IRC

THE HAGUE, THE NETHERLANDS | 12 – 14 MARCH 2019

All systems go!

System dynamics modelling as a tool for assessing rural water sustainability

Paper for the WASH systems symposium

P. Chintalapati, J. Walters, A. Javernick-Will, and K. Linden [United States]

50 years of IRC.
WASH systems that transform lives.

This paper was drafted by P. Chintalapati, J. Walters, A. Javernick-Will, and K. Linden for the All systems go! WASH systems symposium, The Hague, The Netherlands, 12-14 March 2019.

Cite this publication as follows. P. Chintalapati, J. Walters, A. Javernick-Will, and K. Linden. [United States]. 2019. System dynamics modelling as a tool for assessing rural water sustainability

For all proceedings of the All systems go! WASH systems symposium, please check https://www.ircwash.org/proceedings

The local systems influencing rural water service delivery are inherently complex, consisting of a variety of interconnected factors with non-linear and disproportional influence on each other. The unpredictable nature of such systems requires the use of specialized tools to understand how they function and the underlying leverage points through which improvements to performance can be achieved. System dynamics modelling is a tool that has been used for decades in business management and economics applications, but little focus has been applied to the WASH sector. Specifically, this paper discusses the use of causal loop diagrams and stock flow diagrams as methods to better understand the systemic drivers affecting sustainability of rural water service delivery.

Introduction

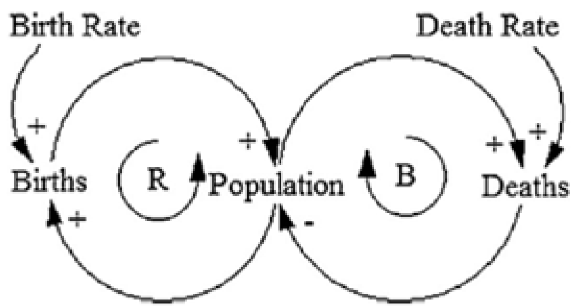
The sustainability of rural water service delivery is a function of a variety of interacting factors, such as government support, capacity of community water committees, maintenance provision, financial resources, and community willingness and ability to pay. The interactions of these factors can be complex, having non-linear or disproportional effects on each other. The delivery of rural water services can therefore be characterized as an interconnected, dynamic and complex system. Complex systems are inherently unpredictable by nature because of the constant change that takes place in their contexts; hindsight is not always a reliable precursor to foresight, and adaptation is required. In complex systems, simple cause-and-effect relationships are not easily discernible, and best-practice approaches may not be effective under such dynamic conditions (Snowden and Boone, 2007). The study of system dynamics seeks to understand the behaviour of complex systems over time. System dynamics modelling methods, such as causal loop diagrams and stock flow diagrams, can be used to illustrate the structure of interacting factors within a complex system. System dynamics modelling has been applied for decades in business management, economics and agriculture, but to date, little focus has been on applications in the WASH sector. This paper describes system dynamics modelling methods and their potential as tools to assess the sustainability of rural water service delivery.

System dynamics modelling methods

Causal loop diagrams

A fundamental component in system dynamics modelling is the identification of feedback processes within the system. Unlike linear causality, where a process is seen as a series of events where outcomes do not affect initiating factors, feedback is a representation of circular causality where cause-and-effect relationships form loops. The nature of the relationships between interacting factors can produce either positive or negative feedback, observed as reinforcing loops or balancing loops, respectively. The various connections between these factors are drawn to form a causal loop diagram, in which arrows signify the direction of effect, and +/– signs demonstrate polarity (+ indicates that more of A leads to more of B; – indicates that more of A leads to less of B). Figure 1 shows an example of reinforcing and balancing loops with polarity using the interacting factors of births, deaths, and population.

