Management of wastewater using septic systems, Social marketing and community engagement,

Modeling strategies to increase resource recovery system adoption

Increasing the adoption of wastewater-based resource recovery systems: Using a community-informed system dynamics model to determine effective strategies

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Presenter*

Christine Prouty is a doctoral candidate and graduate research assistant pursuing her Ph.D. in environmental engineering at the University of South Florida (USF), Tampa. Her research interests include interdisciplinary work investigating the complex interactions between human, engineered, and environmental systems, the benefits of stakeholder involvement at all phases of the a project's life cycle, the water-energy-food-systems nexus, the environmental impacts of tourism development, and the appropriate context into which wastewater-based resource recovery systems should be installed. Christine's dissertation research and various academic activities have provided her the opportunity to work with communities, universities, and NGOs in Barbados and Belize. Her undergraduate degree is also in environmental engineering and was earned at Louisiana State University in 2009.

1.0 INTRODUCTION

Wastewater-based resource recovery systems provide a paradigm shift from the traditional "take, make, waste" style of resource management to another perspective that capitalizes on wastewater's ability to generate energy, reuse water, and recycle nutrients. The adoption and success of these systems is important because they (1) provide alternatives to traditional wastewater treatment that is energy- and resource-intensive (CSS, 2009; Daigger, 2009; Oh et al., 2010), (2) ease the impacts of water scarcity and diminishing water quality, and (3) reduce the pressures to natural resources that are exacerbated by global climate change and population growth (Marsalek, 2011; Thoren et al., 2012). Resource recovery technologies allow households and/or municipalities to mitigate environmental impacts and potentially generate economic profits while still protecting human health (Marsalek, 2011). However, prevalent adoption of these systems worldwide has yet to be seen (Walker et al., 2012). The adoption of resource recovery systems in vulnerable coastal areas is particularly important because their successful implementation could mitigate the environmental consequences of insufficient wastewater treatment due to rapid population growth and unrestricted infrastructure development that often plagues these locations (Wells et al., 2016).

Figure 1 shows a map of the coastal community considered in this study—Placencia, Belize. This area exists as one of the research sites where an interdisciplinary team from the University of South Florida has been working since 2013 on the National Science Foundation's (NSF) Partners in International Research and Education (PIRE) grant entitled "Context Sensitive Resource Recovery Systems." On the peninsula, the primary form of wastewater treatment is two- or three-chambered concrete septic tanks (Halcrow, 2012; Wells et al., 2016). The high permeability of the area's sandy soils potentially inhibits some of the treatment performed by in subsurface portion of traditional systems. Additionally, a lack of routine maintenance to the septic systems results in un- or minimally-treated wastewater, likely rich in nutrients, being discharged into local groundwater or surface water sources reducing the quality (Halcrow, 2012; Wells et al., 2016). Consequently, this research applies the system dynamics approach to consider factors that impact the adoption of decentralized resource recovery systems because these systems may help to mitigate the environmental consequences of development and improve the resilience of this coastal community. Overall, the is to understand the interactions and relationships between factors that influence adoption and success of wastewater-based resource recovery technologies in order to provide decision-makers with a tool that simulates system-level responses to technology implementation strategies and identifies strategies that will improve the adoption of geographically and culturally appropriate resource recovery systems.

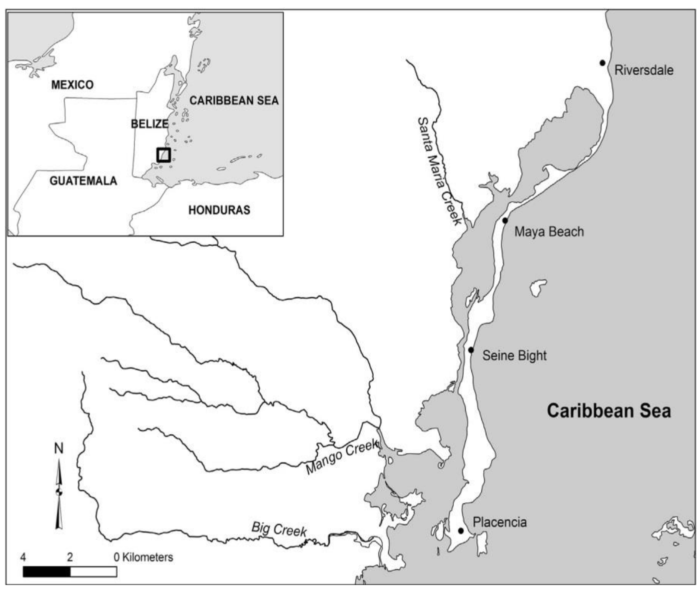

Figure 1: Map of Placencia Peninsula, Belize (prepared by Zaida Darley)

