Botswana, Mozambique, Namibia

Modeling Population and Sustainable Development Challenges in the Era of HIV/AIDS

IIASA PDE User's Manual
Version 1.0

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Part I: General

1. Introduction

The Botswana, Namibia, and Mozambique PDE (Population–Development–Environment) models were developed by the Population Project at the International Institute for Applied Systems Analysis (IIASA, www.iiasa.ac.at/Research/POP/) in Laxenburg, Austria, as an easy-to-use model to test a range of policies via simulation of population–development–environment interactions.

This preliminary user's manual includes the disclaimer, background information, short model descriptions, and instructions on how to use the supporting software (Vensim® Model Reader), how to use the models, and how to run simulations.

2. PDE Model Developers

Warren C. Sanderson and Molly E. Hellmuth developed the Botswana and Namibia PDE models.

- Molly E. Hellmuth developed all water models in cooperation with Kenneth M. Strzepek and David N. Yates, with input from Alyssa Holt.
- Warren C. Sanderson and Molly E. Hellmuth developed the economic models.
- Warren C. Sanderson developed the demographic models with significant help from Kuberin Packirisamy and Annababette Wils.

Annababette Wils developed the Mozambique PDE model.

- She used the input from the demographic models of Botswana and Namibia.
- She also developed the economy and education models for Mozambique.
- Molly E. Hellmuth developed the water model in cooperation with Kenneth M. Strzepek and David N. Yates.

3. File Names of the PDE Models

All data input files are necessary to run the PDE simulation models. For instance, the Mozambique model consists of one model file and two data input files; all three files must be downloaded. Users can download the model and data input files of the desired model by downloading the zip file as listed below.

PDE model	PDE model file (.vmf) and PDE model data input file (.vdf)	Download
Botswana Demographic Model	BotswanaDemographicModel.vmf	BotswanaDemographicModel.zip
Botswana Economic Model	BotswanaEconomicModel.vmf LABORFORCE1.xls	BotswanaEconomicModel.zip
Botswana SER Water Resources Model	BotswanaWaterSER.vmf BOTSHCPOPDEM.vdf climBOTSgen900yrly.vdf	BotswanaWaterSER.zip
Gaborone Water Supply and Demand Model	GaboroneModel.vmf CSGen900yrly.vdf GabHCPOPDEM.vdf	GaboroneModel.zip
PDE Mozambique English version	MozambiqueEnglish.vmf mozinputenglish.vdf climate.vdf	MozambiqueEnglish.zip
PDE Mozambique Portuguese version	MozambiquePortuguese.vmf mozinputportuguese.vdf climate.vdf	MozambiquePortuguese.zip
Greater Maputo City Water Supply and Demand Model (English version)	MaputoStudy.vmf MaputoStudy.vdf	MaputoStudy.zip
Namibia Demographic Model	NamibiaDemographicModel.vmf	NamibiaDemographicModel.zip
Namibia Economic Model	NamibiaEconomicModel.vmf NamibiaLaborForce1.xls	NamibiaEconomicModel.zip
Namibia SER Water Resources Model	NamibiaWaterSER.vmf NAMHCPOPDEM.vdf clim500NAMyrly.vdf	NamibiaWaterSER.zip
Windhoek Water Supply and Demand Model	WindhoekModel.vmf namibiaCSclim1000yr.vdf WindHCPOPDEM.vdf	WindhoekModel.zip

4. Software

The software required to open and run the PDE models – the Vensim® Model Reader – can be downloaded free of charge from www.vensim.com. Any questions regarding the Vensim® Model Reader should be directed to the official Vensim® contact addresses.

For the most up-to-date versions of the PDE models, see www.iiasa.ac.at/Research/POP/pde/.

5. Disclaimer

The PDE models are distributed solely on an "as is" basis. The entire risk as to quality, appropriateness, and performance is assumed by the user. IIASA does not guarantee, warrant, or make any representation regarding the use of, or the results of the use of, these models in terms of correctness, accuracy, or otherwise. The user relies on the models and the results solely at his/her own risk. IIASA does not assume liability for any direct, indirect, incidental or consequential, special or exemplary damages, regardless of whether the user has been advised of the possibility of such damages.

IIASA declines all responsibility for errors or deficiencies in the database or software or in the documentation, for program maintenance, and for upgrading. IIASA also declines any responsibility for updating the data and does not assume liability for damage caused by errors and omissions in the data provided.

The PDE models were developed with Vensim® DSS Software. They can be used with the Vensim® Model Reader, which can be downloaded free of charge from www.vensim.com. Users of the Vensim® Model Reader must agree to the Vensim® Software License conditions. Regarding the Vensim® Model Reader, IIASA does not assume any liability for any direct, indirect, incidental or consequential, special or exemplary damages, regardless of whether the user has been advised of the possibility of such damages.

6. Acknowledgments

The IIASA team wishes to express appreciation to the following country coordinators and collaborators for their helpful input, data support, comments, and energy: Mr. Rebasele Radibe (Botswana); Mr. Lazarus Hangula and Mr. Ben Fuller (Namibia); Mr. Manual da Costa Gaspar, Mr. Emídio Sebastião, and Ms. Maimuna Ibraimo (Mozambique); Mr. Kuberin Packirisamy and Mr. Paul Kibuuka (South Africa); Mr. Hassan Musa Yousif (Cote d'Ivoire); and Ms. Alyssa Holt, Mr. Kenneth Strzepek, and Mr. David Yates (USA).

Part II: PDE Model Descriptions

1. The Botswana PDE Model and the Gaborone Water Supply and Demand Model

1.1. The Demographic Model

The Botswana demographic model was constructed as part of the project to provide information about what would happen to the population of Botswana, which is severely affected by HIV/AIDS, under various scenarios. For example, the model allows policy makers to determine the consequences of alternatives such as a successful program that reduces the riskiness of sexual behavior or a government program to provide HIV/AIDS medication to those in need. In these uncertain times, this kind of information can make the difference between policies that help and policies that do not.

The philosophy behind all our models is that they should be as simple as possible, consistent with staying close to the data and capturing the major structural features of the phenomenon.

Categories

The population is divided (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).

Data on the initial population by age, sex, and education are taken from the 1991 Census of Botswana. Initial data on HIV prevalence by age for females are derived from the 1993 and 1997 Sentinel Surveillance Surveys after adjustment for geographical representativeness. There are no prevalence data for men. Before they can be used, the aggregate prevalence rates have to be adjusted for the relationship between education, fertility, and HIV prevalence and for the effect of HIV on fertility. Because there are no prevalence rate data on men, their incidence rates will be determined based on the incidence rates for females. The relationship between the incidence rates of men and women five years younger than they are is under the control of the user.

Forecasting the Non-HIV/AIDS Population

There has been a great deal written about population forecasting and we need not repeat it here. The non-HIV/AIDS population is projected using the standard cohort component approach. This involves forecasting the total fertility rate by education, life expectancy at birth by education, and migration rates. The time profile of total fertility rates by education and the time profile of life expectancy at birth are both under the control of the user. In the present version of the model, international migration is ignored. The time paths of the total fertility rates and the life expectancies at birth appear in the programs as lookup functions.

Forecasting HIV/AIDS Incidence and Prevalence Rates

The most difficult part of the program is the determination of the HIV incidence rates. This is done by adjusting prevalence rates for two years. In the case of Botswana, these are 1993 and 1997. Given consistent prevalence rates by age at these two dates, it is possible to estimate incidence rates. With incidence rates and prevalence rates, it is possible to estimate a set of age-specific prevalence-incidence relationship equations. This process requires a set of constants that can be specified by the user.

Three constants are required. One specifies the heterogeneity in the riskiness of sexual behavior. Another represents the manner in which those at risk interact with those not at risk. The third specifies the reduction in infectibility due to the use of medication. All appear on the relevant screen.

Forecasting the Number of New Infections

Once the initial prevalence rates and the prevalence-incidence relationships are determined for each single year of age (for 15 through 49 for women), we can compute age-specific incidence rates. Multiplying the number of women at risk of becoming infected at each age with the incidence rate yields the number of newly infected women at each age.

Forecasting the Number with Symptoms and the Number on Medication

The distribution of durations between infection and symptoms is assumed to be normal with a mean and standard deviation determined by the user. The mean can change over time in a way that users can control. The change in the mean duration to the onset of symptoms is also a lookup function and appears on the relevant screen.

With the onset of symptoms there are two possibilities: either the woman begins receiving medication or she does not. The user controls the probability that a newly symptomatic woman begins medication. If the woman begins medication, she is transferred into the status of being HIV positive, asymptomatic, and on medication. Otherwise she is transferred into the symptomatic category. In each year, a woman on medication has a probability of remaining on medication and a probability of becoming symptomatic. This probability is set by the user and can be found on the appropriate screen. Once a woman enters the symptomatic category, there is only one exit, death. The probability that a symptomatic woman dies each year is determined by the user.

Forecasting the Number of Deaths Due to HIV/AIDS

The only deaths due to HIV/AIDS are those of people in the symptomatic (AIDS) category. Deaths of HIV positive, but asymptomatic women are due to other causes. The number of deaths is the product of the number of women in the symptomatic (AIDS) category and the user-specified annual death rate. This death rate is not age specific.

1.2. The Economic Model

The Botswana economic model is what economists call a CGE or computable general equilibrium model. The term “general equilibrium” is sometimes misunderstood to imply that the economy being studied is without distortions, rigidities or disequilibria. In fact, “general equilibrium" models can be used to investigate all sorts of economies from those that are heavily distorted to those that come close to the economists' view of perfect competition.

We have designed the Botswana model to be simple, but yet to incorporate the main features of the Botswana economy. In the following we discuss the economy's production structure, the determination of wages and returns to capital, the structure of demand and savings, the important role played by the Government of Botswana in the economy, and the determination of investment flows.

When the model is run in the Vensim® Model Reader, the screens will guide the user.

Production and Output Prices

The economy is aggregated into three sectors: non-agricultural exports (NAE), non-tradables (NT), and agriculture (including agricultural exports) (AG). The NAE and NT 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. Value-added is represented by a nested constant elasticity of substitution production functions in skilled labor, unskilled labor, and capital. The agricultural sector is modeled on the basis of livestock herd dynamics and is made responsive to rainfall.

Non-agricultural exports include diamonds, other mining products, tourism, and manufacturing exports. The non-tradable sector includes a wide variety of activities from construction to health care. The agriculture sector includes the output of commercial and non-commercial farms and includes exports of live animals and meat.

The advantage of the nested constant elasticity of substitution form is that skilled labor and capital can be made complementary inputs, while the aggregate of the two can be substitutable for unskilled labor. This is the situation commonly found in developing countries.

The price and the quantity of NAE output are assumed to be determined exogenously by international conditions. This is certainly true about diamonds, Botswana's main export. The price and the quantity of NT output are both assumed to be determined endogenously. The price and the quantity of AG output are assumed to be determined exogenously. The price is determined internationally and the quantity is determined by rainfall and initial herd size relative to the level desired by the farmers.

Output in the NT sector and input demands are determined using the assumption of profit maximization. Output in the NAE sector is determined exogenously. Given the output level, inputs are determined so as to minimize the cost of production.

Determination of Wages and Returns to Capital

The supply of skilled labor is assumed to be exogenous and determined from the Botswana demographic model. The wage rate of skilled labor is determined so that the demand for labor at that wage rate is equal to the exogenous supply. The wage rate of unskilled labor is not assumed to clear the market for unskilled labor, allowing unemployment of unskilled labor to exist. In the NT sector, skilled and unskilled wage rates are equal to the respective values of their marginal products.

In Botswana, holding skill level constant, wages in the NAE sector are higher than they are in the NT sector. This is represented by a constant sectoral wage rate ratio. The model also includes a constant ratio of skilled to unskilled wages holding the sector constant. The model assumes that no skilled laborers work in the AG sector.

In the NT sector, the earnings of each unit of capital are equal to the value of the marginal product of that capital. In the NAE sector, return to each unit of capital is determined as a residual, given the price of output, the quantity of output, the prices of the other inputs, the quantities of the other inputs, and the initial stock of capital.

Structure of Income, Demand, and Savings

In the NAE and NT sectors, incomes are earned by skilled workers, unskilled workers, and capital. In the AG sector, all income is assumed to be earned by unskilled workers. Income flows are aggregated across sectors. What remains are the aggregate incomes of skilled workers, unskilled workers, and capital.

Some income goes to pay taxes. What remains can be used to buy the outputs of the NT sector, the AG sector, and imports, or it can be saved. The allocations of the three after-tax earnings to the four possible alternatives are made using three separate extended linear expenditure systems (ELES).

The Role of the Government

The Government of Botswana plays a number of crucial roles in the economy. It provides critical services such as education and health care. It invests in infrastructure, and it varies its level of spending so as to achieve macroeconomic balance. The Government is both a producer of services and a consumer of them. There is only one NT production function, so Government-produced services are not distinguished from other NT outputs. The model distinguishes between Government consumption (including education and health care) and Government investment. It does not subdivide Government consumption by activity, although this would be an easy extension to make. When the Government consumes and invests, it spends money on the outputs of the NT sector and on imports. The proportions spent on NT output and imports differ depending on whether the Government is consuming or investing.

Government revenues come from two main sources: (1) taxes and royalties on incomes that would otherwise go to capital, and (2) tariff revenues. Botswana is a member of SACU, the Southern African Customs Union, which collects all tariff revenue for all of its member countries and then allocates that revenue back to the member countries. Tariff revenue will significantly decrease in the future due to Botswana’s international agreements and the EU-South African Free Trade Agreement. The model distinguishes between the two sources of income and allows the tariff rate to change over time. In the model tax rates differ by sector, but do not change over time. The incorporation of time varying tax rates would be an easy extension.

The Government of Botswana normally runs a budget surplus in order to maintain macroeconomic balance. Government expenditures are adjusted downward when there is inflation in the Pula compared to the currencies of Botswana’s main trading partners, and upward when the reverse is true. In the model, the rate of increase in Government spending changes each year depending on the previous year’s growth rate of nominal income and on the previous year’s rate of relative inflation. The sensitivity of changes in Government spending to the relative rate of inflation is a parameter that may be changed by the user.

Investment

The fraction of capital income saved and invested depends on the profitability of the NAE and the NT sectors. Returns experienced in those sectors in 1991 are taken as a benchmark. When returns exceed the benchmarks, investment rates increase and vice versa. The sensitivity of investment to profitability is set by the user.

1.3. The Water Models

The water models are designed to provide forecasts of future regional water supply and demand for Botswana, in order to determine the sustainability of the water supply under various forecasts of economic, population, and climate changes. There are two models for Botswana, one for the specific case of Gaborone and one for the Socio-Ecological Region level.[1]

Figure 1 shows a schematic of the water model. The water model breaks the region of interest down into the pertinent watersheds that contribute water to the surface and groundwater supply. The water that is available to consumers is the surface water runoff that is captured by surface infrastructure, or the groundwater recharge that allows sustainable abstraction. This water is then available as supply for the end users, or demand centers.

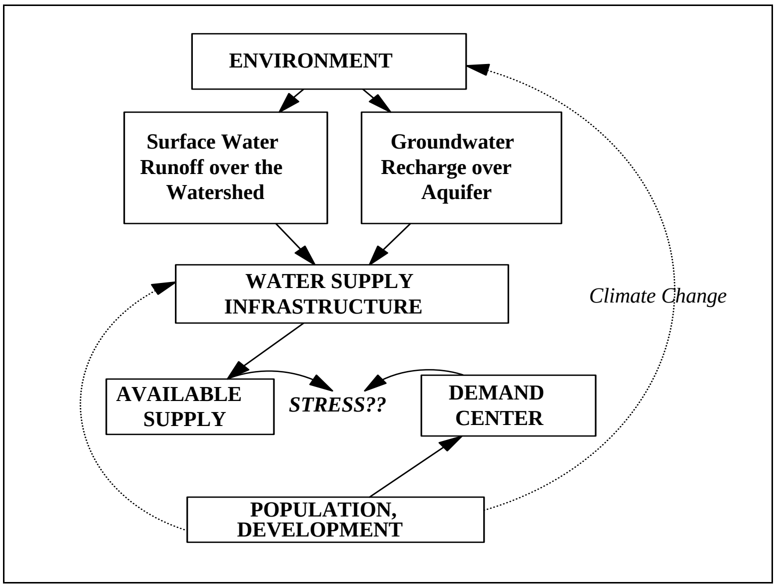

Figure 1. Water model schematic.

