Living in a Small, Crowded Room: Scenarios for the Future of Mauritius

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In this article, future scenarios for Mauritius are described with a special focus on the interaction of different factors which can limit or hinder growth. Mauritius is a small, densely populated island where natural and human resource limits are obvious. The scenarios describe current trends on Mauritius well. They give a fine-tuned feeling for the differential impacts of labor, land, water, and pollution absorption capacity. They show that at various points in the course of development different limiting factors function, and thus it is necessary to give attention to all major factors of production and limitation in one holistic setting.

INTRODUCTION

Imagine you live in a small apartment. Then you receive a raise at work and you buy more furniture which is squeezed in with the old. And a child arrives and another, so the bedroom becomes the children's room, and the living room doubles as a bedroom. Then a washing machine comes, but the old mini-plumbing is not sufficient. Sooner or later, the situation is resolved by moving to a bigger apartment. Unfortunately, small countries experienc-

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ing growth in wealth and population numbers cannot move up the street. They have to live with the space and water given to them. Ultimately, we, as a human race, have to live with the Earth's fixed size.

This paper uses a computer simulation model of a small country, Mauritius, to explore the effects and possibilities of economic or population growth under various regimes of policy and technological advance in a fixed, crowded setting. This model was developed in a three-year case study on population, development, environment interactions on Mauritius. The study was conducted at the International Institute for Applied Systems Analysis (IIASA) under the leadership of Wolfgang Lutz, funded by the United Nations Population Fund (UNFPA), in cooperation with the Government and the University of Mauritius. The main results were recently published in book form (Lutz, 1994). The authors of this paper were part of the core team of researchers and did the scenario work in that study together with Einar Holm (University of Umea, Sweden). This paper uses four of the sixteen scenarios described in the main study.

The classical economists saw fixed natural resources (mainly land) as the ultimate reason that (population and economic) growth would lead to decreasing, then zero, marginal returns. Models begun in the 1930s (Harrod, 1939; Domar, 1946) and developed in the 1950s (Lewis, 1954; Domar, 1946) made the accumulation of physical capital the source of wealth. Since this must be accompanied by a certain abstinence from consumption, Coale and Hoover (1958) saw a growing, consuming population as a constraint on development. Later models removed natural resources and physical capital and placed human capital in the center stage of development (Simon, 1981; and less strongly, Boserup, 1981). However, there is a growing forum of natural and social scientists alike who would have natural resources back on the stage (e.g., Ehrlich & Ehrlich, 1990; Abernethy, 1993; the new Meadows et al., 1992 which reiterates its message that the Earth's limits limit us). Good overviews of the literature and the ongoing discussion are given by Keyfitz (1991; 1993).

The Mauritius economy is modelled squarely in the middle between population on the one side, and limited natural resources on the other. Physical capital shortages function less centrally as they are supplemented by foreign investment which develops partly hand in glove with export demand. A small export-oriented country like Mauritius might be able to get away with high consumption by relying on foreign capital (the price for this would be that a part of the surplus would leave the country again). In such an open system, we have put the old, classic constraints of economic growth—natural resources and labor force—on either side of the economy again.

The smallness of the island makes environmental constraints very obvious. It is like being in a small, crowded room: Whenever you move in any one direction, you are bumping into a wall of limited water availability, limited land availability, limited beach space, etc. You acquire a feeling for constraints and how to deal with them in a strong, practical manner which is not possible when looking at a huge geographical area—for example, the room which is our Earth also has walls which limit us, but they are so far out from a human scale that we find it difficult to imagine them as real.

Constraints on Mauritius are real. Even in the nineteenth century, Mauritius had to manage its water supply for the dry season. With industrialization, there has been increasing pollution which has affected the rich marine ecology around the island. With higher standards of living, tourism, and irrigation, demands for water have increased greatly. Already this has led to water shortages. Further expansion will certainly stress the water supply.

All of the available land—excluding that which is steep mountains, and which is necessary as a water catchment reserve—has long since been either cultivated or urbanized. An extension of any sector means either land productivity must increase or other activities must give way.

The same is paradoxically, presently true of labor—human supply—in Mauritius. The labor market is tight, and labor force participation rates are high. It is no longer possible to have economic growth by mopping up unemployment as happened in the 1980s. Here too, either the productivity has to increase, or less productive activities must give way. The labor squeeze expresses itself in a shortage of workers in the sugar cane fields. Expanding through immigration is an option for the labor force which does not apply to land and water. It is, however, badly tolerated in Mauritius.

HISTORY OF MAURITIUS

Mauritius, tiny as it is, offers many good answers to our questions on the interaction between population-environment-economy, on the effect of population on the environment and the consequences for sustainable development. It is a very small world which is very well-documented by excellent data, isolated from the rest of the world like a laboratory, ready for experiments.

Its history is an almost unique success story. In 1960, it was a poor, underdeveloped island with Malthusian population growth, due to very high fertility, above 6 children per woman, and a fully agricultural economy dependent on land area for expansion. In 1960 there was no more land available. It was the perfect worst case. In the next decades to 1980, the country managed to arrange a very rapid fertility decline to replacement level in the absence of economic growth. However, the population growth momentum did leave the country with a large number of unemployed young adults by 1980. Then, in the next decade, the country managed to change its stagnant economy, high unemployment situation into one of rapid growth so that by 1990, there was no unemployment on the island.

The country of Mauritius is located in the Indian Ocean east of Madagascar. Presently, it has a population of a little over a million people. It consists of one main volcano island, 1800 square kilometers large, and a number of very small islands spread in the Indian Ocean. This makes it one of the most densely-populated countries in the world. Per square kilometer the main island, Mauritius, is well-endowed with water from rainfall, and a set of aquifers and lakes which store the water outside of the rainy season. However, because of present high population density, Mauritius belongs to the category of water-poor countries, where water is a limited and possibly limiting resource. Before the first people lived on the island, it was covered in tropical forest. Presently, there is almost no virgin forest left.

