INTERNATIONAL RESEARCHERS

THE SCIENCE DMZ: FLOW – PRESSURE MEASUREMENT (NRW) SCADA FUNCTIONING AND HYDRAULIC MODELING IN FAISALABAD, PAKISTAN

Usman Iqbal and Guy More

Volume No.4 Issue No.3 September 2015

www.iresearcher.org

ISSN 2227-7471

THE INTERNATIONAL RESEARCH JOURNAL "INTERNATIONAL RESEACHERS"

www.iresearcher.org

editor@iresearcher.org

INTERNATIONAL RESEARCHERS is peer-reviewed, supported by rigorous processes of criterion-referenced article ranking and qualitative commentary, ensuring that only intellectual work of the greatest substance and highest significance is published.

INTERNATIONAL RESEARCHERS is indexed in wellknown indexing diectories

with ICV value 5.90

and moniter by

THE SCIENCE DMZ: FLOW – PRESSURE MEASUREMENT (NRW) SCADA FUNCTIONING AND HYDRAULIC MODELING IN FAISALABAD, PAKISTAN

Usman Iqbal[1, 2], Guy More[2]

[1]Water Resources Engineer, Centre of Excellence in Water Resources Engineering, University of Engineering and Technology, Lahore, Pakistan
[2]ARTELIA Ville & Transport SAS au capital de 4671 840 € SIREN 444 523 526 RCS Grenoble 6 rue de Lorraine 38130 Echirolles

(PAKISTAN)

[1] usmaniqbaluaf@yahoo.com and [2] more-guy@orange.fr

ABSTRACT

The city Faisalabad is the third largest metropolitan of Pakistan with population of about 2.8 million. The objectives are indicating the level of leakage in order to prioritize leak detection in Faisalabad. The leak detection was done once the network zoning was completed on the zones and all hydraulic zones were tested by conducting a zero pressure test which confirms the isolation of each zone. The portable flow meters were installed on all flow points in the pipeline network. All flow data was collected during the flow measurement, also used for hydraulic modeling. From the measurement the parameters are concluded as, (a) for better results the continuous supply was used, (b) flow and pressure logged at five minutes intervals at each flow points (c) average pressure over 24*hr* (in our case minimum or either maximum), (d) minimum night flow between 00:00 and 01:00 A.M including large users (e) average daily consumption and average daily level of leakage. The use of DF JUNIOR acoustic detectors and MICROCORR Touch Correlator for the location of leaks for Faisalabad system was helpful in determination of water loss via leakage and variation of leakage due to leakage patterns. The ArcGIS 9.10 and WaterGEMS were used and there are a huge variation of pressure was noted on network due to Terminal Reservoir ON/OFF (Maximum = 2.40 *bar*, Average = 1.38 *bar*, Minimum = 0.36 *bar*). The minimum night flows are less than 0.40 *l/s/km* and for DMZ 6, 10, 15 and 16, the minimum night flow values are less than 0.10 *l/s/km* and do not require leak detection. For the largest pipes, 3 Ultrasonic Flow meters of ULTRAFLUX brand was installed at the outlet Chenab Pumping Station (DN 1500) and at the inlet Terminal Reservoir (DN 1500). The third one installed at the new arterial main (DN 1000) connected to Jica line. Two number of ENDRESS/HAUSER (E + H) level sensors with digital display was installed at new and old reservoirs at Terminal Reservoir. All these equipments were linked to the Sofrel GPRS data logger connected to the SCADA via a SIM card. We included also the new and old existing Bulk Meter at Terminal Reservoirs. 62 Remote Terminal Units (Sofrel LS42) and 1 SCADA Master Unit was use, 55 Flow measurements data and 52 Pressure measurements data. In WATERGEMS, closed valves are not a special feature; they are modeled by closing a pipe, and have been integrated to the model. At the end of study we determine the number of leaks, to repair them and to maintain maximum flow rate in pipeline distribution network of Faisalabad as per requirements and peak demand. We recommend that this study conduct after every 10 years in-order to avoid the losses due to leakage of water and to maintain the continuous flow patterns in multiple sites. About 60% of repairs on pipes ≤ DN 100 and houses connections, 40% of repairs on pipes ≥ DN 100 which includes (10% of repairs on pipes of DN 300, 5% of repairs on pipes DN 250, 15% of repairs on pipes DN 200). The survey was carried out on 585 large customers and largest consumers without water meters in place were investigated in-order to define the interest of implementing a metering. The component of leakage was investigated such as (a) background leakage (b) burst leakage. The backward leakage was investigated initially using the standard criteria such as network length, number of connections, average pressure, later once leaks was repaired and the second measurement was carried out. The burst leakage was calculated deducting background leakage from average leakage level. The average estimation made in the flow and pressure measurement was 414 *l/s*. Leakages and unaccounted consumptions in Arterial main was modeled by simulating some outlets in the Arterial main and by calibrating these outlets in order to totalize an average flow around 880 *l/s*. The variation in DMZ1, 2 was = 2,450 in 15,800 hours, 2,250 in 16,700 hours (recorded). The Hourly

Hydraulic Pattern Consumption_Pattern_DMZ3 dictates Curve1 = Curve3 at 2,350 Multiplier within 5,900, 15,800 hours and the middle Curve at 2,270 (when, Curve1=Curve3≠Curve2). The representation within DMZ4 different than DMZ 5 (Curve1<Curve2<Curve3=DMZ4), (Curve1>Curve2<Curve3). The DMZ6 Hourly Consumption pattern depicts Curve1≠Curve2≠Curve3. The huge leakages within DMZ7 was observed with (Curve1<Curve2 and Curve3>Curve2) and comparison of DMZ 7 in opposition to DMZ 8 provides (Curve1>Curve2<Curve3). The DMZ 9, 10 provides similar results with DMZ7, 8. So DMZ 7, 8 = DMZ 9, 10 and Curve1<Curve3, DMZ9=DMZ10 (in consumption). DMZ11, 12, 13 shown that consumption>production (prevailing poor conditions due to excessive leakage in Faisalabad), so (Curve1<Curve2<Curve3=DMZ11), (Curve1<Curve2>Curve3=DMZ12), (Curve1<Curve2>Curve3). DMZ15-A presents (consumption ≠ production). The fluctuations in Multipliers was recorded maximum at 10,800 hours, the consumption patterns are increasing from 6,900 – 10,800 hours and after that consumption decline to 15,800 and 22,200 hours (2,000< 2,600>2,400>2050=Multiplier). As noted that the consumption rate within DMZ15-B.1<DMZ15-B.2 (50,400<59,375 at 90,000 hours).The leaks exceeds production in DMZ 15-B.3, a peak was obtained on 20,900 at 16,200 hours and DMZ15 -B.3>DMZ15-B.4 in consumption (20,900 at 16,200 hours>12,950 at15, 900 hours).

KEYWORDS: DF JUNIOR Acoustic Detectors; MICROCORR Touch Correlator; SCADA; DMZ; DMA; ArcGIS 9.10; Water GEMS; Non Revenue Water; Water Leakage; ULTRAFLUX; ENDRESS/HAUSER (E+H); Sofrel LS42; Insertion flow meter; Pressure data logger.

1. INTRODUCTION

The water demand in Faisalabad is currently above twice the capacity of the production of the city and the current water coverage rate is only 50%. The aim of this study is only to extend the production and distribution capacity of the city notably with leak detection using DF JUNIOR acoustic detectors and MICROCORR Touch Correlator. Indeed, the current state of the existing water supply network of Faisalabad identifies poor levels of performance with irrational distribution, irregular pressure, extensive leakage, with specific respect to water losses, and lack of the basic monitoring tools.

The DM was connected with Arterial Main Network through one unique node and the flow, pressure was measured at each and every entry point continuously through the installation of Bulk Meters. One connection node to the Arterial Main was corresponding to one entry point to a fully isolated area. At present only 105 of 2,465 industrial and commercial connections in Faisalabad are equipped with water meters. Despite the small quantity, those 105 large customers represent approximately 50% of total WASA revenue collection. The supply of right capacity and quality of water at the correct time to meet the demand of consumers, and the main target in water supply is to deal with leakages and due to excessive leaks the disturbance of water profile. On transmission lines (main reservoirs and arterial mains), the implementation of ultrasonic technology for flow metering for accuracy, smooth installation/ removing operation, in addition regarding hydraulic district metering implementation the first class electro-magnetic bulk flow meters for DN 300, 250, 200 for accuracy and operation and balance water monitoring was used. The major obstacles faced by utilities in infrastructure replacement are: (i) understanding when replacement will be required, (ii) how to schedule it over several decades, and (iii) how to pay for it in a fiscally prudent manner (AwwaRF, 2007, Zalewski, 2002).

Leakages seem inevitable, thus making it difficult to provide the right quantity and quality of clean drinking water on a timely basis (Kleppen, 2011). Kingdom et al. (2006) reported that, water losses in developing countries average approximately 50%, with the greatest fraction emanating from leakages. Mutikanga et al., (2009) reported levels of water losses of about 40% for the National Water and Sewerage Corporation (NWSC) of Kampala (Uganda). The major causes of water losses in Harare are: (i) old pipe networks dating back to the 1960s (ii) lack of knowledge of the water distribution networks (inadequate records), and (iii) low awareness on partitions of NRW, (City of Harare, 2011).

Furthermore, there are no set methodologies or tools that can be used to analyze, reduce and control different components of water losses in the distribution system in developing countries (Farley, 2003). However, several methods exist for detecting water distribution system leaks (Lahlou, 2011). In addition, correlator devices can listen at two points simultaneously to pin-point the exact location of a leak (EPD, 2007). Since leakage is pressure driven, all efforts resulting in the reduction of water pressure will reduce the water leakage to some extent. For example, doubling pressure will result in approximately 41% increase in leakage (WRC, 2001). Water pressure during the off-peak periods; tend to be much greater than the peak periods (McKenzie and Wegelin, 2009). The type of pressure control is useful in areas where water pressures build up during the off-peak periods, typically during the night when most of the consumers are asleep (McKenzie and Wegelin, 2009). The Night Flow Analysis Modelling (McKenzie, 1999) is the best practice analysis and monitoring strategy for the water leakage within a District Metered Area (DMA), (Hunaidi, 2010). This analysis is done when the customer demand is at its minimum and therefore the leakage component is at its largest percentage of the flow.

2. STUDY AREA

The study was undertaken in Faisalabad, Pakistan. Faisalabad is the third largest city of Pakistan with an estimated population of 2.8 million. Faisalabad stands in the rolling flat plains of northeast Punjab, the most populous province of Pakistan. The city has an average elevation of 184 meters above sea level and stands between longitude 73o74 East and latitude 30o31.5 North. The water network of Faisalabad was divided in 16 zones, and each zone divided in DMAs. The zoning design was realized on the GIS Software. During this activity all updates and modifications of the water network was carried out using pre-historical maps of Faisalabad network and present surveys (DMZ1-DMZ16), with total 94 DMAs. At the beginning of the zoning design the water network length was 1200 km. At the end of design the total length of the water networks was 1611.54 ≈1612 km. Table 1 dictates zone numbers with network length (Faisalabad), number of data monitoring areas. The Google Earth Map for Faisalabad is shown in Fig. 1. Faisalabad extracted map along with boundary line (Fig. 2). The structure of Faisalabad using GIS dictates the updates of network zoning (Fig. 3) and DMZ classification (Fig. 4).

Table 1: *Zone Number with Network Length and Number of DMAs (Faisalabad)*

ZONE #	Network Length	Number of DMAs
DMZ 1	52.02	3
DMZ 2	125.29	10
DMZ 3	71.29	5
DMZ 4	150.18	8
DMZ 5	86.81	7
DMZ 6	120.41	7
DMZ 7	133.04	7
DMZ 8	93.67	5
DMZ 9	115.77	7
DMZ 10	128.99	7
DMZ 11	246.33	11
DMZ 12	163.29	9
DMZ 13	13.83	2
DMZ 14	13.75	1
DMZ 15	86.96	4
DMZ 16	9.91	1
Total	**1612**	**94**

The general view of network represent all zone, the color changing represents the boundaries between zones. On the details of the zones, all valves and flow point position are showing. The color changing represents the boundaries between DMA.

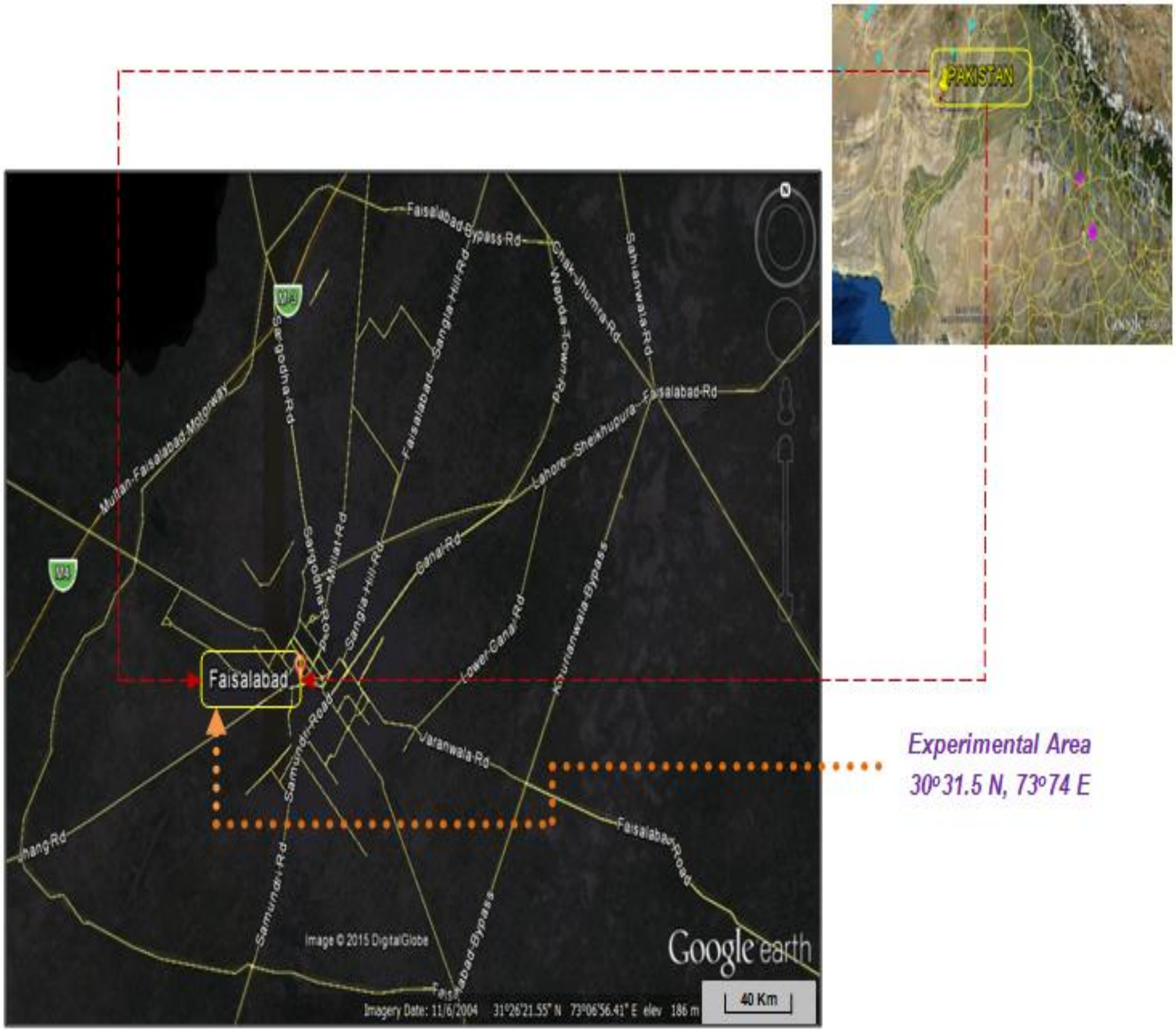


Fig. 1: *Location plan of Faisalabad Pakistan (Google Earth Map)*

The city Faisalabad detailed network map along with defined boundary lines is shown in Fig. 2. About half the total length of this pipeline (Arterial Main) is located within the city, both in low density as well as high populated areas. The critical network areas concerning pipe leakages are, (a). Old Cast Iron Pipes and (b). Old PVC, AC pipes. The critical network areas are mostly concentrated in the centre of Faisalabad and old colonies. The exact identification of critical districts was results from leak detection using standard instrumentation of leakage. Different axes are identified to explain these problems such as:

- **Monitoring tools:** Hydraulic Modeling.
- **Measurement tools:** Improvement of Bulk Metering.
- **Reduction of water losses**: Leak Detection and Repair, Pressure Regulation.

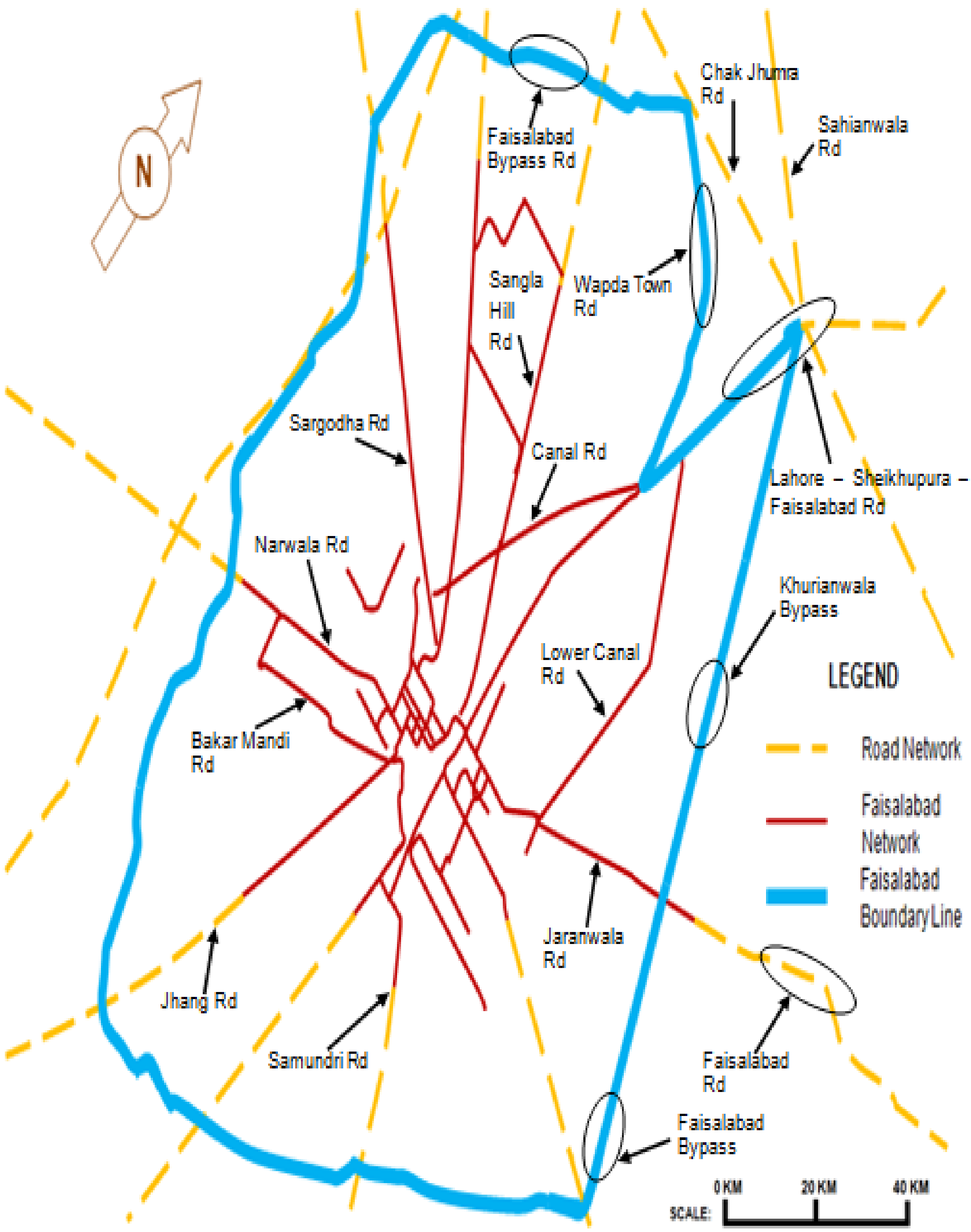


***Fig. 2:** Faisalabad network extracted map using GIS along with boundary line*

2.1 STRUCTURE OF GIS

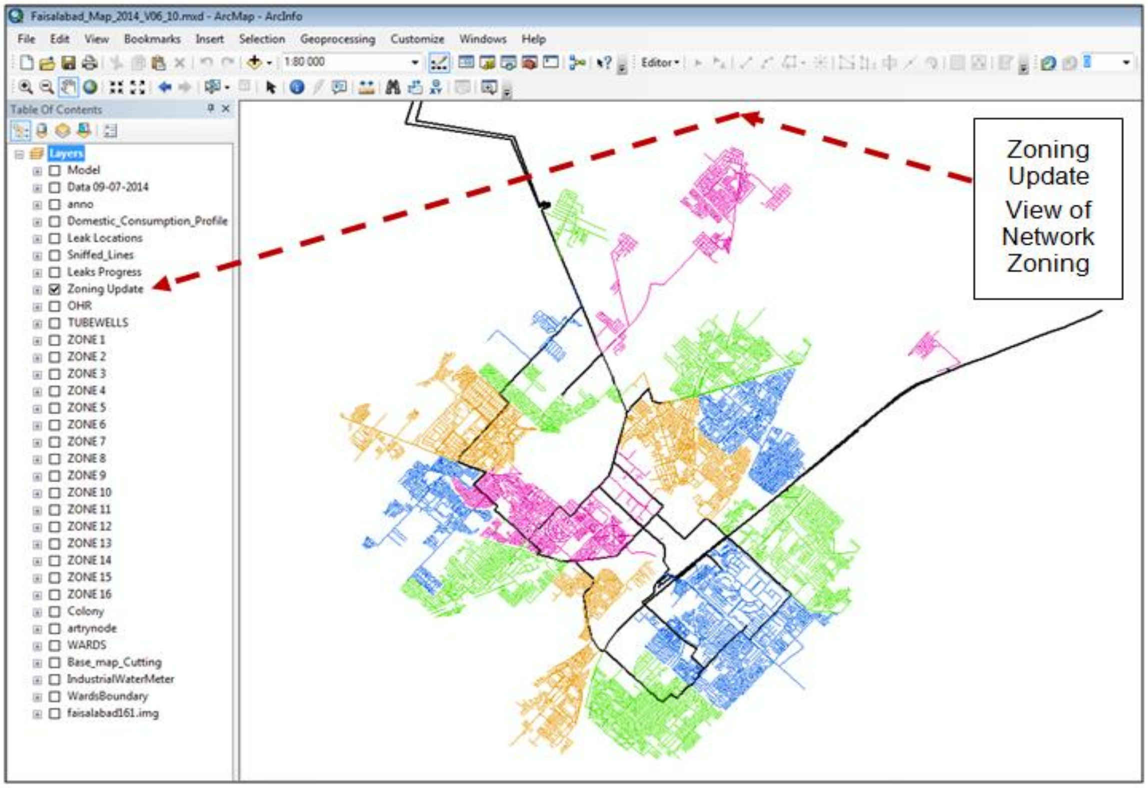


Fig. 3: Zoning update of Network Zoning for Faisalabad, Pakistan

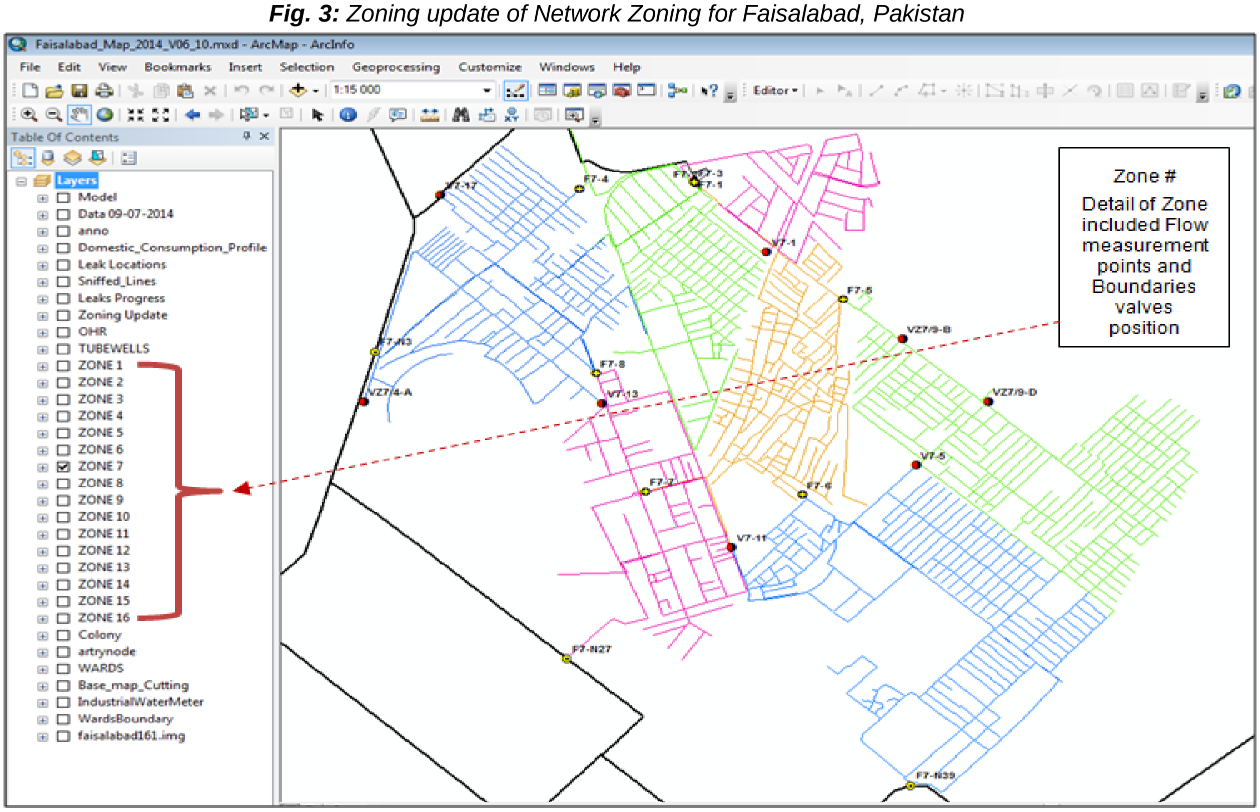


***Fig. 4:** Faisalabad structure with DMZ classification*

3. **APPARATUS/ EQUIPMENT USED**

a. Insertion flow meter b. Ultrasonic flow meter c. Pressure data logger

Fig. 5: *Equipment for experimental study (Faisalabad)*

4. **STUDY OBJECTIVES**

A. Installation of Ultrasonic Flow Meters, Endress/Hauser Level Sensor (E + H), and linkage of Sofrel LS42, GPRS Data Loggers with SCADA.
B. To extend the water production and distribution by means of leak detection using DF JUNIOR acoustic detectors and MICROCORR Touch Correlator.
C. The implementation of ultrasonic technology, hydraulic district metering for flow metering, and accuracy in Faisalabad.
D. Modeling of Faisalabad along with Arterial Main/Pipeline distribution network using ARCGIS 9.10 and Water GEMS and to determine water consumption patterns for Faisalabad with daily volume and average flow rates.

