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Computation of Non-Revenue Water using Step Test for Achieving 24x7 Water Supply

M. R. Mulay[1], K. S. Bhole[2], Sanjay Dahasahasra[3]
[1]Associate Professor, A.P. Shah Institute of Technology, Thane, India
[2]Assistant Chief Engineer, Maharashtra Jeevan Pradhikaran, Nagpur, India
[3]Former President, IWWA and Former Member Secretary, Maharashtra Jeevan Pradhikaran, Mumbai, India

Abstract: An effective management of water supply systems becomes a need of an hour due to less availability of water resources in order to preserve and supply good quality water in sufficient quantities at adequate pressures to the consumers. However, a large fraction of the total input of water coming into a system goes unaccounted due to water losses and non-metered connections that leads to heavy loss of this precious commodity causing less revenue generation.

Inadequate supply of water to consumers due to water losses through leakages, illegal service connections further increases the complexity of the water management practices. It is observed that the maximum leakage occurs in the distribution system and house service connections and is around 80% of the total leakages in the system while the remaining percentage covers the loss at source, transmission system, treatment plants and service reservoirs.

Loss of water due to leakages and illegal connections contributes to Non-Revenue Water (NRW). In order to achieve the 24x7 water supply, water utility must know about the water coming into the system and losses occurred in the system. Generally, a step test is carried out to compute NRW of the water supply system.

Therefore, the objective of this paper is to discuss how the step test is carried out for the computation of NRW in achieving 24x7 water supply. Under Twinning program of Maharashtra Jeevan Pradhikaran (MJP) and RanHill Pvt. Ltd. Kualalampur, this test was carried out for one city near Mumbai.

Keywords: Water Audit, Non-Revenue Water (NRW), operational zone, District Metered Areas (DMA), Step Test.

I. INTRODUCTION

Water is a precious resource, limited in quantity and critical for the economic development of nation. However, developing countries worldwide face significant challenges in managing increasing demand for urban water because of industrialization, urbanization and the potential impacts of global warming on freshwater supply (Eduardo Araral & Wang, 2013). Moreover, not all water produced reaches the customers to generate revenue for water utilities but a significant portion of it is lost, due to leakage from water mains and unauthorized water consumption.

Water audit identifies how much water is lost and the loss of revenue against the same. It helps the utility to select and implement programs to reduce distribution system losses.

Water audits should be performed annually to help managers to adjust priorities, monitor progress, identify new areas of system losses, and establish new maintenance goals.

A water audit followed by the leak detection program can help water utilities reduce revenue losses and make better use of water resources.

Effective water management scheme aims at understanding the standard water balance, exact assessment of leakages (Mauro De Marchis & Barbara Milici, 2019) and minimizing/ avoiding non-revenue water.

Urban utilities in India aspire for a pressurized 24x7 continuous supply system for improving service delivery. However, as of today in India, only two small towns supply 24x7 water supply.

The main reason of an intermittent water supply is very high NRW values in Indian cities (Figure 1). The average NRW value in India is 38% which is on higher side.

