Study of Urban Water Demand and Distribution System Reliability – A Case Study of Maharagama Water Supply Scheme, Sri Lanka

D.M.S.S. Dissanayake and R.L.H.L. Rajapakse

ABSTRACT

Significant variation of flow could be identified during the day for Maharagama water supply scheme. Diurnal problem curve indicates that there is a significant problem level, which is more than 40% of service level, during the day. The system operates at a low Hourly Peak Factor (HPF) value of 1.5, moderate Minimum Night Flow Factor (MNF) of 0.4 and Daily Peak Factor (DPF) of 1.1. Water supply system pumping capacity was found to be inadequate to cater the peak demand of the scheme. It reveals that elevation and the distance have a considerable effect on Level of service for Maharagama WSS and Service level has a significant effect on consumption quantity as well, affecting overall revenue. Aim of this study is to assess water demand, evaluate distribution performance of semi urban water supply scheme, and propose management recommendations as an initial approach that will eventually lead to the development of established guidelines for system assessment and operation. In the present study, monthly consumption per connection derived for the past 13 years from 2002 to 2014 and the daily average flow obtained for Mondays through Sunday for five weeks were studied by applying multiple statistical analysis using Small Samples Theory (SMT). A System Water Balance Model was used to generate the instant flow rate time series of demand from the available service reservoir level data and pumping data. Generated out-flow time series was analyzed using Large Sample Theory of statistics. Level of service variation with the proposed parameters was assessed with Principle Component Analysis (PCA) and simple tabular methods. Results were verified with field surveys con-ducted across the study area. The purpose of a water supply distribution system is to provide safe drinking water to each consumer with adequate quantity and acceptable quality. For the operational as well as designing aspects, it is crucial to estimate water demand that is how much water is needed and the variation in demand that is when it is needed. Every year, more than 100,000 new consumers are added to the National Water Supply and Drainage Board (NWSDB) database and the demand for pipe borne water is ever increasing. Out of the piped schemes maintained by NWSDB, only 36% has the capacity to provide 24 hour supply (NWSDB, 1998). Hence, the demand is a very important parameter which requires due consideration when considering urban water supplies.

KEYWORDS: Water Demand, Level of Service, Water Distribution Systems, Hourly Peak Factor, Minimum Night Flow, Daily Peak Factor.

1. Introduction

The purpose of a water supply distribution system is to provide an uninterrupted, pressurized service of safe drinking water with adequate quantity and acceptable quality to all consumers. The rapid increase in population density in a service area, increased number of connections, increased demand, etc., in combination with various other limiting factors could lead to numerous issues of inadequate supply and low pressure. Piped water is supplied to 43.4% of the population at present, which is over 8.5 million people in Sri Lanka (Annual Report, NWSDB 2013). However, disparities in service coverage across regions are still prominent, despite the massive investments made (over rupees 20,000 million a year) during the last few decades in the water sector in Sri Lanka. The total population in Sri Lanka was 20.30 million in the year 2012 (Census & Statistics Department, 2012 Census). Out of this, 3.7 million are living in urban areas, which amounts to 18.3% of the total population. At present, 80% of this population has access to safe drinking water where 43.7% is provided with pipe borne water supplies (Annual Report, NWSDB 2013). Out of the piped schemes maintained by the National Water Supply and Drainage Board (NWSDB), only 36% has the capacity to maintain an uninterrupted 24-hour supply, while majority of the other schemes have a 12-hour continuous supply on average (Urban Water Supply Policy, NWSDB). Every year, more than 100,000 new consumers are added to the NWSDB database and the demand for pipe borne water is ever increasing. Hence, the demand is a very important parameter which requires due

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consideration in the planning and design of urban water supply schemes.

Water demand in an area is the result of water consumption by individual people and industries in that area, reflecting their behavior and habits. For the operation as well as the designing aspects, it is crucial to estimate water demand, that is how much water is needed, and the variation in demand, that is when it is needed (De Silva, 2011). The current practice in Sri Lanka is to use basic statistical data such as population growth rate and per capita consumption to estimate the water demand. In the recently designed water supply projects, assumed diurnal variations and peak factors based on the results of foreign studies have been used without much insight.

