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SIMULATION STUDY OF WATER REUSE SYSTEM FOR A REGENERATIVE HOUSEBOAT BY EPANET

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Urbanization affluence, together with the impact of climate change, poses a significant threat to water resources. Future water crises must be solved in a sustainable manner. The aim of this research is to introduce a multi-demand water infrastructure for a regenerative houseboat. This research reflects a simulation study of four different greywater reusing scenarios. On-site water treatment units are selected as possible source-associated solutions for sustainability. The design for the multi-demand water system will be implemented into the houseboat structure located on the Kaiapoi River in New Zealand. The water infrastructure includes river water storage, roof catchment, and greywater and black water treatment units. The simulation for water infrastructure is created by EPANET under real-life conditions, using average household data for water consumption and wastewater discharge. The study uses the concept of reservoirs for water sources. The results from EPANET show that it is possible to simulate this infrastructure and provide a dynamic model for a real case scenario. It is explained that 12.1% of water is saved if toilet flushing alone uses treated greywater. If greywater is treated for reuse in the washing machine and shower, then 25.3% and 66.3% of water are saved, respectively. A portion of treated greywater can also be pumped to the water treatment unit for drinking purposes, thereby using zero water from a river source.

Keywords: Greywater, Net-zero water, Multi-demand water system, Greenhouse, Sustainability.

1 INTRODUCTION

Freshwater shortage due to population growth, industrial activities, and climate change, along with corrupted or insufficient water infrastructure for under-developed societies, is one of the high-ranked risks. Water scarcity is a physical matter if there is a lack of water sources for future needs, or an economic matter if there is insufficient finance to access water (Tsoumachidou *et al*. 2017). A water reticulation system, which delivers water to residential and commercial places, requires significant maintenance in many places and cannot satisfy developed subdivisions with certainty. Water stress can also be significant for decentralized places in rural areas, which might have no access to centralized water and wastewater reticulation systems. Water reuse at source can challenge the maintenance or replacement requirements for current infrastructure systems.

Water reclamation reduces pressure on freshwater sources, demand for water treated to potable standards and wastewater reticulation, and treatment units. The reuse system can be as simple as reclaiming greywater for toilet flushing or an advanced multi-demand unit providing treated water for all non-potable purposes (Jeong *et al*. 2018). Different treatment units are involved in the multi-demand system to treat water to the levels necessary for the end-use.

The application of a multi-demand water reuse system first must be understood and simulated. The system includes separate piping networks for potable water, greywater, and black water. It has been reported that up to 32.5% of water is saved when greywater is reused for toilet flushing and irrigation in a residential place (Zhang *et al*. 2010). Different treatment units are required to reuse greywater for potable and non-potable purposes. Although extra pipe networks and treatment units are disadvantages of a multi-demand water system, reducing freshwater demand and moving towards sustainability motivate residents to build the necessary new infrastructure (DiGiano *et al*. 2009).

New Zealand has a growing interest in recycling water using sustainable technologies. However, there are very few regenerative water designs in New Zealand. This project is based on a boat structure that requires an on-site water treatment unit and natural sources of water (e.g., river or roof catchment). Net-zero water infrastructure is a new innovative system that utilizes water and wastewater management strategies. The purpose of this system is to zero the total water consumption from the grid and maximize the use of alternate water sources. Traditionally, the focus of civil infrastructure has been safety and aesthetics, with little thought given to the impact the infrastructure has on its surroundings. Multi-demand water is rarely used in infrastructure projects, but over the past decade, it has begun to gain attraction in the civil engineering industry.

The aim of this project is to design a multi-demand water and energy infrastructure for a boat structure located on the Kaiapoi River. The design of the structure will be floating on a tidal river, as shown in Figure 1. Therefore, the river usage and discharge must be considered (as a "one-way consumption, then discharge system" will not be suitable and breach the health and safety regulations). The average temperature in Kaiapoi is 12 °C, and the average rainfall is 629 mm. The tidal range for the Kaiapoi River is from 0.32 m to 1.84 m. As well as considering tidal changes on the Kaiapoi River, the structure must maintain a stable buoyancy force with constant water and air storage at the bottom of the structure. Black water and solid waste management, drinking water consumption and storage, energy consumption, and bathroom heating must be considered, recognizing that the structure is in an isolated environment.