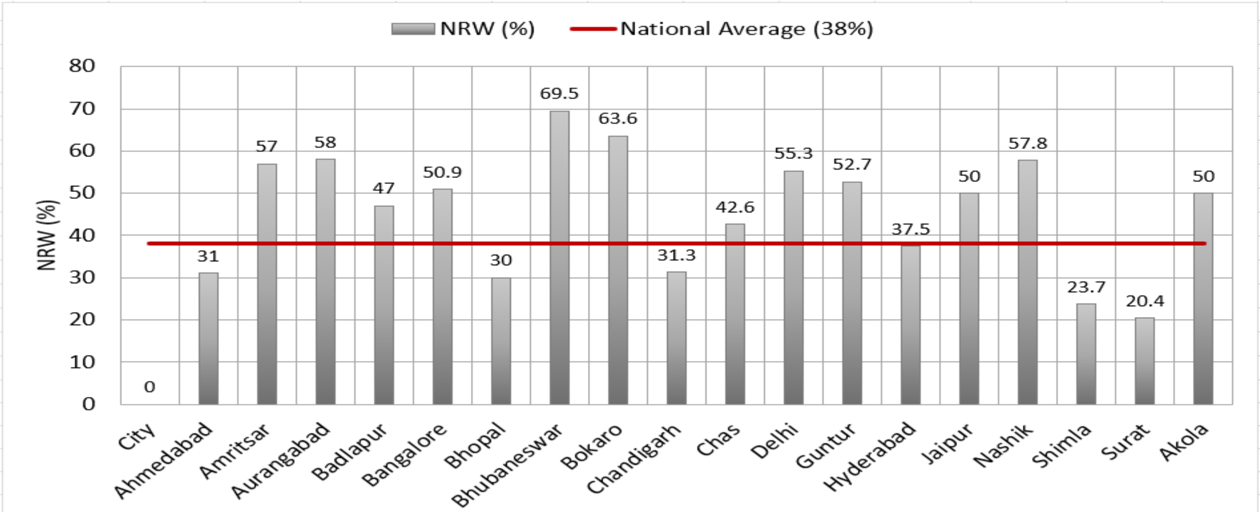

Figure 1: NRW (%) of Indian cities
(Source: MOUD, June 2012)

In order to transform existing intermittent water supply to 24x7 system of the water works owned by Maharashtra Jeevan Pradhikaran (MJP), a twining program was organised between MJP and RanHill Pvt. Ltd., Kuala-Lumpur. In the planning of 24x7 system, it was decided to first compute the NRW of the city. Hence, the “Step” test was planned in one zone of Badalapur city near Mumbai.

Objective of this paper is to discuss the Step test which was carried out to plan priorities of water loss program. NRW is defined as,

$$NRW = \frac{Water\ put\ into\ system - Total\ water\ billed}{Water\ put\ into\ system}\ x\ 100 \qquad (1)$$

To improve the financial health of water utility and improve service delivery, it is imperative to know the values of NRW in various District Metering Areas (DMAs) of the city and then plan to reduce NRW. Values of NRW indicate the efficiency of a water supply system. Quantification of the total amount of water lost is achieved by conducting a system-wide water audit, which is internationally known as a *water balance*. (Marcele Elisa Fontanaa et. al, 2016). A standard water balance is shown in Table 1. Total input of water in a water distribution network can be divided into two parts, (a) Revenue water and (b) Non-revenue water.

Table 1: Standard Water Balance

<table>
<tr><td rowspan="9">System Input Volume</td><td rowspan="4">Authorized Consumption m³/year</td><td rowspan="2">Billed Authorized Consumption m³/year</td><td>Billed Metered Consumption (Including water exported)</td><td rowspan="2">Revenue Water m³/year</td></tr>
<tr><td>Billed Unmetered consumption</td></tr>
<tr><td rowspan="2">Unbilled Authorized Consumption m³/year</td><td>Unbilled Metered Consumption</td><td rowspan="7">Non-Revenue Water m³/year</td></tr>
<tr><td>Unbilled Unmetered Consumption</td></tr>
<tr><td rowspan="5">Water Losses (NRW) m³/year</td><td rowspan="2">Commercial Losses m³/year</td><td>Unauthorized Consumption</td></tr>
<tr><td>Metering Inaccuracies and Data handling error</td></tr>
<tr><td rowspan="3">Physical Losses m³/year</td><td>Leakages on Transmission and/or Distribution Mains</td></tr>
<tr><td>Leakages and Overflows at Utility’s Storage Tanks</td></tr>
<tr><td>Leakage on Service Connections up to point of Customer metering</td></tr>
</table>

The percentage of physical losses is influenced not only by the deterioration of piped network, but also by the total amount of water used, system pressure, and the degree of supply continuity. The percentage of commercial losses depends on the degree of effort exerted in identifying illegal connections and in repairing meters.