[1] For a complete description of the methodology of the water model, see "Methodological Framework of the Southern African Integrated (SAINT) Model of Water Supply and Demand" by Molly E. Hellmuth, Kenneth M. Strzepek, and David N. Yates (2000). Draft available from the author: hellmuth@iiasa.ac.at.

The SER Water Supply and Demand Model

The Socio-Ecological Regions (SERs) are shown in Figure 2.

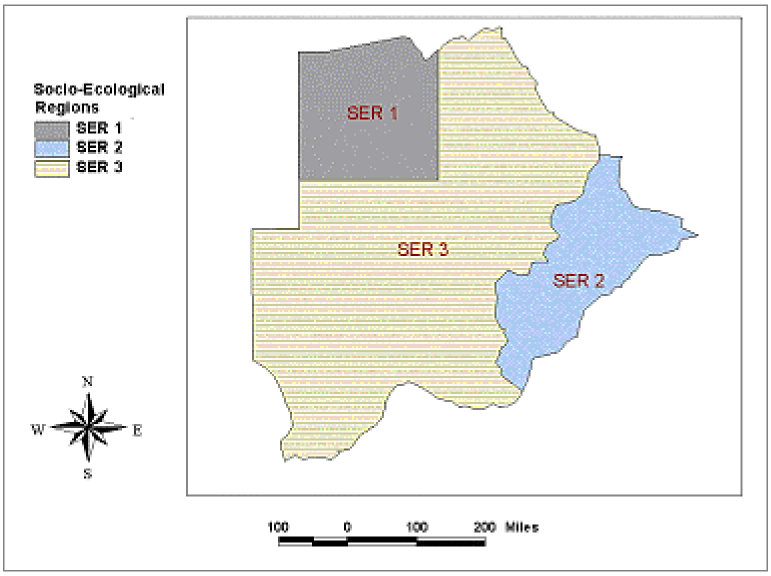

Figure 2. Socio-Ecological Regions.

There are five major hydrologic basins that were aggregated into macro basins from sub-basin maps (ALCOM, FAO) and delimited for analysis: Upper Zambezi, Okavango Delta, Orange River, Southern Interior, and the Limpopo. These basins are shown in Figure 3.

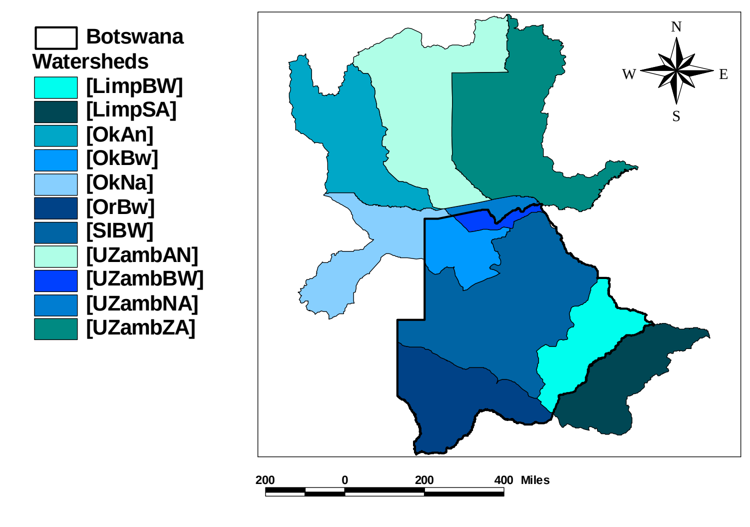

Figure 3. Modeled water basins.

The modeled watershed sub-basins do not always directly correlate to the SERs. One could attribute the Okavango Basin to SER1, and the Orange, Southern Interior, and Upper Zambezi Basins to SER3. The Limpopo Basin and SER2 correspond directly. The amount of available water for each of these basins changes, depending on the scenario. The water is distributed amongst the SERs according to the percentage of the basin area they cover, the capacity of the infrastructure to store or transfer water to consumers, and the sustainable groundwater recharge rates. There is a macro reservoir for each SER center, which represents the total storage available for the SER. Similarly, the sustainable level of recharge which can be extracted for human consumption was modeled for each basin and then summed over the SER it supplies.

The connection of the water models to the population and development models occurs on both the water supply and demand sides. On the water demand side, population size, GDP per capita, and sectoral GDP drive the water use of the domestic, industrial, institutional, mining, energy, agricultural and livestock consumers. Domestic water use changes as a result of incomes (GDP per capita), urbanization, and population size. Industrial, Energy and Institutional water demands are linearly related to the total industrial and commercial output, which changes with each population scenario. The water demands for irrigation are unequally distributed throughout the year, depending on the growing cycle of crops. On average, 14,000 cubic meters per hectare are used every year, which means that irrigation technology is rather inefficient. The growth of water use in mining is driven by changes in the exports economic sector. Livestock water use changes as a result of changes in livestock production, which may grow or decline depending on the economic demand.

Scenario Options

The following variables may be changed or turned on (=1) or off (=0) depending on the choice of the modeler:

1. Time Scale: The model may be run at the monthly or yearly time scale, which allows the user to consider seasonal effects of water supply.
2. Start Time: Changing this value allows the user to consider scenario choices under different climate conditions. Since we do not know what future precipitation or temperature will be, the user may pick a number between 0 and 970 to choose a future climate.[2]
3. Climate Change: This allows the user to run the model with future climate change assumptions incorporated. The Hadley Center Global Circulation Model produced predictions in future variations of precipitation and temperature by month. Set to 1 if you would like to consider the effects of climate change.
4. Groundwater Scenario: Turn on by setting equal to 1. Groundwater resources can be expanded to meet some of the growing pressure on the surface water supply.[3]
5. Demand Side: Set this value to 1 if you would like to consider conservation measures in water consumption. This scenario reduces future industrial water consumption by changing the efficiency of water consumption over time. It reduces domestic water consumption by assuming zero growth in low and high income per capita domestic water use.
6. Percent Efficient: To consider the effects of higher water use efficiency in industrial use, please modify the Efficiency variable to incorporate the percentage of reduction in water use. This will gradually become more efficient as we move from 2002 to 2021.

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[2] The start time is a random number to start the model with a different climate. For instance, if you type in 12, it will take the first month of precipitation (i.e., January, "year 12"). If you type in 780, it will take the first month of precipitation that is found in data series 780. Since we do not know what the future climate will be, auto- and cross-correlated 1000-year monthly data series of precipitation, temperature and vapor pressure were created.

[3] This option must be used with caution and knowledge of realistic future sustainable groundwater abstractions. Figures of expected future groundwater extractions for each SER are turned on if the groundwater scenario is used.

Case Study: The Gaborone Water Supply and Demand Model

As Gaborone continues to grow as a result of urbanization, so will the city's water needs. The infrastructure of the existing water supply system as well as possible new sources were modeled. Figure 4 shows the existing infrastructure for Gaborone.

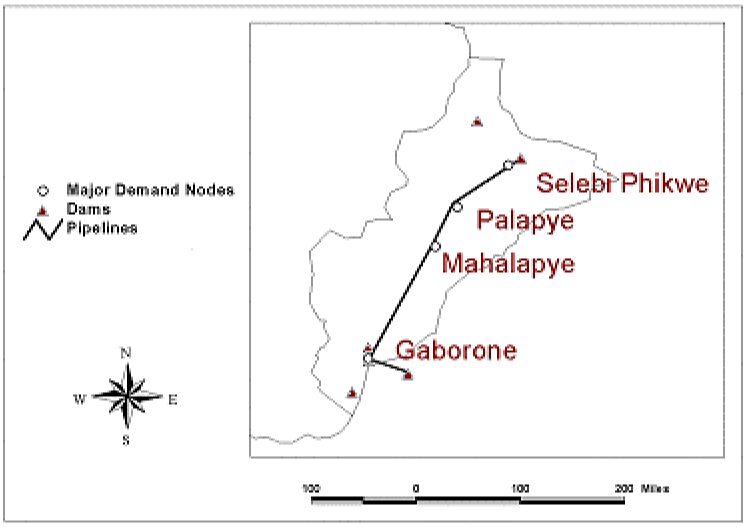

Figure 4. Existing infrastructure for Gaborone.

Greater Gaborone's water supply currently comes from four main reservoirs: the Gaborone Reservoir, the Bokaa Reservoir, the Nnywane Reservoir, and the Molatedi Reservoir (South Africa). Additionally, the North South Carrier (NSC), which began operating in 1999, provides water from the Letsibogo Dam. The Palla Road wellfield groundwater supplies for the greater Gaborone region were also modeled. Four main demand nodes were included in the model: Greater Gaborone,[4] Palapye,[5] Mahalapye,[6] and Selebi-Phikwe.[7] It was necessary to incorporate these additional centers as they share water supplies with Gaborone through the NSC. Gaborone was given priority for the water supply from the NSC.

Additionally, there are rule curves that are applied to each of these sources to allow for efficient use of storage. The demand was allocated in the following manner:

1. Water demands are calculated at each node. The Gaborone demand is at the top of the hierarchy.
2. Water is transferred to the Gaborone Dam from the Molatedi Dam following the agreement made between Botswana and South Africa: If the Molatedi Dam is more than 25% full, 7.2 million cubic meters per year may be transferred, otherwise Botswana receives only half of this entitlement.
3. Water is transferred from the Bokaa and Nnywane[8] Dams to Gaborone (if necessary).

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[4] Includes Gaborone, Lobatse, Tlokweng, Mogoditshane, Mochudi, Ramotswa, Metsemetlhabe, Gabane, Oodi, Modipane, Packlani, Mokolodi, Otse, and Mogobane.
[5] Includes Palapye and Morupule.
[6] Includes Mahalapye, Kalamare, and Shoshong.
[7] Includes Selebi-Phikwe and Mmadinare. They currently consume water from the Shashe Dam and are expected to be connected to the NSC to relieve pressure on the Shashe Dam which also feeds Francistown's demands.
[8] Nnywane storage was transferred into Gaborone Dam to simplify the modeling process.

4. Gaborone demands are first met by the sustainable amount of groundwater which is available from recharge, then by surface supplies.
5. If the Gaborone Dam is less than 50% capacity, water is transferred from the north via the NSC.
6. Water is transferred from the NSC to meet the demands in Palapye and Mahalapye.

The water demands that are modeled for each of the above demand nodes are Domestic, Industrial, Institutional and Energy. The population, which is broken into urban and rural water users drive the Domestic demands. The per capita water use rate for these two categories is allowed to grow as per capita income grows, until they eventually reach a maximum water use saturation level. Industrial, Institutional and Energy consumption are driven by changes in annual GDP in the non-tradables economic sector (described in the Economic Model Description). This is assumed to be a linear relationship.

Scenario Options

The following variables may be changed or turned on (=1) or off (=0) depending on the choice of the modeler:

1. Time Scale: The model may be run at the monthly or yearly time scale, which allows the user to consider seasonal effects of water supply.
2. Start Time: Changing this value allows the user to consider scenario choices under different climate conditions. Since we do not know what future precipitation or temperature will be, the user may pick a number between 0 and 970 to choose a future climate.
3. Climate Change: This allows the user to run the model with future climate change assumptions incorporated. The Hadley Center Global Circulation Model produced predictions in future variations of precipitation and temperature by month. Set to 1 if you would like to consider the effects of climate change.
4. Demand Side: Set this value to 1 if you would like to consider conservation measures in water consumption. This scenario reduces future industrial water consumption by changing the efficiency of water consumption over time. It reduces domestic water consumption by assuming zero growth in low and high income per capita domestic water use.
5. Percent Efficient: To consider the effects of higher water use efficiency in industrial use, please modify the Efficiency variable to incorporate the percentage of reduction in water use. This will gradually become more efficient as we move from 2002 to 2021.

In addition, experienced users may wish to change other variables, such as initial storage capacities or water losses. The user can change the dates that the satellite cities of Palapye and Mahalapye are connected to the NSC supply.

2. The Namibia PDE Model and the Windhoek Water Supply and Demand Model

2.1. The Demographic Model

The Namibia demographic model was constructed as part of the project to provide information about what would happen to the population of Namibia, which is severely affected by HIV/AIDS, under various scenarios. For example, the model allows policy makers to determine the consequences of alternatives such as a successful program that reduces the riskiness of sexual behavior or a government program to provide HIV/AIDS medication to those in need. In these uncertain times, this kind of information can make the difference between policies that help and policies that do not.

The philosophy behind all our models is that they should be as simple as possible, consistent with staying close to the data and capturing the major structural features of the phenomenon.

Categories

The population is divided (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).

Data on the initial population by age, sex, and education are taken from the 1991 Census of Namibia. Initial data on HIV prevalence by age for females are derived from the 1994 and 1998 Sentinel Surveillance Surveys after adjustment for geographical representativeness. There are no prevalence data for men. Before they can be used, the aggregate prevalence rates have to be adjusted for the relationship between education, fertility, and HIV prevalence and for the effect of HIV on fertility. Because there are no prevalence rate data on men, their incidence rates will be determined based on the incidence rates for females. The relationship between the incidence rates of men and women five years younger than they are is under the control of the user.

Forecasting the Non-HIV/AIDS Population

There has been a great deal written about population forecasting and we need not repeat it here. The non-HIV/AIDS population is projected using the standard cohort component approach. This involves forecasting the total fertility rate by education, life expectancy at birth by education, and migration rates. The time profile of total fertility rates by education and the time profile of life expectancy at birth are both under the control of the user. In the present version of the model, international migration is ignored. The time paths of the total fertility rates and the life expectancies at birth appear in the programs as lookup functions.

Forecasting HIV/AIDS Incidence and Prevalence Rates

The most difficult part of the program is the determination of the HIV incidence rates. This is done by adjusting prevalence rates for two years. In the case of Namibia, these are 1994 and 1998. Given consistent prevalence rates by age at these two dates, it is possible to estimate incidence rates. With incidence rates and prevalence rates, it is possible to estimate a set of age-specific prevalence-incidence relationship equations. This process requires a set of constants that can be specified by the user.

Three constants are required. One specifies the heterogeneity in the riskiness of sexual behavior. Another represents the manner in which those at risk interact with those not at risk. The third specifies the reduction in infectibility due to the use of medication. All appear on the relevant screen.

Forecasting the Number of New Infections

Once the initial prevalence rates and the prevalence-incidence relationships are determined for each single year of age (for 15 through 49 for women), we can compute age-specific incidence rates. Multiplying the number of women at risk of becoming infected at each age with the incidence rate yields the number of newly infected women at each age.

Forecasting the Number with Symptoms and the Number on Medication

The distribution of durations between infection and symptoms is assumed to be normal with a mean and standard deviation determined by the user. The mean can change over time in a way that users can control. The change in the mean duration to the onset of symptoms is also a lookup function and appears on the relevant screen.

With the onset of symptoms there are two possibilities: either the woman begins receiving medication or she does not. The user controls the probability that a newly symptomatic woman begins medication. If the woman begins medication, she is transferred into the status of being HIV positive, asymptomatic, and on medication. Otherwise she is transferred into the symptomatic category. In each year, a woman on medication has a probability of remaining on medication and a probability of becoming symptomatic. This probability is set by the user and can be found on the appropriate screen. Once a woman enters the symptomatic category, there is only one exit, death. The probability that a symptomatic woman dies each year is determined by the user.