5. **DATA COLLECTION AND METHODOLOGICAL PROCEDURE OVERVIEW**

The suitable hydraulic modeling package with GIS data base connection with ArcGIS 9.10 and the main input data for modeling Faisalabad water network was, (a). Layout of pre-historic pipe networks, (b). Discharge, pressure head, Variation in Flow (day/ night), (c). Pressure zone boundaries, (d). Size, type and estimated friction factor of pipe based on the age and pipe material type, (e). Valve data (size and type), (f). Customer consumption data for the selected nodal points, (this was extracted from billing information), (g). Demand data based on the different consumer's categories, (h). Finally the data was digitized in the GIS database, (Twenty-four hour of measurement during the continuous supply was necessary to calibrate the model. Twenty-four hour simulations as well as at peak hours was carried out for two scenarios), (i) For the current situation, and (ii) for a future, improved scenario. The three stage of hydraulic division are: District Metering (DM), District Metering Area (DMA), and Step Test. In Faisalabad, the DM was matched with actual general structure of the network.

6. **METHODOLOGY**

6.1 **LEAK DETECTION**

We use DF JUNIOR acoustic detectors and MICROCORR Touch Correlator for the location of leaks for whole Faisalabad pipeline distribution network. Acoustic detection DF JUNIOR: differentiation of listening of the ambient noise with and without leak and Correlator MICROCORR Touch: access to the varies manus of parameters setting before a correlation, finally listening leak detection stick.

6.1.1 NOISE CORRELATOR – MICROCORR TOUCH

6.1.1.1 Installation and Programming the correlator on the Ground

We install, using procedure and programming the correlator the ground. Installation of two captors in contact with the water pipeline (valve, house connection) and selection of the mode to be used according to the site. Measurement of length between the two captors by the measuring wheel. Then finally programming the correlator by using the length between the two captors, and the diameter and the material of the water pipeline.

6.1.1.2 Analysis and Interpretation from the Graph on the Correlator

Explanation from graph to distinguish the curve between the normal consumption and the leak. According to the results on the graph, if there is a curve that shows a leak, to locate exactly where is the leak by moving the captors on the water network.

6.1.2 GROUND MICROPHONE – DF JUNIOR

6.1.2.1 Installation and use of DF JUNIOR on the Ground

We install DF JUNIOR on the ground, to position the piezoelectric sensor, this receives the sound from the environment, directly on the water pipeline or to follow or on asphalt by using mechanical component in combination the sensor. To adjust the noise and the sensitivity by using the receiver box carry case including a screen.

6.1.2.2 To Recognize the Sound of Leakage from other kinds of noise on the Ground

To distinguish between a regular sound from a leak and other sounds which increase or decrease, such as consumption or due to the traffic movement, using in combination, the headphone (to recognize the sound) and the sensitivity of the sensor shown on the screen on the receiver box carry case.

6.2 THE SOFTWARE – CALCULATION METHOD

The hydraulic system of Faisalabad was modeled with Water GEMS, software designed by BENTLEY. This is a computer program for evaluate specific fluid systems with water and it is used for modeling multifaceted networks or problems, develop master plans/ develop action plans.
It was simulated the hydraulic and qualitative behavior of the water in a network of Faisalabad under pressure and calculations was performed by the software are based on conditions of pressure in corresponding DMZ and DMAs, adequate flow under the laws of hydraulics, for each pipe segment (parts) and for each node (Faisalabad).

The determination of pressures and flow rates involves the techniques like simultaneous solution of Kirchoff's laws (only use as reference for clarification), in network pipe section. For this, the software uses the method of calculating the nonlinear equations of Hardy-Cross, since the networks are at least partially meshed. Literally, the algebraic sum of water flows into and out of a closed system must be zero (junction rule) and the algebraic sum of pressure losses must be zero on each loop (loop rule).

6.2.1 MODELING STEPS

The main steps of modeling are:

1. Choice of elements to model: essential first step where you have to decide the level of detail of the model, based on the target of modeling.
2. Constitution of the database: collection and synthesis of data on the pipes, structures, topography consumption.
3. Developing software format and import.
4. Getting network measurements : measurement operation or remotely managed data
5. Calibration of the model: adjustment of parameters and model validation.

6.2.2 COMPONENTS

The network was imported from Arc GIS to Water GEMS, including all the features of imported items, and errors that come with it.

6.2.2.1 **Static Data – Nodes**

Most of network nodes were represent a physical modification, that is to say a starting antenna, a change in diameter, a high point or a service customer.
Nodes are characterized by, (a) Elevation (provided in Faisalabad by a Digital Elevation Model (DEM), rather approximate), (b) Consumption, (c) The primary and secondary network of Faisalabad were modeled; 3315 nodes distributed throughout the network.

6.2.2.2 **Sections**

The sections represent the lines between two network nodes. They are characterized by: (a) Length (b) Inner diameter, (c) Roughness.

6.3 DMZ ANALYSIS

Daily analysis of DMZ minimum night flow was controlled in the same time slot and to monitor flow we recommend establishing a spreadsheet "excel" a monthly minimum night flow chart of each DMZ. The calculation of the water losses for each DMZ using following formula.
“Calculation method”

Minimum Night flow – Reference Flow – Large User

The unit used is l/s to convert m³/h to l/s, the formula is $\left(\frac{m^3}{h}\right) \div 3.6 = \ l/s$
To classify the priority of intervention for the second phase. We recommend the comparison of the minimum night flow by calculating the ratio in l/s/km.

6.4 DMA ANALYSIS

The programming and Installation of the electromagnetic insertion flow meters on the DMA according the map of the DMZ selected. To close the boundaries valves between DMA. Start the flow measurement to record the minimum night flow of each DMA. One night of measure is sufficient to obtain the minimum night flow. Finally calculation of the water losses for each DMA through.

“Calculation method”

Minimum Night flow – Reference Flow – Large User

The unit used is l/s to convert m3/h to l/s, the formula is $\left(\frac{m^3}{h}\right) \div 3.6 = \ l/s$
To classify the priority of intervention for the Third phase we recommend the comparison of the minimum night flow by calculating the ratio in *l/s/km*.

6.5 LEAK DETECTION

We Start injection of helium on DMA selected and the day after start the sniffing along the streets of DMA to locate the leaks. During sniffing it was necessary to refresh the holes in the street pavement with a drill machine. For new DMA that have not been inspected by us was first having to drill every 4 meters the streets before sniffing. For each localized leak, a form was filled with the following elements.
(a) Leak number, (b) DMZ and DMA number, (c) Address of the leak, (d) Date of detection (e) Name of team, (f) Date of transmission to the repair team.

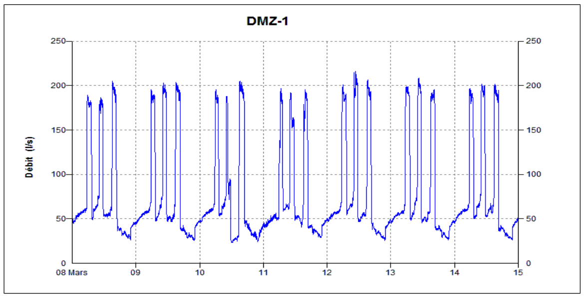
6.6 LEAK REPAIR

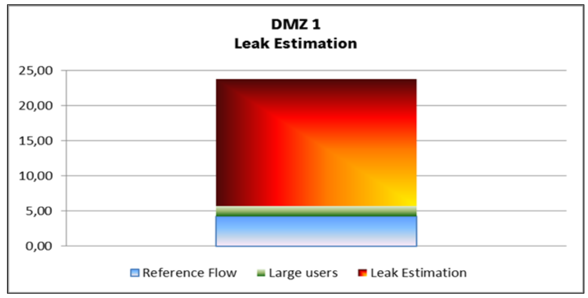
After each repair, the leak form was completed (for our research) with the following elements. (a) Repair date, (b) Name of team, (c) Type of the leak, (d) Pipe diameter, (e) Depth of pipe, (f) Pipe material. All these elements were recorded in a database.

7. RESULTS AND DISCUSSIONS

7.1 DMZ 1

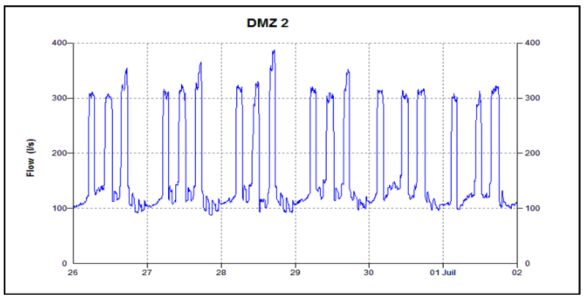
Flow and pressure measurement were carried out from March 8th to March 15th

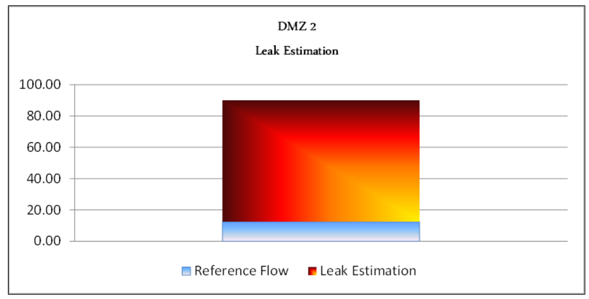




DMZ 2

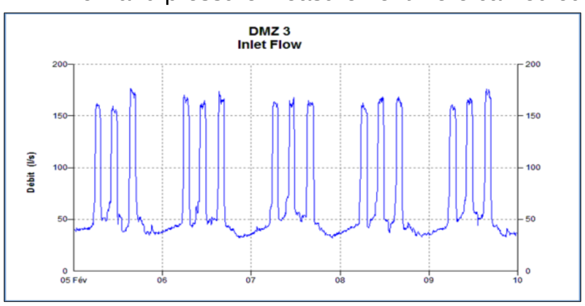
Flow and pressure measurement were carried out from June 26th to July 1st

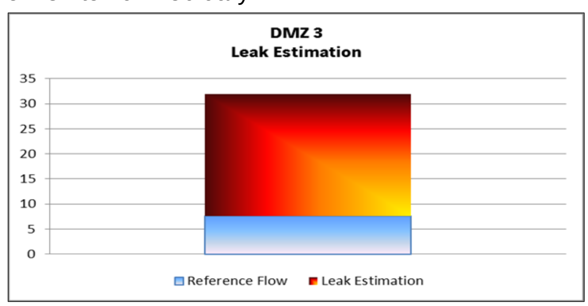




DMZ 3

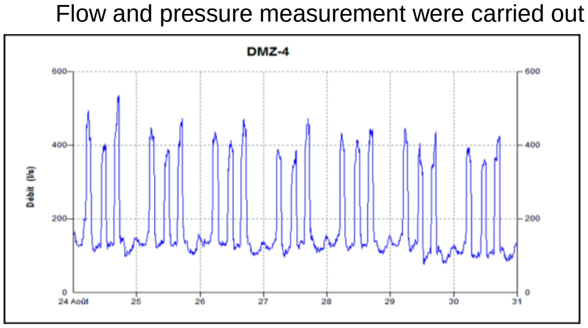
Flow and pressure measurement were carried out from 5th to 10th February

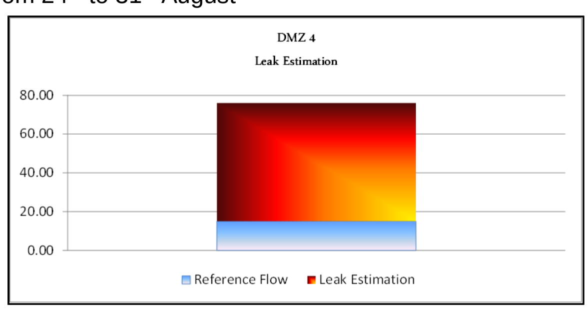




DMZ 4

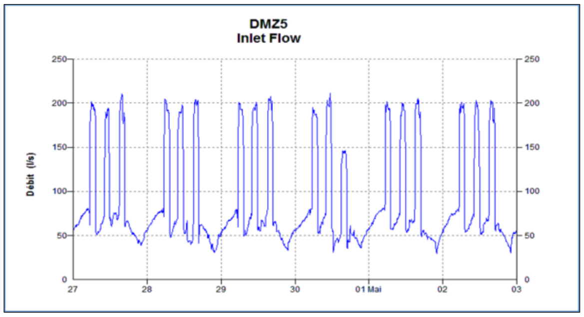
Flow and pressure measurement were carried out from 24th to 31st August

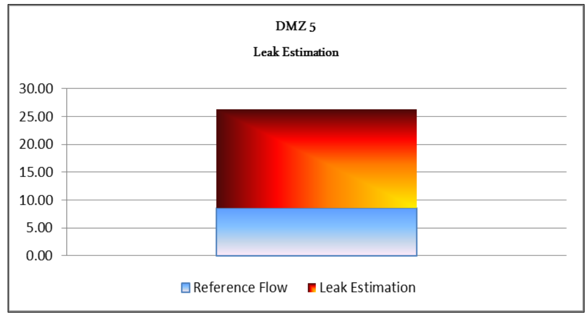




DMZ 5

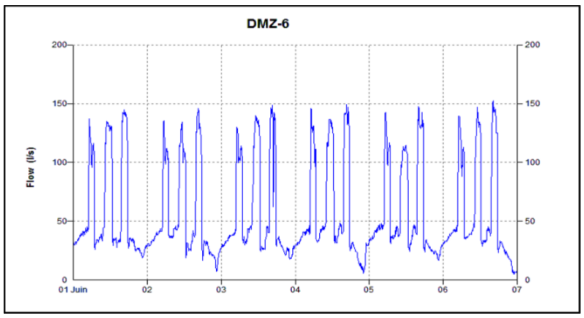
Flow and pressure measurement were carried out from 27th April to 3rd May

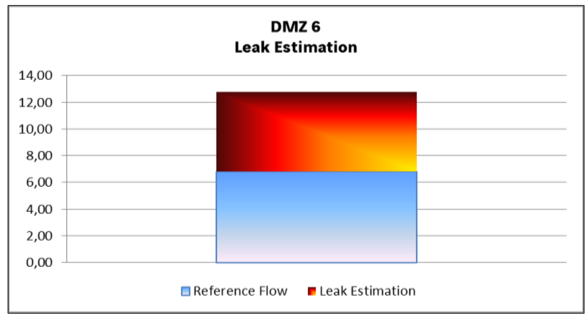




DMZ 6

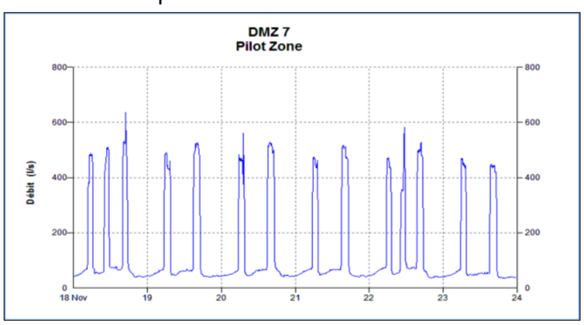
Flow and pressure measurement were carried out from 1st to 7th June

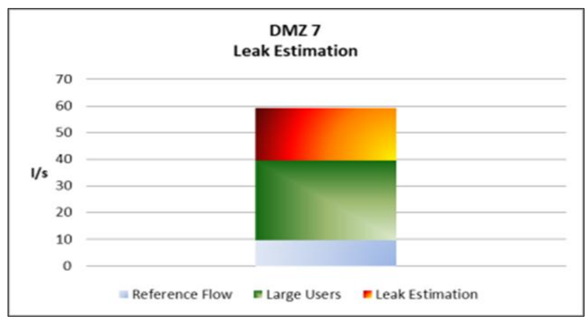




DMZ 7

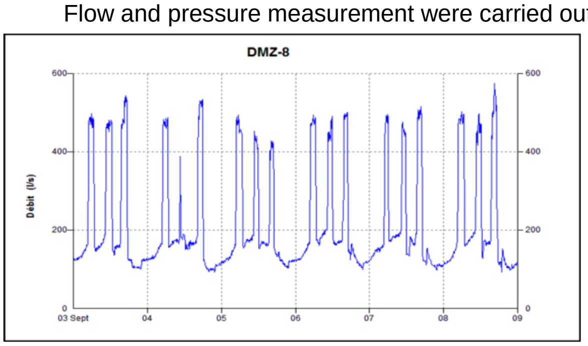
Flow and pressure measurement were carried out from 18th to 24th November

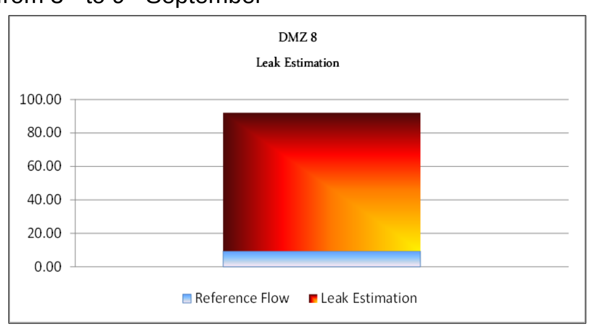




DMZ 8

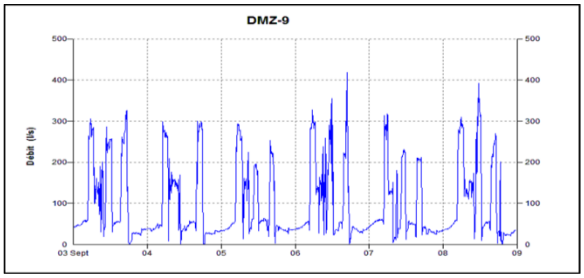
Flow and pressure measurement were carried out from 3rd to 9th September

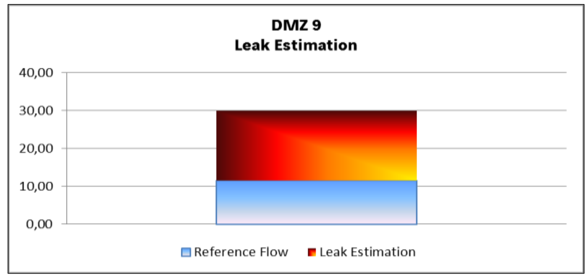




DMZ 9

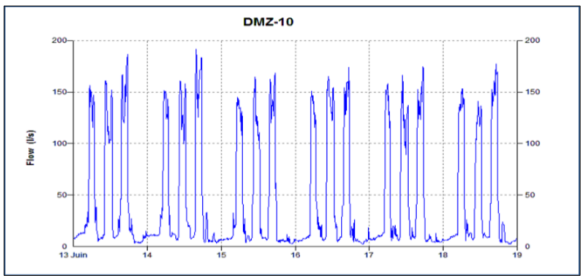
Flow and pressure measurement were carried out from 3rd to 9th September

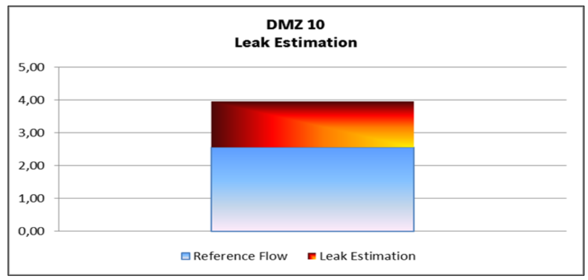




DMZ 10

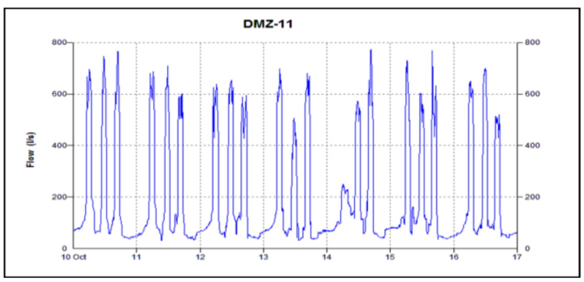
Flow and pressure measurement were carried out from 13th to 19th June

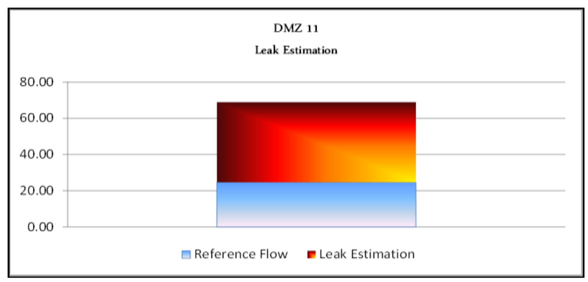




DMZ 11

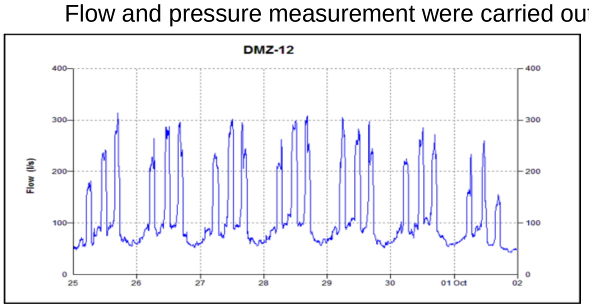
Flow and pressure measurement were carried out from 5th to 10th February

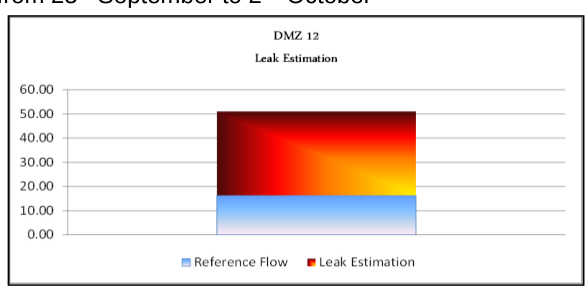




DMZ 12

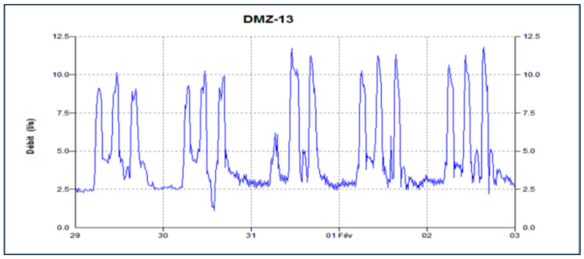
Flow and pressure measurement were carried out from 25th September to 2nd October

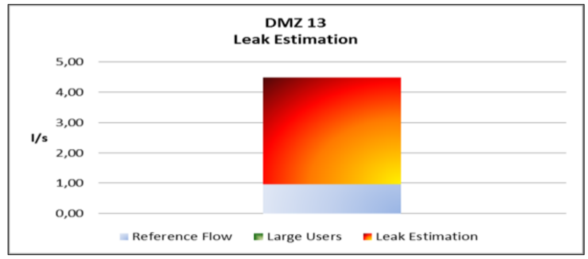




DMZ 13

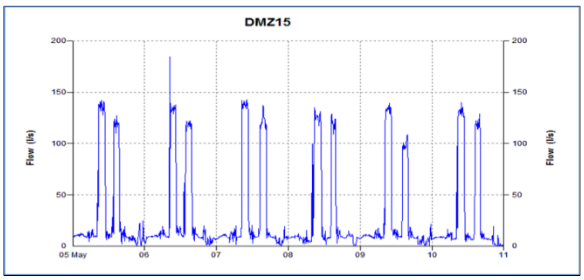
Flow and pressure measurement were carried out from 29th January to 3rd February 2014

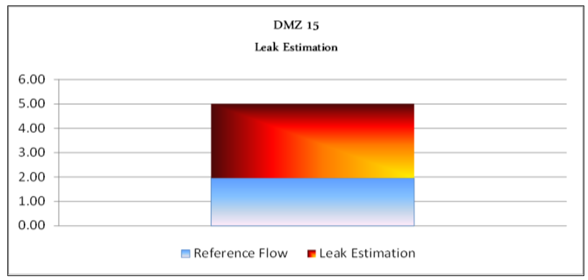




DMZ 15

Flow and pressure measurement were carried out from 4th April to 17th June 2014





DMZ 16

Flow and pressure measurement were carried out from 3rd to 9th September 2014

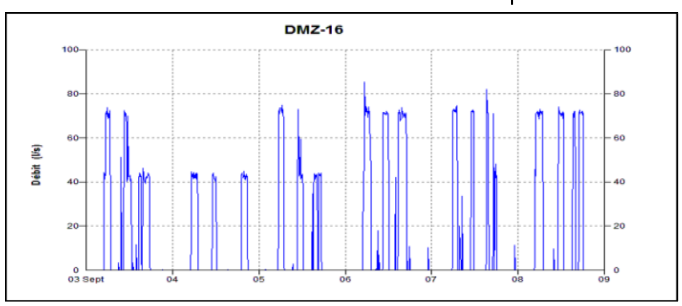


Fig. 6: *Flow and Pressure measurement (DMZ 1 – DMZ 16)*

The water demand patterns are also utilized and adjusted accordingly to reflect the change to recent consumption values and peak factors, with the assumption that base consumer usage patterns remain the same (GCW, 2009). The standard demand patterns are not able to represent water demands' stochastic nature (Todorovic et al., 2011) or the inverse relationship of peaking factors to connections/population size – peaking factors reduce with increasing connected households (Todorovic et al., 2011).