In the eigthteenth century a small population of European settlers and African slaves inhabited the island. With the abolition of slavery by the British in 1815 and the beginning of a policy to concentrate on sugar export as the backbone of the economy, two things happened: a couple of hundred thousand Indian laborers were brought to the island to work on the sugar cane plantations, and in the span of the next 50 years, almost all of the Mauritian forest was cleared—much of it for sugar cane. Until today, the Indian population is the majority on this multiracial island, and sugar cane waves greenly on 50% of the island area.

After World War II, due to better medicine and insecticides, mortality plummeted, fertility increased slightly, and population growth soared, as in many countries. Also, the sugar cane yield was increased enormously by input of better seeds and fertilizer. By 1960 the potential for sugar cane increases had been exhausted, but the population was increasing at the rate of 3% p.a. There was no industry on the island; almost everything except sugar was imported, including most of the food. However, the social infrastructure of the island—schools and medical care—were relatively good.

Alarmed by forecasts for the future of the island, which foresaw a continued population growth with no base for economic expansion (Titmuss & Abel-Smith, 1968; Meade et al., 1968), a major effort was launched to decrease fertility. This was done very successfully in the late 1960s and the 1970s in the absence of economic growth. How was this possible? The education of women was relatively high; the medical distribution system for contraceptives was good; the system was small and manageable; and the church did not oppose. These seem to be factors that contributed to the success.

Throughout this time, the economy was sustained by a stable sugar price. In the 1960s import substitution industries—food processing, furniture—were set up. Because of the small base of the island, the limit was reached by 1970. From this time, efforts to widen the export base to industrial products were undertaken and an Export Processing Zone (EPZ) was created. In the first 10 years there was little growth here, and in 1980 unemployment was around 20% of the working population. From 1983, there was a sudden rapid expansion in the textile industry which absorbed all workers. By 1990, real GDP in purchasing power parity was $5,750 (with a GNP per capita of $2,310) which now makes it a middle income country (UNDP, 1993, p. 138).

Certainly the high level of education, the stable political situation, and the relatively well-developed infrastructure on Mauritius were important factors supporting this industrial growth. Presently, Mauritius is eager to widen its export base to other products (World Bank, 1991). In 1990, the country had an extremely open market; exports were 80% of GDP (CSO, 1992). It imported about two-thirds of its food needs in 1986 (Ramkissoon, 1991). The domestic market is and will remain small.

OVERVIEW: OTHER COMPUTER SIMULATION MODELS

The Mauritius model, described below, is a computer simulation model made to run holistic scenarios of the future. As such it follows, in a very much humbler way, the tradition of other computer models which were made famous by the world models of Forrester (1971), Meadows et al. (1972), and Mezarovic and Pestel (1974). These models had tremendous political impact, were admired and criticized severely. Yet they did not evolve. Warren Sanderson (1994, p. 52) says:

> . . . World3 and models like it could be made to produce continued growth or collapse depending on assumptions about unknown and, possibly, unknowable parameters. Without substantial improvement in our knowledge of the underlying relationships needed to build a global model of sustainable devel-

opment, further development of World3 was, in 1973, and still remains a fruitless exercise. This is why modelers never built on the World3 foundation.

Parallel to the world models, at least two regional computer simulation models in the Forrester/Meadows tradition, where parameters could be specified, were made. One was a Sahel study (Picardi, 1974), the other of the Kivu region in Rwanda (Wils et al., 1976). Both of these models were based on real, empirical data. Other regional or national models were made. The BACHUE models are often cited. These are much more complex than the above models, and include an intricacy of population, economic, policy, and environment variables. The BACHUE models, too, were discontinued.

Computer modelling, of course, was not discontinued. On the contrary, during the 1980s we saw an enormous computer software development along with models. We see, however, each discipline turned away from other disciplines, making its own models. At IIASA in demography, multistate population projection was developed by Rogers and his collaborators (Rogers & Willekens, 1986) so that education, labor status, and other variables could be easily included in age-group models. Environmental computer models to forecast future pollution paths in broad economic settings were made. The RAINS computer model at the same institute (Alcamo et al., 1991), which tracks the costs and effects of acid rain, its causes and its control, now aids European policy makers in international negotiations. Geographic information systems (GIS) have become a field of their own. GIS are basically a child of geography, but they can incorporate economic, social, or natural data. Computer models of the economy have flourished, econometrics dominates the discipline, and we now have continual, exact prognoses of growth rates of many economic variables. Hundreds of other models were developed.

The Mauritius model asks: Can we, after ten years of learning a lot about modeling in our separate disciplines, take another shot at making a multidisciplinary model, a model which equally incorporates the population, development, and the environment?

THE MAURITIUS PDE-MODEL

Let us begin by being very modest in our claims. The Mauritius model is an attempt to reestablish interdisciplinary population, development and environment (PDE) modeling, but it is not an attempt to replace World3, BACHUE and other large models. What we learn from Mauritius will not answer global questions. Let us take these scenarios as policy advice to the Mauritius government, showing them where they will have bottlenecks on the growth-path, and remember them foremost in this setting. Later, returning to other, bigger questions, perhaps the example of Mauritius will enter our minds as a helpful, empirically-based handle on these questions, perhaps supporting a thesis or providing contrary evidence.

The model which was developed allows much interaction with the user or scenario-maker. As Sanderson (1994) says, many of the parameters, the links between the population, the environment, and the economy in the world are not known. To account for this, the links in the Mauritius model are made flexible, or soft-wired. Without fixed hard-wired links, making a particular scenario is the result of many trial runs, many tests. For this reason, the model is specifically tailored for running scenarios quickly. As a policy tool, the model needs to allow the user flexibility at those points where human action can influence the system, e.g., in pollution control, export promotion, or tax rates.

The model has four modules. These four modules and the links for the Mauritius model are shown in Figure 1. All of the parts of the model are related to the other parts.