Forecasting the Number of Deaths Due to HIV/AIDS

The only deaths due to HIV/AIDS are those of people in the symptomatic (AIDS) category. Deaths of HIV positive, but asymptomatic women are due to other causes. The number of deaths is the product of the number of women in the symptomatic (AIDS) category and the user-specified annual death rate. This death rate is not age specific.

2.2. The Economic Model

The Namibia economic model is what economists call a CGE or computable general equilibrium model. The term “general equilibrium” is sometimes misunderstood to imply that the economy being studied is without distortions, rigidities or disequilibria. In fact, “general equilibrium” models can be used to investigate all sorts of economies from those that are heavily distorted to those that come close to the economists’ view of perfect competition.

We have designed the Namibia model to be simple, but yet to incorporate the main features of the Namibia economy. In the following we discuss the economy’s production structure, the determination of wages and returns to capital, the structure of demand and savings, the important role played by the Government of Namibia in the economy, and the determination of investment flows.

When the model is run in the Vensim® Model Reader, the screens will guide the user.

Production and Output Prices

The economy is aggregated into three sectors: non-agricultural exports (NAE), non-tradables (NT), and agriculture and agriculture-based manufacturing (AG). The NAE and NT 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. Value-added is represented by a nested constant elasticity of substitution production functions in skilled labor, unskilled labor, and capital. The agricultural sector, AG, is modeled using a Cobb-Douglas production function with inputs of skilled labor, unskilled labor, capital, imports, and intermediate goods purchased from the NT and the AG sectors.

Non-agricultural exports include diamonds, other mining products, tourism, and manufacturing exports. The non-tradable sector includes a wide variety of activities from construction to health care. The agriculture sector includes the output of commercial and non-commercial farms, fisheries, and all manufacturing based primarily on agricultural inputs.

The advantage of the nested constant elasticity of substitution form is that skilled labor and capital can be made complementary inputs, while the aggregate of the two can be substitutable for unskilled labor. This is the situation commonly found in developing countries.

The price and the quantity of NAE output are assumed to be determined exogenously by international conditions. This is certainly true about diamonds, Namibia’s main export. The price and the quantity of NT output are both assumed to be determined endogenously. The price of AG output is assumed to be determined exogenously, while the quantity is endogenous. AG exports are the difference between AG production and domestic AG consumption.

Output and input demands in the NT and AG sectors are determined using the assumption of profit maximization. Output in the NAE sector is determined exogenously. Given the output level, inputs are determined so as to minimize the cost of production.

Determination of Wages and Returns to Capital

The supply of skilled labor is assumed to be exogenous and determined from the Namibia demographic model. The wage rate of skilled labor is determined so that the demand for labor at that wage rate is equal to the exogenous supply. The wage rate of unskilled labor is not assumed to clear the market for unskilled labor, allowing unemployment of unskilled labor to exist. In the NT sector, skilled and unskilled wage rates are equal to the respective values of their marginal products.

In Namibia, holding skill level constant, wages in the NAE sector are assumed to be the same as in the NT sector. The user can change this assumption and specify a constant sectoral wage rate ratio. The model also includes a constant ratio of skilled to unskilled wages in the NAE and NT sectors. The wage rate of skilled workers in the AG sector (mainly for people in agriculture-based manufacturing) are assumed to be the same as those in the NAE and NT sectors. Unskilled wage rates, however, are assumed to be different. The ratio of the unskilled wage rate in AG to those in the NAE and NT sectors is set by the user.

In the NT and AG sectors, the earnings of each unit of capital are equal to the value of the marginal product of that capital. In the NAE sector, the return to each unit of capital is determined as a residual, given the price of output, the quantity of output, the prices of the other inputs, the quantities of the other inputs, and the initial stock of capital.

Structure of Income, Demand, and Savings

In all three sectors, incomes are earned by skilled workers, unskilled workers, and capital. Income flows are aggregated across sectors. What remains are the aggregate incomes of skilled workers, unskilled workers, and capital.

Some income goes to pay taxes. What remains can be used to buy the outputs of the NT sector, the AG sector, and imports, or it can be saved. The allocations of the three after-tax earnings to the four possible alternatives are made using three separate extended linear expenditure systems (ELES).

The Role of the Government

The Government of Namibia plays a number of crucial roles in the economy. It provides critical services such as education and health care. It invests in infrastructure, and it varies its level of spending so as to achieve macroeconomic balance. The Government is both a producer of services and a consumer of them. There is only one NT production function, so Government-produced services are not distinguished from other NT outputs. The model distinguishes between Government consumption (including education and health care) and Government investment. It does not subdivide Government consumption by activity, although this would be an easy extension to make. When the Government consumes and invests, it spends money on the outputs of the NT sector and on imports. The proportions spent on NT outputs and imports is different for Government consumption and investment.

Government revenues come from two main sources: (1) taxes and royalties, and (2) tariff revenues. Namibia is a member of SACU, the Southern African Customs Union, which collects all tariff revenue for all of its member countries and then allocates that revenue back to the member countries. Tariff revenue will significantly decrease in the future due to Namibia’s international agreements and the EU-South African Free Trade Agreement. The model distinguishes between the two sources of income and allows the tariff rate to change over time. In the model tax rates can differ by sector, but do not change over time. The incorporation of time varying tax rates would be an easy extension. In this version, the model uses the same tax rate of value-added in all three sectors.

Namibia has committed itself to a policy of one-to-one conversion between the Namibian dollar and the South African rand. Therefore, the Government of Namibia cannot let the rate of inflation in Namibia differ significantly from the rate of inflation in South Africa. The Government of Namibia normally runs a budget deficit. It faces two constraints on how large a deficit it can run. First, it cannot run such a large deficit that it generates inflation relative to South Africa. Second, it cannot continually run deficits that endanger the ability of the country to repay its foreign debt. Our model takes these two constraints into account. In the model, the rate of increase in Government spending changes each year depending on the previous year’s growth rate of nominal income, on the previous year’s rate of relative inflation, and on the last year’s ratio of the deficit to nominal gross domestic product. The sensitivities of changes in Government spending to the relative rate of inflation and to the relative size of the deficit are parameters that may be changed by the user.

Investment

The fraction of capital income saved and invested depends on the profitability of the NAE and the NT sectors. Returns experienced in those sectors in 1991 are taken as a benchmark. When returns exceed the benchmarks, investment rates increase and vice versa. The sensitivity of investment to profitability is set by the user.

2.3. The Water Models

The water models are designed to provide forecasts of future regional water supply and demand for Namibia, in order to determine the sustainability of the water supply under various forecasts of economic, population, and climate changes. There are two models for Namibia, one for the specific case of Windhoek and one for the Socio-Ecological Region level.[9]

Figure 5 shows a schematic of the water model. The water model breaks the region of interest down into the pertinent watersheds that contribute water to the surface and groundwater supply. The water that is available to consumers is the surface water runoff that is captured by surface infrastructure, or the groundwater recharge that allows sustainable abstraction. This water is then available as supply for the end users, or demand centers.

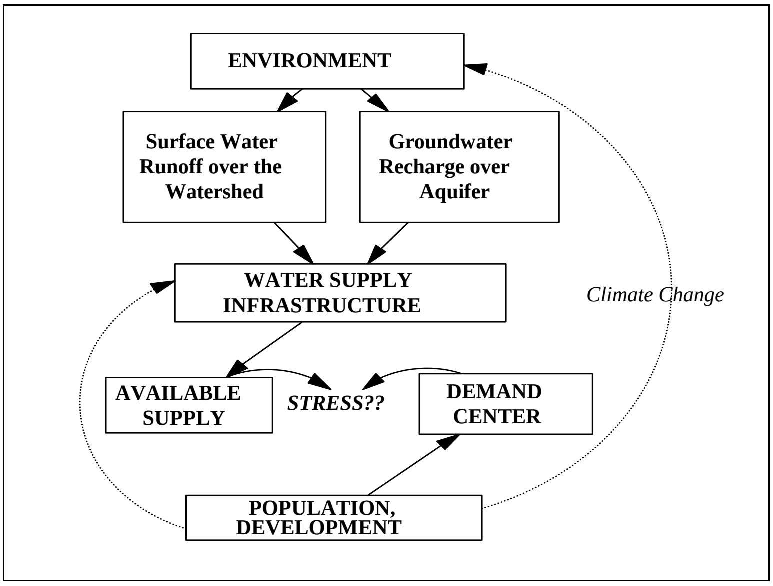

Figure 5. Water model schematic.

[9] For a complete description of the methodology of the water model, see “Methodological Framework of the Southern African Integrated (SAINT) Model of Water Supply and Demand” by Molly E. Hellmuth, Kenneth M. Strzepek, and David N. Yates (2000). Draft available from the author: hellmuth@iiasa.ac.at.

The SER Water Supply and Demand Model

The Socio-Ecological Regions (SERs) are shown in Figure 6.

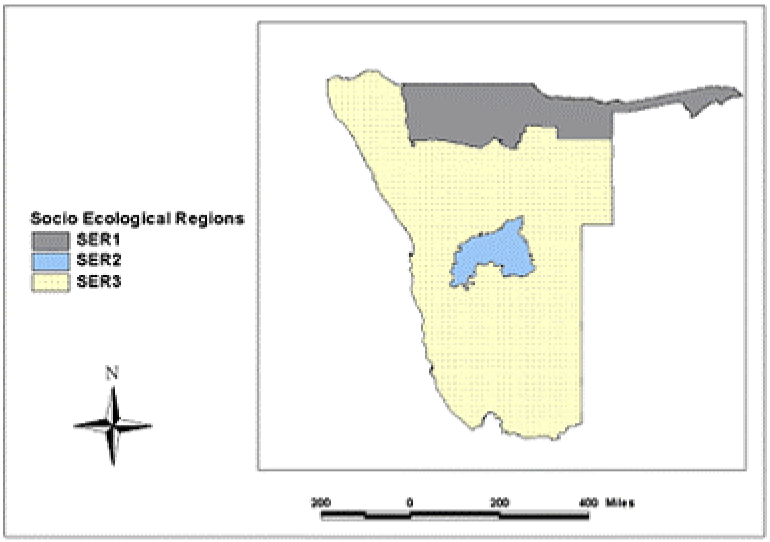

Figure 6. Socio-Ecological Regions.

There are 17 major hydrologic basins that were aggregated into macro basins from sub-basin maps (ALCOM, FAO) and delimited for analysis. These basins are shown in Figure 7.

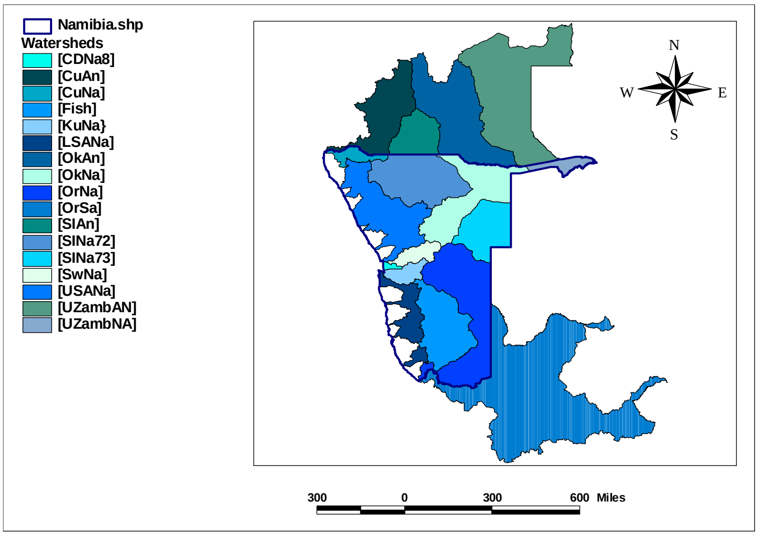

Figure 7. Modeled water basins.

Water from these basins is distributed to demand nodes by use of information about surface water supply infrastructure and groundwater recharge rates. There is a macro reservoir for each SER center, which represents the total storage available for the SER.

Similarly, the sustainable level of recharge which can be extracted for human consumption was modeled for each basin and then summed over the SER it supplies.

The connection of the water models to the population and development models occurs on both the water supply and demand sides. On the water demand side, population size, GDP per capita, and sectoral GDP drive the water use of the domestic, industrial, institutional, mining, energy, agricultural and livestock consumers. Domestic water use changes as a result of incomes (GDP per capita), urbanization, and population size. Industrial, Energy and Institutional water demands are linearly related to the total industrial and commercial output, which changes with each population scenario. The water demands for irrigation are unequally distributed throughout the year, depending on the growing cycle of crops. On average, 15,000 cubic meters per hectare are used every year, which means that irrigation technology is rather inefficient. The growth of water use in mining is driven by changes in the exports economic sector. Livestock water use changes as a result of changes in livestock production, which may grow or decline depending on the economic demand.

Scenario Options

The following scenario options can be run:

1. Time Scale: The model may be run at the monthly or yearly time scale, which allows the user to consider seasonal effects of water supply.
2. Start Time: Changing this value allows the user to consider scenario choices under different climate conditions. Since we do not know what future precipitation or temperature will be, the user may pick a number between 0 and 970 to choose a future climate.[10]
3. Climate Change: This allows the user to run the model with future climate change assumptions incorporated. The Hadley Center Global Circulation Model produced predictions in future variations of precipitation and temperature by month. Set to 1 if you would like to consider the effects of climate change.
4. Demand Side: Set this value to 1 if you would like to consider conservation measures in water consumption. This scenario reduces future industrial water consumption by changing the efficiency of water consumption over time. It reduces domestic water consumption by assuming zero growth in low and high income per capita domestic water use.
5. Percent Efficient: To consider the effects of higher water use efficiency in industrial use, please modify the Efficiency variable to incorporate the percentage of reduction in water use. This will gradually become more efficient as we move from 2002 to 2021.

Case Study: The Windhoek Water Supply and Demand Model

As Windhoek continues to grow as a result of urbanization, so will the city's water needs. The infrastructure of the existing water supply system as well as possible new sources were modeled. Figure 8 shows the existing infrastructure for Windhoek.

Windhoek currently gets its water supply from the following surface sources: Omatako, Von Bach, and Swakoppoort Dams. Current and future groundwater supplies include the Windhoek, Grootfontein, Goblentz and Tsumeb aquifers. The Gammams reclamation works recycles a portion of Windhoek's wastewater and was also included.

[10] The start time is a random number to start the model with a different climate. For instance, if you type in 12, it will take the first month of precipitation (i.e., January, "year 12"). If you type in 780, it will take the first month of precipitation that is found in data series 780. Since we do not know what the future climate will be, auto- and cross-correlated 1000-year monthly data series of precipitation, temperature and vapor pressure were created.

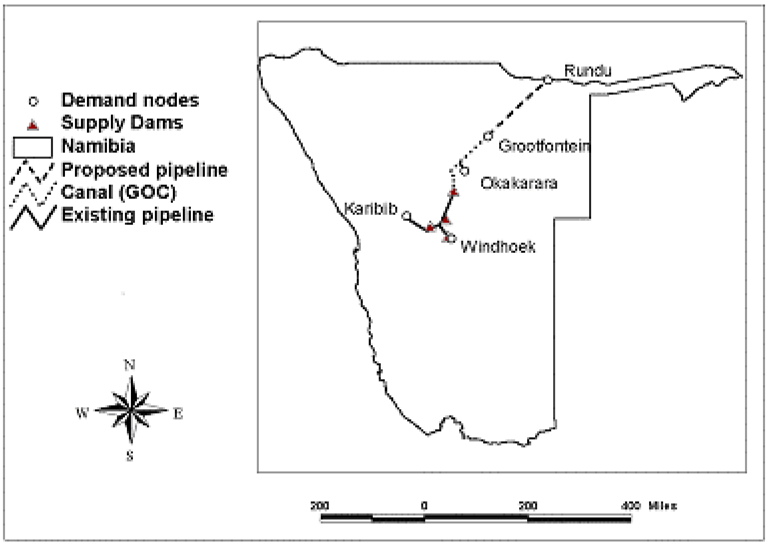

Figure 8. Existing infrastructure for Windhoek.

