WATER RESOURCES SUSTAINABILITY AT SÃO MIGUEL DO ANTA COUNTY, MINAS GERAIS, BRAZIL: A SYSTEM DYNAMICS APPROACH.

SUSTENTABILIDADE DOS RECURSOS HÍDRICOS NO MUNICÍPIO DE SÃO MIGUEL DO ANTA, MINAS GERAIS, BRASIL: UM ENFOQUE EM DINÂMICA DE SISTEMAS.

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ABSTRACT

The equilibrium between agricultural activities and rational land use, economic development and water resources demand is the key factor related to biodiversity preservation and minimum environmental impact in São Miguel do Anta County, Minas Gerais State, Brazil. This work analyzes the consequences of life quality improvement of low-income rural families beneficiary of a federal financing program, and its effects on ecology, environment and water resources sustainability. A model was implemented, assessing water demand, total annual loads, originated from human and agricultural activities. Five scenarios were established, considering climate changes and irrigation practices. Results show the possibility of evaluating the consequences of public policies in economy, ecology and sustainability.

Keywords: Water Resources, Sustainability, Modeling.

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RESUMO

O equilíbrio entre as atividades agrícolas e o uso racional da terra, o desenvolvimento econômico e a demanda por recursos hídricos é o fator chave para a preservação da biodiversidade e um impacto ambiental mínimo no município de São Miguel do Anta, Minas Gerais, Brasil. Esse trabalho analisa as conseqüências das melhoras na qualidade de vida das famílias rurais de baixa renda beneficiadas por programas federais de financiação, e seus efeitos na ecologia, e na sustentabilidade do meio ambiente e dos recursos hídricos. Um modelo foi desenvolvido para estimar a demanda de água, a carga contaminante originada pela atividade antrôpica e agrícola. Cinco cenários foram estabelecidos, considerando mudanças climáticas e nas práticas na irrigação. Os resultados mostraram a possibilidade de avaliar as conseqüências das políticas públicas na econômia, na ecologia e na sustentabilidade.

Palavras-chaves: Recursos Hídricos, Sustentabilidade, Modelagem.

INTRODUCTION

Searching for water resources sustainability is an important and complex task. According to the World Commission on Environment and Development (WCED, 1987), sustainable development is a process in which the economy, the environment and the ecosystems of a certain region change in harmony and in a way that improves in time. To achieve this goal, it is necessary that the country's development plans include water resources use and management policies. The plans proposed to be applied should emphasize the key role of water resources in the socioeconomic development of the regions focused (ASCE, 1985; ENVIRONMENT CANADA, 1993, WORLD BANK, 1993).

It is considered that water will be scarce and polluted in the XXI century, with the occurrence of severe periods of floods and droughts. Thus, water resources must receive growing attention (SIMONOVIC, 2002). Brazil contains one of the biggest world's fresh water stocks, 8% of all freshwater. Approximately 80% of the freshwater spring-heads are in the Amazon region, where 5% of the population lives (FREIRE, 2001). During the last decade, problems such as shortage and contamination of water have demanded increasing attention at federal, state and municipal government, and also of the civil society.

As a consequence of the resolutions of the United Nations Conference on Environment and Development, known as Rio-92, Brazil had implemented innovative mechanisms in water resources use and management. In 1997, the Brazilian Congress regulated the water resources consumption and conservation, through Public Law 9433. This law considers water resources as a vulnerable and finite item, scarce in quantity and quality; and, due to its scarcity, with economic value (FREIRE, 2001; GESUALDI, 2001, PETRELLA, 2001). In 2000, the National Water Agency (Agência Nacional de Águas - ANA) was created with the objective of implementing the National Water Resources Policy. Under the same perspective, the Basin Committees and the Basin Management Plans were established.

