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AN EDUCATIONAL TOOL TO EXAMINE THE DEVELOPMENT CONSTRAINTS IN THE LIMPOPO RIVER BASIN

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AN EDUCATIONAL TOOL TO EXAMINE THE DEVELOPMENT CONSTRAINTS IN THE LIMPOPO RIVER BASIN

The primary goal of our approach is to develop an educational tool for use in capacity building in the Limpopo basin region and train policy making staff. Exercises based on this tool could be put together to develop policy targets for multinational negotiations training and for regional or national vision validation. Consequently, in this work we are interested in understanding the development constraints of the Limpopo River basin in southeastern Africa covering the important countries of South Africa, Zimbabwe, Botswana, and Mozambique. A scenario-based approach is used to understand possible development scenarios of these basin countries. Conceptual and mathematical models have been built (for population, economy, food supply and demand, and water demand, supply, and use) with data from credible sources. This has been incorporated for use in the decision support system Globesight to look into possible futures. Multiple hypothetical scenarios were created and are discussed in this report. Such scenarios may be evaluated then for effectiveness based on conservation effectiveness, cost effectiveness, and desirability of implementation.
1. INTRODUCTION

Over 70 percent of the earth’s surface is covered by water. Of this amount, approximately 97 percent is saltwater, rendering it virtually unusable. Of the remaining 3 percent, 87 percent is inaccessible, being contained within polar ice caps, glaciers, soil, the atmosphere, or deep aquifers. The proportion of available water on the planet that can actually be used is only 0.4 percent.

Water is the primary source of life and is used for a number of purposes. Aside from domestic purposes such as drinking and sanitation, it is also used for agriculture, industry, power generation, navigation, and recreation. Water is a renewable resource, but some of the reused water becomes very polluted and hence unusable, especially if it was previously used for agriculture or industry. This decrease in the quality of water leads to consequences such as public health problems like water-borne diseases and decreased sanitation, danger to existing ecosystems, and limits to the agricultural and economic growth of an area.

Poor water management compounds the problem, and the overuse of groundwater often causes salinization of soil, as happened in the Aral Sea basin in the former Soviet Union (UNESCO, 2000). Deforestation often causes sedimentation and flooding, which change the landscape of an area. Poor planning in dam and reservoir development may damage ecosystems, decrease water flows downstream, and cause flooding. Because irrigation for agriculture comprises the majority of consumed water, unrealistic expectations of crop production, such as growing water-intensive crops in a water-scarce area, waste valuable resources (Susiarjo, 2002).

In this work we are interested in developing a teaching and training tool that helps in understanding the development constraints of the Limpopo River basin in southeastern Africa covering the important countries of South Africa, Zimbabwe, Botswana and Mozambique (Figure 1). We are interested in looking at the possible development scenarios of the basin countries. Conceptual and mathematical models have been built for population, economy, food supply and demand, and water demand, supply, and use. All relevant data has been collected from credible sources. These models have been incorporated for use in the decision support system Globesight to look into possible futures until 2050 (Mesarovic, 1996). Our primary goal is to develop an educational tool for capacity building that consequently can be used in training regional policy making staff. A number of hypothetical scenarios are explored for capacity building.

1.1. Geo-Hydrologic Description of the Basin

The river system that is of interest here, the Limpopo River, is an important river that flows for 1,000 miles (1,600 kilometers) in southeastern Africa. The Limpopo rises in the highlands that separate the Northern Province of South Africa from Botswana and Zimbabwe, and flows through and between these countries before it crosses Mozambique, finally draining into the Indian Ocean (Figure 1). Rudyard Kipling described the river in his story, The Elephant’s Child, as “the great gray-green greasy Limpopo.” It is also called the Crocodile River. Its last 60 miles (97 kilometers) are tidewater. Above this point, the river varies between a trickle in the dry season to a flood in the wet season. The Olifants River is the main tributary of the Limpopo.

The water resources of the Limpopo River basin (area: 412,000 sq km) are shared by South Africa, Botswana, Zimbabwe, and Mozambique, while the Limpopo main-stem (length: 1,500 km) is the international boundary between South Africa and Botswana, and South Africa and Zimbabwe. The basin’s climate varies spatially from arid in the west through semi-arid and temperate in the central zones to semi-arid in
the east, but with a few sub-humid pockets in the center. The environment along the main-stem of the Limpopo is semi-arid throughout its length. Further, its flow is not perennial. The main-stem has more than twenty tributaries, many of which have been developed to a considerable degree. The extent of utilization of main-stem flows varies along its length and depends to a large degree on near-channel alluvial storage of surface flows, as no massive water storage facilities such as dams have yet been built on it. The utilization of main-stem flows has become a point of interest to water planners of all four countries during the 1990s, as tributary development has continued unabated (Boroto, 1997).

South Africa is the most economically powerful country in the region, with a population and economy greater than all the other basin countries combined. Botswana is a landlocked country, having borders with Zimbabwe, South Africa, and Namibia. It is also suffering from the AIDS epidemic, with life expectancy at birth of 35.2 years, and the AIDS prevalence rate among adults is over 35 percent. Botswana transformed itself from a poor country to a relatively rich one with a per capita income of $8000 (2001 US$ PPP). Diamond mining has been the biggest source of growth, currently accounting for a fifth of GDP and 80 percent of exports.

Zimbabwe is a landlocked country in southern Africa. A vast plateau sloping southwest to northeast, whose central part lies at an elevation of 4,000–5,000 ft (1,200–1,500 m), dominates Zimbabwe’s landscape. The Zambezi River forms the country’s northwestern boundary and includes the Victoria Falls, as well as a major dam (completed 1959) that created Lake Kariba. This dam, at more than 2,000 sq miles (5,200 sq km), is one of the world’s largest artificial lakes. The Limpopo and Sabi river basins are in the southeast. Agricultural products, raising livestock, and working the mineral reserves, including gold, are all economically important.