The term demand generally used is based upon the average consumption of water. Nevertheless, when it comes to planning and design, this average consumption alone is not sufficient. Significant variations can be observed in the water consumption in seasonal resolution, monthly resolution, daily resolution and hourly time scale. Further, even in different minutes of the hour, demand variations of even finer scale can be observed. Thus, it is clear that assessing the variations in demand in the entire water supply system is imperative. The accurate assessments will produce a near optimal design as well as proper operation of the scheme, which leads to the improved service to the consumers.

Any underestimation of demand variations will result in an undersized water supply scheme, which will fail to deliver the required quantity of water at the correct pressure to the consumer. Although such schemes are capable of providing the required service levels at the beginning, they fail to do so in the middle or toward the end of the design period. In other words, they reach the design year quite prematurely (Abunada, Trifunović, Kennedy, & Babel, 2014; De Silva, 2011).

Since water supply related services tend to be of primary importance to guarantee good service levels in a sustainable way, the performance of water supply systems must be evaluated. The incorporation of performance assessment techniques in the management practices encourages efficient operation and continuous improvement. Managing water supply distribution network (WDN) is becoming difficult with the increasing population and the demand. A lack of available water, a higher and more uneven water demand resulting from population growth in concentrated areas, unplanned development and urbanisation, more intense use of water to improve general well-being, and the challenge to improve water governance already pose a tremendous challenge to providing and maintaining of satisfactory water services. The ever increasing demand for water has led to environmental problems such as overexploitation of water resources and shifts in the balance of the ecosystem, and it demands to use water in a more conscious and sustainable way. Even though the main concern is the supply side in the modern context, demand is the main governing parameter that allows efficient management of water (Candelieri & Archetti, 2014).

2. Objective

Aim of this study is to assess water demand, evaluate distribution performance of semi urban water supply scheme, and propose management recommendations as an initial approach that will eventually lead to the development of established guidelines for system assessment and operation.

3. Materials and Methods

Maharagama Water Supply Scheme (WSS) supplies water to 29 Grama Niladari Divisions (GND) in Maharagama and Kesbewa District Secretariat Divisions (DSD) in Sri Lanka with 28950 individual connections. From that, 26726 are domestic connections while 2220 are commercial connections. Population density in this area is 5141/km2 and household occupants 3.8 persons (Census & statistics department, 2012 census). Average daily water consumption is 22711m3 with 15-20% network leakage or non-revenue water (NRW) whereas it is going up to 33.43% in western province (NWSDB Annual Report, 2013). Average household monthly consumption was 16.9 m3 in 2013 (NWSDB Annual Report, 2013). Average per capita consumption is approximately 148 l/h/d. Domestic connections are growing at a rate and demand for water is increasing with the growth of population as well. Figure 1 shows the study area map.

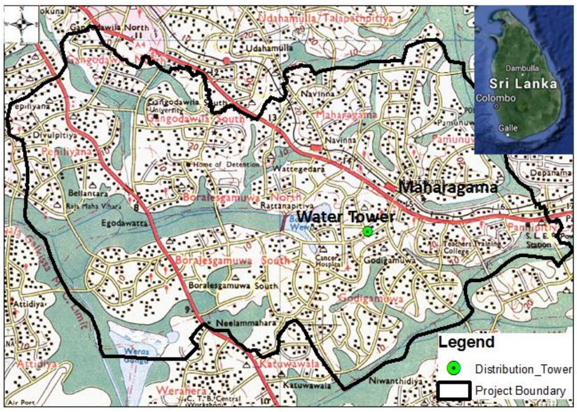

Figure 1 Study area map

In order to represent monthly variation of the demand monthly usage of domestic and commercial consumers of 15 years from January 2000 to December 2014 were collected. Daily inflow and daily pumping data were collected from 2005 to 2014. It is believed that the consumption has a monthly and weekly variation. Hence, hourly pumping data, 10 minutes resolution telemetry data that is levels of service reservoir were collected for five weeks corresponded to five months representing each monsoon period of the year from 2012 to 2014. From the above five months, all 7 days of one complete week (for which the most regular flow data were available) were selected as shown in Table 1.