The groundwater sources in the north are not yet connected as a supply source to Windhoek and are subject to local demands. Von Bach Dam will receive water directly from a water transfer canal from the northern groundwater sources. These additional northern groundwater sources were not explicitly modeled; however, the user can make assumptions of how much water can be sustainably transferred to Windhoek. The current estimate is 3 million cubic meters per year (MCM/a) (personal communication, Martin Harris, NAMWater).

Von Bach Dam is the main driver of the surface supply system for Windhoek because it has the best storage characteristics. Storage characteristics are important because evaporation is the biggest consumer of the water supply. The operating rules for the three dam systems and the groundwater transfer to Windhoek were adapted from CAWMP Interim Phase (Volume 1 – Systems Analysis):

1. Transfer water from the Omatako Dam to the Von Bach Dam at a maximum transfer rate of 30 MCM/a, until the Omatako Dam reaches dead storage level.
2. Transfer water from the Swakoppoort Dam to the Von Bach Dam at a maximum transfer rate of 4 MCM/a, until the Swakoppoort Dam reaches a minimum storage level of 6.60 MCM/a. The transfer capacity will increase to 10 MCM/a in 2003. Swakoppoort Dam also supplies Karibib with water.
3. Compute Windhoek's total water demands. The total demand supplied by the Von Bach Dam will be reduced by supplies from the Windhoek aquifer and the Gammaman reclamation plant. Starting in June 2001, the recycled water will have a capacity of 5 MCM/a; the capacity will be linearly increased to 7.5 MCM/a by 2011. Groundwater is taken at an assumed sustainable rate of 2 MCM/a, although this varies with the monthly recharge rate.
4. Northern groundwater sources can be connected as scenarios. Current estimates place the sustainable amount of groundwater that can be transferred from Grootfontien at 3 MCM/a. The other new groundwater sources are not specifically modeled. The Grootfontein node is already connected (transfer capacity 2.4 cubic meters per second). This water is subject to high losses and will be transferred to avoid projected water shortages.
5. Finally, a scenario can be run where water is abstracted from the Kavango River (1.62 cubic meters per second).

The water demands that are modeled for the Windhoek Municipality are Domestic, Industrial, Institutional and Energy. The Domestic demands are driven by Windhoek Population, which is broken into High and Low Income water users. The water use rates for these two categories are allowed to grow as per capita income grows, but will eventually reach a maximum water use saturation level. Industrial, Institutional and Energy consumption is driven by changes in annual GDP in the non-tradables economic sector (described in the Economic Model Description). This is a linear relationship.

Scenario Options

The following variables may be changed or turned on (=1) or off (=0) depending on the choice of the modeler:

1. Time Scale: The model may be run at the monthly or yearly time scale, which allows the user to consider seasonal effects of water supply.
2. Start Time: Changing this value allows the user to consider scenario choices under different climate conditions. Since we do not know what future precipitation or temperature will be, the user may pick a number between 0 and 970 to choose a future climate.
3. Climate Change: This allows the user to run the model with future climate change assumptions incorporated. The Hadley Center Global Circulation Model produced predictions in future variations of precipitation and temperature by month. Set to 1 if you would like to consider the effects of climate change.
4. GW North On: Set this to 1 if you would like to allow Windhoek to receive additional water supplies from the northern groundwater sources.
5. Maximum Northern Groundwater Transfer: Change this value to allow northern groundwater sources to be transferred to Windhoek.
6. Banking On: Change this value to 1 if you would like to consider the effects of water banking. This means that water is transferred to the Windhoek aquifer instead of into the Von Bach Dam, in order to decrease evaporative losses. For this scenario, runoff into the Von Bach Dam is diverted into the Windhoek aquifer at a loss of 25%, if space permits. The pumping capacity is assumed to be 20 MCM/a. The total Windhoek aquifer capacity is 25 MCM/a.
7. Okavango On: Set this value to 1 if you would like to consider the transfer of water from the Kavango River to Windhoek.
8. Demand Side: Set this value to 1 if you would like to consider conservation measures in water consumption. This scenario reduces future industrial water consumption by changing the efficiency of water consumption over time. It reduces domestic water consumption by assuming zero growth in low and high income per capita domestic water use.
9. Percent Efficient: To consider the effects of higher water use efficiency in industrial use, please modify the Efficiency variable to incorporate the percentage of reduction in water use. This will gradually become more efficient as we move from 2002 to 2021.

In addition, experienced users may wish to change other variables, such as initial storage capacities or water losses.

3. The Mozambique PDE Model

The Mozambique population–development–environment (PDE) model consists of five sectoral models which are incorporated into the integrated Mozambique PDE model. The sub-models are explained separately. They consist of (1) HIV/AIDS model; (2) education model; (3) labor force model; (4) economy model; and (5) water model.

3.1. The Population and HIV/AIDS Model

The population is projected with a cohort component model, the basic demographic tool for projection. It includes single-year age and gender, and age- and gender-specific rates of fertility, mortality, and migration. What sets this model apart is that it includes the epidemiological dynamics of HIV/AIDS.

HIV is an infectious disease, which means there is a relationship between prevalence, incidence, and susceptible population. The more people are infected, the more the disease spreads to the healthy people, so in turn, the more are infected. How quickly new people are infected depends on the relationship between prevalence and incidence, which is determined by biology and behavior.

If an infected person is healed or dies right away, the prevalence never has a chance to build up and cause an epidemic. On the other hand, if an infected person lives with the infection for a long time, prevalence has the opportunity to increase. This is the case with HIV, where the average time until the outbreak of full-blown AIDS in Africa is estimated to be 7–10 years. Once a person in Africa has AIDS, the annual mortality is very high, at least 50% annually.

Factors that can limit the spread of the HIV infection are safe sex practices (especially condom use), treatment of other sexually-transmitted diseases, bottle-feeding infants of HIV-positive mothers and other interventions. In the future a cheap vaccine might halt the disease.

Figure 9 shows these basic dynamics and the intervention points to limit HIV and AIDS. We have incorporated the relationship between prevalence and new incidence. If the relationship is higher, then HIV prevalence rises faster. The model also includes the three intervention possibilities in the figure. Further, all the dynamics are incorporated into a multi-state age- and sex-specific population projection model.[11] With the model, we can make scenarios, which take into account how different rates of the diffusion of HIV and the effects of various policies impact population growth and age structure.

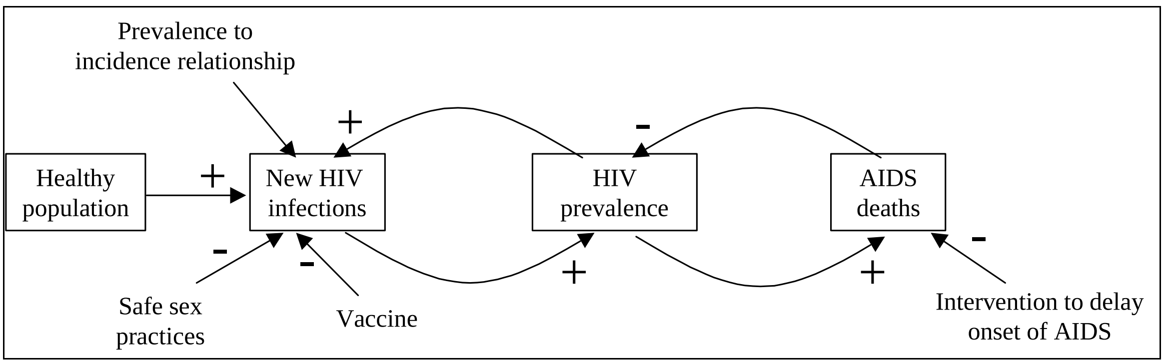

Figure 9. Flow diagram of HIV and AIDS dynamics.

[11] The original version of this model was developed for Botswana by Warren C. Sanderson at the International Institute for Applied Systems Analysis, Laxenburg, Austria.

We have incorporated these dynamics into the population projection by dividing the population into three sub-groups: those without HIV (the NEG population); the HIV-infected group; and those with full-blown AIDS. Each sub-group is divided by single-year age and sex, and the HIV group by years since infection. Basically, people move from the NEG to the HIV population, as given by the new infection rate derived from prevalence. People move from the HIV to the AIDS population as determined by the years since infection and the likelihood of progressing to AIDS.

3.2. Education Model

Basically, the present low levels of educational achievement among Mozambican adults are the result of a past with low school enrollment rates. In the same way, to project future adult education – the essential ingredient for development – one needs to start by projecting school enrollment, including school intake and drop-out rates.

In Mozambique, school entry occurs at many ages, starting at age 5, and ranging up to young adulthood. Most people who enter school do so between the ages of 5 and 12. Similarly, school departure occurs throughout the school cycle. In each grade between 6% and 47% of the students leave (the higher drop-out rates occur at transitions from one school level to the next). Most, but not all, people who leave school are teenagers. This rather complex situation is captured in a model with school enrollment by single-year age groups and single grades from 1–12, as well as separate university enrollment (see Figure 10).

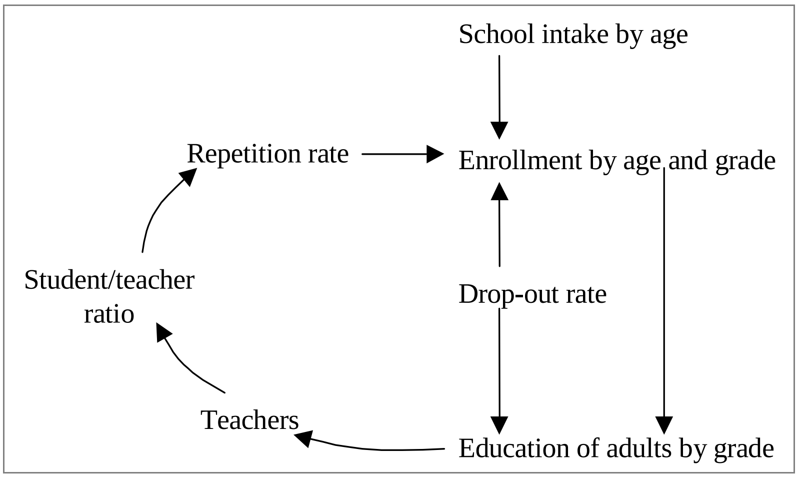

Figure 10. Flow diagram of school enrollment and teacher hiring dynamics captured in the education model.

A particular concern for the country is whether or not there will be enough teachers, particularly at the lower primary school level. This concern is more acute in the face of the HIV/AIDS epidemic. Teachers are expected to have completed the teacher training program, but in many cases, the shortage of teachers leads to hiring people who have simply completed a certain minimum of general education.[12] The number of teachers is important because teachers are needed to fill new classrooms; also, the student/teacher ratio is a measure of

[12] According to data from the Ministry of Education, there were only 366 graduates from the training schools for lower primary education in 1998. This is far less than the increase of lower primary school teachers, from 30,513 in 1998 to 33,363 in 1999 (Instituto Nacional de Estatistica, 2000, *Mocambique em Numeros 1999*, Maputo). In addition, teachers need to be hired to replace those who leave or die. We estimate that in 1998, about 6,000 new teachers were hired at the lower primary school level, far fewer than the qualified graduates.

school quality. A cross-sectional analysis of African countries in 1995 shows that where the student/teacher ratio is lower, the repetition rate is as well.[13] Repetition, which averages 23% in Mozambique, influences enrollment and greatly increases the inefficiency of school. This dynamic is also shown in Figure 10.

The HIV/AIDS model gives the absolute size of each sex and age group. Within each group, the education model calculates the *proportions* who are in school and not in school, by grade. The same proportions are applied to the NEG, HIV, and AIDS statuses. Each sex and single-year age category has a total value of 1. Within that unit, the population is distributed over the education groups. For example, in 1997, at age 5, 0.951 of the boys and girls are not in school and 0.049 are in grade 1. At age 6, 0.842 are not in school; 0.112 in grade 1; 0.041 in grade 2; and 0.005 in post school having achieved first grade.

3.3. Labor Force Model Description

Education does two things to the labor force: it increases the level of skill and therewith the productivity of workers, and it moves people to cities (because the more educated a person is, the more likely he or she lives in an urban area). Meanwhile, AIDS takes people out of the labor force, through death and through home-nursing of AIDS patients. Our model calculates these effects for the urban and rural labor force.

From the HIV/AIDS and education models, we obtain the total population not in school by sex, age, and education achieved. Those with full-blown AIDS are not included. The average labor force participation rates by age, sex and urban or rural residence, from the 1997 Population Census are applied equally, regardless of HIV status or education. This is a simplification, which was dictated by the data. In reality, possibly, those with higher education are more likely to participate in the labor force. Only those with university degrees are assumed to have 100% labor force participation rates. The rates of urbanization are significantly higher for those with more schooling, as the 1997 Population Census shows. This difference is included in the model, so, as the labor force becomes more skilled, it automatically becomes more urban. Moreover, we include an independent, non-education related urban migration force, so that over time, even within each educational level, larger proportions live in cities.

Due to HIV/AIDS, a certain number of potential workers are lost, not only those who have the full-blown disease, but also family members who care for the sick. We assume that care for the sick is a quarter time job (this assumption can be changed) – for every four AIDS patients, one additional person is lost from the labor force because of care. After subtracting those who are caring for the AIDS patients, we have the *actual labor force*.

While the absolute size of the labor force says something, a true reflection of the economic potential of workers includes level of skill as well as size. To capture this economic potential, we calculate the *effective urban* and *rural labor* separately from the absolute labor force size. The effective labor force incorporates relative productivity weights given to each level of skill. The weights were estimated based on a comparison of incomes in different groups. They reflect the income distribution of the 1996 Household Survey. We assume income is ranked by skill – in other words, the unskilled have a lower income than the medium skilled, who have a lower income than the highly skilled. Figure 11 shows the flow diagram of the labor force model.

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[13] Using the database on the UNESCO website: www.unesco.org

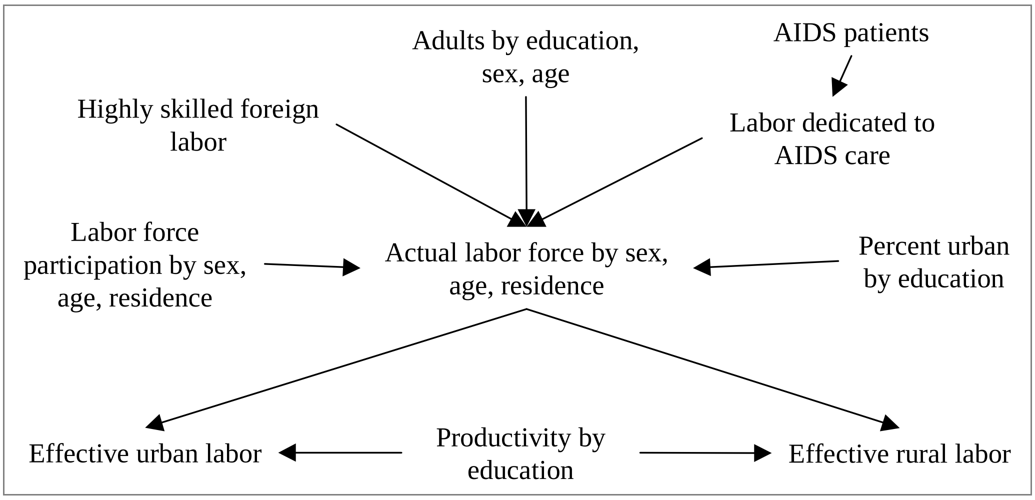

Figure 11. Flow diagram of the labor force model with actual and effective labor force.