This research developed a dynamic system (DS) model aiming to analyze the water resources sustainability in São Miguel do Anta County (SMAC). The SMAC is located in the micro-region of Viçosa, Zona da Mata, Minas Gerais State, Brazil. Due to the expansion of the producing area and the agro-industry activity, the implementation of the National Program to Promote Family Agriculture (Programa Nacional de Fortalecimento da Agricultura Familiar - PRONAF), and the natural population growth, the demand for water resources in SMAC is increasing. The PRONAF provides financial support to small farms, assisting agricultural activities in the region, such as coffee and bean crops, poultry and swine breeding, and horticulture. So, a growing family income has improved the life quality of farmers, which has an impact on water demand. Considering this fact and the natural population growth, it is expected a substantial increase on water demand. Programs destined to economic development, such as PRONAF, are formulated to improve, in a general sense, the social and economic conditions of low-income rural families. However, frequently they not consider the impact that its implementation will cause on natural resources.

The DS model of São Miguel do Anta water resources system (MASMA) was developed to approach a variety of water supply scenarios and its demands for SMAC. The main questions addressed were: What water volume will the SMAC need in the future? Which water supply allows the sustainability of the water resources in the county? The general objective of this research was to obtain a model that characterizes the water resources system in São Miguel do Anta County, Minas Gerais State, Brazil, using the DS principles.

MATERIAL AND METHODS

Area Characterization

São Miguel do Anta County is located in the Viçosa micro-region, Zona da Mata, Minas Gerais State, Brazil (geographic coordinates: 20°40' to 20°50' S and 42°49' to 42°38' W). The County has an area of 152 Km^2 and a population of 6,641 habitants, 50% living in rural areas.

The main water course is Casca River; which is a tributary of Doce River. This basin is located in the southeast region of Brazil; it has a drainage area of 83,000 Km^2; 86% of the area belongs to Minas Gerais State, and the rest to Espírito Santo State. The basin occupies 222 municipalities. The river is 853 Km long (IARHA, 2005).

Due to the socioeconomic development of the municipalities within the basin of the Doce River, water is over-exploited as well as contaminated. In this region, water is classified as Class 3 and 4, highly polluted (IARHA, 2005). The development has caused a negative environmental impact reflected by the precarious conditions in this basin. The native vegetal cover has been practically eliminated, causing high soil erosion and generating acceleration in the sedimentation process of the river channel. Besides, domestic usage, agro-industrial, cattle and the diverting of effluents have also generated negative impacts on Doce River water quality.

The main economic activities in SMAC are agricultural. Among crops are coffee, corn, bean, sugarcane, rice, fruits and vegetables; and among animal breeding, cattle, poultry and swine. The County has a basic power network and potable water distribution and sewer system.

The Systemic Concept

In this research the systemic concept was used as a theoretical base to study the problem. The systemic methodology has a holistic approach once analyzes a problem studying the multiple relationships among the variables which represents the problem; worrying more on that, than on analyzing the variables by themselves. Searching for no static patterns and processes representations or objects. According to SIMONOVIC (2000), the systemic concern has a basic presumption; the dynamic behavior of a problem is represented and reproduced by its own structure.

São Miguel do Anta County Water Resources System Modeling

The MASMA model was developed using the software STELLA 8.0 for windows (STELLA, 2001), according to DS principles. Thus, three stages were completed: conceptualization, mathematical formulation and simulation.

a) Conceptualization Stage

During this stage, it was necessary study and understand the different elements that define the area and how they interact. Initially was necessary to identify the elements that determines the SMAC water resources system structure, producing the causal diagram at the end of this stage.

b) Mathematical Formulation Stage

The starting point was the elaboration of the stock and flow diagram. After that, the equations that define the SMAC water resources system were defined. The MASMA causal diagram enables the stock and flow diagram design which describes, in details, the system operation (fig. 1).