Using this data, the following parameters have been estimated: average day demand, which is the average daily water use for the year; maximum day demand, which is the highest daily use for the year; and peak hour demand, which is the estimated maximum hour of water use during the year.

Table 1 Data duration details for dynamic analysis

Year	Month	Date	
		From	To
2013	December	22	28
2014	April	13	19
2014	June	22	28
2014	July	06	12
2014	Aug	03	09
2014	Oct	10	16

Data were checked for missing periods and visual examinations were also carried out. Consumption data were checked against inflow data and difference compared with Non-Revenue Water (NRW) percentage calculated by NWSDB. It shows no significant deviation of data. Abnormal deviations of monthly consumption were observed during visual checking and corrected identified rap around values of monthly usage by distributing off through respective months. Some years of data were removed from the study set since they found to be not reliable. Year 2000, 2001 and part of year 2002 were removed. This error may due to early years just after commissioning the system. Figure 2 and figure 3 show some important results.

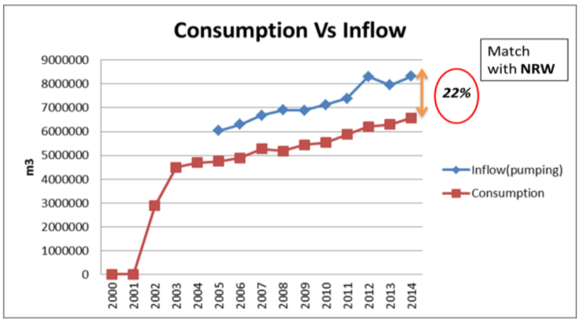

Figure 2 Annual consumption comparisons with inflow for Maharagama WSS

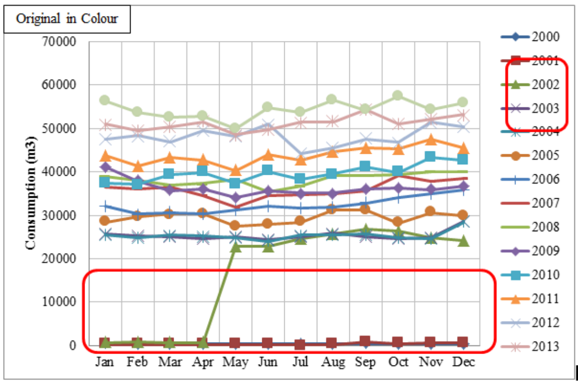

Figure 3 Monthly consumption comparisons of 15 years for Maharagama WSS

4. Methodology

In the present study, monthly consumption per connection derived for the past 13 years from 2002 to 2014 and the daily average flow obtained for Mondays through Sunday for five weeks were studied by applying multiple statistical analysis using Small Samples Theory (SMT). **A** System Water Balance Model was used to generate the instant flow rate time series of demand from the available service reservoir level data and pumping data. Generated out-flow time series was analyzed using Large Sample Theory of statistics. Level of service variation with the proposed parameters was assessed with Principle Component Analysis (PCA) and simple tabular methods. Results were verified with field surveys conducted across the study area.

5. Discussion

Significant seasonal variation in water consumption could not be observed in the study for Maharagama area and this is presumably due to the year round tropical climate in Sri Lanka with no significant seasonal variations. Past studies also have confirmed that there is no seasonal variation in domestic water consumption in the country (De Silva, 2011). Moreover, no monthly variation of consumption could be observed for Maharagama Water Supply Scheme. Further, the two month average and quarterly average consumption were estimated and studied and any significant trend could not be observed in those parameters as well. That implies that the consumers in Maharagama have adapted to a routine lifestyle throughout the year and system of supply remains constant (Rajapakshe & Gunaratne, 2005; Domene & Saurí, 2006; Jansen & Schulz, 2006). As a tropical country, Sri Lanka does not experience significant variation in temperature during the year. A statistical analysis of water use in New York City has shown that daily per capita water use on days above 25°C increases by 11 litres/°C (roughly 2% of current daily per capita use) (Protopapas et al., 2000). Hence, the uniform temperature over the year could be another reason for constant water consumption pattern.