Zimbabwe’s economy relies heavily on agriculture, and on related manufacturing industries such as textiles and sugar production. Mining, primarily gold, is also a major activity. Zimbabwe achieved an average 1.7 percent GDP growth between 1991–5, 7.3 percent in 1996, and 3.5 percent in 1997. The economy contracted by about 5 percent in 2000 and continued to contract in 2001 given the decline in revenues from agriculture, manufacturing, and tourism. Recent flooding and droughts in the region have also had an adverse impact on the economy and livelihoods of rural populations.

Mozambique has a long coastline and one of the large per capita renewable water resources in southern Africa (11,020 cu m/capita). Its population stands at 20 million as of 2001. Mozambique has long been considered poor, with low life expectancy at birth (35 years) and with 8 percent of the living population with HIV/AIDS. With a reasonable growth rate of 9.1 percent in 2001, Mozambique’s GNP is US$3.8 billion with a balanced economy of 33 percent agriculture, 25 percent industry, and the remainder services.

Mozambique’s per capita water withdrawal for agriculture is the lowest among the four basin countries. There are a tremendous amount of non-Limpopo based water resources in the north of the country, and hence it does not need to consume much of the Limpopo’s resources. Irrigated agriculture has low yields but has potential to grow.

2. MODELING FOR THE FUTURE

In a world that faces constant change, scientists strive to model accurately the plausible futures of many different systems. Simulation provides a window into the future that can help nations study possible consequences for action and inaction, and it gives policy makers a tool to prevent catastrophes from happening. On a global
scale, the two most important commodities are food and water, and each country in the world is striving to ensure that it can sustain a population now and in the future. Industrialized countries have an easier time of it, and developing countries often struggle. For this reason, it is important to model possible futures of developing countries since simulation, of which scenario analysis is an often-used approach, can aid researchers in developing strategies for the futures of these nations.

2.1. Scenario Generation Approach

Scenario analysis should accommodate a multitude of factors – conceptual (verbal), relational (models), and numerical (data) – that can be interrelated in a coherent manner. It integrates two complementary components of a comprehensive scenario analysis (the yin and the yang, see Figure 2): verbal vision scenarios (also called "narrative scenarios") along with the use of models for numerical assessment (sometimes referred to as "quantitative analysis"). Lack of one or the other renders a scenario analysis incomplete.

Unless the alternative futures presented are documented as feasible (not just forecasted as probable, and perhaps not necessarily even likely) and solidly taken into account based on scientific knowledge, they will lack the required credibility. On the other hand, if they are based solely on aspects of reality that can be presented in numerical form, they will not address important – indeed, crucial – factors of society, political and individual aspirations, uncertainty of societal and individual choices that are yet to be made, future events, and so on. What is needed is an approach that is broad (general) enough, yet logically consistent, indicating the “causality flows” – what depends on what, how the future evolves in time. It must represent feedbacks and other interdependencies, and so on.

2.2. Model Highlights

To study the future evolution of the countries in the Limpopo basin using a dominant relationship approach we modeled the following aspects (Sreenath, 2001):

- population
- economy
- water demand
- supply and consumption
- food supply (cereal land, yield, and production)
- food demand and food deficit.

The models are based on difference-equations and work on an annual timescale. Data was compiled from various credible sources (World Resources Institute, 1998; FAO Statistical Database; World Development Indicators; Shiklomanov, 1999; UNH/GRDC; FAO Land and Water Development Division). The block diagram of the overall model is shown in Figure 3.

2.3. Mathematical Representation

The population dynamics are represented by a first order difference equation as shown below:

\[ pop_t = pop_{t-1} \times (1 + \frac{r_{pop}}{100}), \]
where \( \text{pop}_t \) represents the population in year \( t \) in millions and \( \text{rpop}_t \) is the rate of population change.

The economy of each country is represented by \( \text{gnp}_t \) – the gross national product (GNP) and the rate of change of GNP as \( \text{rgnp}_t \). Then the following equation represents the dynamics of economy:

\[
\text{gnp}_t = \text{gnp}_{t-1} \times (1 + \frac{\text{rgnp}_t}{100}) .
\]

The GNP per capita \( \text{gnp}_{t,pc} \) can then be formulated as:

\[
\text{gnp}_{t,pc} = \frac{\text{gnp}_t}{\text{pop}_t} .
\]

The calorie per capita is represented by \( \text{cl}_{pc} \), then the total annual calories can be formulated as:

\[
\text{cl} = \text{cl}_{pc} \times \text{pop} \times 365 ,
\]

and the total annual food demand in tons is given by

\[
\text{fd}_{dm} = \frac{\text{cl} \times k_{cl}}{10^6} ,
\]

while the food demand per capita is

\[
\text{fd}_{dm,pc} = \frac{\text{fd}_{dm}}{\text{pop} \times 10^3} .
\]

The total arable land of each country is represented by \( \text{ld}_{ar} \) and the rate of change of total arable land is \( \text{rld}_{ar} \). Then the following equation represents the dynamics of the total arable land in the country:

\[
\text{ld}_{ar} = \text{ld}_{ar-1} \times (1 + \frac{\text{rld}_{ar}}{100}) .
\]

The total land under cereal is then the total arable land times the cropping intensity \( k_{cr} \), which accounts for multi-cropping, that is, that some land may be used more than once during a year to grow crops. This is then given by:

\[
\text{ld}_{cl} = \text{ld}_{ar} \times k_{cr} .
\]

The irrigated cereal land \( \text{ld}_{irrigated,cl} \) is given by:

\[
\text{ld}_{irrigated,cl} = \text{ld}_{cl} \times \left( \frac{k_{irrigated}}{100} \right) ,
\]

where \( k_{irrigated} \) is the percentage of total cereal land under irrigation.

The dynamics of the growth of the yield are represented by a first-order difference equation as shown below:
\[ yld_{t} = yld_{t-1} \times (1 + \frac{ryld_t}{100}) , \]

where \( yld_t \) represents the population in year \( t \) and \( ryld_t \) is the rate of growth of the yield.