Furthermore, water demand profiles are usually gathered after long intervals, such as every three to five years, and may be outdated and not relevant to current periods. Hence, such patterns are of little use in modeling small or detailed network models or for predicting future water demands (Todorovic et al., 2011). Smart water metering would be expected, as a minimum, to convey daily meter readings between the water utility and the water meter, and potentially to customers as well. Finer levels of data capture (in seconds, minutes or hourly) could also be programmed into the loggers to enable more detailed analysis to be carried out (e.g. Beal and Stewart, 2011; Britton et al., 2013; Mead, 2008; Willis et al., 2011a). Typical household end-use studies report total and individual end-use consumption values (per capita and/or per household) as well as such details as diurnal consumption patterns, peak flows and the time of peaks (e.g. Beal and Stewart, 2011; Mead, 2008; Willis et al., 2011a). Measuring householders' perceived and actual water consumptions was also performed based on smart metering studies (Beal et al., 2013). Non-revenue water (NRW), which is the unbilled water prior to water supply reaching households (DERM, 2010; GCW, 2009), will not be considered, as the study focuses on direct household water consumption.

The householder has little control over leakage unless measures are taken to identify and rectify the problem. This latter possibility was demonstrated by Beal and Stewart (2011), whose reported leakage intervention resulted in lower leakage (post Winter 2010 results); although the increase in leakages in later periods indicates an ongoing requirement for leakage identification and communication to reduce this wastage (Britton et al., 2013; Beal and Stewart, 2011).

Table 2: *Number of connections, Daily average and Min. Night Flows, Reference Flows (0.10, 0.02, 0.06, 0.07 l/s/km), Large users consumption and Water loss estimation for Faisalabad*

#	No. of Connect - ions	Flow Recorded during Period (*m³*)	Daily Average Flow (*m³*)	Min. Night Flow (*l/s*)	Reference flow (0.10 *l/s/km*)	Reference flow (0.02 *l/s/km*)	Reference flow (0.06 *l/s/km*)	Reference flow (0.07 *l/s/km*)	Large Users Consumption (*l/s*)	Water Losses Estimation (*l/s , l/s/km*)
DMZ 1	4006	45 885	6 803	23.79	4.27 *l/s*	–	–	–	1.38	18.14 , 0.43
DMZ 2	13080	*85 157*	14 526	90.00	12.52 *l/s*	–	–	–	0.00	77.48 , 0.62
DMZ 3	10486	*29733*	5915	32.00	7.13 *l/s*	–	–	–	0.00	24.87 , 0.35
DMZ 4	13313	119 256	17 036	76.00	15.02 *l/s*	–	–	–	0.00	60.98 , 0.41
DMZ 5	10112	44 656	7 443	24.01	8.64 *l/s*	–	–	–	0.00	17.72 , 0.21
DMZ 6	7143	29 082	4 850	12.80		–	6.82 *l/s*	–	0.00	5.98 , 0.06
DMZ 7	14 159	66 195	11 032	59.03		–	–	9.25 *l/s*	30.00	19.78 , 0.15
DMZ 8	6872	123 970	20 661	93.67	9.37 *l/s*	–	–	–	0.00	82.63 , 0.88
DMZ 9	4257	35 465	5 910	30.00	11.58 *l/s*	–	–	–	0.00	18.42 , 0.16
DMZ 10	5817	23 060	3 845	3.97		2.58 *l/s*	–	–	0.00	1.39 , 0.01
DMZ 11	16 031	117 892	16 840	68.85	24.63 *l/s*	–	–	–	0.00	44.22 , 0.18
DMZ 12	10 304	69 166	9 880	51.00	16.33 *l/s*	–	–	–	0.00	34.67, 0.21
DMZ 13	679	2 011	402	4.50	0.97 *l/s*	–	–	–	0.00	3.53 , 0.36
DMZ 14	NO WASA WATER									
DMZ 15	2 195	15 322	2 550	5.00	1.96 *l/s*	–	–	–	0.00	3.04 , 0.15
DMZ 16	935	6 833	1 140	0.00	0.00 *l/s*	–	–	–	0.00	0.00 , 0.00

Large Users Consumption (l/s)

DMZ 1 (Minimum)

DMZ 7 (Maximum)

7.2 FLOW AND PRESSURE MEASUREMENT ANALYSIS

The Average pressure was recorded during the measurements on arty node and on network (Table 3).

Table 3: *Number of DMZ with average pressure at inlet point and at Network in whole Faisalabad*

DMZ #	Average Pressure recorded at inlet point		Average Pressure recorded on Network	
	Terminal Reservoir ON Max. 2.40 (*bar*)	Terminal Reservoir OFF Min. 0.36 (*bar*)	Terminal Reservoir ON Max. (*bar*)	Terminal Reservoir OFF Min. (*bar*)
DMZ 1	1.60	0.19	0.38	0.02
DMZ 2	1.05	0.24	0.28	0.01
DMZ 3	0.89	0.16	0.08	0.03
DMZ 4	1.00	0.10	0.33	0.00
DMZ 5	0.59	0.04	0.03	0.00
DMZ 6	0.39	0.01	0.14	0.00
DMZ 7	0.88	0.11	0.10	0.01
DMZ 8	0.90	0.18	0.08	0.00
DMZ 9	0.57	0.11	0.24	0.00
DMZ 10	0.68	0.05	0.06	0.00
DMZ 11	0.36	0.06	0.08	0.00
DMZ 12	0.44	0.12	0.07	0.00
DMZ 13	0.60	0.03	0.51	0.00
DMZ 14	NO WASA WATER			
DMZ 15 (*)	1.70	0.00	0.67	0.00
DMZ 16 (*)	1.28	0.03	1.28	0.03

(*) Independent Zone, not supplied by Terminal Reservoir

The pressure data loggers on the inlet of the DMA are located on the main pipe. The other pressures data loggers are located on the service pipe. The weak pressures recorded we remind the equivalent pressure value between 1 bar and the water level in meter. 1 *bar* = 10 meter of water level, 0.1 *bar* = 1 meter of water level and 0.01 *bar* = 10 centimeter of water level.

7.3 DAILY PRODUCTION CALCULATION FOR DMZ

The average volume was recorded during the measurements (DMZ 1 to DMZ 16) in Faisalabad.

Table 4: *Calculations for daily production (m^3)*

Faisalabad Daily Average Inlet of DMZ (m3)											
	DMA1	DMA2	DMA3	DMA4	DMA5	DMA6	DMA7	DMA8	DMA9	DMA10	TOTAL
DMZ 1	1 201	3 784	1 818								6 803
DMZ 2 (*)	14 526										14 526
DMZ 3	889	423	2 200	1 398	1 005						5 915
DMZ 4 (*)	22 800										17 036
DMZ 5	1 422	2 689		985	355	1 500	300				7 443
DMZ 6	4 850										4 850
DMZ 7	577	2 500	2 244	2 414	2 651	2 890	2 281				11 032
DMZ 8 (*)	20 662										20 661
DMZ 9 (*)	5 911										5 910
DMZ 10 (*)	3 850										3 845
DMZ 11 (*)	16 800										16 840
DMZ 12 (*)	10 460										9 880
DMZ 13	193	213									402
DMZ 14 (**)	No WASA Water										0
DMZ 15	820	290	202	200							2 550
DMZ 16	1 139										1 140
										Total	**128 833**

(*) DMA not completed (**) not connected at WASA system

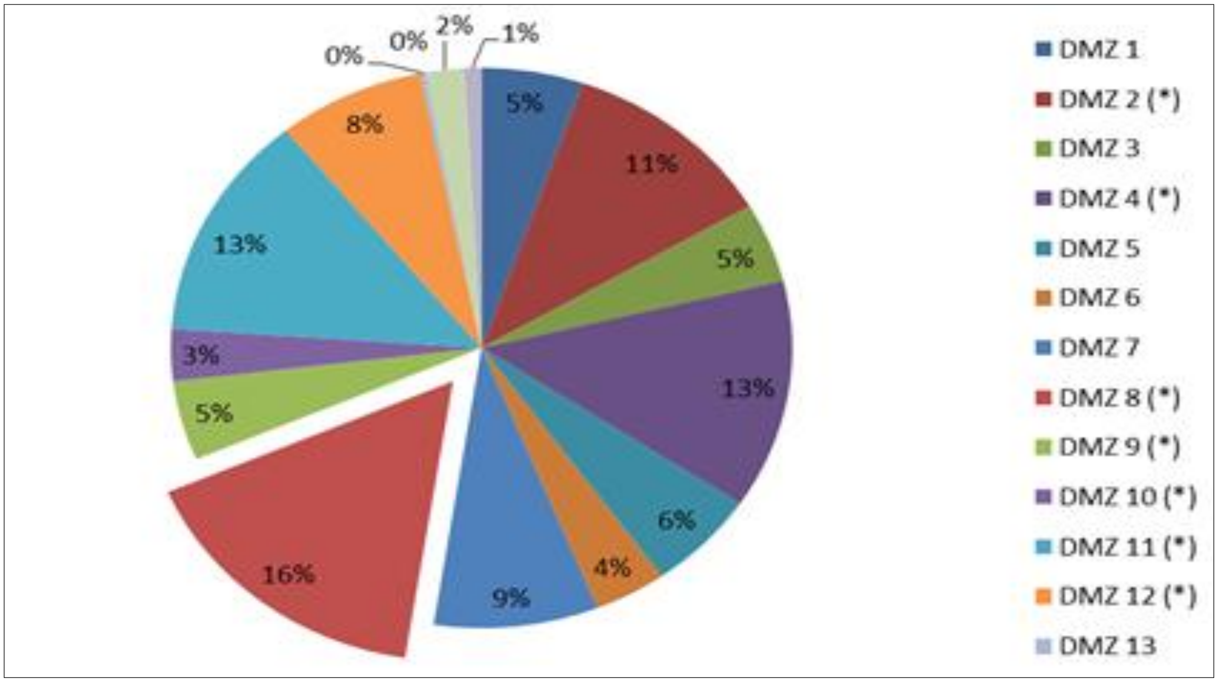


Fig. 7: *Daily average volume injected on DMZ 128 833 m^3*
Not included arterial main

This Volume is supplied by Terminal Reservoir during 6 hours (pressure 2.40 *bars*) and 18 hours by gravity (pressure 0.33 *bar*). The Fig. 7 represents the daily average volume injected on Data Monitoring Zone.

Measured minimum flow [l/s]-Reference Flow [l/s/km]*length [km]- Exceptional demand [l/s]: The reference flow for Faisalabad is shown (Fig. 8).

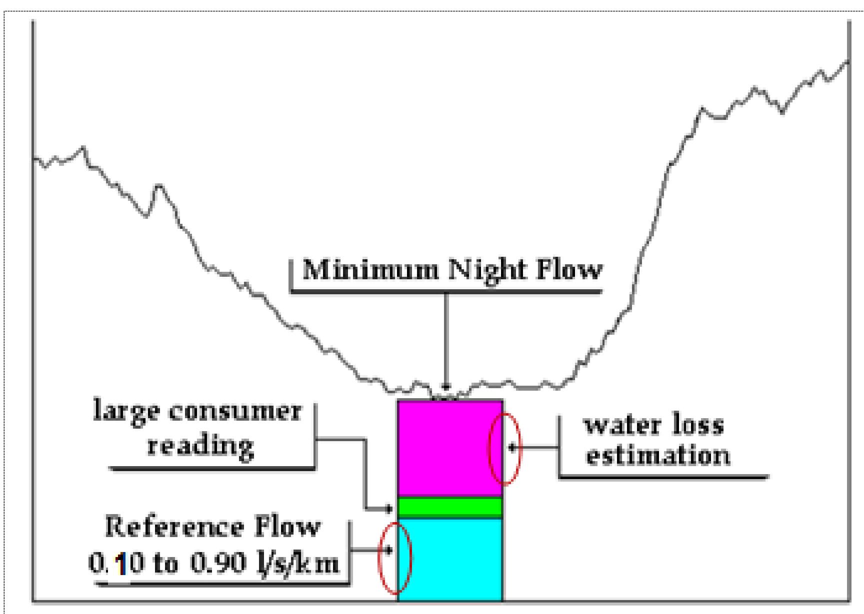


Fig. 8: *Reference flow used for Faisalabad was 0.10 l/s/km*

7.4 WATER LOSSES CALCULATIONS

Table 5: *Faisalabad calculations for water losses*

Faisalabad Water Losses Estimation (l/ s)											
	DMA 1	DMA 2	DMA 3	DMA 4	DMA 5	DMA 6	DMA 7	DMA 8	DMA 9	DMA 10	TOTAL
DMZ 1	3,50	11,03	3,61								18,14
DMZ 2 (*)	77,48										77,48
DMZ 3	3,36	1,96	11,67	4,53	3,60						24,87
DMZ 4 (*)	95,42										60,98
DMZ 5	0,91	12,23		4,58	0,00	0,00	0,00				17,72
DMZ 6	1,21	1,52	1,16	0,70	0,78	0,35					5,98
DMZ 7	0,00	0,00	3,05	3,31	3,39	10,03	0,00				19,78
DMZ 8 (*)	82,63										82,63
DMZ 9 (*)	18,42										18,42
DMZ 10 (*)	1,39										1,39
DMZ 11 (*)	44,22										44,22
DMZ 12 (*)	34,67										34,67
DMZ 13	1,64	1,90									3,53
DMZ 14 (**)	No WASA Water										0,00
DMZ 15	3,78	0,00	0,00	0,00							3,78
DMZ 16	0,00										0,00
										Total	**413,59**

Water losses estimation = 413.59 *l/s*

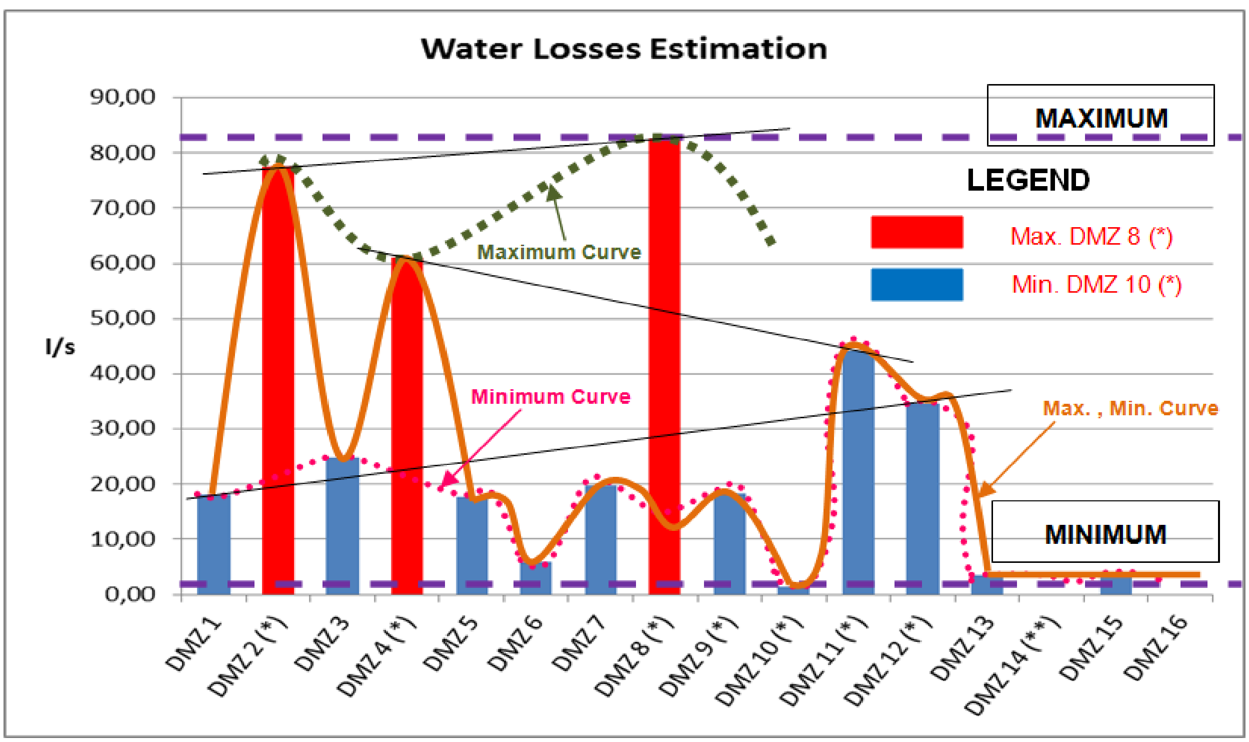


Fig. 9: *Leak detection priority is DMZ 8 (0.88 l/s/km) DMZ 2 (0.62 l/:/km) DMZ 4 (0.41 l/s/km)*

For the rest of the DMZs, the minimum night flows are less than 0.40 l/s/km. For DMZ 6, 10, 15 and 16, the minimum night flow values are less than 0.10 l/s/km and do not require leak detection.

7.5 ESTIMATION OF NETWORK PERFORMANCE

A. Calculation of the Yield

$$Yield\ (\%) = \left(\frac{\text{Water Consumed}}{\text{Water Produced}}\right) X\ 100$$

7.5.1 Water Produced

Daily production was calculated firstly by the bulk meters installed at Chenab pumping station and Terminal Reservoir, Secondly by flow measurement on small tube wells, Tertiary for Jica tube well by calculation of difference of water levels of reservoir and pumps capacity.

Daily production by Bulk Meter	140000 *m³/day*
Daily production by flow meter	5000 *m³/day*
Daily production estimate	60000 *m³/day*
Total	**205000 *m³/day***

7.5.2 Water Sold

In Faisalabad, there no domestic waters meter installed at house connections and it is impossible to know exactly the consumption. For calculation purposes, we estimated 0.840 m³/day consumption per connection. The number of connections is 111000 and our estimate of water consumed is:

(111 000 x 0.840) = **93240 m³/day**

Yield

$$\left(\frac{93\ 240\ \text{m}^3/\text{day}}{205\ 000\ \text{m}^3/\text{day}}\right) X\ 100 = 45\ \%$$

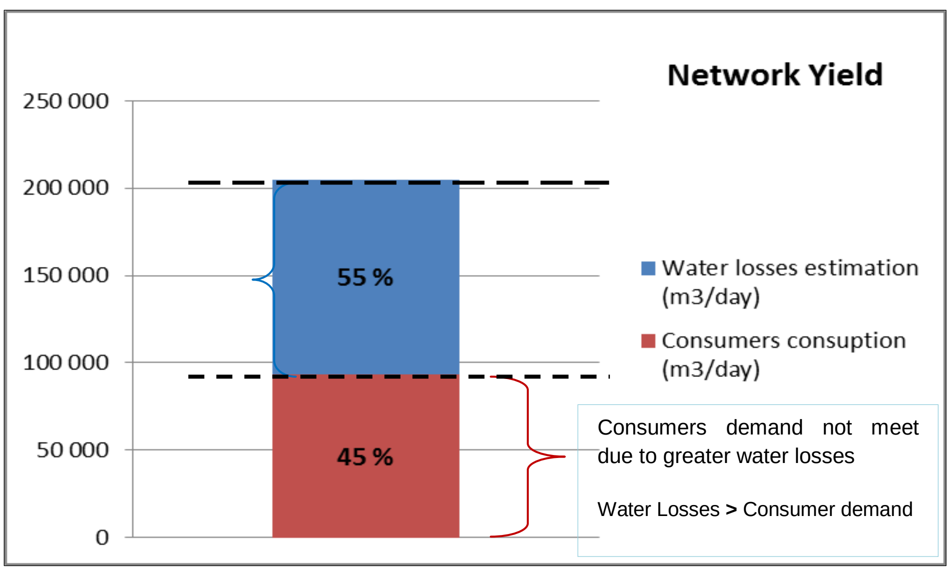


Fig. 10: *Network yield with water loss estimation and consumers consumption*

According to the rating standard performance, Faisalabad network was classified in “Bad” category as it has a value less than 70%. The water network yield with consumer’s consumption and estimated water losses is shown in Fig. 10.

Table 6: *Categories with respect to yield and notations*

Yield	90%	85%	80%	75%	70%	Less than 70%
Notation	Excellent	Good	Average	Mediocre	Poor	Bad

B. CALCULATION OF THE ILL

ILL = Indications of the water Losses per Length of network (m^3/km)

$$ILL = \frac{\text{Water produced} - \text{Water Sold}}{\text{Network Length}}$$

Daily production-- = **205000 m^3**
Daily consumed-- = **93240 m^3**
Network length-- = **1600 km**

$$\frac{205\,000\, m^3 - 93\,240\, m^3}{1\,600\, km} = 70\, m^3/km$$

The results obtained both at the level of performance or of ILL are weak. To improve the results government needs to reorganize its leak repair teams and create a new department specialized in the flow measurement and analysis and leaks detection. The leak detection analysis and flow estimations is shown in Fig. 11.

Fig. 11: *Analysis of leak detection and flow measurement in Faisalabad*

Table 7: *Results of Leak Detection and Leaks repaired details with respect to DMZ*

LEAK DETECTION RESULTS								
Number of Leaks Detected							497	
Number of Leaks Repaired							416	432
Number of Excavation not allowed							16	
Remaining Leak Repair							65	
Time Repair							39	
DETAILS OF LEAKS REPAIRED BY DMZ								
DMZ #	PP Pipe	SC Service Connection	SP Service Pipe	MT Water Meter	VA Valve	OT Other	NO Error	Total by DMZ
DMZ 1	1	21	6	0	0	1	9	38
DMZ 2	2	6	1	0	0	0	1	10
DMZ 3	4	25	4	0	1	6	17	57
DMZ 4	0	24	0	0	0	0	7	31
DMZ 5	1	31	9	0	1	4	14	60
DMZ 6	0	25	4	0	0	0	11	40
DMZ 7	21	68	13	0	1	5	35	143
DMZ 8	0	0	0	0	0	0	0	0
DMZ 9	0	0	0	0	0	0	0	0
DMZ 10	0	23	1	0	0	0	8	32
DMZ 11	0	0	0	0	0	0	0	0
DMZ 12	0	0	0	0	0	0	0	0
DMZ 13	0	4	1	0	0	0	0	5
DMZ 14	0	0	0	0	0	0	0	0
DMZ 15	0	0	0	0	0	0	0	0
Total	29	223	38	0	3	16	102	416
Percent	7%	54%	9%	0%	1%	4%	25%	

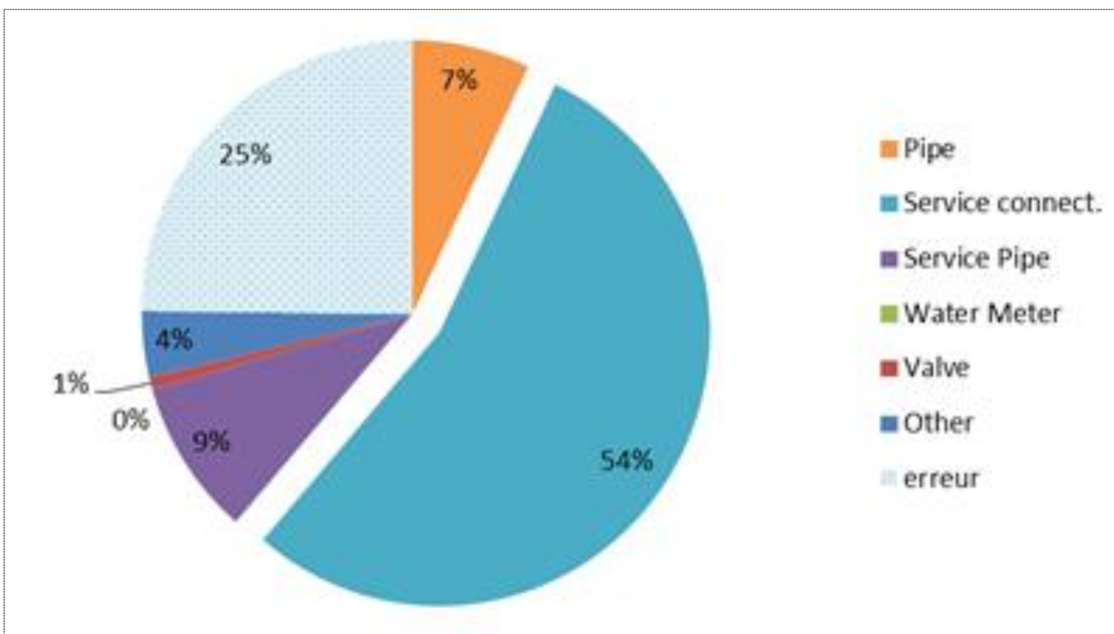


Fig. 12: *Leak Repaired by DMZ*

The largest numbers of leakages was located on service connections. The main reasons are, (a) the quality of collar clamp, (b) quality of gasket and the fittings used, (c) No drilling machine was used to drill the pipe. The hole is carried out with hammer and chisel. The experiment using experimental setup at site is shown in Fig. 13.