Domestic consumption as well as the commercial consumption follows no monthly patterns and any monthly variation was not observed in per connection consumption. In Maharagama, the domestic consumption per month per connection is 20±3 m3. This is increased to 26.3±4 m3 in commercial category of consumers. In Maharagama, still a significant part being rural areas, it was reported that the people still use groundwater for a portion of their daily consumption and the recorded consumption is slightly low due partly to this. Two peaks could be identified and the morning peak is the highest while the evening peak is relatively flattened. The consumption follows a similar pattern almost every day regardless of minor changes from day to day. Flow is minimum at the early hours of the day and this generally represents leakage and filling up of storage tanks specially in high elevated and distant areas from the service reservoir. These storage tanks are not filled up during the daytime due to low pressure in the system. This is reflected in the tank water level variation, too. Flow increases sharply as the day advances, reaching a peak value around 7:00 to 8:00 a.m. Afterwards, the consumption drops down raises slightly again during early hours of the night as people use more water when they return home. However, this peak did not grow as expected and as it should have been, otherwise. This fact implies that the evening demand is not adequately met up to the level of morning demand by Maharagama WSS and the supply is prematurely curtailed. Then the consumption gradually drops to a minimum towards the midnight and early hours of the next day (Fig. 4).

It is further observed that the peak is less even when the water level is highin the balancing tank, implying that the mid-day peak is not that significant for Maharagama WSS. The hourly flow oscillates within almost similar minimum levels (MNF) and maximum levels (HPF).

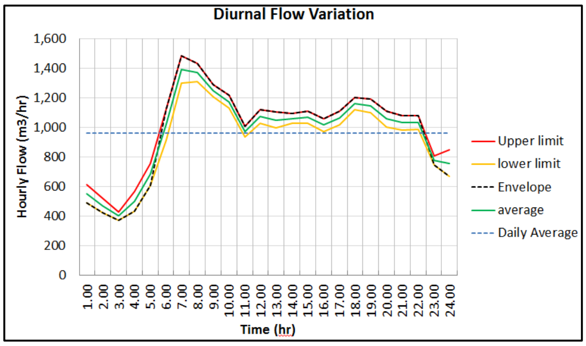

Figure 4 Diurnal Flow Variation

Diurnal problem curve derived from the field survey data indicates that there is a significant problem level, which is more than 40%, during the day (Fig.5). It is noted that a good service level with lesser number of issues reported prevails only during early hours of the day. When the demand increases, the reported problem level also increases.

In can be deduced then that the peak water supply demand in Maharagama WSS is not met even during the morning hours. Even though the morning peak is as high as 1.5 times the average hourly demand, the highest problem level recorded at the same time. That indirectly indicates the un-catered demand at the peak time. Hence, the obtained flow variation curve can be considered as the consumption pattern of the Maharagama area and obviously not the demand pattern.

The estimated Mid-night Flow factor (MNF) of 0.4 indicates that there still is a significant flow during the mid-night and early morning. This may be due to the filling up of domestic (household) storage tanks and leakages, which further indicates that there exists a large number of domestic storage tanks in the area and thus, the system is less reliable in consumer point of view.

The distribution system possibly is of domestic nature. High Hourly Peak Factor (HPF), Low MNF are inherent properties of a system where the consumption is mainly domestic. Very low evening HPF of 1.20 could be due to the insufficiency of the hydraulic capacity of the distribution system. The system can meet only a HPF of 1.20 during the evening peak and the remaining quantity of water is delivered through the enhanced flow during lean hours. A survey conducted in most part of the distribution area revealed a large number of household storage tanks and it was reported that some of the low pressure areas receive water only in the night time.

