A study of ecological sanitation as an integrated urban water supply system: case study of sustainable strategy for Kuching City, Sarawak, Malaysia
Darrien Mah Yau Seng, Frederik Josep Putuhena, Salim Said and Law Puong Ling

ABSTRACT

A city consumes a large amount of water. Urban planning and development are becoming more compelling due to the fact of growing competition for water, which has lead to an increasing and conflicting demand. As such, investments in water supply, sanitation and water resources management is a strong potential for a solid return. A pilot project of greywater ecological treatment has been established in Kuching city since 2003. Such a treatment facility opens up an opportunity of wastewater reclamation for reuse as secondary sources of water for non-consumptive purposes. This paper aims to explore the potential of the intended purposes in the newly developed ecological treatment project. By utilizing the Wallingford Software model, InfoWorks WS (Water Supply) is employed to carry out a hydraulic modeling of a hypothetical greywater recycling system as an integrated part of the Kuching urban water supply, where the greywater is treated, recycled and reused in the domestic environment. The modeling efforts have shown water savings of about 40% from the investigated system reinstating that the system presents an alternative water source worth exploring in an urban environment.

Key words | ecological sanitation, greywater, Kuching city, recycling, urban, water supply

BACKGROUND

Kuching is the capital city of the East Malaysia State of Sarawak, established at the banks of Sarawak River on the North-Western part of Borneo Island. The longitude and latitude of Kuching is 01°33’N, 110°25’E. The city is located in the district of Kuching. The district covers an area of 1863 km², and is one of three districts within the First Division. Kuching is the most populous city in the state, with a population of 579, 900 (2006 census) and a density of 322/km².

Kuching Water Board is the responsible authority to supply clean water for the Kuching city. Its jurisdiction supply boundary covers an area of 730 km². The Sarawak Public Works Department manages the public water supply services to rural areas under its Water Supply Section. The Board has long relied on its Batu Kitang water treatment plant upstream of Sarawak River for more than 97% of water production. Though Sarawak River system as the main freshwater abstraction for the capital city is fortunately rich in its reserve and hydrology, this advantaged physical environment is increasingly challenged when placed in the context of the dynamic social environment of Kuching city. Kuching city is the fastest growing area placing great pressure on the water supply and has seen a rapid growth in water demand.

Effectively managing the water supply and demand requires a sustainable approach which manages the natural resource together with community demands, both consumptive and uses, and not forgetting also the environmental needs. The local practiced water supply management still focuses on strategic direction and priorities revolving
around water supply, infrastructure, water reticulation and management of water storages. Sustainable water supply into the future would embrace the concept of Integrated Water Resources Management (IWRM) where the new challenge requires a very different response.

To cater for a change for sustainable and ecologically efficient use of water supply, water resources and wastewater management must come together in addressing the water cycle under the IWRM processes. Diversifying the supply options is one way to reduce dependency on sole sources of supply (Mkandla et al. 2005). In order to decrease the pressure on the finite water resources, wastewater need not be thrown away after one time use but can be prompted for reclamation of household wastewater. Recycling and reuse of wastewater can be a water source for non-consumptive purposes where lesser quantities of potable water are used for purposes other than drinking. This lowers water supply costs, as potable water is expensive in treatment costs and the needs of storage facilities management.

The current local water uses are construed along the lines of a one-time use of water. The system is conceptualized as a flow-through system. Little attention is placed on the safe management of the huge volumes of wastewater. Greywater is produced when water is discharged from household appliances and water using fixtures such as showers, baths, washing machines, kitchen and laundry sinks. It excludes water discharged from toilets and urinals (black water). Presently, the wastewater from households in Kuching is partly treated. Only the black water undergoes a partial treatment in septic tanks before the overflow is discharged to the storm water drains. The greywater is released untreated to the storm water drains also. Both black and grey water eventually run into Sarawak River. Therefore the water quality of drains, streams and rivers in Kuching is heavily polluted. Greywater contains a number of bacteria that may include disease causing organisms. It also contains a number of pollutants including organic matters, nutrient loads, salts and detergents. However, it is possible to collect and reuse greywater as it can be treated to a less health-hazardous standard. Since greywater is generated directly in every household in just about equal volumes every day independent of the weather, it presents a constant resource.