3.4. The Economic and Water Models

Figure 12 shows a flow diagram of the economic and water models. Economic production is divided into urban and rural sectors (equivalent to industry and services versus agriculture). Urban production is defined by a Cobb-Douglas function,[14] which includes effective urban labor, capital stock, and productivity. Changes in the capital stock are determined by the rate of domestic investment as a proportion of GDP. Agricultural production is essentially a function of effective rural labor, productivity, and the effect of soil moisture and rainfall.

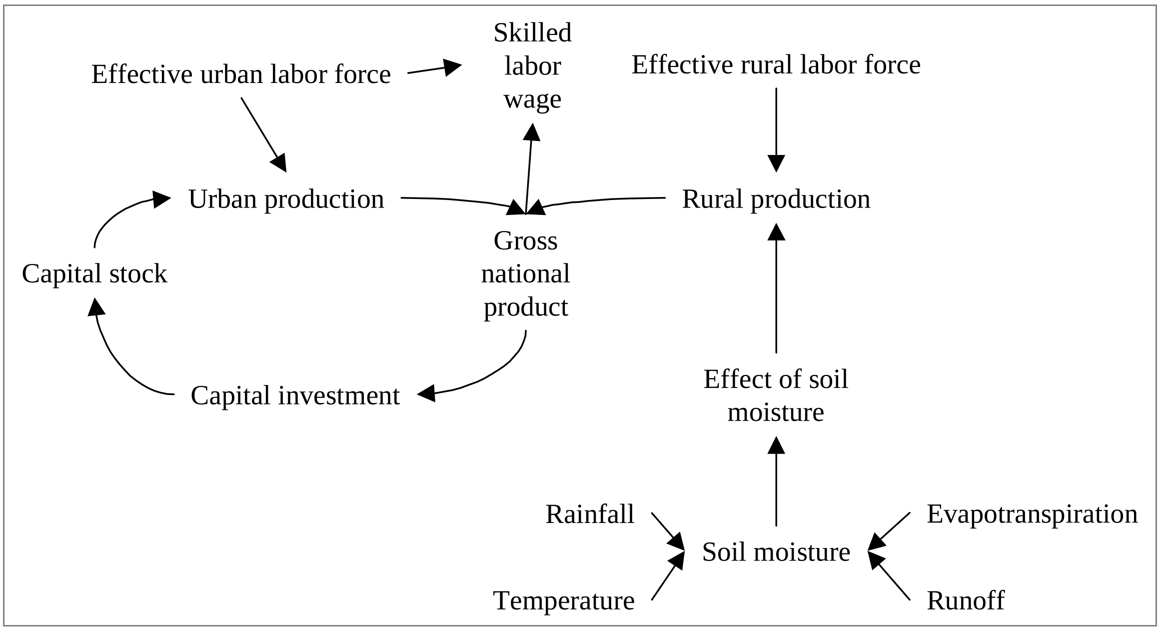

Figure 12. Simplified flow diagram of economic and environmental dynamics captured in the economic and water models.

[14] A standard economic formulation, which is discussed in most textbooks on macro-economics.

The model also calculates wage for highly skilled labor with a university degree or more, with a model developed by Kibuuka.[15] The basic assumption is that an increase in the demand for skilled labor is determined by economic growth: when the demand for skilled labor rises, wages rise. The supply of skilled labor is determined by two factors: the size of the skilled population and the wage rate. A lower wage rate reduces the supply. The size of the professional labor force is increased by university graduates and foreign labor and reduced by migration and deaths, which follow from the HIV/AIDS model.

The water model uses a physically-based hydrologic approach to calculate soil moisture.[16] The model includes 25 national and international rainfall catchment areas, which supply water for the major international rivers running through Mozambique. Not all water is available for extraction or crop growth. Most of it is lost through evapotranspiration and runoff. The model calculates the complex non-linear dynamics of these processes, including rainfall, temperature, vapor pressure, latitude, and soil moisture capacity. Unfortunately, it was not possible to find data, which would allow us to model in detail the effects of the timing and quantity of rainfall on agricultural output. The connection of rain and harvest is therefore very simple: a curve specifying the relative reduction of harvest as a function of rain shortfall in March.

3.5. Case Study: The Greater Maputo City Water Supply and Demand Model

As the urban centers in Mozambique expand, so will the demands on the water infrastructure – namely the water pipes, treatment, and reservoirs. The Greater Maputo City water model focuses on the Pequenos Limbobos reservoir and the Umbeluzi River basin that feeds it. The river basin is modeled in the same way as the river basins in the Mozambique model (see previous section). The reservoir is basically a bathtub; the faucet is runoff from the river basin and the drain is the extraction of water for irrigation, household, and commercial or industrial use. The model also includes natural reservoir loss through evapotranspiration and excess drainage when the reservoir is full (see Figure 13).

The water demands for irrigation, household use and commercial/industrial use are each formulated separately. The growth in household water demand comes from the product of three trends: population growth, more people connected to pipes, and consumption increases for those who are connected to pipes. Each of these three factors is set in user-defined scenarios. Industrial and commercial water demands are linearly related to the total industrial and commercial output, and the user defined scenario for output growth rate. By far the biggest user of the water from Pequenos Limbobos and the Umbeluzi river that feeds it, is irrigated agriculture. Water demand is unequally distributed throughout the year, dependent on the growing cycle of crops. On average, 11-15,000 cubic meters per hectare is used every year, which means that irrigation technology is rather inefficient, and a little under 7000 hectare were irrigated in the Greater Maputo City area. The user can define the water use per hectare changes over time and area irrigated.

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[15] Kibuuka, Paul (1997) The Projected Supply and Demand for Professional and Technical Workforce in Botswana and the Impact of AIDS 1991-2020. Unpublished manuscript, available from the author: paulk@dbsa.org.

[16] Hellmuth, M., K.M. Strzepek, and D.N.Yates (2000) Methodological Framework of the Southern African Integrated (SAINT) Model of Water Supply and Demand. Draft available from the author: hellmuth@iiasa.ac.at.

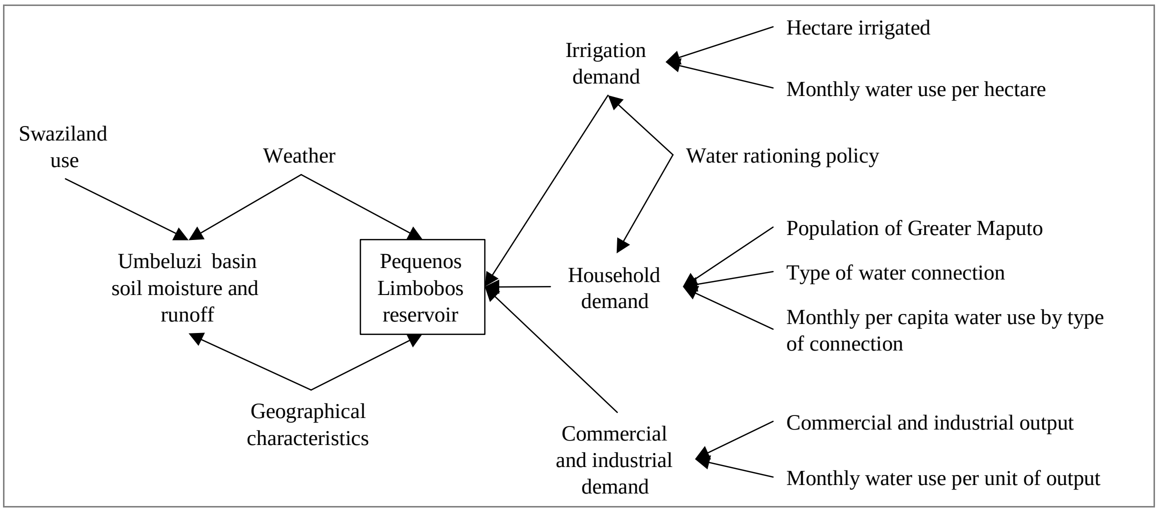


Figure 13. Flow diagram of the Greater Maputo City water model.

Water demands drain the Pequenos Limbobos reservoir. Once the reservoir is dry, no more water is available. The model calculates the water deficits, but does not alter the demands. As water shortages are a possibility, the user can implement two types of policies when the reservoir reaches dangerously low levels: household water use rationing and cutting off all irrigation water.

Part III: PDE Model User's Guide

1. Download and Installation of the Vensim® Model Reader and the PDE Models[17]

Download the PDE model file and the supporting data input file(s) for the model of choice and the Vensim® Model Reader. For a full list of model data files, see Part I, Section 3.

Install the Vensim® Model Reader by double clicking on the EXE or HXQ file, depending on your platform.

2. Vensim® Model Reader – Menu, Toolbars and Their Functions

When starting the Vensim® Model Reader for the first time, you will see the following on your screen (see Figure below). In the following we describe the functions of the Menu and the Toolbars.[18] We will explain how to set up and run simulations based on PDE model examples.

[17] The PDE models were programmed and designed on a Microsoft® platform and have not been used or tested on other platforms.

[18] This manual is based on the Vensim® Model Reader, Version 4.1b (1988-2000. Vensim® Model Reader Manual and Vensim® DSS Manuals, Ventana® Systems, Inc., USA). Causal Tracing®, Reality Check®, Vensim® and Ventana® are registered trademarks of Ventana® Systems, Inc. Venapp® and the Ventana® Logo are trademarks of Ventana® Systems, Inc. Vensim® is covered by United States Patents 5,428,740 and 5,446,652. Patents are pending in the United States and other countries related to portions of the Vensim® software.

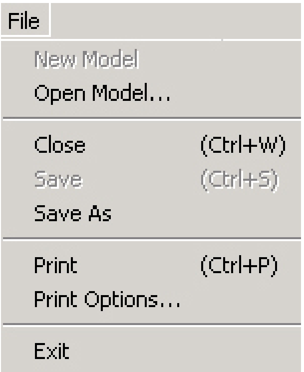
2.1. Title Bar, Menu, Main Toolbar, Vertical Toolbar, Bottom Menu

Title Bar

The title bar shows the file name of the model that is open (in our figure above *GaboroneModel.vmf*) and the workbench variable (*Var:Relative Storage[BASIN]).* A workbench variable is a variable which is "active" and which has been selected by double clicking on the variable name or by using the variable selection control in the control panel (**Windows>Control Panel>Variable on the Menu**).

Menu

Items that are not shown in bold are not available menu commands.



File>Open Model... opens an existing model. The current model will be closed.

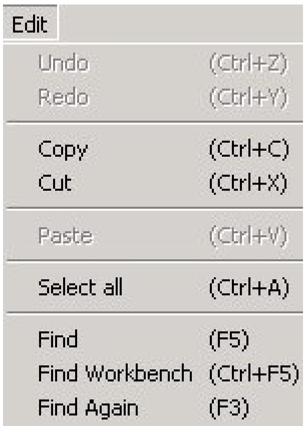
File>Close closes the currently active window.

File>Save As applies only when you have a graph or a table in the foreground. It saves the contents of the foreground window as a metafile or a text file.

File>Print prints the contents of the foreground window.

File>Print Options... allows the user to set the printer and other functions. The same dialogue is available when you choose **File>Print**.

File>Exit closes Vensim.



Edit>Copy copies the contents of the selected window to the clipboard.

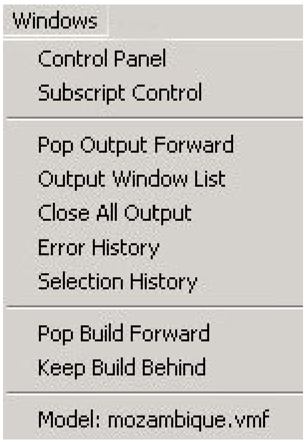
Edit>Cut cuts (deletes) the contents of the selected window to the clipboard.

Edit>Select All selects everything in view.

Edit>Find helps to look for a variable in the model.

Edit>Find Workbench finds the variable which is named in the title bar.

Edit>Find Again finds another occurrence of the highlighted variable, if there is more than one.



Windows>Control Panel (explained later in this chapter).

Windows>Subscript Control (explained later in this chapter).

Windows>Pop Output Forward brings all output windows (graphs, tables and others) to the foreground.

Windows>Output Window List displays all active output windows.

Windows>Close All Output closes all output windows except those which have been locked.

Windows>Error History informs about error messages.

Windows>Selection History lists the variables which have been selected in the workbench.

Windows>Pop Build Forward brings the model window to the foreground and puts all output windows in the background.

Windows>Keep Build Behind puts the model window in the background and keeps it there, even when you click on it.

View>Zoom lets you zoom in or out; the **Fit to Screen** option keeps the whole screen visible without scrolling up or down.

Help>Instruction opens the help manual provided by Vensim.

Help>Keyword Search allows you to search by name for help.

Main Toolbar

Most of commands in the menu can be made using the main toolbar. The name listed after the button image appears when you move the mouse over the button in the top toolbar.

 **Open Model** opens an existing model.

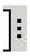
 **Save** saves the contents of the foreground window as a metafile or text file.

 **Print** prints the contents of the foreground window.

 **Copy** copies the contents of the foreground window to the clipboard.

Set up a Simulation sets up a simulation. After clicking on the **Set** icon you will be able to make changes to the constants or lookup tables.

Name the Simulation to be Made allows you to name a new simulation.

 **Select a Simulation Name** opens a file selection dialogue. You can select an existing run to overwrite or create a new one.

 **Run a Simulation** starts a simulation or run of the model.

 **Start a Game** starts a gaming simulation.

 **Run Reality Checks** starts a reality check only when the model contains reality check equations.

Build Windows–show/circulate brings the model structure (sketch view) to the foreground and the output windows to the background without closing them.

Output Windows–show/circulate brings the output windows to the foreground.

Control Panel opens the control panel dialogue.

Subscript Control opens the subscript control dialogue.

After clicking on the **Set** button you will find a few new command icons. These buttons are needed to make changes to the model constants and lookup tables. They are the following:

Select an Integration Technique specifies the integration technique that will be used to run the model. By clicking on the icon you can switch between Euler and RK4 (fourth order Runge Kutta with an automatic step size adjustment). This is not available in all models.

List the Datasets to be Used for Data Variables and

Select a Dataset Name opens a file selection dialogue. Choose the file(s) you want to work with or type directly in the box. If you want to use more than one file, separate each by a comma.

Change Model Constants opens a dialogue box that contains all of the model constants, which can be changed directly in the dialogue box. Click **Close** when finished.

Change Lookups opens a dialogue box that lists all lookup tables of the model. Mark the lookup table of choice and click on **Modify** to open the graphical lookup editor. Once you have made your changes, click **OK**.

Stop Simulation Setup stops the simulation setup and will cancel any changes you might have done!

Vertical Toolbar

The Vensim® Model Reader generates graphic and table outputs that can be pasted into documents. The necessary toolset can be found on the vertical toolbar. Tools for structural analysis and dataset analysis are also available on this toolbar (for more information, see Section 2.2.).

Causes Tree shows a tree-type graph of the causes of a workbench variable.

Uses Tree shows the uses of a variable.

Loops lists the feedback loops of the workbench variable.

Document documents the workbench variable and shows the equations, units of measure and definitions.

Causes Strip shows the graph of the workbench variable and the graphs of the causes of the workbench variable. If more simulations are loaded they will be separated by a line.