The total food production \( fd^pr \) is the yield times the total cereal land,
\[ fd^pr = ld^{cl} \times yld , \]

with the food balance \( fd^{bal} \) being the difference between food production and demand
\[ fd^{bal} = fd^pr - fd^{dm} . \]

The water consumption \( wt^{cn}_k \) for the four sectors \( k \) – domestic \( (dom) \), agriculture \( (agri) \), industry \( (ind) \), and recreation \( (rec) \) is represented by a coefficient of water consumption \( kwt^{cn}_k \) times population, GNP of the industrial sector, population, and irrigated cereal land respectively,
\[
\begin{align*}
wt^{cn}_{}^{\text{dom}} &= \left( \frac{kwt_{dom}^{cn} \times pop_{}}{1000} \right), \\
wt^{cn}_{}^{\text{ind}} &= \left( \frac{kwt_{ind}^{cn} \times gnp_{ind}}{1000} \right), \\
wt^{cn}_{}^{\text{agri}} &= \left( \frac{kwt_{agri}^{cn} \times ld^{cl}_{\text{irrigated}}}{1000} \right), \text{ and} \\
wt^{cn}_{}^{\text{rec}} &= \left( \frac{kwt_{rec}^{cn} \times pop_{}}{1000} \right),
\end{align*}
\]

with the total water consumption \( wt^{cn} \) being the sum of the consumption in the four sectors,
\[ wt^{cn} = \sum_k wt^{cn}_k, k \in \{\text{dom, agri, ind, rec}\} . \]

The water demand \( wt^{dm}_k \) in the four sectors is the water consumption in the sector divided by the efficiency of water consumption in that sector \( wt^{eff}_k \),
\[
\begin{align*}
wt^{dm}_{}^{\text{dom}} &= \left( \frac{wt_{dom}^{cn} \times 100}{wt_{dom}^{eff}} \right), \\
wt^{dm}_{}^{\text{ind}} &= \left( \frac{wt_{ind}^{cn} \times 100}{wt_{ind}^{eff}} \right), \\
wt^{dm}_{}^{\text{agri}} &= \left( \frac{wt_{agri}^{cn} \times 100}{wt_{agri}^{eff}} \right), \text{ and} \\
wt^{dm}_{}^{\text{rec}} &= \left( \frac{wt_{rec}^{cn} \times 100}{wt_{rec}^{eff}} \right),
\end{align*}
\]

with the total water demand \( wt^{dm} \) being the sum of the demand in the four sectors,
\[ wt^{dm} = \sum_k wt^{dm}_k, k \in \{\text{dom, agri, ind, rec}\} . \]
The renewable water resources per capita \( rwr^{pc} \) are the total renewable water resources \( rwr \) divided by the population,
\[
rwr^{pc} = \frac{rwr \times 1000}{pop}.
\]
The ultimate water resources \( uwr \) are then equal to the renewable water resources times a coefficient \( kuwr \) and are represented as:
\[
uwr = \frac{kuwr \times rwr}{100},
\]
with the ultimate water resources per capita, \( uwr^{pc} \), being the ultimate water resources divided by the population in millions,
\[
uwr^{pc} = \frac{1000 \times uwr}{pop}.
\]
The primary water resources, \( pwr \), can then be represented as the ultimate water resources times a coefficient \( kpwr \)
\[
pwr = \frac{uwr \times kpwr}{100}.
\]
The limit of water consumption \( w_{lim}^{cn} \) is the primary water resources times the evaporation ratio \( kevap \),
\[
w_{lim}^{cn} = \frac{pwr \times kevap}{100},
\]
with the water balance \( w_{bal} \) being the difference between the water consumption and water demand,
\[
w_{bal} = w_{cn} - w_{dm}.
\]

### 2.4. Modeling and Data Assumptions

The following assumptions were made for some of the model parameters. For example, when the efficiencies of water use (a difficult piece of data to obtain) for domestic, industrial, and agricultural sectors were not readily available, we made educated guesses as to the values (see Appendix F for a description of variables). However, it should be noted that users have the ability to change the data when more accurate or better data becomes available.

- We took data on the renewable water resources (RWR), also known as the "annual renewable water" (AWR), of countries from various sources (Shikalamanov, 1999; World Resource Institute, 1998; Gleick, 2000; and national estimates). RWR are essentially the average annual runoff of past and present precipitation. As better data becomes available we are able to integrate the updated data easily into our model.
- We assumed a potential utilization factor for RWR for each country. This factor depends mainly on the seasonal and inter-annual variability of precipitation, and potential storage facilities. Most of the countries have utilization factors of
around 60 percent, and dry countries up to 85 percent. Our data point for this value was the coefficient of utilizable water resources.

- The product of RWR and the utilization factor results in the utilizable water resources (UWR) of a country. UWR is the amount of water that can ultimately be utilized, with full development of surface and subsurface storage and conveyance facilities. In principle, this value included the sustainable use of groundwater supplies, which is essentially the amount of natural and artificial recharge of aquifers. However, there is very little data on this for our region of interest, and hence educated guesses were made.

- We considered the primary water resources (PWR). These are the annual average amount of UWR that is presently being utilized through water storage and conveyance facilities. The primary water supply (PWS) differs from water withdrawals by the users in that such withdrawals include both PWR and the amount of PWR that is recycled through various uses in the system. Thus, the total amount of withdrawals can be much larger than PWR. This extremely important distinction between PWS and withdrawal has generally been neglected in other studies of water supply and demand – often with substantial errors as a result (Susiarjo, 2002).

Given this background on the variables, we used a table from the International Water Management Institute (IWMI) to get water use or consumption data (IWMI, 2000). When such data were not available, a reference country with similar background was chosen, and efficiencies and per capita data were adopted (Gleick, 2000).

The product of the water consumption values and appropriate driving factor gives the water consumption intensity for each sector. For domestic use, the population drives the equation. For industry, it is GNP, and for agriculture, it is the amount of cultivated land in the country. Now that we have the intensity values, we used these values as inputs in order to calculate future values of water consumption for our scenarios. Also, after we determined the water consumption values for each sector, we totaled the data and compared it with the reference consumption value we generated previously. If these two numbers are close to each other, we have successfully estimated the efficiency values for each sector of water usage. This is a helpful tool because it verifies a substantial amount of our data.