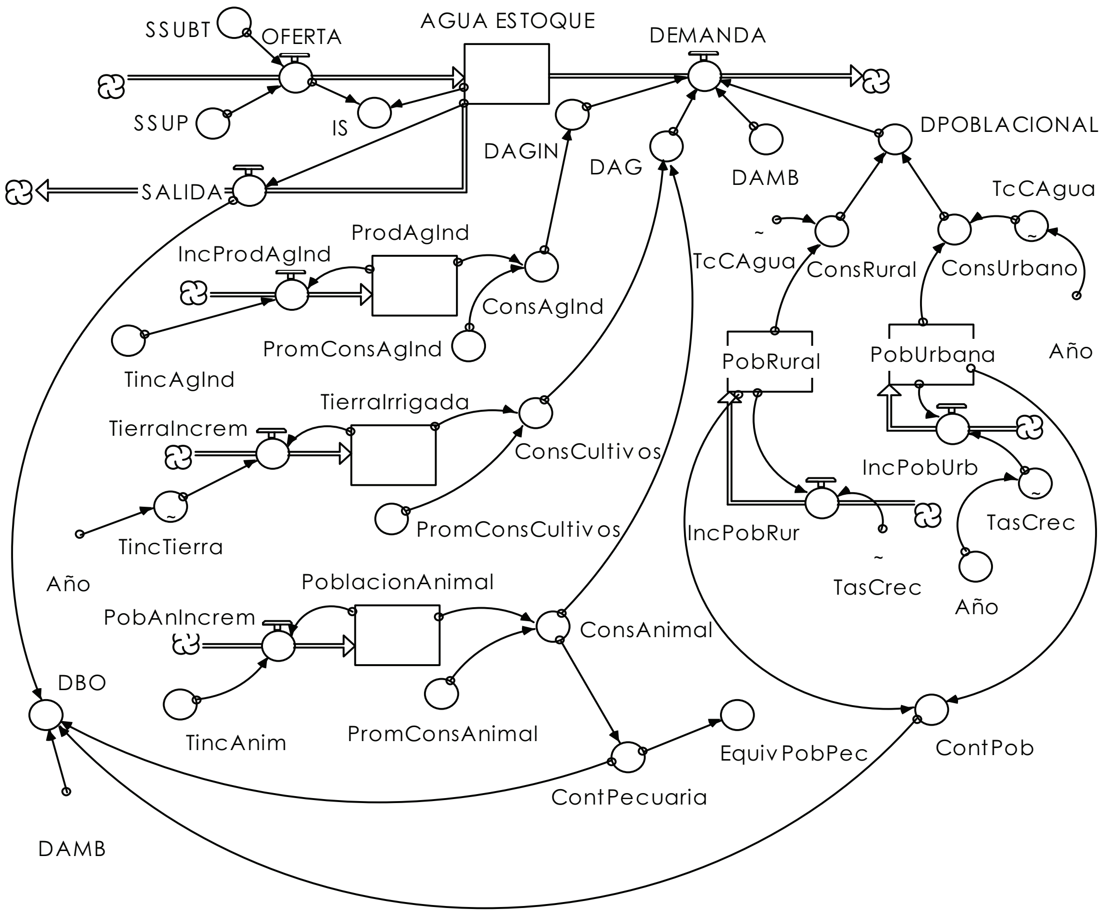

FIGURA 1. Stock and Flow Diagram for São Miguel do Anta County Water Resources System.

b.1) Mathematical Description of MASMA.

Dynamic Simulation models were done using differential equations mathematically solved by a time dependent algorithm.

b.2) Water Demand Estimation. Equation (1) shows the relationship among the variables used to describe MASMA.

D = DAGIN + DPOBLACIONAL + DAG + DAMB (1)

where D is the total volume of demanded water; DAGIN is the demanded water in the agro-industrial sector; DPOBACIONAL includes both, urban and rural demanded water for domestic consumption; DAG is water demand for agriculture; and DAMB is the environmental water demand. All of them in cubic meters.