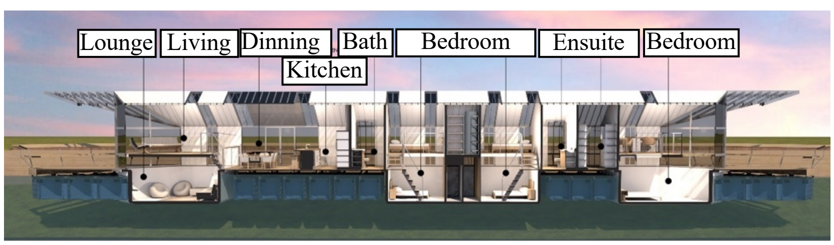

Figure 1. Side view of the Houseboat (Bologna 2018).

To successfully complete this design, decentralized water and wastewater technologies must be evaluated along with the feasibility study of multi-demand water reuse system. The project includes researching and collecting existing data involving the area of the proposed structure (e.g., water quality data from Kaiapoi River). The new infrastructure is modeled using EPANET developed by the United States Environmental Protection Agency. The model is developed for different scenarios and water-saving results are then generated. The model is more complex when the number of demands increases since it considers the level of water quality required for each demand. In this research, the following four scenarios are considered in modeling:

- Scenario 1: rain and river are the main source + greywater reuse for toilet flushing;

- Scenario 2: Scenario 1 + greywater reuse for washing purposes;
- Scenario 3: Scenario 1 + greywater reuse for all non-potable purposes;
- Scenario 4: Scenario 1 + greywater reuse for all potable and non-potable purposes;

2 WATER SYSTEMS

In accordance with AS/NZS 1547 (2012) (on-site domestic wastewater management), in Section 5.4.1 – Wastewater Treatment Units, the wastewater treatment unit system must have enough capacity to be able to treat all wastewater outputs from the demand points of the infrastructure. It must avoid any offensive odors or build-up of solids in the treatment system and use minimal energy resources, which is beneficial since the houseboat is using regenerative energy to run the structure.

The multi-demand water system for the proposed houseboat consists of two main natural resources, roof runoff and river. Water from the roof will be collected around the entire perimeter of the roof, which has an area of 186 m². The collected rainwater will then go through a treatment unit, which will filter out water impurities, followed by disinfection. This filtered water is enhanced to drinking water quality and is used for potable purposes. Surface water will be collected from the river and treated to enhance water quality to the drinking standard. The treatment process of filtration, followed by UV disinfection manufactured by Microlene, has been selected for this research. It consists of a three-stage filtration and disinfection system that provides a safe and hygienic water supply.

Greywater is an important asset to the net-zero infrastructure as it will allow the recycling of large quantities of water. Water will be recycled from the washing machine, dishwasher, showers, and hand basins and sent to the greywater treatment unit. It is important to have an extensive treatment unit that can handle a large flow. The proposed greywater treatment unit GWTS1000 is manufactured by Aqua2use and can filter up to 1000 L/d. The GWTS1000 comprises both mechanical filtration and biological filtration plus UV-C disinfection. The pre-filtration removes large and small particles, catching between 60-90% of suspended solids. The next step in the treatment process is the biological treatment, where the water undergoes progressive 3-D biofiltration. After the bio-filtration, the water flows through a stainless-steel chamber UV-C system for disinfection. On average, around 60% of household water use can be recycled as greywater. If four people live on the houseboat, an estimate of 996 L/d can be recycled and since the GWTS1000 can treat 1000 L/d, this system is enough for the houseboat infrastructure (Aqua2Use 2018).

Water collected from flushing toilets will be sent to a black water treatment unit. The black water treatment unit for the proposed design is a BioFicient® Domestic Wastewater Treatment System. It has a four-stage treatment system consisting of sedimentation, physical separation, biozone treatment, and chlorination.