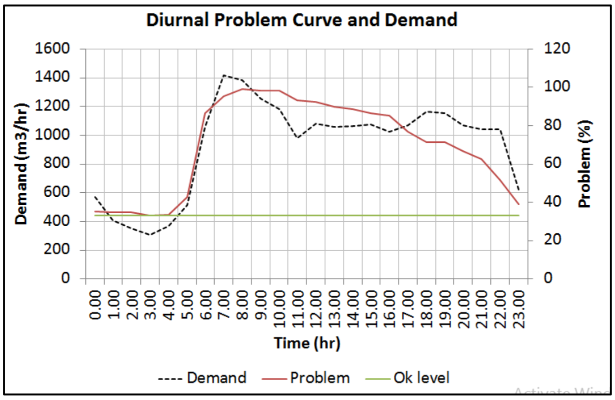

Figure 5 Diurnal Problem Curve

The existing systems operating at very low HPF and Daily Peak Factor (DPF) values should be augmented to improve the supply (De Silva, 2011). Under such augmentation, the availability of water at the service reservoirs should be increased and the pump capacity should also be upgraded as required. The capacities of the service reservoirs should also be increased if necessary, to allow for the increased rates of withdrawals during peak hours. The distribution system should be reinforced to convey the increased demand to the consumers living in all parts of the service area without any inconvenience. Level of service shows significantly

low indices in high-elevated areas above 20 m MSL for the Mahragama area. From the identified problem areas of Maharagama, except one area (528), the elevation has a significant effect on service level. Distance also indicates to have an effect but threshold value could not be identified. When the combined effect of elevation and distance are considered, a threshold value of 44 can be identified for deteriorated level of service (Fig 6). There are three outliers from this threshold from the identified seven problem areas. Those three outliers indicates higher pipe diameter than others and pipe diameter can also be a governing parameter determining the level of service for those areas. For the present study, however only three parameters contributing towards the level of service were namely Pipe diameter, Distance and Elevation considered. There can be similar other combined effects of these three and perhaps other parameters affecting the level of service and these should be further studied.
Low level of service areas show less per connection consumption than in other areas. and the fact implies restrained supply to those areas while the data from the last 6 years shows a greater decrease in level of service than that observed during the first 6 years, presumably due to higher demand and high connection density.

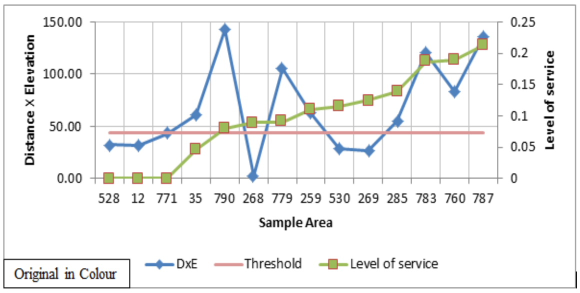

Figure 6 Combined effects of Distance and Elevation on level of service

6. Conclusions and Recommendations

System Water Balance study for service reservoir and sample consumer survey alone is capable enough to identify major deficiencies in the water distribution network.
Elevation, distance and pipe diameter have a considerable effect on determining Level of service in a water supply scheme.
Service level has a significant effect on consumption quantity and it is more significant in last six years.
There is no monthly consumption variation can be observed in Maharagama Water Supply Scheme as whole and for domestic and commercial categories separately as well.
The diurnal flow curve observed is actually not representing the real demand of the Maharagama area. It can be interpreted as a present consumption pattern.
Comparatively, Maharagama consumption pattern has a two-peak variation and Colombo consumption pattern follows three-peak variation.
Morning peak occurs at the same time at 07.00 for both Colombo and Maharagama whereas evening peak shifted one hour early at 18.00 for Maharagama WSS.
There is a considerable level of problems on water supply service during the day, specially during the peak hours, for Maharagama Area.
This type of study is very important prior to system upgrade or augmentation in order to plan better results.
This study should continue to cover the comparatively old systems in Colombo and outstations.
Such studies are helpful and essential to understand the behavior of the systems and to check the effectiveness of the design. This also helps to plan the augmentation work and to develop design guidelines for the forthcoming schemes of similar nature.
Focus should be made to zoning of the distribution system based on critical parameters identified on level of service and threshold values of technical parameters such as HPF, MNF and Tank water level. This will help to improve performance of the scheme as well as the operations.

7. Acknowledgments

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8. References

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