FIGURE 1. EXAMPLE CAUSAL LOOP DIAGRAM SHOWING REINFORCING AND BALANCING LOOPS



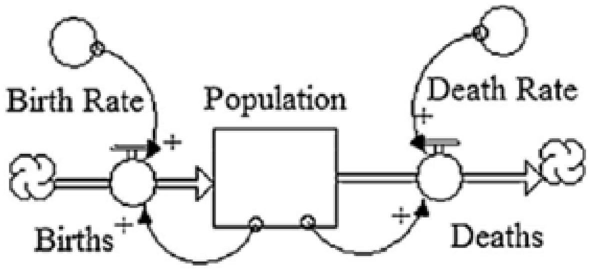
Source: (Walters et al., 2016)

To apply this technique to the rural water sector, interviews, discussions, and factor mapping workshops are necessary to develop a list of the interconnected factors within the system, as well its underlying structure. Drafted causal loop diagrams are then presented to and critiqued by stakeholders knowledgeable with the sector and system. An iterative, collaborative approach is necessary to yield an agreed-upon, representative diagram. Nevertheless, the feedback loops and polarity designated by causal loop diagrams can only hypothesize the behaviour of the system. Figure 2 is an example causal loop diagram for a rural water system. It shows how factors related to financing, maintenance, and institutional coordination all affect water point functionality, and ultimately water access and use. In this example, increased investments by government and donors enable the installation of new infrastructure, as well as the repair of existing infrastructure, both contributing water access through different paths: the former through reduction in distance to water points, and the latter through increased water point functionality. Funding for mechanics training programs increases the number of available mechanics to conduct preventative routine maintenance, improving water point functionality. Water usage creates a revenue stream for water committees through tariffs, providing a source of income that can fund maintenance services; however, usage also creates operating and maintenance costs, resulting in a balancing loop.

Stock flow diagrams

Whereas causal loop diagrams can qualitatively represent the behaviour of a system by displaying the causal relationships of interacting factors, a different tool is necessary to build off these diagrams and apply data to quantitatively model the system: stock flow diagrams, in which stocks represent components of a system that can accumulate. Stocks can be tangible (like water in a tank, people in a town, or money in a bank account) or intangible (like happiness, knowledge, or confidence) but in either case must be somehow measurable at a given point in time. In the case of intangible stocks, rankings or scales can be used to apply metrics to the model. Flows are events or activities that cause stocks to change over time and can metaphorically (and often literally) be thought of as verbs to the nouns of stocks (Richmond, 2003). Examples of flows are depositing or withdrawing money from a bank account, filling or draining a bathtub, and learning or forgetting information. External factors, whether as stocks or flows, can affect how flows change stocks, and are often linked to each other either directly, or through the use of converters. Converters are operators used to mathematically link the effects of factors to each other and help maintain unit consistency across different types of factors. For example, water point functionality, defined as a ratio of time (e.g., average functional days per month), affects a water committee's flow of income from water sales through a convertor that multiplies the number of functional days by the volume of water sales and the tariff per specified volume. Convertors can also be applied as independent factors, specified with constant values, that directly affect a flow. Figure 3 shows the births, deaths, and population example in a stock flow diagram, with birth rate and death rate as convertors.

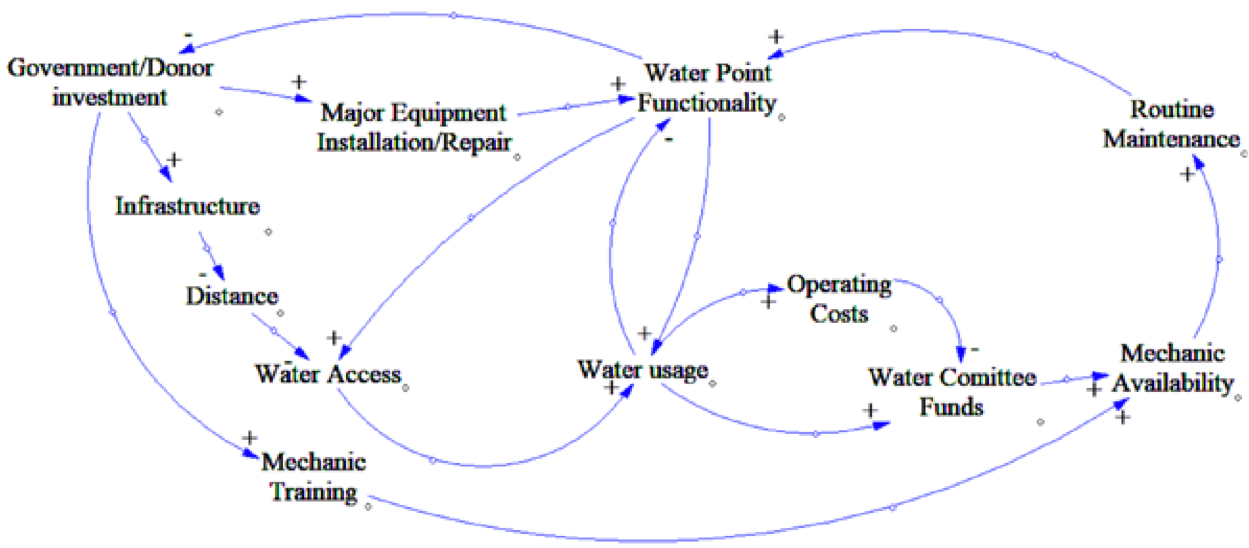
FIGURE 3. EXAMPLE STOCK FLOW DIAGRAM



Source: (Walters et al., 2016)