There are financial, environmental and health considerations involved in wastewater treatment. Kuching city is generally flat, low-lying with only small possibilities for gravity piping. In addition a large part of the city is deep peat, which may decompose due to draining effect of the sewers and thus may lead to breaking sewers and rising mains. A centralized sewer management with sewer piping is therefore not in favour considering the local conditions. Ecological Sanitation (Ecosan) facilities are considered as an alternative to centralized wastewater system. Kuching city did not practice water recycling. Treated greywater can be used as processed water for flushing for toilet, for watering the garden and for cleaning.

**ECOLOGICAL SANITATION**

In June 1999, the State Government of Sarawak, in collaboration with the Danish Cooperation on Environment and Development (DANCED), initiated the Sustainable Urban Development Project in Sarawak. The project was based on the wish to enhance sustainable urban development in Kuching city and other urban centers in Sarawak. Kuching city was selected as the key project area to implement an Urban Environment Management System (UEMS) (NREB 2001). It was decided to focus on two prioritized issues as a starting point. River quality and solid waste management were selected as the areas of concern. Ecosan system is a cost-effective effort in part of the UEMS initiatives (NREB/DID 2004) devised to take care of household wastewater.

In the buildings in Sarawak and in generally all Malaysian houses, the black water channels are separated from the greywater channels. This facilitates a source separating Ecosan system. The quantity and quality of wastewater can be controlled at the household level (Esrey et al. 1998). Based on this, Ecosan project in Kuching city is targeted at lowering the nutrient loads in waterways and reducing the pollutant loads in our rivers. It makes sense in the case of Kuching city where water abstraction and wastewater dumping are practically done on the same Sarawak River system.

The philosophy of Ecological Sanitation is based on the concept of human excreta and wastewater as a valuable resource to be recovered and recycled, rather than as a
waste product to be disposed of (Langergraber & Muelleger 2005). Ecosan systems enable the recovery of nutrients from human faeces and urine for the benefit of agriculture, thus helping to preserve soil fertility, assure food security for future generations, minimize water pollution and recover bioenergy. They ensure that water is used economically and is recycled in a safe way to the greatest possible extent for purposes such as irrigation or groundwater recharge. This concept is very similar to the IWRM principles where wastewater is re-integrated as a major component in the water cycle. Countless efforts all over the world are trying various ways of wastewater recycling and reuse. Some interesting websites like http://www.ecosan.org, http://www.ecosanres.org and http://www.gtz.de/en share information on Ecosan projects all over the world.

Experiences of Ecosan approach in different regions have showcased the successful reuse of treated wastewater. The Sweden–China cooperation on the Erdos Eco-Town Project in Dongsheng, Inner Mongolia has demonstrated the first major attempt to build an entire town applying on-site Ecosan. The greywater is treated which includes aeration and post-chlorination and storage pond prior to domestic reuse (EcoSanRes 2007).

The KfW is the donor organization which finances investment and accompanying consulting services on behalf of the German Ministry for Economic Cooperation and Development (BMZ). Its Frankfurt office building has the greywater from hand washing, cleaning and kitchen collected in a separate gravity pipe system. The treated greywater through Ecosan method is used for toilet flushing and cleaning (GTZ 2005).

The model project in Kuching city only involves the treatment of lower strength greywater. A structure of constructed wetlands with integrated aerobic filter using the Norwegian technology and sizing (Jenssen et al. 2005) is adopted in the pilot facilities in a residential Taman Hui Sing in Kuching since 2003. The facilities cover a rather small area of about 2.5 m × 4 m. A 3D depiction of such a structure is shown in Figure 1. The pilot device connects to nine households of single-storey detached houses with an average of five persons per household. Greywater from the kitchen, shower and washing machine is channeled to the Ecosan facilities. The greywater is treated through the Oil and Grease Tank, then pumped to and sprayed on the Vertical Biofilter and later the Horizontal Biofilter. However, black water is confined in the septic tank without any overflow to the natural waterways and later transported to a sludge treatment plant. In future, black water will be fed to a biogas plant to produce energy and fertilizer.