Fig. 13: *Site experiment using Leak Detection Devices*

7.6 **LEAK REPAIR**

The leak repairs were conducted at various locations of Faisalabad during experiment. At the beginning most leaks were repaired with rubber straps and the major leaks were carried out with the appropriate fittings. In the future, increasing the pressure in the system will cause additional leaks on these poorly executed repairs.

The operation of leakages repair at various sites in Faisalabad is shown in Fig. 14.

Fig 14: *Leaks repair and appropriate fittings in Faisalabad during Leak Detection*

7.7 **EQUIPMENTS INSTALLATION**

For the improvement of Faisalabad City water distribution network 49 ENDRESS/HAUSER bulk meters and 42 CLA-VAL PRV for the network zoning was used.

Bulk Meter	DN300 mm…………………………………………………………	No. 16
	DN250 mm…………………………………………………………	No. 16
	DN200 mm…………………………………………………………	No. 17
PRV	DN300 mm…………………………………………………………	No. 17
	DN250 mm…………………………………………………………	No. 25

For the largest pipes, 3 Ultrasonic Flow meters of ULTRAFLUX brand was installed at the outlet Chenab Pumping Station (DN 1500) and at the inlet Terminal Reservoir (DN 1500). The third one installed at the new arterial main (DN 1000) connected to Jica line. Two number of ENDRESS/HAUSER level sensors with digital display was installed at new and old reservoirs at Terminal Reservoir. All these equipments were linked to the Sofrel GPRS data logger connected to the SCADA via a SIM card. We included also the new and old existing Bulk Meter at Terminal Reservoirs. The installation of instrumentation in Faisalabad network is shown in Fig. 15.

Fig. 15: *Installation of 3 Ultrasonic Flow meters, 2 Endress/Hauser Level Sensor and linkage of Sofrel GPRS Data Loggers with SCADA*

7.8 **SCADA AND CASE OF FAISALABAD**

The 62 Remote Terminal Units (Sofrel LS42) and 1 SCADA Master Unit was use for improvement of Faisalabad city network and the following parameters was noticed:

1. 55 Flow measurements data
2. 52 Pressure measurements data

3. 3 Tank level measurements data
4. 6 DMZ fully equipped
5. 5 DMZ partially equipped

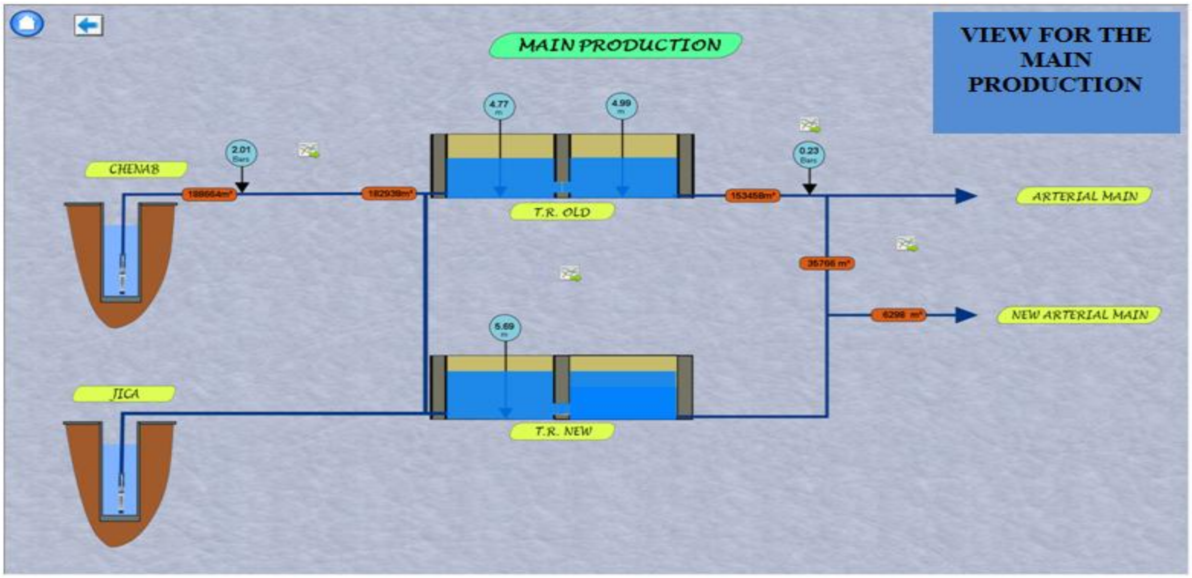


Fig. 16: *View for the main production (Faisalabad)*

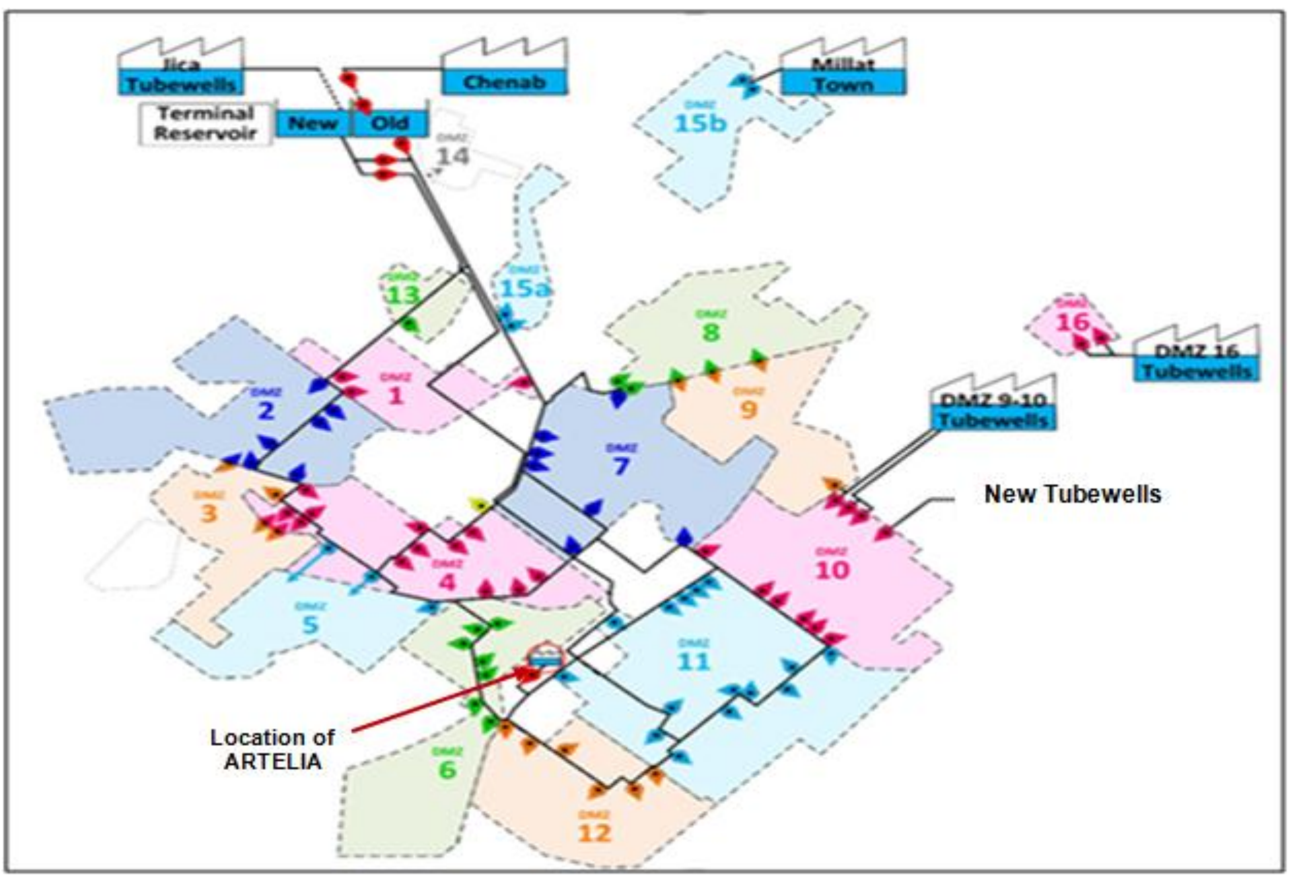


Fig. 17: *Faisalabad DMZ, DMAs with Tube wells and Terminal Reservoir location*

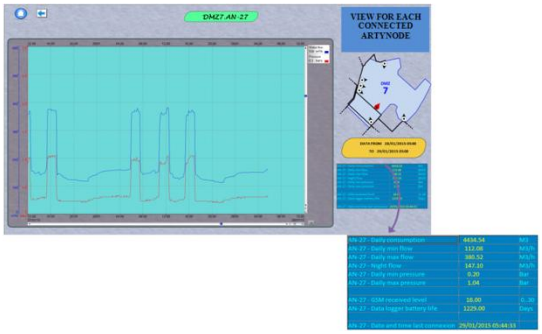


Fig. 18: *View for each connected arty node*

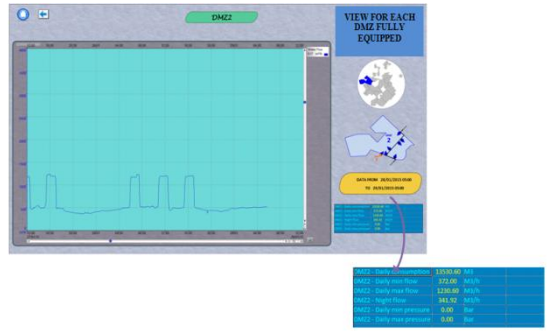


Fig. 19: *View of each DMZ fully equipped*

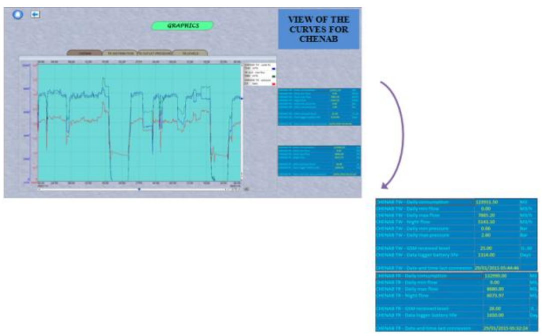


Fig. 20: *View of the Graphs of Chenab*

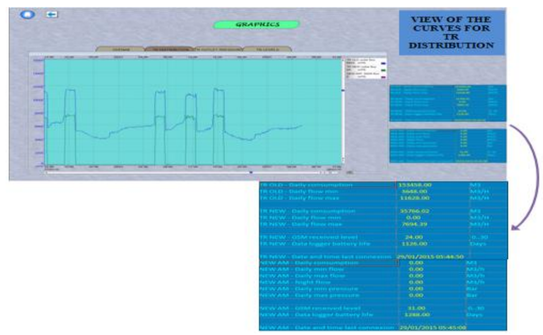


Fig. 21: *View of the graphs for TR Distribution*

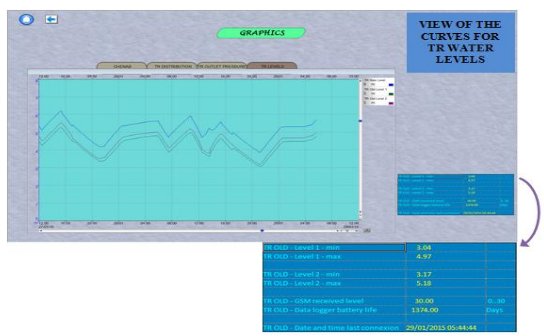


Fig. 22: *View of the graphs for TR Water Levels*

7.9 VALVES AND CONSUMPTION ALLOCATION

In WATERGEMS, closed valves are not a special feature; they are modeled by closing a pipe, and have been integrated to the model. For information, there is almost no closed valve in Faisalabad. Total of 111 024 connections are present in Faisalabad._The consumption associated to each DMZ was uniformly distributed at the nodes of each DMZ and adjusted during the calibration phase. According to the flow measurement, the following table below (Table 8) represents the average flow rates and daily volumes used for the calibration in each DMZ (Data Monitoring Zone-Faisalabad). The water consumption patterns for Faisalabad city is shown in Fig. 23.

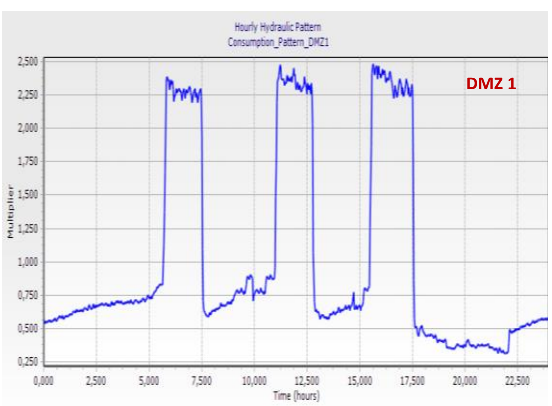
Table 8: *DMZ with daily volume and average flow rates*

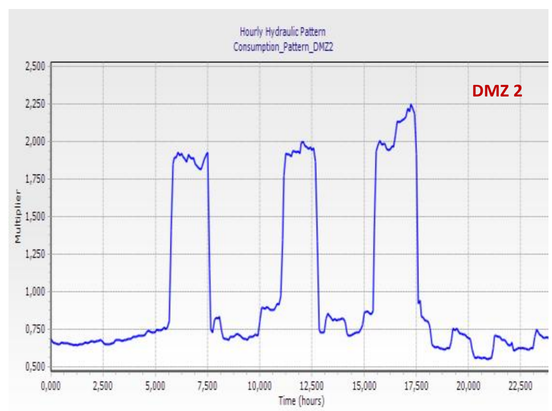
DMZ	Average flow rate (m^3/h)	Daily volume (m^3)
DMZ 1	261,54	6 277,07
DMZ 2	521,33	12 512,03
DMZ 3	229,09	5 498,12

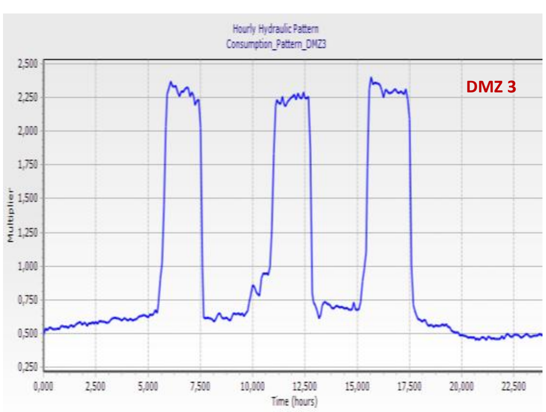
DMZ 4	1 011,55	24 277,23
DMZ 5	192,63	4 623,06
DMZ 6	181,28	4 350,65
DMZ 7	483,66	11 607,83
DMZ 8	698,81	16 771,45
DMZ 9	335,00	8 039,95
DMZ 10	140,91	3 381,81
DMZ 11	795,61	19 094,68
DMZ 12	376,36	9 032,62
DMZ 13	22,67	544,18
DMZ 15 A	30,21	724,93
DMZ 15 B.1	15,69	376,61
DMZ 15 B.2	18,08	434,02
DMZ 16	53,61	1 286,76
Total		128 833,00

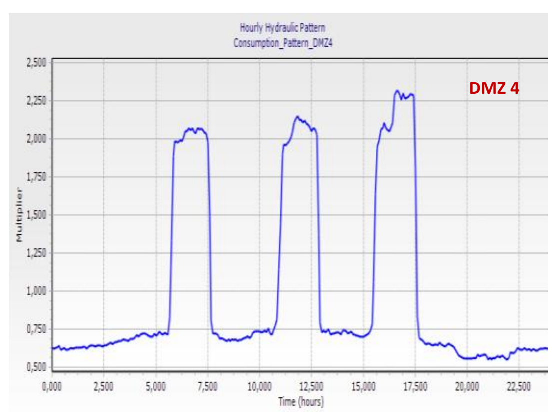
7.10 CONSUMPTION PATTERNS

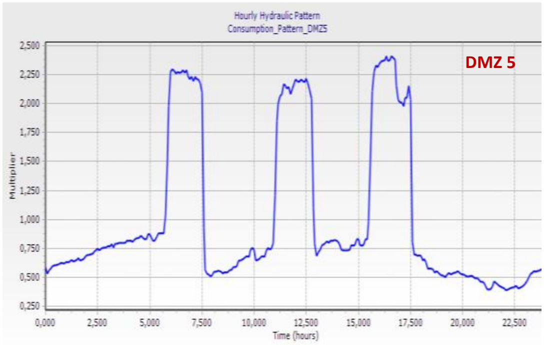
Consumption patterns were determined from measurements.

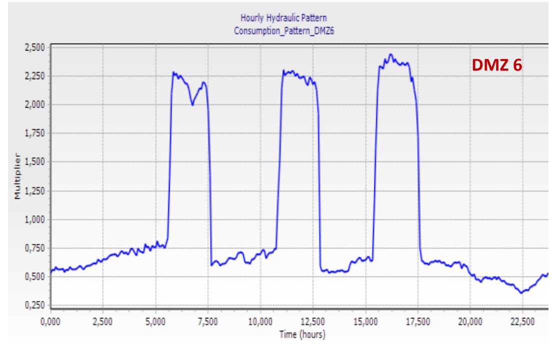


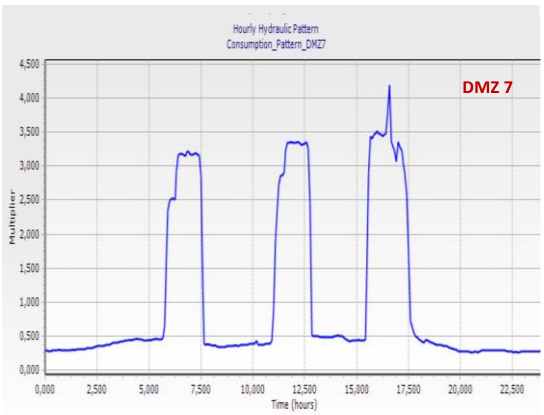


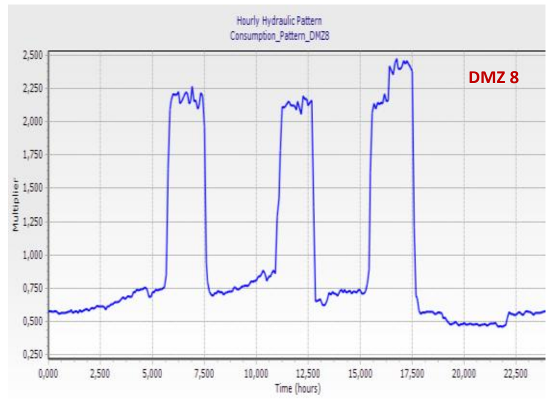


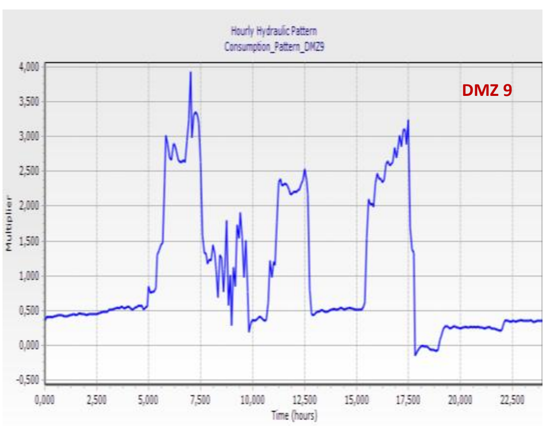


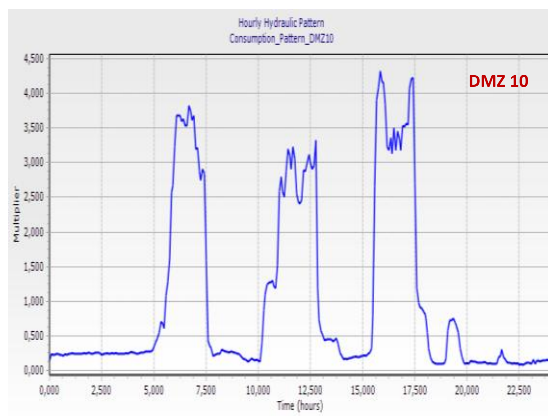

Hourly Hydraulic Pattern
Consumption_Pattern_DMZ5
DMZ 5
Multiplier
Time (hours)

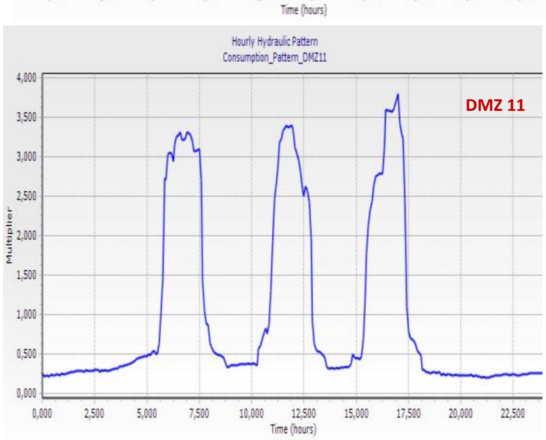

Hourly Hydraulic Pattern
Consumption_Pattern_DMZ6
DMZ 6
Multiplier
Time (hours)

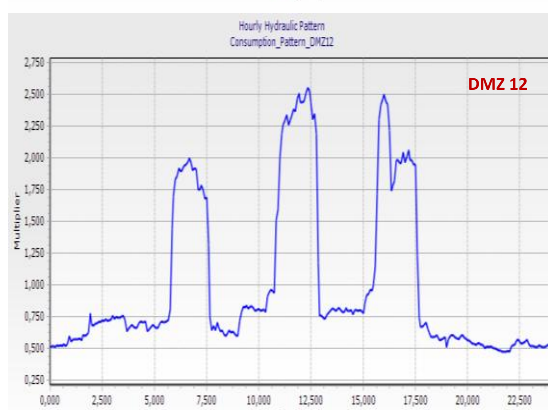

Hourly Hydraulic Pattern
Consumption_Pattern_DMZ7
DMZ 7
Multiplier
Time (hours)


Hourly Hydraulic Pattern
Consumption_Pattern_DMZ8
DMZ 8
Multiplier
Time (hours)


Hourly Hydraulic Pattern
Consumption_Pattern_DMZ9
DMZ 9
Multiplier
Time (hours)


Hourly Hydraulic Pattern
Consumption_Pattern_DMZ10
DMZ 10
Multiplier
Time (hours)


Hourly Hydraulic Pattern
Consumption_Pattern_DMZ11
DMZ 11
Multiplier
Time (hours)


Hourly Hydraulic Pattern
Consumption_Pattern_DMZ12
DMZ 12
Multiplier
Time (hours)

