

NETWORK ANALYSIS OF WATER DISTRIBUTION SYSTEM IN URBAN AREAS USING EPANET 2.2 SOFTWARE

Hocine LAKHDARI - student, PhD, Technical University of Civil Engineering,
e-mail: lakhdari_hocine@hotmail.fr

Andrei-Mugur GEORGESCU - Prof. univ. dr. ing. PhD Thesis Supervisor, Technical University of Civil Engineering, Faculty of Hydrotechnics, Construction and Environmental Protection,
e-mail: andrei_georgescu2003@yahoo.com

Abstract: This study evaluates the hydraulic performance of the water distribution network of the Municipality of Oradea, Romania, using EPANET 2.2. A hydraulic model consisting of 270 pipes, 260 junction nodes, pumping stations, and storage reservoirs was developed to assess the operational behavior of the network. Two hydraulic simulation approaches were applied: Demand Driven Analysis (DDA) and Pressure Driven Analysis (PDA). The comparison between these approaches aimed to investigate the influence of pressure-dependent demand on network performance and to determine the suitability of each method for hydraulic assessment.

The hydraulic performance of the system was evaluated using key indicators including nodal pressure, pipe flow velocity, pressure reliability, and demand satisfaction. The simulation results showed that the network generally operates within acceptable hydraulic limits. Pressure values remained sufficient to satisfy consumer demands, while pipe flow velocities were found to be consistent with the recommendations of European standard EN 805 and Romanian standard NP 133-2022. The comparative analysis demonstrated that Pressure Driven Analysis (PDA) provides a more realistic representation of network behavior under variable pressure conditions by accounting for pressure-dependent demand variations. The results confirm the applicability of EPANET 2.2 as an effective tool for simulating hydraulic systems and demonstrate the advantages of PDA for evaluating the operational performance of urban water distribution systems under realistic operating conditions.

Keywords: Water distribution network, EPANET 2.2, hydraulic simulation, demand driven analysis, pressure driven analysis.

1. Introduction

Urban water distribution networks are essential infrastructures that ensure the continuous supply of drinking water to residential, commercial, industrial, and public consumers. Faced with urban population growth and increasing water demand, distribution networks are becoming more complex and require effective hydraulic management to maintain adequate pressure, sufficient flow rates, and acceptable service reliability. Consequently, hydraulic modeling has become a fundamental tool for evaluating network performance, identifying operational failures, and supporting planning and rehabilitation decisions [1].

The hydraulic analysis of water distribution networks is traditionally performed using numerical simulation models based on the principles of conservation of mass and energy. Modern simulation software allows engineers to evaluate pressure distribution, flow velocities, head losses, and system reliability under a wide range of operating conditions. Among these tools, EPANET 2.2 is widely recognized for its ability to simulate pressurized water distribution networks and analyze their hydraulic behavior [2].

A crucial aspect of hydraulic simulation is the representation of consumer demand. Classical demand-driven analysis (DDA) assumes that the required demand at each node is fully met, regardless of the available pressure. While this assumption is generally acceptable under normal operating conditions, it can produce unrealistic

results in the event of a pressure deficit, leading to negative pressures or an overestimation of the distributed water flow.

To overcome these limitations, EPANET 2.2 incorporates pressure-driven analysis (PDA), which establishes a direct relationship between nodal pressure and distributed demand. In PDA mode, water consumption decreases when the pressure drops below the required level, thus providing a more realistic representation of network performance during abnormal operating conditions, consumption peaks, or hydraulic failures [3].

Although both approaches are available in EPANET 2.2, few studies have evaluated their comparative application to large municipal distribution networks. Furthermore, the practical implications of choosing between demand-based analyses (DDA) and pressure-based analysis (PDA) for assessing network reliability and demand-side performance remain insufficiently documented for many existing urban networks.

The municipality of Oradea operates a large water distribution network supplied by pumping stations and reservoirs. Evaluating the hydraulic performance of this network is essential to verify its compliance with applicable operational requirements and design standards.

Although the hydraulic simulation of water distribution networks has been the subject of numerous studies, many analyses still rely exclusively on demand-driven analysis (DDA), which assumes that all consumer demands are fully met, regardless of the available network pressure. This assumption can lead to unrealistic results in the event of pressure deficits due to operational failures, consumption peaks, or network constraints. The introduction of pressure-driven analysis (PDA) in EPANET 2.2 offers an alternative approach that takes into account the dependence of water demand on available pressure and allows for the simulation of partial demand satisfaction.

Despite the growing interest in PDA-based modeling, comparative applications of DDA and PDA to urban water distribution networks limited. Therefore, the main objective of this study is to evaluate the hydraulic performance of the Oradea municipality's water distribution network and to compare the results obtained using DDA and PDA. The study focuses on pressure distribution, flow velocity, pressure reliability, and demand satisfaction to determine whether the network operates within the limits recommended by European and Romanian standards.

2. Background of water distribution network analysis

Analysis of water distribution networks is a fundamental part of water resources engineering studies. It aims to understand network behavior under varying operating conditions and ensure efficient and adequate water delivery to all consumers. This analysis relies on hydraulic principles, such as the laws of conservation of mass and energy [4], to study pressures and dispositions within pipes and nodes, and to identify losses due to friction or leakage[5]. It also contributes to evaluating the efficiency of pumps and reservoirs, identifying weaknesses or bottlenecks, and predicting network performance during emergencies or periods of increased demand. Specialized mathematical models and simulation software are used to support decision making, improve design, reduce waste, and ensure the long-term sustainability of the water distribution networks [6],[7].

Many methods have been used in the past to calculate flows in network of pipes. Such methods range from graphical methods to the use of physical analogies and finally to the use of mathematical models [8], [9].

For example, one of the earliest methods into finding solution to water flow and pressure in water distribution networks includes the popular Hardy Cross method. Which is an iterative method for determining the flow in piping systems where the inputs and outputs are known, but the flow inside the network is unknown [10]. This method was later made obsolete by computer solving algorithms using the Newton-Raphson method or other solution methods for example (The Simultaneous node method, loop method, the linear method (Simultaneous Pipe Method), and the gradient method (Simultaneous Network Method) that removed the need to solve nonlinear systems of equations by hand [8]. All of these methods matrix formulations of the network problem in order to take advantage of the full power of modern day computers. The development of these computational methods led to modern hydraulic modeling software such as EPANET, which used the Global Gradient Algorithm (GGA) proposed by Todini and Pilati [11] to solve and analyze network equations accurately and efficiently, making it one of the most widely used software packages for water distribution system analysis.

Modern hydraulic analysis goes far beyond simply calculating pressures and flow rates. Current research aims to improve the reliability, resilience, and operational efficiency of water distribution networks through advanced numerical modeling and optimization techniques. Pressure-driven analysis (PDA), for example, is increasingly replacing traditional demand-driven analysis (DDA) in cases of insufficient pressure because it more accurately represents the physical relationship between available pressure and demand. PDA is particularly useful for assessing network performance during pipe bursts, pump shutdowns, fire incidents, and water shortages situations where consumer demand cannot be fully met [12], [3].

In parallel, optimization methods based on genetic algorithms, evolutionary computation, and multi-objective optimization have been widely adopted to determine optimal pipe diameters, pump operating schedules, pressure management strategies, and rehabilitation plans, while minimizing construction and operating costs and maximizing system reliability [13],[14], [15]. Recent studies have also highlighted the importance of resilience assessment, leakage reduction, and pressure management for the sustainability of water distribution systems, as excessive pressures directly lead to increased leakage rates, higher energy consumption, and accelerated infrastructure deterioration [16], [17].

The latest developments in this field integrate hydraulic models with geographic information systems (GIS), supervisory control and data acquisition (SCADA) systems, Internet of Things (IoT) sensors, and digital twin technologies. These intelligent systems enable continuous monitoring, real-time simulation, predictive maintenance, and rapid decision-making, significantly improving the operational resilience and sustainability of urban water supply networks [18], [19]. Consequently, software platforms such as EPANET 2.2, which integrates the global gradient algorithm along with demand-driven analysis (DDA) and pressure-driven analysis (PDA), remain among the most widely used tools in research and engineering due to their accuracy, computational efficiency, open-source availability, and flexibility for integrating advanced hydraulic analyses [11], [20].

3. Justification for the use of EPANET 2.2 (new version)

EPANET was originally developed by the U.S. Environmental Protection Agency (EPA) to simulate the hydraulic behavior and water quality of pressurized water distribution networks. The latest version, EPANET 2.2 (2020), represents a significant

improvement over previous versions thanks to the integration of pressure-driven analysis (PDA) in addition to the traditional demand-driven analysis (DDA), while retaining the global gradient algorithm for hydraulic calculations. These improvements make EPANET 2.2 particularly well-suited for evaluating network performance, both under normal operating conditions and in pressure deficit scenarios. Since the objective of this study is to compare DDA and PDA analyses for the same distribution network, EPANET 2.2 provides a consistent calculation framework that allows both analyses to be performed using identical network data and hydraulic assumptions. Furthermore, EPANET is a widely validated and used open-source hydraulic modeling tool, ensuring transparency, reproducibility, and accessibility for research and engineering applications. These characteristics make EPANET 2.2 a reliable and suitable platform for the hydraulic analysis performed in this study.

3.1. Advantages of new version EPANET 2.2

Although EPANET 2.2 is an enhanced version of EPANET 2, it retains the core functionality of the previous version while introducing several significant improvements. The main enhancement lies in the integration of pressure driven analysis (PDA), complementing the traditional demand driven analysis (DDA). In EPANET 2, hydraulic simulations were limited to DDA, which assumes that demand is always fully met, regardless of available pressure. Consequently, in cases of insufficient pressure, EPANET 2 could produce unrealistic results, including negative nodal pressures. By integrating PDA, EPANET 2.2 provides a more realistic representation of network behavior by linking supplied demand to available pressure [3].

4. Study area

In this work, for the hydraulic calculations and optimization of the water distribution network, the municipality of Oradea was considered. The water distribution system of the municipality serves both domestic and industrial consumers.

The study area covers the entire municipality of Oradea, which is supplied by five main water pumping stations and a repumping station for the high-pressure zone. The water distribution network was modeled numerically using the Epanet 2.2 software package. The model is comprised of 270 pipes and 260 nodes, representing the major network of the city.

The water being distributed entirely by pumping, from the source to the final consumer. An important element of the system is the storage reservoirs with a capacity of (2 x5000 m³ and 4 x100 m³) are a crucial component of the system, ensuring the regulation of pressure regime and flow in the network.

To create the hydraulic model of the network, topographic data (geodetic elevations), and physical characteristics of the network (nodes and pipes, lengths, diameters, material), pumping station characteristics, and water demand data (consumers) were obtained from the water utility and from previous hydraulic studies. Based on these data, a numerical model of the distribution network was completed and used to simulate different operating conditions and to assess the hydraulic behavior of the system within the study area.

5. Methodology

The hydraulic model of the Oradea water distribution network was developed using EPANET 2.2, based on available network data, including pipe characteristics, junction elevations, reservoir levels, pumping stations, and water demands at the nodes. The hydraulic network was prepared in AutoCAD and then converted to an EPANET compatible format using EpaCAD.

To evaluate the system's hydraulic performance, two simulation approaches were applied: demand driven analysis (DDA) and pressure driven analysis (PDA). DDA assumes that all consumer demands are fully met, regardless of the available pressure, while PDA takes into account the dependence of the supplied demand on the nodal pressure and thus provides a more realistic representation of the system's behavior in the event of a pressure deficit.

The analysis was conducted under steady-state conditions. Hydraulic performance was assessed using four key indicators: nodal pressure distribution, flow velocity in the pipes, pressure reliability, and demand response rate. Simulation results obtained from the two approaches were compared and evaluated against the recommendations of EN 805 and NP 133-2022 particularly with regard to pressure and velocity, to determine whether the network operates within acceptable hydraulic limits and to assess the advantages of pressure-based modeling for urban water distribution networks.

6. Results and discussions

The pipe network diagram for the study area was extracted, as mentioned previously, and is shown in Figure 1.

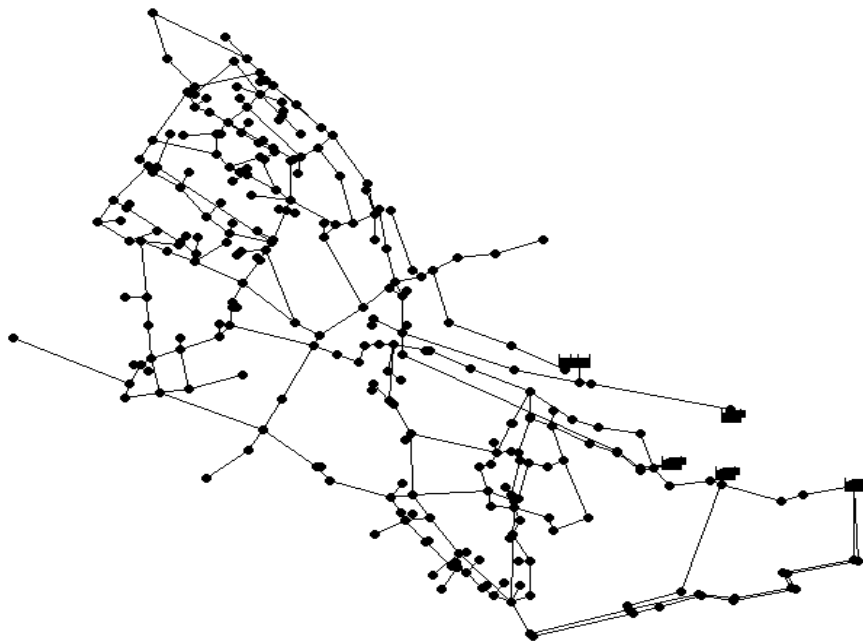


Fig. 1 - Pipe network in EPANET.

6.1 Simulation results according to DDA

Table – 1 represents the principal characteristics of the pipe network used in the DDA simulation. The input data : length of each section of network pipes, the corresponding

diameter required for water flow, the roughness coefficient of the inner wall of the pipe used to carry the water flow in the network, while the flow rate and flow velocity in the pipe are the hydraulic results (computed values) by EPANET.