A key to food production is water. The total water flow into and out of each basin county is used for computation, not the flows based on individual rivers. Proportional water use from the Limpopo can then be computed. The vast majority of the inflow of water to Zimbabwe came from South Africa, and nearly the entire outflow travels into Mozambique. This means that values for the total inflow and outflow for the country were equivalent to that from South Africa and that going to Mozambique minus any use plus loss in Zimbabwe. This rendered the hydrological water supply model substantially simpler.

### 2.5. Scenario Analysis (Food Scenarios)

The three scenarios that we looked at are called “reference,” “delayed reference,” and “realistic optimistic.” The reference scenario considers the future if current trends continue in each of the countries. We used this as the baseline with which we compared the other two scenarios. It also served as a guide to verify that our results for the other two scenarios were feasible.
2.5.1. **Scenario 1: Reference (Business as Usual: BAU)**

In this scenario we extended the FAO projections for the following variables (FAO Technical Report, 2015–30):

- cropping intensity
- percentage of irrigated land.

We decided to model a status quo scenario as our basis, so we extended the FAO projections of the above variables to the year 2050. In this scenario, we assume that a continuation of such trends is feasible. Thus, we developed the reference scenario. We assumed an increase in the calorie to grain conversion ratio. This could occur because of two factors. The first is an increase in grain efficiency. If a country is able to produce more food efficiently, this value will rise. Second, a shift in diet towards a larger percentage of meat will raise the value, because more calories will come from non-grain sources, such as grazing and non-cereal feed.

We also assumed that the irrigated land as a percentage of total cultivated land would remain constant. Even if cultivated land increases, the amount of irrigated land in each country is so small that it does not affect the value of cultivated land significantly. The data we used are shown in Appendix B.

The graph in Figure 4 shows calorie demand per capita for the four countries. Food demand per capita (in tons) is given in Figure 5. It is important to note that food demand per capita is a portion of the calorie demand per capita, since calorie demand per capita also includes animal products from non-grain sources such as grazing and non-cereal feed.

In Zimbabwe and South Africa, food production is expected to rise faster than food demand. As a result both countries, which currently have a food surplus, will see this surplus increase (Figure 6). This is in contrast to Mozambique and Botswana, where the food deficits will continue to grow. The corresponding water balance for the four countries is shown in Figure 7. The negative water balance in South Africa exists if the demand needs to be met. However, in reality, the irrigated agriculture demand will not be met at the desired level. Clearly, a negative water balance is not feasible.

2.5.2. **Scenario 2: Delayed Reference**

Here we have assumed a reasonable, but somewhat pessimistic scenario. We looked at the FAO projections for the countries, as in the reference scenario, but instead of reaching the values projected at 2030, we chose to reach those same values at 2050. The data tables for this scenario are in Appendix C. Again, we used these variables to drive the scenario:

- cropping intensity
- percentage of irrigated land.

See Figures 8 and 9 for cultivated land and crop yield assumptions respectively. In this scenario, we assume that calorie demand per capita will increase at a slower rate than in the reference scenario. Since our population projections remain constant over the scenarios, food demand will grow at a slower rate than in the reference scenario.

We also assume cultivated land and yields will grow more slowly than in the reference scenarios. Hence, food production will grow more slowly than in the reference scenario. However, food demand is expected to increase much faster than food production, and by 2020 Zimbabwe will go from being a net exporter to a net importer of food. South Africa, which had a food surplus, will continue to do so but at a much lower level than in the reference scenario, and Mozambique will have a much
greater deficit (Figure 10). Thus, in contrast to the present situation where food production adds to GNP, the food sector would become a drag on the economy, since food would need to be imported. The water balance would also be affected in a similar fashion, with South Africa expected to have a smaller water surplus, and Zimbabwe running into water deficit. Mozambique and Botswana are not going to be greatly impacted (Figure 11).

2.5.3. Scenario 3: Realistic Optimistic

In this scenario, we assumed that calorie demand per capita will increase faster than in the previous one, but not as fast as in the reference scenario (Figure 12). Hence food demand is slightly higher than in the delayed reference scenario, but cultivated land and yield increase faster in this scenario than in scenario 2, so food production is greater. The food balance for the four countries is shown in Figure 13. In this scenario, food production is expected to increase faster than food demand, so food surplus is maintained, albeit not at as great a level as in the reference scenario. Figure 14 shows the water balance for this scenario. As can be expected, South Africa has a greater surplus than in the previous scenario but Zimbabwe continues to have a deficit, albeit slightly smaller.

2.6. Scenario Analysis (Water Scenarios)

The second set of scenarios we developed was for the water situation in the region. The fact that the water available in one country is dependent on the water flowing out of another country makes this model more complex. For example, if an upstream country were to start withdrawing and as a consequence consuming more water, then less water would be available for the next downstream country, and so on.

As with the food model, we chose three scenarios: reference, delayed reference, and realistic optimistic. We first describe each scenario individually, then draw a comparison between the scenarios. In each scenario we examined three possibilities. First, we adjusted the evaporation ratio, which represents a country’s ability to store and convey water, as well as water used for the environment. We raised this value until the total water consumption was equal to the lower limit. However it is not possible to have an evaporation ratio higher than 75 percent since there is a basic quantity of water necessary to sustain the ecology of the country (Encarta Encyclopedia Online). Thus, if a country used every drop of available water for irrigation, the needs of animals and plants would not be met, with potentially disastrous consequences. So if we had to increase the amount of usable water (that is, supply) further, we can decrease the uncommitted utilizable water by adjusting the coefficient of primary water resources (PWR). This value represents the total water supply in a country. If we cannot store any more water, the only way to get the limit to match with the usage is to increase the total water supply. That way the current efficiency numbers make the scenario possible, and we do not have to go over the 75 percent limit. However, the PWR cannot be greater than the UWR because that is the maximum available water supply.