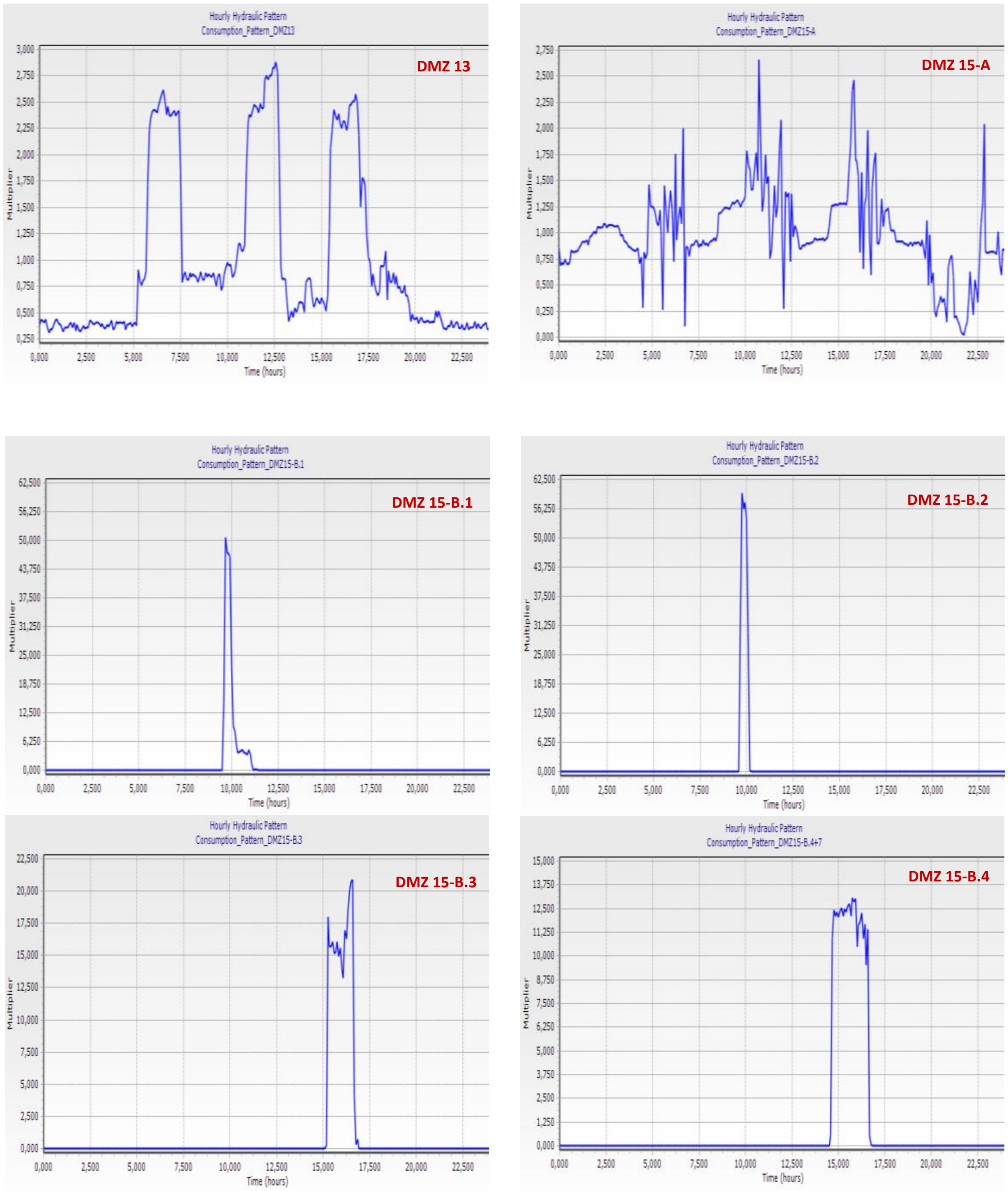


Fig. 23: *Water Consumption patterns for whole Faisalabad (DMZ 1 – DMZ 15)*

The results for ***Figures 23*** representing that, The ***HOURLY HYDRAULIC PATTERN CONSUMPTION_PATTERN_DMZ1*** was implemented by draw a relationship between Time (hours) versus Multiplier (on X-axis, Y-axis). The variation for DMZ1 dictates that at each point a lot of variation within this area of Faisalabad and the highest variation were recorded at 2,450 in 15,800 hours. The previous curves also present higher results but last curve are maximum. The ***HOURLY HYDRAULIC PATTERN CONSUMPTION_PATTERN_DMZ2*** shows that the flow vary on second to hourly basis, the three curves indicating non normality of consumption in existing (DMZ2) area. No doubt the consumption is much higher than water production; the maximum value of Multiplier was recorded at 2,250 against time 16,700 hours. The Graph for ***HOURLY HYDRAULIC PATTERN***

CONSUMPTION_PATTERN_DMZ3 depicts that the Curve1 = Curve3 at 2,350 Multiplier on 5,900, 15,800 hours. The middle curve is at 2,270 approximately both curves was implemented with some error (Curve1 = Curve3 ≠ Curve2). The Graph for ***HOURLY HYDRAULIC PATTERN CONSUMPTION_PATTERN_DMZ4*** shows that there is a smooth relationship existing between both Curve 1, 2 and 3. In other words there is smooth increasing line from start up to end in DMZ4 (Curve1 < Curve2 < Curve3). The Graph for ***HOURLY HYDRAULIC PATTERN CONSUMPTION_PATTERN_DMZ5*** presents that the Curve1 > Curve2 and Curve2 < Curve3. The variation in patterns are existing because the consumption in pattern1 are huge the suddenly drops in Curve 2 and again rise in Curve 3. The Curve 3 has representation of highest patterns than that of first two curves. The Graph for ***HOURLY HYDRAULIC PATTERN CONSUMPTION_PATTERN_DMZ6*** portray that there is a rising manner obtained from Pattern1-Pattern3. After 5,000 hours a sudden rise of Multiplier was occurred up to 22, 60 and then drop and the similar situations was located in Curve 2, and 3 (Curve1 ≠ Curve2 ≠ Curve3). The Graph for ***HOURLY HYDRAULIC PATTERN CONSUMPTION-PATTERN_DMZ7*** dictates that the first two curves are very smooth but in third curve there is a shocking rising occur due to uppermost water consumption. This consumption was occurred due to over usage of water as a result of water leakage due to pipes gaps/faults (in this case Curve1 < Curve2, Curve3 > Curve2). The Graph for ***HOURLY HYDRAULIC PATTERN CONSUMPTION_PATTERN_DMZ8*** indicating that the similar conditions was occur within DMZ7 and DMZ8, but little variations in sense of consumption (Curve1 > Curve2 < Curve3). The Graph for ***HOURLY HYDRAULIC PATTERN CONSUMPTION_PATTERN-DMZ9, 10*** indicating that there were much higher consumption fluctuations within DMZ9, 10 was recorded. DMZ9 (Curve1 > Curve2 < Curve3) for DMZ10 (Curve1 > Curve2 < Curve3, so Curve 1 < Curve3). DMZ 9 = DMZ 10 (in consumption). The Graph for ***HOURLY HYDRAULIC PATTERN CONSUMPTION_PATTERN_DMZ11, 12, 13*** dictates that the consumption is much higher than that of water production within DMZ 11, 12, and 13. These three DMZ's presenting poor conditions because water loss due to excessive leakages in Faisalabad areas (Curve1 < Curve2 < Curve3 = DMZ11), (Curve1 < Curve2 > Curve3 = DMZ12), (Curve1 < Curve2 > Curve3). The consumption of water pattern is shown in Graph's of ***HOURLY HYDRAULIC PATTERN CONSUMPTION_PATTERN_DMZ15-A, 15-B.1, 15-B.2 and 15-B.3, 15-B.4***. The Graph for ***DMZ 15-A*** is representing shocking wave of consumption (consumption ≠ production). The fluctuations in Multipliers was recorded maximum at 10,800 hours, the consumption patterns are increasing from 6,900 – 10,800 hours and after that consumption decline to 15,800 and 22,200 hours (2,000 < 2,600 > 2,400 > 2050 = Multiplier). The ***DMZ 15-B.1*** presents only one peak/curve at 50,400 against time 90,000 hours. As noted that the consumption rate within ***DMZ 15-B.1 < DMZ 15-B.2*** (50,400 < 59, 375 at 90,000 hours). The DMZ15 is very large due to this reason it was divided in large proportions. The leaks exceeds production in ***DMZ 15-B.3***, a peak was obtained on 20,900 at 16,200 hours ***and DMZ15-B.3 > DMZ15-B.4*** in consumption (20,900 at 16,200 hours > 12,950 at15, 900 hours).

Leakages in DMZ, unaccounted consumptions and leakages in Arterial Main

Leakages in the DMZ are included in the consumption profiles. The average estimation made in the flow and pressure measurement was 414 *L/s*.

Leakages and unaccounted consumptions in Arterial main was modeled by simulating some outlets in the Arterial main and by calibrating these outlets in order to totalize an average flow around 880 *L/s*.

7.11 MODEL CALIBRATION – PRINCIPLES OF CALIBRATION

Calibration of a model is to adjust the parameters of which we can't have a precise value (roughness, consumption, elevation) so that the values calculated by the model are close to the values measured in reality. The hydraulic model calibration consists of the following major steps:

7.11.1 Data analysis

Selection of reference measurements and integration of the profiles chosen in the model.

7.11.2 Calibration of volume

Making the water balance of the system based on the flow measurement, adjusting the controls and consumptions.

7.11.3 **Level tank calibration**

Theoretically, if the tank levels are calibrated, so volumes should be good and the opposite. One has to adjust the parameters of the filling valves at the hydraulic elements

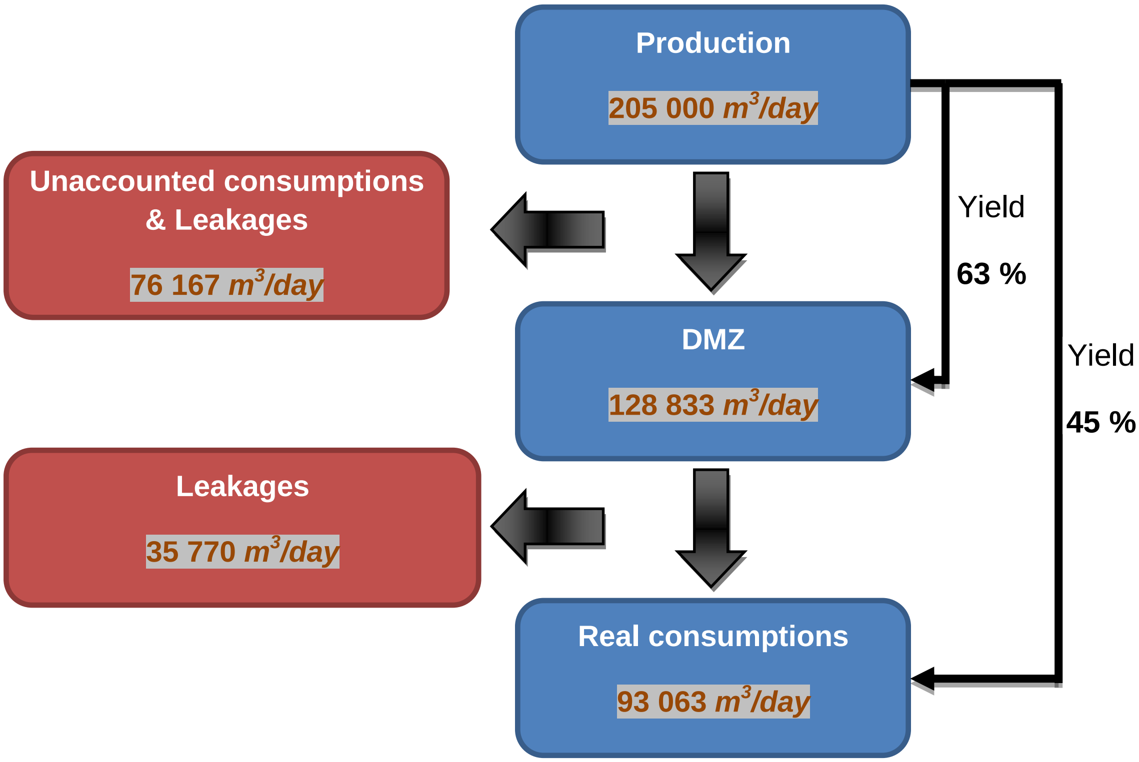


Fig. 24: *DMZ leakages, unaccounted consumptions, productions and real consumptions with yields*

(head losses at the entrance) and distribution valves (head losses). One can also adjust the roughness of the inlet pipe and the pump station operating instructions.

7.11.4 **Flow rate calibration**

Changing roughness and diameters. The higher the pipe's roughness is, or the smaller its diameter is, the more head loss at constant flow rate there will be, or the lower the flow rate will be.

7.11.5 **Pressure calibration**

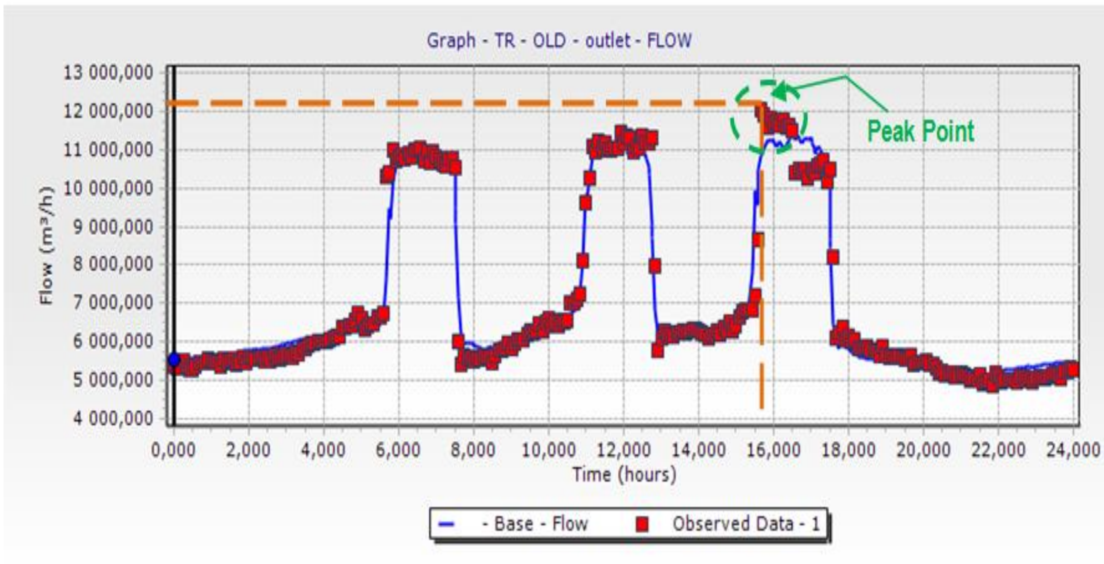
This step is also done by changing the roughness and diameters. However, it allows a finer calibration of the model. First of all, one realizes a setting according to the static pressure. Then, one may change the elevation of some nodes. And finally, one realizes a setting according to the pressure profiles (dynamically, when the flow rate changes) adjusting once again the diameters and roughness.

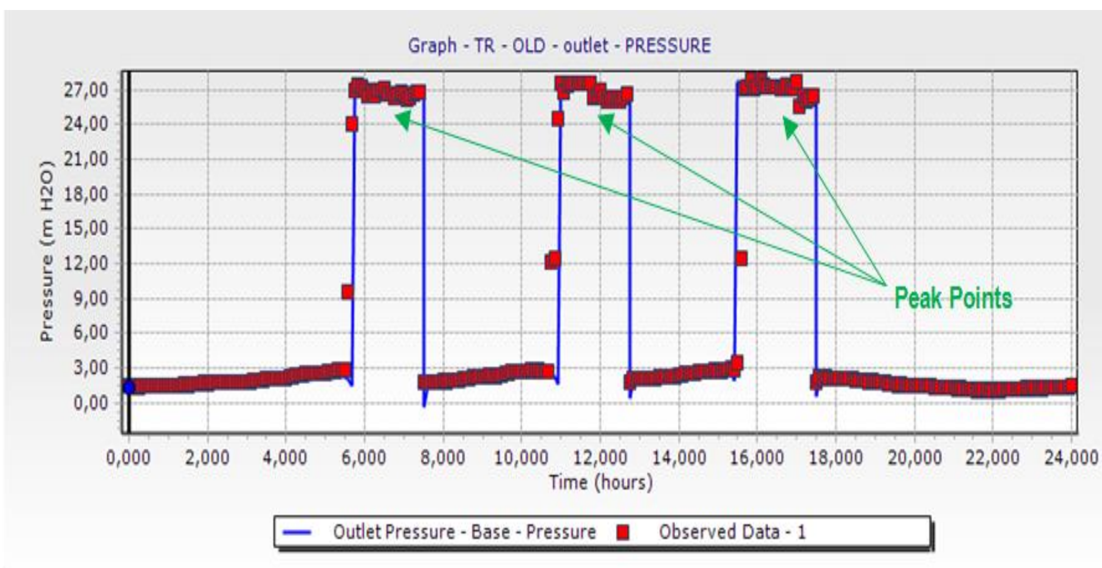
7.12 **Calibration Results**

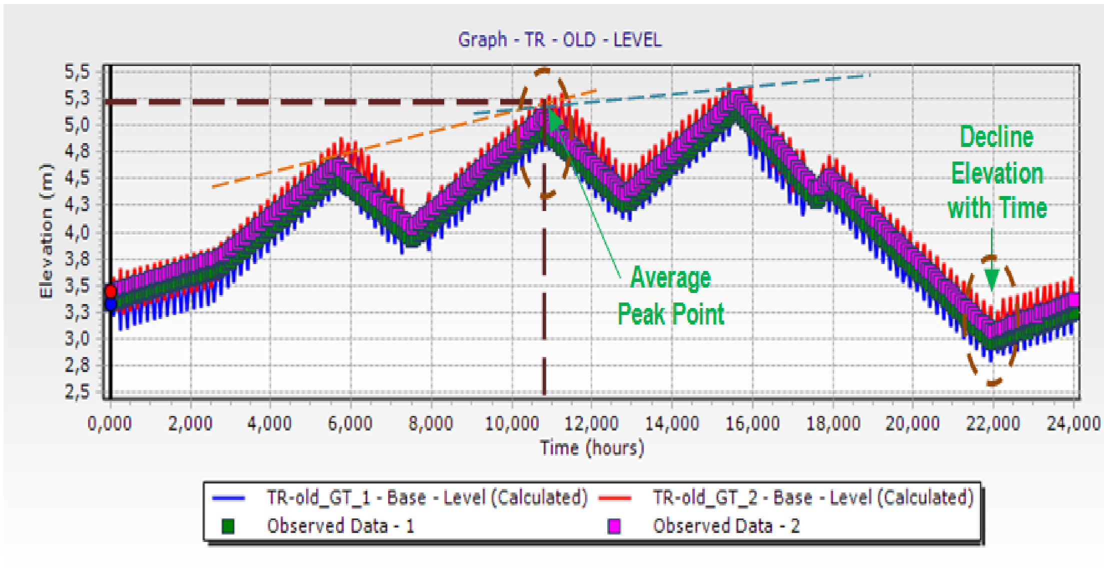
The values calculated by the model are close to the values measured in reality. It means that the calibration is well done and we can now use the model by simulating different network configurations. The calibrations were done for DMZ and for Terminal Reservoirs old as well as new.

TERMINAL RESERVOIR:

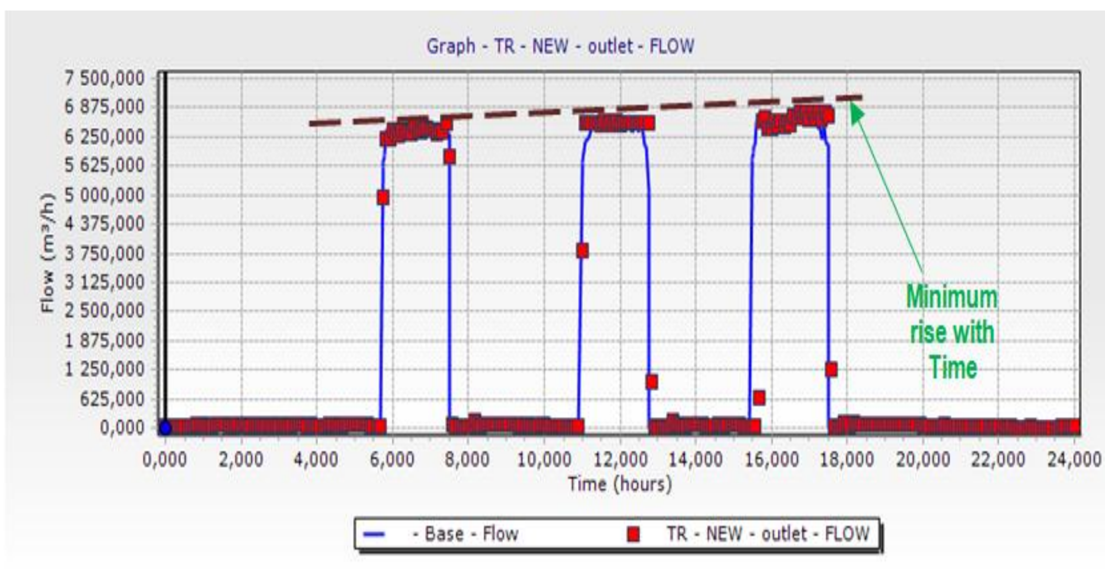
TERMINAL RESERVOIR OLD – OUTLET FLOW:-

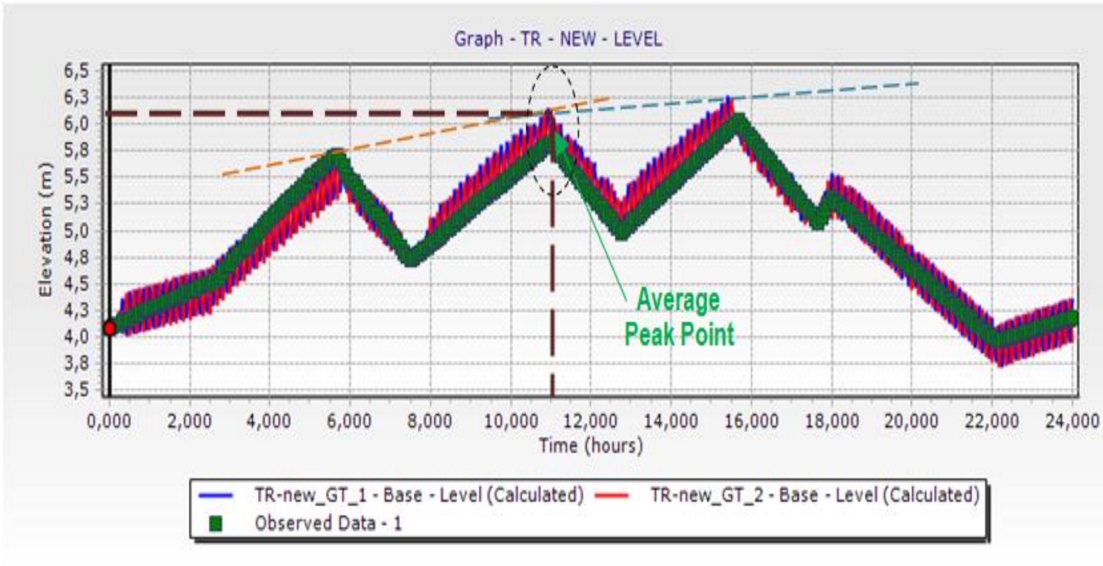




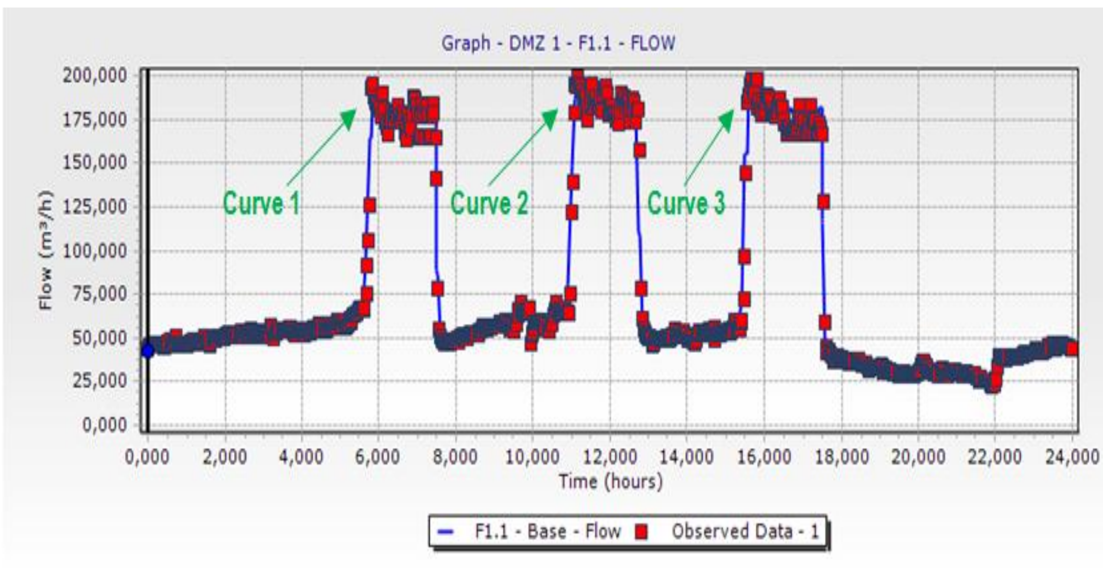


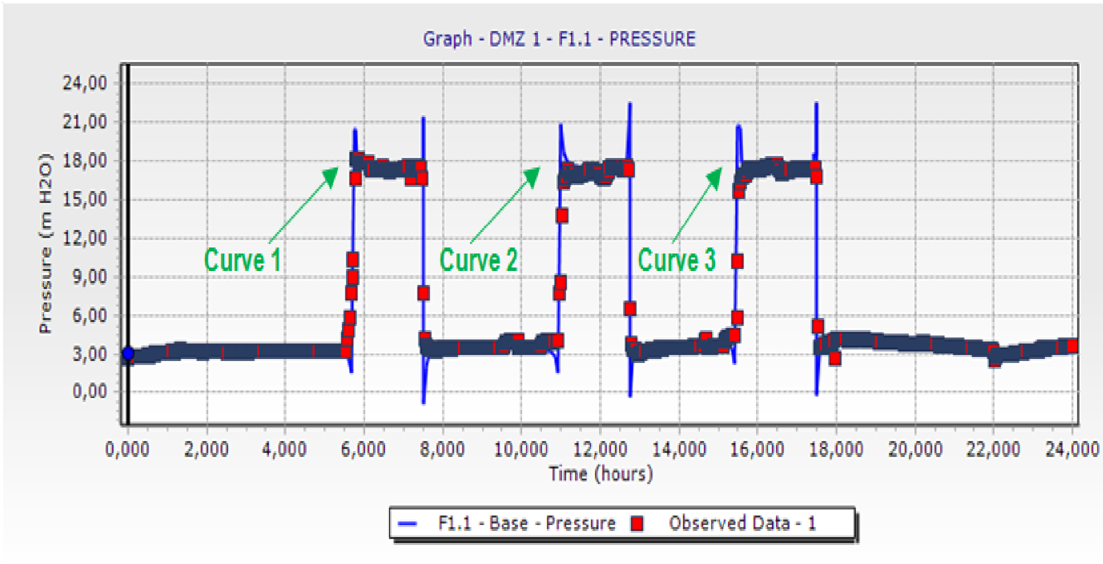
TERMINAL RESERVOIR NEW LEVEL – OUTLET FLOW:-



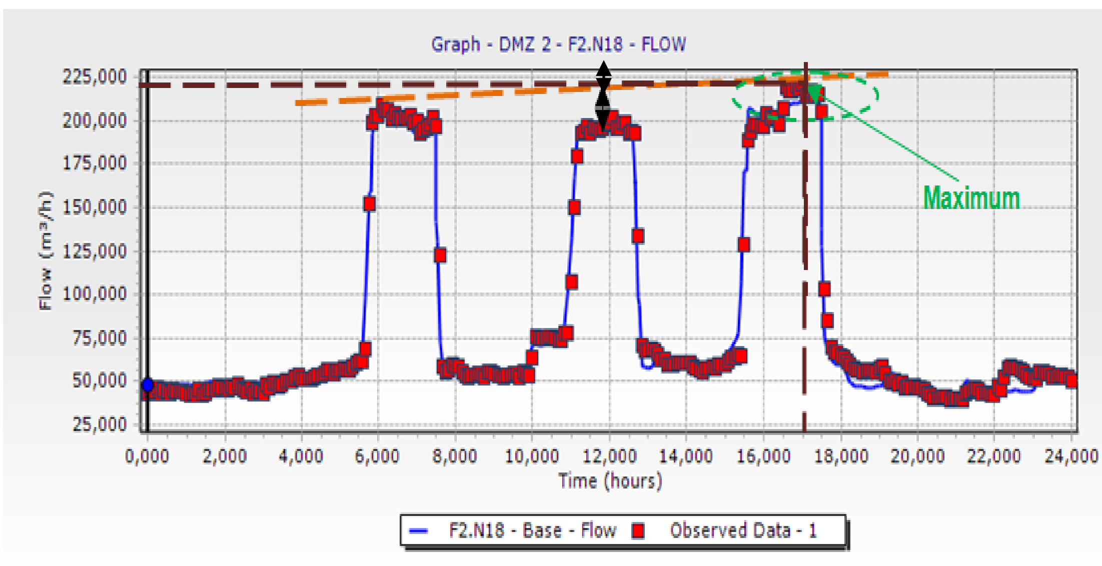

Graph - TR - NEW - LEVEL
Elevation (m)
Time (hours)
Average Peak Point
TR-new_GT_1 - Base - Level (Calculated)
TR-new_GT_2 - Base - Level (Calculated)
Observed Data - 1