Table 1. Details of network from EPANET tool (DDA case)

Link ID	input data			Computed values	
	Length	Diameter	Roughnes	Flow	Velocity
	m	mm	(ϵ) mm	L/S	m/s
Pipe 1	218	705.2	0.01	-196.37	0.50
Pipe 2	113	881.14	0.01	-574.26	0.94
Pipe 3	2000	881.14	0.01	-574.26	0.94
Pipe 4	100	881.14	0.01	-574.26	0.94
Pipe 5	700	705.2	0.01	377.89	0.97
Pipe 6	600	881.14	0.01	-669.22	1.10
Pipe 7	400	881.14	0.01	-671.62	1.10
Pipe 8	450	881.14	0.01	-676.82	1.11
Pipe 9	400	881.14	0.01	-682.02	1.12
Pipe 10	255	881.14	0.01	-684.42	1.12
Pipe 11	420	881.14	0.01	-687.02	1.13
Pipe 12	110	881.14	0.01	-690.22	1.13
Pipe 13	100	881.14	0.01	-504.90	0.83
Pipe 14	650	555.2	0.01	-191.22	0.79
Pipe 15	220	555.2	0.01	-196.52	0.81
Pipe 16	720	555.2	0.01	-206.42	0.85
Pipe 17	870	158.6	0.01	17.60	0.89
Pipe 18	870	705.2	0.01	271.59	0.70
Pipe 19	860	705.2	0.01	271.59	0.70
Pipe 20	860	158.6	0.01	17.60	0.89
Pipe 21	210	158.6	0.01	17.60	0.89
Pipe 22	210	705.2	0.01	271.59	0.70
Pipe 23	600	705.2	0.01	-271.59	0.70
Pipe 24	600	158.6	0.01	-16.30	0.83
Pipe 25	300	158.6	0.01	16.30	0.83
Pipe 26	300	705.2	0.01	271.59	0.70
Pipe 27	700	705.2	0.01	271.59	0.70
Pipe 28	400	158.6	0.01	16.30	0.83
Pipe 29	552	96.8	0.01	3.80	0.52
Pipe 30	1380	96.8	0.01	-7.20	0.98
Pipe 31	1050	705.2	0.01	271.19	0.69
Pipe 32	1050	96.8	0.01	-6.50	0.88
Pipe 33	400	705.2	0.01	271.19	0.69
Pipe 34	200	277.6	0.01	-40.50	0.67
Pipe 35	450	277.6	0.01	40.50	0.67
Pipe 36	170	220.4	0.01	19.90	0.52
Pipe 37	350	176.2	0.01	20.60	0.84
Pipe 38	110	176.2	0.01	14.90	0.61
Pipe 39	200	110.2	0.01	5.70	0.60
Pipe 40	175	96.8	0.01	4.60	0.63
Pipe 41	180	176.2	0.01	19.90	0.82
Pipe 42	320	312.8	0.01	-68.57	0.89
Pipe 43	290	312.8	0.01	-70.57	0.92
Pipe 44	290	493.6	0.01	-261.40	1.37
Pipe 45	320	493.6	0.01	255.10	1.33
Pipe 46	400	555.2	0.01	249.20	1.03
Pipe 47	240	555.2	0.01	221.40	0.91
Pipe 48	10	198.2	0.01	32.64	1.06
Pipe 49	330	198.2	0.01	26.74	0.87
Pipe 50	404	493.6	0.01	182.66	0.95
Pipe 51	92	493.6	0.01	179.66	0.94
Pipe 52	100	96.8	0.01	4.20	0.57
Pipe 53	70	440.6	0.01	-148.36	0.97
Pipe 99	620	493.6	0.01	-139.26	0.73
Pipe 100	180	705.2	0.01	-350.19	0.90
Pipe 101	380	96.8	0.01	4.60	0.63
Pipe 102	332	705.2	0.01	-363.19	0.93
Pipe 103	120	141	0.01	10.00	0.64
Pipe 104	432	312.8	0.01	49.97	0.65
Pipe 105	140	141	0.01	10.00	0.64
Pipe 106	170	141	0.01	10.00	0.64
Pipe 107	170	246.8	0.01	23.97	0.50
Pipe 108	270	625.8	0.01	-223.93	0.73
Pipe 109	497	96.8	0.01	6.60	0.90
Pipe 110	140	625.8	0.01	-244.53	0.80
Pipe 111	328	158.6	0.01	15.70	0.79
Pipe 112	365	141	0.01	14.50	0.93
Pipe 113	1100	96.8	0.01	5.20	0.71
Pipe 114	510	96.8	0.01	5.30	0.72
Pipe 115	108	141	0.01	-14.70	0.94
Pipe 116	730	96.8	0.01	5.10	0.69
Pipe 178	75	352.6	0.01	84.72	0.87
Pipe 179	58	158.6	0.01	19.90	1.01
Pipe 180	200	176.2	0.01	19.90	0.82
Pipe 181	50	246.8	0.01	29.90	0.63
Pipe 182	200	220.4	0.01	29.90	0.78
Pipe 183	100	220.4	0.01	24.90	0.65
Pipe 184	120	220.4	0.01	29.90	0.78
Pipe 185	136	277.6	0.01	-54.80	0.91
Pipe 186	102	312.8	0.01	-54.58	0.71
Pipe 187	450	220.4	0.01	24.68	0.65
Pipe 188	70	220.4	0.01	19.80	0.52
Pipe 189	280	96.8	0.01	4.88	0.66
Pipe 190	280	220.4	0.01	29.90	0.78
Pipe 191	382	246.8	0.01	-39.92	0.83
Pipe 192	270	220.4	0.01	24.90	0.65
Pipe 193	386	312.8	0.01	-64.82	0.84
Pipe 194	402	625.8	0.01	-224.99	0.73
Pipe 195	290	625.8	0.01	-251.69	0.82
Pipe 196	180	220.4	0.01	24.90	0.65
Pipe 197	380	793.4	0.01	-290.29	0.59
Pipe 198	300	176.2	0.01	19.90	0.82
Pipe 199	103	881.14	0.01	-313.19	0.51
Pipe 200	100	176.2	0.01	14.90	0.61
Pipe 201	65	176.2	0.01	24.00	0.98
Pipe 202	210	141	0.01	9.10	0.58
Pipe 203	214	158.6	0.01	14.90	0.75
Pipe 204	130	176.2	0.01	14.90	0.61
Pipe 205	70	198.2	0.01	24.90	0.81
Pipe 206	139	198.2	0.01	-24.90	0.81
Pipe 207	475	158.6	0.01	-10.77	0.54
Pipe 208	50	141	0.01	14.90	0.95
Pipe 209	98	158.6	0.01	-17.60	0.89
Pipe 210	280	158.6	0.01	10.00	0.51
Pipe 211	50	141	0.01	-10.00	0.64
Pipe 212	885	396.6	0.01	-87.58	0.71

Pipe 54	60	176.2	0.01	19.90	0.82		Pipe 213	218	493.6	0.01	-117.62	0.61
Pipe 55	450	493.6	0.01	-171.46	0.90		Pipe 214	784	176.2	0.01	18.44	0.76
Pipe 56	310	493.6	0.01	184.15	0.96		Pipe 215	1030	352.6	0.01	58.22	0.60
Pipe 57	280	881.14	0.01	-421.57	0.69		Pipe 216	600	881.14	0.01	-528.12	0.87
Pipe 58	140	881.14	0.01	-424.17	0.70		Pipe 217	347	220.4	0.01	-23.82	0.62
Pipe 59	132	881.14	0.01	-425.77	0.70		Pipe 218	1182	881.14	0.01	-505.52	0.83
Pipe 60	120	198.2	0.01	24.90	0.81		Pipe 219	299	312.8	0.01	51.70	0.67
Pipe 61	180	176.2	0.01	14.90	0.61		Pipe 220	559	96.8	0.01	6.70	0.91
Pipe 62	150	881.14	0.01	-524.70	0.86		Pipe 221	140	158.6	0.01	18.30	0.93
Pipe 63	80	141	0.01	14.90	0.95		Pipe 222	180	176.2	0.01	14.90	0.61
Pipe 64	450	881.14	0.01	-567.30	0.93		Pipe 223	120	220.4	0.01	29.90	0.78
Pipe 65	600	493.6	0.01	111.36	0.58		Pipe 224	441	277.6	0.01	-37.00	0.61
Pipe 66	50	141	0.01	9.10	0.58		Pipe 225	392	881.14	0.01	-423.60	0.69
Pipe 67	1250	705.2	0.01	377.89	0.97		Pipe 226	110	277.6	0.01	43.18	0.71
Pipe 68	38	141	0.01	-21.53	1.38		Pipe 227	110	176.2	0.01	19.90	0.82
Pipe 69	405	220.4	0.01	-28.23	0.74		Pipe 228	130	141	0.01	9.10	0.58
Pipe 70	890	277.6	0.01	-52.83	0.87		Pipe 229	255	123.4	0.01	7.48	0.63
Pipe 71	60	176.2	0.01	14.90	0.61		Pipe 230	160	176.2	0.01	-20.72	0.85
Pipe 72	750	881.14	0.01	-596.42	0.98		Pipe 231	1308	158.6	0.01	17.60	0.89
Pipe 73	80	176.2	0.01	14.90	0.61		Pipe 232	400	881.14	0.01	-373.32	0.61
Pipe 74	605	220.4	0.01	-29.80	0.78		Pipe 233	623	881.14	0.01	359.22	0.59
Pipe 75	310	220.4	0.01	24.90	0.65		Pipe 234	20	110.2	0.01	5.80	0.61
Pipe 76	193	440.6	0.01	137.60	0.90		Pipe 235	238	220.4	0.01	28.02	0.73
Pipe 77	220	220.4	0.01	19.90	0.52		Pipe 236	120	176.2	0.01	19.90	0.82
Pipe 78	155	440.6	0.01	116.80	0.77		Pipe 237	200	96.8	0.01	3.92	0.53
Pipe 79	320	220.4	0.01	19.80	0.52		Pipe 238	750	198.2	0.01	17.17	0.56
Pipe 80	95	352.6	0.01	77.20	0.79		Pipe 257	315	493.6	0.01	-250.30	1.31
Pipe 81	75	440.6	0.01	74.20	0.49		Pipe 258	275	312.8	0.01	58.58	0.76
Pipe 82	70	220.4	0.01	19.90	0.52		Pipe 259	490	625.8	0.01	-271.33	0.88
Pipe 83	360	352.6	0.01	51.70	0.53		Pipe 260	300	79.2	0.01	-4.00	0.81
Pipe 84	160	176.2	0.01	14.90	0.61		Pipe 261	300	881.14	0.01	-550.62	0.90
Pipe 85	60	220.4	0.01	19.90	0.52		Pipe 262	130	220.4	0.01	19.90	0.52
Pipe 86	350	246.8	0.01	27.40	0.57		Pipe 263	350	55	0.01	-2.20	0.93
Pipe 87	50	176.2	0.01	19.90	0.82		Pipe 264	300	176.2	0.01	-19.90	0.82
Pipe 88	200	158.6	0.01	19.73	1.00		Pipe 265	120	176.2	0.01	19.90	0.82
Pipe 89	230	881.14	0.01	-586.22	0.96		Pipe 266	300	246.8	0.01	29.90	0.63
Pipe 90	150	220.4	0.01	19.90	0.52		Pipe 267	20	793.4	0.01	283.03	0.57
Pipe 91	630	881.14	0.01	561.02	0.92		Pipe 268	200	793.4	0.01	279.73	0.57
Pipe 92	274	220.4	0.01	30.30	0.79		Pipe 269	300	705.2	0.01	274.73	0.70
Pipe 93	170	176.2	0.01	19.90	0.82		Pipe 270	250	705.2	0.01	268.93	0.69
Pipe 94	544	66	0.01	3.30	0.96		Pump 404	#N/A	#N/A	#N/A	574.26	0.00
Pipe 95	100	352.6	0.01	63.18	0.65		Pump 402	#N/A	#N/A	#N/A	495.60	0.00
Pipe 96	200	352.6	0.01	62.28	0.64		Pump 401	#N/A	#N/A	#N/A	512.10	0.00
Pipe 97	200	352.6	0.01	59.38	0.61		Pump 403	#N/A	#N/A	#N/A	331.97	0.00
Pipe 98	140	198.2	0.01	-15.94	0.52							

* Note from the table regarding negative flow rates:

Negative flow rate values do not indicate physically negative discharge. They simply indicate that the actual flow direction is opposite to the direction initially assigned during network construction in EPANET. The flow rate magnitude remains correct, while the negative sign indicates reverse flow relative to the assumed pipe orientation.