**Figure 1** | Graphical of ecological sanitation design (Jenssen et al. 2005).
Baseline monitoring and sampling results indicated a high efficiency of the pilot system. The project is under constant supervision and observation to check any irregularities in the operation. The average values for treated greywater show more than 90% removal of BOD, COD, TSS and ammonia (Jenssen et al. 2005). The effluent meets the WHO greywater requirements (WHO 2006). Levels of indicator bacteria meet the European swimming water standards (Jenssen et al. 2005).

After treatment, the treated greywater is however released back to the river system as treated wastewater without reusing it though the treated water is of good quality. It is quite a waste to throw away the good resources. The quality of the effluent from the Ecosan system is suitable for a number of discharge and reuse options (Jenssen 2005). Such treatment facilities open up the potential of greywater reclamation for reuse.

**MODELING OF ECOSAN SYSTEM**

Reuse of treated greywater facilitates water savings exceeding 50% (Radcliffe 2004). Non-consumptive water reuse has an excellent and well-documented performance track record, which to date has featured no documented health problems, strong public acceptance and good regulatory compliance (Radcliffe 2004). In order to evaluate a proposed system, the modeling process of using a mathematical representation of the real system is commonly performed. By using network simulations, which replicate the dynamics of a proposed system, problems can be anticipated and solutions can be evaluated before time, money and materials are invested in a real-world project.

Hydraulic modeling of a centralized, large scale treatment system and reuse of its effluent is largely available in the literature for the purpose of irrigation and industry. A decentralized in nature on-site small scale recycling system is not common in records. In the present works, modeling of Ecosan to investigate the possibility of reusing the treated greywater as an integrated part of the water supply system is made possible with the assistant of the Wallingford Software model, InfoWorks Water Supply (WS) software. The modeling approach is tested on a medium system in Tabuan Jaya residential area. Such modeling is beneficial in understanding the appropriate analysis methodology for designing the water supply/recycle systems. At the same time, the model shall be used as a model-project to adapt the methodology to local conditions and to allow for replication of the small system to a larger system elsewhere.

The Tabuan township (see Figure 2) is the suburban satellite town of Kuching city, located about 5 km away from the city center. Tabuan Jaya is one of the residential areas which has a standing establishment of over 20 years. It covers an area of 0.85 km² with a dense population of close to seven thousand. The housing estate is most accessible by using the Wan Alwi Road, one of the main roads connecting Kuching city to Kota Samarahan. The Kuching Water Board trunk water main was laid alongside of Wan Alwi Road branching from Simpang Tiga to supply clean water to Kota Samarahan and Siburan areas. The consumers of Tabuan Jaya are tapping clean water from the same trunk water main.

Tabuan Jaya is surrounded by the Tabuan River which forms a triangulated-shape delta. There are three bridges (see Figure 2), which are (1) the bridge that connects to Foo Chow Road, (2) the bridge that connects to Tabuan Desa, and (3) the bridge that connects to Tabuan Desa Indah. Water supply pipelines do not cross the river for the first two bridges, however pipeline crossing is observed at the third bridge supplying water to Tabuan Desa Indah. For modeling purpose, the pipeline is assumed to stop at the third bridge making Tabuan Jaya an isolated system to accommodate investigations.

Further analysis of the Tabuan Jaya housing estate with a Geographical Information System (GIS) tool would enhance the appropriate analysis of fitting the domestic scale Ecosan system into the urban water supply network.

**GEOGRAPHICAL INFORMATION SYSTEM**

In recent years, considerable interest has been focused on the use of GIS as a decision support system, particularly in the context of a holistic approach of water resources management, and is indeed a great challenge and an important milestone. Providing the responsible agencies...
with a comprehensive GIS model, the system conditions, if presented visually as geographical data, facilitates proper planning of urban water supply facilities.