2.0 THEORETICAL FRAMEWORK

This study used two theoretical frameworks—theory of adoption and diffusion of innovations and theory of planned behavior—to reflect the mechanisms involved in the adoption and sustainability of resource recovery technologies.

2.1 Theory of Diffusion of Innovations

In 1962, Rogers' Theory of Diffusion of Innovations was developed to represent the four dynamic aspects involved in process of technology adoption — (1) the innovation, (2) a social system, (3) the communication channels, and (4) time. For this study, the innovation being considered is a wastewater-based resource recovery system. The social system is the boundary within which the innovation will diffuse— Placencia, Belize. Next, there are various communication channels, both formal and informal, that disseminate knowledge and persuade potential adopters such as advertisements, interpersonal communication (i.e. word-of-mouth), personal research, and site demonstrations. Finally, time is the aspect that influences different factors to initiate, stop, or delay during the sequential adoption phases. These four aspects are outlined in Figure 2 showing their sequential impact on the process of technology adoption.

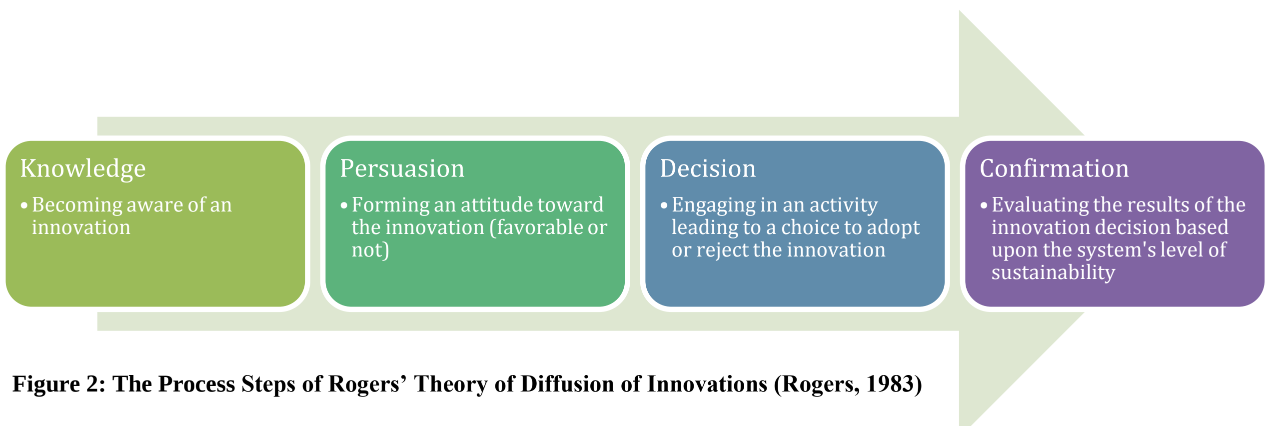

Figure 2: The Process Steps of Rogers' Theory of Diffusion of Innovations (Rogers, 1983)

Soon after Rogers' publication (1962), the Bass diffusion model (1969) emerged and has continued to be a prominent backdrop for studies investigating the factors that influence technology adoption. In particular, Sterman (2000) used a system dynamics approach to adapt the Bass model and added detail to reflect the interactions between factors (i.e. word of mouth, advertising effectiveness) as they impact the adoption rate. Overall, the process steps outlined in Rogers' theory and the behavior highlighted in Bass' model are the relevant aspects that were adapted into the structure of this study's model.

