A System Dynamics Model for the Investigation of Additional Source of Raw Water from the Reclaimed Effluent Water from a Constructed Wetland Domestic Sewage Treatment Plant in the University of Lagos, Nigeria

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Abstract
There exist a gap in the demand and supply of water supply to the University of Lagos, Nigeria (Unilag). The University mainly depends on internal boreholes and municipal supply (the Lagos State Water cooperation) as sources of water supply to the University. While a number of boreholes serve as the source of raw water to the University's water treatment plants, the municipal water is pumped directly for distribution. In addition to water shortages that do arise occasionally from these sources, the combined quantities of the internal and municipal water supply are far below the current water demand of the University. It has been established, from another study, that the quality of water from the University's constructed wetland based domestic sewage treatment plant (CWDSTP) is acceptable as source of raw water for further treatment. In this study, a System Dynamic Model is developed to examine the quantity and impact of the water reclaimed from the CWDSTP in reducing water stress in the Unilag by closing the existing gap between water demand and supply. The results obtained from the study shows that 76.2% of the University's water demand can be met as against the current 42.6% supply level. An additional 3,141m3 of raw water can be added to the available raw water sources.

Keyword: Water supply, water stress, reclaimed water reuse, supply and demand gap.

INTRODUCTION
The importance of water supply to a community cannot be over emphasized. Both humans and every living thing need water to survive. Water covers over 70% of the Earth. The conservation of water is a global issue as global water crisis deepens Fishman (2011). The University of Lagos (Unilag), Nigeria, one of the foremost Universities in Africa was established in 1962. The current population of the University is about 85,000 with no significant improvement made to the water supply system over the years. The water demand has risen from a figure of 2.48 million litres per day (mlpd) 1991 to 10.75 mlpd 2013, whereas the water supply situation has declined to 5.051 mlpd in 2013. This has led to a serious gap of about 5.70 mlpd between water supply and demand in the University (Adeniran et al, 2013). The two sources of water supply to the University (Municipal supply and internal treatment facilities are can no longer cope with the rising demand for water. There is therefore the need to find additional sources of water supply to increase the current supply level. An option yet to be taken advantage of is the reclaimed effluent from the University's Constructed Wetland Sewage Treatment Plant.

Water reuse has gained prominence in recent time and reclaimed water is an important component of water management. Reclaimed water is derived from domestic wastewater, industrial wastewater and storm runoff that have been processed or treated. The process of reclaiming water, sometimes called water recycling or water reuse, involves a highly engineered, multi-step treatment process that speeds up nature's restoration of water quality. The process provides a high-level of disinfection and reliability to ensure that only water meeting stringent requirements leaves the treatment facility Amy *et al*., (2005). The treatment of wastewater for reuse in the drinking water system of Windhoek ,Namibia was found, after a three-month trial period, to be of exceptional high quality measured by national and international water quality criteria with respect to organics, particle(turbidity) and bacterial(faecal coliform) removal (Menge, 2005). Also Adeniran (2011) reported the reuse of reclaimed domestic sewage effluent under tropical conditions for toilet flushing, flower wetting and catfish farming. Reused water is usually a constant and reliable supply, particularly with sources such as treated sewage effluent or industrial discharges. Many waters suitable for reuse are produced in large volumes, which if not used, would be merely discharged into the environment or the receiving water bodies. In addition, the reuse of wastewaters for purposes such as agricultural irrigation reduces the amount of water that needs to be extracted from environmental water sources (Gregory 2000, USEPA 1992). The use of recycled water for drinking is less common because many people are repelled by the thought of water that has been in our toilets going to our taps. But a few countries like Singapore, Australia and Namibia, and states such as California, Virginia and New Mexico are already drinking recycled water, demonstrating that reclaimed wastewater can be safe and clean, and help ease water shortages. Eighty percent (80%) of public water supply systems rely to some extent on ground water, which is a form of recycled water in the natural water cycle. Raw water from a selected source should be of sufficient quality and quantity such that it can be economically treated to produce finished water which complies with the potable water quality requirements. Factors that influence the choice of the raw water source should include reliability, treatability, environmental impact, and economics. Raw water characteristics such as microbiological quality, turbidity, pH, alkalinity, colour, Total Organic Carbon, Total Suspended Solids, iron, manganese, algal counts and temperature determines the type and extent of treatment required for a particular source of water (U.S. EPA, 1992). In the University of Lagos, Nigeria underground water sources constitute 60% of the water supply to the University, the remaining 40% comes from the municipal source which has to be paid for. The combined internal and external sources can only meet about 46.89% (5,041m3/day) of the estimated current water demand (10,750m3/day) of the University. Adeniran et al (2013) have confirmed that reclaimed effluent water from the constructed wetland is suitable for reuse as additional source of raw water for the University's water supply system.