The third situation is to begin with an adjustment of PWR before the evaporation ratio. Here we see what amount of increase in the water supply would be necessary if we did not improve water storage techniques. Given these different situations, we can evaluate which is more feasible and which would have a greater effect. We executed this plan for each of the three scenarios.

After the analysis with the evaporation ratio and the PWR, we set up the other extreme where we keep those constant and change the irrigation water withdrawal
intensity. This equates to growing crops that require less water. So we keep the efficiency constant and adjust the demand.

2.6.1. Scenario 1: Reference (Business as Usual: BAU)
In this scenario we first increased the evaporation ratio to 75 percent (maximum) and then increased the PWR. The second half of this scenario has us keeping the evaporation ratio constant at 50 percent and changing the coefficient of PWR.

Here we see that we would have to increase the water supply from 8 percent to 13.5 percent, which is more than a 50 percent increase. This conclusion represents an increase in technology that would allow more access to water than before.

For set 2, where we adjusted the intensity, we see that we would have to decrease the intensity by 50 percent to account for the same adjustment as from set 1. This might not be possible, but it would have to be done in order to leave the efficiency constant. Figures 15 to 19 show the potential water resources, water consumption limits, and the total water consumption for the scenario in the three different cases. Note that water consumption would be the same in the first two cases, since we are looking only at the supply here. The water consumption limits for South Africa, Mozambique, and Botswana are kept constant over all the scenarios, as shown in Figure 16.

2.6.2. Scenario 2: Delayed Reference
In this scenario we took the data from the food model delayed reference scenario, and ran the same conditions for the water model. We found that an evaporation ratio of 73 percent would be enough to reach the lower limit (Figure 20).

For the situation where we simply adjusted the coefficient of PWR, we see that we have to increase the value from 8 to 11.5 by 2050 to reach the lower limit.

For the second set, the amount of water used per unit of land (km3 per hectare) decreased to 3,100 in the year 2050. This means that the change in water usage for the crops would not be as effective, as a lower intensity signifies greater efficiency.

The potential water resources for South Africa, Mozambique, and Botswana are also kept constant through all the scenarios (Figure 21). Consumption limits for the three sets of various food demand situations are given in Figure 22. The corresponding total water consumption is shown in Figures 23 and 24.

2.6.3. Scenario 3: Realistic Optimistic
In this scenario we increased the evaporation ratio to 75 percent and then had to increase the coefficient of PWR. We found that a new ratio of 8.5 would be enough to reach the lower limit. The total water consumption for this scenario is shown in Figures 25 and 26. Then we kept the evaporation ratio constant and only adjusted the PWR.

In the second set for this scenario we kept the efficiency constant again and adjusted the intensity of water consumption for irrigation. Here we see that the trend continues, and we have to decrease the intensity.

Now that we have studied the two extreme cases, we can consider the most likely situation. It would probably be most beneficial and feasible to employ a combination of our two strategies, increasing efficiency and total water supply, as well as reducing the irrigation intensity. It would be very difficult to improve the situation by only focusing on one or the other, so a blend would be the best solution.

For the water scenarios, we varied a total of three constraints in different combinations to develop the scenarios. Changing the evaporation ratio is equivalent to changing the amount of water allowed to sustain the ecology. A change in the
Coefficient of primary water resources represents an increase in the amount of water that is available, given current efficiency and technology. Also, changing the intensity of irrigation water consumption equates to changing the amount of water that a given crop needs to grow (potatoes and rice require more water than wheat, per unit of production).

### BAU Set 1

<table>
<thead>
<tr>
<th>Variable</th>
<th>Initial</th>
<th>New</th>
<th>Variable</th>
<th>Initial</th>
<th>New</th>
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<td>75</td>
<td>Evaporation ratio</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
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<td>9.4</td>
<td>Coefficient of PWR</td>
<td>8</td>
<td>13.5</td>
</tr>
</tbody>
</table>

### BAU Set 2

<table>
<thead>
<tr>
<th>Variable</th>
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</thead>
<tbody>
<tr>
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<td>2500</td>
</tr>
</tbody>
</table>

### Pessimistic Set 1

<table>
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<th>New</th>
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<tbody>
<tr>
<td>Evaporation ratio</td>
<td>45</td>
<td>73</td>
<td>Evaporation ratio</td>
<td>50</td>
<td>50</td>
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<tr>
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<td>8</td>
<td>8</td>
<td>Coefficient of PWR</td>
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### Pessimistic Set 2

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<td>3000</td>
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### Realistic optimistic set 1

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<th>Variable</th>
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### Realistic optimistic set 2

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<td>3100</td>
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</tbody>
</table>

Sources: Shiklomanov, 1999; World Resources Institute, 1998; and IWMI, 2000.

The projected population of all of the four Limpopo River basin countries we studied is shown in Figure 27 (UN 2000 Revised Population Projections). For all three scenarios, the populations are going to stay the same. The driving factors for the different scenarios are the changes in the aforementioned rates or variables.
3. CONCLUSION

This project as a whole has the potential for very positive implications. The primary goal of creating a set of educational materials (background, model, data, and hypothetical scenario studies) has been accomplished. The use of such results helps in capacity building exercises to promote research and policy making in the Limpopo River basin nations. The effects can be explored on economic growth, increased environmental consciousness because of more efficient use of water resources, and beneficial cooperative alliances between and among regional basin countries. These positive implications set the core or base of stability, and the policy making staff in the countries can build upon the hypothetical scenarios given here for better understanding.

On a cautionary note, it is important that results are properly interpreted. Our approach makes it possible to train policy making staff in setting policy targets, not policy implementation. For example, one nation might look at a scenario and assume water need for a neighboring nation is much too low to justify its own high consumption of water resources. In a scenario such as this problems will certainly arise, and training policy making staff in conducting joint scenario exercises would be helpful. This can subsequently be used as a starting point for negotiations.

An alternative use of our approach could be in validating a vision that a particular nation or group of nations may want to embrace through joint participatory exercises. Again proper training is crucial in this regard.