2.2 Theory of Planned Behavior

This theory builds upon the factors that motivate an adopter to perform a certain behavior. The foundation of the Theory of Planned Behavior (TPB) finds its basis in the Theory of Reasoned Action (TRA) whose primary components are (1) an individual's attitudes, (2) normative beliefs, (3) intentions and, (4) behavior. However, the distinguishing characteristic between TPB and TRA, and the justification for its inclusion in the model, is the addition of an adopter's perceived behavioral control. This variable represents the individual's ability to achieve some goal (i.e. wastewater treatment or recovery of nutrients in effluent) based upon the performance of a specific behavior (i.e. adoption of a resource recovery system). Regardless of an individual's attitude, their perceived behavioral control directly impacts their intention (to act) and indirectly influences their behavior (adoption). Perceptions of control become more accurate when one is informed of what is required to reach a specified goal and actually has the ability to achieve it (Madden et al., 1992). These notions are reflected in variables such as experience with wastewater technologies, personal research, and stakeholder power.

3.0 METHODS, DATA, AND MODEL STRUCTURE

3.1 Methods and Data

A mixed-method approach is employed in this study to reflect the complexity of the system-level dynamics influencing the adoption and success of resource recovery systems. The methods include water quality analysis, social science techniques, and computational modeling. The scope of this paper will focus on the system dynamics computational modeling approach.

3.1.1 Computational Modeling: System Dynamics

The system dynamic (SD) modeling method provides a means by which simultaneous interactions and feedbacks among multiple factors (e.g. economic, environmental, geographic, health, and technical parameters) can be considered as they impact the system's behavior over time (adoption and success). The SD framework enables the modeler to represent the system's structure by mathematically defining relationships, feedbacks, and delays occurring between factors, execute these simultaneously in Vensim® software, and reveal the system's behavior over time (Sterman, 2000; Pejic-Bach and Ceric, 2007; Forrester, 2009).

This study pairs the SD approach with nuanced perspectives from the community, particularly technology adopters and those responsible for the system's operation and maintenance. These individuals and institutions are oftentimes most capable of explaining (1) the localized issues influencing the adoption of the resource recovery systems, (2) the factors impacting the system's intended use, and, ultimately, (3) the elements affecting its successful treatment of wastewater to specified discharge standards. The collection of community-based knowledge to explain local dynamics for development projects is becoming more encouraged, particularly by international funding organizations like the United States Agency for International Development (USAID) that stated, "Local people understand their situations far better than external actors. They will understand the ways that multiple layers of history, politics, interests and formal and informal rules shape the current situation and what is possible to change. They will have views, perhaps divergent, on the contours of a local system (USAID, 2014)."

3.1.2 Data

This site-specific model benefits from qualitative and quantitative data—157 surveys, 76 semi-structured interviews, and hundreds of hours of participatory observations from 2013-2016.

3.2 Model Structure: Stock Flow Diagram

The stock-flow diagram reflects a hierarchical process that begins with a stakeholder's initial awareness. The awareness rate is driven by a function of advertising effectiveness and advertising frequency. Furthermore, the persuasion rate is directly influenced by perceived behavioral control which has already been explained in the Theoretical Framework. Next, adoption rate is influenced by word-of-mouth and stakeholder learning. Word-of-mouth is positively comprised of adopters and potential adopters, while it is reduced by those who have adopted but are not yet sustaining their systems. Stakeholder learning is comprised of site demonstrations and one's relative advantage for resource recovery systems in comparison to the traditional technology (i.e. septic tanks). Moving upward from there, the scale of design for resource recovery systems and the number of users directly impact operation and maintenance (O&M) costs and the system's treatment efficiency.

Further investigating the sustainability portion of the model, the number of system users influences the BOD and TSS loading rates which are reduced by technology-specific efficiency equations. The BOD and TSS performance impacts the environmental viability which is determined by the system's ability to meet the Belize Department of Environment's (DoE) domestic wastewater effluent standards (BDoE, 2009). Next, environmental and economic viability are linked based upon the financial penalties for breaking DoE standards. These penalties have a negative impact on economic viability only when the frequency of regulation enforcement is relatively high. Furthermore, the cost of sustaining the system is increased by the frequency of repairs and decreased by the net savings remaining after system costs. Ultimately, the baseline for economic viability considers net savings after costs alongside a small portion of a system owner's income. Overall, social viability reflects the owner or operator's ability to read the user's manual for instructions to properly sustain the system, so some secondary schooling is necessary for basic literacy. Putting this all together, the sustainability rate is determined by a