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To a large extent, the level of NRW is an indicator of how well a utility is managed. GIS based Hydraulic model is vital in NRW reduction activity which is the major building block for achieving 24x7 water system (Dahasahasra et al, 2007; Tabesh and Delavar, 2003). Pressurized supply system may result in increase in NRW; however, installation of district flow meters, functioning of domestic meters on consumer connections will indicate areas where quantum of NRW is high and efforts to minimize NRW can be concentrated.

It is crucial to have strategy for the prevention of water losses starting from the planning and design phase of a project since it is challenging to detect water losses in distribution systems. It will be the ideal situation if all the losses that occur in the water distribution network could be detected and water loss is prevented at least for some period (Perera et.al., 2018).

II. PROCEDURE OF STEP TEST

A. Concept of DMA

In order to carry out STEP test, the first task is creation of DMA. It is defined as a discrete area of a water distribution network usually created by the closing the valves in which the quantity of water entering and leaving the area are metered. DMA receives water from bulk line coming from ESR and supplies continuous water through 100% metering of consumers.

Due to population increase, demand increases and it is observed that in many cities of India, the pipelines are laid haphazardly by ULBs in expanding areas that disturbs the hydraulics of distribution system causing inequitable distribution and low pressures and eventually uncontrollable from O&M point of view. Before the advent of DMAs, leaks were repaired only when they were visible (passive leakage control).

To get rid of passive leakage management, the DMA concept was first introduced to the UK in early 1980's. As leakage is linked to pressure, reduction in pressure is one of the significant elements of a NRW reduction strategy (S. Tsitsifli et.al, 2017). To implement pressure management, it is suggested that the water distribution network should be divided into smaller hydraulic isolated sub zones, called District Meter Areas (DMAs). With smaller sub-zones, an active leakage control is possible. NRW can be computed easily for DMAs. Thus, by creating DMAs, water utility can better target NRW reduction program, isolate water quality problems, and manage overall system pressure to allow for 24/7 water supply throughout the network. A typical DMA is shown in Figure 2.

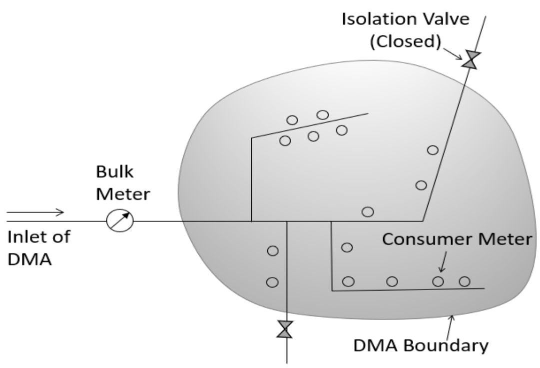

Figure 2: Typical DMA

So, if the entire distribution network is divided into number of operational zones (OZs) which are further divided into number of sub zones called as District Metered Areas (DMA), an active leakage control and of course the effective O&M is possible. Study of minimum night flow (MNF) is the most widely adopted analytical methods for leakage detection. It is carried out by isolating the entire distribution network into smaller zones called as DMA which is easier to be supervised and controlled (A. Candelieri et.al, 2013). One zone at a time is created and leaks detected and repaired, before moving on to create the next zone. This methodical approach progressively improves the hydraulic characteristics and supply of the water distribution network. For achieving the effective NRW reduction strategy, not only the identification of priority areas of distribution network and the method of network operation needs to be taken into account, but also required introduction of new methodologies and guidelines to assess, monitor and control various components of NRW. (Roland Liemberger, 2005). NRW can be computed easily for DMAs. Thus, with DMAs, water utility can better target NRW reduction program. With the reduced levels of NRW, water utility can definitely attain Millennium Development Goals (MDGs) by decreasing the proportion of society without access to safe drinking water (G. M. G Farrok, 2016)

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Step test is generally used to compute NRW within DMA. The name 'step' in this test has come from the appearance of graph shown in Figure 5, which resembles with steps of staircase. When the rise of step is too large then corresponding section has more NRW. If size of DMA is large, it should be split into smaller section, called as Sub-DMA. Step tests narrows search for leakage spot.