Graph shows a graph of the workbench variable with a different colored line for each loaded simulation (and each subscript element, if multiple subscripts are selected).

Table shows the value of the workbench variable at each time in a table. Same contents as the graph.

Runs Compare lists the changed variables (constants and/or lookups) to compare the simulation setup.

Bottom Menu

Show the Previous View and **Show the Next View** (**Page Up** / **Page Down**) navigates through the model.

Choose a View to Look at shows the list of available views.

Dialogue Toolbar

Delete this window or click on .

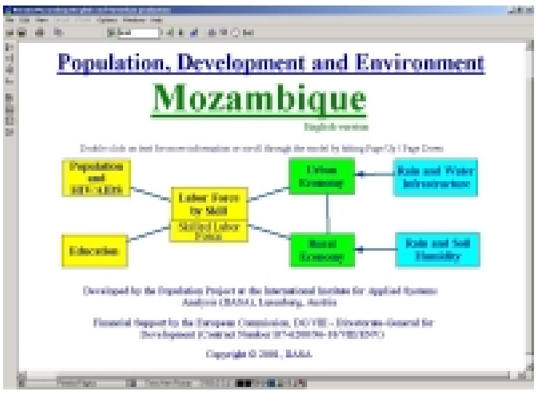
Lock this window. When you click on **Windows>Close All Outputs** in the menu, the locked output will not be deleted.

Print the contents of this window or **File>Print**.

Save the contents of this window (as a text or wmf file) or **File>Save As**.

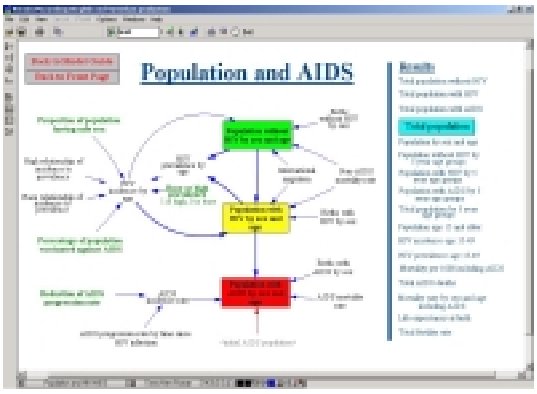
2.2. Tools to Understand the Structure of a Model

To start a model click on **File>Open Model…** in the menu or on the button and choose the model in the selection window. In our example, the Mozambique PDE model (*MozambiqueEnglish.vmf*) will open with the following:



Choose the part of the model you want to view by clicking on the box in the flow diagram (in our example *Population and HIV/AIDS*) or **Choose a View** (Population and HIV/AIDS) at the bottom menu. You can also click on the title on the front page. You will enter the **Model Guide** which lists all of the available views. Click on *Population and HIV/AIDS*.

You will pop into the flow diagram of the *Population and HIV/AIDS model* (see below). It shows a simplified structure of the model, the relationships of the variables and the feedbacks (which are not so visible).



To better understand the model we use a powerful tool called Causal Tracing®. This helps us understand why things change. Two different causal relations can be checked: the CAUSES and the USES of a variable. In the following sections we explain how to do this.

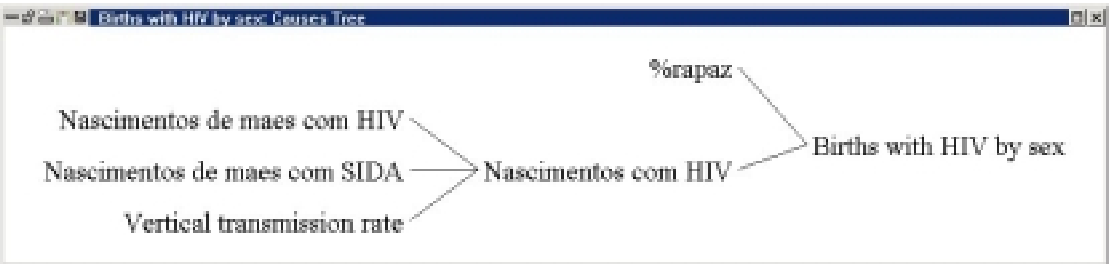
Interpretation of a Causes Tree

Example: We want to understand what causes *Births with HIV by sex*.

When you move the mouse over a variable, a small text box with yellow background will appear. The information written in this text box will be (i) the unit for the variable, and/or (ii) comments. For *Births with HIV by sex* the message will be *people* (the unit).

If you double click on this variable it will turn into a workbench variable. It turns into a workbench variable when it shows up on the title bar. You will see the information **Vensim:MozambiqueEnglish.vmf Var:Births with HIV by sex[sex,hivstat]**. The name following the variable name in the square brackets **[sex,hivstat]** indicates the availability of a subscript. We will ignore the use of the subscript at the moment and come back to it later (see Part III, Section 3.2).

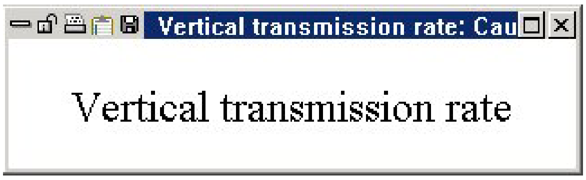
Next, click on the **Causes Tree** button  on the vertical toolbar. The following Causes Tree Diagram dialogue will appear on the screen:



We can see that *Births with HIV by sex* is caused by %boys (%rapaz) and by births with HIV (Nascimentos com HIV). Further, we can see that *Births with HIV by sex* is caused by births by mothers with HIV (Nascimentos de maes com HIV), births by mothers with AIDS (Nascimentos de maes com SIDA) and the vertical transmission rate.

Simply explained, this means that the number of children who are born HIV positive, provided by sex, are calculated in this model by the number of children born with HIV and the fraction of how many children are boys. Further, the number of children who are born HIV positive are caused by a combination of three factors: the number of pregnant mothers who are HIV positive, the number of mothers who have AIDS, and the vertical transmission rate (the transmission of the HIV virus from the HIV-positive mother to the child).

Now we would like to understand the causes for the vertical transmission rate. Repeat the procedure as explained above. Double click on the variable *vertical transmission rate* in the Causes Tree Diagram dialogue; the variable will turn into a workbench variable. Then click on the **Causes Tree**  button:

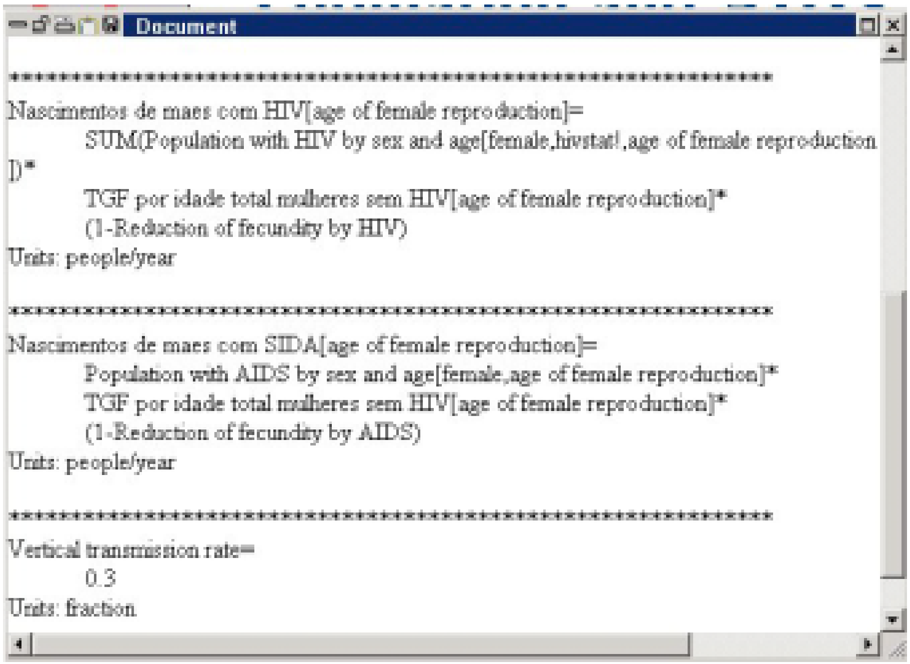


There are no causes of the vertical transmission rate. In this case it is a constant.

Variable Units and Equations

We would like to understand how these input variables cause HIV-positive births. Or in other words, what are the equations and units? The cause variables, *%boys* and *Births with HIV*, are not visible in the *Population and HIV/AIDS* View, so we cannot move the mouse over the variable to get the text box with the necessary information, as we can for variables available in **View**.

Let's check the units and equations of all the cause variables of *Births with HIV* in the Causes Tree Diagram output window. Create a workbench variable for *Births with HIV* by double clicking on the variable. Click afterwards on the **Document** button  on the vertical toolbar. Repeat this procedure for the other variables. The following Document output window will appear (part of it is shown here).



Document

****
Nascimentos de maes com HIV[age of female reproduction]=
SUM(Population with HIV by sex and age[female,hivstat!,age of female reproduction
])*
TGF por idade total mulheres sem HIV[age of female reproduction]*
(1-Reduction of fecundity by HIV)
Units: people/year

****
Nascimentos de maes com SIDA[age of female reproduction]=
Population with AIDS by sex and age[female,age of female reproduction]*
TGF por idade total mulheres sem HIV[age of female reproduction]*
(1-Reduction of fecundity by AIDS)
Units: people/year

****
Vertical transmission rate=
0.3
Units: fraction

All of the variables are listed in one Document dialogue. The order of listing is always the same, according to the rules below:

1) The variable name and an equal sign.
2) The equation.
3) The unit of the variable.
4) The line which separates the variables.

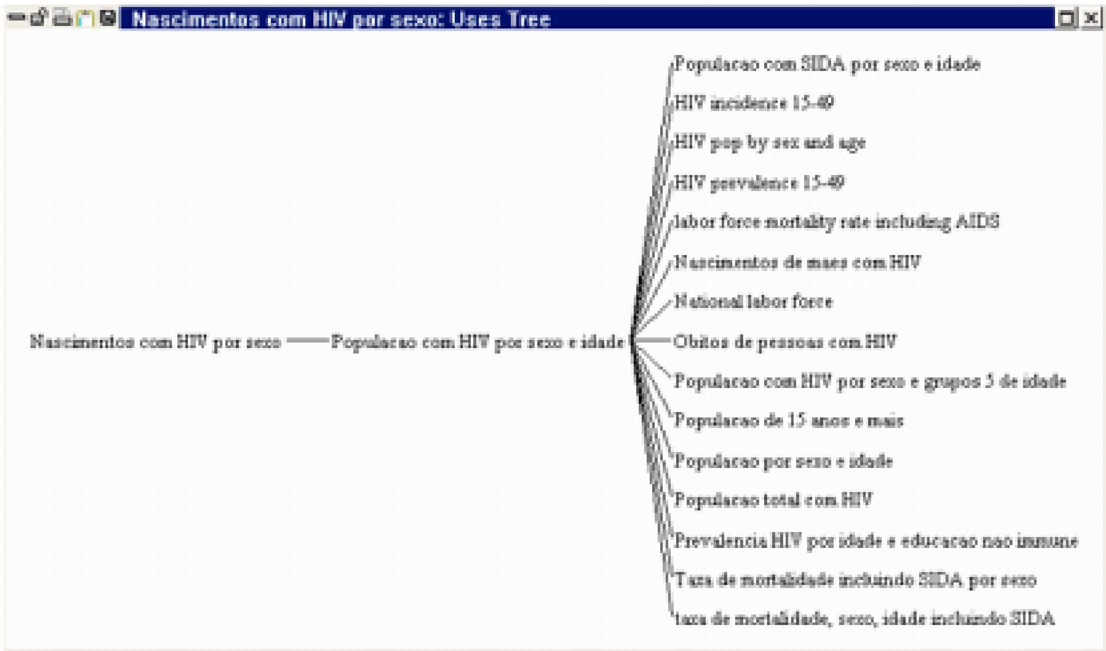
Based on the list above, the number of children born with HIV per year (*Births with HIV*, Unit: people/year) is the sum of the number of children born by mothers who are HIV positive and by mothers who already have AIDS per year (*Births of mothers with HIV* and *Births of mothers with AIDS*, unit=people/year). This sum is then multiplied by the *vertical transmission rate* which is a fraction of the value of 0.3 (i.e., 30 percent of the children born by mothers with HIV and AIDS are born HIV positive). This leads to the conclusion that the higher the number of children born by mothers with HIV and AIDS in combination with a higher vertical transmission rate, the higher the number of births of HIV-positive children. This is a simplified analysis of what we analyzed in our example, but we have to remember that we did not check on other causes that might influence this relationship, or if feedback exist.

Because of the long list in the Document output window, all of the variables will not be visible at the same time. You can scroll through the list by clicking on the scroll bar to the right of the output window.

Note: As long the Document output window is active, all of the variables will be listed.

Interpretation of the Uses Tree

We would like to see if the variable *Births with HIV by sex* manipulates other variables. Double click on the variable, then click on the **Uses Tree** button  on the vertical toolbar. You will get the following Uses Tree output window.



The variable influences and affects other variables. In our example we see that the number of HIV-infected births has many impacts, such as on the HIV-positive population (*Populção total com HIV),* the labor force mortality rate including AIDS, and many others. If you wish to see the equations and units, follow the same procedure as explained in the section *Variable Units and Equations:* Click on the variable of interest and then on the **Document** button.

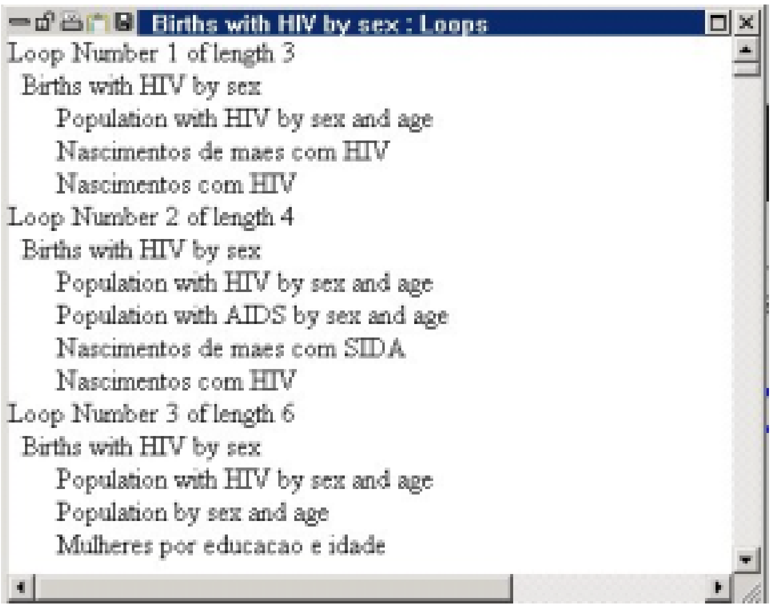
Feedback Loops

What are (causal) feedback loops?

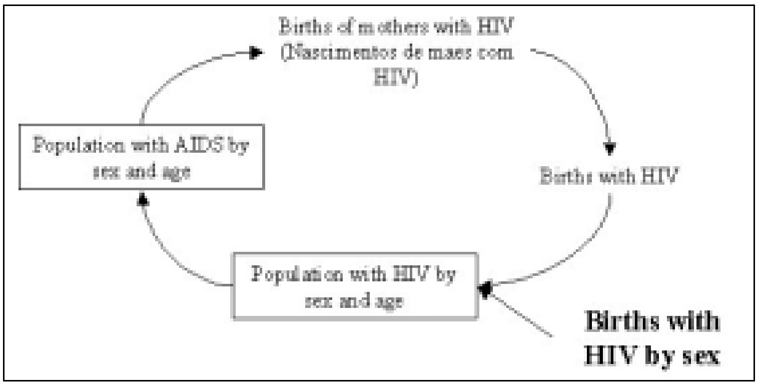
A causal loop diagram portrays the information feedback in a system. Feedback is a process in which an indicator goes through a chain of causal relations to re-affect itself. Feedbacks are divided into positive and negative feedback loops. On the one hand, a feedback is *positive* if an increase in a variable leads to a further increase in the same variable. Positive feedback is found in systems that produce exponential behavior. On the other hand, a feedback is *negative* if an increase in a variable leads to a decrease of the same variable. Negative feedback drives balancing or stabilizing systems that produce asymptotic or oscillatory behavior.