The objective of this work is to apply System Dynamics (SD) model in the examination of water that can be reclaimed from the constructed wetland sewage treatment plant with aim of reducing the existing water stress on the campus.

MATERIALS AND METHODS

The Study area

The study area, the University of Lagos, Lagos Nigeria, is located in the South Western part of Nigeria on geographical coordinates of 6° 27' 11" North, 3° 23' 45" East and is located in the heart of Lagos metropolis and has a direct link to the Lagos lagoon. Figure 1 shows the map of the University relative to the continent of Africa.

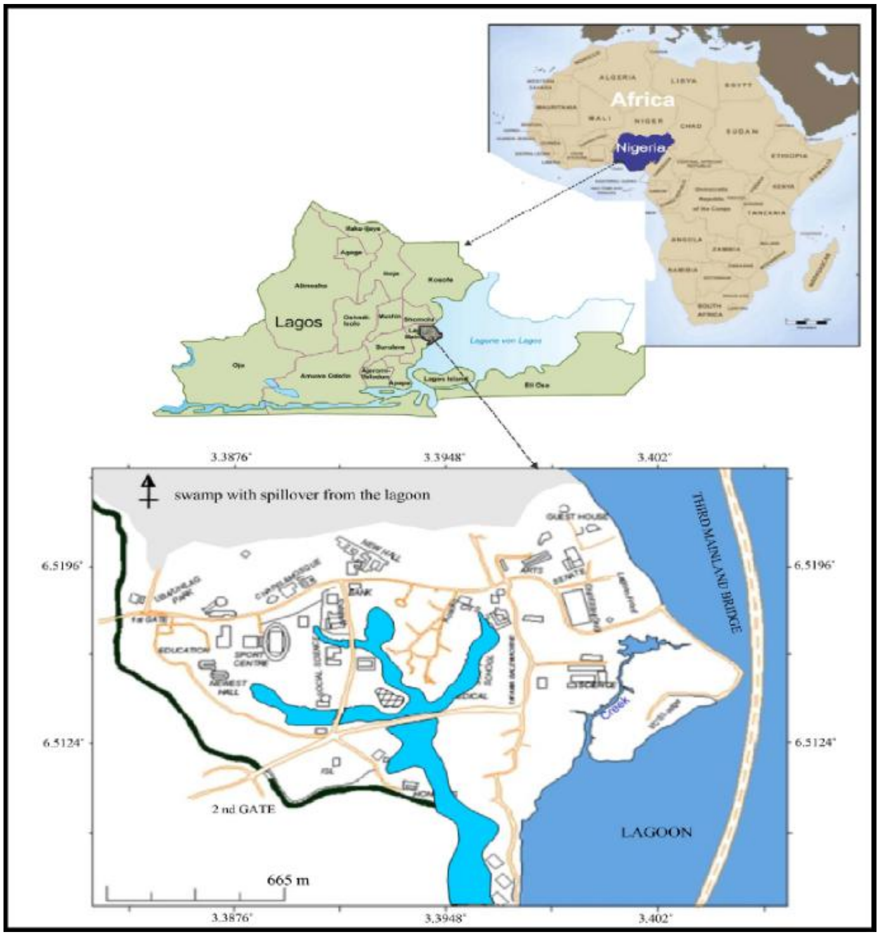

Figure 1: Map of the University of Lagos

University Of Lagos Water and Wastewater Treatment Systems

Water Supply Treatment System

The processes involved in the production and supply of water in order to (i) make it suitable for human consumption and (ii) make it available at the various end users; include a complex of physical, chemical, biological and mechanical methods Twort et al. (1994). The water treatment processing in the University involves not only purification and removal of various unwanted and harmful impurities, but also transportation with the aid of prime movers through conduits as well storage in specially designed pressure vessels and tanks. The methods adopted in processing water include (a) those aimed at improving organoleptic properties of water (clarification, decoloration, and deodorization), (b) those which ensure epidemiological safety (chlorination) and (c) those by which the mineral composition of water is conditioned (softening). The method of water processing is chosen upon preliminary examination of the composition and properties of the raw water source to be used and comparison of these data with the standard specification expected of the final processed water. A section through the Water Treatment and Supply system is shown in Figure 2.