The water demanded in the agro-industrial sector was not included due to the lack of data. The variable was incorporated within the model just waiting for available data in the future.

b.3) Available water supply estimate. The total available water supply is expressed by the following equation (2), as a mass balance

S = SSUP + SSUBT + SRET (2)

where S is the total available water supply; SSUP is the surface available water supply; SSUBT is the available groundwater supply; and, SRET is the return available water supply. Units are cubic meters.

b.3.1) Surface water. The potential surface water resources were estimated through Casca River hydrometric historical data. For this study, it was considered the average flow registered for a time series of 50 years (TEIXEIRA SOUZA, 1993).

b.3.2) Groundwater. The groundwater availability was estimated considering that five percent of the total annual rainfall infiltrates deeply in the aquifer. The total rainfall information, available and reliable, was obtained from Viçosa weather stations (DNM, 1992). These data were used to estimate the annual available groundwater volume.

b.4) Water resources system evaluation. To evaluate the water resources system operation, criteria such as dependability, vulnerability and recovery capacity, were considered (JINNO et al., 1995; XU et al, 1998). During this research, a sustainability index (SI) was used (XU, et al., 2002). SI is defined as the relationship between a possible water deficit and the corresponding supply in a certain region. SI can be mathematically described as:

$$SI = \begin{cases} (S-D)/S & S \rangle D \\ 0 & S \leq D \end{cases} \quad (3)$$

where D is the water demand, and S is the available water supply. If the value of SI is greater than 0.2, it indicates a low or no stress of water supply, which implies that water demand is less than or equal to 80% of the potencial water supply, whereas those smaller than 0.2 reflect vulnerable conditions, i.e., water demand is greater than 80% of the potencial water supply. SI=0 indicates an unsustainable water supply, i.e., water demand already equals or exceeds all available local water resources.

b.5) Water Quality. To analyze water quality, it was only considered the Biochemical Oxygen Demand (BOD) generated by the human population and by poultry, swine and cattle herds. The contamination generated by agriculture could not be included due to the lack of data.

Human contamination load represents the individual contribution per unit of time, and is usually expressed as the contamination mass generated by an individual in a unit of time. It is considered that a person generates, as a mean value, an organic contamination equal to 54 g hab^{-1} d^{-1} (VON SPERLING, 1996).

Regarding wastewater monitoring, the population equivalent is an important parameter to characterize agricultural and industrial waste. It refers to the amount of oxygen demanded for the biodegradation of the contamination generated by those activities; it is the same average oxygen demanded by the wastewater produced by a person in one day (VON SPERLING, 1996). For practical calculations, it is assumed an oxygen demand of 54 g hab^{-1} d^{-1} per person.

c) Simulation Stage. This stage involves the use of the model developed during this research to answer the questions that were raised. In Results and Discussion is presented the simulation stage.

RESULTS AND DISCUSSION

The simulation provided the amount of water required by each segment, and the available water supply. Using the available data obtained in 1996, water demand was simulated to the period comprised between 1996 and 2004. Thereafter MASMA was calibrated, showing satisfactory results.

To determine the dimensional consistency of MASMA the following equivalence was verified:

Water Offer = Water Demand + Water leaving the system (4)

As the behavior of the model was reliable, the model was calibrated. The validation process emphasizes on prediction patterns, more than on precise results, especially when a model is designed to foresee the long term behavior of a certain system under study (BARLAS, 1996).

The results obtained from the MASMA calibration, through certain known parameters, for the period 1996 - 2004, were satisfactory. No model can be 100% validated, because some included variables cannot be quantified; and also, some suppositions are made (by the model) to maintain the behavior of the key parameters, although sometimes are different from reality.

Simulation Stage: application of the dynamic simulation model.

The simulation process was done by analyzing five supply and demand scenarios (Table 1), and considering the following specifications:

· Time horizon: consist of 32 simulations. Each time increment for the differential equations defining the model was characterized by one unit per year, producing a time horizon of 32 years;

· Time step selected equal to one year; and

· Integration method: differential equations were used to describe the complex relationship in the dynamics system. These equations were solved through Euler's method, which is the most frequently used and characterized by the adoption of a constant flow during each time step (STELLA, 2001).

TABLE 1. Proposed and evaluated scenarios using MASMA.

Scenario	Class	Description
1	BaU	Business-as-Usual
2	Climatic change	Water offer reduced by 10%
3	Climatic change	Water offer reduced by 20%
4	Irrigated area incremented	50% of agricultural land is irrigated
5	Integrated scenario	Combine scenarios 3 & 4

The effect of adding financial resources from PRONAF was demonstrated through the increase of the productive activities in SMAC in the last five years. This is reflected in the agricultural sector production data, and it has been used to estimate crop water requirements and its future tendencies.