It is laborious and time consuming (Widy Saparina, 2016)

It is mentioned in the DMA Management Manual, published by IWA, (2006) about the DMA technique, which states that by carefully reducing the area of DMA by closing valves on each section and at the same time observing changes in flow rate of the bulk-meter. If there is a large drop-in flow rate then it indicates a leak in the section of pipe which has just been closed." To evaluate the level of leakage in the DMA, it is required to calculate the system's Net Night Flow (NNF). The value of NNF is then obtained by subtracting the Legitimate Night Flow (LNF) from the Minimum Night Flow (MNF). The MNF is the lowest flow into the DMA over a 24-hour period, which generally occurs at night when consumption is minimum (Ranhill NRW Manager's Handbook, 2008).

B. Precautions to be Taken Before Test

Before conducting a STEP test, ensure that the DMA is perfectly hydraulically discrete. This can be ensured by conducting the "*zero pressure test*" keeping all valves including the inlet are closed and checking if the pressure in the DMA drops to zero. It confirms the water entering from the other area if the pressure does not drop to zero (Yukun Hou, 2018). It is used to check whether a particular DMA is watertight. The procedure is as follows:

1) Indicate the boundary valves with different colour.
2) Inform the consumers about the test and arrange the test at night, say between 1 am to 4 am.
3) Plans of DMA boundary, boundary valves, and the DMA inlet valve should be kept ready.
4) Set up a pressure gauges at key locations within DMA
5) Close the DMA entry valve to isolate the DMA.
6) The pressure at the pressure gauge will drop. If the drop of pressure is immediate, the DMA is isolated perfectly.
7) If the pressure does not fall, then inspect the boundary valve and find the culprit valves.
8) Faulty valves should be replaced.
9) After the test is over, and water supply is restored, pressure gauge should indicate correct pressure.
10) If there is zero water pressure through the DMA, it means the boundaries of that area are watertight.
11) The isolation valves to be used for making segments must be tested for its functioning, they should be leakage proof.

DMA is divided into small sections by closing valves. Each small section is shut off at night (www.matchpointinc.us). Before any valves are closed, the minimum night flow (MNF) is recorded. It is called as "START" MNF value. Then, as each valve is closed systematically, this is called a "STEP" and the new MNF is recorded. The difference between the start and the new flow is the "STEP" value which is approximate NRW value.

III. CASE STUDY

The test was carried out in one DMA of the Badlapur city which is near to the Mumbai in India, total population residing in the DMA is 5,242. Part of the DMA chosen for step test consist of population of 3,669 through 304 house service connections. (Jagdish K. Vishe & Pravin S.Chaudhari, 2019) carried out quantitative assessment of Non-Revenue Water of Badlapur Municipal Council and it is mentioned that the NRW levels in the case study area ranges between 35 - 43% that are higher than the standard benchmark value. Network of DMA is shown in Figure 3. Using isolation valves, 9 segments are created which are shown in Figure 4.