3 METHODOLOGY

A multi-demand water system for the houseboat is schematically shown in Figure 2. The input for Storage tank 1 is from the roof catchment and the river, providing drinking water for the demand points such as the sink, basins, showers, dishwasher, and washing machine. The output from these demand points goes into the greywater treatment unit and is then stored in Storage tank 2. Demand points introduced in each scenario receive treated greywater.

The designed system is modeled by EPANET for four different scenarios. EPANET, a hydraulic computer model, is software that can model the dynamic water network using demand patterns. The model includes components such as reservoirs, pumps, storage tanks, pipes, nodes, and valves. EPANET is capable of modeling any size of the water network. A demand pattern can be applied for each demand point. The Hazen-Williams equation is selected to calculate head-loss in EPANET. PVC pipe with a 50 mm diameter is used in this model for piping. Barrels are used as storage tanks. A valid curve is used for each pump to adjust the pressure level in the system.

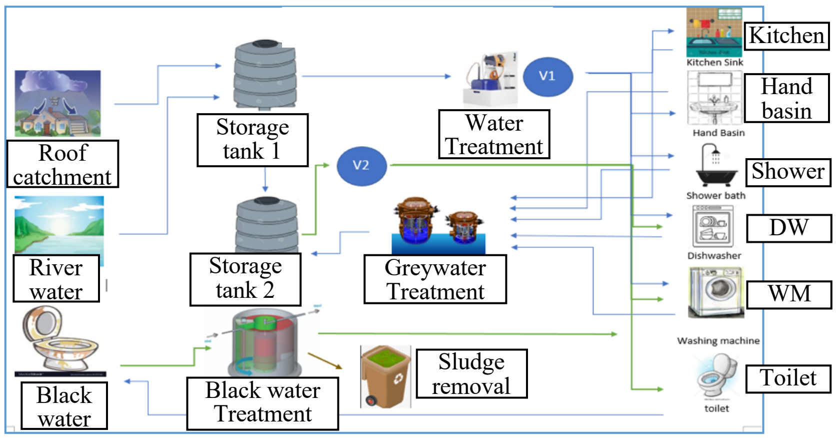

Figure 2. Schematic drawing for the multi-demand water system.

4 EPANET MODELING

A model is created for each scenario, and scenario 4 is presented in Figure 3. A reservoir is used for river and rain sources. Source water from the river and rain is directed into the water treatment unit (WTU) by pumps. The tank level is increased to adjust the pressure level in the houseboat. A demand point with a relevant demand pattern is then assigned to a washing machine (WM), dish washer (DW), kitchen sink, main and en-suite showers, main and en-suite bathrooms, and main and en-suite toilets. The Greywater treatment unit (GWTU) is collecting water from all discharge points except toilets. The Black water treatment unit (BWTU) treats toilet discharge. The infrastructure imitates the possible pipe networking from the architectural design of the houseboat.

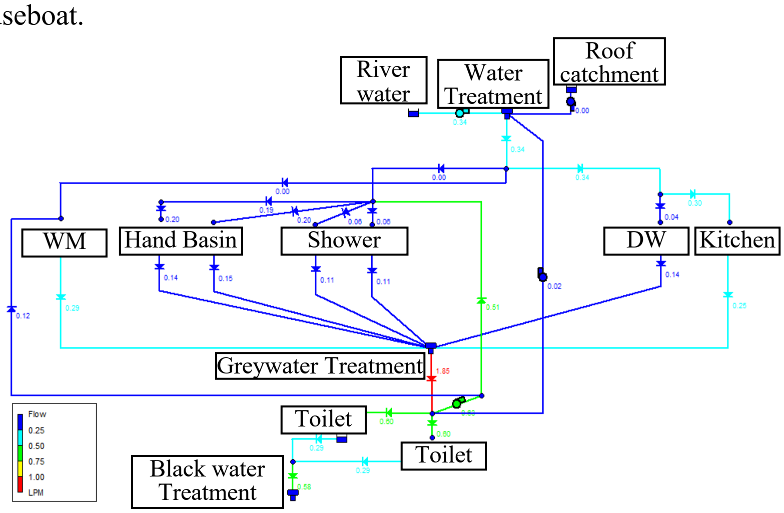

Figure 3. Scenario 4 for greywater reuse in EPANET.