This project has analyzed the relationship between water and food. They are inseparable, and both must be considered in order to represent the system accurately. Similarly population, water, land, and economy have to be represented to the level of depth that the users desire. With our modular approach we can accomplish this. For example, if one desires that the population be modeled to include sex, cohorts, urban/rural, fertility, mortality, and so on, this can easily be done. All of these factors help determine the scenarios and are essential for valid and usable results. Additional factors such as HIV/AIDS mortality, infection, and prevalence rates could be added as desired. Similar changes could be effected for other modules such as economy, food production, supply and demand, and water demand, supply, and use. Local policy making staff could be trained to make such enhancements themselves.

In summary, in this report we have presented a scenario analysis approach based on a symbiosis of qualitative and quantitative information. Using the Globesight reasoning support system we created a detailed model of the Limpopo River basin. We produced multiple representative scenarios that explore the water and food situation in the region.

This tool could be used to train policy making staff of the different basin countries, and as a result could be useful for capacity building in the region. Joint participatory training sessions would be useful in getting a better understanding among the staff of the different countries. Also, this approach could be used for validating a regional or a national vision.

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Shiklomanov, I. (ed.) 1999., *World Water Resources at the Beginning of the Twenty-first Century*, SHI (State Hydrological Institute)/UNESCO.


University of New Hampshire/Global Runoff Data Center (UNH/GRDC). http://www.grdc.sr.unh.edu


APPENDIX A: VISUAL C++ CODE FOR THE LIMPOPO BASIN MODEL

/***************************************************************************/
/* Limpopo Model */
/* */
/* Created: November 15 2001 */
/* Last Updated: November 15 2001 */
/* */
/***************************************************************************/
#include "stdafx.h"
#include <stdio.h>
#include "math.h"
#include "limpopomod.hh"
int r,j;
static float spop[reg],sldar[reg],syl[r][reg],sldar_irrig[reg],sldar_rf[reg],
syl_rf[reg],syl_irrig[reg],fd_pr_t_le[v][reg],sgnp[reg];
long model(long firstYear, long year, FILE *fpl)
{  
/* POPULATION */
/* */
//Total Population
for(r=0;r<reg;r++) {
    r_pop[r] = r_pop_d[r]*r_pop_m[r];
    if (year > firstYear) {
        pop[r] = spop[r]*(1 + r_pop[r]/100.);
    }
}
/* */
/* ECONOMY */
/* */
//Total GNP
for(r=0;r<reg;r++) {
    r_gnp[r] = r_gnp_d[r]*r_gnp_m[r];
    if (year > firstYear) {
        gnp[r] = sgnp[r]*(1 + r_gnp[r]/100.);
    }
    gnp_ind[r] = (k_gnp_ind[r]/100)*gnp[r];
    gnp_pc[r] = gnp[r]/pop[r];
}
/* */
/* FOOD DEMAND */
/******************************************************************************/
for(r=0;r<reg;r++) {
    cl_dm_t[r] = cl_dm_pc[r]*pop[r]*365;
    fd_dm_t[r] = k_cl_g[r]*cl_dm_t[r]/1000000;
    fd_dm_t_pc[r] = fd_dm_t[r]/pop[r]*1000;
}

/*********************** First Level Model ****************************/

* FOOD SUPPLY
*

>Total Land
for(r=0;r<reg;r++) {
    r_ldar[r] = r_ldar_d[r]*r_ldar_m[r];
    if (year > firstYear) {
        ldar[r] = slda[r]*(1 + r_ldar[r]/100.);
    }
    ldcl[r] = crp_int[r]*ldar[r];
    //Irrigated Land
    ldcl_irrig[r] = (k_ldcl_irrig[r]/100)*ldcl[r];
}

>Total Yield
for(r=0;r<reg;r++) {
    r_yld[r] = r_yld_d[r]*r_yld_m[r];
    if (year > firstYear) {
        yld[r] = syld[r]*(1 + r_yld[r]/100.);
    }
}

>Total Production
for(r=0;r<reg;r++) {
    fd_pr_t_f[r] = ldcl[r]*yld[r];
}

>Food Balance
for(r=0;r<reg;r++) {
    fd_bal[r] = fd_pr_t_f[r] - fd_dm_t[r];
}

*********************** WATER DEMAND ****************************/

for(r=0;r<reg;r++) {
    //Water Consumption
    wt_cn_dom[r] = (wt_cn_int_dom[r]*pop[r])/1000;
    wt_cn_ind[r] = wt_cn_int_ind[r]*gnp_ind[r];
    wt_cn_agri[r] = (wt_cn_int_irrig[r]*ldcl_irrig[r])/1000;

    //added recreational water consumption 11-25-01
    wt_cn_rec[r] = (wt_cn_int_rec[r]*pop[r])/1000;
    wt_cn_t[r] = wt_cn_dom[r]+wt_cn_ind[r]+wt_cn_agri[r]+wt_cn_rec[r];

    //Water Demand
    wt_dm_dom[r] = wt_cn_dom[r]/(wt_dm_eff[r]/100);
    wt_dm_ind[r] = wt_cn_ind[r]/(wt_dm_eff[r]/100);
    wt_dm_agri[r] = wt_cn_agri[r]/(irrig_eff[r]/100);
}
//added recreational water demand 11-25-01
wt_dm_rec[r] = wt_cn_rec[r]/(wt_rec_eff[r]/100);
wt_dm_t[r] = wt_dm_dom[r]+wt_dm_ind[r]+wt_dm_agri[r]+wt_dm_rec[r];
}