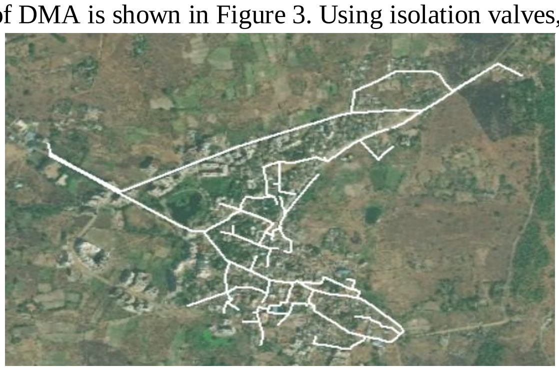

Figure 3: Network of the selected DMA in Badlapur city

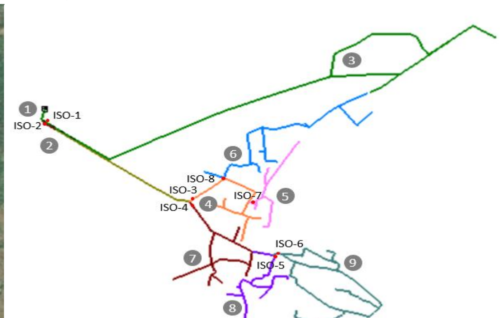

Figure 4: Nine segments in DMA created by isolation valves (shown in grey circles)

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A. Test Procedure

The test started at 12 PM (00:00 hours) to determine Minimum Night Flow (MNF). As the name implies it is to be conducted at night when legitimate consumption is less.

1) Before closing valves, initial MNF was noted which is 48.43 liters/ minute.
2) Isolation valve, ISO-6 is closed thus, Segment 9 is closed, hence flow in it is zero. The bulk meter reading (42.72 liters/ minute) at the outlet of the ESR is taken. The results are shown in Column 1 of Table 2.
3) Isolation valve, ISO-5 is now closed in addition to ISO-6 and thus, Segments 8 and 9 are closed, hence flow in these two segments is zero. The bulk meters reading (which is 37.79 L/M) at the outlet of the ESR is taken. The results are shown in Column 2 of Table 2.
4) The above steps are repeated till last Segment 1 is closed.
5) The valves are then systematically opened in the reverse direction and the MNF is again recorded. Accordingly, flow in Segment 1 is recorded first. Results are shown in Table 3
6) The process of opening valves is repeated till all the segments are opened one by one and each time the smart meter (bulk meter) readings (MNF in liters per minute) are noted.

The results of MNF are plotted against the time as shown in Figure 5. Also, MNF (NRW) in each segment is computed as shown in Figure 5.

Table2: Sequence of systematic closing of isolation valves

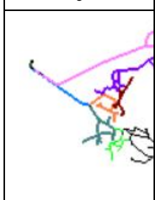
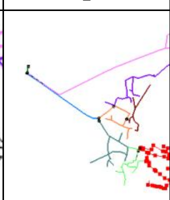
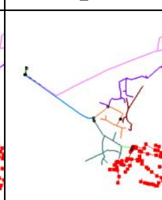
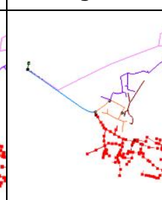
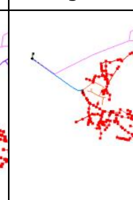
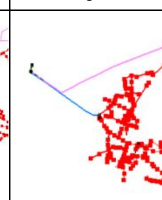
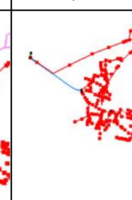
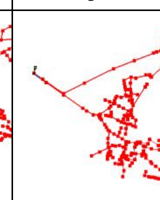
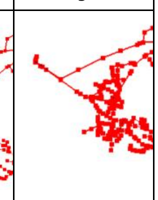
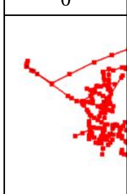
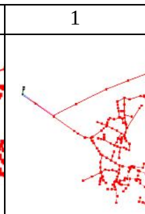
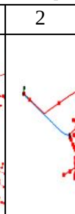
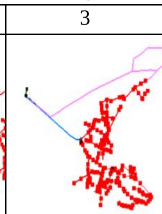
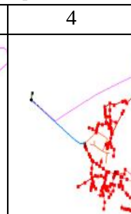
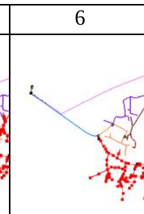
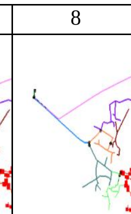
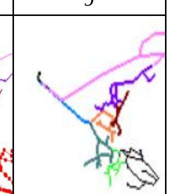
Sequence of segment (s) closed is in red colour									
0	1	2	3	4	5	6	7	8	9
									