Figure 4 shows a simple example of how stock flow diagrams can be applied to model groundwater use in a rural community. Pumping rates are dictated by population statistics and collection frequency. Dotted convertors signify data being pulled from other stock flow models. Pumping is also dictated by pump functionality, based on the availability of financial resources, equipment, and maintenance. Figure 5 shows that water usage and sales enable an influx of water committee funds, which can be used to provide maintenance through the procurement of equipment and mechanic services. The expenditure is a function of the breakdown rates of different water

FIGURE 2. EXAMPLE CAUSAL LOOP DIAGRAM OF RURAL WATER SYSTEM



point components and their corresponding costs, along with the necessary time to conduct repairs on the various components and hourly wage of the mechanic. This example is provided for illustrative purposes and is meant to demonstrate how system dynamics modelling can be used in the rural water sector. Model structure and influences of factors must be determined by thorough information gathering and data collection for each system.

Anticipated applications

System dynamics modelling using causal loop diagrams and stock flow diagrams can be applied as a tool to better understand rural water systems and assess how interventions affect sustainability of rural water supply. The USAID Sustainable WASH Systems Learning Partnership is currently investigating how preventative maintenance models can improve the reliability of rural water service

FIGURE 4. EXAMPLE STOCK FLOW MODEL OF GROUNDWATER USE IN A RURAL COMMUNITY

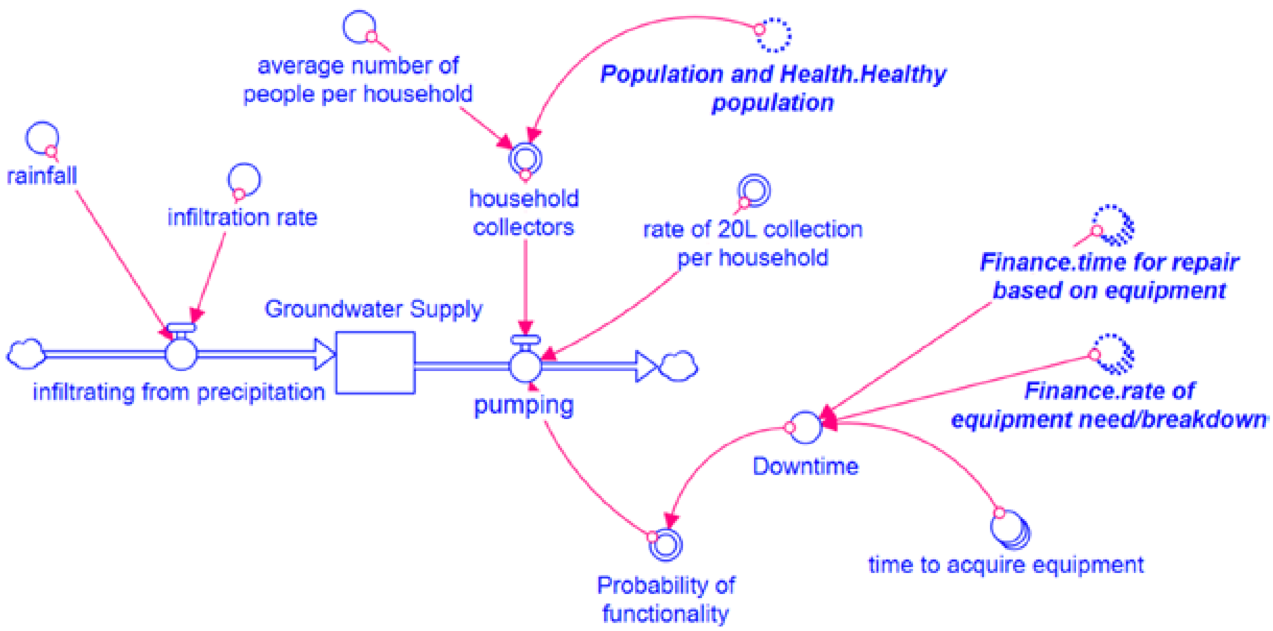
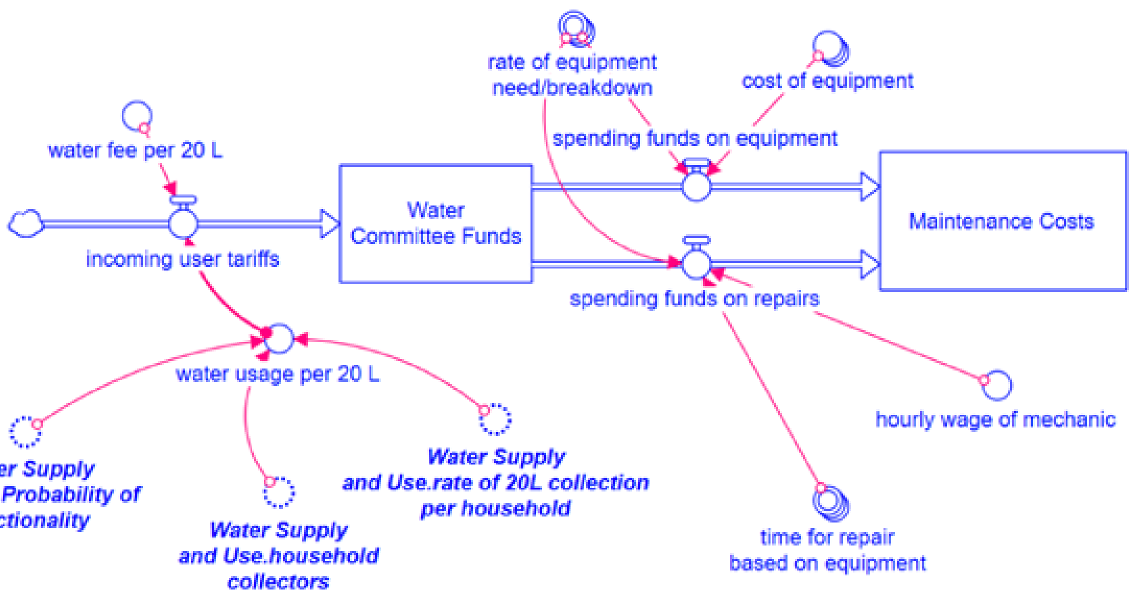


FIGURE 5. EXAMPLE STOCK FLOW MODEL OF FINANCES FOR RURAL WATER SUPPLY