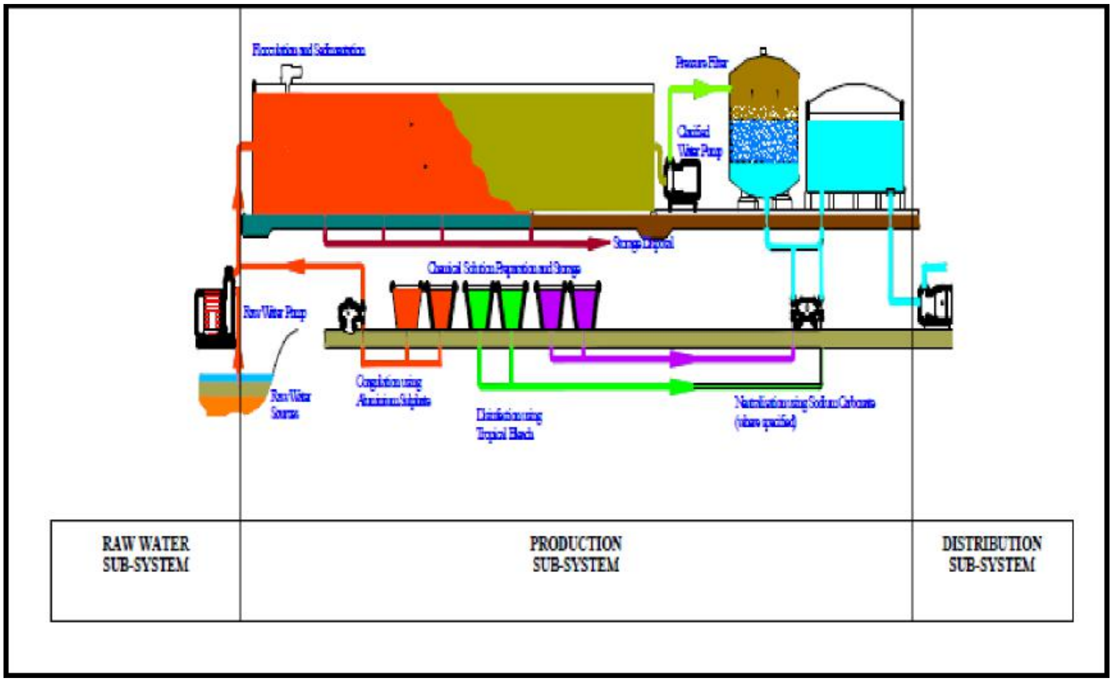

Figure 2: Section through Unilag Water Supply System.

Wastewater Treatment and Reclaim System

The wastewater generated from the distribution system is then processed through a constructed wetland based sewage treatment plant. The wastewater from the University community are conveyed in sewers ranging from 100mm to 200mm diameter from homes, hostels, offices, classrooms and laboratory to the central sewage pumping sump located at Service Area. The wastewater is pumped to and held in the oxidation ponds, which are planted with water hyacinth to prevent mosquito infestation and to increase the quality of the sewage influent to the anaerobic reactor (Septic Tank). Large particles are screened off in a primary treatment chamber containing stainless steel screen. The pretreated water is further treated under anaerobic condition in a purposely designed Septic Tank. The effluent from the Septic Tank is then channelled into the constructed wetland system through a 150mm sewer pipe. The wetland was achieved in concrete with waterproof underlay to prevent pollution to the underground water and eliminate water infiltration into ground water. The total area of the nine (9No.) constructed wetland cells is 1540m2 with an average depth of 0.65m. Water hyacinth is planted on the influent sewage cell while *cyperus papyrus* is planted on the remaining cells containing sand of average grade size 0.1mm to 0.35mm. Figure 3 is the layout of the Constructed Wetland Sewage Treatment system.