The requirement of maps in terms of contents, quality and accuracy vary from organization to organization. Comprehensive maps are required for planning and execution by engineering water supply works. For water supply works, to show a concept for distribution system and layout of plots in a local plan, in an urban area, a 1:2000 large scale map is adequate. The 1:2000 ratios cadastre map shapefiles of Kuching city (see Figure 3), maintained and updated till 2002 by the Sarawak Land and Survey Department, is sourced to develop the intended GIS system. The shapefiles contain the following information:

- **Block and Lot Numbers**
- **Lot Lines**
- **Lot Dimensions**
- **Building Footprints**
- **Street Names**
- **Water Bodies**
- **Contour and height in mass points**

A city transforms its environment and landscape hauled by the momentum of development activities. The expansion of the built-up areas and the transformations resulted in land surfaces and valleys being reshaped into domestic, enterprises and institutions, eventually leading toward urbanization. This also has posed serious implications on the freshwater resources in the region. A city like Kuching requires a large input of freshwater. By mapping the urban land uses, breaking down to domestic, commercial, industry and public institutions in different layers to provide a full picture in one integrated system (see Figure 4), it is easy to view and interrogate.

By using the ESRI ArcView software, the model calculated a total of 1335 units of domestic houses in the Tabuan Jaya housing estate, where the residential area contains 372 units (27.87%) of single storey terrace, 704 units (52.73%) of double storey terrace, 127 units (9.51%) of single storey semi-detached and 132 units (9.89%) of double storey semi-detached houses. These houses are built in the branched smaller roads alongside two main roads, namely the Bayor Bukit Road in the west and Keranji Road in the east. The distribution of the housing typology is shown in Figure 4. The current research would like to concentrate on the domestic users; thereby the commercial users are not included for the case study.
The next step is how to fit the Ecosan system to the Tabuan Jaya public water supply system. The major principles of Ecosan are that the system is on-site local treatment of greywater and decentralized in nature. Taking the Hui Sing pilot project as reference (about the size of $2.5\text{ m} \times 4\text{ m}$), the system is expected to be small and suitable for urban environment. According to Sarawak State Planning Unit, the State Government is considering enforcing wastewater management on all new housing developments. The developments should be equipped with an Ecosan system, where every 60–70 houses has one treatment system. To meet such a requirement in an established housing estate like Tabuan Jaya (with a total of 1335 houses), the authority would need to build about 19 Ecosan systems scattered around Tabuan Jaya, where the availability of land would be an issue. In this work, the number of houses is hypothetically increased to a more achievable target of about 150–200 houses with one treatment system, where only about seven Ecosan systems are needed. The GIS model assists in delineating the Tabuan Jaya into seven zones (see Figure 5). Each zone is one stand alone looped recycle system. The main criteria for setting up those zones depend on the empty land available in the residential area.

The most important step towards efficient water and wastewater management is the generation of reliable base data through the conversion of existing data into a newly developed integrated information system. What is lacking and the main focus to customize the sourced cadastre into water supply applications require the adding of the following to the existing GIS:

- **Water Mains**
- **Customers’ Information**

With GIS software—ESRI ArcView in combination with InfoWorks WS, these features are extracted from existing Kuching Water Board records, plotted, overlaid in different layers, statistical analysis carried out on them and spatial searches conducted. Customizing “Customers’ Information”, particularly the water use data, and “Water Mains” are discussed in the subsequent sections. Water supply operations are becoming increasingly data-intensive. The GIS approach finds its role as an effective tool to help water managers in planning and developing the water supply management and should be envisaged on this bigger picture.

Urban development and analysis of spatial and temporal water consumption are effectively and efficiently done...
with the help of GIS. Having regards that water withdrawal is practically done in a customer’s property, which has a variety of land uses (e.g. residential or non-residential). Data on these urban land uses and water consumption patterns, in which two different sets of data are easily collected, is integrated into one single analysis system and stored within a GIS model for easy maintenance. Such an integrated analysis and monitoring system based on GIS and database management technologies provides an understanding of the current water demands and the application of available technologies - in the case of this work, domestic-scale Ecosan recycle system as an alternative urban water source to the specific problem of rising water demands.

WATER CONSUMPTION PATTERNS

Although Kuching Water Board makes a large number of flow measurements, such as those at customer meters for billing and at treatment plants for production monitoring, data on usage change over time is sadly practically non-existent in records. A true picture of daily variation is very important and no effort should be spared on this. The temporal variations in water usage for municipal water systems typically follow a 24-hour cycle called a diurnal demand pattern.