Table 2. Nodal demands at nodes of the network (DDA case)

Node number	Demand L/S	Pressure m	Node number	Demand L/S	Pressure m	Node number	Demand L/S	Pressure m
Junc 1	0.00	49.11	Junc 91	6.20	52.97	Junc 182	24.90	54.69
Junc 2	0.00	55.22	Junc 92	4.70	51.54	Junc 183	19.90	53.12
Junc 3	0.00	49.04	Junc 93	10.00	50.71	Junc 184	0.00	53.81
Junc 4	0.00	54.61	Junc 94	6.00	50.08	Junc 185	2.40	56.78
Junc 5	17.30	54.45	Junc 95	10.00	49.69	Junc 186	0.00	54.89
Junc 6	2.40	53.95	Junc 96	10.00	49.61	Junc 187	0.00	54.97
Junc 7	5.20	53.09	Junc 97	4.90	51.52	Junc 188	0.00	56.55
Junc 8	5.20	53.47	Junc 98	5.90	51.58	Junc 189	0.00	56.24
Junc 9	2.60	49.24	Junc 99	8.70	51.68	Junc 190	19.90	55.58
Junc 10	3.20	49.61	Junc 100	9.60	50.98	Junc 191	0.00	54.88
Junc 11	5.30	47.71	Junc 101	5.10	39.79	Junc 192	24.90	56.42
Junc 12	9.90	47.90	Junc 102	1.20	50.01	Junc 193	14.90	55.50
Junc 13	0.00	48.65	Junc 103	4.00	48.03	Junc 194	29.90	54.85
Junc 14	0.00	50.75	Junc 104	5.20	42.26	Junc 195	0.00	56.81
Junc 15	5.90	50.70	Junc 105	5.30	45.26	Junc 196	19.80	56.83
Junc 16	3.40	34.73	Junc 106	0.80	46.92	Junc 197	10.00	57.40
Junc 17	3.80	33.08	Junc 107	5.80	37.24	Junc 198	0.00	57.54
Junc 18	0.00	44.84	Junc 108	5.80	47.30	Junc 199	14.90	57.47
Junc 19	0.00	41.08	Junc 109	4.80	43.57	Junc 200	2.70	57.75
Junc 20	1.30	40.56	Junc 110	14.90	44.26	Junc 201	11.60	54.29
Junc 21	0.00	38.27	Junc 111	4.00	42.43	Junc 202	6.50	54.93
Junc 22	0.00	37.13	Junc 112	6.00	42.75	Junc 203	0.00	55.63
Junc 23	6.50	26.04	Junc 113	6.70	41.41	Junc 204	9.10	56.14
Junc 24	0.00	48.24	Junc 114	9.40	38.73	Junc 205	14.90	53.69
Junc 25	0.00	47.84	Junc 115	7.10	26.45	Junc 206	0.00	53.94
Junc 26	0.00	48.14	Junc 116	5.80	44.19	Junc 207	0.00	57.32
Junc 27	0.00	47.86	Junc 117	19.90	47.60	Junc 208	24.90	57.13
Junc 28	0.00	47.72	Junc 118	0.00	47.84	Junc 209	1.80	57.71
Junc 29	0.00	53.50	Junc 119	4.30	51.11	Junc 210	13.70	58.92
Junc 30	2.00	53.70	Junc 120	0.00	49.40	Junc 211	24.90	58.12
Junc 31	7.80	55.08	Junc 121	19.90	49.29	Junc 212	3.00	57.73
Junc 32	5.90	53.50	Junc 122	0.00	47.67	Junc 213	19.90	56.75
Junc 33	6.10	53.55	Junc 123	0.00	46.90	Junc 214	8.10	58.06
Junc 34	4.80	54.82	Junc 124	1.20	54.74	Junc 215	14.90	57.06
Junc 35	6.30	53.58	Junc 125	0.00	54.97	Junc 216	5.80	58.05
Junc 36	2.40	51.52	Junc 126	0.00	54.95	Junc 217	8.30	58.12
Junc 37	19.90	53.20	Junc 128	24.90	53.16	Junc 218	5.00	56.23
Junc 38	7.90	53.79	Junc 129	0.00	51.52	Junc 219	7.10	55.63
Junc 39	9.30	53.00	Junc 130	19.90	47.43	Junc 220	29.90	55.65
Junc 40	2.60	53.10	Junc 131	0.00	47.49	Junc 221	3.40	54.49
Junc 41	1.60	53.05	Junc 132	24.90	47.37	Junc 222	14.90	54.14
Junc 42	6.30	53.09	Junc 133	9.10	44.04	Junc 223	11.90	54.95
Junc 43	24.90	52.76	Junc 134	0.90	44.27	Junc 224	19.90	54.26
Junc 44	14.90	52.74	Junc 135	19.90	44.50	Junc 225	3.30	54.66
Junc 45	27.70	53.17	Junc 136	1.50	44.96	Junc 226	6.70	49.89
Junc 46	14.90	52.72	Junc 137	7.70	45.05	Junc 227	8.00	54.72
Junc 47	3.00	54.03	Junc 138	8.50	48.87	Junc 228	6.40	55.77
Junc 48	4.00	53.92	Junc 139	2.20	53.96	Junc 229	10.40	54.96
Junc 49	19.90	51.71	Junc 140	19.90	54.84	Junc 230	3.10	54.24
Junc 50	3.20	51.90	Junc 141	7.60	56.27	Junc 231	10.60	53.87
Junc 51	2.60	51.80	Junc 142	0.90	52.64	Junc 232	19.90	55.00
Junc 52	4.20	53.56	Junc 143	4.60	50.58	Junc 233	6.70	56.07
Junc 53	4.60	49.43	Junc 144	8.40	52.17	Junc 234	9.10	55.76
Junc 54	1.10	49.96	Junc 145	0.00	53.73	Junc 235	17.60	53.45
Junc 55	0.00	43.62	Junc 146	2.90	51.85	Junc 236	0.00	55.29
Junc 56	14.90	43.41	Junc 147	16.30	53.48	Junc 237	0.40	47.39
Junc 57	0.00	49.85	Junc 148	5.70	53.16	Junc 238	6.50	34.27
Junc 58	19.90	49.66	Junc 149	11.60	54.53	Junc 239	2.40	48.30
Junc 59	0.00	47.45	Junc 150	5.40	55.18	Junc 240	14.90	48.25

Junc 60	0.00	47.51		Junc 151	0.00	55.05		Junc 241	0.90	53.77
Junc 61	24.90	47.19		Junc 152	0.00	54.98		Junc 242	8.20	52.13
Junc 62	0.00	46.90		Junc 153	29.90	55.02		Junc 243	0.90	54.42
Junc 63	0.90	47.46		Junc 154	0.00	55.91		Junc 244	3.30	56.51
Junc 64	19.90	47.21		Junc 155	24.90	55.74		Junc 245	2.10	57.54
Junc 65	19.80	46.67		Junc 156	29.90	55.33		Junc 246	2.30	54.14
Junc 66	2.50	47.02		Junc 157	2.80	56.22		Junc 247	3.30	35.61
Junc 67	3.00	46.89		Junc 158	19.90	50.95		Junc 248	1.10	54.10
Junc 68	14.90	46.00		Junc 159	3.30	47.37		Junc 249	0.80	53.38
Junc 69	2.60	46.86		Junc 160	0.10	47.48		Junc 250	1.50	45.46
Junc 70	19.90	46.87		Junc 161	19.90	47.22		Junc 251	4.00	51.78
Junc 71	0.00	46.31		Junc 162	0.00	47.75		Junc 252	2.20	41.25
Junc 72	14.90	46.15		Junc 163	0.00	49.67		Junc 253	0.00	53.78
Junc 73	19.90	47.06		Junc 164	24.90	51.07		Junc 254	19.90	53.38
Junc 74	4.40	47.13		Junc 165	0.00	53.20		Junc 255	2.60	51.68
Junc 75	5.30	46.72		Junc 166	24.90	47.83		Junc 256	19.90	51.54
Junc 76	19.90	46.56		Junc 167	2.40	48.08		Junc 257	29.90	50.79
Junc 77	5.30	50.54		Junc 168	-19.90	48.36		Junc 258	3.30	54.49
Junc 78	10.20	50.69		Junc 169	-1.30	48.29		Junc 259	5.00	54.44
Junc 79	19.90	51.07		Junc 170	0.00	54.92		Junc 260	5.80	52.29
Junc 80	10.40	50.16		Junc 171	14.90	50.99		Resvr 4	196.37	0.00
Junc 81	6.70	52.33		Junc 172	0.00	48.68		Resvr277	-283.03	0.00
Junc 82	9.70	52.18		Junc 173	0.00	56.04		Resvr401	-512.10	0.00
Junc 83	14.90	51.56		Junc 174	0.00	54.61		Resvr402	-495.60	0.00
Junc 84	1.90	51.60		Junc 175	29.90	54.57		Resvr403	-331.97	0.00
Junc 85	7.10	50.25		Junc 176	29.90	54.07		Resvr404	-574.26	0.00
Junc 86	19.90	50.69		Junc 177	0.00	54.25				
Junc 87	3.30	43.86		Junc 178	0.00	53.32				
Junc 88	0.00	53.76		Junc 179	0.00	51.90				
Junc 89	10.80	53.15		Junc 180	19.90	51.68				
Junc 90	9.10	52.86		Junc 181	24.90	54.48				

Table 2 presents the results of the hydraulic simulation for the study area, under the Demand Driven Analysis (DDA). It presents the effective nodal flows ((water supplied at each junction under the simulated operating conditions) and the corresponding nodal pressures. The prescribed water demands at the nodes constitute the input data for the hydraulic model, while the values in Table 2 represent the hydraulic response of the network. The spatial distribution of these hydraulic variables is illustrated in Figures 2 to 4.

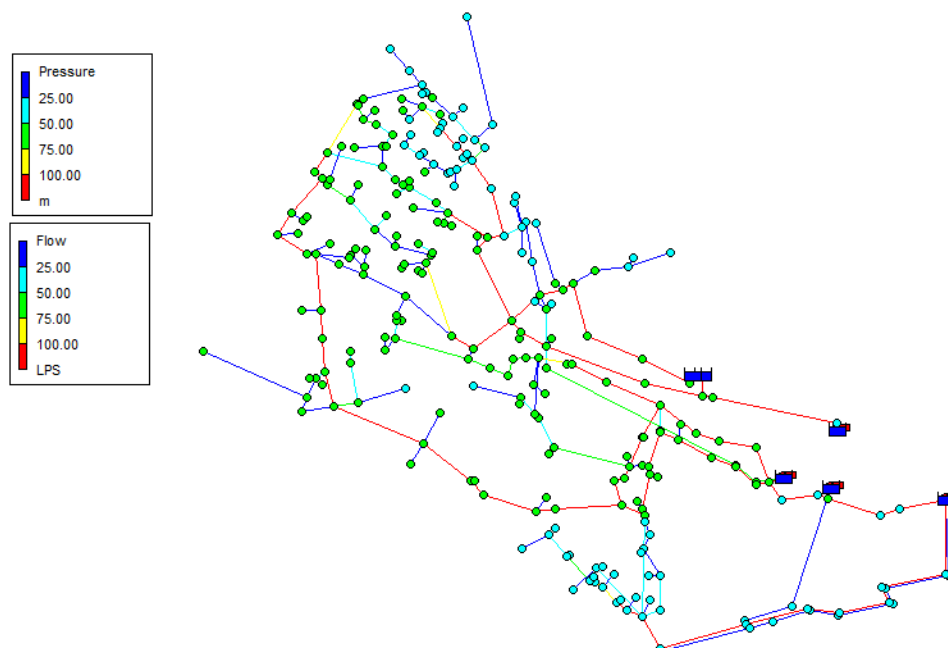


Fig. 2 - Simulation: Pressure - flow.

Figure 2 presents the results of the hydraulic simulation obtained using the DDA analysis. Pressure values are displayed at the junction nodes, while flow are indicated in the connecting pipes. These results provide a comprehensive representation of the hydraulic behaviour of the distribution network and allow the identification of areas with suitable pressure and corresponding flow conditions.

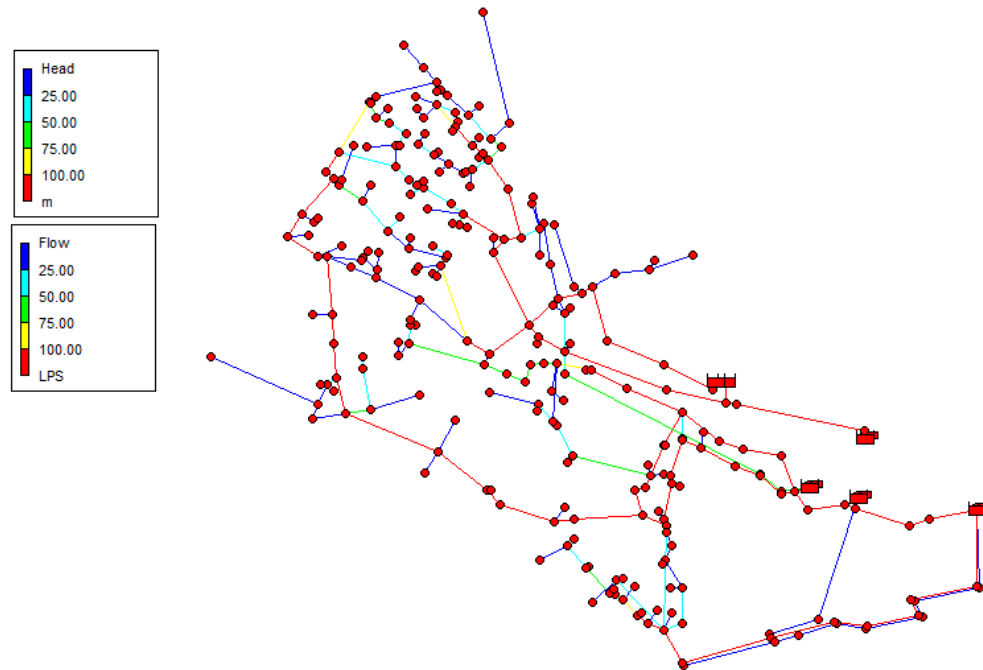


Fig. 3 - Simulation: Head - flow.

Figure 3 illustrates the hydraulic head distribution at the junction nodes along with the corresponding flow in the connecting pipes obtained from the hydraulic simulation. It should be noted that the hydraulic head is computed at the network nodes, whereas flow is calculated for the connecting pipes. The combined presentation of these variables provides a comprehensive view of the hydraulic behavior of the water distribution network.

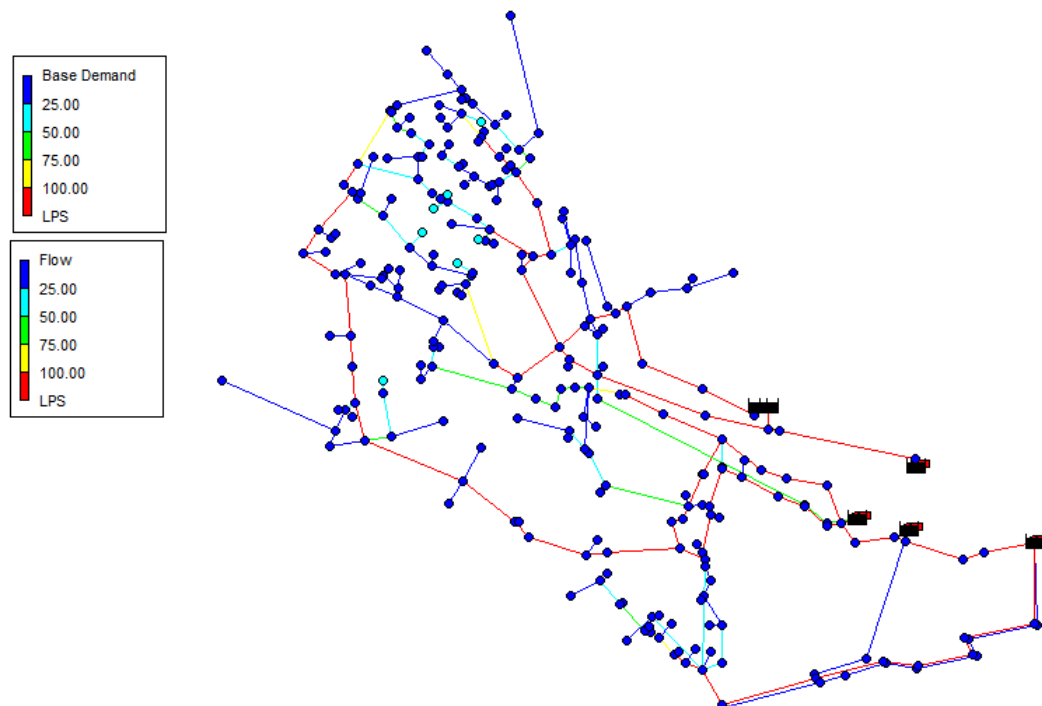


Fig. 4 - Simulation: Base demand - flow.