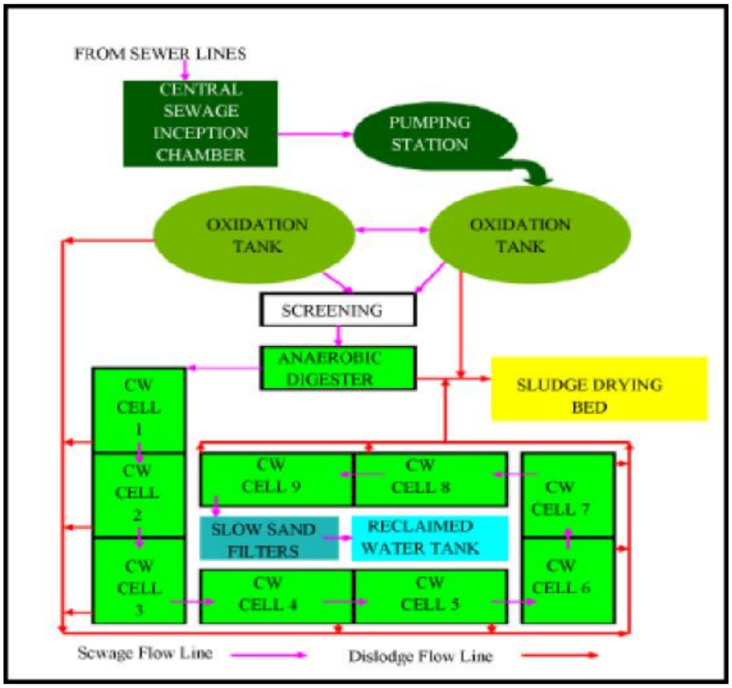

Figure 3: Layout of Unilag Constructed Wetland Sewage Treatment Plant

System Dynamics Modeling

With the complexity involved in the water supply and wastewater treatment systems, there is the need for evolving a tool that can capture the complexity of water production and wastewater treatment and effluent reclaim variables. A System Dynamics modelling technique was therefore adopted to capture the dynamics of the system.

System dynamics models are causal mathematical models (Barlas, 1996). In system dynamics modelling (SDM) the underlying premise is that the structure of a system gives rise to its observable and thus predictable behaviour (Forrester, 1968, 1987). The first step in any system dynamics modelling project is to determine the system structure consisting of positive and negative relationships between variables, feedback loops, system archetypes, and delays (Sterman, 2000; Wolstenholme, 2004). This understanding of system structure requires a focus on the system as a whole. Holistic system understanding is a necessary condition for effective learning and management of complex systems as well as consensus building. These are important goals in their own right. Additionally, systems modelling and simulation supports policy analysis and evaluation (Morecroft, 1992). System dynamics allows simple ideas to be combined into models of complex systems and processes; it makes the integration of modeling and experimentation a simple matter (Adeniran, 2013). In particular, SDM involves:

(i) Defining problems dynamically, in terms of graphs over time;
(ii) Striving for an endogenous, behavioral view of the significant dynamics of a system, a focus inward on the characteristics of a system that themselves generate or exacerbate the perceived problem;

(iii) Thinking of all concepts in the real system as continuous quantities interconnected in loops of information feedback and circular causality;

(iv) Stocks or accumulations (levels) in the system and their inflows and outflows (rates);

(v) Formulating a behavioral model capable of reproducing, by itself, the dynamics problem of concern. The model is usually a computer simulation model expressed in nonlinear equations, but is occasionally left un-quantified as a diagram capturing the stock-and-flow/causal feedback structure of the system; Deriving understandings and applicable policy insights from the resulting model; and

(vi) Implementing changes resulting from model-based understandings and insights (Richardson and Andersen, 2010).

The principles of SD are well suited for modeling and application to water resources and environmental problems (Fletcher et al., 1998, Ford 1999) and (Deaton and Winebrake, 2001). This fact is corroborated by Nirmalakhandan (2002). The behaviour in space can also be simulated using SD framework (Tangirala et al, 2003). Huang and Chang (2003) described SD as an emerging tool with great potentials for improved understanding of environmental systems. It has also been successfully deployed to model the strategic planning of the University of Ibadan water supply system (Adeniran and Bamiro, 2010).