Scenario 1 is modeled, assuming greywater is reused for toilet flushing only. For scenario 2, greywater is treated and reused for the washing machine and toilet flushing when needed. The rest of the generated greywater is treated and discharged. Scenario 3 reuses greywater for all non-potable purposes. Scenario 4 adds a separate pipe to the piping system available in scenario 3 for transferring treated greywater into the WTU. Pipe flow rates are shown in this model and described using the legend. The flow rates vary during dynamic modeling over 24 hours.

5 RESULTS AND DISCUSSIONS

Results from modeling are compared from the least complex scenario (1) to the most intensive scenario (4). Scenarios 1 to 4 are saving 12.1%, 25.3%, 66.3%, and almost 100% of water, respectively. The flow in the main water pipe between WTU and all demands is plotted for all four scenarios, as shown in Figure 4. The use of water from rain and river sources is about 40% larger in scenarios 1 and 2 compared to 3 and 4. Scenario 4 shows the same pattern as scenario 3 since a portion of treated greywater is returned to the WTU for potable purposes.

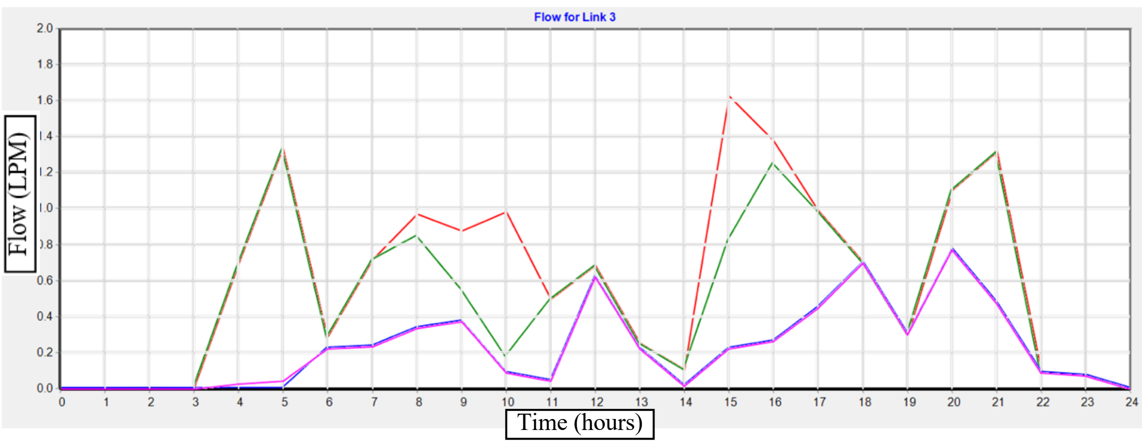

Figure 4. Main water pipe flow (LPM) for Scenario 1 (—), Scenario 2 (—), Scenario 3 (—) and Scenario 4 (—).