Figure 4 represents the spatial distribution of the prescribed base demands and the corresponding pipe flow in the water distribution network. The colored junction nodes represent the base demands used as input data for the hydraulic model, while the colored pipe segments indicate the flow computed by the EPANET simulation. This figure demonstrates how the spatial distribution of consumer water demands influences the resulting flow patterns throughout the pipe network under the simulated operating conditions.

Figure 5 shows the representation of distribution network between pressure at each node and flow velocity in the pipes. Knowing these two fundamental factors allows us to determine the most important factor, the velocity range, which in turn enables us to assess the suitability of the pipe diameter for the flow and pressure.

The flow velocity in network pipes is another factor to consider when determining the required pipe volume and diameter.

It should be noted that there are differences regarding this velocity range among various reference sources. For example, some sources state the following:

- The water velocity in the pipes will be around 0.50 m/s. While not strictly required, velocities above 1 m/s and those below 0.50 m/s should be avoided. Low velocities promote the formation of deposits that can be difficult to remove. Therefore, in secondary waterways, it is sometimes necessary to provide systematic discharge points at certain locations: wash down or irrigation points, fire department operations, etc., because velocities often remain below 0.50 m/s. Maximum velocities of around 1 m/s allow for increased water consumption without significant inconvenience to consumers [21].

- According to the European standard EN 805 [22], the economical velocity in drinking water distribution network pipes varies between 0.5 m/s and 2.0 m/s, depending on the pipe type and local conditions.

The standard EN 805 [22] states the following: In practice, it is advisable to avoid excessively high or low velocities. A range of 0.5 m/s to 2.0 m/s can be considered appropriate. However, in specific circumstances, velocities up to 3.5 m/s may be acceptable. For pumping lines, a financial assessment should be undertaken to determine the most economical diameter of the pumping line in order to minimize the investment cost and the present value of pumping. The resulting velocity will normally be between 0.8 m/s and 1.4 m/s [22].

- According to the Romanian design norms (NP 133-2022); the typical flow velocity range varies between 0.6 and 2.0 m/s, depending on the network's operating scenarios.

For fire suppression, the velocity must remain below 3 m/s, while a minimum of approximately 0.3 m/s is recommended to preserve the quality of the distributed water [23].

Therefore, as we have observed in Table 1 and in corresponding Figures, the velocity range is between 0.5 to 2 m / s, as indicated in the European standard EN 805.

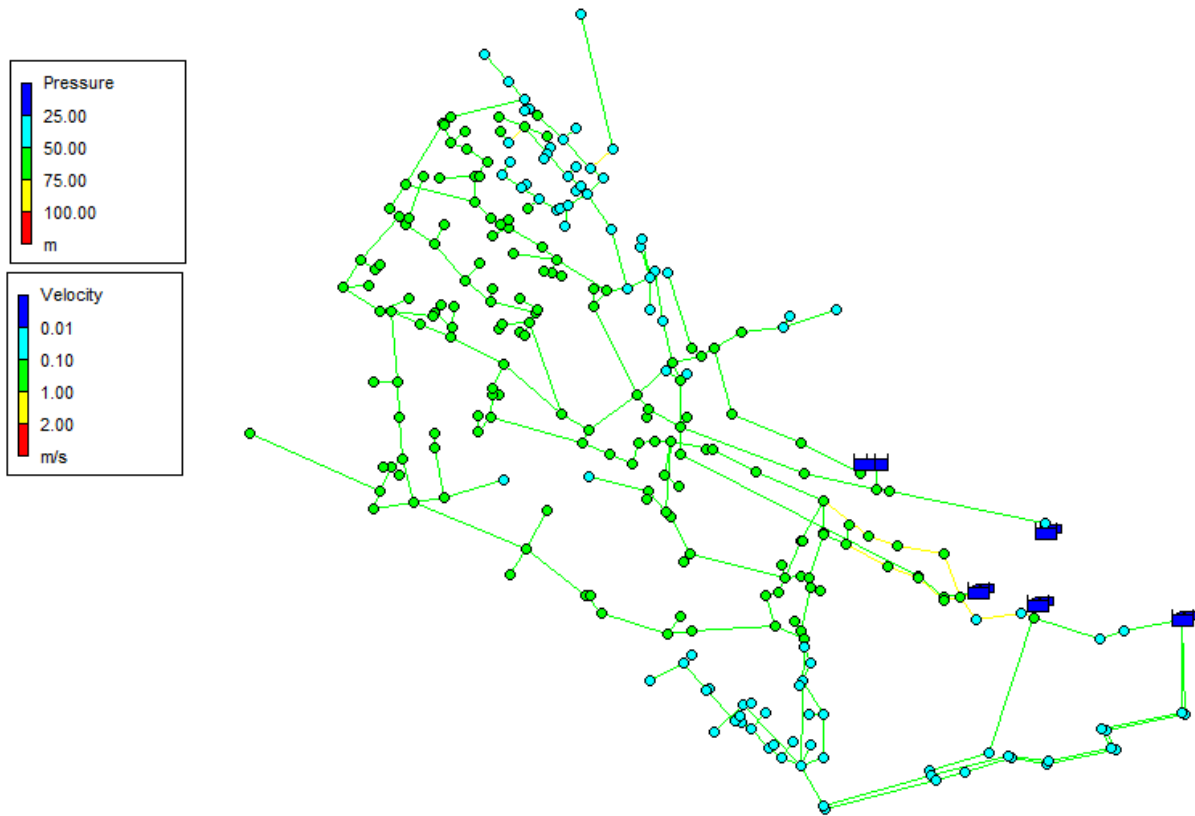


Fig. 5 - Simulation: pressure - velocity.

6.2 Simulation results according to PDA

The pressure driven demand formulation adopted in this study is based on a standard calibration methodology within the framework of identifying the discharge coefficient (C) and the pressure exponent (γ) associated with the emitter equation (1).

$$q = C \times P^\gamma \quad (1)$$

Where: q = flow rate, P = pressure, C = discharge coefficient, and γ = pressure exponent [3].

Following an analysis conducted for two case studies in a previously published article [24], concerning Algeria and Romania, the results obtained for the Romanian case were presented in Table (3).

Table 3. The coefficients adopted (Case of Romania) [24]

Designation	Form of the equation	Coefficients	
	$q = c \cdot p^\gamma$	c	γ
04 apartment / floor on 10 floors	$q = 0,340 p^{0,6}$	0,340	0,6
05 apartment / floor on 10 floors	$q = 0,377 p^{0,6}$	0,377	0,6

6.2.1. Entering the coefficients into the hydraulic model

The emitter pressure parameters (C and γ) were entered into the EPANET water distribution network model, specifically at nodes representing residential demand clusters in zones defined on the hydraulic model, as classified within the categories defined in Table (3). The study area is characterized by Type 04 to 05 residential buildings (see Table 3), with four to five apartment units per floor.

The nodes where the parameters were entered into the hydraulic model were as follows:

1. Complex Rezidential Iosia –Résidence. Strada Oneștilor 7r Oradea:
Junc 252, Junc 253 (05 apartment / floor on 10 floors)
2. Ansamblul Rezidențial Luceafărul - Promoteur immobilier Calea Aradului 4:
Junc 254, Junc 255, Junc 259 (04 apartment / floor on 10 floors)
3. Immeuble en copropriété nucetului nr 9 Oradea:
Junc 48, Junc 51, Junc 52, Junc 57, Junc 61 (05 apartment / floor on 10 floors)
4. Victoria Rezidențial Nufărul - Promoteur immobilier. Strada Ciheiului 35 Oradea:
Junc 79, Junc 83, Junc 84, Junc 87, Junc 293 (05 apartment / floor on 10 floors)
5. Victoria Rezidențial Berzei (zona Gării) - Promoteur immobilier Strada Berzei 4 Oradea:
Junc 127, Junc 128, Junc 129, Junc 165, Junc 166 (05 apartment / floor on 10 floors)
6. Strada selimbarului:
Junc 200, Junc 206, Junc 207, Junc 208, Junc 209, Junc 210, Junc 211(05 apartment / floor on 10 floors)
7. Strada selimbarului:
Junc 185, Junc 203, Junc 204, Junc 205 (05 apartment / floor on 10 floors).

In the present work, a comparative case study is carried out to evaluate the two analyses currently implemented in EPANET 2.2. For pressure analysis, the flow variation coefficients defined in the (Table 3) are employed. The observed differences were then examined according to the simulation performed on the model.

Table 4. Details of network from EPANET tool (PDA case)

Link ID	input data			Computed values	
	Length	Diameter	Roughness	Flow	Velocity
	m	mm	mm	L/S	m/s
Pipe 1	218	705.2	0.01	-187.28	0.48
Pipe 2	113	881.14	0.01	-574.86	0.94
Pipe 3	2000	881.14	0.01	-574.86	0.94
Pipe 4	100	881.14	0.01	-574.86	0.94
Pipe 5	700	705.2	0.01	387.59	0.99
Pipe 6	600	881.14	0.01	-694.65	1.14
Pipe 7	400	881.14	0.01	-697.05	1.14
Pipe 8	450	881.14	0.01	-702.25	1.15
Pipe 9	400	881.14	0.01	-707.45	1.16
Pipe 10	255	881.14	0.01	-709.85	1.16
Pipe 11	420	881.14	0.01	-712.45	1.17
Pipe 12	110	881.14	0.01	-715.65	1.17
Pipe 13	100	881.14	0.01	-525.29	0.86
Pipe 14	650	555.2	0.01	-196.26	0.81
Pipe 15	220	555.2	0.01	-201.56	0.83
Pipe 16	720	555.2	0.01	-211.46	0.87
Pipe 17	870	158.6	0.01	17.60	0.89
Pipe 18	870	705.2	0.01	284.44	0.73
Pipe 19	860	705.2	0.01	284.44	0.73
Pipe 20	860	158.6	0.01	17.60	0.89
Pipe 21	210	158.6	0.01	17.60	0.89
Pipe 22	210	705.2	0.01	284.44	0.73
Pipe 23	600	705.2	0.01	-284.44	0.73
Pipe 24	600	158.6	0.01	-16.30	0.83
Pipe 25	300	158.6	0.01	16.30	0.83

Link ID	input data			Computed values	
	Length	Diameter	Roughness	Flow	Velocity
	m	mm	mm	L/S	m/s
Pipe 138	80	220.4	0.01	32.62	0.86
Pipe 139	122	246.8	0.01	-35.36	0.74
Pipe 140	190	176.2	0.01	21.00	0.86
Pipe 141	150	176.2	0.01	14.90	0.61
Pipe 142	200	96.8	0.01	6.10	0.83
Pipe 143	70	220.4	0.01	-19.90	0.52
Pipe 144	214	198.2	0.01	27.30	0.88
Pipe 145	150	220.4	0.01	24.90	0.65
Pipe 146	120	220.4	0.01	24.90	0.65
Pipe 147	152	158.6	0.01	-24.90	1.26
Pipe 148	325	352.6	0.01	-79.70	0.82
Pipe 149	50	220.4	0.01	19.90	0.52
Pipe 150	70	220.4	0.01	24.90	0.65
Pipe 151	260	440.6	0.01	-124.50	0.82
Pipe 152	100	141	0.01	9.10	0.58
Pipe 153	148	440.6	0.01	-134.50	0.88
Pipe 154	140	176.2	0.01	-19.90	0.82
Pipe 155	88	493.6	0.01	-155.90	0.81
Pipe 156	140	277.6	0.01	57.28	0.95
Pipe 157	245	141	0.01	16.50	1.06
Pipe 158	1280	96.8	0.01	7.10	0.96
Pipe 159	354	110.2	0.01	-5.80	0.61
Pipe 160	227	110.2	0.01	-5.80	0.61
Pipe 161	77	141	0.01	10.02	0.64
Pipe 162	100	220.4	0.01	19.90	0.52

Pipe 26	300	705.2	0.01	284.44	0.73
Pipe 27	700	705.2	0.01	284.44	0.73
Pipe 28	400	158.6	0.01	16.30	0.83
Pipe 29	552	96.8	0.01	3.80	0.52
Pipe 30	1380	96.8	0.01	-7.20	0.98
Pipe 31	1050	705.2	0.01	284.04	0.73
Pipe 32	1050	96.8	0.01	-6.50	0.88
Pipe 33	400	705.2	0.01	284.04	0.73
Pipe 34	200	277.6	0.01	-40.50	0.67
Pipe 35	450	277.6	0.01	40.50	0.67
Pipe 36	170	220.4	0.01	19.90	0.52
Pipe 37	350	176.2	0.01	20.60	0.84
Pipe 38	110	176.2	0.01	14.90	0.61
Pipe 39	200	110.2	0.01	5.70	0.60
Pipe 40	175	96.8	0.01	4.60	0.63
Pipe 41	180	176.2	0.01	19.90	0.82
Pipe 42	320	312.8	0.01	-67.95	0.88
Pipe 43	290	312.8	0.01	-69.95	0.91
Pipe 44	290	493.6	0.01	-271.60	1.42
Pipe 45	320	493.6	0.01	265.30	1.39
Pipe 46	400	555.2	0.01	259.40	1.07
Pipe 47	240	555.2	0.01	231.60	0.96
Pipe 48	10	198.2	0.01	33.56	1.09
Pipe 49	330	198.2	0.01	27.66	0.90
Pipe 50	404	493.6	0.01	191.94	1.00
Pipe 51	92	493.6	0.01	188.94	0.99
Pipe 52	100	96.8	0.01	6.93	0.94
Pipe 53	70	440.6	0.01	-152.22	1.00
Pipe 54	60	176.2	0.01	22.59	0.93
Pipe 55	450	493.6	0.01	-178.01	0.93
Pipe 56	310	493.6	0.01	188.71	0.99
Pipe 57	280	881.14	0.01	-440.85	0.72
Pipe 58	140	881.14	0.01	-446.19	0.73
Pipe 59	132	881.14	0.01	-447.79	0.73
Pipe 60	120	198.2	0.01	27.62	0.90
Pipe 61	180	176.2	0.01	17.62	0.72
Pipe 62	150	881.14	0.01	-552.04	0.91
Pipe 63	80	141	0.01	14.90	0.95
Pipe 64	450	881.14	0.01	-594.64	0.98
Pipe 65	600	493.6	0.01	110.37	0.58
Pipe 66	50	141	0.01	9.10	0.58
Pipe 67	1250	705.2	0.01	387.59	0.99
Pipe 68	38	141	0.01	-21.41	1.37
Pipe 69	405	220.4	0.01	-28.11	0.74
Pipe 70	890	277.6	0.01	-52.71	0.87
Pipe 71	60	176.2	0.01	14.90	0.61
Pipe 72	750	881.14	0.01	-620.26	1.02
Pipe 73	80	176.2	0.01	17.43	0.71
Pipe 74	605	220.4	0.01	-34.86	0.91
Pipe 75	310	220.4	0.01	24.90	0.65
Pipe 76	193	440.6	0.01	144.69	0.95
Pipe 77	220	220.4	0.01	19.90	0.52
Pipe 78	155	440.6	0.01	123.89	0.81
Pipe 79	320	220.4	0.01	19.80	0.52
Pipe 80	95	352.6	0.01	84.29	0.86
Pipe 81	75	440.6	0.01	81.29	0.53
Pipe 82	70	220.4	0.01	19.90	0.52
Pipe 83	360	352.6	0.01	58.79	0.60
Pipe 84	160	176.2	0.01	17.43	0.71
Pipe 85	60	220.4	0.01	22.47	0.59
Pipe 86	350	246.8	0.01	31.92	0.67
Pipe 87	50	176.2	0.01	22.45	0.92