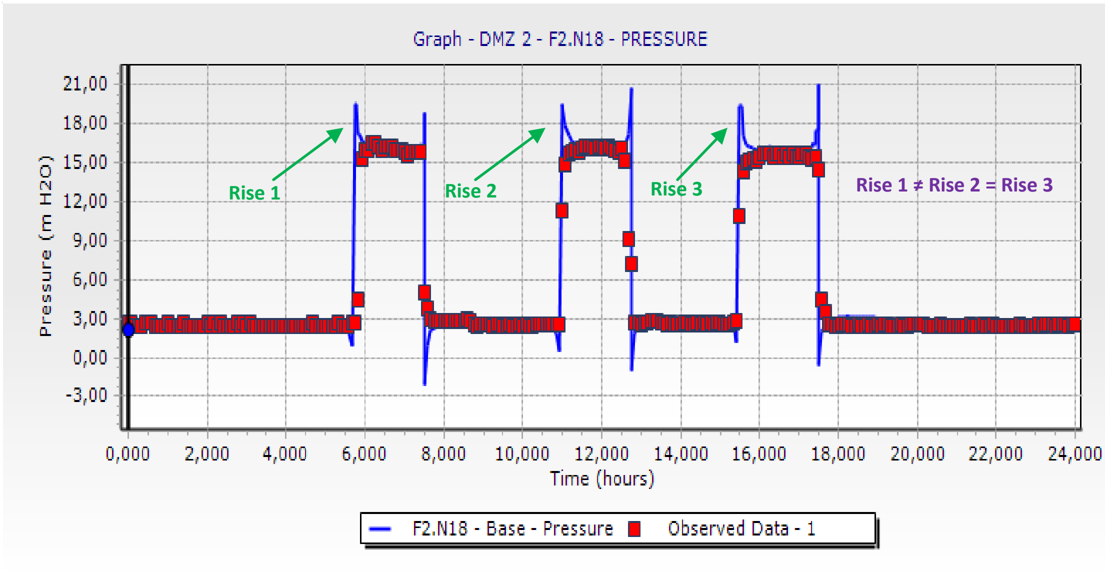
DMZ 1:-


Graph - DMZ 1 - F1.1 - FLOW
Flow (m³/h)
Time (hours)
Curve 1
Curve 2
Curve 3
F1.1 - Base - Flow
Observed Data - 1

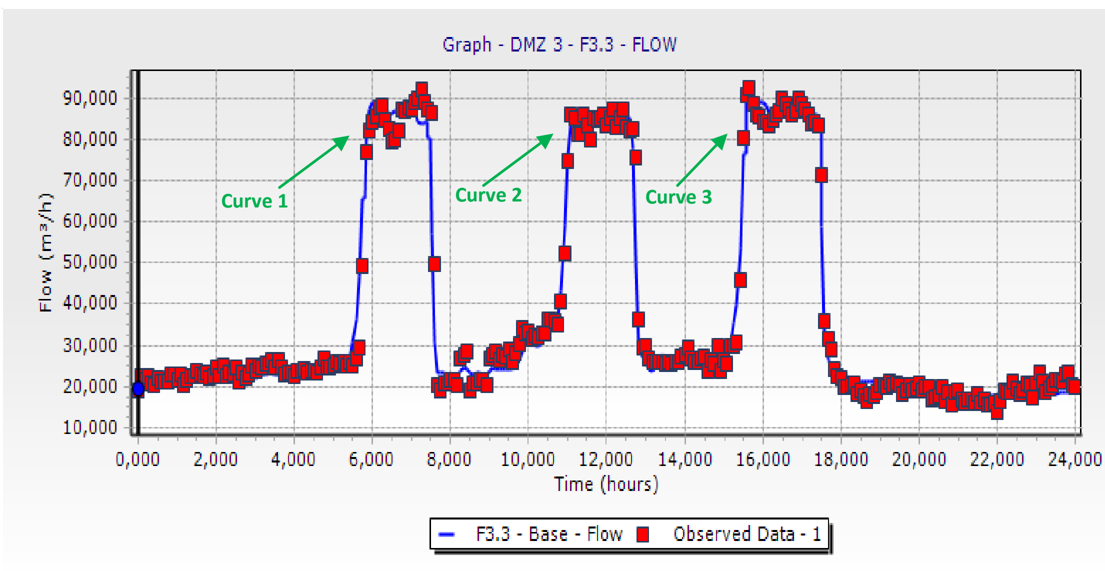

Graph - DMZ 1 - F1.1 - PRESSURE
Pressure (m H2O)
24,00
21,00
18,00
15,00
12,00
9,00
6,00
3,00
0,00
Curve 1
Curve 2
Curve 3
0,000 2,000 4,000 6,000 8,000 10,000 12,000 14,000 16,000 18,000 20,000 22,000 24,000
Time (hours)
F1.1 - Base - Pressure
Observed Data - 1

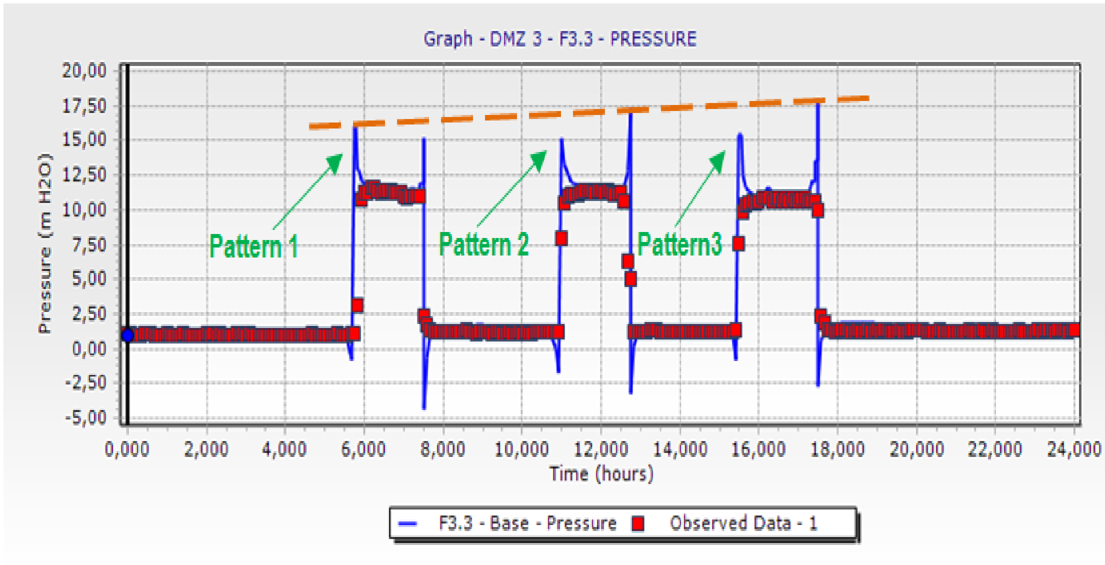
DMZ 2:-


Graph - DMZ 2 - F2.N18 - FLOW
Flow (m³/h)
225,000
200,000
175,000
150,000
125,000
100,000
75,000
50,000
25,000
Maximum
0,000 2,000 4,000 6,000 8,000 10,000 12,000 14,000 16,000 18,000 20,000 22,000 24,000
Time (hours)
F2.N18 - Base - Flow
Observed Data - 1

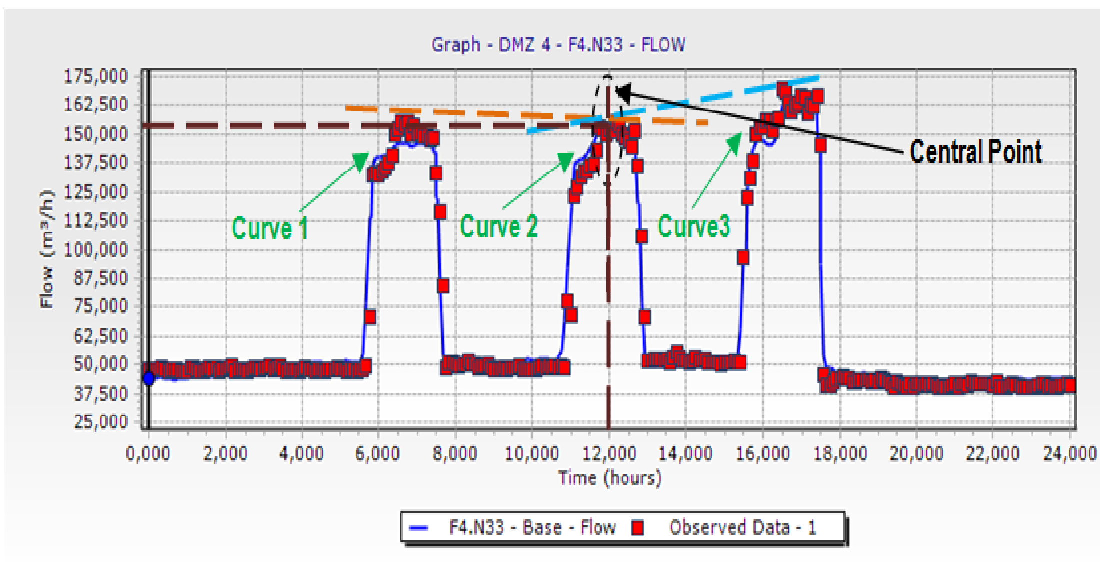

Graph - DMZ 2 - F2.N18 - PRESSURE
Pressure (m H2O)
21,00
18,00
15,00
12,00
9,00
6,00
3,00
0,00
-3,00
Rise 1
Rise 2
Rise 3
Rise 1 ≠ Rise 2 = Rise 3
0,000
2,000
4,000
6,000
8,000
10,000
12,000
14,000
16,000
18,000
20,000
22,000
24,000
Time (hours)
F2.N18 - Base - Pressure
Observed Data - 1

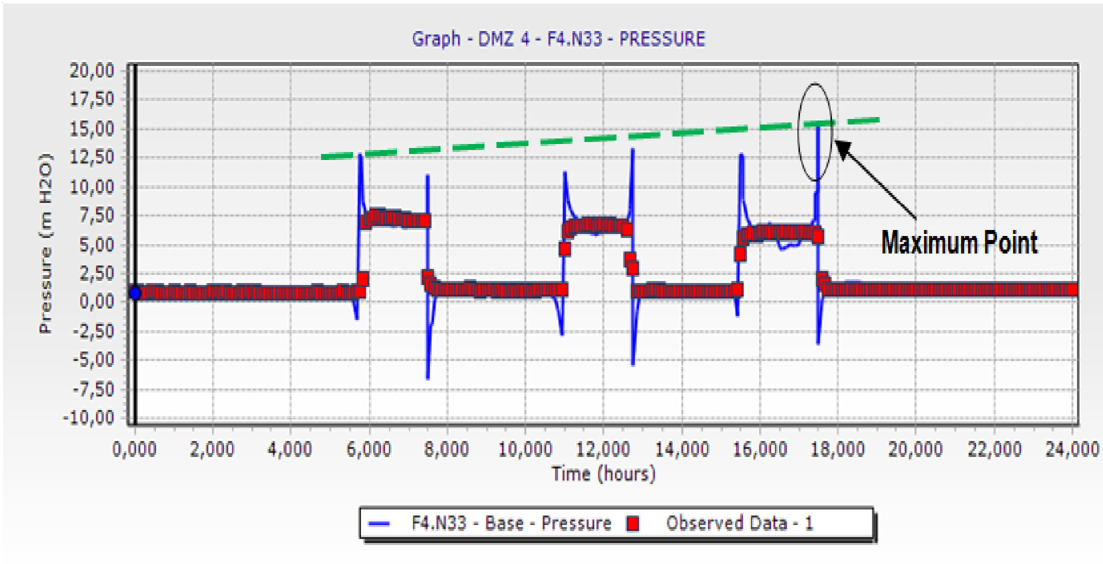
DMZ 3


Graph - DMZ 3 - F3.3 - FLOW
Flow (m³/h)
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
Curve 1
Curve 2
Curve 3
0,000
2,000
4,000
6,000
8,000
10,000
12,000
14,000
16,000
18,000
20,000
22,000
24,000
Time (hours)
F3.3 - Base - Flow
Observed Data - 1

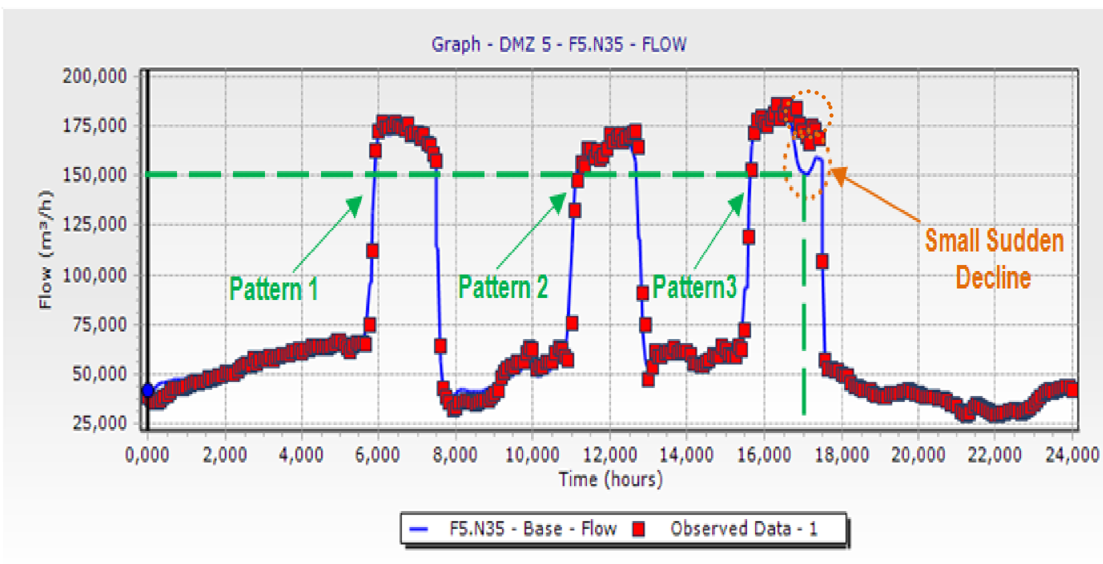

Graph - DMZ 3 - F3.3 - PRESSURE
Pressure (m H2O)
Time (hours)
Pattern 1
Pattern 2
Pattern3
F3.3 - Base - Pressure
Observed Data - 1

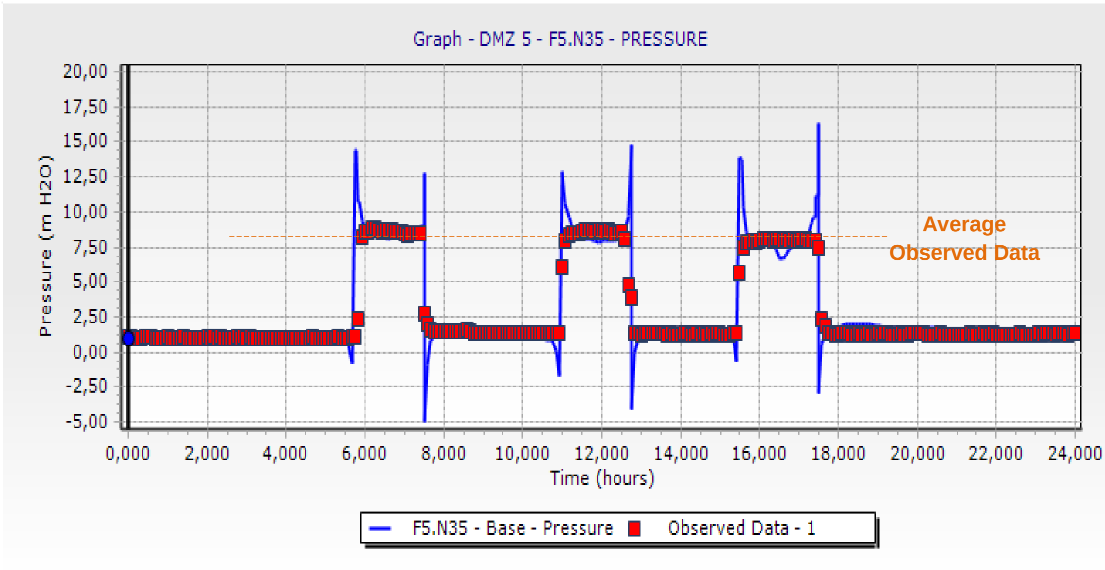
DMZ 4:-


Graph - DMZ 4 - F4.N33 - FLOW
Flow (m³/h)
Time (hours)
Curve 1
Curve 2
Curve3
Central Point
F4.N33 - Base - Flow
Observed Data - 1


Graph - DMZ 4 - F4.N33 - PRESSURE
Pressure (m H2O)
Time (hours)
Maximum Point
F4.N33 - Base - Pressure
Observed Data - 1

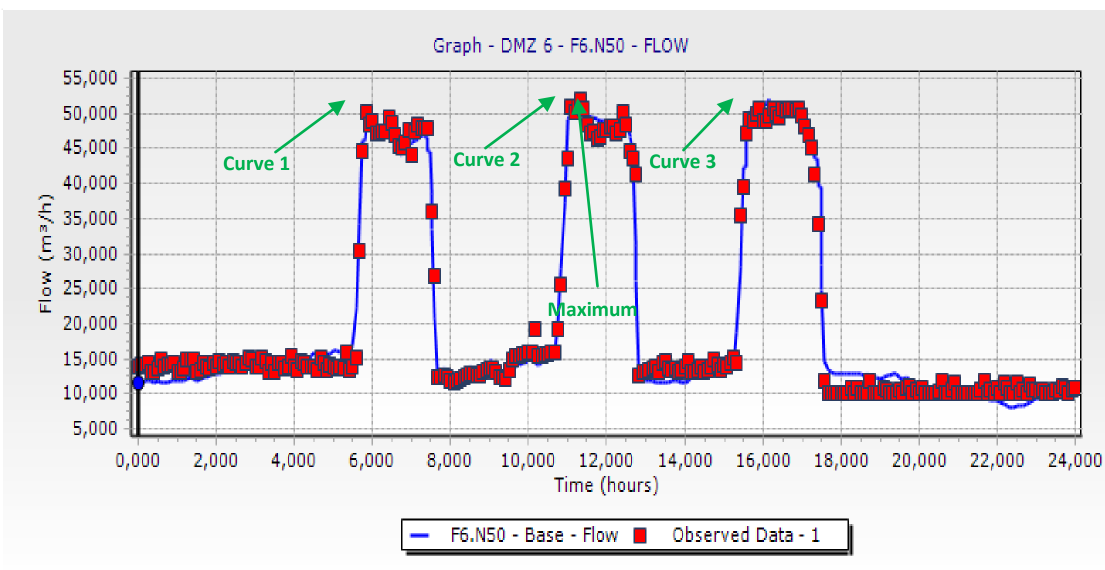
DMZ 5:-


Graph - DMZ 5 - F5.N35 - FLOW
Flow (m³/h)
Time (hours)
Pattern 1
Pattern 2
Pattern3
Small Sudden Decline
F5.N35 - Base - Flow
Observed Data - 1

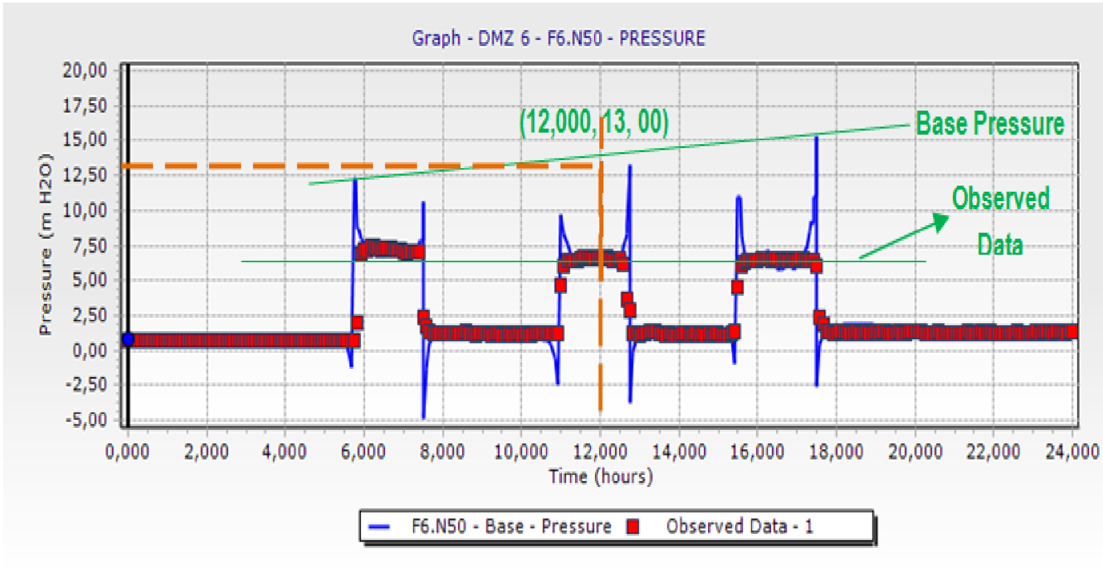


Graph - DMZ 5 - F5.N35 - PRESSURE
Pressure (m H2O)
20,00
17,50
15,00
12,50
10,00
7,50
5,00
2,50
0,00
-2,50
-5,00
0,000
2,000
4,000
6,000
8,000
10,000
12,000
14,000
16,000
18,000
20,000
22,000
24,000
Time (hours)
Average Observed Data
F5.N35 - Base - Pressure
Observed Data - 1