Scenario 1, Business-as-Usual (BaU), means that the current tendencies of growth, consumption, and water supply are stable. Scenario 2 considers 10% reduction of water supply due to climatic changes, without variations in all other variables. Scenario 3 considers 20% water supply reduction due to climate change. Scenario 4 considers that 50% of the total available land under cultivation is irrigated. Scenario 5 combines scenarios 3 and 4.

Scenarios Results

The obtained results were analyzed in two ways. First the results from scenario 1, BaU, were presented in a detailed manner; and then the obtained results for SI were presented for the five studied scenarios.

The BaU scenario simulation did not consider any parameters variation in the model; so, it maintains the current tendencies. This can be used as a basis for future studies. The parameters in BaU scenario reflected the tendencies of long term economic growth in

SMAC, Minas Gerais State (Table 2).

TABLE 2. Business as Usual (BaU) scenario main parameters.

Main Parameters/Year	2003-2011	2011-2019	2019-2027	2027-2035
Population growth rate (%)	1.32	1.32 - 1.11	1.11 - 0.9	0.9
Human water demand (L $hab^{-1}d^{-1}$):				
Urban	137.6	137.6	137.6	137.6
Rural	100.0	100.0	100.0	100.0
Reclaimed agricultural land (%)	0.6	0.6	0.6	0.4
Crop water requirements (1000 m^3 ha^{-1})	5 – 6	5 – 6	5 – 6	5 – 6

Considering water demand for environment, agriculture and population, one can observe that, as a percentage, agricultural water requirements will be 13% in 2011, 15% in 2019, 17% in 2027, and 20% in 2035. The population's demand corresponds to 0.9% in 2011 and in 2019; 0.95% in 2027; and 1% in 2035. The environmental water demand was considered constant, being 33.5 million m^3 per year (MMC $year^{-1}$). This is the minimum flow in the river channel necessary to maintain the ecosystems alive, representing 86% of the water demand in 2011; 84% in 2019; 82% in 2027; and, 79% in 2035.

It is important to point out that water demands will gradually increase, due to agro-industry and urbanization. In a similar way, the agricultural activity will increase water requirements because of the expansion of irrigated area and breed animals.

Considering the estimated water requirements, most of the water goes to agricultural activities. These results show agriculture as the main economic activity in the county. The main cultivated crops regarding area, productivity and water consumption are coffee, corn and bean. Agricultural activities such as cattle, poultry, and swine breeding are also important. Cattle's breeding is the most active sector in agriculture, growing at a rate of 5% yearly.

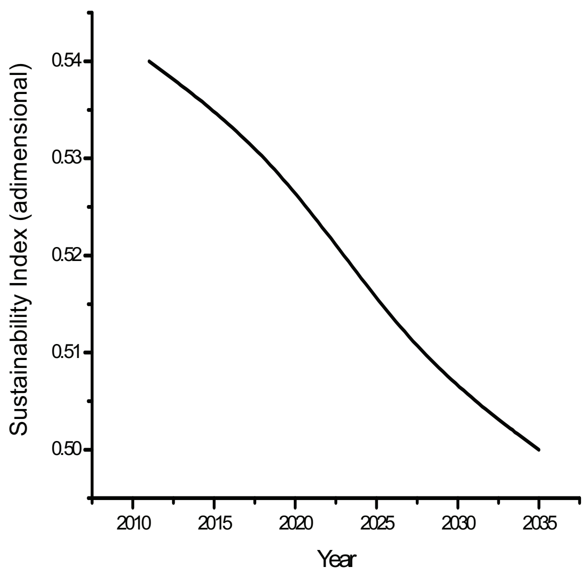

FIGURA. 2. Sustainability Index estimated for the 2003-2035 period.