Pipe 163	103	123.4	0.01	-9.88	0.83
Pipe 164	235	141	0.01	-14.18	0.91
Pipe 165	210	220.4	0.01	19.90	0.52
Pipe 166	362	246.8	0.01	-34.08	0.71
Pipe 167	100	220.4	0.01	-29.90	0.78
Pipe 168	100	220.4	0.01	24.90	0.65
Pipe 169	20	440.6	0.01	-98.23	0.64
Pipe 170	640	440.6	0.01	-98.23	0.64
Pipe 171	648	277.6	0.01	57.29	0.95
Pipe 172	240	158.6	0.01	16.47	0.83
Pipe 173	250	220.4	0.01	27.64	0.72
Pipe 174	40	158.6	0.01	22.57	1.14
Pipe 175	185	198.2	0.01	-36.41	1.18
Pipe 176	271	493.6	0.01	-157.92	0.83
Pipe 177	105	493.6	0.01	-157.92	0.83
Pipe 178	75	352.6	0.01	83.81	0.86
Pipe 179	58	158.6	0.01	19.90	1.01
Pipe 180	200	176.2	0.01	19.90	0.82
Pipe 181	50	246.8	0.01	29.90	0.63
Pipe 182	200	220.4	0.01	29.90	0.78
Pipe 183	100	220.4	0.01	24.90	0.65
Pipe 184	120	220.4	0.01	29.90	0.78
Pipe 185	136	277.6	0.01	-54.80	0.91
Pipe 186	102	312.8	0.01	-55.49	0.72
Pipe 187	450	220.4	0.01	25.59	0.67
Pipe 188	70	220.4	0.01	19.80	0.52
Pipe 189	280	96.8	0.01	5.79	0.79
Pipe 190	280	220.4	0.01	29.90	0.78
Pipe 191	382	246.8	0.01	-39.01	0.82
Pipe 192	270	220.4	0.01	24.90	0.65
Pipe 193	386	312.8	0.01	-63.91	0.83
Pipe 194	402	625.8	0.01	-241.73	0.79
Pipe 195	290	625.8	0.01	-268.43	0.87
Pipe 196	180	220.4	0.01	24.90	0.65
Pipe 197	380	793.4	0.01	-307.03	0.62
Pipe 198	300	176.2	0.01	19.90	0.82
Pipe 199	103	881.14	0.01	-329.93	0.54
Pipe 200	100	176.2	0.01	14.90	0.61
Pipe 201	65	176.2	0.01	24.00	0.98
Pipe 202	210	141	0.01	9.10	0.58
Pipe 203	214	158.6	0.01	14.90	0.75
Pipe 204	130	176.2	0.01	14.90	0.61
Pipe 205	70	198.2	0.01	24.90	0.81
Pipe 206	139	198.2	0.01	-24.90	0.81
Pipe 207	475	158.6	0.01	-11.54	0.58
Pipe 208	50	141	0.01	14.90	0.95
Pipe 209	98	158.6	0.01	-17.60	0.89
Pipe 210	280	158.6	0.01	10.00	0.51
Pipe 211	50	141	0.01	-10.00	0.64
Pipe 212	885	396.6	0.01	-88.49	0.72
Pipe 213	218	493.6	0.01	-119.67	0.63
Pipe 214	784	176.2	0.01	19.58	0.80
Pipe 215	1030	352.6	0.01	65.60	0.67
Pipe 216	600	881.14	0.01	-551.96	0.91
Pipe 217	347	220.4	0.01	-23.86	0.63
Pipe 218	1182	881.14	0.01	-529.36	0.87
Pipe 219	299	312.8	0.01	59.57	0.78
Pipe 220	559	96.8	0.01	9.00	1.22
Pipe 221	140	158.6	0.01	23.26	1.18
Pipe 222	180	176.2	0.01	17.38	0.71
Pipe 223	120	220.4	0.01	32.69	0.86
Pipe 224	441	277.6	0.01	-42.57	0.70

Pipe 88	200	158.6	0.01	18.96	0.96	Pipe 225	392	881.14	0.01	-439.53	0.72
Pipe 89	230	881.14	0.02	-610.06	1.00	Pipe 226	110	277.6	0.01	43.14	0.71
Pipe 90	150	220.4	0.01	19.90	0.52	Pipe 227	110	176.2	0.01	19.90	0.82
Pipe 91	630	881.14	0.01	584.86	0.96	Pipe 228	130	141	0.01	9.10	0.58
Pipe 92	274	220.4	0.01	30.30	0.79	Pipe 229	255	123.4	0.01	7.44	0.62
Pipe 93	170	176.2	0.01	19.90	0.82	Pipe 230	160	176.2	0.01	-20.76	0.85
Pipe 94	544	66	0.01	3.30	0.96	Pipe 231	1308	158.6	0.01	17.60	0.89
Pipe 95	100	352.6	0.01	62.08	0.64	Pipe 232	400	881.14	0.01	-389.29	0.64
Pipe 96	200	352.6	0.01	61.18	0.63	Pipe 233	623	881.14	0.01	375.19	0.62
Pipe 97	200	352.6	0.01	58.28	0.60	Pipe 234	20	110.2	0.01	5.80	0.61
Pipe 98	140	198.2	0.01	-24.42	0.79	Pipe 235	238	220.4	0.01	27.66	0.73
Pipe 99	620	493.6	0.01	-149.79	0.78	Pipe 236	120	176.2	0.01	19.90	0.82
Pipe 100	180	705.2	0.01	-359.89	0.92	Pipe 237	200	96.8	0.01	3.56	0.48
Pipe 101	380	96.8	0.01	4.60	0.63	Pipe 238	750	198.2	0.01	15.82	0.51
Pipe 102	332	705.2	0.01	-372.89	0.95	Pipe 239	75	176.2	0.01	-17.02	0.70
Pipe 103	120	141	0.01	10.00	0.64	Pipe 240	114	352.6	0.01	81.21	0.83
Pipe 104	432	312.8	0.01	49.35	0.64	Pipe 241	210	176.2	0.01	19.90	0.82
Pipe 105	140	141	0.01	10.00	0.64	Pipe 242	170	352.6	0.01	61.31	0.63
Pipe 106	170	141	0.01	10.00	0.64	Pipe 243	217	220.4	0.01	36.41	0.95
Pipe 107	170	246.8	0.01	23.35	0.49	Pipe 244	1175	277.6	0.01	39.09	0.65
Pipe 108	270	625.8	0.01	-255.35	0.83	Pipe 245	2395	312.8	0.01	-60.15	0.78
Pipe 109	497	96.8	0.01	6.60	0.90	Pipe 246	375	396.6	0.01	92.77	0.75
Pipe 110	140	625.8	0.01	-275.95	0.90	Pipe 247	660	141	0.01	-10.79	0.69
Pipe 111	328	158.6	0.01	15.70	0.79	Pipe 248	235	396.6	0.01	106.59	0.86
Pipe 112	365	141	0.01	14.50	0.93	Pipe 249	30	176.2	0.01	14.90	0.61
Pipe 113	1100	96.8	0.01	5.20	0.71	Pipe 250	150	352.6	0.01	-61.18	0.63
Pipe 114	510	96.8	0.01	5.30	0.72	Pipe 251	350	110.2	0.01	-8.20	0.86
Pipe 115	108	141	0.01	-14.70	0.94	Pipe 252	97	110.2	0.01	-4.46	0.47
Pipe 116	730	96.8	0.01	5.10	0.69	Pipe 253	290	176.2	0.01	-22.26	0.91
Pipe 117	420	96.8	0.01	5.80	0.79	Pipe 254	327	881.14	0.01	-391.39	0.64
Pipe 118	440	625.8	0.01	267.20	0.87	Pipe 255	535	396.6	0.01	108.07	0.87
Pipe 119	865	793.4	0.01	476.40	0.96	Pipe 256	300	141	0.01	13.00	0.83
Pipe 120	70	176.2	0.01	19.90	0.82	Pipe 257	315	493.6	0.01	-260.50	1.36
Pipe 121	190	793.4	0.01	448.90	0.91	Pipe 258	275	312.8	0.01	57.48	0.75
Pipe 122	175	725.2	0.01	328.18	0.79	Pipe 259	490	625.8	0.01	-280.19	0.91
Pipe 123	225	246.8	0.01	36.87	0.77	Pipe 260	300	79.2	0.01	-4.00	0.81
Pipe 124	200	96.8	0.01	5.80	0.79	Pipe 261	300	881.14	0.01	-574.46	0.94
Pipe 125	160	176.2	0.01	17.39	0.71	Pipe 262	130	220.4	0.01	19.90	0.52
Pipe 126	348	96.8	0.01	6.40	0.87	Pipe 263	350	55	0.01	-4.17	1.76
Pipe 127	185	312.8	0.01	-65.73	0.86	Pipe 264	300	176.2	0.01	-19.90	0.82
Pipe 128	500	625.8	0.01	-276.16	0.90	Pipe 265	120	176.2	0.01	19.90	0.82
Pipe 129	192	277.6	0.01	44.30	0.73	Pipe 266	300	246.8	0.01	38.10	0.80
Pipe 130	160	176.2	0.01	19.90	0.82	Pipe 267	20	793.4	0.01	314.45	0.64
Pipe 131	100	198.2	0.01	24.40	0.79	Pipe 268	200	793.4	0.01	311.15	0.63
Pipe 132	22	176.2	0.01	24.30	1.00	Pipe 269	300	705.2	0.01	306.15	0.78
Pipe 133	530	396.6	0.01	-118.52	0.96	Pipe 270	250	705.2	0.01	300.35	0.77
Pipe 134	175	198.2	0.01	38.20	1.24	Pump 404	#N/A	#N/A	#N/A	574.86	0.00
Pipe 135	240	220.4	0.01	19.90	0.52	Pump 402	#N/A	#N/A	#N/A	513.50	0.00
Pipe 136	367	198.2	0.01	35.40	1.15	Pump 401	#N/A	#N/A	#N/A	532.49	0.00
Pipe 137	230	220.4	0.01	32.65	0.86	Pump 403	#N/A	#N/A	#N/A	341.55	0.00

Table 5. Nodal demands at nodes of the network (PDA case).

Node number	Demand L/S	Pressure m	Node number	Demand L/S	Pressure m	Node number	Demand L/S	Pressure m
Junc 1	0.00	49.00	Junc 90	9.10	52.33	Junc 180	22.57	50.00
Junc 2	0.00	55.11	Junc 91	6.20	52.45	Junc 181	27.64	52.77
Junc 3	0.00	48.94	Junc 92	4.70	51.35	Junc 182	24.90	53.64
Junc 4	0.00	54.48	Junc 93	10.00	50.52	Junc 183	19.90	52.10
Junc 5	17.30	53.91	Junc 94	6.00	49.93	Junc 184	0.00	52.79
Junc 6	2.40	53.45	Junc 95	10.00	49.55	Junc 185	2.40	55.83