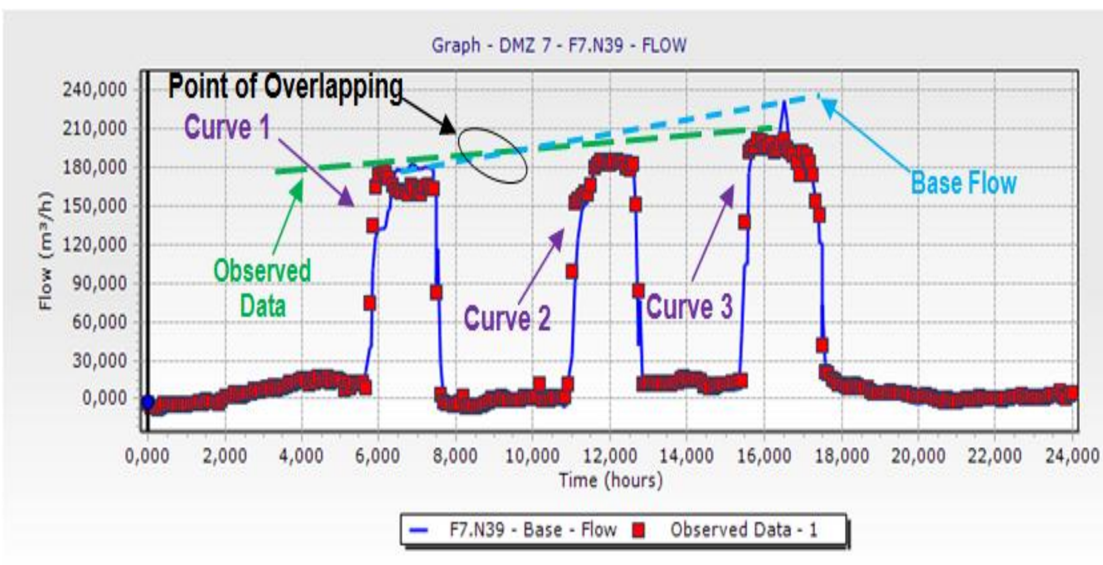
DMZ 6:-

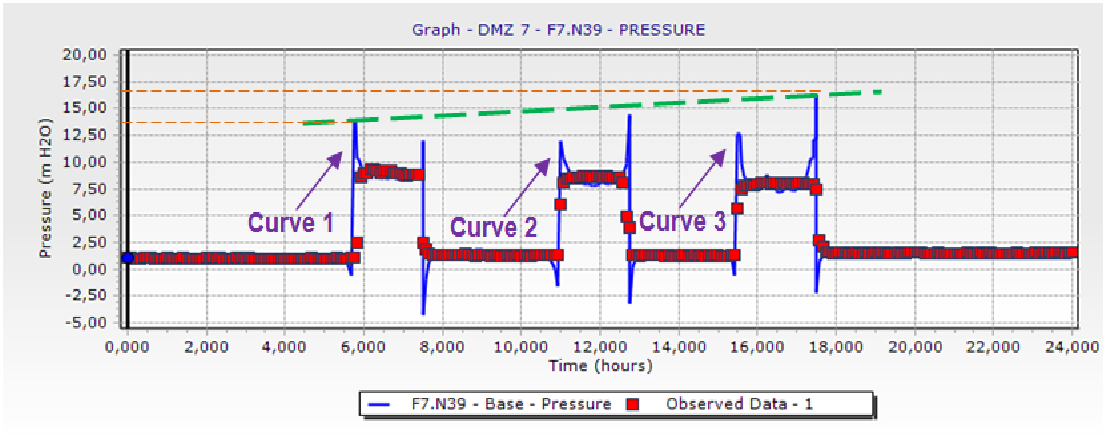


Graph - DMZ 6 - F6.N50 - FLOW
Flow (m³/h)
55,000
50,000
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0,000
2,000
4,000
6,000
8,000
10,000
12,000
14,000
16,000
18,000
20,000
22,000
24,000
Time (hours)
Curve 1
Curve 2
Curve 3
Maximum
F6.N50 - Base - Flow
Observed Data - 1

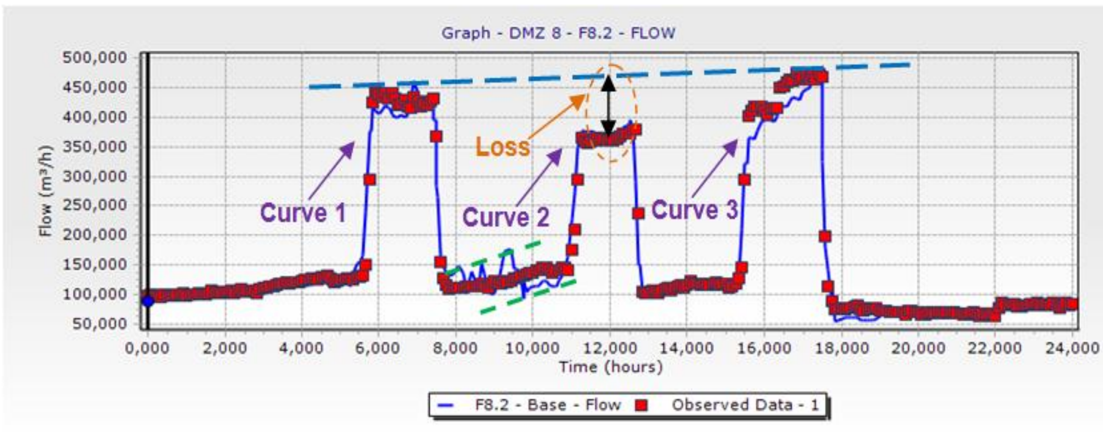

Graph - DMZ 6 - F6.N50 - PRESSURE
(12,000, 13, 00)
Base Pressure
Observed
Data
Pressure (m H2O)
20,00
17,50
15,00
12,50
10,00
7,50
5,00
2,50
0,00
-2,50
-5,00
0,000
2,000
4,000
6,000
8,000
10,000
12,000
14,000
16,000
18,000
20,000
22,000
24,000
Time (hours)
F6.N50 - Base - Pressure
Observed Data - 1

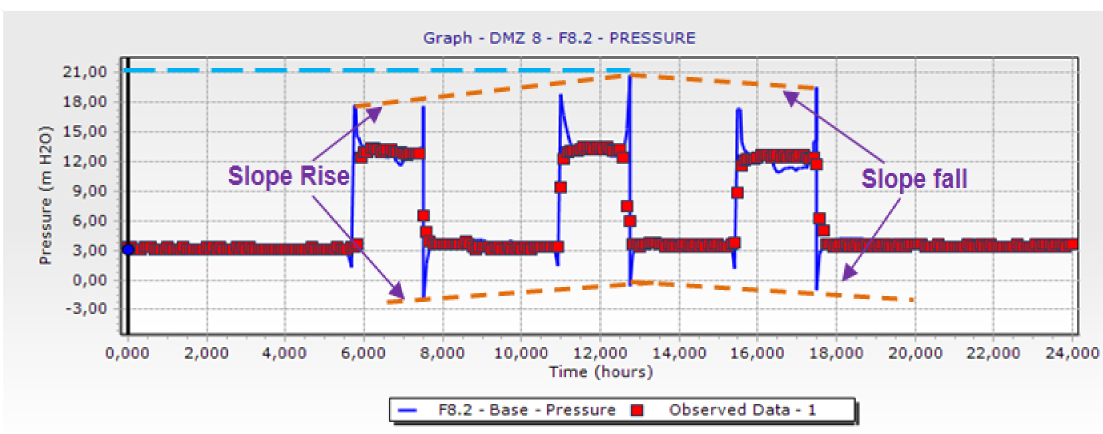
DMZ 7:-


Graph - DMZ 7 - F7.N39 - FLOW
Point of Overlapping
Curve 1
Curve 2
Curve 3
Observed
Data
Base Flow
Flow (m³/h)
240,000
210,000
180,000
150,000
120,000
90,000
60,000
30,000
0,000
0,000
2,000
4,000
6,000
8,000
10,000
12,000
14,000
16,000
18,000
20,000
22,000
24,000
Time (hours)
F7.N39 - Base - Flow
Observed Data - 1

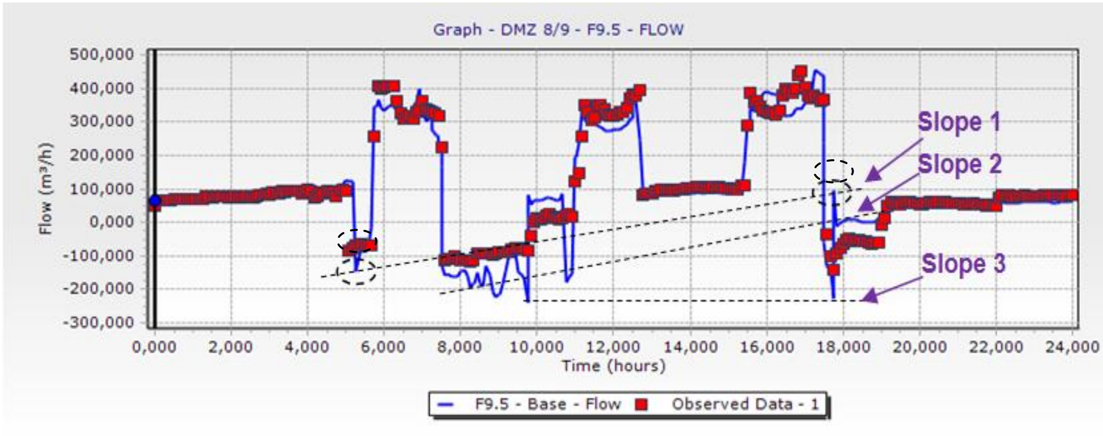

Graph - DMZ 7 - F7.N39 - PRESSURE
Pressure (m H2O)
Time (hours)
Curve 1
Curve 2
Curve 3
F7.N39 - Base - Pressure
Observed Data - 1

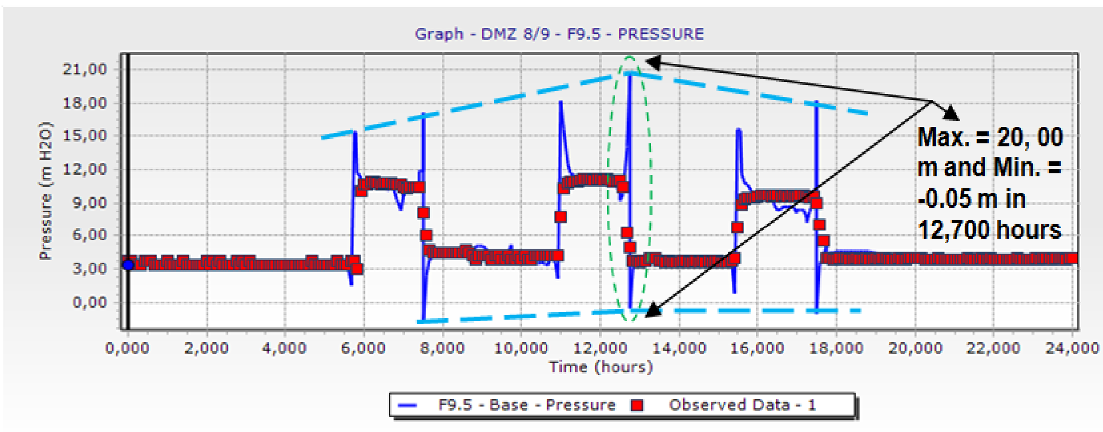
DMZ 8:-


Graph - DMZ 8 - F8.2 - FLOW
Flow (m³/h)
Time (hours)
Loss
Curve 1
Curve 2
Curve 3
F8.2 - Base - Flow
Observed Data - 1

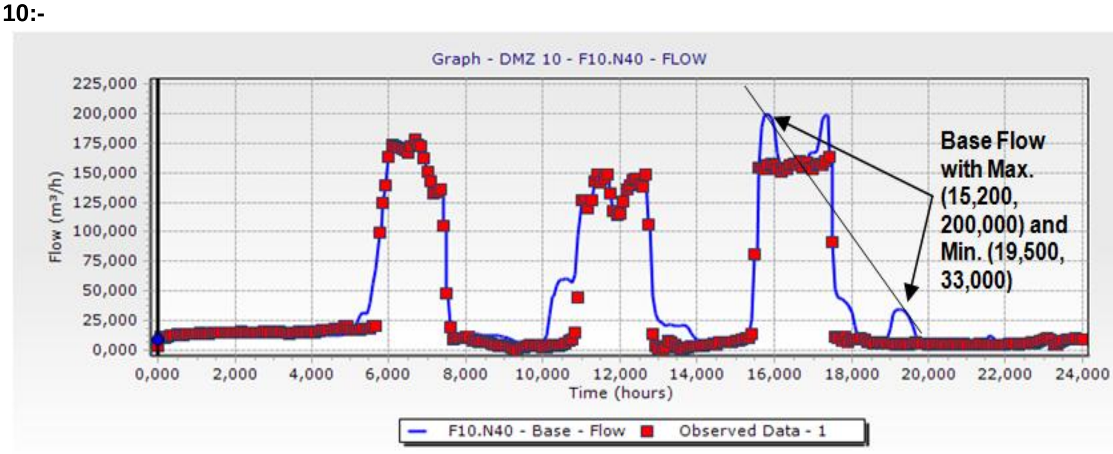

Graph - DMZ 8 - F8.2 - PRESSURE
Pressure (m H2O)
Time (hours)
Slope Rise
Slope fall
F8.2 - Base - Pressure
Observed Data - 1

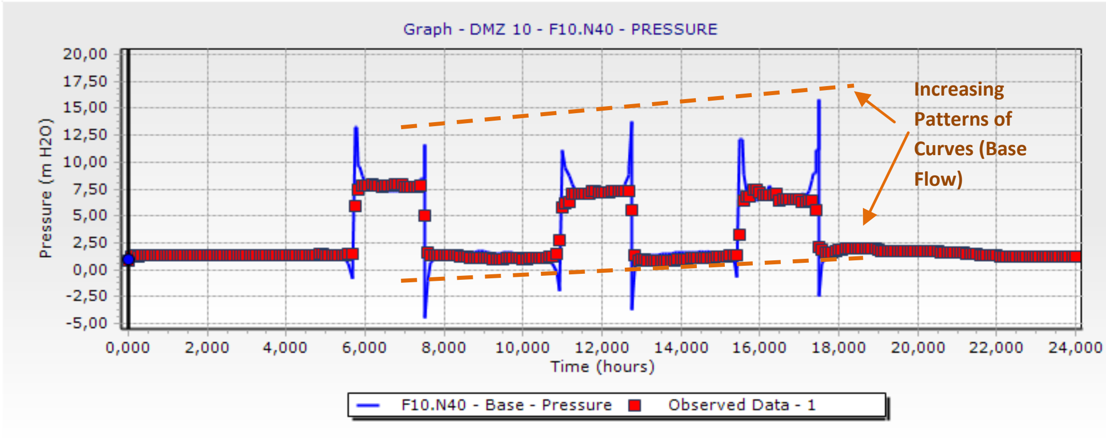
DMZ 9:-


Graph - DMZ 8/9 - F9.5 - FLOW
Flow (m³/h)
Time (hours)
Slope 1
Slope 2
Slope 3
F9.5 - Base - Flow
Observed Data - 1

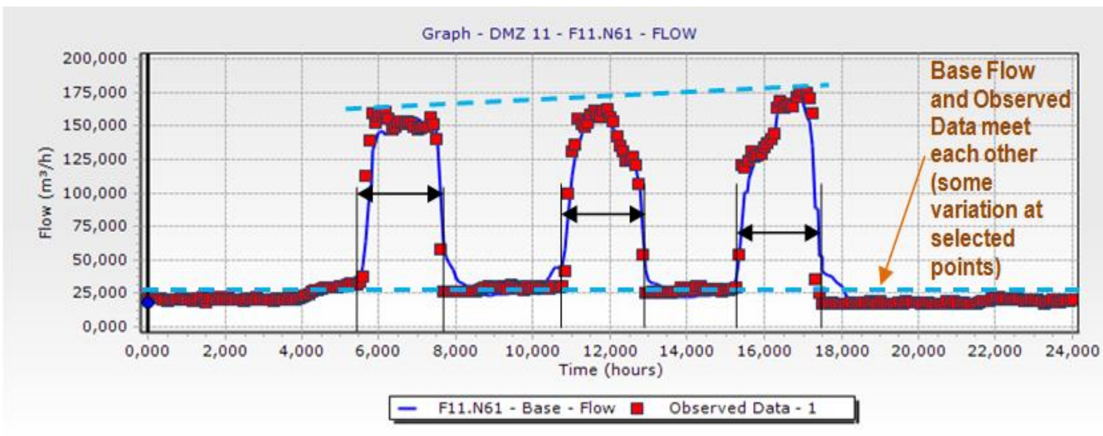

Graph - DMZ 8/9 - F9.5 - PRESSURE
Pressure (m H2O)
Time (hours)
Max. = 20, 00 m and Min. = -0.05 m in 12,700 hours
F9.5 - Base - Pressure
Observed Data - 1

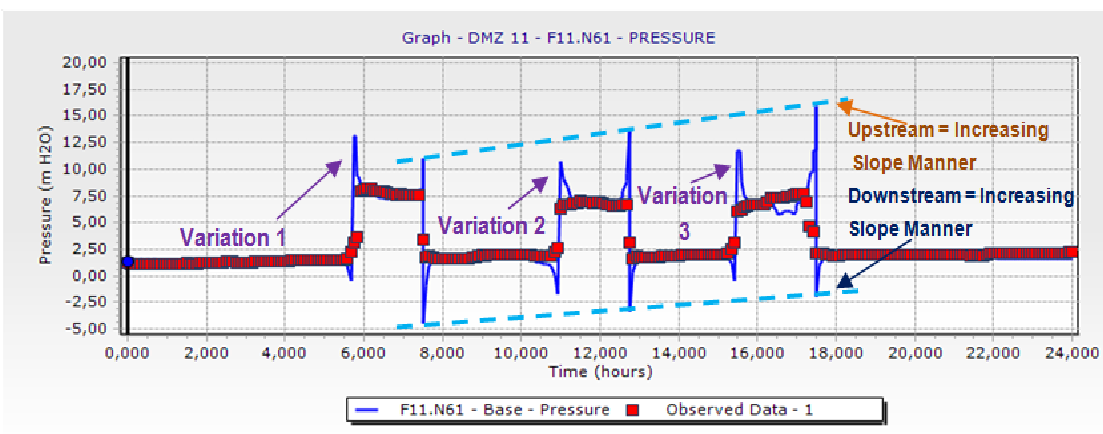
DMZ 10:-


Graph - DMZ 10 - F10.N40 - FLOW
Flow (m³/h)
Time (hours)
Base Flow with Max. (15,200, 200,000) and Min. (19,500, 33,000)
F10.N40 - Base - Flow
Observed Data - 1

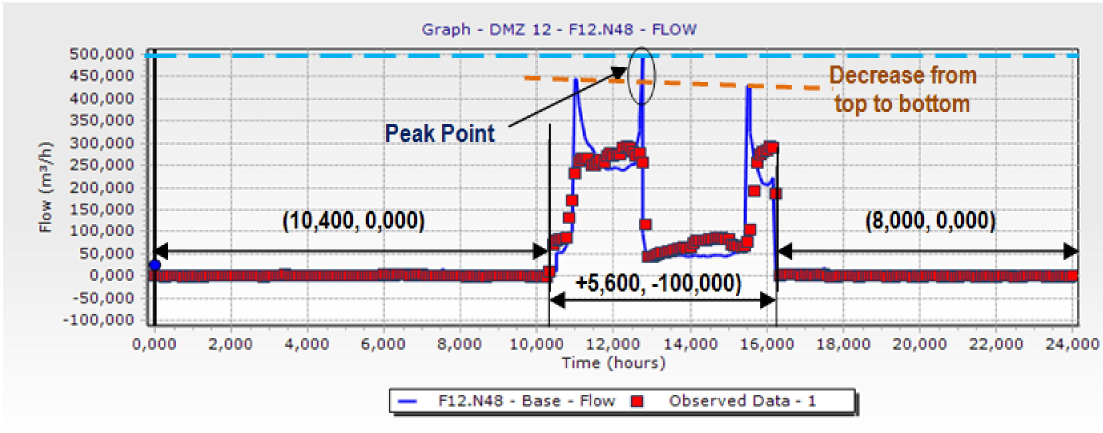

Graph - DMZ 10 - F10.N40 - PRESSURE
Pressure (m H2O)
Time (hours)
Increasing Patterns of Curves (Base Flow)
F10.N40 - Base - Pressure
Observed Data - 1

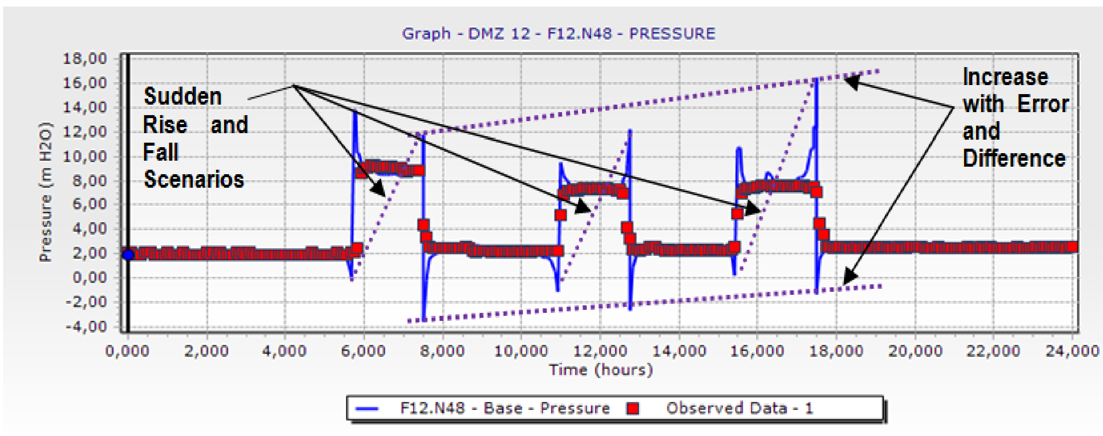
DMZ 11:-


Graph - DMZ 11 - F11.N61 - FLOW
Flow (m³/h)
Time (hours)
Base Flow and Observed Data meet each other (some variation at selected points)
F11.N61 - Base - Flow
Observed Data - 1

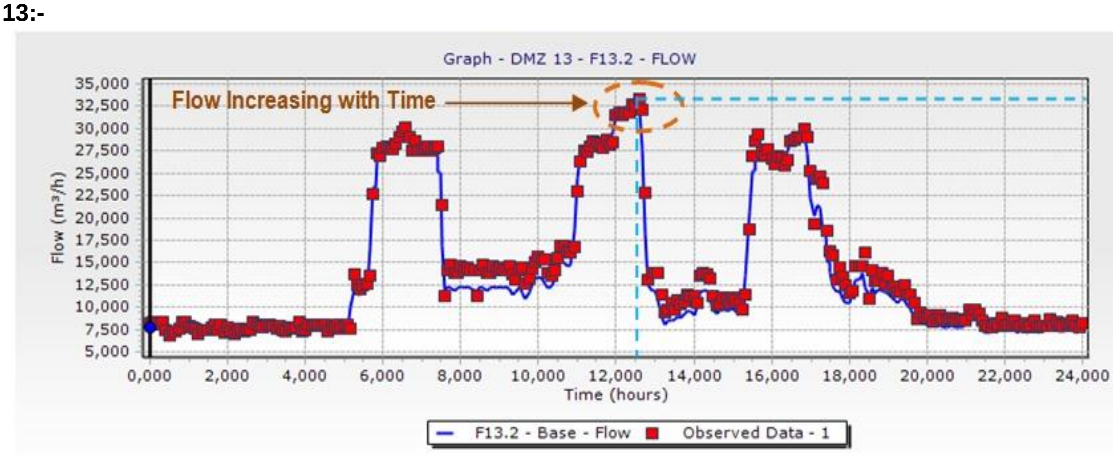

Graph - DMZ 11 - F11.N61 - PRESSURE
Pressure (m H2O)
Time (hours)
Variation 1
Variation 2
Variation 3
Upstream = Increasing Slope Manner
Downstream = Increasing Slope Manner
F11.N61 - Base - Pressure
Observed Data - 1

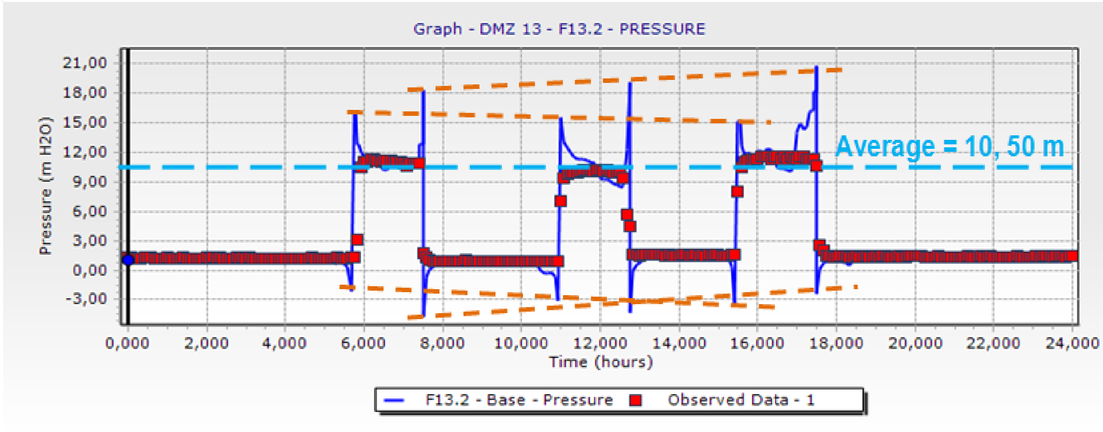
DMZ 12:-


Graph - DMZ 12 - F12.N48 - FLOW
Decrease from top to bottom
Peak Point
(10,400, 0,000)
(8,000, 0,000)
+5,600, -100,000)
Flow (m³/h)
Time (hours)
F12.N48 - Base - Flow
Observed Data - 1

