# Addressing Sustainability, HIV-AIDS, and Water Resource Questions in Botswana

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**Abstract:** An integrated population, economic, and water resource model was developed to address sustainable development questions for Botswana. Traditionally, water resources planning models have considered the implications of different assumptions of population and economic growth on the sustainability of existing water resources supply; however, this model extends that capability to consider feedbacks from one model component to another. The water model uses a physically based hydrologic rainfall-runoff model, with surface and groundwater components, to produce monthly runoff and groundwater recharge at the watershed scale. Surface runoff and recharge are the inflows into surface and groundwater water reservoirs. The demographic sub model is a standard multi-cohort model that forecasts the population by age, sex, rural, urban, education and hiv/aids status. The economic sub-model is a computable general equilibrium model with three sectors: agriculture, non-agricultural exports, and non tradables. The model runs an ensemble of scenarios, including climate change, HIV-AIDS, health, economic, and water conservation scenarios, whose output is probabilistic in nature.

## 1. INTRODUCTION

This paper includes an overview of the Botswana PDE-IWS model, including a qualitative description of the water model components, the population and economic models and a description of the model linkages.

## 2. THE WATER MODEL

The water model is composed of a rainfall-runoff model, surface and groundwater reservoirs, and a water demand model. The rainfall-runoff model uses simplified but physically based, mathematical descriptions of hydrologic processes to assess climate impacts on river basins (Yates 1996, Nemec and Schaake, 1982; Lettenmaier and Gan, 1990; Nash and Gleick, 1991; Kaczmarek, 1993; Yates and Strzepek, 1996). This model requires 3 parameters for calibration, and may be run at time steps varying from hourly to daily to monthly (see Yates 1996 for details). It is a lumped conceptual model, which uses a soil moisture balance to drive the runoff and infiltration processes. Runoff fills virtual surface reservoirs while infiltration recharges virtual groundwater systems within each SER.

For both the surface and groundwater models, a water mass balance is computed at each time step using the virtual reservoir as the control volume. These supply reservoirs, balance inflows, evaporative and human demands, as well as inter basin transfers, at each time step.

The water demand model computes the following demands at each time step: Domestic, Institutional, Energy, Industrial, Mining, Livestock and Irrigation. Water consumption in each of these sectors is driven by economic and/or population changes.

## 3. THE POPULATION SUB-MODEL

The population model is described in detail in Sanderson (2001a, 2001b, 2002a, 2002b, forthcoming 2004). The model divides the population,

1) by age (100 ages from 0 through 99+);
2) by sex (female and male);
3) by education (primary and below, secondary, tertiary);
4) by HIV status (HIV negative; HIV positive, asymptomatic, and not on medication; HIV positive, asymptomatic, and on medication; and AIDS, i.e., symptomatic);

5) by number of years since HIV infection (15 categories from infected this year to infected 14 or more years, for people who are HIV positive, asymptomatic, and not on medication);
6) by sexual behavior risk group (not at risk, sometimes at risk); and 7) by onset of sexual activity (for young women and men).

## 4. Botswana Economic Model

The Botswana economic model is a computable general equilibrium (CGE) model, based on the structure of the BMW CGE model that was produced by Becker et al. (1992) for a study on the Indian economy. The advantage of using CGE models for integrated assessments is that they allow for the impacts of policy decisions to be distributed across the sectors, as equilibrium in all markets is sought. The model is based The BMW model has 10 sectors, while the Botswana model was aggregated into three, including non-agricultural exports (NAE), non-tradables (NT), and agriculture (including agricultural exports) (AG).

## 5. Linking the Models

The main purpose of combining the three PDE sub-models is to create an integrated model that can evaluate the implications of feedback processes of the different sub-components. This section will describe the specific model links that were incorporated, in the following order: 1) population- water, 2) population-economy, 3) economy- water, 4) economy- population, 5) water- population, and 6) water- economy.

Population- Water

Starting with the population/water relationship, the population has first order effects on both the water resource and the economy. Both rural and urban population stocks factor into determining the respective amount of domestic water consumed.