Junc 7	5.20	52.61	Junc 96	10.00	49.46	Junc 186	0.00	53.99
Junc 8	5.20	53.02	Junc 97	4.90	51.39	Junc 187	0.00	54.09
Junc 9	2.60	48.82	Junc 98	5.90	51.49	Junc 188	0.00	55.68
Junc 10	3.20	49.22	Junc 99	8.70	51.61	Junc 189	0.00	55.36
Junc 11	5.30	47.36	Junc 100	9.60	50.89	Junc 190	19.90	54.70
Junc 12	9.90	47.55	Junc 101	5.10	39.69	Junc 191	0.00	54.02
Junc 13	0.00	48.33	Junc 102	1.20	49.94	Junc 192	24.90	55.56
Junc 14	0.00	50.38	Junc 103	4.00	47.96	Junc 193	14.90	54.68
Junc 15	5.90	50.32	Junc 104	5.20	42.19	Junc 194	29.90	54.03
Junc 16	3.40	34.35	Junc 105	5.30	45.19	Junc 195	0.00	56.46
Junc 17	3.80	32.70	Junc 106	0.80	46.78	Junc 196	19.80	56.48
Junc 18	0.00	44.52	Junc 107	5.80	37.10	Junc 197	10.00	57.10
Junc 19	0.00	40.76	Junc 108	5.80	46.84	Junc 198	0.00	57.24
Junc 20	1.30	40.24	Junc 109	7.28	43.12	Junc 199	14.90	57.17
Junc 21	0.00	37.95	Junc 110	17.39	43.70	Junc 200	2.70	57.46
Junc 22	0.00	36.81	Junc 111	6.40	40.46	Junc 201	11.60	53.75
Junc 23	6.50	25.72	Junc 112	8.45	42.36	Junc 202	6.50	54.28
Junc 24	0.00	47.88	Junc 113	6.70	41.01	Junc 203	0.00	54.98
Junc 25	0.00	47.45	Junc 114	9.40	38.33	Junc 204	9.10	55.49
Junc 26	0.00	47.74	Junc 115	7.10	26.05	Junc 205	14.90	53.04
Junc 27	0.00	47.43	Junc 116	5.80	43.36	Junc 206	0.00	53.29
Junc 28	0.00	47.28	Junc 117	19.90	47.16	Junc 207	0.00	56.48
Junc 29	0.00	53.25	Junc 118	0.00	47.39	Junc 208	24.90	56.28
Junc 30	2.00	53.47	Junc 119	4.30	50.47	Junc 209	1.80	56.86
Junc 31	7.80	54.86	Junc 120	0.00	48.63	Junc 210	13.70	58.10
Junc 32	5.90	53.03	Junc 121	19.90	48.52	Junc 211	24.90	57.30
Junc 33	6.10	53.08	Junc 122	0.00	46.85	Junc 212	3.00	56.93
Junc 34	4.80	54.47	Junc 123	0.00	46.07	Junc 213	19.90	55.94
Junc 35	6.30	53.28	Junc 124	1.20	53.77	Junc 214	8.10	57.25
Junc 36	2.40	51.09	Junc 125	0.00	53.97	Junc 215	14.90	56.26
Junc 37	19.90	52.75	Junc 126	0.00	53.96	Junc 216	5.80	57.26
Junc 38	7.90	53.34	Junc 128	24.90	52.81	Junc 217	8.30	57.33
Junc 39	9.30	52.40	Junc 129	0.00	51.17	Junc 218	5.00	55.46
Junc 40	5.33	52.51	Junc 130	19.90	47.08	Junc 219	9.89	54.62
Junc 41	1.60	52.47	Junc 131	0.00	47.14	Junc 220	32.69	54.59
Junc 42	6.30	52.52	Junc 132	24.90	47.02	Junc 221	5.89	53.45
Junc 43	27.62	52.12	Junc 133	9.10	43.69	Junc 222	17.38	52.99
Junc 44	17.62	52.05	Junc 134	0.90	43.92	Junc 223	14.68	54.27
Junc 45	27.70	52.61	Junc 135	19.90	44.15	Junc 224	19.90	53.59
Junc 46	14.90	52.15	Junc 136	1.50	44.61	Junc 225	3.30	53.99
Junc 47	3.00	53.51	Junc 137	10.22	44.70	Junc 226	9.00	45.74
Junc 48	4.00	53.38	Junc 138	11.13	48.56	Junc 227	8.00	53.86
Junc 49	22.59	51.09	Junc 139	2.20	53.66	Junc 228	6.40	55.01
Junc 50	3.20	51.34	Junc 140	19.90	54.56	Junc 229	10.40	54.25
Junc 51	2.60	51.23	Junc 141	7.60	55.99	Junc 230	3.10	53.47
Junc 52	6.93	52.50	Junc 142	0.90	52.43	Junc 231	10.60	53.10
Junc 53	4.60	48.90	Junc 143	4.60	50.37	Junc 232	19.90	54.23
Junc 54	1.10	49.44	Junc 144	8.40	51.97	Junc 233	6.70	55.29
Junc 55	0.00	43.10	Junc 145	0.00	53.23	Junc 234	9.10	54.99
Junc 56	14.90	42.89	Junc 146	2.90	51.35	Junc 235	17.60	52.68
Junc 57	0.00	49.32	Junc 147	16.30	53.00	Junc 236	0.00	55.18
Junc 58	19.90	49.13	Junc 148	5.70	52.88	Junc 237	0.40	46.92
Junc 59	0.00	46.92	Junc 149	11.60	54.25	Junc 238	6.50	33.95
Junc 60	0.00	46.99	Junc 150	5.40	54.88	Junc 239	2.40	47.74
Junc 61	24.90	46.67	Junc 151	0.00	54.75	Junc 240	14.90	47.68
Junc 62	0.00	46.39	Junc 152	0.00	54.68	Junc 241	0.90	53.26
Junc 63	0.90	46.91	Junc 153	29.90	54.72	Junc 242	8.20	51.41
Junc 64	19.90	46.66	Junc 154	0.00	55.46	Junc 243	0.90	53.78
Junc 65	19.80	46.06	Junc 155	24.90	55.30	Junc 244	3.30	55.78
Junc 66	2.50	46.41	Junc 156	29.90	54.88	Junc 245	2.10	56.75
Junc 67	3.00	46.26	Junc 157	5.62	55.78	Junc 246	2.30	53.61
Junc 68	17.43	44.91	Junc 158	19.90	50.51	Junc 247	3.30	35.29

Junc 69	2.60	46.23	Junc 159	3.30	47.02	Junc 248	1.10	53.69
Junc 70	19.90	46.15	Junc 160	0.10	47.13	Junc 249	0.80	52.89
Junc 71	0.00	45.32	Junc 161	19.90	46.87	Junc 250	4.03	45.13
Junc 72	17.43	45.11	Junc 162	0.00	47.40	Junc 251	4.00	51.06
Junc 73	22.47	46.35	Junc 163	0.00	49.32	Junc 252	4.17	27.33
Junc 74	4.40	46.43	Junc 164	24.90	50.72	Junc 253	0.00	53.26
Junc 75	5.30	45.90	Junc 165	0.00	51.91	Junc 254	19.90	52.87
Junc 76	22.45	45.69	Junc 166	24.90	47.48	Junc 255	2.60	51.00
Junc 77	5.30	49.90	Junc 167	2.40	47.73	Junc 256	19.90	50.85
Junc 78	10.20	50.06	Junc 168	-19.90	48.01	Junc 257	29.90	50.44
Junc 79	19.90	50.43	Junc 169	-1.30	47.94	Junc 258	3.30	54.49
Junc 80	10.40	49.49	Junc 170	2.75	53.18	Junc 259	5.00	54.43
Junc 81	6.70	51.77	Junc 171	14.90	50.64	Junc 260	5.80	52.25
Junc 82	9.70	51.61	Junc 172	0.00	48.33	Resvr 4	187.28	0.00
Junc 83	14.90	51.00	Junc 173	2.80	55.21	Resvr 277	-314.45	0.00
Junc 84	1.90	51.05	Junc 174	2.75	53.26	Resvr 401	-532.49	0.00
Junc 85	7.10	49.69	Junc 175	32.65	53.13	Resvr 402	-513.50	0.00
Junc 86	19.90	50.14	Junc 176	32.62	52.24	Resvr 403	-341.55	0.00
Junc 87	3.30	43.30	Junc 177	2.73	52.46	Resvr 404	-574.86	0.00
Junc 88	0.00	53.25	Junc 178	2.71	51.81			
Junc 89	10.80	52.99	Junc 179	2.67	50.28			

Table 5 presents the results of the hydraulic simulation for the study area, under the Pressure Driven Analysis (PDA). It presents the effective nodal flows ((water supplied at each junction under the simulated operating conditions) and the corresponding nodal pressures. The prescribed water demands at the nodes constitute the input data for the hydraulic model, while the values in Table 5 represent the hydraulic response of the network. The spatial distribution of these hydraulic variables is illustrated in Figures 6 to 7.

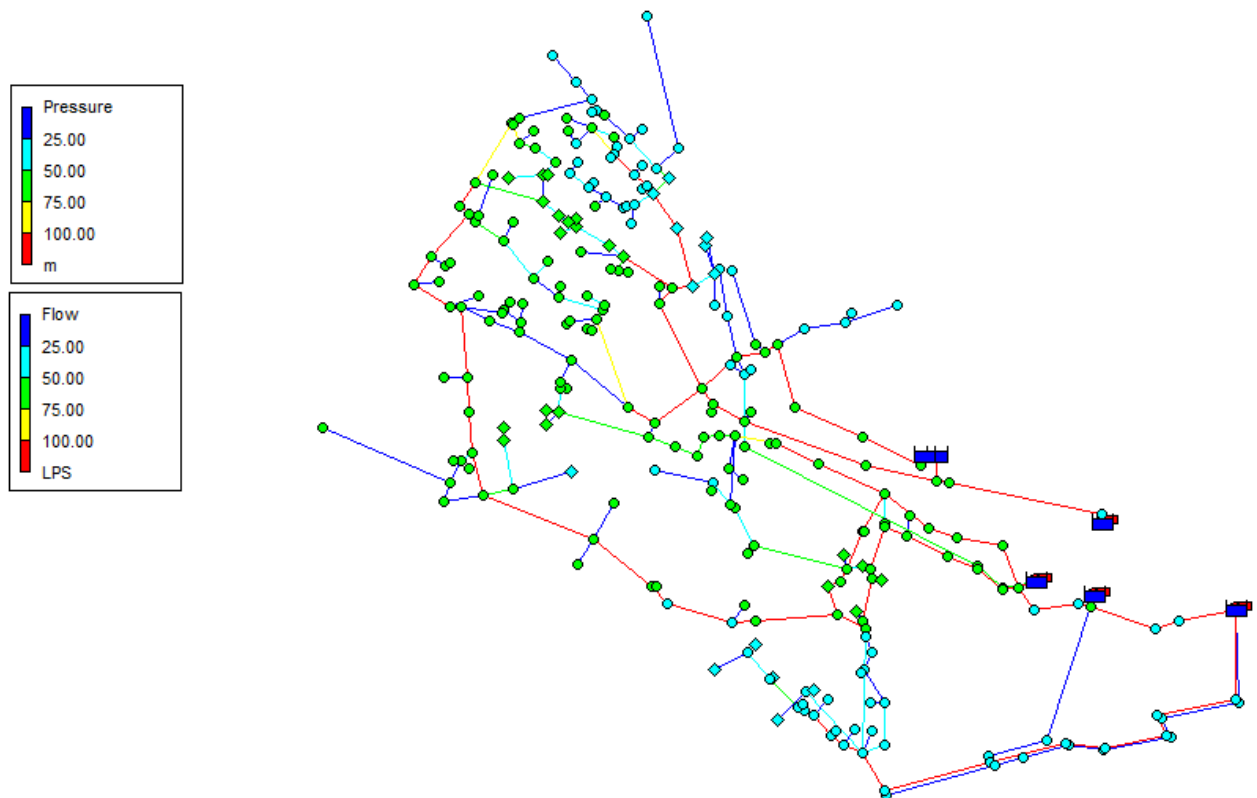


Fig. 6 - Simulation: Pressure - flow.

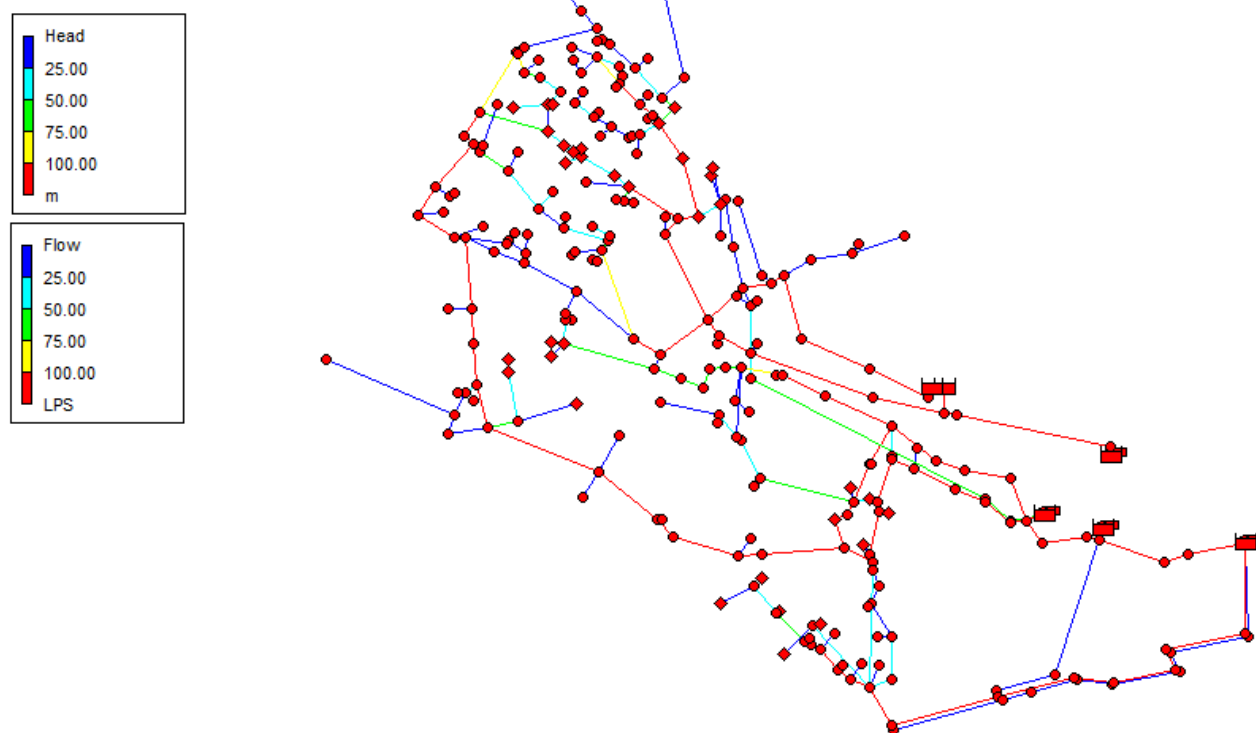


Fig. 7 - Simulation: Head - flow.