Modeling Concept for the Water Supply and Effluent Reclaim System

A System Dynamics approach was adopted in the formulation of the simulation model. System dynamics tools allow for an intuitive approach to the modeling of dynamical systems from any field of knowledge where there exists, a feed-back situation. System Dynamics modelling can easily be deployed even by young learners (Forrester, 1992). According to Donella Meadows (1991), **"***System dynamics is a software-based technique for thinking and computer modeling that helps its practitioners begin to understand complex systems—systems such as the human body or the national economy or the earth's climate. Systems tools help us keep track of multiple interconnections; they help us see things as a whole."* System Dynamics modelling has attracted considerable attention over the past few decades. In a particular sense, System Dynamics is concerned with the use of models and modelling techniques to analyze complex systems and policy issues with a view of getting the right combination of scenarios to accomplish an efficient strategic planning for the system being modeled (Adeniran, 2013).

The concept of the model consists of interconnectivities and feed back loops between the major factors of population, water production, water distribution, wastewater production and effluent or wastewater reclaimed (Figure 4).

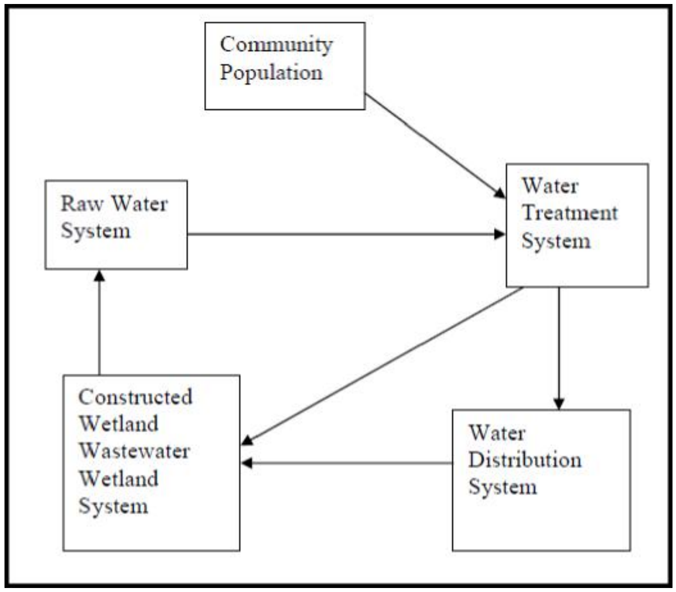

Figure 4: Concept of Water Supply and Reclaimed Water Model

Model Development

VENSIM platform was then used to capture the contributing stocks and other variables of the system (Figure 5)