Developing a diurnal curve for a specific customer requires more information than can be extracted from typical billing records. More intensive data collection methods are
needed to portray the time-variant nature of the demands. Manually reading a customer's water meter at frequent intervals is undertaken to gather the required field data. The field investigation is carried out in the months of no obvious festive celebration, non-school holiday season and drier months of April-March (2007) and another cycle in July (2007) to collect at least 6 days per cycle of random samplings. As one might expect, weekend usage patterns often differ from weekday patterns. The current investigation is carried out during weekdays (from Monday to Thursday), exclusive of weekends (Friday to Sunday) at random sampling of households according to their property types.

For this study, housing typology is chosen as sampling criteria of household water as the household water using habits and behaviors are not known. Zhang & Brown (2005) reported that housing typology is one common sampling criterion for developing countries in the absence of more detailed user characteristics. It is assumed that customers in the same property category use water in a similar pattern, but in different quantities (Kindler & Russell 1984). These data are later analyzed to normalize the profiles.

InfoWorks WS expresses demand by using a constant baseline demand multiplied by a dimensionless demand...
pattern multiplier at each time increment. The water demand for each customer is calculated using the formulas:

\[
\text{Water Demand } i = Q_{\text{base}} \times \text{Mult } i
\]  

where

\[ Q_{\text{base}} = \text{base demand} \]
\[ \text{Mult } i = \text{dimensionless multiplier at } i\text{th time step} \]

\[
\text{Mult } i = \frac{Q_i}{Q_{\text{base}}}
\]

where

\[ Q_i = \text{demand in } i\text{th time step} \]

The baseline demand is often chosen to be the average daily demand. The series of demand pattern multipliers models the diurnal variation in demand and can be reused at nodes with similar usage characteristics (Mays 2000). Figures 6 to 9 illustrate the investigated customer diurnal curves for the Tabuan Jaya residential area.

Generally, three peak hours are observed in the domestic users. There is relatively low usage at night when most people sleep, increased usage during the early morning hours as people wake up and prepare for the day, increased usage during the middle of the day, and finally, increased usage again in the early evening as people return home. Water use rate in the evening is higher than the usage during the day. However, it is interesting to find out that the sub-categories exhibit different tendencies of water usage during the three peak hours. Currently there are no concrete reasons to explain the observations. Further consumer surveys on detailed water use data would be needed.

After consumption rates are determined, the water use is spatially distributed as demands, and stored in the ESRI ArcView model database. The wealth of spatial data generated can be integrated into a common platform for water distribution systems via InfoWorks WS modeling system. This process is referred to as loading the model, where the water use data is assigned to model nodes.

**INFOWORKS WATER SUPPLY (WS)**

Access to geospatial database is important in supporting wise water supply management; however, water utilities planning require further information. Water distribution networks are basically hydraulic systems. InfoWorks WS is one of the hydraulic solutions of an industrial standard Joint-Engine Technology (JET) Relational Database, WesNet flow simulation engine and Spatial Analysis tools, providing a single application which integrates water supply networks modeling for efficient planning and operation activities. InfoWorks WS integrates the existing ESRI packages into its own platform rather than replacing them, in which ESRI spatial attributes are used to facilitate

<table>
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<th>Average water use (l)</th>
<th>Multiplier</th>
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</thead>
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<td>23</td>
<td>0.004</td>
</tr>
<tr>
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<td>836</td>
<td>0.18</td>
</tr>
<tr>
<td>0600–0900</td>
<td>777</td>
<td>0.17</td>
</tr>
<tr>
<td>0900–1200</td>
<td>842</td>
<td>0.18</td>
</tr>
<tr>
<td>1200–1500</td>
<td>614</td>
<td>0.13</td>
</tr>
<tr>
<td>1500–1800</td>
<td>367</td>
<td>0.08</td>
</tr>
<tr>
<td>1800–2100</td>
<td>1,167</td>
<td>0.25</td>
</tr>
<tr>
<td>2100–2400</td>
<td>60</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Number of sampling = 20 houses
Daily average = 4,680 l/household

*Figure 6 | Water use patterns for single storey terrace houses in Tabuan Jaya.*
hydraulic analysis and decision support processes related to supply region and distribution networks.