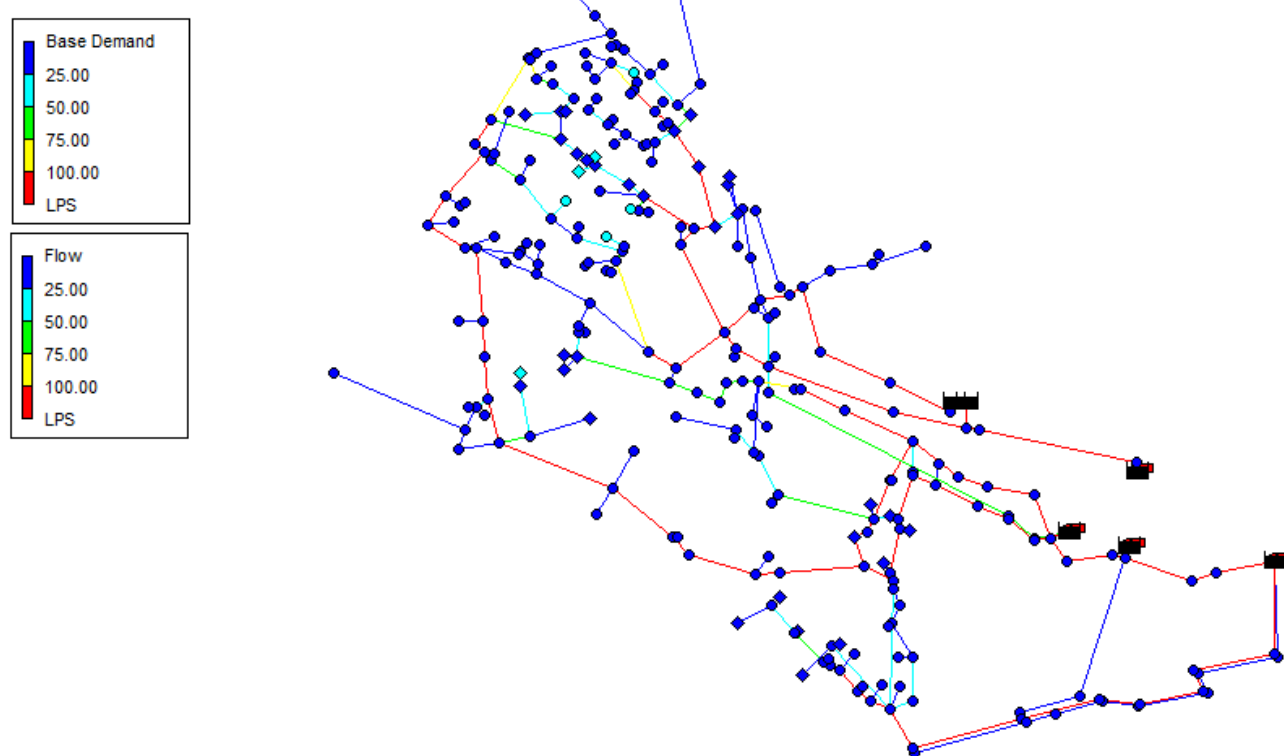


Fig. 8 - Simulation: Base demand - flow.

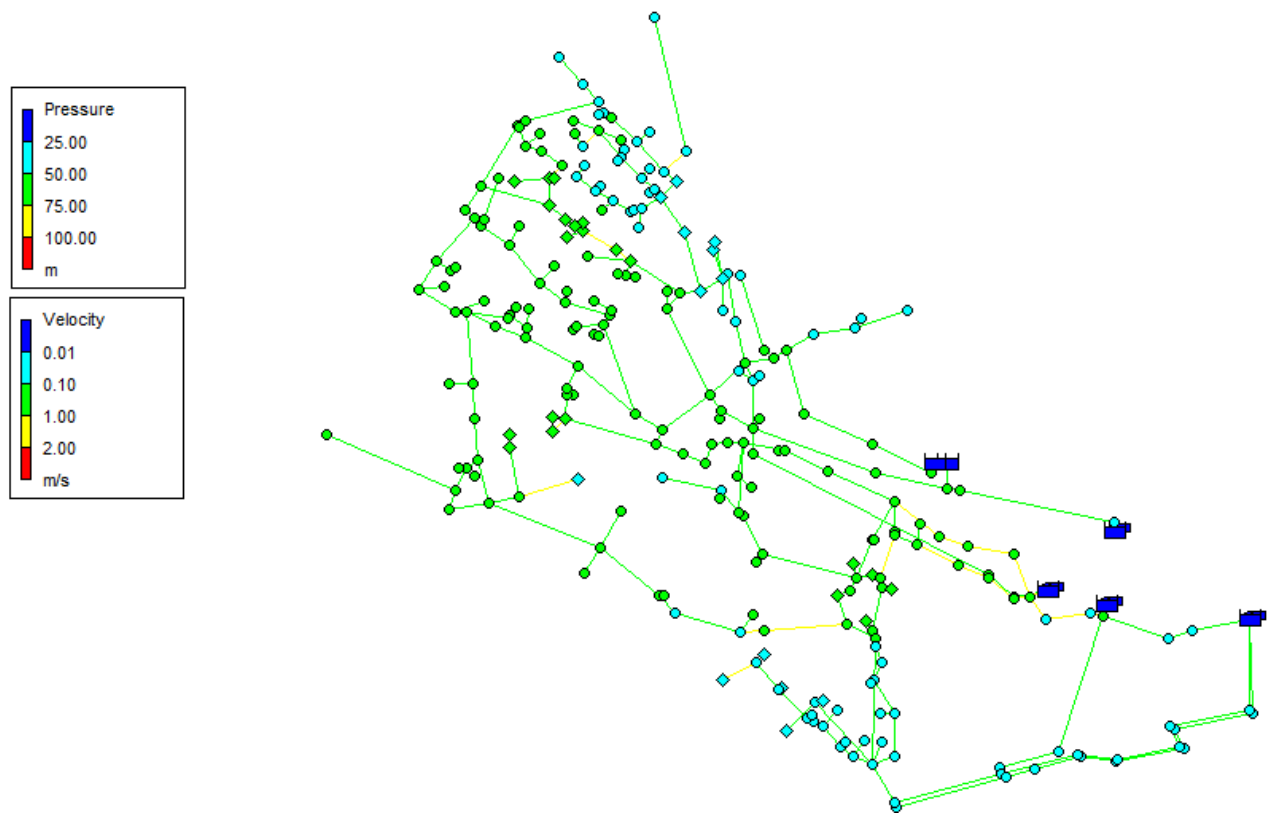


Fig. 9 - Simulation: pressure - velocity.

Based on Tables 2 demand driven analysis (DDA) and pressures driven analysis (PDA), the following comparison is shown in Table 6, which shows the difference in the pressure value between the two analyses.

Table 6. The differences between DDA and PDA Analyses.

Node number	DDA Pressure (m)	PDA Pressure (m)	The difference (m)
Junc 1	49.11	49.00	0.11
Junc 2	55.22	55.11	0.11
Junc 3	49.04	48.94	0.1
Junc 4	54.61	54.48	0.13
Junc 5	54.45	53.91	0.54
Junc 6	53.95	53.45	0.5
Junc 7	53.09	52.61	0.48
Junc 8	53.47	53.02	0.45
Junc 9	49.24	48.82	0.42
Junc 10	49.61	49.22	0.39
Junc 11	47.71	47.36	0.35
Junc 12	47.90	47.55	0.35
Junc 13	48.65	48.33	0.32
Junc 14	50.75	50.38	0.37
Junc 15	50.70	50.32	0.38
Junc 16	34.73	34.35	0.38
Junc 17	33.08	32.70	0.38
Junc 18	44.84	44.52	0.32
Junc 19	41.08	40.76	0.32
Junc 20	40.56	40.24	0.31
Junc 21	38.27	37.95	0.32
Junc 22	37.13	36.81	0.32
Junc 23	26.04	25.72	0.32
Junc 24	48.24	47.88	0.36
Junc 135	44.50	44.15	0.35
Junc 136	44.96	44.61	0.35
Junc 137	45.05	44.70	0.35
Junc 138	48.87	48.56	0.31
Junc 139	53.96	53.66	0.3
Junc 140	54.84	54.56	0.28
Junc 141	56.27	55.99	0.28
Junc 142	52.64	52.43	0.21
Junc 143	50.58	50.37	0.21
Junc 144	52.17	51.97	0.2
Junc 145	53.73	53.23	0.5
Junc 146	51.85	51.35	0.5
Junc 147	53.48	53.00	0.48
Junc 148	53.16	52.88	0.28
Junc 149	54.53	54.25	0.28
Junc 150	55.18	54.88	0.30
Junc 151	55.05	54.75	0.30
Junc 152	54.98	54.68	0.30
Junc 153	55.02	54.72	0.30
Junc 154	55.91	55.46	0.45
Junc 155	55.74	55.30	0.44
Junc 156	55.33	54.88	0.45
Junc 157	56.22	55.78	0.44
Junc 158	50.95	50.51	0.44

Junc 25	47.84	47.45	0.39
Junc 26	48.14	47.74	0.4
Junc 27	47.86	47.43	0.43
Junc 28	47.72	47.28	0.44
Junc 29	53.50	53.25	0.25
Junc 30	53.70	53.47	0.23
Junc 31	55.08	54.86	0.22
Junc 32	53.50	53.03	0.47
Junc 33	53.55	53.08	0.47
Junc 34	54.82	54.47	0.35
Junc 35	53.58	53.28	0.3
Junc 36	51.52	51.09	0.43
Junc 37	53.20	52.75	0.45
Junc 38	53.79	53.34	0.45
Junc 39	53.00	52.40	0.6
Junc 40	53.10	52.51	0.59
Junc 41	53.05	52.47	0.58
Junc 42	53.09	52.52	0.57
Junc 43	52.76	52.12	0.64
Junc 44	52.74	52.05	0.69
Junc 45	53.17	52.61	0.56
Junc 46	52.72	52.15	0.57
Junc 47	54.03	53.51	0.52
Junc 48	53.92	53.38	0.54
Junc 49	51.71	51.09	0.62
Junc 50	51.90	51.34	0.56
Junc 51	51.80	51.23	0.57
Junc 52	53.56	52.50	1.06
Junc 53	49.43	48.90	0.53
Junc 54	49.96	49.44	0.52
Junc 55	43.62	43.10	0.52
Junc 56	43.41	42.89	0.52
Junc 57	49.85	49.32	0.53
Junc 58	49.66	49.13	0.53
Junc 59	47.45	46.92	0.53
Junc 60	47.51	46.99	0.52
Junc 61	47.19	46.67	0.52
Junc 62	46.90	46.39	0.51
Junc 63	47.46	46.91	0.55
Junc 64	47.21	46.66	0.55
Junc 65	46.67	46.06	0.61
Junc 66	47.02	46.41	0.61
Junc 67	46.89	46.26	0.63
Junc 68	46.00	44.91	1.09
Junc 69	46.86	46.23	0.63
Junc 70	46.87	46.15	0.63
Junc 71	46.31	45.32	0.99
Junc 72	46.15	45.11	1.04
Junc 73	47.06	46.35	0.71
Junc 74	47.13	46.43	0.7
Junc 75	46.72	45.90	0.82
Junc 76	46.56	45.69	0.87
Junc 77	50.54	49.90	0.64
Junc 78	50.69	50.06	0.63
Junc 79	51.07	50.43	0.64
Junc 80	50.16	49.49	0.67
Junc 81	52.33	51.77	0.65
Junc 82	52.18	51.61	0.57
Junc 83	51.56	51.00	0.56
Junc 84	51.60	51.05	0.55
Junc 85	50.25	49.69	0.56
Junc 86	50.69	50.14	0.55

Junc 159	47.37	47.02	0.35
Junc 160	47.48	47.13	0.35
Junc 161	47.22	46.87	0.35
Junc 162	47.75	47.40	0.35
Junc 163	49.67	49.32	0.35
Junc 164	51.07	50.72	0.35
Junc 165	53.20	51.91	1.29
Junc 166	47.83	47.48	0.35
Junc 167	48.08	47.73	0.35
Junc 168	48.36	48.01	0.35
Junc 169	48.29	47.94	0.35
Junc 170	54.92	53.18	1.74
Junc 171	50.99	50.64	0.35
Junc 172	48.68	48.33	0.35
Junc 173	56.04	55.21	0.83
Junc 174	54.61	53.26	1.35
Junc 175	54.57	53.13	1.44
Junc 176	54.07	52.24	1.83
Junc 177	54.25	52.46	1.79
Junc 178	53.32	51.81	1.51
Junc 179	51.90	50.28	1.62
Junc 180	51.68	50.00	1.68
Junc 181	54.48	52.77	1.71
Junc 182	54.69	53.64	1.05
Junc 183	53.12	52.10	1.02
Junc 184	53.81	52.79	1.02
Junc 185	56.78	55.83	0.95
Junc 186	54.89	53.99	0.90
Junc 187	54.97	54.09	0.88
Junc 188	56.55	55.68	0.87
Junc 189	56.24	55.36	0.88
Junc 190	55.58	54.70	0.88
Junc 191	54.88	54.02	0.86
Junc 192	56.42	55.56	0.86
Junc 193	55.50	54.68	0.82
Junc 194	54.85	54.03	0.82
Junc 195	56.81	56.46	0.35
Junc 196	56.83	56.48	0.35
Junc 197	57.40	57.10	0.30
Junc 198	57.54	57.24	0.30
Junc 199	57.47	57.17	0.30
Junc 200	57.75	57.46	0.29
Junc 201	54.29	53.75	0.54
Junc 202	54.93	54.28	0.65
Junc 203	55.63	54.98	0.65
Junc 204	56.14	55.49	0.65
Junc 205	53.69	53.04	0.65
Junc 206	53.94	53.29	0.65
Junc 207	57.32	56.48	0.84
Junc 208	57.13	56.28	0.85
Junc 209	57.71	56.86	0.85
Junc 210	58.92	58.10	0.82
Junc 211	58.12	57.30	0.82
Junc 212	57.73	56.93	0.80
Junc 213	56.75	55.94	0.81
Junc 214	58.06	57.25	0.81
Junc 215	57.06	56.26	0.80
Junc 216	58.05	57.26	0.79
Junc 217	58.12	57.33	0.79
Junc 218	56.23	55.46	0.77
Junc 219	55.63	54.62	1.01
Junc 220	55.65	54.59	1.06