The population module (Prinz, 1992) calculates the population by age, sex, and seven socioeconomic states which are given by the level of education and labor force participation. The module allows changes in fertility, mortality, migration, school participation, and labor force entry, and is thus very flexible. Education and labor force participation are not demographic variables in the strict sense, but they are population characteristics that are considered to be very relevant variables for fertility levels, migration, economic productivity, and the possibility of technological change.

The economic module (Wils, 1993) is based on an input-output structure. It calculates the economic product depending on export and government demand. Investments and consumption are endogenous. The module is modified by education of the labor force, labor productivity and income distribution. The extreme openness of the Mauritian economy allows for a module in which exports are the main growth factor for the economy.

The land-use module distinguishes five major types of land use: sugar cane, other agriculture, urban, "unusable," and beaches. The module reconciles competition for the limited land area by the different uses either by giving priority to the most productive user or by giving priority to a certain use protected by government policy (e.g., sugar cane growing) (Holm, 1994). The water module (Toth, 1992) calculates the demand for water

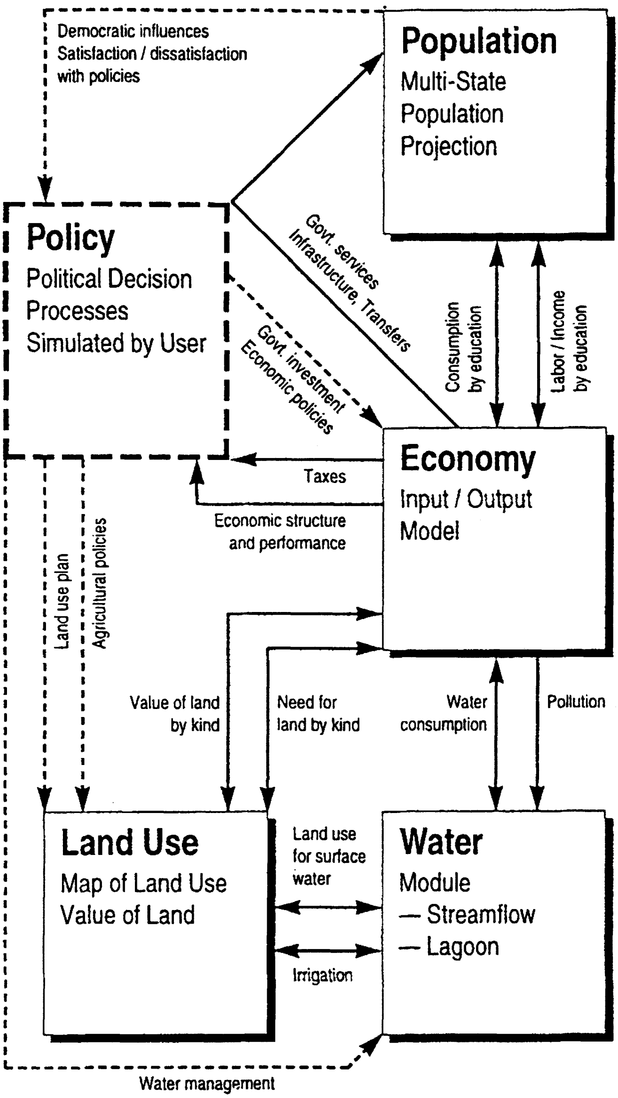

FIGURE 1. The basic structure of the PDE-Mauritius model. (Source: IIASA.)

from the economy and private consumers for net use and for pollution dilution. It also calculates the supply of water available to be used. The user must define a policy to reconcile demand and supply.

The government policy module is a collection of variables on government policy which interact with the other four modules in various places. Government policy is maintained as an area where human decision-making is the only key to action.

All of these modules are linked. Some of these links are hard-wired. That is, they are automatic. But many of them are soft-wired, that is, the scenario-builder has to define them. For example, the land competition reconciliation is hard-wired. But the choice whether greater productivity or a government policy determines the rules of reconciliation is soft-wired. Also, as mentioned above, the balance between water supply and demand is soft-wired: the user must define policies to balance them.

MAKING SCENARIOS WITH THE MODEL

To make a scenario, the user must follow two steps:

1) make an initial specification of all the scenario assumptions concerning the future development in the guiding variables of population, economy, land use and water;
2) run multiple calibrating versions of the scenario by making small changes in selected variables in order to balance labor, water, land, and government budget, or to obtain some other specified result (e.g., a targeted GNP per capita, or a certain division of land use).

This second step is a reflection of the observation that many of the feedback loops, for example from environment to the economy, or from the economy to population, are complex or unknown, and simple and adequate recipes for dealing with such feedback are not available. The model requires the user to specify and deal with the feedback by iteration. In this way, the user becomes much more familiar with the connections in the system of the model than if the model were a black box which equalized, optimized and balanced everything in a manner hard to understand.

The model calculates the population first according to the assumptions made for fertility, mortality, migration, and transition rates out of school and to and from the active labor force. There is no direct feedback from the other modules. Then, the model calculates the economy, including total GNP, per capita private consumption, labor force requirements, and investments. The economic module calculates labor force requirements, but does not check back with the population module if these requirements actually equal the supply. This is a soft feedback which is left to the user to implement. The land requirement and land availability are partially equalized internally along with the economic module. If urban growth proceeds to take over the whole island, the model cannot balance land demand and supply. The last calculations of the model are the water requirements based on the economic output and the population size and how much water is available. The water requirements and effluents are calculated with internal feedback regarding irrigation. If water demand exceeds supply, the model reduces irrigation. If at zero irrigation the demand still exceeds the supply, the model calculates how much water is needed without regard to how much is available. The rest of this soft feedback is left to the user of the model.