***************

*  WATER SUPPLY  *
***************

//Renewable Water Resources Flow
rwr[southafrica] = irwr[southafrica]+inflow_non_limpopo[southafrica];
outflow[southafrica] = rwr[southafrica] - wt_dm_t[southafrica];
inflow[botswana] = k_inflow[botswana]/100*outflow[southafrica];
rwr[botswana] = irwr[botswana] + inflow[botswana] + inflow_non_limpopo[botswana];
outflow[botswana] = rwr[botswana] - wt_dm_t[botswana];
inflow[zimbabwe] = k_inflow[zimbabwe]/100*outflow[botswana];
rwr[zimbabwe] = irwr[zimbabwe] + inflow[zimbabwe] + inflow_non_limpopo[zimbabwe];
outflow[zimbabwe] = rwr[zimbabwe] - wt_dm_t[zimbabwe];
inflow[mozambique] = k_inflow[mozambique]/100*outflow[zimbabwe];
//inflow_non_limpopo[mozambique] = rwr[mozambique] - irwr[mozambique] -
inflow[mozambique];
rwr[mozambique] = irwr[mozambique] + inflow[mozambique] +
inflow_non_limpopo[mozambique];
outflow[mozambique] = k_discharge/100*(rwr[mozambique] - wt_dm_t[mozambique]);
for(r=0;r<reg;r++) {
    rwr_pc[r] = rwr[r]/pop[r]*1000;
    uwr[r] = k_uwr[r]/100*rwr[r];
    uwr_pc[r] = uwr[r]/pop[r]*1000;
    pwr[r] = k_pwr[r]/100*uwr[r];
    wt_cn_t_lim[r] = evap_ratio[r]/100*pwr[r];
    //Water Balance
    wt_bal[r] = wt_cn_t[r] - wt_cn_t_lim[r];
}

***************

*  BACKUP VARIABLES  *
***************

for(r=0;r<reg;r++) {
    spop[r] = pop[r];
    sgnp[r] = gnp[r];
    sldar[r] = ldar[r];
    syld[r] = yld[r];
    sldar_rf[r] = ldar_rf[r];
    sldar_irrig[r] = ldar_irrig[r];
    syld_rf[r] = yld_rf[r];
    syld_irrig[r] = yld_irrig[r];
}
return 1;
}
# APPENDIX B: DATA TABLES FOR BUSINESS AS USUAL (BAU) SCENARIO

## Zimbabwe

<table>
<thead>
<tr>
<th>Variable name</th>
<th>Year</th>
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## South Africa

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Sources: World Bank; FAO Statistical Database; World Resources Institute.
APPENDIX C: DATA TABLES FOR PESSIMISTIC SCENARIO

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<th>South Africa</th>
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<th>Botswana</th>
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Sources: World Bank; FAO Statistical Database; World Resources Institute, 1998.
### APPENDIX D: DATA TABLES FOR REALISTIC OPTIMISTIC SCENARIO

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#### South Africa

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#### Mozambique

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<td>0.8</td>
<td>0.09</td>
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</table>

#### Botswana

<table>
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<th>Rate</th>
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<th>Value</th>
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</thead>
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<tr>
<td>r_lidar_d</td>
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</tr>
<tr>
<td>r_yld_d</td>
<td>2030/2050</td>
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<table>
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<tr>
<th>Variable</th>
<th>Year</th>
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<th>South Africa</th>
<th>Mozambique</th>
<th>Botswana</th>
</tr>
</thead>
<tbody>
<tr>
<td>crpint</td>
<td>2050</td>
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<td>0.362</td>
<td>0.74</td>
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<td>k_ldcl_irrig</td>
<td>constant</td>
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<td>0.59</td>
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Sources: World Bank; FAO Statistical Indicators; World Resources Institute, 1998.
### APPENDIX E: DATA FROM THE FAO TECHNICAL REPORT (2015–30)

<table>
<thead>
<tr>
<th>Total food demand</th>
<th>Table 3.1</th>
</tr>
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<tbody>
<tr>
<td><strong>Time range</strong></td>
<td><strong>Value</strong></td>
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<tr>
<td>1995–2030</td>
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<table>
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<th>Food production</th>
<th>Table 3.1</th>
</tr>
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<tbody>
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<td><strong>Time range</strong></td>
<td><strong>Value</strong></td>
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<td>2015</td>
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<td>2030</td>
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<td>2015–30</td>
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<tr>
<td>1995–2030</td>
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<td><strong>Time range</strong></td>
<td><strong>Arable</strong></td>
</tr>
<tr>
<td>1991–7</td>
<td>231</td>
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<tr>
<td>2030</td>
<td>288</td>
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<td>Growth Rate</td>
<td>0.65</td>
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</table>

<table>
<thead>
<tr>
<th>Irrigated land</th>
<th>Table 4.9</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Time range</strong></td>
<td><strong>Value</strong></td>
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<td>1995–2030</td>
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<table>
<thead>
<tr>
<th>Irrigation efficiency</th>
<th>Table 4.10</th>
</tr>
</thead>
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<td>1995–7</td>
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<td>2030</td>
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<table>
<thead>
<tr>
<th>Annual yield growth rate</th>
<th>Table 4.12</th>
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<td><strong>Time range</strong></td>
<td><strong>Value</strong></td>
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<tr>
<td>1995–2030</td>
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</table>
### Food consumption per capita

**Table 2.2**

<table>
<thead>
<tr>
<th>Time range</th>
<th>Value</th>
<th>Units</th>
<th>Growth rate</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995–7</td>
<td>2058</td>
<td>kCal/person/day</td>
<td>0.54</td>
<td>percent</td>
</tr>
<tr>
<td>2015</td>
<td>2280</td>
<td>kCal/person/day</td>
<td>0.54</td>
<td>percent</td>
</tr>
<tr>
<td>2030</td>
<td>2470</td>
<td>kCal/person/day</td>
<td>0.54</td>
<td>percent</td>
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</table>

Sources: World Bank; FAO Statistical Database; IWMI, 2000; World Resources Institute, 1998.
## APPENDIX F: CONSOLIDATED DATA TABLE