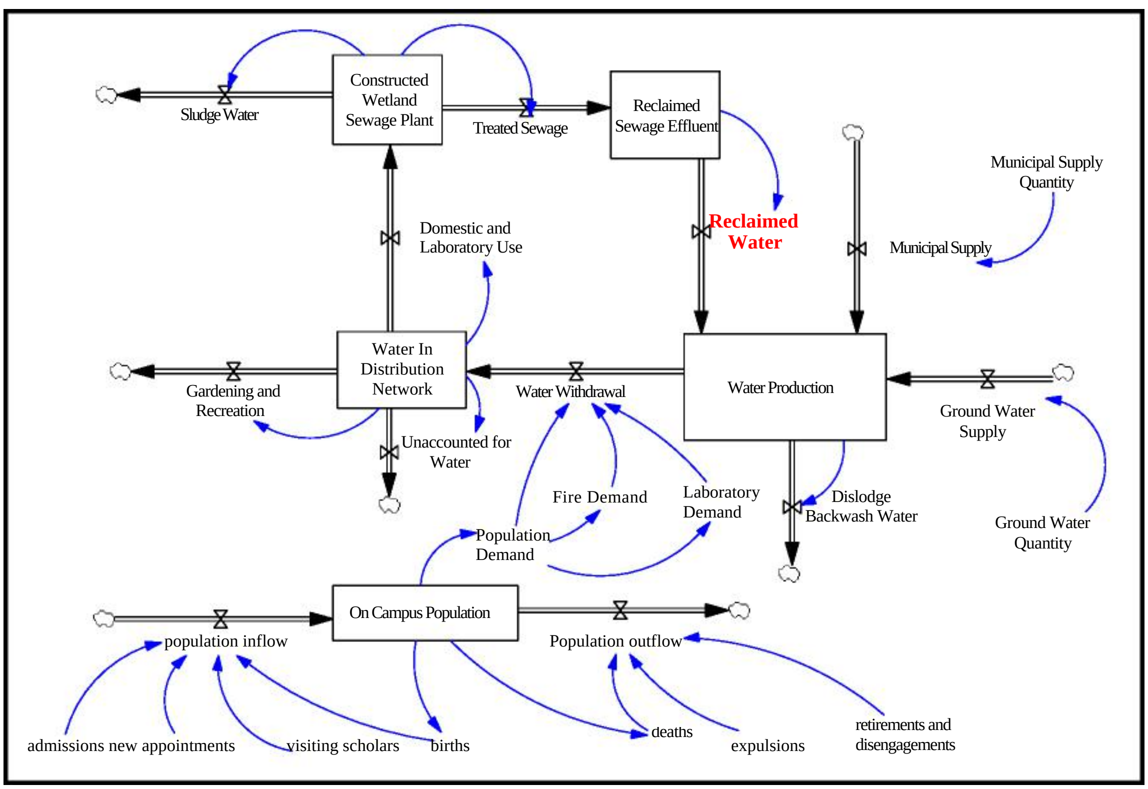

Figure 5: System Dynamics Model for the Reclaimed Water Model

APPLICATION OF THE MODEL AND RESULTS

The primary objective of the model is to investigate as to the quantity of water that can be added to the existing water supply if the reclaimed water from the constructed wetland sewage treatment plant is utilized and to examine the impact of the addition on the current water stress on the campus. The following scenarios were investigated with the model.

Scenario 1: Current situation where the reclaimed is not utilized.

Scenario 2: A situation where the reclaimed water is utilized as additional source of raw water.

The graph obtained from the VENSIM modeling platform is as shown in Figure 6. The result of the scenario simulations is also shown in Table 1.

Figure 6: Output Graph of Scenario Investigation

(Scenario 1- No Reclaim Water; Scenario 2 - 100% Reclaimed Water)

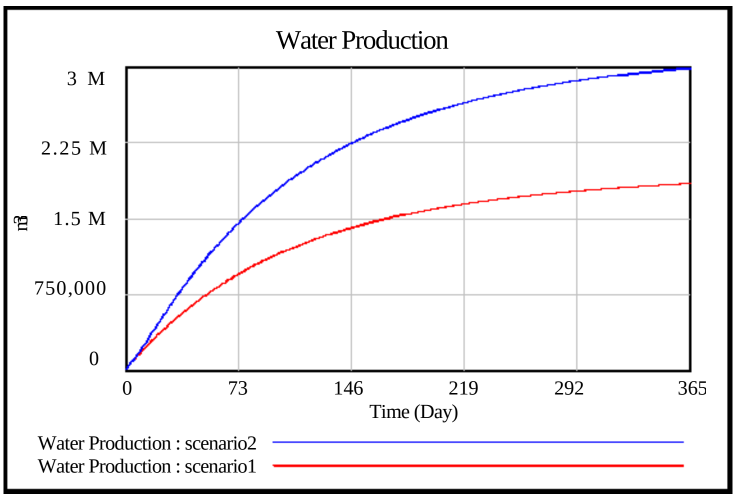

Table 1: Water Supply Availability Before and After Reclaimed Water Re-Use

Scenario	Reclaimed Water	Annual Water Production Cu.m.	Daily Water Production Cu.m.	Current Water Demand Cu.m.	% Water Availability
1	0%	1,840,000	5,051	10,750	46.89
2	100%	2,990,000	8,192	10,750	76.20

It is seen from Figure 5 and Table 1.0 that the water stress would be reduced if the effluent from the constructed wetland can be reclaimed as additional source of raw water.

CONCLUSION

A system dynamics model has been developed to integrate the water supply system with the sewage system of the University of Lagos, Nigeria. The versatility of the SD model was utilized to examine the impact that the reuse of reclaimed effluent water would have on the current water stress on the campus. It is easily seen that System Dynamics can be use to suggest alternative solutions to water resources problems. The model developed is capable of other simulation investigations including water in the distribution, population and wastewater treatment.

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