Junc 87	43.86	43.30	0.56
Junc 88	53.76	53.25	0.51
Junc 89	53.15	52.99	0.16
Junc 90	52.86	52.33	0.53
Junc 91	52.97	52.45	0.52
Junc 92	51.54	51.35	0.19
Junc 93	50.71	50.52	0.19
Junc 94	50.08	49.93	0.15
Junc 95	49.69	49.55	0.14
Junc 96	49.61	49.46	0.15
Junc 97	51.52	51.39	0.13
Junc 98	51.58	51.49	0.09
Junc 99	51.68	51.61	0.07
Junc 100	50.98	50.89	0.09
Junc 101	39.79	39.69	0.1
Junc 102	50.01	49.94	0.07
Junc 103	48.03	47.96	0.07
Junc 104	42.26	42.19	0.07
Junc 105	45.26	45.19	0.07
Junc 106	46.92	46.78	0.14
Junc 107	37.24	37.10	0.14
Junc 108	47.30	46.84	0.46
Junc 109	43.57	43.12	0.45
Junc 110	44.26	43.70	0.56
Junc 111	42.43	40.46	1.97
Junc 112	42.75	42.36	0.39
Junc 113	41.41	41.01	0.4
Junc 114	38.73	38.33	0.4
Junc 115	26.45	26.05	0.4
Junc 116	44.19	43.36	0.83
Junc 117	47.60	47.16	0.44
Junc 118	47.84	47.39	0.45
Junc 119	51.11	50.47	0.64
Junc 120	49.40	48.63	0.77
Junc 121	49.29	48.52	0.77
Junc 122	47.67	46.85	0.82
Junc 123	46.90	46.07	0.81
Junc 124	54.74	53.77	0.97
Junc 125	54.97	53.97	1.00
Junc 126	54.95	53.96	0.99
Junc 128	53.16	52.81	0.35
Junc 129	51.52	51.17	0.35
Junc 130	47.43	47.08	0.35
Junc 131	47.49	47.14	0.35
Junc 132	47.37	47.02	0.35
Junc 133	44.04	43.69	0.35
Junc 134	44.27	43.92	0.35

Junc 221	54.49	53.45	1.04
Junc 222	54.14	52.99	1.15
Junc 223	54.95	54.27	0.68
Junc 224	54.26	53.59	0.67
Junc 225	54.66	53.99	0.67
Junc 226	49.89	45.74	4.15
Junc 227	54.72	53.86	0.86
Junc 228	55.77	55.01	0.76
Junc 229	54.96	54.25	0.71
Junc 230	54.24	53.47	0.77
Junc 231	53.87	53.10	0.77
Junc 232	55.00	54.23	0.77
Junc 233	56.07	55.29	0.78
Junc 234	55.76	54.99	0.77
Junc 235	53.45	52.68	0.77
Junc 236	55.29	55.18	0.11
Junc 237	47.39	46.92	0.47
Junc 238	34.27	33.95	0.32
Junc 239	48.30	47.74	0.62
Junc 240	48.25	47.68	0.57
Junc 241	53.77	53.26	0.51
Junc 242	52.13	51.41	0.72
Junc 243	54.42	53.78	0.64
Junc 244	56.51	55.78	0.73
Junc 245	57.54	56.75	0.79
Junc 246	54.14	53.61	0.53
Junc 247	35.61	35.29	0.32
Junc 248	54.10	53.69	0.41
Junc 249	53.38	52.89	0.49
Junc 250	45.46	45.13	0.33
Junc 251	51.78	51.06	0.72
Junc 252	51.33	51.25	0.08
Junc 253	53.78	53.26	0.52
Junc 254	53.38	52.87	0.51
Junc 255	51.68	51.00	0.68
Junc 256	51.54	50.85	0.69
Junc 257	50.79	50.44	0.35
Junc 258	54.49	54.49	0
Junc 259	54.44	54.43	0.01
Junc 260	52.29	52.25	0.04
Resvr 4	0.00	0.00	0.00
Resvr277	0.00	0.00	0.00
Resvr401	0.00	0.00	0.00
Resvr402	0.00	0.00	0.00
Resvr403	0.00	0.00	0.00
Resvr404	0.00	0.00	0.00

To ensure network reliability, four analytical sections must be addressed as follows:

a. Pressure Reliability

Pressure reliability is assessed based evaluates how many nodes meet the minimum required pressure.

The reliability indicator is:

$$R_p = \frac{N_{acceptable}}{N_{total}}$$

Where:

$N_{acceptable}$: nodes with pressure $\geq$ minimum required pressure.

The acceptable Pressure Nodes meant that the pressures at all intersection points were sufficient to supply the network.

This means no node has pressure below the acceptable limit, as demonstrated in this study.

Therefore: $N_{acceptable} = 260 \text{ node}$

N_{total} : total nodes in the network. $N_{total} = 260 \text{ node}$

The reliability indicator $R_p = 1$

Interpretation:

Pressure reliability: $R = 100\%$

This means all nodes meet the required pressure level in the simulation.

b. Demand Satisfaction Ratio (DSR)

This measures how much of the required demand is actually delivered.

The indicator is:

$$DSR = \frac{Q_{supplied}}{Q_{required}}$$

Where:

$Q_{required}$: nodal demand entered in the model.

$Q_{supplied}$: actual discharge the network is able to deliver under present operating conditions [25].

The study showed that the hydraulic simulation model provided sufficient water for the network.

Therefore: $Q_{supplied} = Q_{required}$

Therefore, Demand Satisfaction Ratio is: $DSR = 1$

This means that:

100 % of the required demand is satisfied.

c. Velocity Compliance

Velocity compliance ensures if pipe velocities are within recommended standards.

The velocity range is: $0.5 \leq V \leq 2 \text{ m/s}$

This is within the range of the European standard EN 805.

This range is explicitly cited in the discussion of velocity limits.

Velocity compliance: 100 %

Interpretation:

This means that the selected pipe diameters are hydraulically suitable for the operating conditions.

7. Discussion

The hydraulic analysis performed with EPANET 2.2 demonstrates that the water distribution network operates under satisfactory hydraulic conditions, both in demand driven analysis (DDA) and pressure driven analysis (PDA) modes. However, the interpretation of the results must take into account the requirements of applicable standards and the operational characteristics of urban water distribution networks.

The nodal pressure results obtained from the DDA simulation indicate pressure values between approximately 26 and 58 m across the entire network. These values are higher than the minimum pressure generally required for drinking water supply and ensure adequate service conditions for consumers. The pressure reliability index calculated for the network is $R_p = 1.0$, indicating that all analyzed nodes meet the minimum pressure requirement. From an operational perspective, this result confirms that the existing pumping and storage infrastructure is capable of maintaining satisfactory pressure conditions throughout the study area.

Velocity analysis also demonstrates good hydraulic performance. Most flow velocities in the pipes are between 0.5 and 2.0 m/s, in accordance with the recommendations of EN 805 for drinking water distribution networks. Furthermore, the values obtained comply with the Romanian Design Norms NP 133-2022, which recommends velocities generally between 0.6 and 2.0 m/s under normal operating conditions and allows higher values under specific operating conditions. Maintaining velocities within this range is advantageous because it reduces the risk of sediment deposition associated with low velocities, while avoiding excessive head loss and pipe wear caused by high velocities. Therefore, the selected pipe diameters appear hydraulically appropriate for current demand conditions.

The demand satisfaction analysis also confirms the satisfactory performance of the network. The demand satisfaction ratio (DSR) was 1.0, indicating that all required demand was met during the simulation period. This result suggests that the existing infrastructure has sufficient hydraulic capacity to meet current consumer demand without experiencing pressure-related supply deficits.

One of the main contributions of this study lies in comparing DDA and PDA simulations within the same urban water distribution network. While the DDA method assumes that all demands are fully met, regardless of available pressure, the PDA method explicitly incorporates the pressure dependence of demand through emitter equations. In this case, the differences between the two approaches were relatively small, as the network operated under favorable pressure conditions. Nevertheless, the PDA method provided a more realistic representation of consumer behavior and network performance by accounting for pressure-related demand variations.

The comparison demonstrates that, while the DDA method remains adequate for evaluating networks operating under normal conditions, the PDA method offers significant advantages for assessing system behavior in abnormal operating scenarios, such as consumption peaks, equipment failures, pressure deficits, or emergency situations. Therefore, the PDA method can be considered a more robust tool for assessing the reliability and resilience of urban water distribution networks.

The PDA formulation adopted in this work was calibrated using pressure–flow relationships derived from residential buildings consumption characteristics. The discharge coefficient (C) and the pressure exponent (γ) introduced into the model hydraulic represent the pressure sensitivity of consumer demand and allow for the simulation of realistic variations in the supplied flow rate. Through the integration of

these calibrated parameters, the PDA model provides a more accurate assessment of network resilience and service reliability under various operating conditions.

Overall, the results indicate that the water distribution network complies with the hydraulic recommendations of EN 805 and NP 133-2022 standards regarding pressure levels, flow velocities, and service reliability. At the same time, the study highlights the importance of adopting pressure based simulation approaches to obtain more realistic estimates of water distribution and network performance under varying operating conditions.

8. Conclusions

This study enabled the development and calibration of a hydraulic model of the Oradea drinking water distribution network using EPANET 2.2 and the evaluation of its performance through demand analysis (DDA) and pressure analysis (PDA). The analysis covered 270 pipes and 260 nodes supplied by pumping stations and reservoirs, thus providing a comprehensive representation of the urban water distribution system.

The results showed that the network meets the main hydraulic performance requirements recommended by European standard EN 805 and Design Norms NP 133-2022. Nodal pressures remained within acceptable operational limits, generally between 26 and 58 m, while flow velocities in the pipes were mostly within the recommended range of 0.5 to 2.0 m/s. Furthermore, the pressure reliability index reached 100% and the demand satisfaction rate was 1.0, demonstrating the network's ability to fully meet consumer demand under the simulated operating conditions.

The scientific contribution of this work lies in the comparative evaluation of the DDA and PDA approaches applied to a large Romanian urban water distribution network. Unlike conventional studies that rely exclusively on demand-driven simulations, this research incorporates pressure-dependent demand modeling using emitter coefficients representative of residential areas. The comparison demonstrates that the PDA method offers a more realistic representation of network behavior because it takes into account the interaction between pressure availability and water consumption.

Another important finding is that, while both methods produced satisfactory results under normal operating conditions, the PDA method offers a superior ability to assess network performance during pressure deficits, peak consumption periods, and abnormal operating scenarios. This underscores the added value of EPANET 2.2's pressure-driven modeling functionality for reliability and resilience assessments.

Therefore, this study contributes to the existing body of knowledge by demonstrating the applicability of hydraulic modeling based on the PDA method to Romanian urban water distribution systems and by providing a standardized assessment framework that combines pressure reliability, flow compliance, and demand-side performance indicators. Future research could extend the analysis to emergency situations, pipe bursts, leak scenarios, and long-term network optimization studies to more accurately assess system resilience.

References

- [1] Mays, Larry W., (ed. 2000). *Water Distribution System Handbook*. 1st ed. New York: McGraw-Hill, <https://www.accessengineeringlibrary.com/content/book/9780071342131>.
- [2] Walski, T.M. (1984). *Analysis of water distribution systems*. ISBN 0-442-29192-2
- [3] Rossman, L. A., Woo, H., Tryby, M., Shang, F., Janke, R., & Haxton, T. (2020). *Epanet 2.2 user manual; water infrastructure division*. Center for Environmental Solutions and Emergency Response.
- [4] Bhawe, Gupta and Gupta, R. (2006) *Analysis of water distribution networks*. Oxford, U.K.: Alpha science International. ISBN 978-1-84265-359-3
- [5] Whitman, B. E., Walski, T., Barnard, T. E., Durrans, S. R., & Lowry, S. (2021). *Computer applications in Hydraulic Engineering*. Bentley Institute Press.
- [6] Edition, T. (2012). *Computer Modeling of Water Distribution Systems*. ISBN 978-1-58321-864-8
- [7] Walski, T. M., Chase, D. V., Savic, D. A., Grayman, W., Beckwith, S., & Koelle, E. (2003). *Advanced water distribution modeling and management*.
- [8] Ormsbee, L. E. (2006). The history of water distribution network analysis: The computerage. In *Water Distribution Systems Analysis Symposium 2006* (pp.1-6).
- [9] Cooper, J. P. (2018). *Computer modeling of water distribution systems* (4th ed., Manual of Water Supply Practices M32). American Water Works Association.
- [10] Cross, H. (1936). *Analysis of flow in networks of conduits or conductors*. University of Illinois. Engineering Experiment Station. Bulletin; no. 286.
- [11] Todini, E., & Pilati, S. (1988). A gradient algorithm for the analysis of pipe networks. In *Computer applications in water supply: vol. 1---systems analysis and simulation* (pp. 1-20).
- [12] Rossman, L. A. (2000). *EPANET 2: users manual*.
- [13] Todini, E. (2000). *Looped water distribution networks design using a resilience index based heuristic approach*. *Urban Water*, 2(2), 115–122.
- [14] Kapelan, Z. S., Savic, D. A., & Walters, G. A. (2005). *Multiobjective design of water distribution systems under uncertainty*. *Water resources research*, 41(11).
- [15] Farmani, R., Walters, G. A., & Savic, D. A. (2005). *Trade-off between total cost and reliability for Anytown water distribution network*. *Journal of water resources planning and management*, 131(3), 161-171.
- [16] Puust, R., Kapelan, Z., Savic, D. A., & Koppel, T. (2010). *A review of methods for leakage management in pipe networks*. *Urban Water Journal*, 7(1), 25-45.
- [17] Walski, T. M., Chase, D. V., Savic, D. A., Grayman, W., Beckwith, S., & Koelle, E. (2003). *Advanced water distribution modeling and management*.
- [18] Ramos, H. M., McNabola, A., López-Jiménez, P. A., & Pérez-Sánchez, M. (2019). *Smart water management towards future water sustainable networks*. *Water*, 12(1), 58.
- [19] Gheisi, A., Forsyth, M., & Naser, G. (2016). *Water distribution systems reliability: A review of research literature*. *Journal of Water Resources Planning and Management*, 142(11), 04016047.
- [20] Conejos Fuertes, P., Martínez Alzamora, F., Hervás Carot, M., & Alonso Campos, J. C. (2020). *Building and exploiting a Digital Twin for the management of drinking water distribution networks*. *Urban Water Journal*, 17(8), 704-713.
- [21] Dupont, A. (1974). *Hydraulique urbaine Tome 2, ouvrages de transport élévation et distribution des eaux*. Edition Eyrolles.
- [22] EN, B. (2000). 805: 2000 *Water supply-Requirements for systems and components outside buildings*.
- [23] Dezvoltării, M., & Administrației, L. P. (2022). Normativ privind proiectarea, execuția și exploatarea sistemelor de alimentare cu apă și canalizare ale localităților.
- [24] Lakhdari, H., & Georgescu, A.-M. (2025). Calibration of water distribution network models and comparison between (DDA) and (PDA). *Journal of Applied Mathematics and Physics*, 13(9), 2853–2875. <https://doi.org/10.4236/jamp.2025.139163>
- [25] Boxall, J., & Maksimovic, C. (2009). *Integrating Water Systems: Proceedings of the Tenth International Conference on Computing and Control in the Water Industry 2009*. CRC Press.