The **Loops** tool displays a list of all feedback loops passing through the workbench variable. The **Loops** display provides useful information on model interactions. The list starts with the shortest loop, i.e., the loop which involves the least number of variables. Loops involving more than 32 intermediate variables will not be listed. If more than 50 loops are found, you will be asked if you want to see more than the first 50.

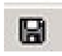
Using the variable *Births with HIV by sex*, let's see how many feedback loops exist. Turn the variable into a workbench variable and click on the **Loops** button. The following question will appear: There are 112 loops – do you want to see more than the first 50? Click on **No**. You will receive the following output window (an extraction). The order is always the same, starting with the smallest loop in increasing order.



Let's construct a causal loop diagram of loop number 2 with the length of four variables. The cause diagram shows *Population with HIV by sex and age* that is fed by the flow of *Births with HIV by sex.* The loop is a positive feedback loop. It shows a closed chain of cause and effect in which a higher HIV-positive population leads to more births with HIV, and in which more HIV-positive births lead to a still larger HIV-positive population.



Output Windows: Save Data, Export Figures, Window Order

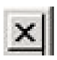
The contents of the output windows can be saved by clicking the **Save** button  on the dialogue toolbar or on the top toolbar, or by clicking **File>Save As** on the menu. This applies only when you have a graph or table in the foreground, i.e., when the dialogue is active. The graphical outputs will be saved as a metafile (placeable wmf format) and the Document, Loops, Causes Trees, Uses Trees and Tables as text files (txt). The text files can be opened with any spreadsheet program, so that you can work with the data.

Parts of the dialogue contents can be saved or copy-and-pasted by pressing the mouse button tightly and moving the mouse over the parts to be copied in the output window. Press Ctrl+C or **File>Copy** and paste, for instance, to Word.

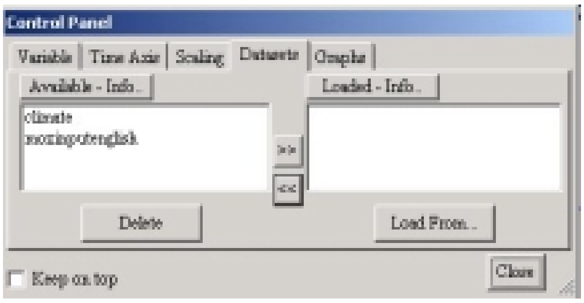
Perhaps you have too many windows open in the foreground and want to move them to the background without deleting or closing them. Go to **Windows>Pop Output Forward**. All dialogue boxes will move to the foreground. If you are interested in only one specific dialogue, it is not necessary to search within the open windows. Go to **Windows>Output Window List** and double click on the output you want to look at. The respective window will appear in the foreground.

2.3. Loading Datasets (Input Data and Scenarios) and Viewing Graphs of Simulations

You wish to explore the impacts of different scenarios on a certain variable. It might happen that when you double click on a variable and then on the **Graph** button, you will receive the following message:

In this case, close the dialogue by clicking on the  button, then click on **Windows>Control Panel>Datasets**.

Important: The data input and scenario files (.vdf) must be located in the SAME FOLDER as the model file (.vmf).



In the Control Panel window you will see the available datasets on the left (**Available - Info...**). There are two ways to move the dataset you want to load: either double click on the dataset, or single click on the dataset to mark it and click on the  button in the middle of the window. To unload the information use the  button. As an example, you can load *climate* and *mozinputenglish* (the model input data files). Click on **Close** when both file names are visible in the **Loaded - Info...** window. Now you can display graphs and tables of results of interest.

3. Hands-On Examples To Run Simulations

3.1. PDE Mozambique Model, English Version

Let's continue with the already open model (*MozambiqueEnglish.vmf*) and stay in the *Population and HIV/AIDS* View. In our example we want to learn more about the impact on the total population size of the introduction of a vaccine in the year 2005 that is accessible to 50% of the population, compared to the non-availability of a vaccine. Now we will need to change the variables in order to answer this question.

To Change the Variables and to Run a Simulation

Click on the **Set up a Simulation**  button on the top toolbar. This button will now change into the **Stop Simulation Setup** button . All variables that can be changed are highlighted in blue.[19]

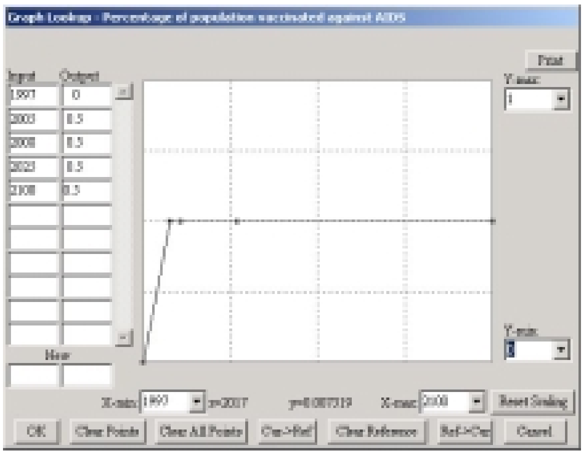
Double click on *Percentage of population vaccinated against AIDS* to turn the variable into a workbench variable. A graph lookup dialogue window appears. We see that the loaded base scenario of the model does not introduce a vaccine, so we do not have to change the lookup function. Let's run the first simulation. We'll name the simulation *novaccine*, so type *novaccine* into the **Name the Simulation to be Made** box (see image below).

Click on **Stop**  and then on **Run a Simulation** .[20]

Let's run the next simulation, the introduction of a vaccine. Click on the **Set** button and double click on the *Percentage of population vaccinated against AIDS* variable. Now we have

[19] The model structure and the input data cannot be changed in Vensim® Model Reader.
[20] Should you receive a warning, ignore it and close the window.

to change the variable. There are two ways to do this: (i) move the line of the graph by using the drag-and-drop method, or (ii) enter the data in the table on the left. Let's type in the new data. In the Input column, we'll change the year 2004 to 2005; in the Output column we'll change the values from 0 to 0.5 (for 50%) for the years 2005 and later. Close the window by clicking on **OK**.

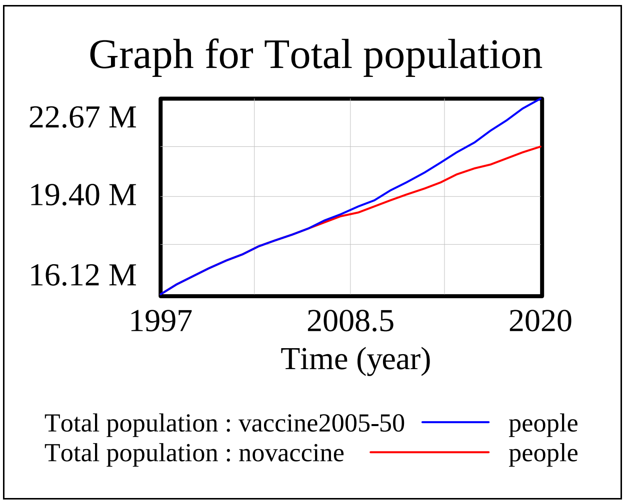


Enter the name *vaccine2005-50* for this simulation. Run the simulation by clicking on the **Run** button.

Note: Every new simulation will be saved as a *.vdf file in the same folder as the model.

Graph Output

We would like to compare the effects of both simulations on the total population size. We will examine the differences with a graph. Double click on *Total Population* (workbench variable) which is located on the right of the same screen. On the vertical toolbar click on the **Graph** button  and a Graph dialogue including both simulations will appear. You can see that the results for both runs are the same until 2005. This is the year of the assumed introduction of a vaccine which is accessible for 50% of the population (*vaccine2005-50* simulation). After this data point, the lines separate with a bigger population size for the *vaccine2005-50* scenario compared to the *novaccine* scenario.



The size of the graph can be changed in the Vensim® Model Reader. Move the mouse over the right or bottom border until you see the following arrow ↔. Drag the arrow until the graph is the desired size.

To retrieve a table output click on the **Table**  icon on the vertical toolbar.

To Change the Range of a Graph

If you would like to have the scale of a graph range from the minimum to the maximum value, click on the menu **Windows>Control Panel>Scaling**. Choose **Vertical Scaling Raw** and click on **Close**. Click again on the **Graph** button on the vertical toolbar. A new graph output window will appear on the screen.

Other graph layout functions of the Control Panel are:

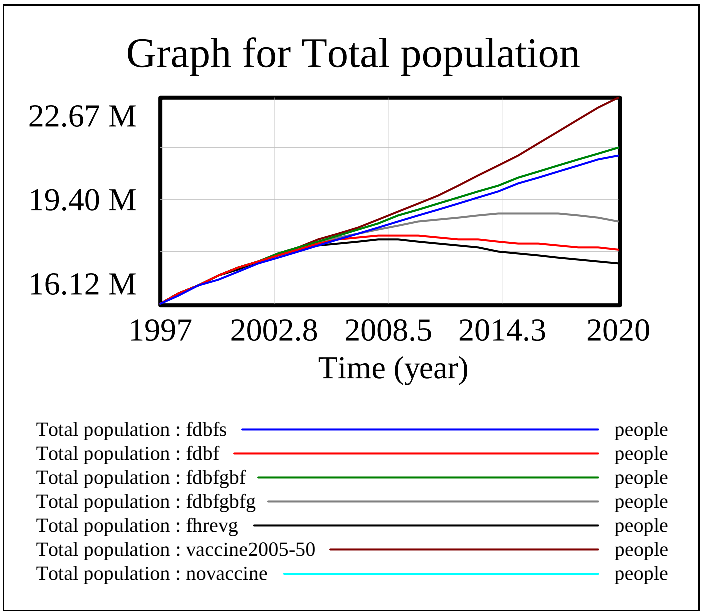
Scaling>Graph Divisions chooses the number of horizontal and vertical division lines.

Time Axis chooses the range of the X-Axis – the range of the years. Type in the desired range. If you want to return to the full time range, click **Reset to Full Range.**

The range can also be changed by pressing “Ctrl” (for the Y-axis) or “Shift” (for the X-axis) and dragging the mouse over the range to be displayed. Click afterwards on the **Graph** button to generate a new graph.

Too Many Simulations are Displayed in the Graph

Let’s say that you have run several simulations. Now you have a graphical output, for instance, with seven runs (figure below), but you want a figure which displays only two simulations.



Go to **Control Panel>Datasets**. In the control panel dialogue box on the left you will find all of the available datasets (**Available - Info...**). On the right, under **Loaded - Info...** you will see the list of the datasets which are currently loaded and which are displayed in the graph. In our example above, seven datasets are loaded. Mark the datasets to be removed and click on the  button, or double click on the dataset. Close the dialogue and generate a new graph by clicking on the **Graph** icon .

Compare Simulations

To document the changes of the single variables of the simulation, click on the **Runs Compare** button  on the vertical toolbar. The output shows which simulations are compared (first row); if constants or lookup functions have been changed (second row); the name of the variable that has been changed (third row), followed by the numerical information of the change.

Runs Compare compares only the last two simulations.

Comparing vaccine2005-50 and novaccine
******Lookup differences between vaccine2005-50 and novaccine******
Percentage of population vaccinated against AIDS - has changed in value

vaccine2005-50	novaccine
X | Y	X | Y
1997 | 0	1997 | 0
2005 | 0.5	2004 | 0
2008 | 0.5	2008 | 0
2025 | 0.5	2025 | 0
2100 | 0.5	2100 | 0

Note: We recommend that you document all simulations.

Transfer Graphs, Tables, Runs Compare and Views into a Text Processing or Spreadsheet Document

You would like to insert the output, for instance, into a Word document. To paste graphs, tables, runs compare and other output information into a Word document, first mark the output window.

Then choose between two options in the menu:

– **Edit>Save As** saves graphs, causes and uses trees, and causes strips either as Windows metafiles (wmf) or graphics transfer files (gtx). Tables and runs compare can be saved as text files (txt).

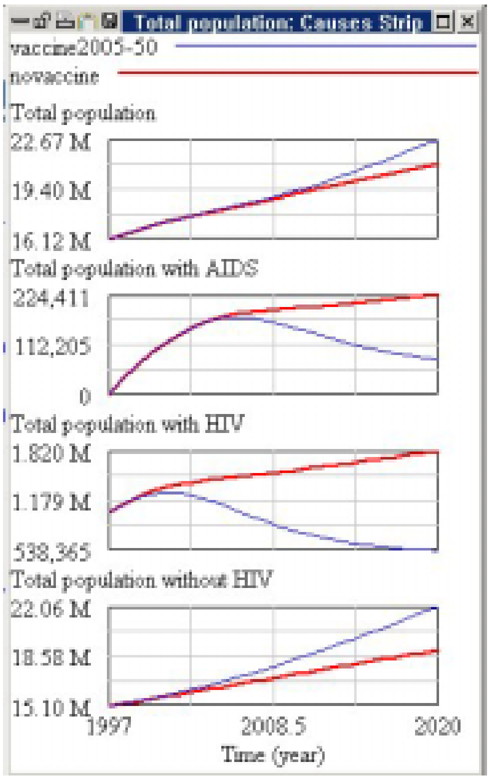
– **Edit>Copy** copies the contents of the active dialogue to the clipboard. **Paste** (or **Paste Special**) the contents of the clipboard into a Word document. You can also paste the contents of the clipboard directly into a spreadsheet program such as Excel.

To export the complete view, select **Edit>Select All** in the menu and follow the steps of the second option above.

Note: The keyboard shortcuts are: **Edit>Copy** "Ctrl+C" and **Edit>Save As** "Ctrl+S".

Interpreting Results Based on the Causes Strip Graphs

You would like to interpret the results of the two simulations. When we check the equation of the workbench variable *Total Population* (click on the **Document** button) we can see that *Total Population* is the sum of *Total population without HIV* plus *Total population with HIV* plus *Total population with AIDS.* Let's analyze the results based on the results of these three cause variables. Click on the **Causes Strip** button  on the vertical toolbar.

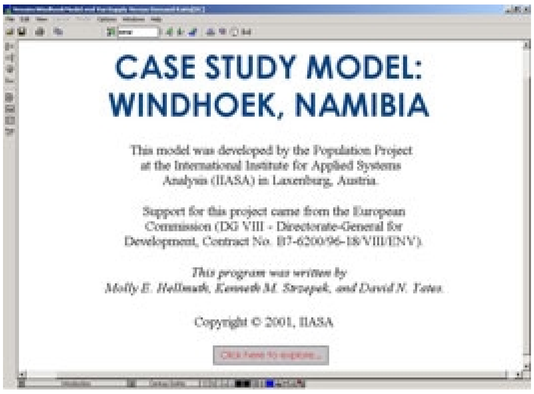


We get an output window which contains four graphs: *Total population* (workbench variable) and the three equation variables.

It shows that the introduction of a vaccine, which is available for 50% of the population, leads to a significant reduction of the HIV-positive and AIDS-infected population over time. Additionally the non-infected population increases faster in the *vaccine2005-50* simulation compared to the *novaccine* simulation.

3.2. The Windhoek Case Study Model

Download the required files into one folder. The model should start with the following view:



To better understand the model structure use the Causal Tracing® tools (for details, see Part III, Section 2.2).