> In some situations the model does not stop calculating when it runs into imbalances in these selected variables. It continues to run "as if" there were sufficient labor, sufficient money, and sufficient water and land. However, in the presentation of the results of the scenario, the imbalance is shown. After running a scenario, the user has to check the results, in particular the results of the variables that need to be balanced. If there is an imbalance, the scenario-maker needs to decide how to deal with it. (Prinz & Wils, 1994, p. 298)

The reason this is left up to the user is that the resolution of labor, budget, water and land conflicts is not unequivocal. For example, assume that an initial scenario specifies an economic boom and a small nongrowing population. This results in a labor shortage. Now, something has to be changed. Either the economic demand has to give way, or the technology is changed to demand less labor, or the population assumptions must be changed. "We, as the modelers, did not hard-wire the decision which of these elements has to change and how much, because we feel that various solutions are possible in reality: if there is tension on the labor market, either the economy will react by growing less than it otherwise could, or labor productivity will increase through innovations and better technology, or the labor force will adapt, or any combination of the three alternatives" (Prinz & Wils).

An advantage to this kind of open model is that one can test various types of reactions to see which would lead to a more desirable future. With a model, if you run into a conflict somewhere in a future scenario year, you can go back to the starting year with knowledge of the conflict and change the path of the future to see if the new plan works better.

SCENARIOS TILL 2020

There are two basic strategies to define future scenarios in general, and to define a longterm scenario for the demographic, economic, and ecologic development of Mauritius in particular: (i) to specify a plausible, desirable, or illustrative path for the major variables and to calculate the resulting consequences of the assumed development, or (ii) to specify ultimate goals in one or some of the output variables and find out what development is necessary to reach the assumed goals. In both cases, possible constraints and limitations have to be considered.

In this paper and in the main study, the second strategy is chosen. A country like Mauritius, well advanced in the demographic transition as well as in the transition to a service economy, raises the question: What has to be done to raise current per capita income—1990 GDP per capita was $5,750 actual purchasing power parity—during the next 30 years to today's highest income level—that of Switzerland, which was $20,900 actual purchasing power parity per capita (UNDP, 1993) or roughly four times the present Mauritian level. In other words, an ultimate income goal is specified for the year 2020 and the other parameters—most prominently education, labor force participation, industrial and service exports, and technological change—are defined to make a realization of this goal possible.

In Mauritius between 1985 to 1990, GDP at factor cost and constant prices grew at a rate of around 8.9% annually (World Bank, 1993), mainly due to the sudden mushrooming of the textile industry. The growth in 1991 and 1992 was lower—4.2 and 6.3%, respectively (CSO, 1993)—but was still a healthy level. To reach Swiss income levels, economic growth would have to continue at this high level, or 4.4% annually, throughout the coming 30 years. An ambitious target, perhaps possible from a purely economic point of view. However, already by today Mauritius has run into limits: There is no unemployment, and all water and land resources are being used. How can growth continue?

Says Nathan Keyfitz (1991, p. 15),

> Average income can increase indefinitely provided the shift to services that we see prominently today continues rapidly enough. No environmental limits prevent more medical services per capita, more education per capita, more and better restaurants, or more and better opera. In fact this is the way a series of writers . . . saw that the economy would inevitably move from primary to secondary to tertiary. Primary is based essentially on land, and the population limit is sharp; secondary

is more flexible, but it still requires materials and energy; tertiary is the most flexible of all, requiring little outside of skill and effort.

Mauritius is quite classic in this respect. Economic growth was initiated by an increase in secondary exports, and Mauritius plans to move in the direction of tertiary service exports. But is the move to a tertiary economy fast enough? The advantage of the PDE Mauritius model is that we can specify, in a concrete situation and using real data, what constraints exist and what decisions have to be made to enable growth within those constraints.

As the factors of production, land, labor and water on Mauritius are used up entirely, growth in any one of the economic sectors requires that either (i) productivity of these factors has to increase substantially, most likely through rapid technological progress, or (ii) supplies have to increase, or (iii) activities in other, less productive sectors have to be reduced; or, any combination of these three alternatives. From purely theoretical considerations we would not know what combinations are sensible and what effect they would have. With the model, however, effects of alternative combinations can directly be calculated and—after a number of efforts—a plausible and successful combination can be derived. Below, a rapid growth scenario till 2020 is proposed for Mauritius. In the specification, we bump into land, labor and water constraints. Ways to overcome these constraints are described. Questions of careful water treatment, a specific sugar policy, and a possible economic crisis are discussed in separate sections.

MODERN POPULATION/ECONOMIC BOOM

This basic scenario is reminiscent of the "usual" scenario for development, which is decreasing population growth, increasing education, and economic growth (going from an agricultural to industrial to post-industrial society), while nature is regarded as the unending supplier of resources. The difference with the "usual" scenario is that our results are embedded in the limited supply of labor and natural resources. The economic aim is to quadruple GDP in 30 years to present Swiss per capita levels.

Continued rapid social development to a "modern population" (society) is reflected in the demographic assumptions: strong increases in life expectancy at birth (76 years for men and 82 years for women by 2020, the current mortality level of Japan) together with a further decline in fertility (to 1.5 children per woman by 2010), and strong increases to modern European levels in school enrolment ratios and female economic activity. This results in a total population size of 1.25 million in 2020 (compared to 1.02 million in 1990, the base year of all our calculations).

To expand the economy from 1990, we mentioned three possibilities: productivity increases in labor, land, or water use; supply increases in these factors; or a reduced output in less productive sectors. Which of the three is most likely? The sugar economy is the least productive user of all three limited resources (land, water, and labor). In 1990, it provided 17.7% of total GDP, while it demanded 57.9% of all water resources and 68.8% of total usable land (or 44.7% of total land). It is likely that any economic growth scenario would immediately result in a reduction of the sugar sector. Therefore, the model was set up in such a way that, unless an explicit sugar policy is specified, the amount of sugar cane grown and processed on the island and the respective amount of water needed to irrigate this sugar cane is automatically reduced to give way to the more productive industrial and service activities. In the economic boom scenario, internal competition cuts sugar exports in half (see Table 1).

Lower sugar production greatly increases the availability of water, land, and to a lesser extent, labor. The question now is whether the industrial or service sector would expand. Experimentation with purely industrial expansion—of textile, but also of other manufactures—shows that with no productivity increases, the maximum expansion would be only to a level twice the present GDP. Then, labor would be used up and maximum pollution levels exceeded. We propose, therefore, that the most productive and resource-efficient service economy is expanded, while the labor and—due to pollution—water-intensive textile exports are not assumed to increase much.