Population—Economy

The population also has a direct effect on the economy through the skilled labor size and labor productivity. In particular, the Non Agriculture Export (NAE) and Non-Tradables (NT) sectors are affected by labor size and productivity. These production sectors are represented at the upper-most level by Cobb-Douglas production functions in value-added, imports, and intermediate goods purchased from the other sectors, whose production functions for these two sectors are as follows:

$$Q_1 = c_1 * n_1^{a1} * m_1^{a14} * int_{12}^{a12} * int_{13}^{a13} \quad \text{Eq. 1}$$

$$Q_2 = c_2 * n_2^{a2} * m_2^{a24} * int_{22}^{a22} * int_{23}^{a23} \quad \text{Eq. 2}$$

where Q1 and Q2 (Pula) are the output of the NAE (1) and NT (2) sectors; c1 and c2 are distribution parameters for each sector; n1 and n2 represent value added (Pula); and int12 and int13 (Pula) represent intermediate goods purchased by the NAE sector from the NT and AG (3) sectors; int22 and int23 (Pula) represent intermediate goods purchased by the NT sector from the NAE and AG sectors; and each a* represents the Cobb Douglas value share for that sector; and m1and m2 (Pula) represent imports for each sector.

Skilled and unskilled labor size and productivity measured by capital are derived from the value-added, nested ces functions, which then impact economic output. The value added ces functions, n1 and n2, (capital, skilled and unskilled labor) are:

$$n_1 = (e_1 * (\phi_1^{\sigma 1h}) + (1-e_1) * ((\mathbf{LPM_U} * LU_1)^{\sigma 1h}))^{(1/\sigma 1h)} \quad \text{Eq. 3}$$

$$n_2 = (e_2 * (\phi_2^{\sigma 2h}) + (1-e_2) * ((\mathbf{LPM_U} * LU_2)^{\sigma 2h}))^{(1/\sigma 2h)} \quad \text{Eq. 4}$$

where e1 and e2 are distribution parameters; σ1h = 1-1/δ1h and σ2h = 1-1/δ2hl. The parameters, δ1h and δ2h are equal to the elasticity of substitition of LU1 and LU2, the unskilled labor in both sectors; LPMU represents the unskilled labor productivity multiplier.

The nested value added skilled labor and capital ces functions, ϕ1 and ϕ2 (Pula) for the NAE (1) and NT (2) sectors are:

$$\phi_1 = (f_1 * (K_1^{\sigma 1l}) + (1-f_1) * (\mathbf{LPM_S} * \mathbf{LS_1}^{\sigma 1l}))^{(1/\sigma 1l)} \quad \text{Eq. 5}$$

$$\phi_2 = (f_2 * (K_2^{\sigma 2l}) + (1-f_2) * ((\mathbf{LPM_S} * \mathbf{LS_2}^{\sigma 2l}))^{(1/\sigma 2l)} \quad \text{Eq. 6}$$

where K1 and K2 represent capital value in the NAE and NT sectors; LPMS is the Labor productivity multiplier for skilled labor; LS1 and LS2 are skilled labor in both sectors; f1 and f2 are distribution parameters; where $\sigma 1l = 1-1/\delta 1l$ and $\sigma 2l = 1-1/\delta 2l$. The parameters, $\delta 1l$ and $\delta 2l$ are equal to the elasticity of substitution.

Finally, the intermediate goods purchased by the NAE sector from the NT and AG sectors and the imports purchased by the NAE sector are defined by:

$$int_{12}=a_{12}*w_{1u}/(P_2*a_1*(1-e_1)*n_1^{(1/\delta 1h-1)}*(\mathbf{LPM}_U*LU1)^{(-1/\delta 1h)}) \quad \text{Eq. 7}$$

$$int_{13}=a_{13}*w_{1u}/(P_1*a_1*(1-e_1)*n_1^{(1/\delta 1h-1)}*(\mathbf{LPM}_U*LU_1)^{(-1/\delta 1h))} \quad \text{Eq. 8}$$

$$m_1=a_{14}*w_{1u}/(P_M*(1+\tau)*a_1*(1-e_1)*n_1^{(1/\delta 1h-1)}*(\mathbf{LPM}_U*LU_1)^{(-1/\delta 1h))} \quad \text{Eq. 9}$$

where P1, P2 and PM are prices of NAE, NT and imports(4); $\tau$ is the tariff rate; w1u is the unskilled NAE wage rate; and $\delta 1h$ is the outer layer substitution elasticity.