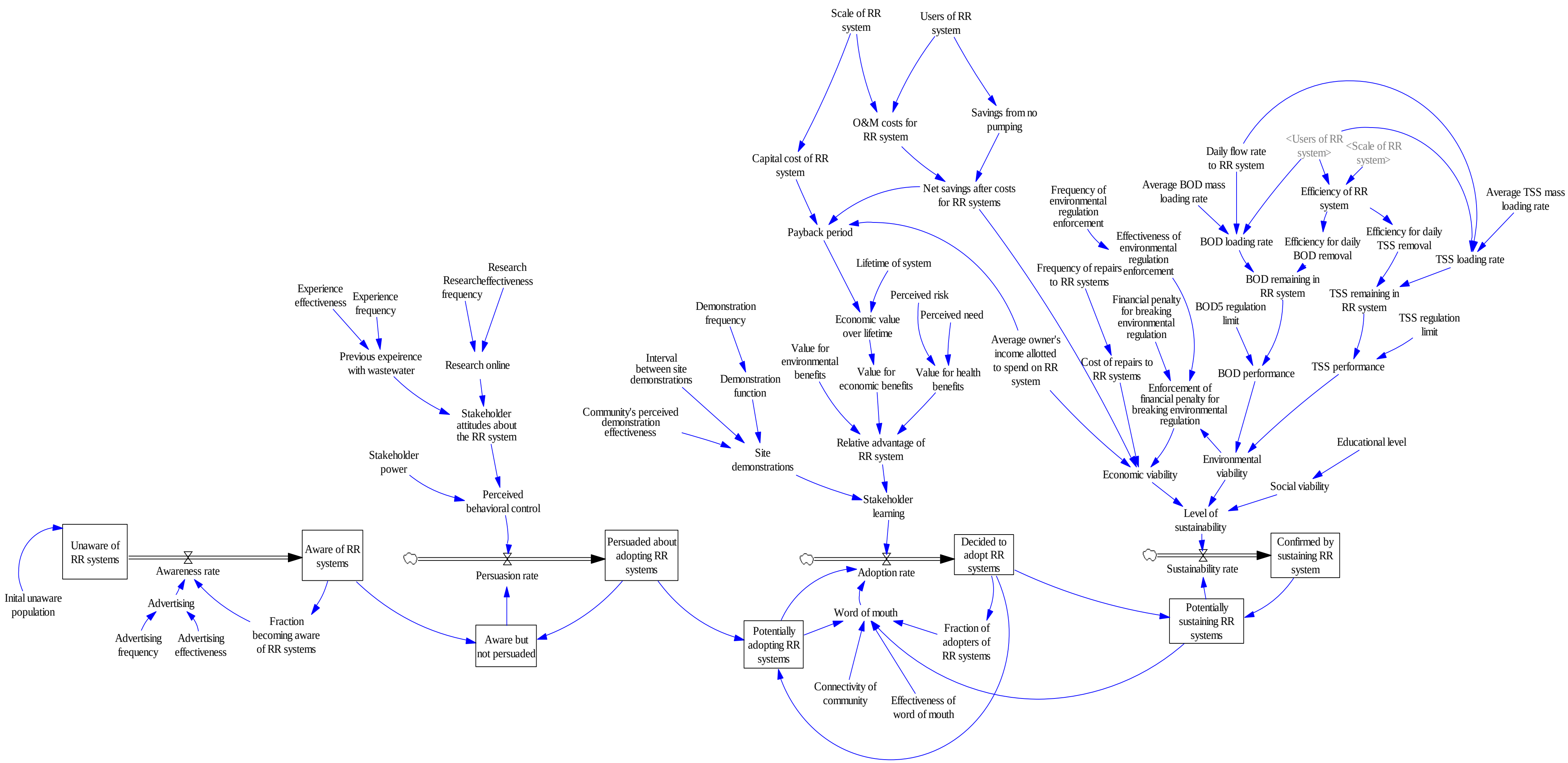

Figure 3: Stock flow diagram of the adoption and success of wastewater-based resource recovery systems in Placencia, Belize

weighed sum of the system's economic, environmental, and social viability with the largest weight on the first factor and equal, smaller weights on the latter two.