Even with this economic transition, with a large portion of the economic output coming from the tertiary sector, labor, land, and water restrictions would strongly limit development on Mauritius. Without productivity increases, the maximum GDP expansion would still be to only twice the present level. Now, with mainly service exports, the labor limits are reached first. Land and water are still available at this level. If there would be enough labor (human-capital-in-the-center approach), however, then the land would run out in this scenario at a GDP level around three times the present level. This is due to urban expansion, which is doubly felt—once by expanding industrial and service activities and then by higher demand for residential space as the people become wealthier.

The only solution, in keeping with the economic expansion envisioned—namely to attain present Swiss per capita income in 2020—is technological innovation to increase labor and land productivity. Technology is one of the key variables in economic development. Solow (1957) and Denison (1974) calculated the amount of economic growth in the United States that was due to technology innovations, and both estimated about 1.5% annually. Enke (1973) says that in the industrialized countries of the world, the (labor) productivity increases due to innovation are "considered to be about 2.5% a year," and in poor countries "perhaps 1.5% typically" (p. 261). In order to attain the Swiss level GDP in 30 years, labor productivity increases of 2.8% annually would be needed. This is optimistic. We do not say it is possible or impossible, but necessary in this scenario.

A vast literature on technology exists, mostly covering the positive side (*Yearbook of Science and Technology*, 1989). Technology is a key variable, but it is not the miracle solution to all our problems. The present direction of technology may well solve every present problem, but in doing so it creates new problems that can be even more difficult. This is admittedly beyond the scope of our work so far.

Through the 2.8% labor productivity increase in all economic sectors, labor demand from the economy grows slowly and keeps pace with the size of the labor force provided with modern population assumptions (610,000 in 2020) even with the large assumed increases in production to reach Swiss GDP levels. What happens to land? Here, we also assume 2.8% annual productivity increases in the urban sectors. In general, in case of small land conflicts, most of the solution is offered by the model. However, land conflicts arising from urban activities themselves cannot be solved by the model. With the assumed productivity change, the remaining land conflict is within the boundaries that can be handled by the model itself: Sugar production is reduced in order to give way for all other sectors. Land used for sugar cane declines from 870 km^2 in 1990 to 444 km^2 in 2020, while land used for urban activities increases from 305 km^2 to 623 km^2 (see Table 1 and also Figure 3).

Even with economic restructuring and technological change, a third limitation prevails: Supply of water at a higher level must be guaranteed in Mauritius. This is not done by increasing productivity, but by increasing "supply" through the construction of new reservoirs, a policy that is already envisaged in Mauritius. In the model, not only the existing but also all newly planned reservoirs, including their (estimated) installation costs and capacities, are incorporated. If all reservoirs are built, total reservoir capacity is enlarged by more than 70%. This, together with the irrigation reduction from growing less sugar cane, is (more than) sufficient to put water demand below the net water flow supplied throughout the scenario.

TABLE 1

Major Scenario Results for Four Consistent Scenarios. Rupee to Dollar Fictional Exchange Rate, Including the Higher Purchasing Power of One Dollar in Mauritius, is Assumed Constant at 1$ $\Re$ 3.9 Rs.

Variable	Starting Value in 1990	Value Reached in the Year 2020 Under Different Scenarios: Modern Population/ Economic Boom Scenario	Boom With Water Treatment Scenario	Boom With Sugar Policy Scenario	Traditional Population/ Economic Crisis Scenario
Population size (in 1,000s)	1,022	1,252	1,252	1,252	1,463
Labor force (in 1,000s)	416	610	610	610	579
Total income (Million Rs)	22,700	114,300	107,800	70,000	27,200
Income per capita (in Rs)	22,200	91,300	86,100	55,900	18,600
Total exports (Million Rs)	19,400	111,000	111,000	62,500	14,500
Government per capita expenditure (index)	100	381	195	256	89
Labor productivity (1990 = 100)	100	231	231	135	65
Land use for sugar cane (in km^2)	870	444	477	770	437
Land use for other agriculture (in km^2)	73	167	163	78	184
Land use for urban activities (in km^2)	305	623	583	324	365
Land productivity (1990 = 100)	100	232	232	232	100
Total water demand (m^3/second)	12.0	13.0	11.5	14.1	12.4
Dilution flow required (m^3/second)	2.4	2.3	0.6	2.7	1.6
Concentration of BOD in the lagoon (kg/m^3)	0.27	0.56	0.15	0.43	0.23
Water treatment investments (Million Rs)	0	0	4,750	0	0

Source: Prinz and Wils, 1994.

If water demand from nonirrigation would exceed water supply, this conflict would have to be solved by the user.

Having solved all the labor, land, and water constraints, one more adjustment has to be made. In this scenario, the budget balance is highly positive. We choose to let tax rates remain unchanged and increase per capita government consumption, which mainly comprises education, health and pension expenditures. In order to compensate the huge budget surplus, per capita government consumption can be increased 4.6% annually over the whole period, or fourfold by 2020 (Table 1). We note that the immense increases in the expenditures on and in the quality of education and health care are parallel to the labor productivity increases, although this is not a hard-wired result of the model itself.

BOOM WITH WATER TREATMENT

A negative effect of the above-described modern population/economic boom scenario is the rapid increase in organic waste concentration in the extremely sensitive lagoon. This is shown in Figure 2. The biological oxygen demand (BOD) increases from 0.27 kg/m^3 in 1990 to 0.56 kg/m^3 in 2020. The biological oxygen demand (BOD) is the inverse of the organic waste concentration; i.e., it is the oxygen demand needed to keep the current organic waste concentration unchanged. The high BOD levels mean there is a nutrient enrichment in the lagoon. Eutrophication results in the proliferation of certain species, usually algae but also sea urchins in Mauritius, at the cost of other species, and results in an impoverishment of aquatic life. It is believed that this may kill the corals. In 1982, a UNEP study showed that roughly two-thirds of the corals were still alive but that "urgent immediate measures must be taken in order to prevent further deterioration" (Ramjeawon, 1991). The issue of water pollution in the lagoon indeed is another aspect of the smallness of Mauritius: Not only are the natural resources scarce on the island itself, but also around the island. Mauritius is almost entirely surrounded by coral reefs, but since the island is small, so is the surface area of its surrounding lagoons. With smaller lagoons, less absolute amounts of pollution lead to toxic concentrations.