Figure 2 shows the Sustainability Index (SI) behavior along the studied time horizon. As previously discussed, SI greater than 0.2 indicates low or no water supply stress, and so water demand is smaller or similar to 80% of the potential water supply. SI value, smaller than 0.2, represents a vulnerable condition, and water demand is greater than 80% of the potential water supply. The estimated SI of 0.54 in 2011; 0.53 in 2019; 0.51 in 2027; and 0.49 in 2035 indicates that an average 50% of the available water is going to be used. Thus, the system is being exploited in a sustainable way.

Table 3 shows the BOD load diverted projected for the period 2003 – 2035 in Casca River. For comparative purposes, it is important to remember that domestic wastewater has a BOD mean value of 300 mg L^{-1} (VON SPERLING, 1996).

TABLE 3. Human and animal daily loads.

Daily Loads/Year	2011	2019	2027	2035
Human Origin Load (BOD in kg day^{-1})	411	440	472	505
Animal Origin Load (BOD in kg day^{-1})	4 683	6 919	10 222	15 103
BOD (mg $L^{-1}day^{-1}$) diverted into the river	0.11	0.17	0.25	0.38

Data allows to infer that in 2011, 2019, 2027 and 2035 the contamination generated by the cattle herds will be equivalent to the produced by 86,719; 128,123; 189,300 and 280,000 people, respectively. These results indicate that water quality is being seriously compromised by this activity, increasing three folds the BOD load in the river. Cattle breeding is responsible for more than 90% of the pollution spilled into the SMAC's water body.

Water Resources Sustainability Evaluation

The obtained SI were analyzed (Table 4) in order to achieve an objective way to compare the impact of each scenario on water availability in SMAC.

TABLE 4. Sustainability Index (SI) estimated for the five scenarios studied.

Scenario / Year	2011	2019	2027	2035
1	0.54	0.53	0.51	0.50
2	0.48	0.47	0.46	0.44
3	0.42	0.41	0.39	0.36
4	0.47	0.46	0.44	0.42
5	0.34	0.32	0.30	0.27

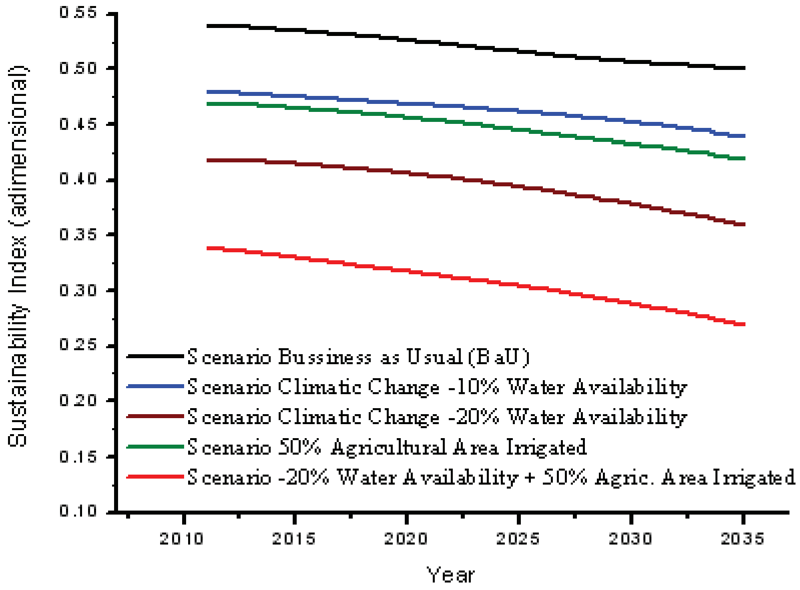

FIGURA. 3. Sustainability Index estimated for the five scenarios studied, 2003-2035 period.