Modeling involves a series of abstractions. First, the real pipe networks in the system are represented in maps and drawings of those facilities. Then, the maps are converted to a model which represents the facilities as links and nodes. Another layer of abstraction is introduced as the behaviors of the links and nodes, i.e. the water use patterns and flows, are described mathematically. The model equations are then solved, and the solutions are typically displayed on maps of the system or as tabular output. A model's value stems from the usefulness of these abstractions in facilitating efficient design of system improvements or better operation of an existing system. A flowchart of the modeling process is shown below (Figure 10).

Model-based simulation is a method for mathematically approximating the behavior of real systems. A water distribution system consists of a series of closed pipes carrying clean water, whereas the greywater system consists of closed collection pipes transporting the wastewater that

<table>
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<td>0300–0600</td>
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<td>97</td>
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<td>0900–1200</td>
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<td>94</td>
<td>0.14</td>
</tr>
<tr>
<td>1500–1800</td>
<td>66</td>
<td>0.10</td>
</tr>
<tr>
<td>1800–2100</td>
<td>162</td>
<td>0.23</td>
</tr>
<tr>
<td>2100–2400</td>
<td>50</td>
<td>0.07</td>
</tr>
</tbody>
</table>

Number of sampling = 20 houses
Daily average = 1,030 l/household

Field measured water use
Estimated average water use

<table>
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<th>Time</th>
<th>Average water use</th>
<th>Multiplier</th>
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<tbody>
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<td>9</td>
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<td>0300–0600</td>
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<td>0600–0900</td>
<td>91</td>
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<tr>
<td>0900–1200</td>
<td>95</td>
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</tr>
<tr>
<td>1200–1500</td>
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<tr>
<td>1500–1800</td>
<td>188</td>
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<tr>
<td>1800–2100</td>
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<td>0.25</td>
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<tr>
<td>2100–2400</td>
<td>154</td>
<td>0.14</td>
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</tbody>
</table>

Number of sampling = 15 houses
Daily average = 1,130 l/household

Field measured water use
Estimated average water use
the pipe material differs from the former. Both systems share the similarity hydraulically. The InfoWorks WS packages employed mathematics that covers the fluid properties, energy concepts due to frictions and most importantly the network hydraulic principles (Mays 2000). Such modeling theories are fundamental theories in engineering hydraulics and therefore not further discussed here.

The InfoWorks WS model is used to evaluate two scenario settings as in the subsequent sections.

**CONVENTIONAL WATER SUPPLY SYSTEM MODELING APPROACH**

This scenario shows the existing settings of delivering potable water to the consumers. Therefore, well-developed methodology for the water supply network modeling is applied.

The network data the Kuching Water Board owned is in the traditional paper record drawings and graphics-only Computer-Aided Drafting (CAD) formats. The system map of the Tabuan Jaya residential area is only available in paper map form. Therefore the pipelines and related information are digitized and stored in the ESRI ArcView environment where they are added as thematic layers to the previously sourced GIS cadastre map. The customized GIS that combine graphics and data can assist in abstracting the topology data and general network parameters such as length and depth, for InfoWorks WS model building.

Tabuan Jaya water distribution system is a combination of looped and branched systems. Those pipelines are in the forms of Asbestos Cement (AC) and Ductile Iron (DI). The main trunk along Wan Alwi Road is 400 mm AC. The known minimum pressure head of the Kuching Water Board water main is 18 m. From the big pipe, Tabuan Jaya residents are gaining clean water at three tapping points. This flow is then distributed locally to the users through a series of progressively smaller pipes or mains (see Figure 11). The pipeline size that is mostly used is the diameter of 150 mm (6").

