

## **System Dynamics Approach: A Novel Water Resource Management Tool**

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### **Abstract**

Urban wastewater management has become a challenge in India as infrastructural development and regulations have not kept pace with population growth and urbanization. Wastewater management needs much more attention than it has received so far due to increasing water scarcity, concerns about the effect of wastewater on receiving water. However, incorporation of management schemes into wastewater infrastructure system is a complex decision making process, involving various economical, technological, and environmental criteria. System dynamics is a policy-based methodology that evaluates the effect of policy changes on a system. The main purpose of system dynamics is to better understand the complex and dynamic systems and suggest the changes in the decision-making rules so as to improve the performance. System dynamics is fundamentally used to understand policy decisions and feedbacks. It is a decision support tool which helps to achieve sustainable water management.

**Keywords:** System dynamics; wastewater management; policy decisions; feedback.

### **1. Introduction**

India's population, which is over one billion, is now fast converging on cities in search of opportunities and a new way of life. Annually, more and more people are moving into cities, and the figures are expected to reach about 600 million by 2030 making India more peri-urban than rural. Already, there is enormous pressure on planners to provide utility services, and water supply is a priority, especially where peri-urban water is exported formally or informally to fulfill city requirements. At the same time, the urban return flow (wastewater) also increases, which is usually about 70-80% of the water supply.

According to recent projections, India's urban population of 380 million (2008) is expected to increase to 590 million by 2030, twice the current population of USA (MGI, 2010), with regional cities expanding at a faster rate than the larger cities.. Already, many cities can be now considered as 'sponges' absorbing water from peri-urban and rural areas through formal and informal channels. A large number of these growing cities are located in major river basin catchments, taking fresh water away and discharging wastewater back into the catchments with poor-quality water and pollutants above the permissible levels being released into the environment (MoEF, 2009) and thus polluting irrigation water as well as posing major challenges for urban wastewater management.

Wastewater generation across Class-I cities (498) and Class-II towns (410) has been assessed by institutions involved in water supply and sewage treatment. Estimates show that about 80% of water supplied is returned as wastewater (CPCB, 2009). With the expansion of cities over time, wastewater generation has correspondingly increased while investments in treatment capacities have varied significantly. Although several cities could show an increase in treatment capacity, the majority struggled to keep pace with urban growth as data from more than 900 Class-I cities and Class-II towns showed (Bhardwaj, 2005; CPCB, 2009). In 2007, total urban wastewater generation was around 38,000 mld which was three times the existing treatment capacity of about 12,000 mld. However, the survey also revealed that nearly 39% of the treatment systems were not performing to their capacity due to lack of connectivity to the sewage network systems, and/or other priorities and availability of funds of the respective municipalities. To meet the 2050 projected wastewater generation (estimates of 122,000 mld) for the country, its strategies for wastewater treatment will need to have clear goals and investment plans in the years to come (CPCB, 2009).

Wastewater management and treatment cannot be planned in isolation. They have to be a core part of the strategic plans for water supply (World Bank, 2004). Wastewater management needs much more attention than it has received so far. This is required from the perspectives of both health and water resources management. Water scarcity being reported from many parts of the country, planners need to have a strategy on how best to utilize the various water resources, including untreated, partially treated and fully treated wastewater, for different productive purposes.

## **2. System Dynamics Approach**

The Theory of system dynamics was created in 1956 by Prof. J.W. Forrester in Massachusetts Institute of Technology.

System dynamics is a policy-based methodology that evaluates the effect of policy changes on a system. For any system, the decisions that we make affect the behaviour of the system. System dynamics tries to find out the factors that cause the characteristic behaviour of that system. Then how the system reacts to the changes associated with these factors is observed. Based on these reactions, the changes in policy are then suggested. Thus the main purpose of system dynamics is to better understand the complex and dynamic systems and suggest the changes in the

decision-making rules so as to improve the performance. System dynamics is fundamentally used to understand policy decisions and feedbacks.

With the help of computer simulation technology, it can analyse the dynamic behaviour and predict the development tendency of the system numerically. The theory of system dynamics is based on a set of first order differential equations, which is expressed as numerical integration by Euler method in SD model.

The advantage of this method is that it simplifies the study of a complex system over time and in handling highly nonlinear, high order, multivariable and multiple feedback problems (Zhang, 2012). Its capabilities to quantitatively simulate the dynamic consequences of various policies make it an ideal decision support tool for strategic policy testing and selection (Xi and Poh, 2013).

Several system dynamics models have been developed for water resources management. A review of SD applications in water resources is done by (Winz et al, 2009). (Mirchi et al, 2012) have provided a synthesis of system dynamics tools for water management. Two notable applications of SD for water management in the South West US are (Gober et al, 2011) and (Dawadi and Ahmad, 2012) that address water management in response to climate change. Another relevant SD application is (Ahmad and Prashar, 2010) that describe a model to evaluate municipal water conservation policies in South Florida.