Segment closed is Nil	Segment closed is 9	9+8	9+8+7	9+8+7+5	9+8+7+5+6	9+8+7+5+6+4	9+8+7+5+6+4+3	9+8+7+5+6+4+3+2	All closed
Valve to be closed is NIL	Valves to be closed is 6	6,5	6,5,4	6,5,4,7	6,5,4,7,8	6,5,4,7,8,3	6,5,4,7,8,3,1	6,5,4,7,8,3,1,2	6,5,4,7,8,3,1,2,0 (All closed)
START MNF (L/m) 48.43	MNF (L/m): 42.72	37.79	28.2	25.2	18.9	13.8	9.86	5.86	0

Table3: Sequence of systematic opening of isolation valves

Sequence of segment (s) opened is in red colour									
0	1	2	3	4	5	6	7	8	9
									
Segment opened: Nil	1	1,2	1,2,3	1,2,3,4	1,2,3,4,6	1,2,3,4,6,5	1,2,3,4,5,6,7	1,2,3,4,5,6,7,8	1,2,3,4,5,6,7,8,9 All segments are opened
Valves opened: Nil	0	0,2	0,2,1	0,2,1,3	0,2,1,3,8	0,2,1,3,8,7	0,2,1,3,8,7,4	0,2,1,3,8,7,4,5	0,2,1,3,8,7,4,5,6 All opened
MNF (lit/m): NIL	5.9	10	14.1	18.6	25.7	29	38.1	43.1	48.43

Note: The values of MNF in the sequence of one by one opening of segments are slightly observed to deviate from the values earlier noted while closing the segments.

Before conducting the STEP test, legitimate night flow (minimum night consumption) was measured by visiting the properties within the DMA such as hospital, bus stand etc. where the night consumption was observed and averaged out.

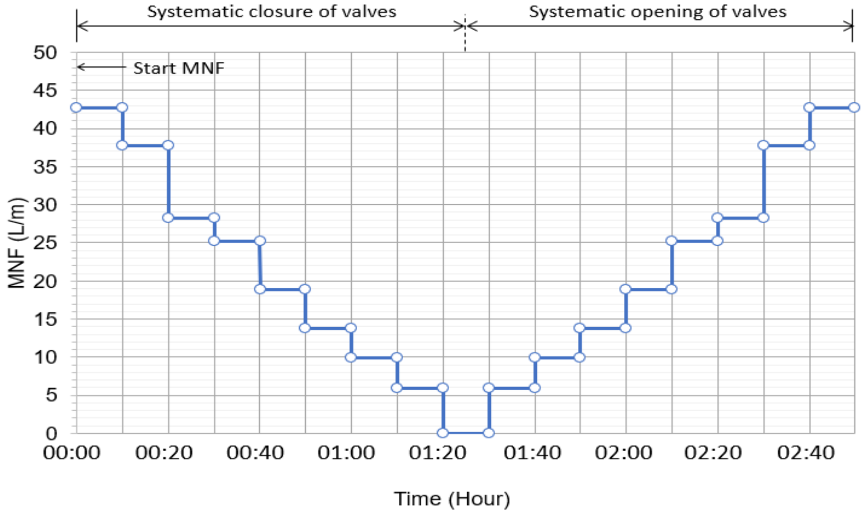


Figure 5: Values of MNF Vs. Time

Such legitimate night flow was established and was observed as 4.9, say 5 Liters per connection per hour on average basis, i.e., 0.083333 L/m. It may be observed that it is quite less compared to MNF. NRW values are computed by subtracting LNF from the values of MNF. The computation is shown in Table 4 and Figure 6