![Figure 9](http://iwaponline.com/jwh/article-pdf/7/1/169/397137/169.pdf)

**Figure 9** Water use patterns for double storey semi-detached houses in Tabuan Jaya.

<table>
<thead>
<tr>
<th>Average water use</th>
<th>multiplier</th>
</tr>
</thead>
<tbody>
<tr>
<td>0000–0300</td>
<td>19</td>
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<tr>
<td>0300–0600</td>
<td>952</td>
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<td>0900–1200</td>
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<td>1200–1500</td>
<td>551</td>
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<tr>
<td>1500–1800</td>
<td>776</td>
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<tr>
<td>1800–2100</td>
<td>1,490</td>
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<tr>
<td>2100–2400</td>
<td>155</td>
</tr>
</tbody>
</table>

Number of sampling = 15 houses
Daily average = 5,490 l/household

The buildings being served are connected to the mains by small pipes called service lines or connections.

A network defines how the components of a water distribution system are interconnected. Network data includes the traditional data mainly composed of two
primary types—node and pipe data. A node represents the water system feature at specific location. The water distribution model has many types of nodal elements. Tabuan Jaya is intended to be modeled as a disconnected system where it is not necessary for the trunk main to be fully included. The trunk main is modeled at the tapping points as Boundary Nodes instead to impose a requirement within the network that simulates flows entering the system. Demand nodes are nodes where the water demand data is attached. Junction nodes are locations where pipes meet.

The model uses link elements to describe the pipes conveying water from one node to another. In the real world, individual pipes are usually manufactured in lengths of about 6 meters (18 or 20 feet), which are then assembled in series as a pipeline. Real-world pipelines also have various fittings, such as elbows, valves etc. For modeling purposes, a segment of pipes and associated fittings can all be combined into a single pipe element provided they have the same characteristics (size, material, etc.) throughout the length (Mays 2000).

Figure 11 | Pipelines network in Tabuan Jaya.

Figure 12 | An all-link network.
Next is the process of selecting for inclusion the model parts of the hydraulic network that have a significant impact on the behavior of the system. Attempting to include each individual service connection in a large system in a model could be a huge undertaking. However, the effort of capturing every feature of the small scale Tabuan Jaya system cannot be spared to investigate the impact of a greywater system to complete the important recycling loops in the domestic environment.

As depicted in Figure 12, it is possible to include all the individual connections, as no skeletonization at all where it is termed as an All-Link network. In this case, there is a junction at each service tap, with a pipe and junction at each house. This process is done manually where water use data is attached to each relevant node.

HYPOTHETICAL GREYWATER SYSTEM MODELING APPROACH

This scenario represents the hypothetical settings in addition to the conventional water supply system in which the treated effluent from the Ecosan facilities is reclaimed and reused in the domestic environment.

Little is known about the household water use patterns. Tchobanogulous et al. (1991) reported that 60–90% of the water consumed becomes wastewater. However, a study of the local wastewater characteristics (Ling et al. 2005) in two housing estates of Tabuan Jaya and Taman Satria Jaya reported a much lower rate. It was observed that the wastewater production is about 35–40% of the water consumed, which could be due to the internal leakage in the aging household pipes. Both Tabuan Jaya and Taman Satria Jaya have a standing history of over 20 years of establishment. Therefore, for the Ecosan modeling purposes in Tabuan Jaya, the water use patterns were presumably taken as greywater production is about 50% of water consumed, while human consumption is about 10%. The remaining volume is assumed as the one-time uses that would be thrown away. The modeling assumptions are depicted in a schematic diagram as shown in Figure 13. These assumptions were treated as the embedded Control Data that defined the operational rules of the investigated network.

InfoWorks WS is not custom-made to model Ecosan facilities. Thereby, the elements are simplified and modified in the model. The Oil and Grease Tank and the Biofilters (combining both the vertical and horizontal) are modeled as two wet wells, as shown in Figure 14. The pumps are modeled in parallel, which is a normal practice.
The greywater is to be transported to and fro by a series of closed Polyethylene (PE) pipes. These pipes are expected to be laid beside the storm water drains at the backyard of the consumers’ houses. They are similarly represented as nodes and links in the hydraulic network.

The current modeling approach only concerns the inflow and outflow of greywater in this system. Due to the on-site nature of Ecosan facilities, the loss of water is expected to be small. The water quality in the greywater system is not within the present scope. However, the InfoWorks WS package supports the water quality modeling and one important event of risk modeling, where it is possible to predict the propagation of bacteria species. Such information is lacking at the moment.