### 3. Methodology

The System Dynamics model takes certain steps along the time axis in the simulation process. The first step is problem articulation. The model needs to address a specific problem and should not try to model the whole complexity of a system. Therefore, the model must have a specific goal, solve a specific need, and simplify rather than attempt to emulate an entire system in detail. The clear definition of the problem also identifies the model boundaries. After that the system structure is described qualitatively by making causal loop diagrams. They present how various variables in the system affect each other. They also portray whether the relationships are positive (reinforcing) or negative (balancing). Figure 1 shows the causal loop diagram for waste water management case showing positive and negative interactions.

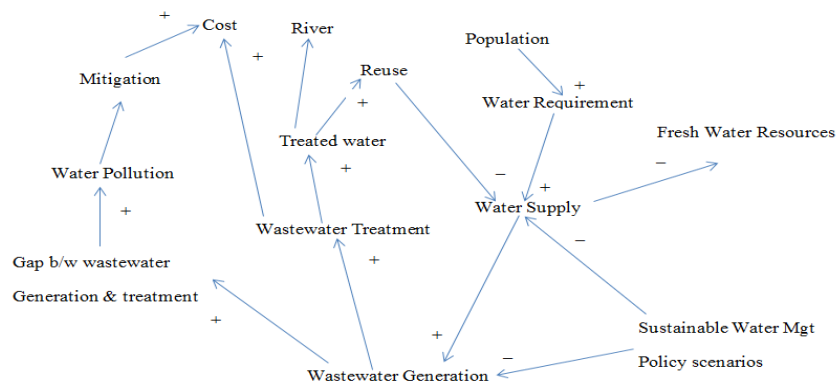
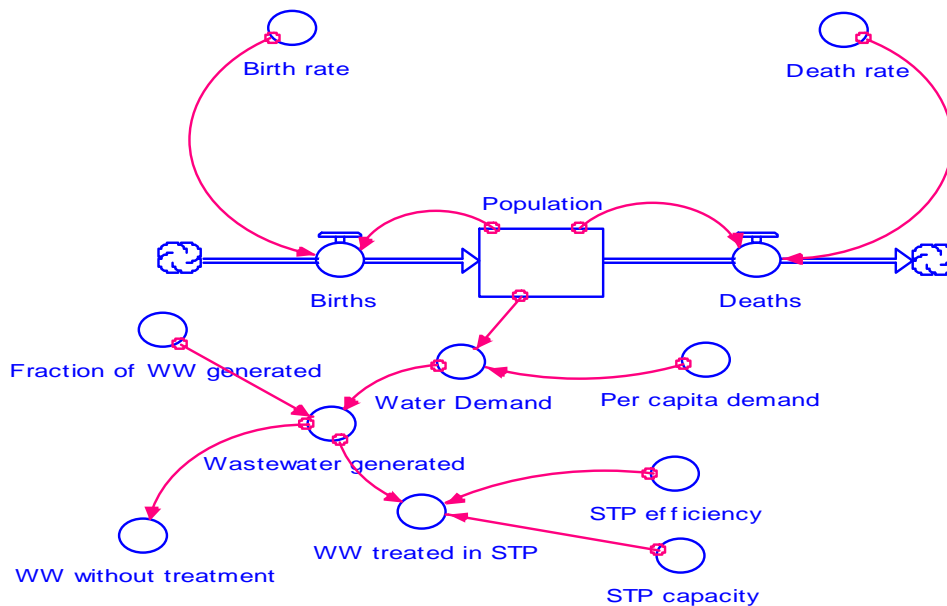


Figure1. Causal loop diagram for waste water management model

Stock and Flow models are then developed from the causal loop diagrams by adding levels and rates variables and system delays. They provide the information about the values of various variables and the rate at which those values are associated with them. They provide us with the quantitative aspects of the system. Equations and values of collected data are put in these models and simulation is done. First of all baseline scenario will be developed and then new policies and decisions can be made, and the model will run again. Better results imply improvement, and worse results indicate another attempt. At this stage, the model becomes a great learning tool and a powerful simulator for developing entirely new strategies, structures, and decision rules. Figure 2 shows model of wastewater management case. Through this model we can project the values of future and make suitable policies accordingly.



**Figure2.** Stock and Flow diagram of Wastewater management case

Validation and Sensitivity analysis is done to build confidence in the model. Verification and validation of the model is very critical to make sure that the model replicates the real world system and the outputs of the model have meaning. There are various methods through which validation can be done like historical validation, structural validation, dimensional consistency etc. Robustness of the model is determined by sensitivity analysis.

#### 4. Conclusion

System dynamic model is an excellent tool for water resource management it helps us to make projections of population growth, water demand, wastewater generation, water uses and recycle and on the basis of that we can make policy scenarios on wastewater reuse and recycle, rainwater harvesting, pricing, GDP etc. for sustainable development of water resources in conformity with the growing population.

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