. These trends were first extrapolated into the future, and then bent to reflect the qualitative scenarios described in table 9. Obviously, the quantitative scenarios are offered here for illustrative purposes only.

Figure 9, for example, shows observed (1960–1996) and projected (1997–2050) population growth. The observations are hard to interpret because distorted by the 1972 war with Israel. Between 1980 and 1996, population growth rates fell rapidly, and at an increasing pace. Both scenarios assume that this is only temporary. Figure 9 also displays the resulting population sizes. In the high scenario, population increases from the current 60 million to about 140 million. In the low scenario, population increases to about 100 million people.

Figure 10 shows agricultural statistics. Value added per worker and per hectare, yields, total crop production and total food production all steadily rose between 1960 and 1990. The number of people working in agriculture rose until 1980 or so (although less fast than the overall population), and then started to decline. In the early 1990s, irrigated lands were expanded. This led to a decline in average yield and value added per worker. The available data do not say whether the agricultural work force was expanded or not. Other statistics were not affected by the expansion

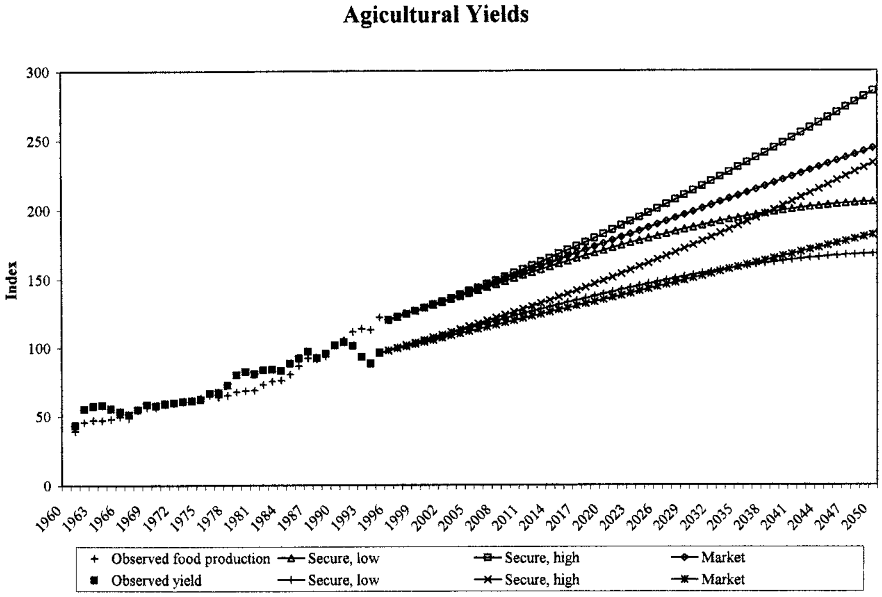

Figure 11. Agricultural yields and food production as observed (1960–1996) and projected (1997–2050) according to two alternative agricultural scenarios, one of which ("food security") is combined with two alternative population scenarios.

Figure 12. Statistics on investment and economic growth.

of irrigated land. Figure 11 projects agricultural production into the future. In the market scenario, we extrapolate the observed trends in crop yield and total food production. In the food security scenarios, we force yield and food production to increase at the same rate as does the population. If the population grows slowly, food security objectives can be met if current productivity trends continue. If the population grows fast, technological progress has to be accelerated.

Figure 12 shows total investment, split out between private investment, government investment and foreign investment. Figure 12 also displays the growth rate of per capita income. No clear pattern emerges. Figure 13 displays projected per capita income growth rates. Because the data do not reveal a clear link with the qualitative scenarios above, these projections are especially speculative; indeed, economic growth will be endogenous is subsequent modeling efforts. If the Egyptian government continues to crowd out private investment while spending large amounts of taxpayers' money on unprofitable investment, though, growth will be low – 1% per year in figure 13. If not, growth can be higher – up to 3% per year as depicted in figure 13. And if Egypt ceases to be a price taker in the international trade market, then growth could be even higher – depicted here at 4% per annum. Figure 13 displays the resulting per capita incomes, as well. They range between $1500 and $8000 per person per year by 2050, compared to the current $1000. Figure 14 finally combines the four alternative per capita income growth scenarios with the two alternative population growth. The Egyptian economy grows from the current $60 billion to anywhere in between $170 and $1120 billion.