In the technological aspect, having two pumps in a single system may be a drawback considering that those pumps would cause quite an amount of maintenance and risks. The first pump is a submerged pump used to enable a pressurized aerobic spraying of the influent on the filtering materials. The second pump is a booster pump to increase the water head so that the treated greywater could be sent back to households. However, technical improvement could always be done literally.

## SIMULATION ANALYSIS

The current simulation results involve the inclusion of a hypothetical Ecological Sanitation greywater recycling system in Zones 1, 2, 3 and 4, while Zones 5, 6 and 7 are excluded to have a better comparison. The water withdrawal data at the three tapping points (for location see Figure 11) is tabulated in Table 1.

With partial inclusion of the Ecosan system, the estimated water use drops 42% at Tapping Point 1 and 41% at Tapping Point 2. The argument is that while the eastern region (Zones 6 and 7) is totally left out of Ecosan system, the water use at Tapping Point 3 is estimated to drop 36%. Take Tapping Point 1 to show an example of water use curve, the comparison of Tabuan Jaya water use rate (in l/s) of an average day is shown in Figures 15 (a)

<table>
<thead>
<tr>
<th>Network types</th>
<th>Tapping point 1</th>
<th>Tapping point 2</th>
<th>Tapping point 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Daily withdrawal (ML)</td>
<td>Max peak values (l/s)</td>
<td>Daily withdrawal (ML)</td>
</tr>
<tr>
<td>Conventional</td>
<td>0.52</td>
<td>11.39</td>
<td>0.29</td>
</tr>
<tr>
<td>Hypothetical Ecosan at Zone 1, 2, 3, 4 and 5</td>
<td>0.30</td>
<td>6.69</td>
<td>0.17</td>
</tr>
</tbody>
</table>

### Figure 15
Water use curve at tapping point 1. (a) Conventional Network, (b) Network with Ecosan.
(for conventional network) and (b) (for Network with Ecosan). The difference between the two graphs is significant since the peak hours at morning, noon and evening are lower during the scenario of greywater being recycled. Of course, such depictions are based on ideal conditions. Real time water uses are expected to be complex and difficult to predict. However, as the water use over the city has increased rapidly due to population expansion, the positive water saving prediction from the Ecosan greywater recycle system is encouraging.

The simulated water uses for the Tabuan Jaya are shown graphically in Figure 16 at one of the peak hours during noon. Lighter tone indicates a much lower water use while the darker tone indicates the opposite. Conventional networks show intense darker tone over the residential area. On the other side, networks with hypothetical Ecosan settings display a combination of light and dark tones, which imply that the water use is lowered with the inclusion of a hypothetical Ecosan into the system.

The saved volumes of water can be a water source to be transferred to other systems. This has achieved the objective of water supply sustainability, indicating that the greywater recycling system is one potential investment worth trying in an urban environment. The investigated Ecosan system potentially solves the wastewater problems in Kuching urban rivers to improve the river water quality, and at the same time, partly solves the water supply problems as a way to meet the water demand. The advantages of the integrated system are too great to ignore in an expanding city like Kuching city.

**CONCLUSIONS**

The introduction of an Ecological Sanitation pilot project in Kuching city is meant for environmental purposes to reduce the pollutant loadings of local waterways and rivers. The effluent is of good quality and released into the storm water drains and it is indeed a waste to throw away the treated water. The State Government is considering enforcing the system; however, the responsible ministry is facing some difficulties in deciding the management and maintenance of such facilities. The current research work presents an opportunity to incorporate the Ecosan facilities as part of
the urban water supply system, rather than solely a sanitation system. The integration of water supply/sanitation is one field which is increasingly gaining the worldwide attention for its public health contribution.

The hydraulic small scale modeling efforts of utilizing InfoWorks WS to investigate the potential of an Ecosan greywater recycling system have shown positive results for the domestic users. The water demand of the different categories of domestic user is lower by an average of about 40%. However, more work is still required such as the energy consumption of implementing such system, the associated costs in the attendant infrastructure involved and the toxicity risks associated with the use of greywater, which would all determine the eventual acceptance of this strategy.

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