Economy—Water

The first order relationship of the economy to the water model is through the economic outputs of real GDP per capita, gross output of non-tradables, and gross output of exports as drivers of the domestic, industrial, energy, institutional, and mining water consumers. Industrial, energy and institutional water demands are linearly related to the total industrial and commercial output, and the growth of water use in mining is driven by changes in the NAE sector. In addition, direct investment in water supply and sanitation can be made.

Economy—Population

The economic model is connected to the population model based on assumptions of government investment levels in HIV/AIDS medication and education. This connection is more thoroughly described in Sanderson (2001a, 2002a, 2002b).

Water—Population

The connection of water to population is through diarrhea incidence. Research indicates that HIV/AIDS individuals are vulnerable to more severe, prolonged and recurrent diarrhea episodes (NIH, 1994), and that the progression rate from HIV to AIDS is influenced by nutrition or stress (Bogden, et al 2000; Timbo and Tollefson, 1994). In the model, diarrhea incidence affects the population in two ways, 1) the AIDS death rate; and 2) the HIV/AIDS progression rate from HIV to AIDS. The number of diarrheal cases per capita, DC, is a function of precipitation. The relationships of total annual diarrhea cases per 10,000 capita for the population age group > 5 and the population age group < 5 and precipitation are:

$$DC>5=-0.0084*P_D^2+3.0292*P_D + 108.62 \quad \text{Eq. 10}$$

$$DC<5 = 14.03*P_D + 1284.7 \quad \text{Eq. 11}$$

The “AIDS death rate multiplier” is normally set to 1, a value of 1 indicates no reduction in the AIDS death rate, zero indicates no AIDS deaths, and values above 1 represent a multiplicative increase in the AIDS death rate. Depending upon the diarrhea incidence, the maximum AIDS death rate increase is 1.1. The “mean incubation time” variable assigns an average time of HIV infection to AIDS diagnosis. Based on historical information, this is normally set at 9 years. Depending upon the diarrhea incidence, the minimum mean incubation time is 8 years.

Water—Economy

The water and economic sub models have a second order connection. Water affects the health of the population through diarrhea incidence, which in turn affects labor size and productivity. Thus, changes in the incubation period of HIV positive individuals will negatively affect the overall skilled labor population and productivity. The Labor Force Multiplier parameter, LPMS,U, which changes the amount of labor going into the production-side of the economic model depending upon the incidence of diarrhea, where the subscript s and u are the skilled and unskilled labor, respectively.

The measure of “Lost Labor Days” (LLD) creates a link between diarrhea and Labor Productivity:

$$LLD = (PPD * LF * ASD) \qquad \text{Eq. 12}$$

where LF is the labor force size, PPD is the percentage of population over 5 with diarrhea, and ASD is parameter describing the average number of sick days per diarrheal episode (ASD= 2 days/episode, Pegram et al., 2002). The percentage of population over 5 with diarrhea, PPD is a function of DC:

$$PPD = DC/10{,}000 \qquad \text{Eq. 13}$$

A relationship between diarrhea incidence and labor productivity can be established. For the skilled and unskilled labor forces there is a negative impact on labor productivity when the predicted diarrhea cases are higher than the mode, and for the skilled laborers there is a positive impact on labor productivity when the predicted diarrhea cases are less than the mode. Then, the Skilled and Unskilled Labor Force Multiplier parameters are equivalent to:

$$\begin{aligned} LPM_S &= 1 && \text{when } DC = \text{ mode} \qquad \text{Eq.14} \\ &= 1 + (LLD_M - LLD)/(LF*WD) && \text{when } DC < \text{ mode} \\ &= 1 - (LLD - LLD_M)/(LF*WD) && \text{when } DC > \text{ mode} \end{aligned}$$

$$\begin{aligned} LPM_U &= 1 && \text{when } DC <= \text{ mode} \qquad \text{Eq. 15} \\ &= 1 - (LLD - LLD_M)/(LF*WD) && \text{when } DC > \text{ mode} \end{aligned}$$

where LLDM is the lost labor days at the mode of diarrhea incidence.

## 6. Conclusions

The Botswana PDE-IWS model methodology was described. The model allows for the examination of feed-forward and feedback processes, the impact of water-related diarrhea on the population could be examined.

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