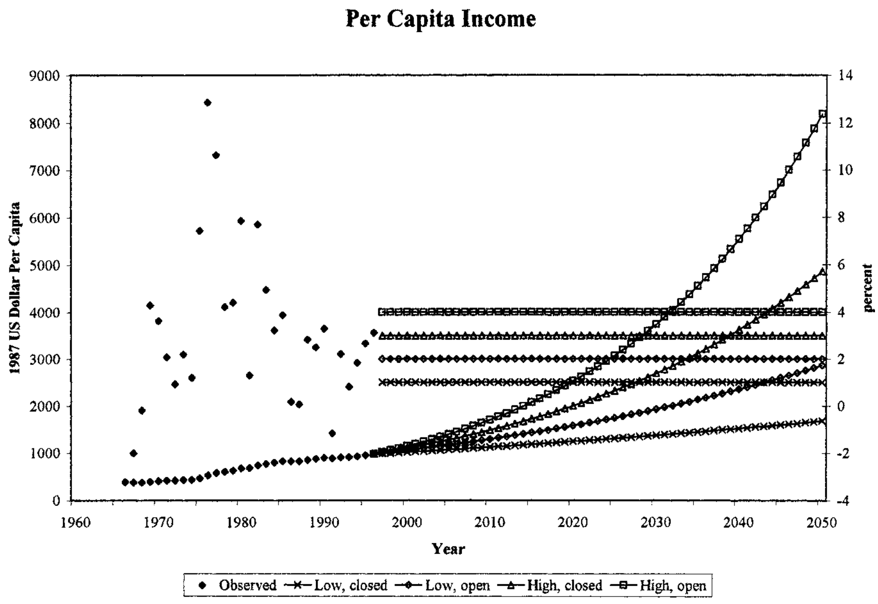

Figure 13. Per capita income as observed (1967–1996) and as projected (1997–2050) according to four alternative growth scenarios, viz. high and low capital formation, and open and closed to international trade. Annual growth is on the right axis, annual income on the left axis.

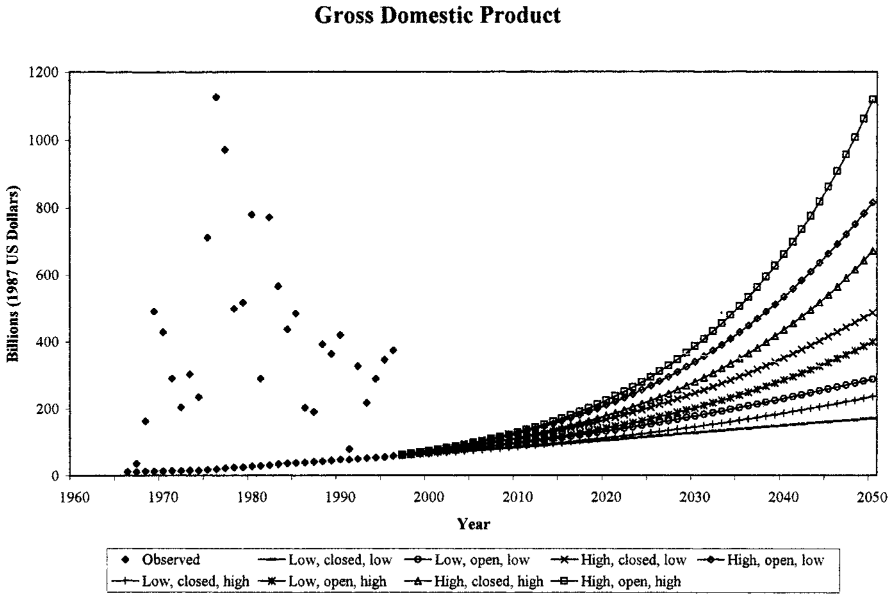

Figure 14. GDP as observed (1966–1996) and as projected (1997–2050) according to four alternative per capita growth scenarios and two alternative population growth scenarios. Annual growth is on the right axis, annual GDP on the left axis.

5. Conclusions

The results reported here successfully track two sets of critical factors that define the space of "not-implausible" scenarios for Egypt's future under climate change. One set depicts representative climate change and climate variability scenarios that span the realm of possibility. A few of these climate *cum* climate variability scenarios would not be very threatening. Others, like the ones that portend dramatic reductions in average flows into Lake Nassar and associated increases in the likelihood of year to year shortfalls below critical coping thresholds would be extremely troublesome, especially if they were cast in the context of increased political instability across the entire Nile Basin. In between, a few scenarios depict futures along which relatively routine and relatively inexpensive adaptation might be anticipated. The ability to adapt to change and to cope with more severe extremes would, however, be linked inexorably to the second set of social–political–economic (SPE) scenarios. These "anthropogenic" scenarios can be viewed as defining the holistic environment within which the determinants of adaptive capacity for water management, agriculture, and coastal zone management must be assessed.

The next challenge, then, is integration: bringing these two sets of scenarios to bear on an integrated assessment of climate change in Egypt in a way that is sensitive both to their diversity and to their implications for adaptive capacity. The results that were reported in section 4 have set the stage in their representations of High- and Low-Capital SPE scenarios for the Egyptian economy. They must now be constrained by the water in the Nile, temperature effects on agricultural productivity, and the costs of coastal zone erosion along the nine representative climate scenarios in ways that are sensitive to their implications with respect to sector-specific adaptive capacities. We expect that the associated savings and investment trajectories will show us how to move a dynamic computable general equilibrium model of the Egyptian economy into the future along 108 different climate/SPE scenario combinations in ways that accommodate detailed manifestations of adaptive capacity.

Acknowledgements

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