If the corals die and the lagoons are polluted, this certainly would mean the end of the tourism industry on Mauritius and would deprive Mauritians of a great source of quality of life. Would it be threatening in further respects? It is not known how fast dead corals would degrade and stop their function of protecting the island from the high seas. Nor is it known how much artificial protection (for example, concrete) would cost.

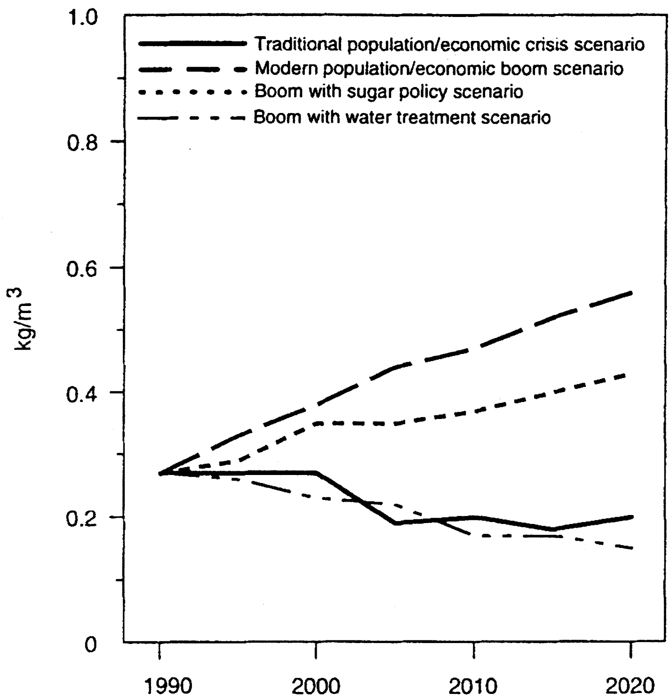

FIGURE 2. Lagoon water pollution measured in terms of biological oxygen demand in the lagoon, four scenarios.

Even if we do not know at what BOD levels life in the lagoon would or could eventually die, we know that already with current organic waste concentrations some smaller parts of the lagoon have started to die. It therefore seems wise to set an upper limit of organic waste concentration which is the 1990 level: 0.27 kg required BOD per m^3 with a desired level of 0.2 kg. per m^3. Is it possible, with a rapidly growing economy, to keep lagoon pollution below this level? And, if it is, what are the costs and to what extent is income growth affected?

In the "boom scenario with water treatment" everything stays the same as in the previous scenario except that no increase in the organic waste concentration in the lagoon is allowed. In order to do so, a considerable amount of waste water has to be treated so that it can be re-used in the production processes. In the water module, water treatment is possible at three different treatment levels which differ by unit cost and effectiveness.

For example, to remove 30% of the BOD from textiles costs 172 Rupees per m^3 of waste water; to remove 90% of BOD costs 604 Rupees; and to remove 95% costs 741 Rupees, all at 1987 prices with present technology. Treatment at the secondary level turned out to be the best combination of costs and effectiveness in almost all sectors.

The sectors that produce large amounts of BOD on Mauritius are sugar milling, the three manufacturing sectors, and tourism. The other sectors produce virtually none (see Toth, 1992). At the most extreme, sugar milling produces 1155 kg of biological oxygen demand per million Rupees output, compared to between 2 and 14 kg per million Rupees output in the service sectors (the differences lying in the productivity of the workers in these service sectors). Only the five most polluting sectors are chosen for treatment. The results are also shown in Figure 2. The BOD level in the lagoons remains low. As a matter of fact, the level is as low as in the economic crisis scenario, which is discussed in a later section.

In order to maintain BID levels between 0.2-0.27 kg per m^3, a constant annual investment of 4.75 billion Rupees is required. These investments are assumed to be lost from the economy because all of the material is imported. The reason for a constant investment even with a growing economy, is that the polluting sectors—mianly sugar milling and textiles—are concentrated in the early years of the scenario. Later, when the economy is more service oriented, a much lower treatment capacity per unit of output is necessary. This transition from an early industrial economy with much pollution (and clean-up required) to a post-industrial economy with much less pollution per unit of output is observed in the developed countries of today.

The required investments in this scenario equal 20% of GDP in 1990 and 5% in 2020, which are unrealistically high amounts. We must therefore fear that until cheaper technology is forthcoming, Mauritius will exceed its small environmental limits.

BOOM WITH SUGAR POLICY

In the modern population/economic boom scenario, land conflicts are solved in such a way that sugar cane has to give way to more productive urban activities. This feature, however, is contrary to current government policy. For many often idealistic reasons, Mauritius is reluctant to give up its sugar cane, and the current policy is to keep the present sugar output. Would it be possible to have both wealth and sugar? What constraints would hit Mauritius if such a policy was realized?

Choosing the option "sugar policy" in the land use module of the PDE-model takes current government views into account. Under these conditions, any demand for sugar is satisfied first, and the remaining land is distributed to the remaining economic activities. A direct impact of this is that industrial and service production is limited at a lower level than is demanded domestically and from abroad, triggering a contraction of the whole economy.

Due to some land productivity increases for sugar, in the future somewhat less land will be required to produce the present amount of sugar. This is shown in Figure 3 on future developments of sugar land. Compare this line to the development under the modern population/economic boom scenario, where there is a smooth, monotonic decrease in land used for sugar cane growing as urban activities crowd sugar out more and more.