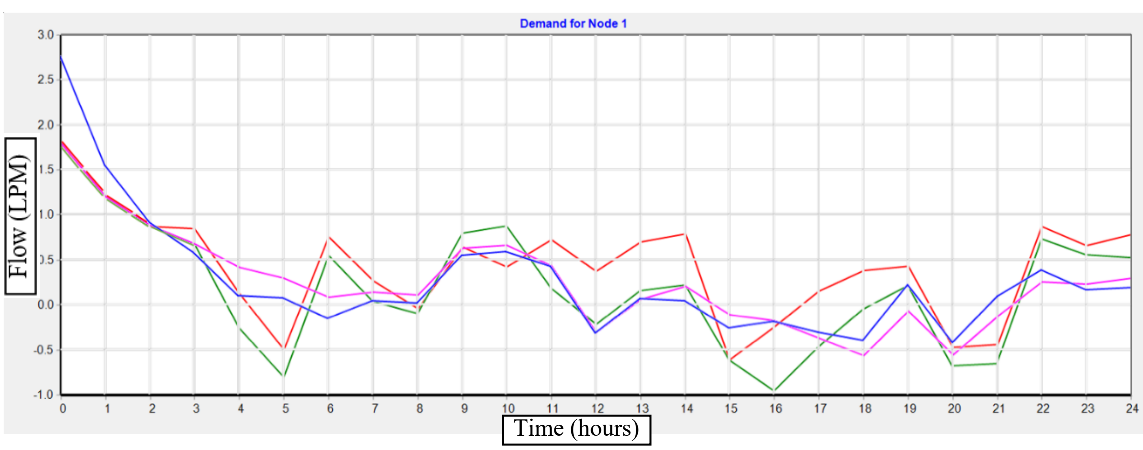

Figure 5. Water treatment unit demand in LPM for greywater reuse in Scenario 1 (—), Scenario 2 (—), Scenario 3 (—) and Scenario 4 (—).

Figure 5 presents the demands for WTU for all scenarios and explains that after the water tank is full, there is less demand for scenario 4 during the day compared to other scenarios. The fluctuation from baseline is maximum 0.5 LPM and 1 LPM for scenarios 4 and 2, respectively.

The demand for GWTU is plotted in Figure 6. Greywater is discharged at the rate of 610 L/d and 490 L/d from the treatment unit to the environment for scenarios 1 and 2. This rate is 80 L/d for scenario 3 and zero for scenario 4.

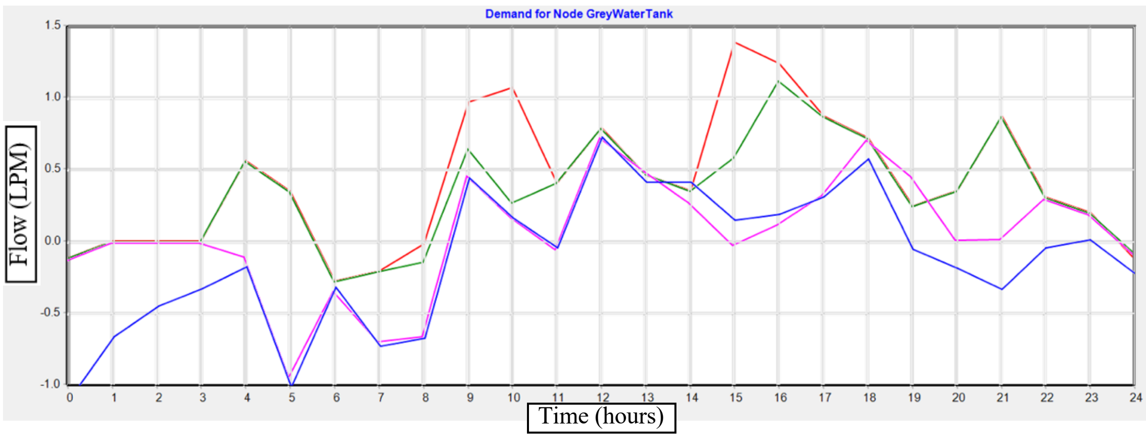

Figure 6. Greywater treatment unit demand in LPM for greywater reuse in Scenario 1 (—), Scenario 2 (—), Scenario 3 (—) and Scenario 4 (—).

6 CONCLUSIONS

The multi-demand water system is a promising green infrastructure for residential houses. Reusing treated greywater will reduce pressure on freshwater sources. The combination of roof catchment and reclaimed water overcomes water scarcity in remote areas. A separate piping system and decentralized treatment unit are required for a multi-demand water system. However, these aspects will reduce costs on the maintenance and treatment requirements for the centralized reticulation systems. This combination enhances the star rating for the green building concept.

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