One can observe, in Table 4 and Fig. 3, that there it was no stress situation neither over-exploitation in the SMAC water resources system, for the first scenario, during the studied period. There is a margin of approximately 30% in water resources availability to permit the increase in agricultural and/or agro-industrial water demand. Regarding the second scenario, estimated available water at year 2035 is 56%, which means that 24% of the water volume is still available without affecting its sustainability. The third scenario produces a reduction in water availability up to 16% when compared to the first scenario; and water availability decreases to a half, affecting significantly the volume of available water. The fourth scenario considers 50% of the agricultural areas as irrigated, showing that this dynamic sector causes significant effects on water availability in SMAC. Therefore, policies intending to improve agriculture must consider the environmental effect of animal breeding and also environmental technologies to preserve water availability at SMAC. Regarding SI, one could note that water availability decreases near 10% in the first scenario, because approximately 60% of the available water is being used. Finally, the fifth scenario presented the lowest SI, closer to 0.2, indicating a stressed or vulnerable water resources system.

CONCLUSIONS

In order to evaluate the sustainability of water resources in the SMAC, five scenarios were examined to understand future increases in water demand, restrictions, and water. Neither stress nor over-exploitation situation was detected in the current water resources system demand tendencies, analyzed through SI. Actually, water is considered highly contaminated, but the pollution will increase as population and economic activities grow, if new policies will not be implemented. The results showed that actual animal and human daily loads are equivalent to a population of approximately 66,000 people, but in 2035 it will grow up to an equivalent of almost 300,000 people, under BaU scenario.

The agricultural sector is the most important economic activity in the SMAC. The water demand by this sector is greater than all the rest; thus, policies to stimulate agricultural activities must be carefully studied, since they will have an important impact on water demand in SMAC. Professionals must be careful regarding decisions related to the agricultural sector.

The first four scenarios presented similar tendencies; the fifth scenario presented a quite different and extreme, but possible, situation. This research can be used as a starting point for future studies on water resources availability at SMAC. The paper presents an innovation in Brazil, once the dynamic systems methodology was applied for the first time for water resources studies. The relationship among the different variables studied on this research, such as population growth, economic and productive sectors, financing entities, ecological and environmental requirements, and developmental policies, can be simulate to pursue a better understanding of the whole system and allow decisions that would guarantee the sustainability of the human population and the environment.

ACKNOWLEDGEMENTS

This study is part of Alba Maria Guadalupe Orellana González's M.Sc in Applied Economics dissertation at Universidade Federal de Viçosa, under the advice Prof. Aziz Galvão da Silva Jr.

REFERENCES

AMERICAN SOCIETY OF CIVIL ENGINEERS (ASCE). *Federal policies in water resources planning.* New York,: ASCE, 1985. 239p.

ARACIL, J. *Introducción a la dinámica de sistemas*. Spain: Alianza Universidad, 1986. 303p.

BARLAS, Y. Formal aspects of model validity and validation in system dynamics. *System Dynamics Review,* Hoboken, NJ,v.12, p.183-210, 1996.

BRASIL. Ministério da Agricultura e Reforma Agrária – DNM. *Normais climatológicas (1961-1990).* Brasília, 1992. 84p.

CHOW, V.T.; MAIDMENT, D.R.; MAYS, L.W. *Applied hydrology*. New York: McGraw-Hill, 1988. 588p.

ENVIRONMENT CANADA (EC). *Federal water policy*. Ottawa: Ministry of National Resources, 1993. 284p.

FREIRE, A.G. *Águas do Jequitinhonha*. Lavras, 2001. 128p. Dissertation (Masters Degree) - Universidade Federal de Lavras, M G, Brazil.

GESUALDI, F. Giù lê mani daí servize pubblici: il caso dell acqua privatizzatta. In: CIPSI. (org) *Acqua bene comune dell umanità: probleme e prospettive*. Udine, ITA: CeVI, 2001. 137p.

JINNO, K.; XU, Z.; KANAMURA, A.; TAJIRI, K. Risk assessment of water supply system during drought. *International Journal of Water Resources Management,* (on-line), v.11, n. 2, p.185-204, 1995.

MATOS, A. T. Tratamento de resíduos agroindustriais. In: ENCONTRO DE PRESERVAÇÃO DE MANANCIAIS DA ZONA DA MATA MINEIRA, 2, Viçosa, 2002. *Anais...* Viçosa, MG: UFV, 2002. p.105-157.