4.0 RESULTS AND DISCUSSION

4.1 Model Validation

Model validation ensures that the simulated results appropriately reflect the system's behavior. One model validation test compares simulation output values (adopters per time) to historic adoption behavior and statistically analyzes the differences using the root mean squared error (acceptable RMSE ≤ 0.7). Figure 4 shows the empirical data (green) of the number of systems EcoFriendly Solutions Ltd. installed within the study area from 2005-2015 along with the simulation's values (blue). Table 1 lists the datasets and RMSE value. Next, using a validated model, input para meters are altering by ±10%-±30% to determine their sensitivity on the model's output. Afterwards, the most sensitive parameters are used to develop and test strategies for improving the adoption and sustainability rates of the resource recovery systems.

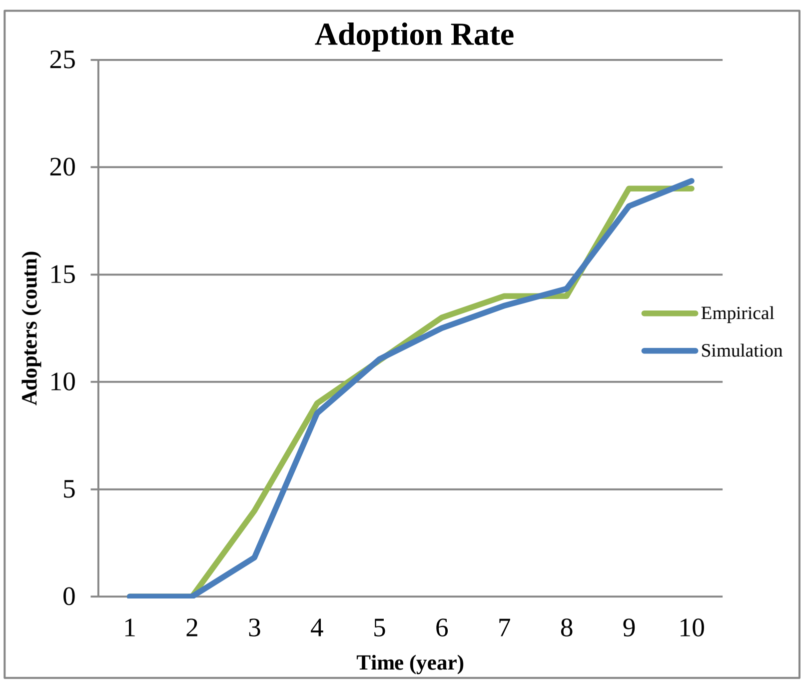

Table 1: Comparison of the mode's simulation outputs and empirical data along with the Root Mean Squared Error (RMSE) statistic

Root Mean Squared Error (RMSE)	Simulation	Empirical
0.79	0	0
	0	0
	1.83	4
	8.54	9
	11.06	11
	12.51	13
	13.55	14
	14.34	14
	18.19	19
	19.36	19

Figure 4: Behavioral validation where the model's simulation is transposed atop empirical, historic data provided by Eco Friendly Solutions, Ltd. of Belize.

4.2 Strategy Development and Testing

Strategies were developed using literature that reflects best practices for stimulating innovation diffusion. Additionally, colleagues in Belize also shared their knowledge about adoption dynamics to justify or negate proposed strategies. Given the limited scope of this paper, one intervention is demonstrated—an increase in advertising frequency.

Consider EcoFriendly's baseline scenario for advertising. They use various forms of media (i.e. television, internet, social media, radio, print) that have a cumulative impact on people, drawing them to awareness. Now consider a strategy where the employee in charge of sharing information, updating the website, or posting promotional material on social media is told to increase the frequency from between 1-3 times per month to 1-5 times per month. The SD model has a hierarchical structure such that the awareness phase is sensitive and influential to the rest of the adoption process. As such, the proposed 65% increase in advertising frequency could increase the number of systems from 19.36 to 22.91, an 18% improvement.

5.0 CONCLUSIONS

This research applies the system dynamics approach to determine the most significant factors that influence the adoption and success of wastewater-based resource recovery systems and tests a potential strategy to increase their adoption. These systems represent an alternative to septic tanks that are not efficiently or effectively treating household effluents in a vulnerable, quickly growing coastal community in Belize. However, without widespread adoption and sustainability of resource recovery systems, their ability to mitigate environmental impacts is dampened. Consequently, decision-makers could use this adaptive tool to simulate strategies that would best influence adoption and sustainability prior to actually using any of their (potentially limited) resources to implement the intervention.