<table>
<thead>
<tr>
<th>Variable name</th>
<th>Symbol</th>
<th>Unit</th>
<th>Zimbabwe</th>
<th>Mozambique</th>
<th>South Africa</th>
<th>Botswana</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arable land</td>
<td>ladar</td>
<td>mil ha</td>
<td>3.2200</td>
<td>3.1200</td>
<td>14.7530</td>
<td>0.3430</td>
</tr>
<tr>
<td>Irrigated land</td>
<td>ladar_irrig</td>
<td>mil ha</td>
<td>0.1170</td>
<td>0.1070</td>
<td>1.3540</td>
<td>0.0010</td>
</tr>
<tr>
<td>Rainfed land</td>
<td>ladar_rf</td>
<td>mil ha</td>
<td>3.1030</td>
<td>3.0130</td>
<td>13.3990</td>
<td>0.3420</td>
</tr>
<tr>
<td>Cereal area harvested</td>
<td>lcl</td>
<td>mil ha</td>
<td>1.6616</td>
<td>2.0118</td>
<td>4.6396</td>
<td>0.0653</td>
</tr>
<tr>
<td>Harvested irrigated area</td>
<td>lcl_irrig</td>
<td>mil ha</td>
<td>0.0864</td>
<td>0.0493</td>
<td>0.8073</td>
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<tr>
<td>Arable land growth rate</td>
<td>R_ladar</td>
<td>percent</td>
<td>1.1400</td>
<td>0.0000</td>
<td>0.9000</td>
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<td>Calorie demand pc</td>
<td>cl_dm_pc</td>
<td>Cal/person/day</td>
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<td>1911.3</td>
<td>2909.3</td>
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<td>Coefficient of calorie to grain</td>
<td>k_cl_gr</td>
<td>gr/Cal</td>
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<td>0.1575</td>
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<td>0.1030</td>
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<tr>
<td>Coefficient of GNP</td>
<td>k_gnp_ind</td>
<td>percent</td>
<td>14.0000</td>
<td>25.2000</td>
<td>30.9000</td>
<td>44.4000</td>
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<tr>
<td>Annual renewable water</td>
<td>arws</td>
<td>km^3/yr</td>
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<td>216.0000</td>
<td>50.0000</td>
<td>14.7000</td>
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<tr>
<td>Coefficient of PWR</td>
<td>k_pwr</td>
<td>percent</td>
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<td>3.0000</td>
<td>47.0000</td>
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<tr>
<td>Coefficient of UWR</td>
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<td>50.0000</td>
<td>40.0000</td>
<td>60.0000</td>
<td>50.0000</td>
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<tr>
<td>Upper limit on Consumption</td>
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<tr>
<td>Coefficient of cultivated irrigated land</td>
<td>k_kcl Irigg</td>
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<td>2.4500</td>
<td>17.4000</td>
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<td>Domestic water efficiency</td>
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<td>3.8000</td>
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<td>3.0000</td>
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<tr>
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<td>1.0000</td>
<td>31.0000</td>
<td>14.0000</td>
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<td>0.0023</td>
<td>0.0009</td>
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<td>ton/ha</td>
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<td>0.0061</td>
<td>0.2306</td>
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<td>Water consumption irrig</td>
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<td>km^3</td>
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</table>

Sources: World Bank; FAO Statistical Database; United Nations 2000 Revision Population Projections; IWMI, 2000; World Resources Institute.
Figure 1. Limpopo River Basin (Source: John Pallett)
Scientific facts, credible data and models etc.

Societal and individual aspirations, uncertainty of future choices etc.

*Figure 2.* Relationship between verbal and quantitative scenarios

Figure 3. Overall block diagram of the Limpopo River model
Figure 4. Calorie demand per capita: reference scenario (cal/person/day)
Figure 5. Food demand per capita: reference scenario (kg/person)
Figure 6. Food balance: reference scenario (million tons)
Figure 7. Water balance: reference scenario
Figure 8. Cultivated land: delayed reference scenario (million ha)
Figure 9: Yield: delayed reference scenario (tons/Ha)
Figure 10. Food balance: delayed reference scenario
Figure 11. Water balance: delayed reference scenario
Figure 12. Calorie demand per capita: realistic optimistic scenario (cal/person/day)
Figure 13. Food balance: realistic optimistic scenario
Figure 14. Water balance: realistic optimistic scenario
Figure 15. Potential water resources: reference scenario
Figure 16. Water consumption limits: all scenarios
Figure 17. Water consumption limits (Zimbabwe): reference scenario
Figure 18. Total water consumption (Zimbabwe): reference scenario
Figure 19. Total water consumption (South Africa, Mozambique, and Botswana): reference scenario
Figure 20. Potential water resources (Zimbabwe): delayed reference scenario
Figure 21. Potential water resources (South Africa, Mozambique, and Botswana): all scenarios
Figure 22. Water consumption limits: delayed reference scenario
Figure 23. Total water consumption (Zimbabwe): delayed reference scenario
Figure 24. Total water consumption (South Africa, Mozambique, and Botswana): delayed reference scenario
Figure 25. Total water consumption (Zimbabwe): realistic optimistic scenario.
**Figure 26.** Total water consumption (South Africa, Mozambique, and Botswana): realistic optimistic scenario
Figure 27. Population projections: all scenarios (millions)

Index entries: Limpopo River Basin, Problematique, Scenario Analysis, Systems-based Modeling, Globesight Reasoning Support System
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27. UNESCO / André Albal

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Constitution of UNESCO (excerpt)
London, 16 November 1945

The Governments of the States Parties to this Constitution on behalf of their peoples declare:

That since wars begin in the minds of men, it is in the minds of men that the defences of peace must be constructed;

That ignorance of each other’s ways and lives has been a common cause, throughout the history of mankind, of that suspicion and mistrust between the peoples of the world through which their differences have all too often broken into war;

That the great and terrible war which has now ended was a war made possible by the denial of the democratic principles of the dignity, equality and mutual respect of men, and by the propagation, in their place, through ignorance and prejudice, of the doctrine of the inequality of men and races;

That the wide diffusion of culture, and the education of humanity for justice and liberty and peace are indispensable to the dignity of man and constitute a sacred duty which all the nations must fulfil in a spirit of mutual assistance and concern;

That a peace based exclusively upon the political and economic arrangements of governments would not be a peace which could secure the unanimous, lasting and sincere support of the peoples of the world, and that the peace must therefore be founded, if it is not to fail, upon the intellectual and moral solidarity of mankind…