PETRELLA, R. Per salvare l'acqua viva. In: CIPSI. (org.*) Acqua bene comune dell umanità: probleme e prospettive.* Udine, ITA: CeVI: 2001. 137p.

SHIKLOMANOV, I. Appraisal and assessment of world water resources. *Water International* (on line) v. 25(1), p. 11-32, 2000.

SIMONOVIC, S. Tools for water management: one view of the future. *Water International*, (on-line) v. 25(1), p. 76-88, 2000.

SIMONOVIC, S. World water dynamics: global modeling of water resources. *Journal of Environmental Management* , Elsevier, v.6, p. 249-267, 2002.

SISTEMAS DE INFORMAÇÕES DE RECURSOS HÍDRICOS (IARHA). *Águas da Bacia do Rio Doce* (Mapas). Disponível em: www.hidricos.mg.gov.br . Accessed on: 15/08/2005

STELLA. *Introduction to systems thinking*. High Performance Systems: NH, 2001. 165p.

TEIXEIRA SOUZA, S. M. (Coord.) *Deflúvios superficiais no Estado de Minas Gerais*. Belo Horizonte: Hidrosistemas, 1993. 325p.

VON SPERLING, M. *Introdução à qualidade das águas e ao tratamento de esgotos*. 2.ed. Belo Horizonte: FCO 1996. 243p.

WORLD BANK (WB). *Water resources management, policy paper*. Washington, D.C.: WB, 1993. 141p.

WORLD COMMISSION ON ENVIRONMENT AND DEVELOPMENT (WCED). *Our common future.* New York: Oxford University Press, 1987. 400p.

XU, Z.X., JINNO, K., KAWAMURA, A., TAKESAKI, S., ITO, K. Performance risk analysis for Fukuoka water supply system. *Water Resources Management*, (on-line) v.12(1), p. 13-30, 1998.

XU, Z.X., JINNO, K., KAWAMURA, A., TAKESAKI, S., ITO, K. Sustainability analysis for yellow river water resources using the system dynamics approach. *Water Resources Management*, (on-line) v.16, p. 239-261, 2002.

LEGENDS

SSUBT = Groundwater
SSUP = Surface water
OFERTA = Annual Water Supply
DEMANDA = Annual Water Demand
IS = Sustainability Index
DAGIN = Agro industrial Sector Water Demand
DAG = Agricultural Sector Water Demand cola
DAMB = Environmental Water Demand
DPOBLACIONAL = Population Sector Water Demand
SALIDA = Volume of water not used in the watershed
IncProdAgInd = Agro industrial Production Annual Increment
TincAgInd = Agro industrial Production Annual Growth Rate
ProdAgInd = Agro industrial Annual Production
PromConsAgInd = Agro industrial Sector Mean Water Consumption
ConsAgInd = Agro industrial Sector Annual Water Consumption
TierraIrrigada = Total Annual Irrigated Area
TierraInc = Irrigated Area Annual Increment
TincTierra = Irrigated Area Annual Growth Rate
Año = year
PromConsCultivos = Plants Mean Water Consumption
ConsCultivos = Plants Annual Water Consumption
PoblaciónAnimal = Animal Total Population
PobAnIncrem = Animal Population Increment
TincAnimal = Animal Annual Growth Rate
PromConsAnimal = Animal Mean Water Consumption
ConsAnimal = Animal Annual Water Consumption
ContPecuaria = Animal Load (BOD)
EquivPobPec = Population Equivalent of Animal Waste Load (BOD)
ConsRural = Rural Area Human Water Consumption
ConsUrbano = Urban Area Human Water Consumption
TcCAgua = Human Water Consumption Annual Growth Rate
PobRural = Total Human Population at the Rural Area
PobUrbana = Total Human Population at the Urban Area
DBO = Human and Animal Load (BOD)
IncPobRur = Rural Area Population Increment
IncPobUrb = Urban Area Population Increment
TasCrec = Human Population Geometric Growth Rate
ContPob = Human Load (BOD)