Table 4: Sequence of valve operations

SN	Section Closed	Valves to be closed	MNF observed at bulk meter at outlet of ESR (lit/min)	MNF (lit/min) Calculated by deducting present reading from previous		Segment	Connections	Legitimate flow, LNF = Col.7 * 0.08333 (L/M)	NRW= MNF-LNF (Col 5 – Col 8) (L/M)	NRW (%) = Col 9 *100/ Col 5
1	2	3	4	5		6	7	8	9	10
0	Nil	All opened	48.43			-	-	-	-	-
1	9	6	42.72	5.71		9	39	3.25	2.46	43.1
2	9+8	6,5	37.79	4.93		8	34	2.83	2.10	42.6
3	9+8+7	6,5,4	28.20	9.59		**7**	**36**	**3.00**	**6.59**	**68.7**
4	9+8+7+5	6,5,4,7	25.20	3.00		5	23	1.92	1.08	36.1
5	9+8+7+5+6	6,5,4,7,8	18.900	6.30		6	34	2.83	3.47	55.0
6	9+8+7+5+6+4	6,5,4,7,8,3	13.800	5.10		4	37	3.08	2.02	39.5
7	9+8+7+5+6+4+3	6,5,4,7,8,3,1	9.86	3.94		3	34	2.83	1.10	28.0
8	9+8+7+5+6+4+3+2	6,5,4,7,8,3,1,2	5.86	4.01		2	29	2.42	1.59	39.7
9	All	All closed	0	5.86		1	38	3.17	2.69	45.9
			Total	48.43			304			

Thus, the STEP test gives approximately the values of NRW in different segments of DMA. If there is sudden increase in value of NRW (as observed in segment 7), then further leak identification by other accurate methods can be made.

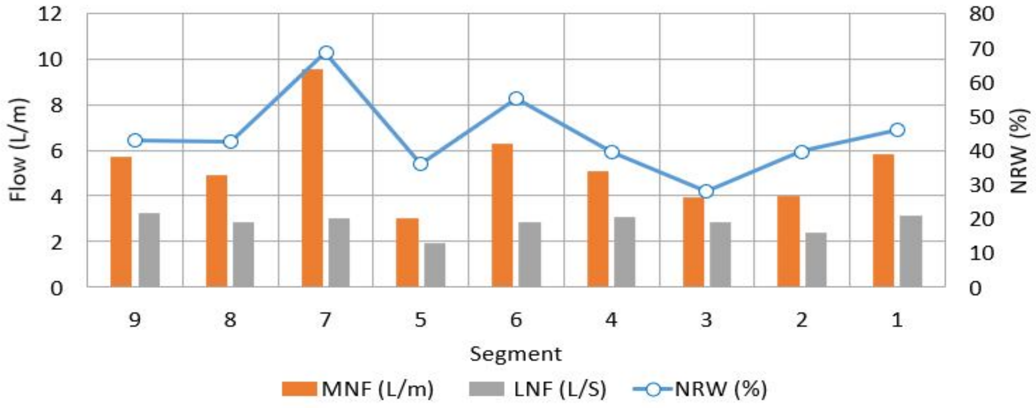


Figure 1: Relationship between MNF, LNF and NRW

IV. CONCLUSIONS

In the recent years, one of the major tasks is focused on the NRW reduction which is very important in achieving the pressurized 24x7 continuous water supply system. In order to accomplish the goal of water loss management and leak detection program various operations needs to be performed. One such significant task is to perform STEP test to compute MNF in various DMAs. This paper presents an overview of how step test is performed, which discusses in detail the tasks required to design and implement such a strategy. With such steps, it is easier to make action plans to reduce NRW to minimum level and can be practically applicable to any distribution network.

It can be concluded from the case study that Step test is essential in improving the leak detection and saving the time for leak location. It helps in detecting the section of pipe where the leaks are identified. Using the results of the Step test, 8 wards of the Badlapur city were converted to 24x7 system.

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