In the sugar policy scenario, urban activities are reduced drastically because of losing the conflict over land use and, as a consequence, total

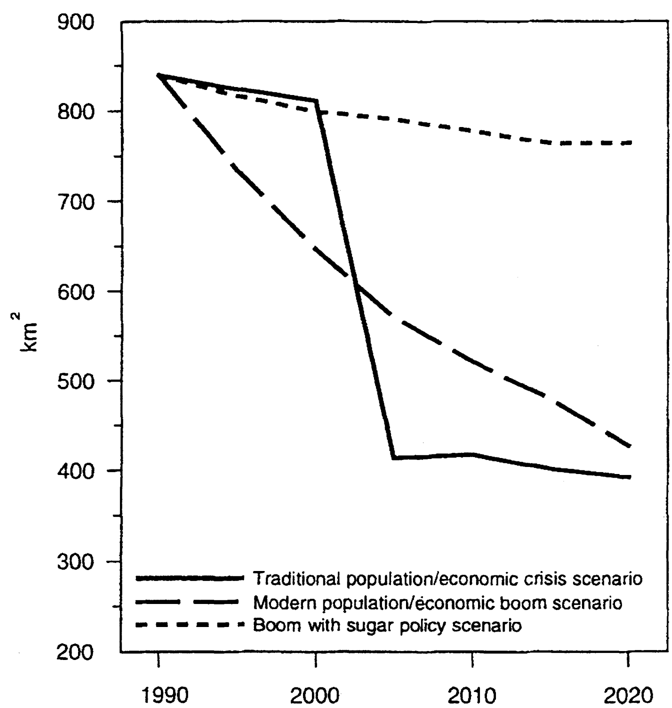

FIGURE 3. The development of sugar land under three scenarios.

exports have to be reduced by some 40% (compare Table 1) compared to the basic boom scenario level. Hence, by 2020 in the "boom scenario with sugar policy," GDP per capita increases threefold instead of fourfold and reaches "only" $14,333 per capita in purchasing power parities.

As a consequence of the lower level of exports and GDP, per capita government expenditure increases are lower, and labor productivity increases would be only 1% annually. Water demand would be higher, just below total water supplied in this scenario. Sugar is the most intense water user on Mauritius. Much water is lost through evapotranspiration of the sugar cane, and then much water is necessary to dilute the biological waste during sugar cane processing. Given more realistic productivity increases, this scenario is probably more likely than the original boom.

TRADITIONAL POPULATION/ECONOMIC CRISIS

A completely different case of the small, crowded room is where the population is growing, but the economy is not. The traditional population in this scenario has a TFR of 3.0, low education and female labor force participation rates, and stagnating life expectancy. In 2020 the total population is 1.46 million. The export crisis in this scenario is substantial: Primary sector exports (sugar) are reduced by 50% in 2000, secondary sector exports (textiles) are gradually reduced by 25% until 2020, and tertiary sector exports remain unchanged. Consequently, income per capita decreases. Production resources are freed up by the export reduction. We can imagine that in a situation of poverty and underemployment as this one, with surplus land and water resources, the following development could occur: Namely, that in reaction to the economic crisis, food imports would be reduced and domestic food production increased correspondingly, to make better use of the surplus labor, land, and water resources.

The idea behind import substitution is that it has a double positive effect: It reduces the amount of money which is "lost" abroad because it reduces imports; and it strengthens the inner economy because there is an increase in domestic production. In its early history, Mauritius was self-sufficient in food for some time, but it has a long tradition in food imports since. Today, Mauritius produces about one-third of the food its population consumes. Food self-sufficiency does not necessarily have high priority in an open export-oriented economy, but it might be a good strategy of sustainable development and resilience to international crises.

To explore the effects of import substitution, we assume almost complete food self-sufficiency by the year 2010. Unit domestic food demand is increased by 50% quinteniall from 2000 to 2010 to around 80% of total food consumption, and imports are reduced by 50% in the period 2000-2005 to the remaining 20% of food consumption. These 20% would be almost only imports of calorie-rich staples, such as wheat which does not grow on Mauritius. In weight it would be more than 20%, but we translate to monetary values in this model. This new production obviously demands an increase in the proportion of land to be used for agriculture. Under crisis assumptions, this land is available because of freed sugar land. In 2020, the land use for other agriculture is 184 km^2 compared to 73 km^2 in 1990, or about one-sixth hectare per person. This is lower than other estimates of land per person needed (e.g., Mollison, 1987) because it does not include firewood, pasture, and 100% staple crops needs. The total land use in 2020 is 986 km^2, which would leave room for more expansion from the point of view of land.

However, as the additional food has to be grown and hence irrigated on the island, the limits of water availability are reached by around 2020. We note that in this scenario, due to the economic constraints, no further reservoirs are built; water storage capacity remains at its 1990 level. In the scenario it is assumed that a large part of the additional food production comes from local agriculture—food grown in household gardens. Therefore, as a consequence of higher demand for irrigation, two water variables were changed for the household sector: specific gross intake (+65% quinteniall between 2000 and 2010) and the rate of water loss (+50% quinteniall over the same period). After 2020, no further increases in food production are possible. The water balance also includes the higher evapotranspiration from more food crops. Of course, more efficient irrigation methods could be used and the sea could be harvested. But all this must be seen in the context of the scenario: Mauritius is poor in this future, and limited in its technical and creative resources.

Figure 4 shows the development of the water demand in this food self-sufficiency scenario. The water demand dips from 2000 to 2005 as the crisis sets in, but the reaction to produce own food has not been fully completed. By 2010, the water demand increases again, because of increased irrigation for local food crops. We see that after 2010 the curve flattens. In 2020, it hits the water supply curve again. At this point, the model reduces irrigation and the productivity of agriculture, depending on the extent of the water shortage. The fact that the water demand curve hits the water supply curve means that there is actually a water shortage solved internally for this scenario year.