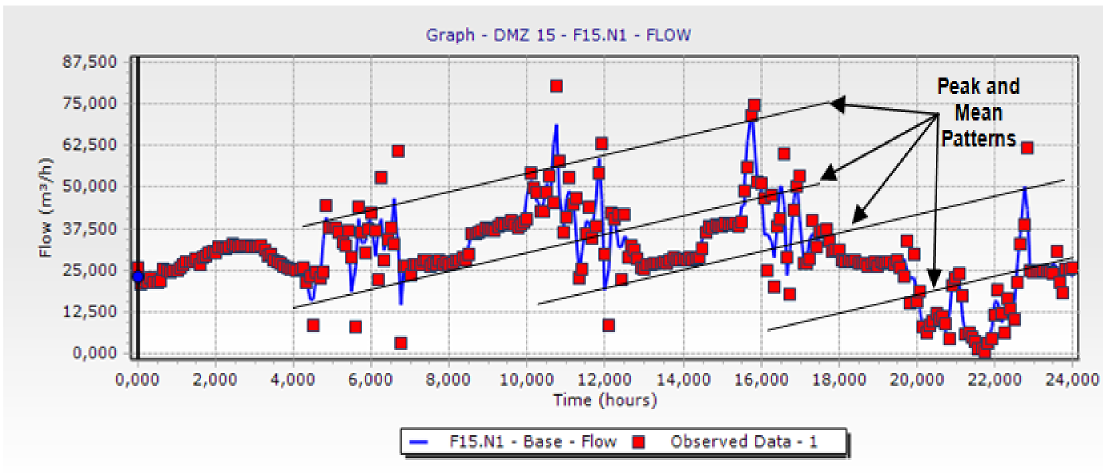

Graph - DMZ 12 - F12.N48 - PRESSURE
Sudden Rise and Fall Scenarios
Increase with Error and Difference
Pressure (m H2O)
Time (hours)
F12.N48 - Base - Pressure
Observed Data - 1

DMZ 13:-


Graph - DMZ 13 - F13.2 - FLOW
Flow Increasing with Time
Flow (m³/h)
Time (hours)
F13.2 - Base - Flow
Observed Data - 1



DMZ 15:-



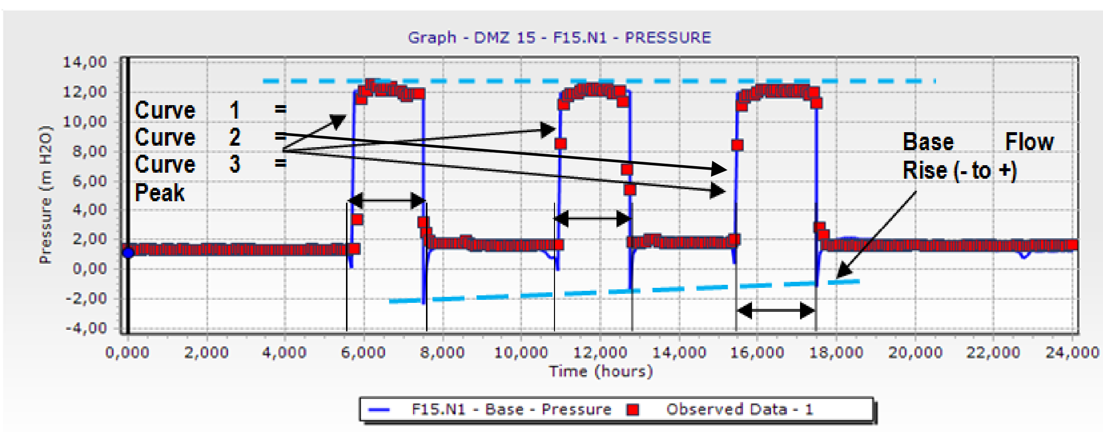


Fig. 25: *Calibration results for Terminal reservoirs and DMZ1 – DMZ 15 for Faisalabad*

The results for ***Figures 25 (DMZ1-DMZ15)*** representing, The ***Graph – TR – OLD – OUTLET - FLOW*** dictates that the Base Flow (*m^3/h*) has slowly increasing with observed data-1 from 55000,00 to 68000,00 (*m^3/h*) in 5,700 hours, and sudden rise of Base Flow (*m^3/h*) was occur from 68000,00 to 11000,000 only in 0.3 hours. At 110000,00 flow reading the Observed Data-1 was recorded from 6,000 to 7.5000 hours and sudden decline was happened between 10000,000 and 11000,000 Base Flow (*m^3/h*) points. The similar situations was observed from 78,000 to 11,080 (hours) and same rise and fall was reoccurs between 11,080 -13, 000 hours and similarly the same situations was observed from 13,000 hours to 24,000 hours. The peak points are 12000,250 (*m^3/h*) at 15,250 hours. The ***Graph – TR – OLD – OUTLET - PRESSURE*** shows that there is a rise and fall in water pressure with respect of time, but three rises are obtained which indicates that almost three peak points are identical with same rise and same fall of curve from 0,000 up to 24,000 hours. The ***Graph – TR – OLD – LEVEL*** is drawn between Elevation in meter (Y-axis) and Time in hours (X-axis). The curve represents three peak points at 4,700 hour, 10,500 hour, 15,250 hour with an average peak at 10,500 hr. At mean time the Elevation is 5,28 meter. There is a one decline point was observed at 22,000 hours out of 24,000 hours. There is a much difference between Curves Terminal Reservoir Old – Outflow and Terminal Reservoir New – Outflow, because the new one curve was implemented after the installation of instrumentation in Faisalabad. The ***Graph – TR – NEW – OUTLET – FLOW*** indicates that the Flow (*m^3/h*) at 0,000 (*m^3/h*) from 0,000-5,800 hours, 5,800-10,950 hours, 10,950-15,250 hours and similarly from 17,200-24,000 hours. There are three rises was occurred between 5,800-7,700 hr, 10,950-12,950 hr and 15,250-17,200 hr. Both rises indicates the same level of flows with a minimum level of differences. The graph in *Fig. 25* dictates that there is an average rise of curve was occurred at 11,000 hours and the Elevation (*m*) of Base Level (calculated) for ***TR-New_GT_1***, Base Level (calculated) for ***TR-New_GT_2*** and Observed Data-1 = 6.2 meter was recorded. The ***Graph – DMZ 1 – F1.1 - FLOW*** was established during experiment at site between Flow (*m^3/h*) and Time (hours). The flow was recorded during each time interval and the variation of flow rate viz-a-viz time interval in shown as per figure ***DMZ 1 – F1.1 – Flow***. The graph for DMZ 1 shows that there was sudden rise in flow from 5,800-7,700 hr, 11,000-12,950 hr, 15,100-17,250 hr and the peak flow was recorded at three points with a minimum fluctuation. There is no one average curve in this case because curve number 2 and curve number 3 shows the same peak respectively. Similarly the graph is plotted between ***Pressure of Water (m) and Time (hours)*** for DMZ 1. The Water Pressure (*m*) was at 3,00 *meter* (constant) trace except between time 5,700-7,500 hour, 11,000-12,850 hour, and 15,500 - 17,400 hour, with no one average curve. The curve 2 and 3 are similar representation. The ***Graph for DMZ 2 (F2.N18 – FLOW***) indicates the maximum flow 224,000 (*m^3/h*) between 16,000-18,000 hours. There is a minimum difference of levels of flow between first two and last curves. According to first, second curves the flow levels at 21,000, 20,000 *m^3/h*. The ***Graph for F2.N18-PRESSURE (DMZ 2)*** is similar to DMZ 1 pressure graph. The Base Pressure and Observed Data – 1 was matched with each other at Pressure (*m* H_2O) from 0,000-5,700 hour, 7,400-10,500 hour, 12,800-15,300 hour, and from 17,300-24,000 hours. Both rise 2 and rise 3 are similar with a minimum variation at 20, 50 *m* of water. The Pressure graph for DMZ 2 dictates that Rise1 ≠ Rise 2 = Rise 3. The ***Graph for DMZ 3 (F3.3 – FLOW)*** shows that the curve 1 and 3 represents the same flow rate of about 95,000 *m^3/h* at times 7,100 and 15,250 hours. The curve 2 shows the average minimum flow 86,000 *m^3/h* between 10,900-12,900 hours. The Base flow and Observed Data was strictly follows to each other at every point and shows the day and night variations. The ***Graph DMZ 3 - F3.3 – PRESSURE*** represents the separate results as compare to DMZ 1 and DMZ 2. This graph depicts there are three different patterns but the slope of graph increase continuously from pattern 1 to pattern 3 with minimum pressure (*m* H_2o) at 16,00 *m* and max. Pressure (*m* H_2o) at 17, 60 *m* in times 5,700 and 17,300 hours respectively. The Base Flow and Observed Data was meet each other at Pressure = 1.5 *m* between 0,000-5,700, 7,300-10,900, 12,800-15,200, and 17,300-24,000 hours. The ***Graph (DMZ 4-F4.N33 – FLOW)*** indicates the comparison between both three curves. The curve 1 declines towards curve 2 and curve 2 rise towards curve 3. Mean while the Curve 2 indicates the central point of Curve 1 and Curve 3. The F4.N33 – Base – Flow and Observed Data – 1 are constant except 5,700-7,700, 10,800-11,900, and 15,200-17,800 hours. The ***Graph (DMZ 4) F4.N33 – PRESSURE*** represents the target point at 15, 00 *m* in 17,300 hours. The similar variations were observed at 5,700 and 11,000 hours for 12, 50 and 10, 50 *m* of pressures. The ***Graph –DMZ 5 – F5.N35 - FLOW*** depicts the similar curvature patterns with peaks at 175,000 *m^3/h*, 174,000 *m^3/h*, and 185,000 m^3/h with small sudden fall at 17,000 hours and the Flow (m^3/h) at this point was 150,000 m^3/h for DMZ 5. The ***Graph – DMZ 5 –F5-N35 – PRESSURE*** depicts that the average Observed Data – 1 of Pressure (*m*) = 8, 75 was recorded against time. The F5.N35 – Base – Pressure was vary from time to time but Observed Data – 1 was constant with time during 24,000 hours but minimum variations was recorded at 5,700, 7,400, 11,000, 12,800, 15,200, 17, 300 hours. The results changes from DMZ to DMZ and accordingly the results for DMZ 6 are much different as compare to others. The Flow Patterns for ***Graph – DMZ 6- F6.N50 – FLOW*** indicates that the maximum flow values were established in middle of 24,000 hours approximately at 12,000 hours is 53,000 m3*/h*. The starting and end rates are same for F6.N50 – Base – Flow and Observed Data – 1 as shown in DMZ 6 Flow diagram. The ***Graph – DMZ6 – F6.N50 – PRESSURE*** explains that the Base Pressure increasing continuously with time from 12, 50 *m*-15, 50 *m* with a middle value of 13,00 m at 12,000 hours. The ***Graph – DMZ 7-F7.N39 - PRESSURE*** shows the overlapping phenomenon between Base Flow and Observed Data – 1. The peaks of Observed Data were increased from 180,000-210,000 m^3/h for 6,000 and 15,700 hours. The F7.N39 – Base – Flow was rises from 181,000 m^3/h to 230,000 m^3/h. The Curve 2 is the middle of both maximum and minimum Curves at 182,000 m^3/h for 12,000 hours. The ***Graph – DMZ7 – F7.N39 – PRESSURE*** depicts that the slope Curve 1 = Min. and Curve 3 = Max Values. The Curve 1 = 13,00 *m* pressure at 5,700 hours but Curve 3 has 16,00 *m* value at 17,300 hours, 14,50 indicates middle vale at 12,000 hours. The ***Graph – DMZ 8 – F8.2 – FLOW*** show that there are small rising and falling patterns exists between Curves 1 and 2, and the Observed Data – 1 and middle line of rising, falling patterns (F8.2 – Base Flow). As usual the results of Curves1 and 3 are again rising and falling (450,000 m^3/h – 470,000 m^3/h), but the value of middle curve is lie between Curves 1 and 3 with loss of value = 100,000 m^3/h. The conditions for ***Graph – DMZ 8 – F8.2 – PRESSURE*** are much different and critical as compare to other DMZ's, because the central curve depicts maximum results than others with value of about 20,00 m for pressure in 12,900 hours. In addition this central curve reflects that the slope rise from Curve 1 to Curve 2, and Slope declines from Curve 2 towards Curve 3. This rise and fall indicates an ideal case of pressure variations within DMZ 8. The same phenomenon was reoccur with Base Flow in down direction the slope rise and fall from Curve to Curve but both curves meet under pressure -0,05 m at 12,900 hours. The Observed Data – 1 are constant within DMZ 8 for 24,000 hours except small variations between 47,00-73,00 hours,10,950-12,950 hours, 15,300-17,300 hours, but the Observed Data – 1 was again constant within these time durations. The ***Graph – DMZ 8/9 – F9.5 – FLOW*** dictates much diversified results and again shows a lot of variations in Base Flow as well as Observed Data – 1. The more fluctuations were observed in the decreasing direction than increasing pattern. Two times the Base flow increase from Curve 1 to Curve 3 and then gives a straight line between Curve1, Curve2 towards Curve 3. The **Graph – DMZ 8/9** represents the minimum variation in F9.5 – Base Pressure and Observed Data – 1 between all curves but the central curves provide a maximum and minimum value (Max. = 20, 00 *m* and Min. = -0.05 *m* in 12,700 hours). As usual the patters in ***Graph – DMZ 10 – F10.N40 – FLOW*** are similar to previous 9 DMZ's curves but the small difference is that the F10.N40 – Base – Flow and Observed Data – 1 are different at peak and downstream points. The maximum Base Flow = 200,000 m^3/h at 15,200 hours and Minimum Base Flow = 33,000 m^3/h at 19,500 hours. The ***Graph – DMZ 10 – F10.N40 – PRESSURE*** point out that the Base Flow is increasing continuously either in upstream direction at points 11,00, 13,50, 15,100 m^3/h and in downstream direction at -3,00, -2,75, -2,50 at fixed times 7,200, 12,800, 17,300 hours. The Observed Data – 1 are recorded constant in this case either with small fluctuations between 1,50 to 7,50 *m* pressure for 24,000 hours. The ***Graph – DMZ 11 – F11.N61 – FLOW*** dictates the rising path from first curvature towards last curvature (both are peak points). The bottom results are very different as compare to other DMZ's, because the Observed Data – 1 and F11.N61 – Base – Flow are mostly follow each other at basement but some variations was recorded between 5,700-7,800, 10,900-12,900, 15,200-17,200 hours. This variation was due to leakages in this DMZ and flow variations. The ***Graph – DMZ 11-F11.N61 – PRESSURE*** dictates, there are three number of pressure Variations due to leakages during 24,000 hours of operation in Faisalabad Arterial Main-Pipe Line Distribution Network. This graph also depicts two conditions (Upstream = Increasing Slope Manner, Downstream = Increasing Slope Manner), difference is that the slopes (pressure) in downward direction increasing from -3, 75 to -2.00 *m* and 11,00 - 16,00 *m* in upper portion. The ***Graph – DMZ 12 – F12.N48 – FLOW*** indicating three peaks but the major peak was at 490,000 m^3/h in 12,800 hours. The other two peaks presents the sudden decrease from top to bottom due to variation of time and variation of Base as well as Observed patterns. According to graph there is a constant line including F12.N48 – Base Flow, Observed Data – 1 was recorded up to (10,400 hours, 0,000 m^3/h) and up to (8,000 hours, 0,000 m^3/h). The major variation was obtained between 10,400 and 16,300 hours i.e (+5,600 hours, -100,000 m^3/h). The (+) values was observed at sides and (-) values was observed at center of curve due to water discharge variations in time. The ***Graph – DMZ 12 – F12.N48 – PRESSURE*** represents major leaks between pressure (m) points at different times during day and night. At one time there is a sudden rise occur and at second moment there was a sudden diminish was observed. At the end the curve dictates that there are rises occur with huge error and difference (start-end). The Observed Data – 1 follow/not follow at some points to F12.N48 – Base – Line. The ***Graph – DMZ 13 – F13.2 – FLOW*** shows that in the presences of highest variations the peak demand curve (middle curve). According to middle curve both F13.2 – Base – Flow and Observed Data – 1 are overlay to each other with peak 33,000 m^3/h at 12,800 hours (ideal case). The **Graph – DMZ**

13 – F13.2 – PRESSURE indicating that both curves are rise and fall in a certain time intervals. Both F13.2 – Base – Pressure and Observed Data – 1 provides an average = 10,50 *m* (pressure). The ***Graph – DMZ15 – F15.N1 – FLOW*** designate that there is a huge flow variation with respect of time in DMZ 15 due to major leakages. The flow rates m3/h was vary day/night, the curve is like a single wave but some variations in curve was observed at the time of equipment installation (peak and mean patterns was observed). Finally the results are derived for ***Graph – DMZ 15 – F15.N1 – PRESSURE***, according to graph the Base Flow is rising at bottom from -2,00 to -1,00 (*m* H2O). This graph states ideal conditions such as Curve 1 = Curve 2 = Curve 3 = Peak, The three peaks within single peak was obtained at 12, 60 (*m* H2O) at different times. According to DMZ 16 Graph both F15.N1 – Base – Pressure and Observed Data – 1 are matched each other except some points. The locations where Base Pressure and Observed Data – 1 was not matched, due to sudden change in pressure variations are most sensitive site of Faisalabad.

8. CONCLUSIONS AND RECOMMENDATONS

The maximum water losses was recorded within DMZ 8 (*) and the minimum water losses was recorded in DMZ 10 (*), for the rest of the DMZs and minimum night flows are less than 0.40 l/s/km. For DMZ 6, 10, 15 and 16, the minimum night flow values are also less than 0.10 *l/s/km* and do not require leak detection. Daily production by Bulk Meters, Flow Meters and estimates was 205000 m^3/d water sold 93540 m^3/d. The Faisalabad network was classified in “Bad” category as it has a value less than 70%. The results obtained both at the rank of performance or of ILL are weak. In WATERGEMS, closed valves are not a special feature and use related to each DMZ was uniformly distributed at the nodes of each DMZ and adjusted. The consumption patterns were varied DMZ to DMZ. Due to the huge differences of pressures due to some major and some minor leaks at various coordinates of Faisalabad city. This study was conducted in-order to enhance the water productivity for Faisalabad and it is concluded that the government will provide the provision in order to arrange similar studies after every 7-10 years, to increase the future production of water for increasing population and as per capita demand. TR-Old-Outlet-Flow represents Base Flow increasing (55000, 00-68000, 00 m^3/h within 5,700 hours with sudden rise = 68000,00-11000,00 in 0.3 hours) and peak points are 12000,250 (m^3/h) at 15,250 hours. The Graph –TR-Old-Level represents three peak points at 4,700 hour, 10,500 hour, and 15,250 hour with an average peak at 10,500 hour. At mean time the Elevation is 5, 28 *meter*. There is a one decline point was observed at 22,000 hours out of 24,000 hours. There are three rises was occurred between 5,800-7,700 hour, 10,950-12,950 hour and 15,250-17,200 hour. Both rises indicates the same level of flows with a minimum level of differences. The graph for DMZ 1 shows that there was sudden rise in flow from 5,800-7,700 hour, 11,000-12,950 hour, 15,100-17,250 hour and the peak flow was recorded at three points with a minimum fluctuation. There is no one average curve in this case because curve number 2 and curve number 3 shows the same peak respectively. Similarly the graph is plotted between Pressure of Water (*m*) and Time (hours) for DMZ 1. The Graph for DMZ 2 (F2.N18 – FLOW) indicates the maximum flow 224,000 (m^3/h) between 16,000-18,000 hours. There is a minimum difference of levels of flow between first two and last curves. According to first, second curves the flow levels at 21,000, 20,000 m^3/h. The Pressure graph for DMZ 2 dictates that Rise1 ≠ Rise 2 = Rise 3. Pressure (m H_2o) at 17,60 m in times 5,700 and 17,300 hours respectively. The Base Flow and Observed Data was meet each other at Pressure = 1.5 *m* between 0,000-5,700, 7,300-10,900, 12,800-15,200, and 17,300-24,000 hours (DMZ3). The Graph – DMZ 10 – F10.N40 – PRESSURE point out that the Base Flow is increasing continuously either in upstream direction at points 11,00, 13,50, 15,100 m^3/h and in downstream direction at -3,00, -2,75, -2,50 at fixed times 7,200, 12,800, 17,300 hours. The Observed Data – 1 are recorded constant in this case either with small fluctuations between 1, 50 to 7, 50 *m* pressure for 24,000 hours. The Graph – DMZ 11-F11.N61 – PRESSURE This graph also depicts two conditions (Upstream = Increasing Slope Manner, Downstream = Increasing Slope Manner), difference is that the slopes (pressure) in downward direction increasing from -3, 75 to -2.00 *m* and 11, 00 - 16, 00 *m* in upper portion. The Graph – DMZ 12 – F12.N48 – Flow indicating three peaks but the major peak was at 490,000 m^3/h in 12,800 hours. The major variation was obtained between 10,400 and 16,300 hours i.e. (+5,600 hours, -100,000 m^3/h). Finally the results was derived for Graph – DMZ 15 – F15.N1 – PRESSURE, according to graph the Base Flow is rising at bottom from -2,00 to -1,00 (*m* H2O). This graph states ideal conditions such as Curve 1 = Curve 2 = Curve 3 = Peak, The three peaks within single peak was obtained at 12, 60 (*m* H2O) at different times. According to DMZ 16 Graph both F15.N1 – Base – Pressure and Observed Data – 1 are matched each other except some points. The locations where Base Pressure and Observed Data – 1 was not matched, due to sudden change in pressure variations are most sensitive site of Faisalabad.

The 62 number Remote Terminal Units (Sofrel LS42) and 1 SCADA Master Unit was use for improvement of network, we recommend that in future the similar studies will conducted in behalf of every city like Faisalabad in order to enhance production and minimize losses via leakages, but similar studies depends on the interest of government and funding. In this study 6 DMZ was fully equipped and 5 DMZ was partially equipped.

REFERENCES

AWWARF (2007) Advancing the Science of Water: AWWARF and Infrastructure Replacement Needs. Denver, Colorado, AWWA Research Foundation. AWWA Publishing.

Beal C and Stewart RA (2011) South-East Queensland Residential End Use Study: Final Report, Urban Water Research Security Alliance Technical Report No. 47.

Britton T, Stewart R, O'Halloran K (2013) Smart metering: enabler for rapid and effective post meter leakage identification and water loss management. Journal of Cleaner Production 54:166-176.

Beal C, Stewart RA (2013) Identifying Residential Water End-Uses Underpinning Peak Day and Peak Hour Demand. Journal of Water Resources Planning and Management. doi:10.1061/(ASCE)WR.1943-5452.0000357.

DERM (2010) Planning Guidelines for Water Supply and Sewerage, Department of Environmental and Resource Management, Queensland Government.

EPD (2007) Water Leak Detection and Repair Program, Environmental Protection Division Watershed Protection Branch, Georgia.

GCW (2009) Gold Coast Water (2009-A), "Desired Standards of Service Review 2008", GHD Final Report Rev 3, October 2009.

Hunaidi, O. (2010) Leakage Management for Water Distribution Infrastructure – Report 1: Results of DMA Experiments in Regina, SK. Canada, National Research Council.

Kleppen, M. H. (2011) Optimization of Small Urban Water Services in Developing Countries by Water Loss Management. Environmental and Health Studies. Hallvard Eikas plass, Telemark University College, Unpublished.

Kingdom, B., Liemberger, R. and Marin, P. (2006) The Challenge of Reducing Non-Revenue Water (NRW) in Developing Countries. How the Private Sector Can Help: A Look at Performance-Based Service Contracting, Washington DC, The World Bank.

McKenzie, R. S. (1999) SANFLOW User Guide: South Africa Water Research Commission, WRC Report No. TT 109/99 Pretoria, South Africa, Water Research Commission.

Mead, N. (2008), Investigation of Domestic Water End Use, Undergraduate Thesis, Faculty of Engineering and Surveying, University of Southern Queensland, Toowoomba, Australia.

Mutikanga, H., Sharma, S. and Vairavamoorthy, K. (2009) Water Loss Management in Developing countries: Challenges and Prospects American Water Works Association Journal, Vol. 101(12), 57-68.

McKenzie, R. S. and Wegelin, W. (2009) Implementation of Pressure Management in Municipal Water Supply Systems. IWA Presentation paper_0309 21st February 2009. Pretoria, South Africa, IWA Publishing.

Todorovic B, Tsakiris G, Prodanovic D (2011) A pilot initiative for improved urban demand estimation based on stochastic analysis of water consumption. Water Utility Journal 1:19-29.

Farley, M. (2003) Non Revenue Water - International Best Practice for Assessment, Monitoring and Control Annual CWWA Water, Wastewater and Solid Waste Conference. Atlantis, Paradise Island, Bahamas.

Lahlou, Z. M. (2011) Leak Detection and Water Loss Control. Morgantown, Virginia, West Virginia University.

WRC (2001) Development of a Pragmatic Approach to Evaluate the Potential Savings from Pressure Management in potable water distributions in South Africa: PRESMAC Report Pretoria, South Africa, Water Research Commission.

Willis RM, Stewart RA, Williams PR, Hacker CH, Emmonds SC, Capati G (2011a) Residential potable and recycled water end uses in a dual reticulated supply system. Desalination 272(1-3):201-211.

Zalewski, M. (2002) Ecohydrology: The use of Ecological and Hydrological processes for sustainable management of water resources. Hydrological Sciences Journal, Vol. 47(5), 805-8017.

STATEMENT:

We hereby confirm that this research paper is our own original work and we have cited all sources that were used. We again corroborate that the contents of this research "**THE SCIENCE DMZ: FLOW – PRESSURE MEASUREMENT (NRW) SCADA FUNCTIONING AND HYDRAULIC MODELING IN FAISALABAD, PAKISTAN"** are product of our own study and no part has been copied from any published source except the references. This manuscript is plagiarism free and this article contains no such material that may be unlawful.