delivery. By working with partner organizations in Kenya, Ethiopia, and Uganda, we are collecting data on the structures of different rural water systems in each context and the interacting factors within them. WASH forums, focus group discussions, factor mapping workshops, social network analyses, and stakeholder interviews have all been used to collect data. This information is being used to develop causal loop diagrams and stock flow models using software such as VenSIM and Stella Architect. The purpose of the analysis is to model both the baseline conditions of the systems and the intervention cases where preventative maintenance is being applied, in order to understand the effect on different sustainability metrics, such as financial viability of service delivery. Furthermore, sensitivity analyses will be conducted to understand how varying different model components affects the sustainability of service delivery. The goal is not just to compare maintenance delivery models across different contexts, but also to identify the leverage points where change can significantly improve the performance and reliability of rural water services.

References

- Richmond, B. 2003. An Introduction to Systems Thinking. High Performance Systems, Inc.
- Snowden, D.J. and Boone, M.E. 2007. A Leader's Framework for Decision Making. Harv. Bus. Rev.
- Walters, J.P., Archer, D.W., Sassenrath, G.F., Hendrickson, J.R., Hanson, J.D., Halloran, J.M., Vadas, P. and Alarcon, V.J. 2016. Exploring agricultural production systems and their fundamental components with system dynamics modelling. Ecol. Modell. 333:51–65. https://doi.org/10.1016/j.ecolmodel.2016.04.015

Keywords

system dynamic modelling, causal loop diagram, stock flow diagram, rural water services, sustainability

Contact details

Pranav Chintalapati
Department of Environmental Engineering
University of Colorado
4001 Discovery Dr, Boulder, CO 80303
Tel: +17202458791
Email: pranav.chintalapati@colorado.edu

50 years of IRC.
WASH systems that transform lives.