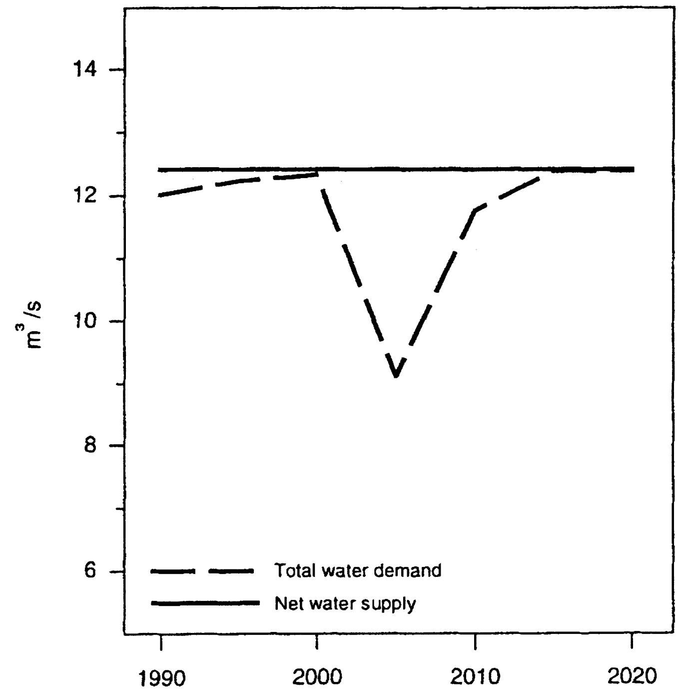

FIGURE 4. Water supply and demand under economic crisis assumptions.

CONCLUSIONS

The Mauritius model and the construction of future scenarios for that country (re)teach us the old adage: "You can't have your cake and eat it too." You cannot expand simultaneously in all directions. Not only that—the limiting factors are *different* at each step of development so that one cannot simply concentrate on one "limit to growth" but continually needs to look at many. As it is impossible for humans to concentrate on many things at once, a computer simulation model is a helpful tool. It "beeps" every time something is wrong somewhere in the system.

The Mauritius model is a neutral participant in the discussion about Malthusian collapse, the realness of natural constraints, or the ability of human ingenuity to overcome every hurdle with substitution and technology. A user can put in assumptions that problems are solved by productivity increases, or that population growth leads to disaster. The model is neutral about that; it calculates the outcome following these assumptions, simulating a real setting with an empirical data base. The user finds out that the first set of assumptions necessitates others in order to make a scenario possible and consistent. Also, the assumptions have to be expressed in real numbers. The user can then ask questions like: "How realistic is that 2.8% annual labor productivity increase that I had to assume to reach my desired GDP and overcome constraints?"

Mauritius is a small island country with limited water resources; good, but not very much agricultural land; and a very high population density with a low population growth rate. It has a high level of social development, and a responsible, democratic government. Sugar exports propped up the economy for more than one and a half centuries, until a recent economic boom driven by textile exports. The government policy is to remain an export-oriented country and to gradually replace textile exports with other manufactures and eventually services. The government would also like to maintain a high level of sugar production, and to keep most of the present sugar land. Sugar cane productivity increases are expected from irrigation and agrotechnology. At the same time, the government is also interested in increasing food self-sufficiency.

We find that fulfilling all of these policies is not going to be possible. Any increase in industrial activity requires water, land and labor, none of which was free in Mauritius at the time of writing. In fact, we find that economic growth was lower in the beginning of the 1990s when there was no unemployment (i.e., no free labor to be used). Water investments in existing planned water reservoirs would increase the water supply for irrigation and manufacturing. An immigration policy could ease the labor market, but for real economic growth, the numbers of immigrants needed are so large that they quite exceed realistic developments—in the boom scenario, until 2020 around 100,000 immigrants on a population of a million. When the immigrants are simply a substitute for labor productivity increases, and lower per capita income while hardly contributing to a higher total GDP, their effects on land and water demand are small at the high levels of income assumed in the boom scenario. Increases in labor productivity are real, but would have to be 2.8% annually in the boom scenario, which is also unrealistic. Therefore, in order to continue to diversify and expand the manufacturing activities, a decrease in another area is necessary. On Mauritius, it turns out that the least productive sector per unit of water, land or labor input is sugar. So it would be logical to reduce it. When sugar cane growing is reduced, it frees up a lot of each of these factors of production, which can be used for manufacturing or services. We do not see an alternative to a reduction in sugar cane growing if the economic activity in the manufacturing and/or service sectors on Mauritius are to expand.

A scenario for food self-sufficiency was explored. The agricultural sector of Mauritius indirectly more than covers food needs—sugar exports pay for the food imports. With the present level of sugar exports, there is not enough land left to attain food self-sufficiency. The choice for sugar is rational because its export value exceeds the value of the food that could be produced on the same land. Also, sugar is more resistant to the cyclones that ravage the island about every seventh year. As long as Mauritius has the possibility to export the sugar it produces, sugar should take precedence over food. In the case of a sugar export crisis, land would be freed up. Food crops could be planted. With present technology, according to the model, about 80% of the food needs of 1.5 million people could be covered (some staples would need to be imported). Then, fixed water resources (not land!) would constrain further expansion. A larger population would lead to more than proportional decreases in per capita consumption (because people compete with agriculture for the scarce water).

Another sector which makes relatively inefficient use of Mauritius' scarce resources is the textile industry. The value added per worker is low compared to other manufacturing and service sectors on Mauritius, and it is a large user of water for dyeing. In fact, the textile industry is being crowded out of the Mauritian economy now—in part because wages are rising, which means that people have the alternative to switch to higher paying jobs (where their value added level is higher if wages reflect productivity). Thus the model suggests exactly what is happening on Mauritius.

If a country like Mauritius shifts to very selective manufacturing and services, that means it has to import food and manufactured products from elsewhere. To a certain extent, therefore, it "enlarges" itself by making use of other countries' room. Herein lies a big weakness of the model: It is national, and the country can export some of its problems. Applied to all countries of the world simultaneously, this would no longer make sense: When our Earth is full, where do we export our problems? Ultimately, by blowing up the Mauritius model to a global scale, we become aware that the Earth, too, is a crowded room, and yet the Earth cannot move up the street.

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