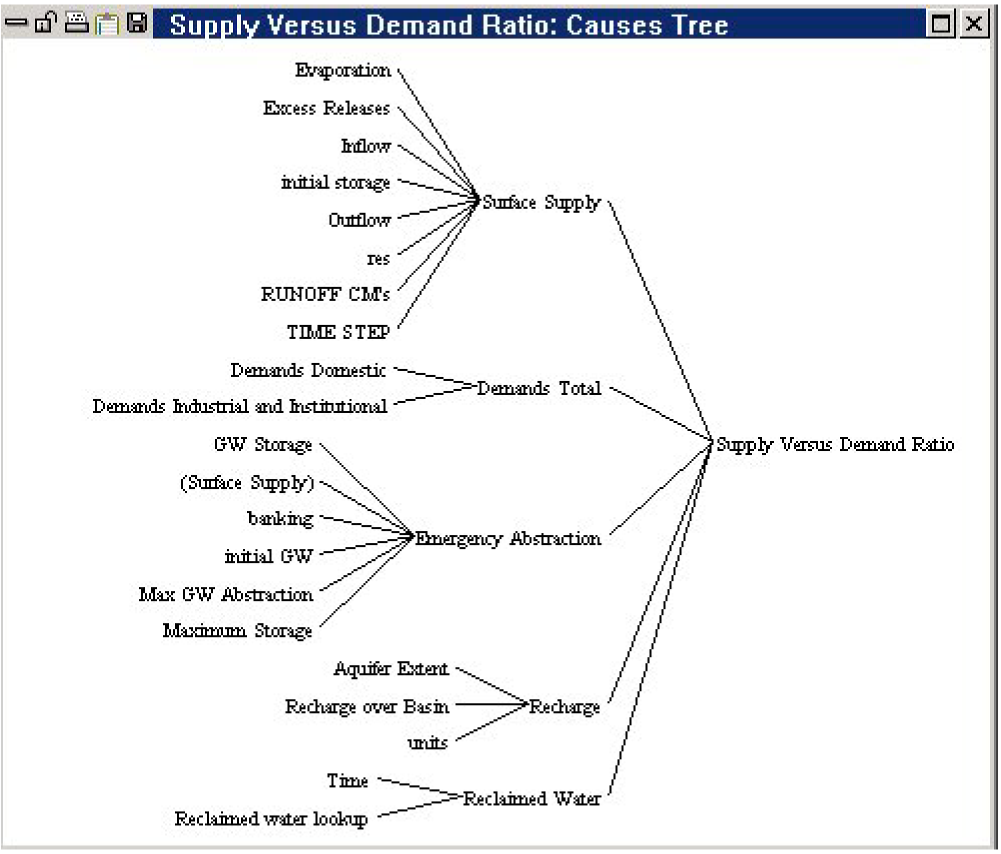
Understanding the Model

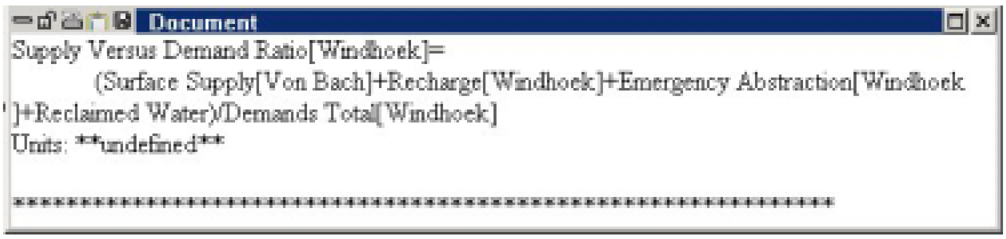
For a descriptive overview of the model, read the model description (see Part II, Section 2.3), follow the navigation system, and read the model flow diagrams.

We are now interested in the impacts of two different scenarios on the S*upply versus Demand Ratio* output variable which represents water stress. This variable is located under *Scenarios.* But first we should check the causes and the equation of this variable. Turn the *Supply versus Demand Ratio* into a workbench variable by double clicking on it. Next, click on the **Causes Tree** button and the **Document** button. We see that the main causes for the ratio are the sums of the *Surface Supply*, *Recharge*, *Emergency Abstraction* and the rate of the

Reclaimed Water to *Demands Total*. The Document dialogue shows that the workbench variable is dimensionless (no unit). Compare it to the Causes Tree window – in the equation we can see how, in mathematical terms, the *Supply Versus Demand Ratio* is determined. To analyze other causes, double click in the Causes Tree window on other variables, followed by a click on the **Causes Tree** button.

The explanation of the meaning of the output value is found in the *Scenario* View. Values between 5 and 2.5 indicate that the system is under stress, while values below 2.5 represent high stress.





How to Find a Desired Variable

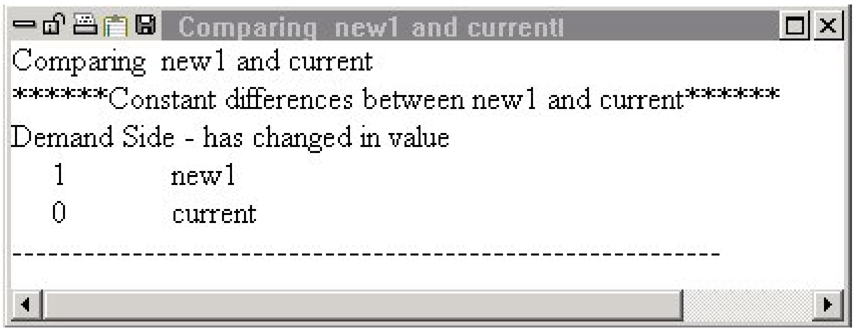
Click on **Edit>Find** in the menu (short-cut key F5) and a selection dialogue appears. Click on the desired variable, then **OK**. The view with the highlighted variable will appear on the screen. If you would like to know if the variable occurs in other views, click on **Edit>Find** again.

Run Scenarios

We are interested in the effects of conservation measures in water consumption as provided in the *Scenario* View compared to no water conservation measures.

Let's start with the no water conservation simulation. Click on the **Set** button . All the changeable variables will be highlighted in blue. Click on **Demand Side**. We can see that in the default setup, no conservation measurements are considered. Click on the **Stop** button , name the simulation (in our example *current*) and click on the **Run** button . Repeat the procedure for the second simulation which takes water conversation measures into account, but change the *Demand Side* scenario option to 1 and name the simulation *new1*.

For simulations where we changed more than one variable, it might be useful to store the information of the simulations. Click on the **Runs Compare** button  and save the output (**File>Save As** in the menu); the runs compare will be saved as a text file.

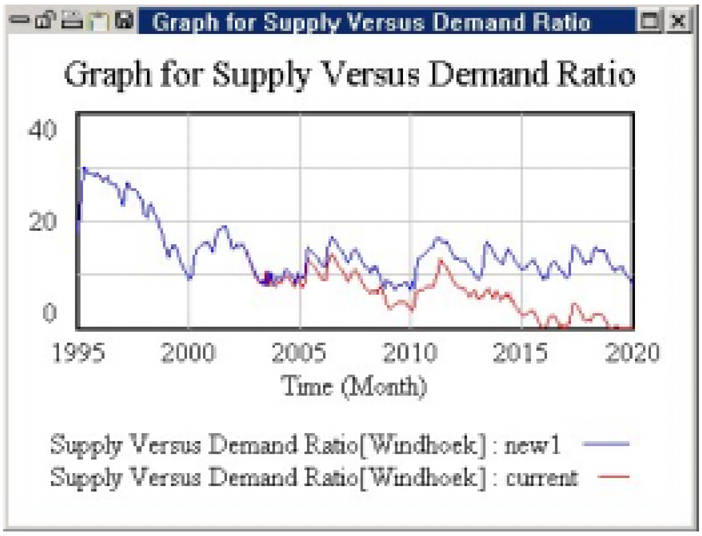


Comparing new1 and current!

Comparing new1 and current
******Constant differences between new1 and current******
Demand Side - has changed in value
1 new1
0 current

View the Results with Graphs and Interpret Them with Causes Strip

To compare both runs with a graph or table, click on the **Graph**  or **Table**  button. Let's view the graph.[21]

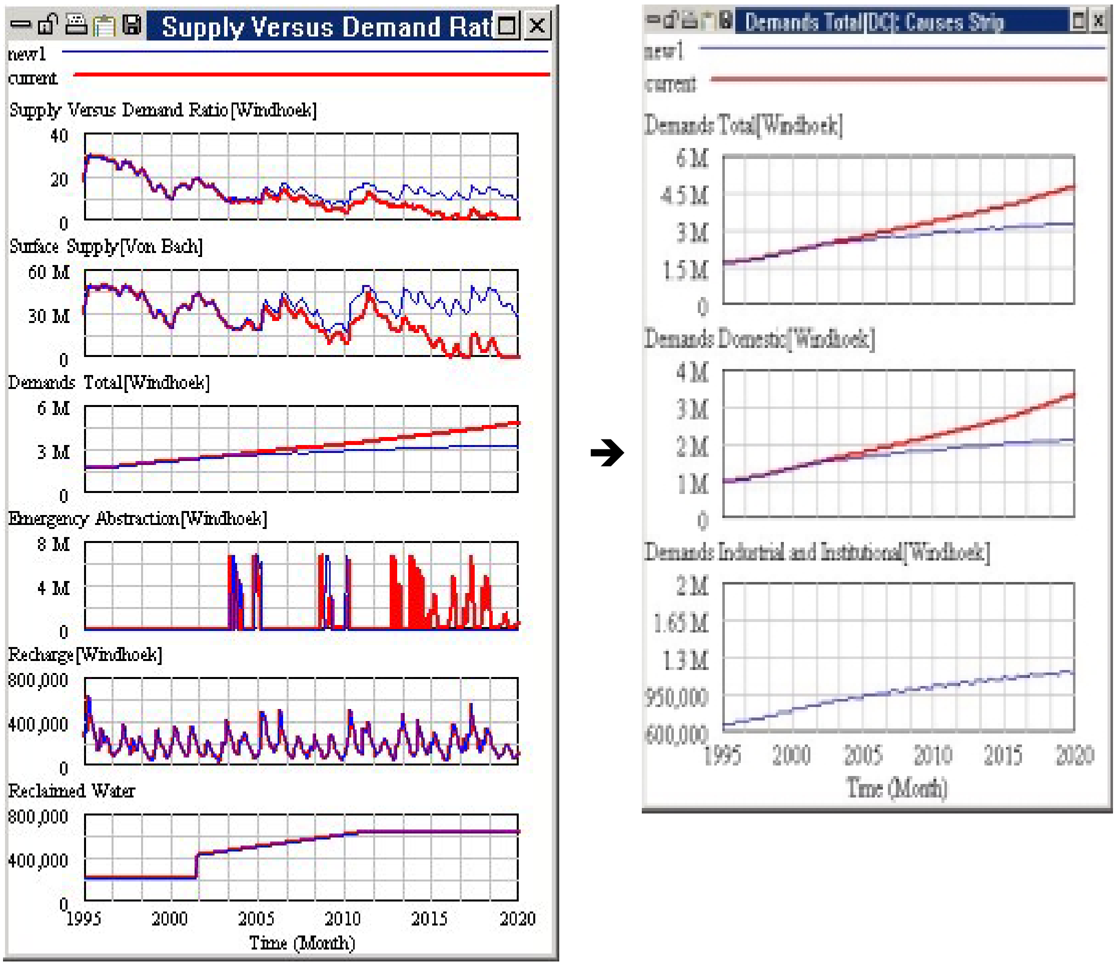


[21] If you wish to change the scaling, or too many runs are loaded in the graph, see Part III, Section 3.1.

We can see that Windhoek is confronted periodically with a “water crisis” with increasing severity up to 2020 in the *current* simulation (where we did not consider any water conservation measures).[22] But we can see significant improvements in water security in the scenario *new1* (where water conservation measures were considered).

To understand the results in the context of the causes, we can look at the Causes Strip, the graphical output of the causing factors as seen in the Causes Tree diagram. Click on the **Causes Strip** button  on the vertical toolbar (make sure that the *Supply Versus Demand Ratio* has been turned into a workbench variable). We will get an output window with six graphs.

In the *Recharge* and *Surface Supply* graphs, for instance, we can see the seasonality of rainfall. The *Recharge* graph shows the same results for both runs, because we did not change the climate scenario options. We can see that the *Surface Supply* from the Von Bach Dam (indicated by the square brackets following the variable name; a subscript; see below) is higher and the *Total Demand* for Windhoek is lower in the *new1* scenario, which considers water conservation measures. You can view the Causes Strip for one of these variables by double clicking on the variable and then on the **Causes Strip** button.



[22] Values between 5 and 2.5 indicate that the system is under stress, while values below 2.5 represent high stress.

Too Many Runs Viewed in the Graph

To move graphs from the foreground to the background without closing them, click on the **Build Windows**  button on the main toolbar or click on **Windows>Keep Build Behind** in the menu. To bring all of the output windows to the foreground, click on the **Output Windows**  button; all open windows will move to the foreground. If you continue to click on the same button, you will circulate through all of the open output windows.

To view a list of all open outputs, click on **Windows>Output Window List** in the menu. Choose the output of interest and click **OK** or double click on it. The output window will move to the foreground.

You can lock  output windows. This makes it much easier to deal with all the output windows. If you use **Windows>Close All Output**, all outputs will be closed except the locked ones.

Subscript Control

We have learned that subscripts are one or more words enclosed in square brackets, which follow the workbench variable name. We see, for instance, in the Causes Strip figure above that a few variables have a subscript named Windhoek and one variable Von Bach.

What are subscripts?

Subscripts allow a single variable to represent more than one thing. Almost all variable types can have subscripts. A variable can have up to eight subscripts separated by commas. The subscripts do not appear in the sketches (flow diagram view).

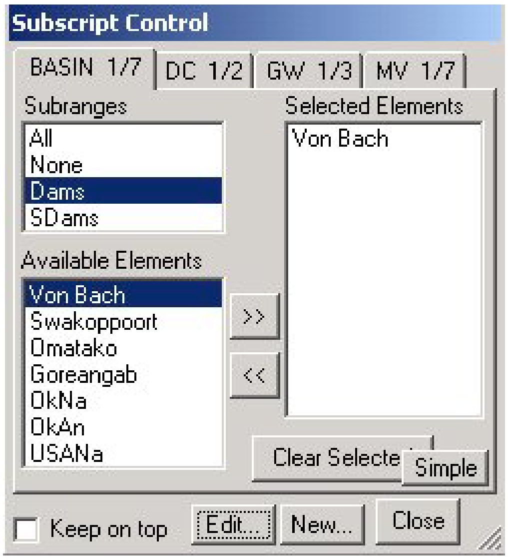
To manage the elements of a subscripted variable that are displayed by the Analysis tools, we have to click on either the **Subscript Control** button  or on **Windows>Subscript Control** in the menu. Simple Subscript Control (see left figure below) contains a list of the Subscript Elements for the applicable Subscript Range.

All selects everything. *None* removes all selections. *Full* opens the Elaborate Subscript Control (see right figure below) for the same Subscript Range.

Available Elements shows all the elements of the Subscript Range.

Selected Subscript Elements are highlighted.

Clicking on a Subscript Element in the Available Elements list highlights it and unhighlights everything else. The  button moves whatever is highlighted in the Available Elements list to the Selected Elements list.



We now choose to select all of the Dams. Double click on **Dams**, then click on the  button. Four Elements will move to Selected Elements. Close Subscript Control and go back to the sketch. Turn *Surface Supply [Von Bach]* into a workbench variable and click on the **Graph** button. We now have the results of four dams. The *current* simulation can be viewed below.